

Coastal dune vegetation of the Ria Formosa (Algarve, Portugal) barrier island system

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Abstract

The Atlantic coastal dunes have been subjected to several disturbances (e.g. coastal erosion, human trampling, invasive alien species and urban pressure), although, there are still some preserved natural areas, including the dune ecosystems in the south coast of Algarve (Ria Formosa) – Portugal, where Professor Salvador Rivas-Martínez, led one of his last geobotanical journeys, in the context of the XI International Meeting of Phytosociology, realised in Faro – Algarve (Portugal, September, 2019). In this work we present an overview of ecologic factors and processes controlling the diversity of plant communities in dune ecosystems, as well as the vascular flora observed in these territories, including species with special conservation interest. Moreover, the sea-level rise resulting in saline intrusion and receding coastlines may affect the southern Portuguese coastal dunes, which are extremely vulnerable habitats. A loss or decline of these ecosystems would affect priority habitats (from Natura 2000 natural and semi-natural habitats) and threatened species. Thus, we present a description of the coastal dune vegetation of the Ria Formosa barrier island system, and identify the priority species for conservation. This information must be addressed strategically for future coastal management plans, to help biodiversity adapt to recent drivers of coastal changes.

Keywords: coastal dune plant communities, Ria Formosa barrier island system, species of conservation priority, pressures on coastal dune habitats.

Introduction

Habitats are very important natural places that need continuously studied to preserve them and their inhabitants, especially the endemic species that characterize them (Cano et al. 2019; Musarella et al. 2020). In fact, different habitats in the world are threatened by different types of pressures and threats (Cano et al. 2017; Piñar Fuentes et al. 2017; Quinto Canas et al. 2018; Spampinato et al. 2018; Spampinato et al. 2019; Cano Ortiz et al. 2020). Coastal dunes are among the most specialized habitats in Europe and act as a barrier to oceanic inundation. They provide for an important morphological and ecological transition from marine to terrestrial environments or internal inundated saltmarshes (Marcenò et al. 2018; NSW 2010). These environments, due to various disturbing factors of human and natural origin, in recent

decades have undergone the almost total disappearance of the dune ridges, of the retro-dune brackish depressions (Giusso del Galdo et al. 2008). Also the introduction of new alien species in the Mediterranean basin can lead to significant damage to natural environments with the loss of habitats and biodiversity by competing for water and nutrients (Musarella et al. 2020; Musarella 2020; Rosati et al. 2020). According to Fenu et al. (2013), in coastal dunes the structure and composition of plant communities is mainly affected by the interaction between incoherence of the substrate, tolerance to inundation, salt spray and sand accretion levels. These steep environmental gradients determine the coexistence of different vegetation community types, in a relatively small space (Fenu et al. 2013), enriched with unique and specialized plants. In this sense, we focused on the Ria Formosa barrier island system (Algarve, southern Portugal), which hosts

several coastal dune habitats which are legally protected (Council Directive 92/43/EEC) and plant species with high conservation priority. Nevertheless, these dune systems are particularly fragile environments and are considered among the most vulnerable to erosion and flooding in southern Europe (EuroSION 2006; Martins et al. 2013). Accordingly, the Portuguese coast faces a growing threat of coastal erosion, induced by anthropic (mainly urban development and tourism pressure) and natural factors, including those generated as a result of climate change (EuroSION 2006; Barbosa et al. 2013). Among these, the risk of increasing flood and over wash could affect the coast of Ria Formosa, which have a fragile dune ridge as ocean defence (Ferreira et al. 2008).

A further aspect of these dune systems is to manage the coastal dunes habitats and priority conservation species in a more integrated perspective with the aim of optimizing its resilience, since the vegetation is an important controlling factor for dune morphology, given that it impedes sand movement (Acosta et al. 2007; Wolfe and Nickling 2016; Sciandrello et al. 2019; Spampinato et al. 2007). According to (Paiva-Ferreira and Pinto-Gomes 2002), type and density of vegetation communities could be used as a bio-indicator of the dune system erosion/accretion stage. Moreover, plants trap aeolian transported sand, promoting dune accretion, by reducing the shear velocity of surface roughness and stabilizing the dune system itself (Mira et al. 2003). Hence, the approach of the present study is therefore to provide a condensed description of the coastal dune vegetation of the Ria Formosa barrier island system. The particular objectives are:

1) indicate the various plant communities, which determine the typical coastal vegetation zonation, as a response to different ecological attributes; 2) evidence the correspondence between plant communities and Directive Habitats types; 3) identify the priority species for conservation.

Study area

Located in the southernmost part of mainland Portugal, the Ria Formosa barrier island represents one of the most important coastal dune systems of the Iberian Peninsula and is part of the Natura 2000 sites (code PTCON0013 - Ria Formosa/Castro Marim). The Ria Formosa dune system consist of two peninsulas (Ancão and Caela) and five dune barrier islands (Barreta, Culatra, Armona, Tavira and Cabanas) (Figure 1), separated by six inlets and spatially distributed to produce a cusped shoreline that extending approximately over 50 km, from Ancão to Cancela, between 8°02'W and 7°31'W (Ceia et al. 2010). These islands protect a back barrier area consisting mainly of tidal flats, salt marshes, small sandy islands and subtidal channels. According to the most recent study of Iberian Peninsula bioclimatic classification by Rivas-Martínez et al. (2017), the study area is classified as mediterranean pluviseasonal oceanic dry thermomediterranean bioclimate. In a biogeographical context and following Rivas-Martínez (2017) the Ria Formosa is included in the Algarve District (Algarve and Monchique Sector, Coastal Lusitania and West Andalusian Province, Mediterranean Region).

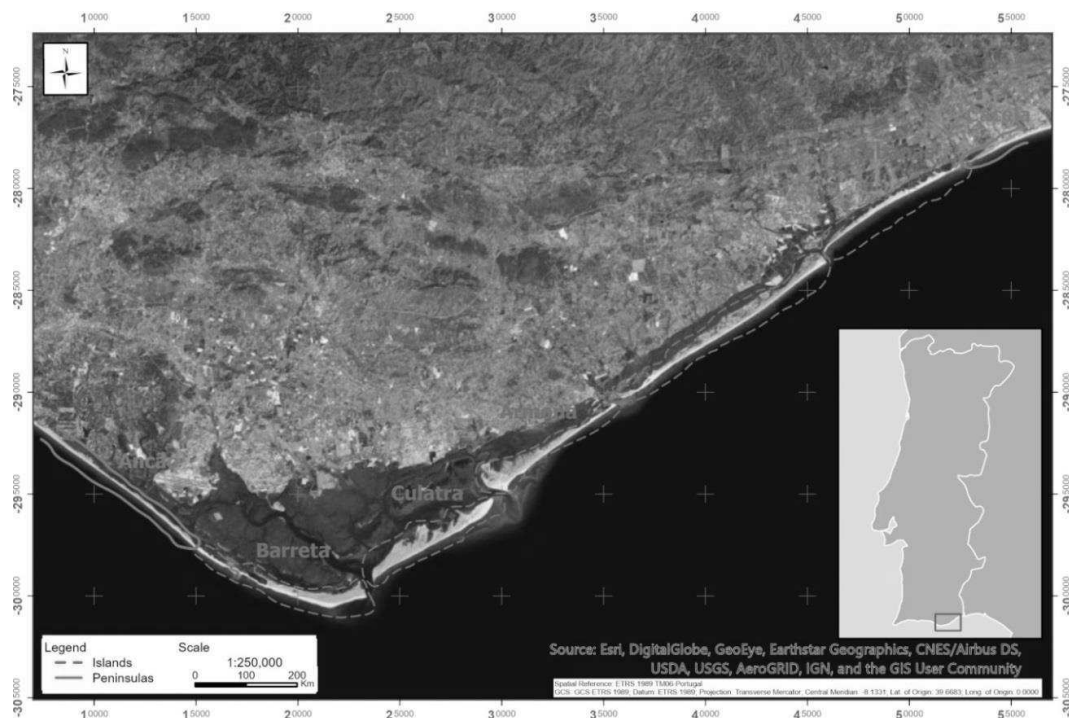


Figure 1. Study area; the green dashes lines indicate the dune barrier islands (Barreta, Culatra, Armona, Tavira and Cabanas) and the blue lines indicate the peninsulas (Ancão and Caela).

Material and methods

The plant communities diagnosis followed past works from Rivas-Martínez et al. (1980), Rivas-Martínez et al. (2002), Costa (1991), Costa et al. (1996), Costa

(2000), Costa et al. (2005, 2011, 2012a, 2012b, 2019), Paiva-Ferreira and Pinto-Gomes (2002), Díez-Garretas and Asensi (2002), Neto et al. (2008), Neto (2009), Biondi and Galdenzi (2014), Sarika et al. (2015), Amigo et

al. (2017), Asensi and Diez-Garretas (2017), Soriano and Costa (2017) and Pinto-Gomes et al. (2019). Syntaxonomical nomenclature followed Rivas-Martínez et al. (2001), Rivas-Martínez et al. (2002), Rivas Martínez et al. (2011) and Costa et al. (2012a). Taxonomic nomenclature follows the work of Coutinho (1939), Valdés et al. (1987), Franco (1971), Franco and Rocha Afonso (1994), Castroviejo (1986) and Costa et al. (2012a). The classification of habitats follows the Portuguese Natura 2000 sectorial plan (ALFA 2004) and the Interpretation Manual of European Union Habitats (European Commission 2013). The selection of the priority species for conservation based on national and international protection catalogues (protection status), rarity and threats levels; data were obtained from herbarium specimens (ALGU Catalogue-Herbarium of University of Algarve), from the literature and field surveys, which were undertaken throughout the study area between 2016 and 2019, for the Red List of Vascular Plants for Mainland Portugal project. Furthermore, we also indicated whether a taxon is included within the European Directive Habitat (Council Directive 92/43/EEC).

Results and discussion

Sand dune habitats occur in complex and dynamic systems, where hostile environmental conditions, such as substrate instability, wind, salt spray exposure, low nutrients, frequent drought, high temperatures as well as erosion and sand burial, can result in the presence of specialized plant species and unique vegetation communities (JNCC 2004; Delaney et al. 2013; Fenu et al. 2013). According to Fenu et al. (2013), the coastal sand dune ecosystems showed a shift of the environmental variables along the sea-inland gradient, concomitantly with the pattern of community types from annual beach communities in the fore dunes to shrub-covered fixed back dunes. In accordance with variation of these patterns along a sea-inland gradient, we present the typical sand coastal vegetation zonation of the Ria Formosa barrier island system. The plant communities, biogeographical and floristic comparison between coastal dune habitats of the Ria Formosa barrier island system, is reported in Table 1.

1 - Annual vegetation of drift lines (Natura 2000 Habitat code: 1210)

This habitat type occurs in sandy substrate at the upper part of the beach, around the high tide mark, where the water-borne material including organic matter (mainly seaweeds) is deposited on the shore and provides nutrients for vegetation. Mediterranean communities that colonizes sandy beaches in the area of accumulations of drift material rich in nitrogenous organic detritus transported by sea, have been syntaxonically included in the *Cakilion maritimae* (*Cakiletalia integrifoliae*, *Cakiletea maritimae*) (Costa et al. 2012a; Rivas-Martínez et al. 2002). Accordingly, the sandy coastal system of the Ria Formosa barrier island begins with the halo-nitrophilous annual forb communities belonging to the association *Salsolo kali-Cakiletum maritimae* (*Cakilion maritimae*), dominated by *Cakile maritima* and *Salsola kali*, which may form only sparse cover. In these formations, the presence of other characteristic elements, such as *Glau-*

cium flavum and *Chamaesyce pepelis*, is very scarce. In fact, the floristic composition of this community is very species-poor, although are highly resilient to harsh conditions of high salinity, wind exposure, human impact, drought, sand mobility and wave inundation. This community are often fragmented, and doesn't tends to occupy large areas due to its narrow and linear nature (Giusso del Galdo et al. 2008; NPWS 2013; Sarika et al. 2015). The presence of some perennial plants from other type of habitat, such as *Elytrigia juncea* subsp. *boreo-atlantica* and *Polygonum maritimum* reveals the contact with the embryonic dunes community (*Elytrigietum junceoboreoatlanticae*; Habitat 2110). Biogeographically, these dunes represent the unique place in Europe where the contact between the two *Elytrigia juncea* Atlantic and Mediterranean subspecies can be observed. On the back-shore side of the barrier islands, the *Salsolo kali-Cakiletum maritimae* is uncommon and most often occurs as fringing saltmarshes (Costa et al. 1996) or contact with *Sporobolus arenarii* community (*Sporobuletum arenarii*) in dune depressions or salt flat dunes, that are inundated by water during spring tides or storms (Rivas-Martínez et al. 2002; Neto et al. 2009; Costa et al. 2012). According to Asensi and Diez-Garretas (2017) and Costa et al. (2000), the association *Salsolo kali-Cakiletum maritimae* presents a Mediterranean distribution and is being replaced north of the Carvoeiro Cape (Portugal) by the Atlantic community *Honckenyo-Euphorbietum pepelis*.

Sarika et al. (2015) highlighted that this habitat contributes to the formation of embryonic dunes and is followed by dune-forming plants such as *Elytrigia juncea*. Nevertheless, the *Salsolo kali-Cakiletum maritimae* exists in a state of instability and may be temporarily absent (some years) due to natural and/or anthropogenic causes (JNCC 2004). In the study area, we hypothesized among the factors that have the most impact to this habitat can be ascribed both to the human activities at the beach, during the spring and summer times (related to the touristic frequentation in form of trampling) and to increasing of the frequency and severity of coastal storms. These disturbances will affect the re-establishment of the community and will affect species range of annual vegetation of drift lines; for example, *Chamaesyce pepelis*, which is distributed throughout Atlantic and Mediterranean coast, has decreased from several localities in the northern and southeastern Iberian Peninsula (Benedí 1997), while the southern Portuguese subpopulations showed a progressive decline and lower values of plant density (few remaining individuals).

2 - Embryonic shifting dunes (Natura 2000 Habitat code: 2110)

Embryonic shifting dunes vegetation are clearly linked to unstable processes resulting from natural coastal dynamics at the dune/beach interface. They are extremely subjected to sand mobility, high salinity of sediments and air (salt spray), and are directly exposed to mechanical action of wind and waves during high tides and storms (Costa et al. 2005; Costa et al. 2012a). In the Ria Formosa barrier islands, the vegetation that colonizes areas of incipient dune formation at the top of a beach have been assigned to the *Elytrigietum junceo-*

boreoatlanticae (*Honckenyo peploidis*-*Elytrigienion boreoatlanticae*, *Honckenyo peploidis*-*Elytrigion boreoatlanticae*, *Ammophiletalia arundinaceae* and *Euphorbio paraliae*-*Ammophiletalia arundinaceae* class), where *Elytrigia juncea* subsp. *boreo-atlantica* and *Elytrigia juncea* subsp. *juncea* are the co-dominant species. *Eryngium maritimum*, *Crucianella maritima*, *Otanthus maritimus*, *Calystegia soldanella*, *Pancratium maritimum*, *Euphorbia paralias*, *Polygonum maritimum*, *Euphorbia paralias*, *Medicago marina* are common characteristic species. Of additional interest is the occurrence of *Elytrigietum junceo-boreoatlanticae* front of the coastal lagoon, in the northern side of the barrier islands, which usually show high rate of cover. According to Costa et al. (Costa et al. 2005), the *Elytrigietum junceo-boreoatlanticae* extends along the Atlantic coast in the Coastal Lusitania and West Andalusia Province, particularly from Cape Mondego (Portugal) to Cádiz (Spain), being replaced in further north up to Cape Mondego by the *Euphorbio paraliae*-*Elytrigietum boreoatlanticae*. As being the first perennial vegetation belt, they represent the initial phase of dune formation, usually less than a meter high, and occur between the *Salsolo kali-Cakiletum maritimae* (Habitat 1210) and shifting dunes with *Loto cretici*-*Ammophiletum arundinaceae*, that not support wave inundation (Habitat 2120).

The *Elytrigietum junceo-boreoatlanticae* is of crucial importance to the creation of new dune habitat or for the long-term survival of the dune system at which it occurs, since these open grass promotes the accumulation of sand from the beach plain into the dune system, then grow to increased heights (like mobile dunes) (Paiva-Ferreira, Rodrigo and Pinto-Gomes 2002; Biondi and Galdenzi 2014; Sarika et al. 2015). Therefore, the existence of this community involves maintaining a continuous supply of sediment (new sand) to beaches. Nevertheless, the survival or expansion of this habitat type is major inhibited both because storm erosion events and human trampling, particularly in the touristic season. Conflicts can also occur between the establishment of the habitat after storm events and the coastal infrastructure, particularly structures constructed directly on the beach, which inhibits the vegetation growth and reduces their protective function.

3 - Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes) (Natura 2000 Habitat code: 2120)

This habitat type encompasses the vegetation of mobile coastal dunes where there is active sand movement and under direct salt-spray influence. There occurs the *Loto cretici*-*Ammophiletum arundinaceae*, dominated by *Ammophila arenaria* subsp. *arundinacea*. This perennial grass has a notable root system developing vertical rhizomes and that resist to sand mobility and consequent burial, playing major role in dune establishment and stabilization (Amigo et al. 2017; Soriano and Costa 2017). The floristic composition of this community contains other characteristic plants from the *Euphorbio paraliae*-*Ammophiletalia arundinaceae*: *Lotus creticus*, *Calystegia soldanella*, *Eryngium maritimum*, *Otanthus maritimus*, *Euphorbia paralias*, *Medicago marina*, *Pan-*

cratium maritimum, *Polygonum maritimum*, among others. In addition, threatened keystone species, such as *Ononis variegata* and *Linaria pedunculata* can also develop on the investigated shifting dunes. Although scarce elsewhere, *Ononis variegata* shows high abundance in shifting dunes that were recently over washed during storms (Armona Island). *Loto cretici*-*Ammophiletum arundinaceae* occurs along the exposed Atlantic coasts of the southern Iberian, between Cape Mondego (Portugal) to Tarifa (Spain). Meanwhile, in Cape Mondego this association is replaced by the *Otantho maritimi*-*Ammophiletum arundinaceae* (Costa et al. 2012a). Typically, in the study area, the shifting dunes along the shoreline are encountered in contact with the communities of embryonic shifting dunes (*Elytrigietum junceo-boreoatlanticae*; Habitat 2110), where occasional exposure to saltwater flooding restricts the growth of *Ammophila arenaria* subsp. *arundinacea*. In the background of the shifting dunes zone, the *Loto cretici*-*Ammophiletum arundinaceae* is replaced by the semi-fixed dunes or grey dunes vegetation (*Artemisio crithmifoliae*-*Armerietum pungentis*; Habitat 2130).

The shifting dunes vegetation are the real builder of the coastal sand dunes (Sarika et al. 2015), since they reduce wind speeds and sand supply to the rest of the dune system and promote dunes stabilization. At present, the rapid erosion of the frontal dune cordon is reducing the area of shifting dunes on the Ria Formosa, which promotes a more rapid transition to semi-fixed dune, and can result in wave overtopping and salinization of the back slope habitat. Hence, evidence suggests that the main drivers that influence the extent and quality of these habitat are increasingly linked to the storms, rising sea level, trampling and decline of coastal sedimentation, due to urban development and coastal protection structures.

4 - *Fixed coastal dunes with herbaceous vegetation (grey dunes) (*priority habitat) (Natura 2000 Habitat code: 2130)

Right behind the shifting dunes, the abiotic factors of the system change rapidly and vegetation is less exposed to the adverse environmental gradients associated with the proximity to the sea and, therefore, the mobile dune gives place to the 'grey dunes' vegetation. This habitat type develops on more or less stabilized soils low in humus, relatively sheltered of the harsh conditions that affect the mobile dunes habitats, such as wind exposure, sand mobility and salt spray. Typically, the 'grey dunes' vegetation of the Ria Formosa barrier islands have been assigned to the *Artemisio crithmifoliae*-*Armerietum pungentis* (Habitat 2130), which forms part of a natural succession from the mobile dune habitats (1210, 2110 and 2120) on the seaward side, to the outer part of the salt-marshes. This community occurs widely around the coasts of the southwest of Iberian Peninsula, ranging from Tagus Estuary (Portugal) to Tarifa (Spain), being replaced in further north up to Cape Mondego by the *Armerio welwitschii*-*Crucianelletum maritimae* (Asensi and Diez-Garretas 2017; Costa et al. 2000). Hence, the *Artemisio crithmifoliae*-*Armerietum pungentis* is well characterized by the co-dominance of *Armeria pungens*, *Artemisia crithmifolia*, *Helichrysum italicum* subsp.

picardii and *Thymus carnosus*. Other characteristic species are *Anthemis maritima*, *Malcolmia littorea*, *Crucianella maritima*, *Aetheorhiza bulbosa*, *Linaria lamarckii*, *Medicago marina*, *Cyperus capitatus*, among others. In the clearings we must highlight some species from *Cutandietalia maritimae* (*Tuberarietea guttatae*), such as *Cutandia maritima*, *Polycarpon alsinifolium*, *Pseudorlaya pumila*, *Silene nicaeensis*, *Hedypnois arenaria*, *Hypocoum littorale*, *Hypocoum procumbens*, *Linaria munbyana* var. *pygmaea*, *Linaria pedunculata*, *Ononis variegata*, *Corynephorus canescens* subsp. *maritimus*, *Echium gaditanum*. The disturbance from human trampling and other activities causes the modification of the sandy ecosystem and, as a consequence, enhances the abundance of subnitrophilous species from *Stellarietea mediae* class like *Vulpia alopecuros*, *Reichardia gaditana*, *Carduus meonanthus*, among others.

Among the plants with high conservational interest we can highlight the occurrence of *Thymus carnosus* (listed in the Habitats Directive Annex II and Annex IV) and *Linaria lamarckii*, endemic species from the Cádiz and Sado Sub-province, which requires special conservation measures to maintain this habitat type. We also stress the presence of other species of great patrimonial value: *Armeria pungens*, *Allium subvillosum*, *Anthemis maritima*, *Hypocoum littorale*, *Hypocoum procumbens*, *Linaria munbyana* var. *pygmaea*, *Linaria pedunculata*, *Ononis variegata*, *Echium gaditanum* and *Plantago macrorhiza*. Apart from other disturbance processes, the main conflict in this habitat type results from habitat loss due to coastal erosion, compounded by sea level rise and reduced sediment supply, will increase, and promote the mobile dunes habitats to move inland and, subsequently, reduce the 'grey dunes' habitat to a narrow strip that can be rapidly destroyed.

5 – *Malcolmietalia dune grasslands* (Natura 2000 Habitat code: 2230)

In the study area, this habitat is typically found on the open spaces of semi-fixed dunes (grey dunes) in which therophytes often dominate and form a special association *Ononido variegatae-Linarietum pedunculatae*. *Linaria pedunculata* and *Ononis variegata* are the main diagnostic species in this association. The floristic composition of these annual grasslands also includes other characteristic species from the *Tuberarietea guttatae* like *Hypocoum littorale*, *Hypocoum procumbens*, *Linaria munbyana* var. *pygmaea*, *Pseudorlaya minuscula*, *Pseudorlaya pumila*, *Cutandia maritima*, *Polycarpon alsinifolium*, *Hedypnois arenaria*, *Silene nicaeensis*, among others. The *Ononido variegatae-Linarietum pedunculatae* extends from the Algarve District (Coastal Lusitania and West Andalusian Province) to Almeria Sector (Murcia and Almeria Province), reaching Morocco and Algeria (Costa et al. 2011). Following Diez-Garretas and Asensi (2002), on more consolidated sands in the Algarve District and Cádiz and Littoral Huelva Sector, occurs a variant of this association, the subass. *linarietosum pygmaeae*, characterized by the presence of *Linaria munbyana* var. *pygmaea*. In Ria Formosa barrier islands, the combined effect of natural instability and direct or indirect effects of human activities could cause a higher risk of extinction of know threatened species occurring in this habitat type, like the Portuguese

subpopulations of *Hypocoum littorale*, *Hypocoum procumbens* and *Linaria munbyana* var. *pygmaea*. For purpose, regional conservation planning should be developed to improve conservation status: ex situ seed conservation, in situ population studies and active protection measures (to minimize human trampling and the spreading of exotic invasive species, such as *Carpobrotus edulis*, for example).

6 – *Inland dunes with open Corynephorus and Agrostis grasslands* (habitat code: 2330)

In the study area, this habitat type encompasses the coastal dune grasslands dominated by *Corynephorus canescens* subsp. *maritimus*, belonging to the association *Echio gaditanae-Corynephorium maritimae*, linked to the alliance *Corynephorion maritimi*. These perennial grasslands are restricted to the coastal and inland dunes of Algarve District, being very scarce and fragmented in the Ria Formosa barrier islands. They occur on more stabilized sandy soils, in contact or open areas of *Artemisia crithmifoliae-Armerietum pungentis*. The dominant species *Corynephorus canescens* subsp. *maritimus* co-exists with *Echium gaditanum*, *Sedum sediforme*, *Plantago macrorhiza*, *Seseli tortuosum*, *Silene nicaeensis*, *Malcolmia littorea*, *Lotus creticus*, *Cyperus capitatus*, among others (Costa et al. 2012b). Furthermore, the human trampling on this habitat promote the abundance of subnitrophilous species. This group includes species from *Linario polygalifoliae-Vulpion alopecuroris* alliance (*Thero-Brometalia*, *Chenopodio-Stellarietea mediae*), such as *Vulpia alopecuros*, *Reichardia gaditana*, *Brassica oxyrrhina*, *Carduus meonanthus*, *Lagurus ovatus*, among others. On the basis of conservation interest, the *Echio gaditanae-Corynephorium maritimae* hosts plant species with conservation interest: *Echium gaditanum* and *Plantago macrorhiza*, which require regional-scale planning to minimize the habitat loss, despite the importance of the *in situ* conservation measures to minimize human trampling impacts.

In this study, we identify 13 threatened species, which includes species listed in the Habitats Directive (Council Directive 92/43/EEC), almost endemic Portuguese species, and also the list of taxa already know as rare in Portugal, including those with significant geographical disjunctions. According to the Red List of Vascular Plants for Mainland Portugal, prepared according to the criteria of the IUCN Red List (Carapeto et al., 2020) two species are in threat category - *Hypocoum procumbens* (Critically Endangered) and *Hypocoum littorale* (Vulnerable) - three classified as Near Threatened (*Chamaesyce peplis*, *Linaria munbyana* subsp. *pygmaea*, *Ononis variegata*) and five species are classified as Least Concern (*Echium gaditanum*, *Linaria lamarckii*, *Linaria pedunculata*, *Plantago macrorhiza*, *Thymus carnosus*).

Accordingly, this study provides a synthetic description of the sand coastal communities along the dune systems of the Ria Formosa barrier island system, on which the different ecological variation determines the mosaic vegetation distribution. These dunes support six habitats that are listed in Annex I of the 92/43/EU Habitats Directive and host a Priority Habitat type (2130), which require special conservation measures. Furthermore, it is noteworthy that these coastal sand dunes habi-

tats are rich in threatened plant species with conservation needs. Although, there is now a high degree of certainty that disturbance processes, linked to anthropogenic in-

duced changes, will affect long-term conservation of the dune habitats, including those generated as a result of climate change.

Table 1.

Plant communities, biogeographical and floristic comparison between coastal dune habitats of the Ria Formosa barrier island system.

Habitat code	Coastal dune association	Biogeography	Characteristics species from the association and higher units
1210	<i>Salsola kali-Cakiletum maritimae</i>	West Mediterranean Subregion	<i>Cakile maritima</i> , <i>Salsola kali</i> , <i>Chamaesyce peplis</i>
2110	<i>Elytrigietum junceo-boreoatlanticae</i>	Coastal Lusitania and West Andalusia Province	<i>Elytrigia juncea</i> subsp. <i>boreo-atlantica</i> , <i>Elytrigia juncea</i> subsp. <i>juncea</i> , <i>Eryngium maritimum</i> , <i>Crucianella maritima</i> , <i>Otanthus maritimus</i> , <i>Calystegia soldanella</i> , <i>Pancreatium maritimum</i> , <i>Euphorbia paralias</i> , <i>Polygonum maritimum</i> , <i>Euphorbia paralias</i> , <i>Medicago marina</i>
2120	<i>Loto cretici-Ammophiletum arundinaceae</i>	Coastal Lusitania and West Andalusia Province	<i>Ammophila arenaria</i> subsp. <i>arundinacea</i> , <i>Lotus creticus</i> , <i>Calystegia soldanella</i> , <i>Eryngium maritimum</i> , <i>Otanthus maritimus</i> , <i>Euphorbia paralias</i> , <i>Medicago marina</i> , <i>Pancreatium maritimum</i> , <i>Polygonum maritimum</i>
2130	<i>Artemisia criihmifoliae-Armerietum pungentis</i>	Cádiz and Sado Sub-province	<i>Armeria pungens</i> , <i>Artemisia criihmifolia</i> , <i>Helichrysum italicum</i> subsp. <i>picardii</i> , <i>Thymus carnosus</i> , <i>Anthemis maritima</i> , <i>Malcolmia littorea</i> , <i>Crucianella maritima</i> , <i>Aethorhiza bulbosa</i> , <i>Linaria lamarckii</i> , <i>Medicago marina</i> , <i>Cyperus capitatus</i>

In this study, we identify 13 threatened species, which includes species listed in the Habitats Directive (Council Directive 92/43/EEC), almost endemic Portuguese species, and also the list of taxa already know as rare in Portugal, including those with significant geographical disjunctions. According to the Red List of Vascular Plants for Mainland Portugal, prepared according to the criteria of the IUCN Red List (Carapeto

et al., 2020) two species are in threat category - *Hypocoum procumbens* (Critically Endangered) and *Hypocoum littorale* (Vulnerable) - three classified as Near Threatened (*Chamaesyce peplis*, *Linaria munbyana* subsp. *pygmaea*, *Ononis variegata*) and five species are classified as Least Concern (*Echium gaditanum*, *Linaria lamarckii*, *Linaria pedunculata*, *Plantago macrorrhiza*, *Thymus carnosus*).

Table 2.

List of coastal dune threatened species of the Ria Formosa barrier island system and their presence in habitats protected by the Habitats Directive (Council Directive 92/43/EEC) (signaled through the respectively habitat column code by "●").

n.º	Species	Family	Habitat code					
			1210	2110	2120	2130	2230	2330
1	<i>Allium subvillosum</i> Salzm. ex Schult. & Schult.f.	Liliaceae	-	-	-	●	-	●
2	<i>Anthemis maritima</i> L.	Asteraceae	-	-	●	●	-	-
3	<i>Armeria pungens</i> (Link) Hoffmanns. & Link	Plumbaginaceae	-	-	-	●	-	-
4	<i>Chamaesyce peplis</i> (L.) Prokh.	Euphorbiaceae	●	●	-	-	-	-
5	<i>Echium gaditanum</i> Boiss.	Boraginaceae	-	-	-	●	-	●
6	<i>Hypocoum littorale</i> Wulfen	Papaveraceae	-	-	-	-	●	-
7	<i>Hypocoum procumbens</i> L.	Papaveraceae	-	-	-	-	●	-
8	<i>Linaria lamarckii</i> Rouy	Scrophulariaceae	-	-	●	●	-	-
9	<i>Linaria munbyana</i> Boiss. & Reut. subsp. <i>pygmaea</i> (Samp.) Rivas Mart.	Scrophulariaceae	-	-	-	-	●	-
10	<i>Linaria pedunculata</i> (L.) Chaz.	Scrophulariaceae	-	-	●	-	●	-
11	<i>Ononis variegata</i> L.	Fabaceae	-	-	●	-	●	-
12	<i>Plantago macrorrhiza</i> Poir.	Plantaginaceae	-	-	-	●	-	●
13	<i>Thymus carnosus</i> Boiss.	Lamiaceae	-	-	-	●	-	-

Accordingly, this study provides a synthetic description of the sand coastal communities along the dune systems of the Ria Formosa barrier island system, on which the different ecological variation determines the mosaic vegetation distribution. These dunes support six habitats that are listed in Annex I of the 92/43/EU Habitats Directive and host a Priority Habitat type (2130), which require special conservation measures. Furthermore, it is noteworthy that these coastal sand dunes habitats are rich in threatened plant species with conservation needs. Although, there is now a high degree of certainty that disturbance processes, linked to anthropogenic induced chang-

es, will affect long-term conservation of the dune habitats, including those generated as a result of climate change.

As evidence by (Houston 2008), general sustainable or adaptive management options to protect and maintain the habitat dune system, tend to focus on dune stabilization and access control systems. Therefore, the predictable impacts of climate change in biodiversity conservation and natural resource management programs will require to minimize the habitat loss and to prevent the regional extinction risk of the threatened species (NSW 2010; Vousdoukas et al. 2020).

The main implications of the recent predictions of increases in sea-level projections for the southern Portuguese coast, will be the erosion of beaches and dunes, and inundation of coastal plains areas and barrier islands. Hence, regional strategic policies recommendation include: i) allow the sand dunes habitats to migrate inland; ii) managing threatened species and areas of high conservation value through regulation, environmental planning instruments and assessment, recovery programs, and the priorities action statement under the threatened species conservation; iii) developing regional biodiversity management plans to identify new priority coastal areas for conservation across the landscape, and; iv) coordinate recovery efforts for threatened species and plant communities.

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