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First finding of *Alternanthera maritima* in Europe (Sicily) and considerations on its morphological peculiarities, ecological requirements, and potential invasiveness

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Abstract. *Alternanthera maritima* was found in the southeastern part of Sicily, marking a new floristic record for both Italy and Europe. This paper provides an analysis of the morphological characteristics observed in the collected specimens and explores the ecological features of the community where they were found. Also, we discuss the taxonomic criticality of the genus and assess the risk that the new finding may become invasive.

Keywords: *Alternanthera maritima*, alien species, Sicily, taxonomic criticality, ecology, potential invasiveness.

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Introduction

Alternanthera Forssk. (Amaranthaceae Juss., Gomphrenoideae Schinz.) is a Neotropical genus with the main center of diversity in South America; only few taxa are native to Africa, Asia, and Australia (Robertson, 1981), while some species are introduced in Central and North America and Europe. According to Euro+Med Plantbase (https://europlusmed.org), Europe hosts 12 casual or naturalised species, mainly spread in West and Central Europe, plus two doubtfully recorded (Figure 1). From the taxonomic point of view, this genus is critical due to its high phenotypic variability, resulting in nomenclatural disarray and misapplications of names. Consequently, the number of the *Alternanthera* species is still debated, ranging from 80 to 200 species (Sánchez-del Pino *et al.*, 2012). [e.g. World Flora Online (http://www.worldfloraonline.org/) includes 149 accepted names, 119 synonyms, and 33 unchecked names].
In Italy, five taxa are recorded (Galasso *et al*., 2018): *A. philoxeroides* is a problematic invasive species (Iamonico *et al.*, 2010) mainly spread along the main rivers of Tuscany and Lazio regions (Iamonico & Sánchez-Del Pino, 2016), while *A. paronychioides* var. *pilosa*, *A. tenella*, and *A. pungens* are casual aliens (Iamonico, 2018). *A. tenella* is reported for Italy from two localities, Florence (Tuscany, Iamonico & Sánchez-del Pino, 2016) and Palermo (Sicily; Scafidi et al., 2016). The other three species were recorded during the last century in NW Italy (Liguria and/or Tuscany) but have not been found recently (Iamonico & Sánchez-Del Pino, 2016).

Recent field investigations in Sicily led to the discovery of a new population of *Alternanthera* in the South-Eastern part of the island. In this paper, we analyze (i) the morphological features of the collected specimens and (ii) the ecological features of the community in which they were found. Also, we will (iii) discuss the taxonomic criticality of the genus and (iv) the risk that the new finding may become invasive.

Study area

In August 2022, we found a population of *Alternanthera* in the children's playground of Sampieri (Scicli, SE-Sicily, Figure 2 A, B) under a thermomediterranean dry bioclimate (Bazan *et al*., 2015). The playground

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covers an area of about 380 m^2 a few meters away from the sea, and it is an obligatory passage point to the beach (Latitude: 36.7207989 N, Longitude: 14.7386386 E, accuracy: 3m). In the playground, there are a few ornamental trees of *Lagunaria patersonii* and *Ceratonia siliqua*, irrigated in summer. The sand dune vegetation next to the playground is nowadays completely altered by urbanization and trampling, but a few psammophilous species still persist (*Cakile maritima*, *Eryngium maritimum*, *Pancratium maritimum*, *Salsola kali*, etc.).

Material and methods

The collected specimens (deposited at the Herbaria PERU and RO; see Thiers, 2023+) were examined by using both the keys and the description of the Flora of Italy (Iamonico, 2018), Flora of Pakistan (Townsend, 1974), Flora of North America (Clemants, 2003), Flora of China (Boijan *et al*., 2003), and Atlas of living Australia (2022+). The floral parts [especially tepals shape and size, and pseudostaminodia structure (appendanges on the androecial tube)], which are crucial for the correct identification in *Alternanthera*, were examined using a stereomicroscope (see e.g., Sánchez-del Pino *et al.*, 2012; Iamonico & Sánchez-Del Pino, 2016; Sindhu et al., 2021). Three vegetation relevés of 0.5 m^2 were sampled in the patches with high cover/abundance of *Alternanthera*, according to the Braun-Blanquet's sampling methodology (Braun-Blanquet, 1928). The Ellenberg Indicators Values (EIVs) extracted from the Flora of Italy (Pignatti *et al*., 2017–2019) were assigned to each species. To define the ecological requirements of the community, we calculated the Community Weighted Mean (CWM) of the EIVs regarding light (L), temperature (T), continentality (C), moisture (M), soil reaction (R), and nutrients (N). Each EIV was weighted by the cover values of the corresponding species, recorded in the three vegetation relevés. The CWM was plotted in a spider chart. Taxonomical and syntaxonomical nomenclature mentioned in the text follows Euro+Med Plantbase (https://europlusmed.org) and Mucina *et al.* (2016), respectively.

Results

Species identification

We found plants characterized by stems prostrate, pubescent, branched, brownish to reddish, the leaves green, ovate to obovate, and inflorescences arranged in sessile glomerules. Among the *Alternanthera* taxa currently recorded in Italy, *A. philoxeroides* is the only one with pedunculate glomerules and, therefore, it can be excluded. The other three species present in Italy have sessile glomerules, but *A. tenella* has leaves lanceolate, while *A. paronychioides* and *A. pungens*, despite having leaves ovate-obovate to elliptic, display tepals villous (hairs barbed in *A. pungens*, not barbed in *A. paronychioides*) and pseudostaminodia triangular (entire or dentate), whereas the Sicilian plants at issue have tepals glabrous and pseudostaminodia laciniate.
In addition to the five aforementioned Italian *Alternanthera* species, the flora of Europe includes the following further six species (Iamonico, 2015+): *A. angustifolia*, *A. bettzickiana*, *A. caracasana*, *A. denticulata*, *A. ficoidea*, *A. nodiflora* [*A. pilosa* Moq., accepted at species rank in Euro+Med PlantBase is, actually, a variety of *A. paronychioides*, i.e. var. *pilosa* (Moq.) Suess. (see Iamonico & Sánchez-Del Pino, 2016); *A. flavogrisea* is doubtfully recorded in the continent (France)]. However, none of these taxa can be ascribed to Sicilian plants, due to the following characters (features of the Sicilian plants in brackets):

- *A. angustifolia* has leaves narrow lanceolate-linear (*vs*. ovate to obovate),
- *A. bettzickiana* is an erect to ascending herb (*vs*. prostrate-diffuse),
- *A. caracasana* has tepals densely villous and pseudostaminodia entire (*vs*. glabrous and laciniate),
- *A. denticulata* has leaves lanceolate (*vs*. ovate),
- *A. ficoidea* has tepals villous (*vs*. glabrous),
- *A. nodiflora* has leaves lanceolate-linear and tepals villous (*vs*. ovate and glabrous).

All things considered, our discovery would represent a new floristic record at the national and European level. So, we tried to consider the other continents. First, it is to be noted that the structure of pseudostaminodia of Sicilian plants (laciniate) is rare in *Alternanthera* (D. Iamonico & I. Sánchez-Del Pino, pers. obs.). Among the known *taxa* occurring in Asia, laciniate pseudostaminodia can be observed in *A. indica* S.Arya, V.S.A.Kumar, Sánchez-Del Pino & Iamonico (a recently described species from Kerala, India; Sindhu *et al*., 2021) and, sometimes in *A. sessilis* (Clemants, 2003). However, none of these two species can be ascribed to sicilian *Alternanthera* since 1) *A. indica* has leaves spathulate (*vs*. ovate) and tepals densely villous (*vs.* glabrous) and 2) *A. sessilis* has leaves obovate to oblanceolate (*vs*. ovate) and

tepals villous (*vs.* glabrous). Concerning the American continents, the only species with inflorescence sessile, pseudostaminodia laciniate, and tepals glabrous is *A. maritima* which has also vegetative characters congruent with plants found in Sicily (stem prostrate, browinsh in the inflorescence part, and leaves green and ovate). The only features which is different would be the typically glabrous stem in *A. maritima*, whereas sicilian plants has stem pubescent. However, as highlighted already by Saint-Hilaire (1833: 437–438) in the protologue of *A. maritima*, as well as by the important treatment of *Telanthera* by Moquin-Tandon [1849: 364, sub *T. maritima* (Mart.) Moq.] in Candolle's *Prodromus*, this species shows a high phenotipic variability, also regarding the hairiness of the stem (from glabrous to pubescent). Also, Pedersen (1990) highlighted again the morphological variability of Martius' taxon *maritima* [sub *A. littoralis* var. *maritima* (Mart.) Pedersen] by including in synonymy both the Saint-Hilaire's and most of Moquin-Tandon's varieties. Note that no recent research was published on this south American species and its infraspecific variability, as well as a quite complicate nomenclature (D. Iamonico in prep.). Therefore, waiting further investigations, we refrain to consider any infraspecific rank and identify sicilian plant as *A. maritima* (following the nomanclature by Clemants, 2003).

Ecology of the taxon

The found taxon colonizes a narrow stripe (7,28 m^2) of the playground, where the soil remains moist even in summer thanks to irrigation; only one plant grew relatively isolated, around 9 m away from the main population. The species grows in rather poor assemblages in which the most frequent species are typical of the phytosociological class *Digitario sanguinalis-Eragrostietea minoris*, such as *Convolvulus arvensis*, *Cynodon dactylon*, *Cyperus rotundus* and *Alternanthera* itself, or of the class *Chenopodietea*, such as *Chenopodiastrum murale* and *Erigeron bonariensis* (Table 1), albeit this last species is often found also in the vegetation of the former class (Mucina *et al*., 2016). The CWM of the EIVs (Figure 2E) highlight the relatively mesophilous character of this vegetation.

Table 1. Vegetation relevés, sampled according to the Braun-Blanquet's method (Braun-Blanquet, 1928).

Relevès	1	2	3
Date	23/08/2022	23/08/2022	23/08/2022
Latitude	36.720799	36.720746	36.720767
Longitude	14.738639	14.738566	14.738566
Accurancy (m)	3	3	3
Plot size (m^2)	0.5	0.5	0.5
Cover (%)	20	90	80
Alternanthera maritima	2	3	3
Convolvulus arvensis	1	3	2
Cynodon dactylon	1	4	
Chenopodiastrum murale		1	
Cyperus rotundus		2	3
Erigeron bonariensis		3	2
Reichardia picroides		1	
Malva sylvestris			1
Tribulus terrestris			2
Portulaca olarecea			2

Discussion

Taxonomic criticality of the genus Alternanthera

The highly diverse neotropical *Alternanthera* was recently shown to be monophyletic within the subfamily Gomphrenoideae (Sánchez-Del Pino *et al.*, 2012) with the capitate stigma being a synapomorphy for the genus. At ranks below the genus, Sánchez-Del Pino *et al*. (2012) identified several main lineages, some still unresolved, and one recently proposed at subgenus level, i.e. subgen. Jamesbondia Sánchez-Del Pino & Iamonico (Sánchez-Del Pino & Iamonico, 2016). More taxonomic difficulties occur at species and infraspecific ranks since the circumscription of several taxa and their morphological variability remain quite obscure. In fact, the number of taxa belonging to *Alternanthera* is currently debated, ranging from 80 to 200

species (see e.g. Sánchez-del Pino *et al.*, 2012; POWO, 2023). Consequently, a comprehensive monograph of the genus *Alternanthera* is still lacking. In the case of the discovered Sicilian population, the rare structure of pseudostaminodia (laciniate) allowed us to reach to an identification.

Additionally, the ecophysiological and phenoptypic plasticity of *Alternanthera* representatives has been indicated as the key factor in colonizing a wide range of habitats with different water availability (Geng *et al*., 2007; van Boheemen *et al*., 2019). The mechanisms underlying environment-induced plastic responses and phenotypic variation have received considerable attention in recent literature (Morange, 2009; Pimpinelli & Piacentini, 2020). Much evidence indicates that phenotypic changes in response to environmental heterogeneity are associated with epigenetic regulation of rapid responses to environmental fluctuation (Marden, 2008; Steward *et al*., 2022). Interestingly, phenotypic variation due to epigenetic reprogramming is reversible and subject to variation from one generation to the next (Gao *et al*., 2010). Since phenotypic variation can occur without corresponding changes in the genome (Banta & Richards, 2018), species identification based on morphological characters is quite challenging, especially if, as in our case, the population consists of relatively few individuals.

Could Sicilian Alternanthera become a potential invader?

Our results suggest that *Althernanthera maritima* participates in a community rich in elements of the phytosociological class *Digitario sanguinalis-Eragrostietea minoris*, i.e. anthropogenous vegetation rich in C4 species on summer-dry sandy to loamy soils with neutral to subalkaline reaction, that could be framed within the alliance *Diplotaxion erucoidis* (Brullo & Marcenò, 1985; Brullo *et al*., 2007). Like other representatives of the genus *Alternanthera*, that colonize fresh river borders or irrigated city gardens (Peña Rivera & Ferrer-Gallego *et al*., 2016), the species seems to be related to soils not too dry even in summer. This is probably the reason why most congeners are spread in the Atlantic regions of Europe (see, for example, the number of species in Belgium, Figure 1), whereas, in the Mediterranean area, occurrences are rarer and more inconstant, probably due to the summer drought stress, acting as a major limiting factor for the spreading of *Alternanthera* species.

In general, most congeners recorded in Europe are casual aliens, with a scattered distribution limited to synanthropic areas (Iamonico, 2015+). These species often disappear after a few generations because of changes in the ecological conditions of the areas where they grow. In contrast, a few *Alternanthera* seem to be successful invaders in Europe. This is the case of *A. philoxeroides*, that is considered invasive along several rivers of Central Italy (Ceschin *et al*., 2006; Iamonico *et al*., 2010; Iamonico & Sánchez-Del Pino, 2016) and Southern France (European and Mediterranean Plant Protection Organization, 2016), participating to vegetation units ascribed to the classes *Potametea*, *Phragmito-Magnocaricetea*, and *Molinio-Arrhenatheretea* (Iamonico *et al*., 2010).

Although only a few representatives of this genus seem to be prone to ecosystem invasion, more *Alternanthera* species are considered potential threats to the ecosystems. For instance, *A. caracasana* and *A. pungens* are mentioned as potential threats in the checklist of plant invaders in Spain (Dana *et al*., 2001).

The arrival of *Alternanthera maritima* (a neophyte native to eastern S-America) in Sicily is probably recent and related to a single human dispersal event. Quite likely, this species will disappear if a change in the management of the playground occurs. In fact, the site where the species was found could act as steppingstone for the colonisation of nearby degraded psammophilous communities, humidified by marine aerosols. Considering that the habitats harbouring most alien species in Sicily are the coastal and synanthropic ones (Guarino *et al*., 2021), the risk of a further spread of this neophyte cannot be completely excluded.

The way to counteract a potential invasion could be either early eradication or annual monitoring of the population so as to act promptly if a tendency to expand will be noticed. This possibility is not unlikely to happen, as some congeners mentioned above began their expansion some decades after their first record (Brunel, 2009; Anderson *et al*., 2015; Sheffield *et al*., 2022).

Conclusions

Based on the results obtained, and having the leaves and floral characters an high taxonomic value in *Alternanthera* (see e.g., Sánchez-Del Pino *et al*., 2012; Iamonico & Sánchez-Del Pino, 2016), Sicilian population, identified as *A. maritima*, would represent a new floristic record not only for Sicily and Italy, but even for Europe.

Sicily being a renowned tourist destination in the centre of the Mediterranean proves to be one of the most fertile receptors of alien species among Italian regions (Mazzola & Domina, 2010). Constant monitoring of new arrivals is essential to prevent these new neophytes from becoming problematic in Mediterranean territories.

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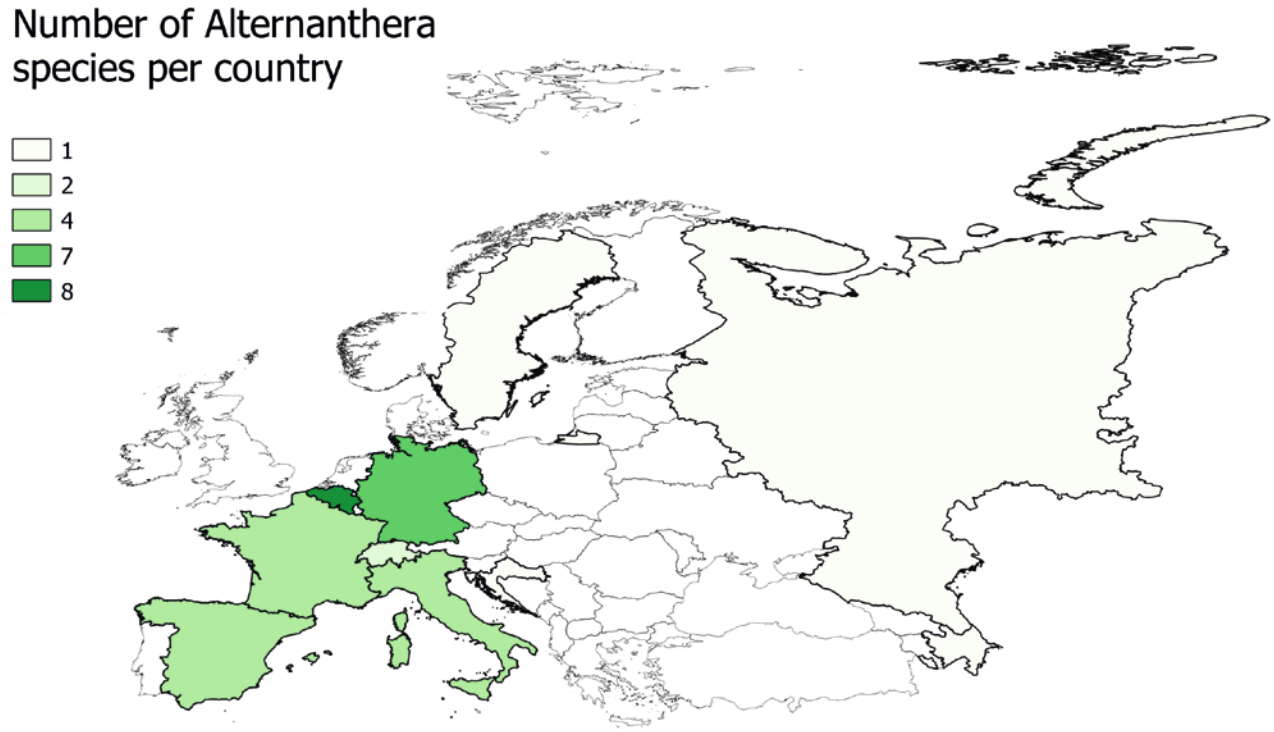

Country	Species / Biogeographical status
Azerbaijan	*A. sessilis (i)*
Belgium	*A. angustifolia (c), A. caracasana (c), A. denticulata (c), A.paronychioides (c), A. nodiflora (c), A. pungens (c), A. sessilis (c), A. tenella (c)*
Croatia	*A. caracasana (i)*
France	*A. caracasana (n), A. flavogrisea (i), A.paronychioides (i), A. philoxeroides (n)*
Germany	*A. bettzickiana (c), A. denticulata (c), A. ficoidea (c), A. pilosa (c), A. pungens (c), A. sessilis (c),*
Italy	*A. philoxeroides (n), A. pilosa (c), A. pungens (c), A. tenella (c)*
Russia	*A. sessilis (c)*
Spain	*A. caracasana (n), A. nodiflora (n), A. pungens (n), A. sessilis (n)*
Sweden	*A. pungens (c)*
Switzerland	*A. denticulata (c), A. ficoidea (c)*

Figure 1. Occurrences of *Alternanthera* species in Europe. The data concerning the species distributions were extracted from the Euro+Med (https://europlusmed.org). The species' biogeographical status is given in brackets: casual alien (c), introduced (i), and naturalized (n); for more details, see https://europlusmed.org/explanations

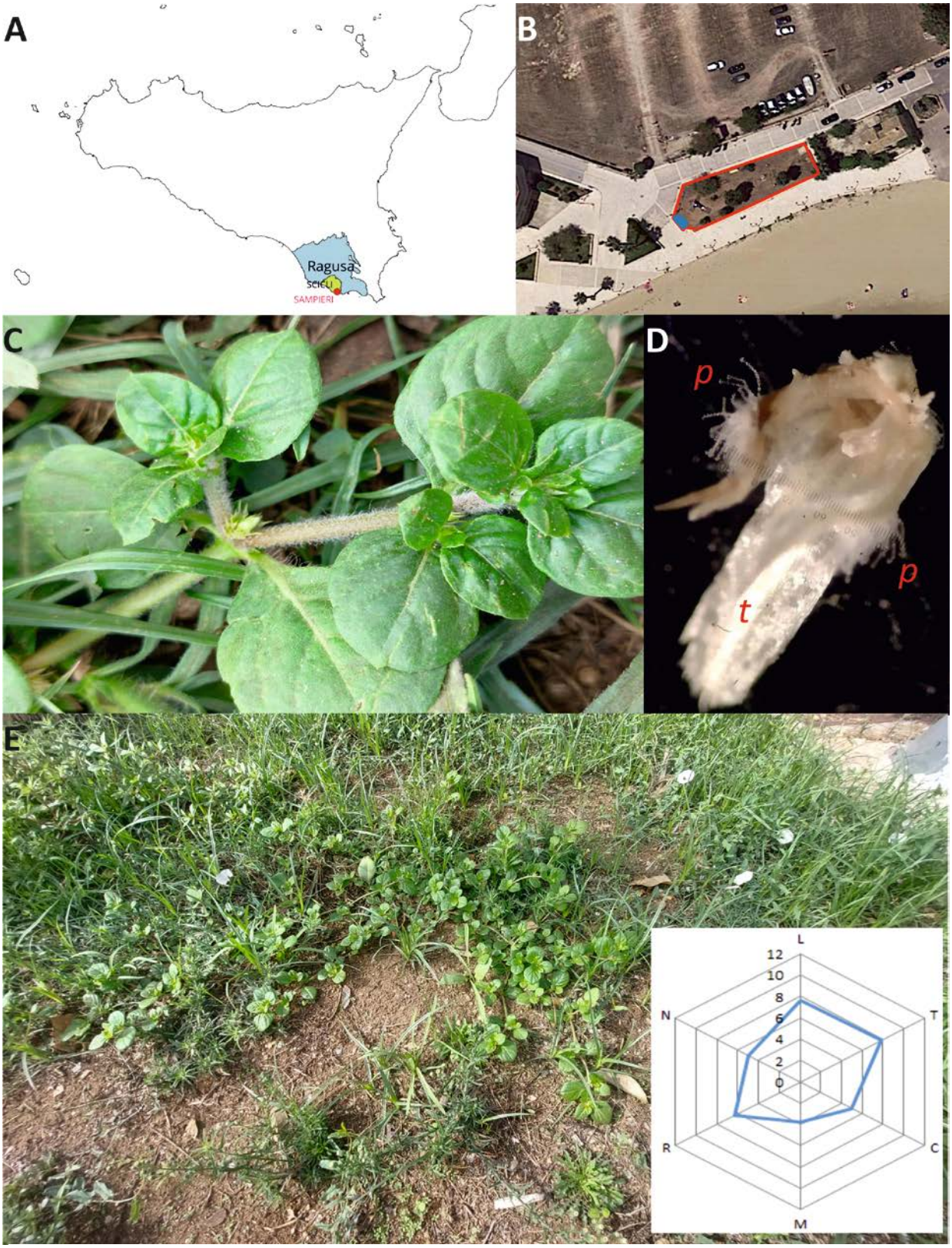

Figure 2. A, location map where *Alternanthera maritima* was found in Sicily. Polygons enclose the territory of Ragusa province (blue) and Scicli municipal area (green), where the red point marks the location of Sampieri village; B, details of the finding area. The children's playground is delimited in red, and the full blue marks the area of occupancy of the species; C, photo with details of the stem, leaves, and one single axillary flower bud; D, photo of tepals (t) and pseudostaminodia (p) of the recorded species; E, photo of the vegetation hosting *Alternanthera* and CWM of the EIVs regarding the three sampled vegetation plots: light (L), temperature (T), continentality (C), moisture (M), soil reaction (R), and nutrients (N).