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Research Article

The alien vascular flora of the Pantelleria Island National Park (Sicily Channel, Italy): new insights into the distribution of some potentially invasive species

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Abstract

Pantelleria is a volcanic island located in the Sicily Channel (Italy), between Sicily and Tunisia. The island, designated a National Park in 2016, hosts an interesting vascular flora of over 600 species including 9 narrow endemics. The island's incredible biodiversity is, however, at risk due to anthropogenic influences, climate change, and, recently, the presence and spread of alien plant species. The Pantelleria alien flora has never been thoroughly investigated, probably because many non-native species were not yet present or so widespread on the island. Now, however, with the increased general awareness of the risks associated with invasive alien species, documentation of the presence of non-native species has been steadily increasing. In this study, field and literature research was carried out to investigate the alien flora of the island. Here, we report the status of a number of non-native plants with known invasive potential. *Cenchrus setaceus* (=*Pennisetum setaceum*) is reported for the first time as naturalized in the island with clear invasive behaviour, while, particularly remarkable for their invasive potential are other studied plants such as: *Acacia saligna*, *Ailanthus altissima*, *Boheravia coccinea*, *Carpobrotus edulis, Leucaena leucocephala* subsp. *glabrata*, *Malephora crocea, Melia azedarach*, *Nicotiana glauca*, *Opuntia ficus-indica, Parkinsonia aculeata, Washingtonia robusta* and a few others less important at the moment, but to be monitored. Although most taxa showed a relatively limited distribution, the trend is to observe an increased invasiveness, which indicates that they can potentially become invasive in Pantelleria as well in the next years or decades. Their limited current distribution suggests that these species are in the early stages of the general invasion curve, when intervention is feasible and most likely to succeed. Therefore, it is most prudent to prioritize management for as many potentially problematic nonnatives as possible, which will contribute greatly to the conservation of native species and ecosystems of Pantelleria. Prevention and management of invasive non-native species—both future arrivals and those already present—are necessary to preserve the peculiar volcanic landscape of Pantelleria, which was shaped by man over the last millennia.

Key words: alien plant species, conservation, *Cenchrus setaceus*, first record, habitat, island biogeography, invasive species management

Introduction

The small Mediterranean islands are characterized by very peculiar plant diversity that comprises a rich heritage of paleoendemics and recently diversified species (Médail 2021). The insular flora is mainly affected by biogeography, distance from the mainland, geological era and human activities. Although their total richness is not yet fully known, these islands are already a treasure of biodiversity, as shown by recent descriptions of new narrow endemic species (e.g., Minissale et al. 2013; Galanos and Tzanoudakis 2019; Sáez et al. 2020; Brullo et al. 2021, 2022; Cambria et al. 2021). However, island biota is also typically more vulnerable to invasive species than mainland areas (Guarino et al. 2021). More worrying, the frequency and number of alien plant species are steadily growing in Sicily (Galasso et al. 2021; Cambria et al. 2022a, b, 2023) and consequently the main island could be source of invasive species that may more easily spread to small neighboring islands such as Pantelleria. Small islands can provide favorable conditions for the establishment of alien plant species, mostly in synanthropic habitats, but also in natural and seminatural communities, which results in heightened risk to local biodiversity. Indeed, the spread of invasive plant species, due to their high competitiveness, can lead to the reduction or even the disappearance of native species, at least at the local scale (Pyšek et al. 2017). Invasive species can also significantly affect the traditional agricultural and rural landscapes, completely changing their physiognomy and considerably raising the maintenance cost for weeding activities (Vicente et al. 2019). In the small Mediterranean islands, this phenomenon would seem to be less relevant up to now than in other areas of the world as for example it is observed in many oceanic islands where the alien flora prevails, as number of taxa, on the native one (Pyšek et al. 2017; Bach et al. 2022). However, it should be considered the long-term trajectory of invasive process and the occurrence of taxa with high invasiveness in Mediterranean ecosystems, whose control will play a likely role in the biodiversity conservation of insular ecosystems (Fois et al. 2020; Sciandrello et al. 2021). Without timely intervention, the spread of invasive alien plants will increase and severely degrade native habitats and plant communities. The occurrence of alien species is normally used to assess the conservation status of habitats of Community interest (Directive 92/43/CE); in fact, this impact is increasingly being studied (Lazzaro et al. 2020).

Our study focused on the volcanic island of Pantelleria, located in the center of the Sicily Channel (Italy), between Tunisia and Sicily, whose native vascular flora comprises over 600 taxa (Pasta and La Mantia 2013). Among them are several narrow endemic taxa of high naturalistic value, such as *Helichrysum errerae* Tineo, *Limonium cosyrense* (Guss.) O.Kuntze, *L. secundirameum* (Lojac.) Brullo, *Serapias cossyrensis* B.Baumann & H.Baumann, *Matthiola incana* (L.) R.Br. subsp. *glandulifera* (Lojac.)

C.Brullo & Brullo, *Anthemis cossyrensis* (Guss.) Guss., *Trifolium nigrescens* Viv. subsp. *dolychodon* (Sommier) C.Brullo, Brullo & Giusso, and *Senecio leucanthemifolius* Poir. subsp. *cossyrensis* (Lojac.) C.Brullo & Brullo. There are also several species of phytogeographic value such as *Limonium parvifolium* (Tineo ex Guss.) Pignatti, *Epipactis microphylla* (Ehrh.) Sw., *Pimpinella lutea* Desf., *Carex illegitima* Ces., *Limodorum trabutianum* Batt., *Brassica insularis* Moris, *Bellium minutum* (L.) L., *Andryala cossyrensis* Guss., *Asplenium marinum* L. and *Ophrys scolopax* Cav. subsp. *apiformis* (Desf.) Maire & A.Weiller.

The volcanic building of Pantelleria began about 0.3 million years ago and initiated a long, explosive, and eruptive period (Civetta et al. 1984; Jordan et al. 2018). Even during this tumultuous time, lava substrates were colonized by plants dispersed naturally from nearby Sicily and Tunisia. The human settlement on the island dates to the beginning of the Neolithic Age, around 9.6–7.7 ka BP (Abelli et al. 2014). The long history of human activities probably contributed to and continues to favor the arrival of non-native species on the island – and some of these have become naturalized. On the basis of literature data and our observations, however, this phenomenon seems recent. Indeed, although the flora of Pantelleria has been investigated by many authors since the 1800s including Calcara (1853), Sommier (1922), Di Martino (1961), Brullo et al. (1977), Gianguzzi (1999, 2017), Mazzola et al. (2001) and Pasta and La Mantia (2013), none of these specifically dealt with the topic of alien species. Only in 2014 was this topic directly addressed, when Galasso et al. (2014) reported the naturalization of *Persicaria senegalensis* (Meisn.) Soják on the island, which was, in fact, a new alien species in Europe.

This paper aims to report new records and updated distributions of the most troublesome alien plant species occurring in Pantelleria. Several species are a severe threat to the fragile environments of the island, due to their high invasiveness and rapid spread. Furthermore, the most invaded habitats are highlighted in order to plan future management activities. Our study does not provide an exhaustive list of the non-native flora of Pantelleria, but it is the first report on the most problematic (and potentially invasive) alien species. Additionally, for each target alien species, we discuss the most suitable management options (monitoring, containment, or eradication) with consideration for their economic and technical feasibility. Moreover, we suggest education programs to spread awareness about the ecological risks associated to the non-native species here taken in consideration.

Study area

Pantelleria (36°44′N; 11°57′E) is a volcanic island located in the Sicily Channel (Italy), between Sicily and Tunisia (Figure 1). On the island live 7352 inhabitants mainly dedicated to agriculture and tourism (ISTAT 2023).

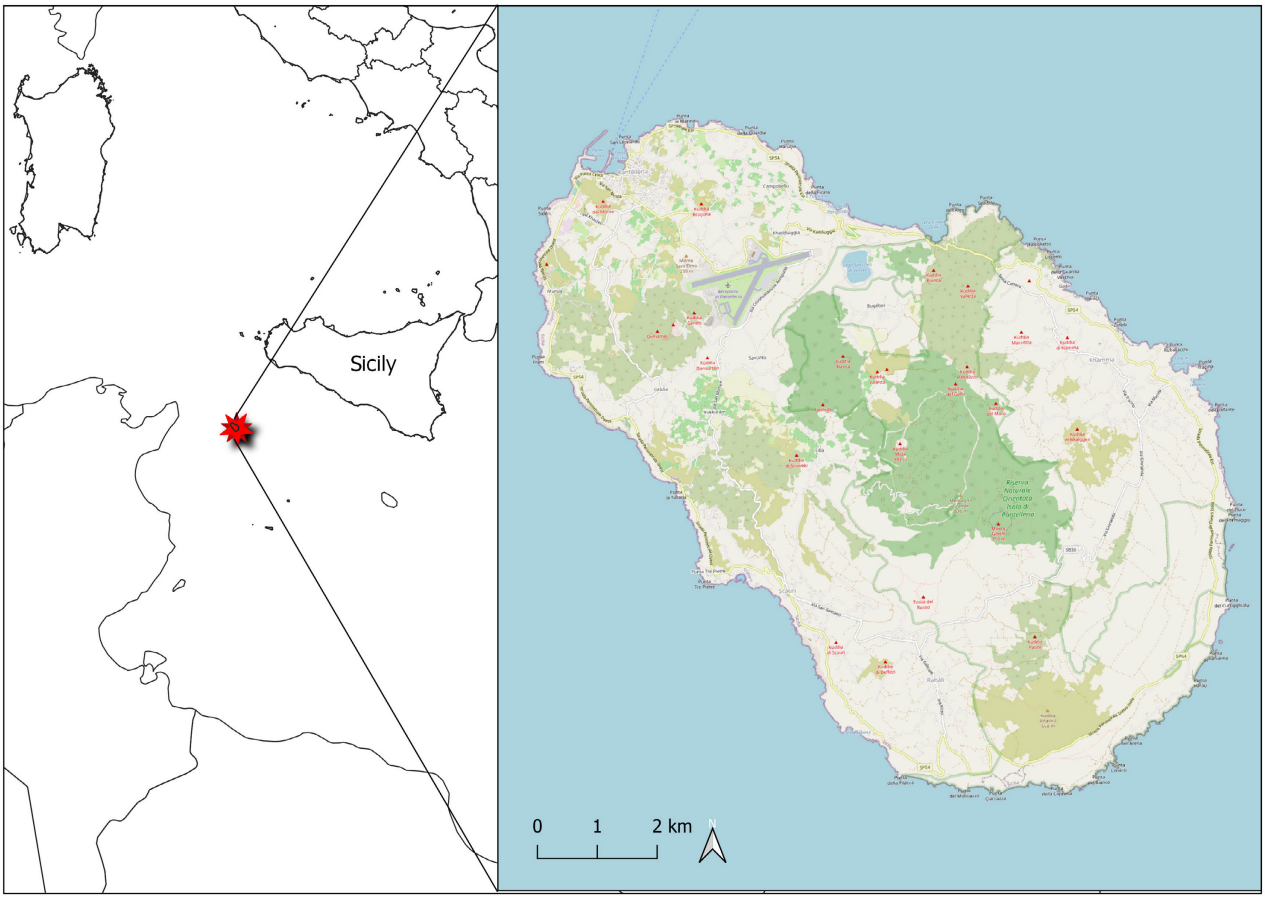

Figure 1. Study area "Pantelleria island" The map of Pantelleria used here and in the following figures is provided by Openstreetmap© (https://www.openstreetmap.org).

The island has a surface of less than 85 km^2 and a maximum altitude of 836 m a.s.l., the peak of Montagna Grande. The island's territory has been a regional nature reserve since 1998, while in 2016 a large area of the island was designated a National Park. Moreover, it hosts three sites belonging to the Natura2000 network: the Special Protection Area (SPA) "Isola di Pantelleria and the surrounding marine area" (Code: ITA010030, Area ≈ 15,800 ha); the Special Area of Conservation (SAC) "Coastal Area, Cliffs and Bagno dell'Acqua" (Code: ITA010020, Area ≈ 3,400 ha); the SAC "Island of Pantelleria: Montagna Grande and Monte Gibele" (Code: ITA010019 Area ≈ 3,100 ha). Traditional agriculture is also important on the island as the agricultural landscape was shaped over centuries by Pantelleria farmers, with typical architectural elements such as the "Dammuso" house and the terracing with dry stone walls. The "vite ad alberello" (head-trained bush vines) was listed since 2014 in the UNESCO Representative List of the Intangible Cultural Heritage of Humanity. The local climate is typically Mediterranean, with a mean annual temperature of 18.1 °C and mean annual precipitation of 408 mm, concentrated over the autumn and winter seasons. According to the bioclimatic classification proposed by Bazan et al. (2015), the area under study is defined as a multi-seasonal Mediterranean oceanic bioclimate, with thermotypes ranging

from lower thermomediterranean to lower mesomediterranean and ombrotypes from upper semi-arid to lower dry.

Materials and methods

The present study was carried out between 2020 and 2022 on Pantelleria Island. The research included field surveys aimed at the mapping of all IAPs surveyed and literature data (GBIF.org 2022). A total of 286 occurrence points were used to make the distribution maps, of which 243 points were from our observations and 43 points were from GBIF.org (https://www.gbif.org/). The geographic coordinates of alien species were recorded using a GPS Montana 680 (Garmin Ltd., USA). Maps for each taxon, investigated in 1 × 1 km square grids according to standard European grid (European Environmental Agency 2017) are presented, which were elaborated by using QGIS tools (QGIS.org 2021). The specimens collected during the surveys on the island are housed in Catania (CAT) (herbarium acronyms follow Thiers 2022+). The taxonomic identification was carried out following the Flora of Italy (Pignatti 2017–2019), while the nomenclature treatment follows Galasso et al. (2018) and subsequent updates reported in the Portal to the Flora of Italy (http://dryades.units.it/floritaly/), and the degree of naturalization was provided according to Galasso et al. (2018). Data regarding the family, life form and chorology were added according to Pignatti et al. (2017–2019) and the Portal to the Flora of Italy (http://dryades.units.it/floritaly/).

For natural environments subject to invasion by alien species we have taken into consideration the habitats indicated in Annex I of the European directive 92/43 EEC (https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en).

Results

Currently, the most widespread species in Pantelleria are *Acacia saligna* (Labill.) H.L.Wendl. (29 plots, 1 × 1 km), *Ailanthus altissima* (Mill.) Swingle (26 plots), and *Carpobrotus edulis* (L.) N.E.Br. (25 plots), while *Cenchrus setaceus* (Forssk.) Morrone (24 plots) is reported for the first time as naturalized in the island. The other species recorded, particularly remarkable for their invasiveness, were *Boerhavia coccinea* Mill. (8 plots), *Leucaena leucocephala* (Lam.) de Wit subsp. *glabrata* (Rose) Zárate (7 plots), *Malephora crocea* (Jacq.) Schwantes (4 plots), *Melia azedarach* L. (13 plots), *Nicotiana glauca* Graham (19 plots), *Opuntia ficus-indica* (L.) Mill. (8 plots), *Parkinsonia aculeata* L. (3 plots), and *Washingtonia robusta* H.Wendl. (2 plots). Table 1 shows for each species information concerning life form, chorology, number of plots occupied, potentially threatened habitat types (according to Directive 92/43/CEE), occurrence in protected areas and invasive status in Sicily. Considering the number of invasive alien species

Table 1. Ecological traits and impact on natural habitats of alien species surveyed on Pantelleria Island. Life form; P, phanerophytes; Ch, chamaephytes; H, hemicryptophytes; NP, nanophanerophytes. Occurrence is percent of the number of plots falling within the National Park. * Alien species of Union concern pursuant to Regulation (EU) No 1143/2014.

Species	Life form	Chorology	N. plots	Affected Habitat types	Occurrence into Park boundary (%)	Status in Sicily
Acacia saligna *	P	Australia	29	5330, 6220*, 9540, 9340, 5210	87	Naturalized
*Ailanthus altissima**	P	Asia	26	6220*, 5330, 9340	54	Invasive
Boheravia coccinea	Ch	Paleotrop.	8	6220*, 5330	29	Invasive
Carpobrotus edulis	Ch	Africa	25	6220*, 5330, 5210, 1240	49	Invasive
*Cenchrus setaceus**	H	Paleosubtrop.	24	5330, 6220*	48	Invasive
Leucaena leucocephala subsp. *glabrata*	P	America	7	6220*, 5330	38	Naturalized
Malephora crocea	Ch	S Africa	4	6220*, 1240, 5330	75	Casual
Melia azedarach	P	Asia	13	6220*, 5330, 9340	42	Naturalized
Nicotiana glauca	NP	America	19	6220*, 5330, 5210, 9340	40	Invasive
Opuntia ficus-indica	P	Neotrop.	8	6220*, 5330,	100	Invasive
Parkinsonia aculeata	P	Neotrop.	3	6220*, 5330, 1150*	100	Invasive
Washingtonia robusta	P	N America	2	5330, 1150*	50	Casual

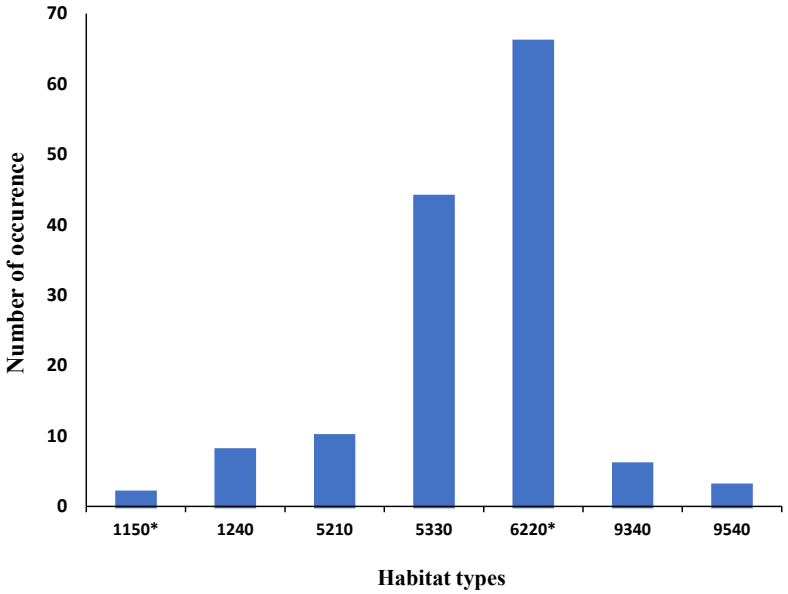

Figure 2. Number of alien species recorded in the habitats of community interest according to the Directive 92/43/CEE. Number of records refers to the plots invaded by the alien species as indicated in Table 1 (168 in total). Habitat types: Habitat 1150* Coastal lagoons; Habitat 1240 Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp.; Habitat 5210 Arborescent matorral with *Juniperus* spp.; Habitat 5330 Thermo-Mediterranean and pre-desert scrub; Habitat 6220* Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*; Habitat 9340 *Quercus ilex* and *Quercus rotundifolia* forests; Habitat 9540 Mediterranean pine forests with endemic Mesogean pines.

occurrences, the most invaded habitats of Pantelleria were the following (in brackets the code reported in the Annex I of the EU Directive 92/43, with asterisk the priority habitats according to the same directive): Coastal lagoons (1150*); Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp. (1240); Arborescent matorral with *Juniperus* spp. (5210); Thermo-Mediterranean and pre-desert scrub (5330); Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea* (6220*); *Quercus ilex* and *Quercus rotundifolia* forests (9340); and Mediterranean pine forests with endemic Mesogean pines (9540); (Figure 2). Moreover, a brief description and the distribution map of each species are hereafter provided.

***Acacia saligna* (Labill.) H.L.Wendl. (Fam. Fabaceae)**

Native to Western Australia, *A. saligna* has been widely used in the Mediterranean basin—including Italy—for reforestation in coastal sites, especially sand dunes (Del Vecchio et al. 2013). Its extensive alteration of coastal dune ecosystems is the reason for its recent addition to the list of invasive alien species of European concern (Regulation EU 1143/2014). In Italy, *Acacia saligna* is considered an invasive species in the southern regions (Galasso et al. 2018) and Sardinia (Lozano et al. 2020). In Sicily, it is regarded as a naturalized plant, but it showed clear invasive behaviour in the understory of Mediterranean pine plantations (Badalamenti et al. 2018). In Pantelleria, *A. saligna* has been widely planted, yet until now its distribution was relatively circumscribed to roadsides and abandoned areas very close to cultivation sites (Figures 3A, 6e). For instance, in the locality Lago di Venere and the surroundings it is in the phase of full naturalization as attested by several growing young plants. However, it needs high attention i.e., dissemination activities on the negative relevance of the species and careful monitoring because it could become more widespread in areas of great naturalistic and landscape interest, taking into account that even after the eventual eradication, the soil seed bank could contribute for years to the repopulation of the sites concerned (Meloni et al. 2015). Furthermore, *A. saligna* currently represents a serious risk for road maintenance activities, especially in the south-eastern sector of the island (i.e., along the road "Strada perimetrale dietro isola").

***Ailanthus altissima* (Mill.) Swingle (Fam. Simaroubaceae)**

The invasiveness of this China-native is known worldwide (Kowarik and Säumel 2007), including throughout Italy, Sicily, and its satellite islands (Badalamenti et al. 2012; Galasso et al. 2018). *Ailanthus altissima* has been present in Sicily for over two centuries, appearing for the first time in the floristic list compiled by Giuseppe Tineo (1802), the first director of the Botanical Garden of Palermo. In the region, Baron Francesco Anca, founder of the Acclimation and Agriculture Society in Palermo in 1861, had an important role in the diffusion of the species, promoting its use both in agriculture and as an ornamental in urban areas (Badalamenti et al. 2012). In Pantelleria, *A. altissima* has been observed in various localities, especially on abandoned terraces and in synanthropic habitats, with limited occurrence in natural contexts until recently (Figures 3B, 6d). During our field surveys, we observed some large nuclei, suggesting that a further spread of the species is very likely. Furthermore, in its invaded range, including Sicily, *A. altissima* is capable of creating monospecific stands not only in synanthropic areas but also in natural habitats (Kowarik and Säumel 2007; Sciandrello et al. 2013, 2014, 2017; Sciandrello and D'Agostino 2014; Minissale et al. 2015; Campagnaro et al. 2022). Therefore, this species should be carefully monitored throughout the island, while isolated young

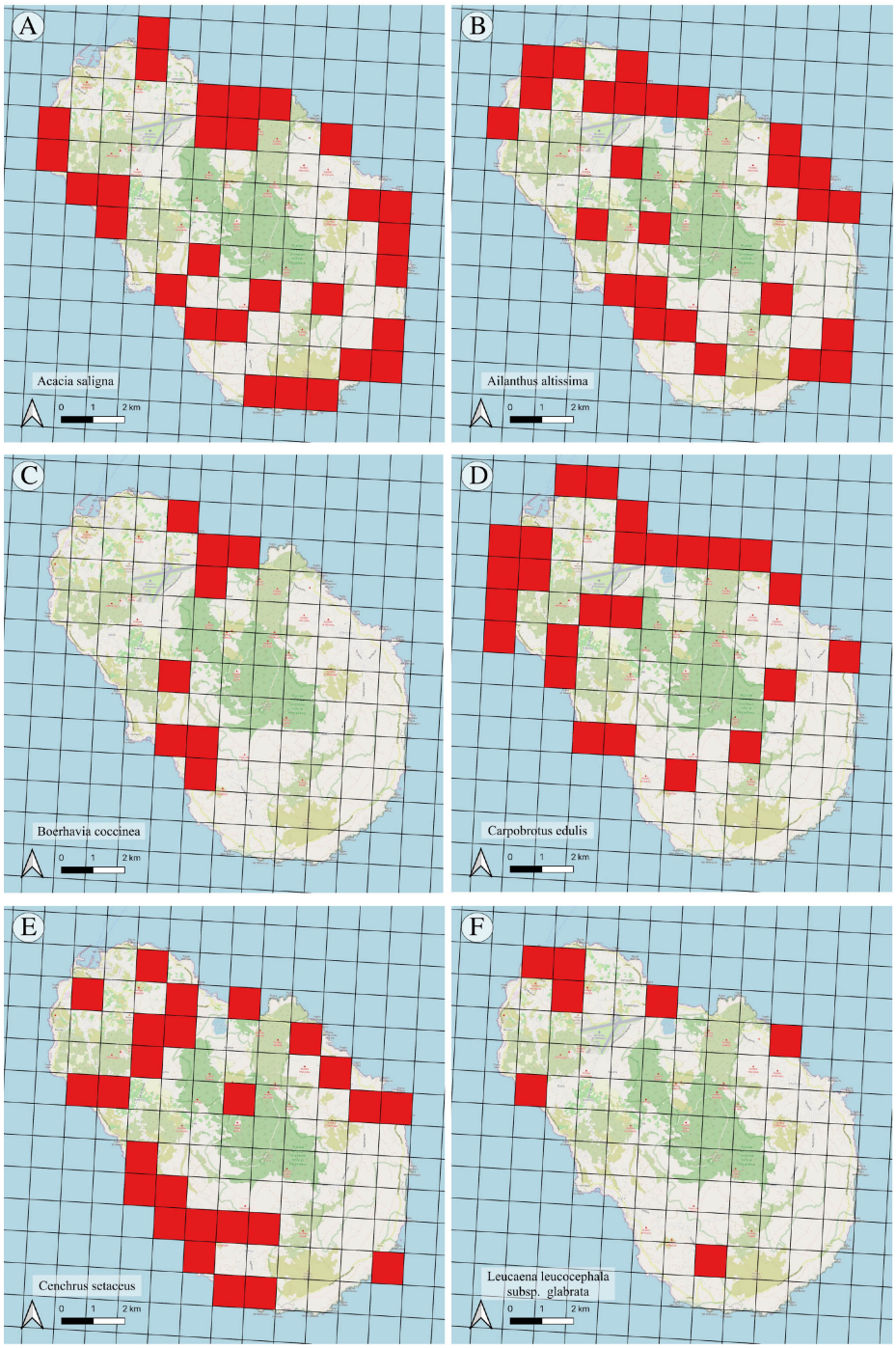

Figure 3. Current distribution of *Acacia saligna* (A), *Ailanthus altissima* (B), *Boheravia coccinea* (C), *Carpobrotus edulis* (D), *Cenchrus setaceus* (E), and *Leucaena leucocephala* subsp. *glabrata* (F) in Pantelleria island (Sicily, Italy).

individuals and nuclei occurring close to natural and seminatural habitats should be eradicated as soon as possible.

***Boerhavia coccinea* Mill. (Fam. Nyctaginaceae)**

Although native to the Americas (Struwig and Siebert 2013), *B. coccinea* has naturalized across all the tropics and is now regarded as a cosmopolitan species. By other authors (Pignatti et al. 2017–2019), it is considered a species of paleotropical origin. *Boerhavia coccinea* is distributed

throughout Central America, South America, Mexico, West Indies, Eurasia, Africa, and Australia (Struwig and Siebert 2013). It is also present on several Pacific islands, including the Hawaiian Islands, where it is an invasive species and a noxious weed (van de Witte 2016). In Europe, *B. coccinea* has been currently recorded only in the southern Italian regions of Sicily, Calabria and Campania (Celesti-Grapow et al. 2009; Musarella et al. 2019). The species was reported for the first time on the Sicilian mainland, near Palermo (sub *Boerhaavia repens* L. subsp. *viscosa* (Choisy) Maire; De Leo 1967), and it quickly spread all over the territory, especially along the coastal belt in the northern sector (Giardina et al. 2007). On the circum-Sicilian islands, *Boerhavia coccinea* was first recorded by Pasta et al. (2017) on Linosa island in 2006. The species was photographed on Pantelleria in August 2010 by one of the authors (EM), who recorded it on the Acta Plantarum forum (Montoleone 2010). Presently, in Pantelleria, *B. coccinea* is rapidly spreading along many roadsides in several locations including Lago di Venere, Bukkuram and the surrounding areas of Scauri (Figures 3C, 6a). Although the species does not tend to invade natural habitats, its uncontrolled spread presents serious economic damage for the cultivated areas as a weed to be kept under control with agricultural tillage. Therefore, it is necessary to develop a management plan for *B. coccinea*, including eradication in areas with sparse populations, and increasing awareness about the risks posed by this species to local community and farmers for the implementation of effective prevention measures.

***Carpobrotus edulis* (L.) N.E.Br. (Fam. Aizoaceae)**

Species native to South Africa and, together with *Carpobrotus acinaciformis* (L.) L. Bolus, represents the most dangerous invasive plant species for biodiversity conservation in coastal areas of Mediterranean-type ecosystems, including Sicily and Maltese Islands (Novoa et al. 2014; Badalamenti et al. 2016a; Podda et al. 2017; Campoy et al. 2018; Mifsud 2021). *Carpobrotus acinaciformis* has not been observed by us in Pantelleria although a record exists (Gianguzzi 2003). In Linosa, a small volcanic island south-west of Sicily, *C. acinaciformis* was found to profoundly change soil properties and associated microbial communities, seriously hindering the natural regeneration of native species (Badalamenti et al. 2016b; Mugnai et al. 2022). Similar ecological impacts can be expected in a comparable insular ecosystem like Pantelleria. Here, the species is widely spread along the coasts of the northern sectors and in many sites it directly competes with several native species of interest such as *Capparis spinosa* L., *Matthiola incana* (L.) W.T.Aiton subsp. *incana* and *Limonium cosyrense*. This latter may be at serious extinction risk due to *Carpobrotus* spread because it is a narrow endemic species thriving in coastal habitats that are preferentially invaded by this invasive species. In particular, *Carpobrotus edulis* has been observed in Punta Spadillo, and is widespread near the

lighthouse (Figures 3D, 6f), where it threatens the existence of *Limonium cosyrense*. Some other very rare species grow in this locality, including *Bellium minutum* (L.) L., whose only Italian population is found there. *Carpobrotus edulis* seriously threatens chasmo-halophilous vegetation characterized by *Limonium cosyrense* and *Juniperus turbinata* Guss. maquis throughout the island. The former is a narrow endemic species, while the latter is a rather rare species in Sicily and nearby islets (Minissale and Sciandrello 2013). These plant communities are also habitats of Community interest according to Directive 92/43 EEC (code 1240 "Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp." and code 5210 "Arborescent matorral with *Juniperus* spp."). *Carpobrotus edulis* is one of the alien plant species to which more attention and management efforts should be given. Indeed, it exerts deleterious impacts on native ecosystems and should be eradicated, with priority attention where it threatens habitats and species of community interest, so eradication is strongly recommended also by means of new techniques that have recently been developed (Lazzaro et al. 2023). This action will be complicated since *C. edulis* is greatly appreciated for its impressive flowers and anti-erosion function and this may encounter some resistance among stakeholders. Therefore, education programs to spread awareness about the ecological risks associated with *C. edulis* will be crucial if we are to reduce its cultivation on the island and limit its spread to coastal areas close to private territories.

***Cenchrus setaceus* (Forssk.) Morrone (Fam. Poaceae)**

It is native to arid regions of the Middle East, North Africa, and some central African countries like Kenya, Somalia, Sudan and Tanzania. It was introduced as an ornamental plant in many countries with warm temperate climate, including those in the Mediterranean region, in the mid-20th century. Globally it is worth of mention the serious invasion of this species in volcanic Hawaii islands, where this species introduced in 1914 is now very abundant and widespread on lava flows and rangeland (Tunison 1992). *Cenchrus setaceus* has been listed as invasive species of European Union concern since 2017 (sub *Pennisetum setaceum* [Forssk.] Chiov.), due to its invasive behavior in the Mediterranean Europe. Several traits have made this species an excellent invader of Mediterranean-type ecosystems, including high drought resistance, fast growth rates (Badalamenti et al. 2016b) and easily wind-dispersed seeds (Williams et al. 1995). The ecological adaptation of *Cenchrus setaceus* to warm and dry environments is apparent in the Maltese Archipelago, where eradication actions are in progress (Mifsud 2022). Although *C. setaceus* is well-known for Sicily as a rapidly spreading invasive alien species (Pasta et al. 2010), its presence had not yet been reported for the Circumsicilian islands. Here, we report the first record for Pantelleria, where it was found thriving in several sites (Figures 3E, 5). The first observation of naturalization events was made

in 2006 (T. La Mantia *personal observation*), when it was found as escaped from cultivated individuals along both sides on a private road. Since then, the natural population of the species, along with the number of cultivated plants, have grown considerably. Although some plants are cultivated in the flower beds, more frequently it grows along roadsides together with native species, where it shows a clear tendency to replace them. Indeed, the high competitive ability of *Cenchrus setaceus* is likely to considerably reduce the distribution of native plants such as *Oloptum miliaceum* (L.) Röser & H.R. Hamasha and *Hyparrhenia hirta* (L.) Stapf (Pasta et al. 2010) on the island. More worrying, we found 8 sites with natural populations composed of more than 10 flowering individuals, indicating a very high rate of spread in Pantelleria.

Moreover, the remarkable ability to colonize lava substrates observed in Hawaii Islands, although in different climatic conditions, is cause for alarm for a volcanic island like Pantelleria. Currently, *Cenchrus setaceus* shows a relatively limited distribution; suggesting that eradication can be reasonably achieved and is technically feasible. Given that most (if not all) nuclei of the species originated from cultivation in private areas, a direct involvement of landowners and local people is of crucial importance for effective eradication.

***Leucaena leucocephala* (Lam.) de Wit subsp. *glabrata* (Rose) S. Zárate (Fam. Fabaceae)**

This species is native to Mexico and probably to Central America and Caribbean countries (Binggeli et al. 1998). *Leucaena leucocephala* has shown a marked invasive behavior worldwide, rapidly spreading in anthropogenic and ruderal habitats as a typical light-demanding pioneer plant, as well as in semi-natural and forest habitats, especially if disturbed frequently (Wolfe and Van Bloem 2012). It was introduced to Sicily in 1793, through the Botanical Garden of Palermo (Raimondo and Domina 2007), while the first naturalization cases were relatively recent and concerned both the southern (Agrigento) and northern coasts (Campofelice di Roccella and Cefalù) of the island (Raimondo and Domina 2007). It was later indicated as a naturalized species in several other coastal areas of Sicily and in the circum-Sicilian islands, including Linosa (Pasta et al. 2017), Favignana (Maggioni 2014) and Lampedusa (Badalamenti et al. 2020). In Pantelleria, the species has been observed at the Lago di Venere and Bukkuram in abandoned areas (Figures 3F, 6c). At this stage, the eradication of spontaneous nuclei is the recommended management option, given the restricted distribution on the island, in order to prevent further spread considering the well-known invasiveness at the global scale and in Mediterranean ecosystems.

***Malephora crocea* (Jacq.) Schwantes (Fam. Aizoaceae)**

It is native to South Africa and has become an invasive species in many areas around the Mediterranean Basin (Battisti and Fanelli 2021). It appears

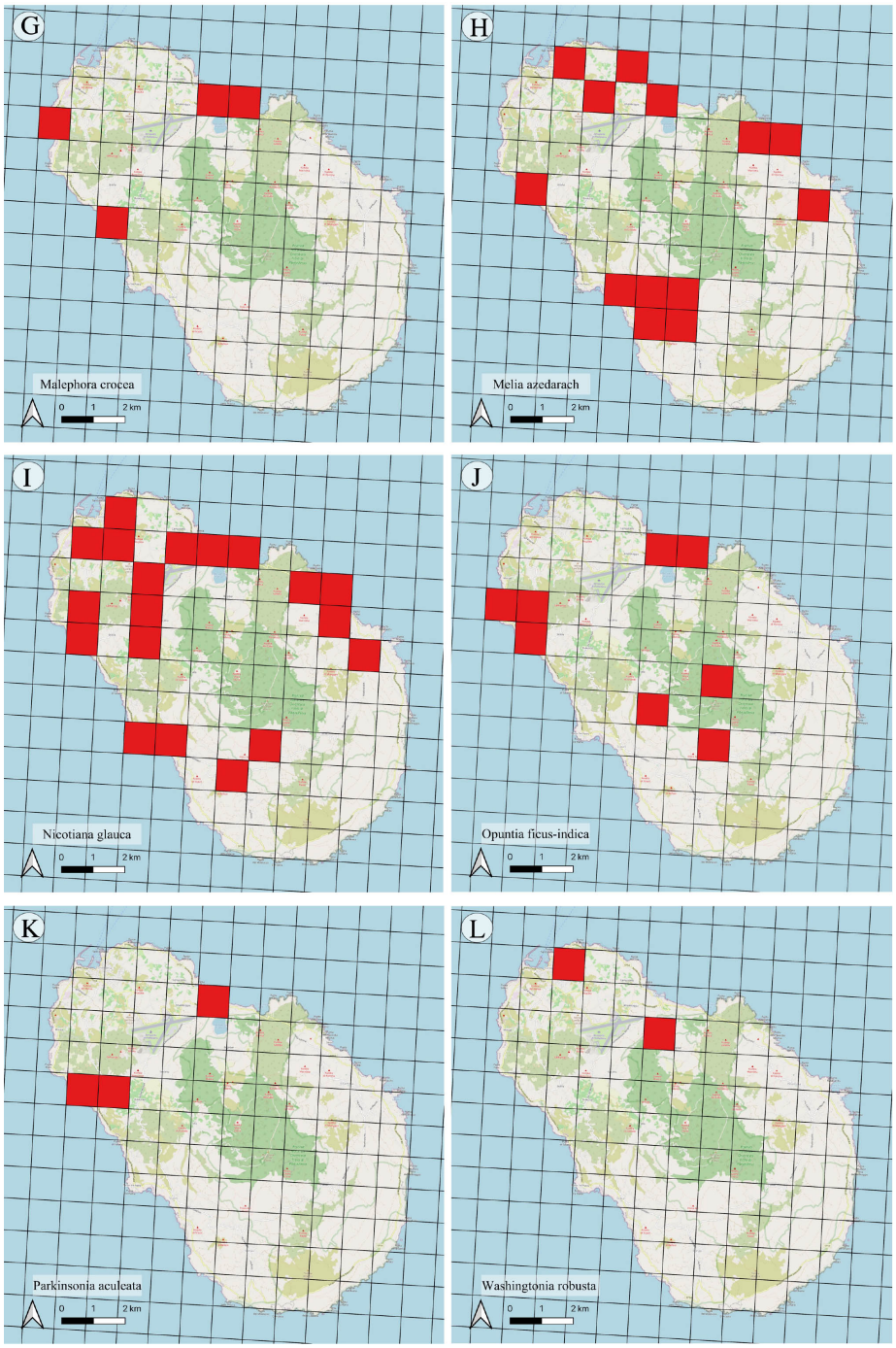

Figure 4. Current distribution of *Malephora crocea* (G), *Melia azedarach* (H), *Nicotiana glauca* (I), *Opuntia ficus-indica* (J), *Parkinsonia aculeata* (K), and *Washingtonia robusta* (L) in Pantelleria island (Sicily, Italy).

to have escaped from gardens close to dwellings, and has spread to habitats including sea cliffs, stream banks, floodplains, and coastal areas. During this study, it was recorded only along the west coast, in the localities of Punta della Mandria and Punta Pietra Rotonda (Figures 4G, 6g). This species grows in the chasmo-halophilous vegetation with *Helichrysum errerae* and *Limonium cosyrense*, which thrive within an important habitat that needs protection actions (code 1240: Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp.). The presence of the

Figure 5. Occurrences of *Cenchrus setaceus* first recorded in Pantelleria island. The plant is undergoing naturalization as it spreads from points of cultivation, as in the two right photos. Spontaneous populations along roadsides were observed as in the left photos. Photographs by Pietro Minissale.

species on the island had already been reported by one of the authors (EM) on the Acta Plantarum Forum (https://www.actaplantarum.org/forum/viewtopic.php?t=46935&p=301686#p301686). Eradication is recommended like *Carpobrotus edulis*, although it is much less abundant and less invasive.

***Opuntia ficus-indica* (L.) Miller (Fam. Cactaceae)**

It is native to Mexico and has become an invasive species in many Mediterranean areas such as Spain, Sicily and Sardinia (Podda et al. 2017). *Opuntia ficus-indica* is very well-known for its edible fruit and, especially in Sicily, is considered an identity element of the landscape by local people (Barbera et al. 1992). On Pantelleria, although it is in widespread cultivation, it still remains rather localized as an invasive plant and is mainly confined to the northern sector of the island, as observed on the rocky ridges overlooking Lago di Venere or in the archaeological area of "Sesi" (Figures 4I, 6h). Therefore, Pantelleria's typical landscape, both natural and agricultural, is almost devoid of it. For this reason, we recommend localized eradication or containment activities only where *Opuntia* threatens local biodiversity. For instance, the species creates some problems in a few areas where it has established itself with substantial populations in the xerophilous Mediterranean scrub, characterized by *Euphorbia dendroides* and *Periploca*

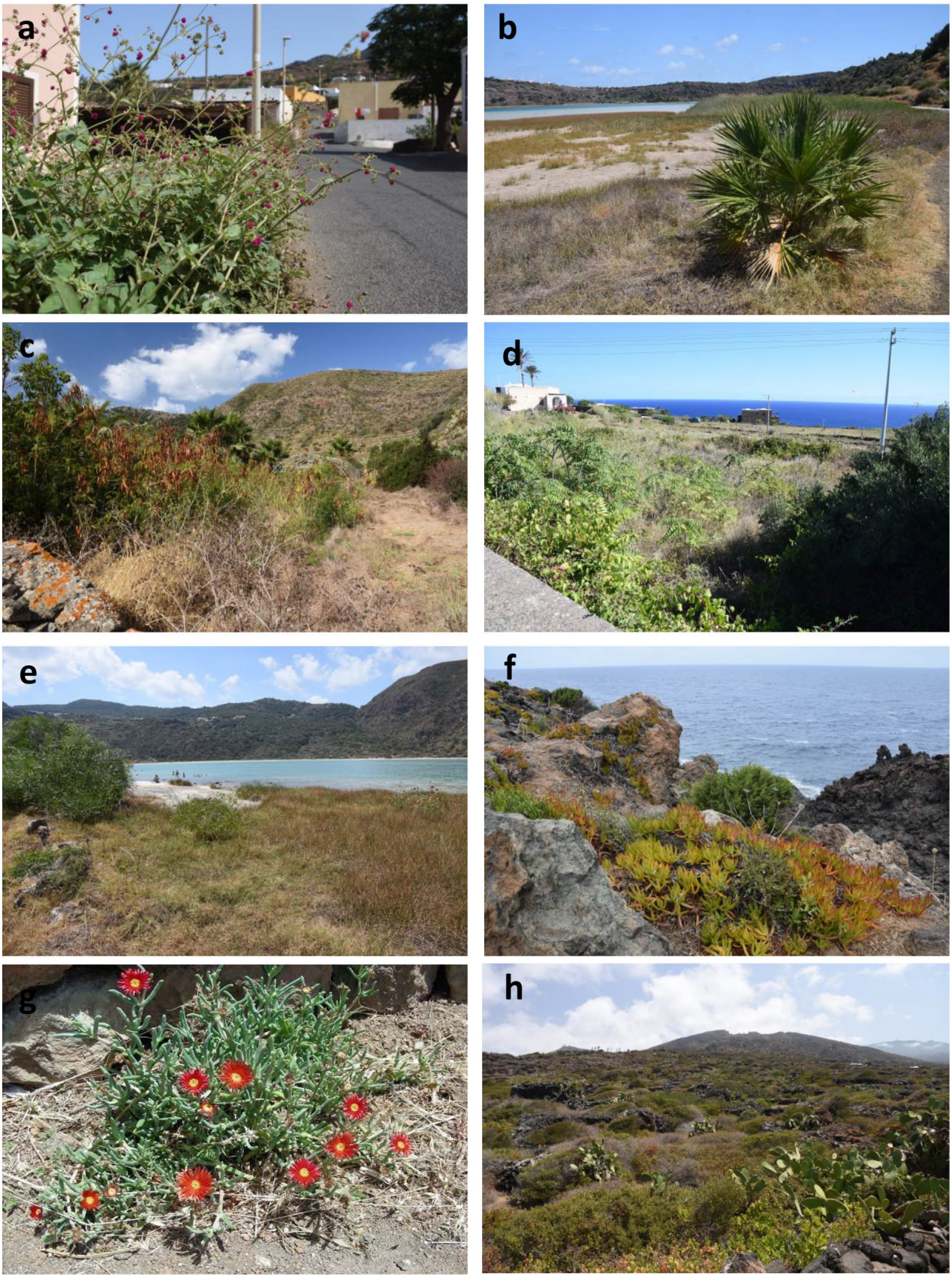

Figure 6. Photo plate of the alien species recorded in Pantelleria island: a) *Boheravia coccinea*; b) *Washingtonia robusta;* c) *Leucaena leucocephala* subsp. *glabrata*; d) *Ailanthus altissima*; e) *Acacia saligna;* f) *Carpobrotus edulis*; g) *Malephora crocea;* h) *Opuntia ficus-indica.* Photographs by Pietro Minissale and Erina Montoleone.

angustifolia, which represents a habitat of community interest (code 5330 Thermo-Mediterranean and predesert scrub).

***Washingtonia robusta* H. Wendl. (Fam. Arecaceae)**

The species is native to California and today is widely used as an ornamental plant in many Mediterranean parks and gardens. According to recent research (Verloove 2013), it shows a good adaptability that facilitates colonization of insular ecosystems. In Pantelleria, it has already become naturalized in many sites; for example, along the Lago di Venere, several young individuals now threaten the sub-hygrophilic vegetation of the lake's shore (Figures 4L, 6b). In addition, another palm tree, *Phoenix canariensis* Chabaud seems to be in incipient naturalization in the same microsite, with a few young spontaneous individuals. This area is a wetland of great naturalistic value due to the presence of several rare species such as *Limonium secundirameum*, a narrow endemic occurring only in this locality, and *Cyperus laevigatus* L. subsp. *laevigatus*, a subtropical species recorded only on Pantelleria within Italian territory. Our study reports the first record of *Washingtonia robusta* for Pantelleria as a naturalized species, for which we suggest the local eradication where it can represent a serious ecological threat to native species and communities along with the constant monitoring of the invasion process throughout the island.

Other non-native plant species

During field surveys, we also recorded the occurrence of other non-native plant species with currently limited distribution in Pantelleria but which have the potential to spread in the coming decades and impact local biota and landscape. We briefly discuss the following six species: *Austrocylindropuntia subulata* (Muehlenpf.) Backeb., *Lantana camara* L., *Melia azedarach* L., *Nicotiana glauca* Graham, *Opuntia stricta* (Haw.) Haw. and *Parkinsonia aculeata* L.

Austrocylindropuntia subulata is a succulent species native to South America that has been observed in just a few sites (e.g., on road slopes along "Strada perimetrale dietro l'isola" in south-eastern sectors, and in the little harbour of Scauri, in the central-western sector). It has also been observed in rocky coastal areas in the harbour of Gadir, where it coexists with *Ailanthus altissima* and *Opuntia stricta*, just a few meters from the sea. This non-native plant has been increasingly observed with self-sown individuals in Sicily, as well as on the surrounding islands (e.g., Lampedusa, *personal observation*), sometimes even in small nuclei. It is also considered invasive in Sardinia (Galasso et al. 2018). Accordingly, we suggest monitoring its naturalization process in Pantelleria.

Lantana camara is native to Mexico and Tropical America and has been only rarely observed in the wild in Pantelleria (e.g., in sub-urban areas in the Arenella locality and in coastal sites in Cala dell'Elefante). However, in

the last decades, this shrub has dramatically expanded its range (Domina and Mazzola 2002; Sciandrello et al. 2014; *personal observations*) and is fully naturalized in Sicily. Furthermore, its invasive potential is recognized worldwide, and the species was included in a world list of the most invasive non-native species more than 20 years ago (Lowe et al. 2000). A regular monitoring of its naturalization process is of crucial importance, also taking into account the wide use and appreciation of the species as an ornamental plant. An awareness campaign could try to discourage the use of *L. camara* in favor of native or at least non-native species that are not potentially invasive.

Melia azedarach is native to S-SE Asia and N Australia and has been observed as spontaneous in fewer than eight sites, primarily roadsides and abandoned areas. In Sicily, this ornamental tree has undergone an apparent increase in its naturalization in the last two decades (Badalamenti et al. 2013), also including small volcanic islands like Linosa (Pasta et al. 2017). For these reasons, the monitoring activities should also focus on this taxon, especially to assess its ability to invade seminatural and natural communities, as this has not yet occurred.

Nicotiana glauca is native to South America and has been recorded in more than 10 sites in Pantelleria, mostly as single individuals in dry-stone walls and ruderal areas. However, the species is already invasive in Sicily, Sardinia and Calabria (Galasso et al. 2018). On Linosa island, this non-native tree showed impressive invasiveness, very abundant natural regeneration, and serious ecological impacts before its eradication during Project LIFE11+ NAT/IT/000093 Pelagic Birds (Pasta et al. 2017). For this reason, great attention should pose to this taxon to avoid a similar invasive process and therefore eradication or at least containment activities are strongly recommended.

Opuntia stricta, native to SE U.S.A. and E and S Mexico, is the most concerning non-native plant as it has already invaded natural habitats in Pantelleria. This succulent species was found thriving in rocky cliffs in coastal areas (e.g., near Arco dell'Elefante, Cala Gadir). It is considered invasive at the national level in Tuscany, Lazio, and Veneto (Galasso et al. 2018), as well as worldwide (Lowe et al. 2000). Apart from the prevention of the invasion of new available sites, the detected nuclei should be eradicated as quickly as possible to protect the native flora and vegetation with which it aggressively competes.

Parkinsonia aculeata is native to Tropical America and has been recorded in two sites: a small area near the "Bagno di Venere" and another area close to "Chiesa della Madonna delle Grazie". In Sicily, this species is rapidly expanding (Bazan et al. 2011), primarily in disturbed and abandoned areas but also in grasslands, showing a tendency to establish dense populations. Therefore, we recommend periodic monitoring in Pantelleria.

Table 2. A comparison between the distribution data of the main invasive non-native plants included in the Management plan of the Natura2000 sites with that provided in the current study.

Species	Distribution data from 2009 (AA VV 2009)	Distribution data (this study) Number of records
Acacia saligna	Not reported	29
Ailanthus altissima	Present within SAC ITA010020 in < 5 nuclei or groups, highly invasive	26
Boheravia coccinea	Not reported	8
Carpobrotus edulis	Present within SAC ITA010020 in < 100 nuclei or groups, highly invasive	25
Cenchrus setaceus	Not reported	24
Leucaena leucocephala subsp. *glabrata*	Not reported	7
Malephora crocea	Not reported	4
Opuntia ficus-indica	Present within SAC ITA010019 and ITA010020 in > 10 nuclei or groups, highly invasive	8
Washingtonia robusta	Not reported	2

To understand the rapid increase in the number and cover of alien plant species in Pantelleria, we compared our distribution data of the main invasive non-native plants with the information provided in the management plan of the Special Areas of Conservation included on the island (Codes ITA010019 and ITA010020) (AA VV 2009) (Table 2). Out of nine non-native invasive species treated in this study, six were not detected just a decade ago. *Ailanthus altissima* has expanded in range over the last few years; however, *Carpobrotus edulis*, *Nicotiana glauca*, and *Opuntia ficus-indica* do not seem to have seriously expanded their presence in Pantelleria.

Discussion

Biodiversity conservation is greatly threatened by invasive alien plants, given their ability to replace native flora and irreversibly change the characteristics of natural ecosystems and landscapes, as observed in various geographical areas of the world (Seebens et al. 2017; Pyšek et al. 2017, 2020; Lenzner et al. 2020; Campagnaro et al. 2022). The number of invasive species and their related impacts are projected to increase worldwide in the next decades due to several factors including ornamental trade, higher disturbance frequency and climate change effects (Vorsino et al. 2014; Park et al. 2020). In Italy, the alien flora has grown considerably over time (Galasso et al. 2018; Laface et al. 2020). However, information about the occurrence and spread of alien plant species is relatively poor and incomplete for the small Mediterranean islands (Celesti-Grapow et al. 2016; Pasta et al. 2017). Indeed, these islands could function as strategic locations where effective invasive species management practices could be put into practice. The strategies and actions (e.g., the prevention of an introduction) necessary to tackle invasive species could be more easily and successfully implemented because islands are physically separated environments. Small islands host a fragile biota but, for the small size of natural populations, their vascular flora is rich in endemic species generally more fragile and less competitive in occupying space than many invasive alien species. Thus, timing is of crucial importance also because interventions

should avoid any damage to native species while maximizing the damage to invasive species.

The number and extent of spread of alien plant species recorded in Pantelleria raise concern for the long-term conservation of the island's natural and seminatural habitats. In fact, the uncontrolled spread of invasive alien plants can affect not only native plant species and communities, but also sites of great naturalistic importance such as the "Bagno di Venere", a wetland of fundamental importance for the peculiar plants that grow there, for the geochemical peculiarities of the lake that allow the presence of siliceous stromatolites (Cangemi et al. 2010), and as resting and nesting habitat for birds (Corso et al. 2012). The good management practices of protected areas and the indications of the European Habitat Directive, relating to the protection of natural and seminatural habitats, require the implementation of adequate conservation and management measures, including actions to counter the threat of alien species (Lazzaro et al. 2020). Particular attention must be paid to the species already identified as presenting a high risk of invasion within this geographic context (Lazzaro et al. 2019). *Acacia saligna, Ailanthus altissima,* and *Cenchrus setaceus* are already listed as species of Union interest (Regulation EU 1143/2014), and there are severe restrictions on the keeping, importing, selling, breeding, and growing these species in the territories of the European Union. Hence, to preserve the natural ecosystems and landscape traits of Pantelleria from these alien species, the effective implementation of the EU Regulation would be sufficient. In addition to these three species, *Carpobrotus edulis* is the alien species reaching the highest priority for control actions in Pantelleria.

Furthermore it is noted that among the species presented in this study some groups of plants, such as succulents, woody Fabaceae, and more in general thermophilus and/or drought resistant species, are relatively over-represented, thus fitting into a broader context, that is a more general trend of increase in these groups identified in Mediterranean islands (Celesti-Grapow et al. 2016; Cerrato et al. 2023) and that may be relevant in view of current—and future—global warming.

The management of alien species, especially on islands, cannot ignore the involvement of the local community (Shackleton et al. 2019), and should include appropriate communication actions that disseminate knowledge about the risks associated with the uncontrolled spread of invasive species. For instance, in the Maltese Islands, located in the Strait of Sicily, the careless introduction in the early 2000s of *Cenchrus setaceus* led to its rapid naturalization and now the government has launched an intense eradication campaign, also involving the local population for reporting (Mifsud 2022). The local community involvement is just one of the scopes of the Project "Gestione e controllo delle piante aliene a Pantelleria" (PRJ-0742) that has been launched and funded by Pantelleria National Park. Local

people will also be actively engaged in the recording of alien species occurrences, following the new frontiers of citizen science. In this regard, the local community could be really interested, not so much in the protection of biodiversity, of which most people, unfortunately, have little awareness (European Commission 2019; Oliveira et al. 2020), but rather in the conservation of the landscape identity. This can be understood as "perception of the uniqueness of a place" (Stobbelaar and Pedroli 2011), and is particularly felt in Pantelleria because of its volcanic history and its absolutely unique and recognizable rural and natural landscapes (Barbera and La Mantia 1998; Gianguzzi 1999; Barbera and Cullotta 2012; Sunguroğlu Hensel 2020; D'Ascanio et al. 2021). This shared perception elicits feelings of protectiveness that inspire to action. Education and communication can then connect landscape identity with the reality that biodiversity is responsible for the very uniqueness of the place to which the local community feel connected.

Since some alien plants become invasive and can profoundly alter landscape traits within a few years, with cooperation among the municipality, National Park and local communities, efforts to manage invasive non-native species will contribute to the conservation of the unique habitats of Pantelleria, and the vast array of endemic species they support.

In conclusion, this study can provide useful information for ensuring the conservation of the natural habitats of Pantelleria, through the identification of the plant taxa to which more management efforts should be put.

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Authors' contribution

PM: research conceptualization, sample design and methodology, investigation and data collection, data analysis and interpretation, funding provision, ethics approval, writing – original draft, writing – review and editing. SC: investigation and data collection, writing – review and editing. EM: investigation and data collection. GT: investigation and data collection, distribution maps elaboration writing – review and editing. GGG: writing – review and editing. SS: research conceptualization, writing – review and editing. EB: research conceptualization, investigation and data collection, writing – original draft, writing – review and editing. TL: research conceptualization, data analysis and interpretation, funding provision, writing – review and editing.

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