

# The meaning of mainland Portugal beaches and dunes' psammophilic plant communities: a contribution to tourism management and nature conservation

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**Abstract** Due to their position of interface between the sea and land, the flora and vegetation of coastal beaches and dunes, occupy ecologically extreme, sensitive, unique and valuable habitats. The occurrence of a large number of endemic *taxa* and specific plant associations endowed with key ecological services and adapted to a stressful and harsh environmental gradient, gives them a high interest for nature conservation and an important role in sustainable territorial planning. However, such ecosystems are vulnerable to the disruption caused by several anthropogenic sources. Among other global threat factors, the inevitable sea rise caused by climate change and, at a local scale, the non-negligible implications of trampling caused by disorderly coastal touristic exploitation, growing construction pressure in the littoral, and a seasonal population boom in late spring and in summer, plus all derivate forms of pollution, are threat factors to their integrity. Therefore, a correct planning of the touristic economic activities requires the understanding of the vegetation composition and spatial distribution patterns, intrinsically determined by their biogeographic context in the Euro-Siberian or Mediterranean Regions. This comprehensive work, based on a broad phytogeographic

study, brings together disperse information on plant communities of the Portuguese sandy coasts (beaches and dunes), by analysing floristic compositions, chorology and ecological characteristics, and matching them with the “Nature 2000” network habitats. Resilience and vulnerability are also studied. In a nature conservation perspective, a positive balance (and a sustainable co-existence) between the preservation of natural values and human development in the Portuguese coast, will benefit with the integration of this knowledge in coastal planning and management activities.

**Keywords** Beaches · Dunes · Plant communities · Portugal · Tourism · Nature conservation

## Introduction

Psammophilic communities can be grouped in two main geosystem types with different morphological, lithological, structural and substrate characteristics, specific flora and vegetation (Neto 2002). Beaches and coastal dunes are submitted to the direct influence of sea salt spray and breezes. The “more interior dunes” are far from the sea influence, and were not studied in the present work.

Portuguese beaches and coastal dunes are oligotrophic environments, with ages inferior to 4,000 years B. P., incipient pedogenetic evolution, weak water retention capacity, low pH, and a total absence of podzolization (Moreira 1985; Neto et al. 2004). Biophysical characteristics are related to the distribution in two major European Biogeographic Regions, Mediterranean (South) and Euro-Siberian (North) (Honrado et al. 2010), progressively varying from North to South for climatic

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reasons: general reduction of precipitation rates, lower incidence of aestival fogs, and increasing temperature in the South. The frontier between these regions converges to the Portuguese northwest coastline, where Euro-Siberian and Mediterranean coastal species come across and migrate between the two regions (Izco 1989). The geographical transition is, for some communities, in Tagus River (“Rio Tejo”), a natural discontinuity barrier; for others in “Ria de Aveiro” (Quiaios - Figueira da Foz) (Ribeiro 1986; Costa et al. 1998a, b). “*Quiaios*” beach is a noticeable transitional area, showing stronger Euro-Siberian characteristics in its Northern limits (influenced by “*Serra da Boa Viagem*”) and Mediterranean in the Southern ones (Cape Mondego). Although a transition range exists between the North and South, the Tagus River demarks a dividing line in climatic and landscape characteristics. Despite a generally temperate, the climatic differences between North and South are evident. The North is mainly influenced by the Atlantic, recording higher precipitation, lowest annual medium temperatures, larger temperature ranges, and a more significant occurrence of summer fogs. To the south of Tagus River, the Mediterranean influences are stronger and clearly manifested by hottest and longer summers, shorter winters and lower precipitation.

Euro-Siberian and Mediterranean plant communities are undoubtedly differentiated (Neto et al. 2007). In addition, as is typical from most marine beaches and dune habitats (Barbour et al. 1985), vegetation also experiences a well-marked littoral-inland gradient. The results of Acosta et al. (2009) highlight the importance of the coastal dune zonation (embryonic dunes, primary, semi-stabilized and stabilized dunes) for species conservation because they harbour progressively higher species richness. Species distribution depends on environmental requirements and spatial interactions among plants (Feagin et al. 2005; Feagin and Wu 2007). Relations between vegetation cover, soil and geomorphological factors are determinant in the environmental variation (Lee et al. 2000; Kim and Yu 2009) and in the occurrence of clearly defined ecological gradients (Van Der Maarel 2003; Frederiksen et al. 2006). The understanding of physical gradient drivers like distance to the sea and profile length (Frederiksen et al. 2006; Honrado et al. 2010), sand grain size, pH, salinity, sand stability (Neto 1993), or microclimates (Neto 1994) is important for the interpretation of communities distribution patterns (Kumler 1997).

Psammophilic flora and fauna, including terrestrial invertebrates confined to that specific type of habitat (Howe et al. 2009), have few species in common with other terrestrial ecosystems (Acosta et al. 2005), being specialized in relatively spatially isolated and low sized communities (Neto et al. 2007). Being subjected to strict ecological conditions like the constant influence of sea salt spray and winds, periodic storms and over-flow from the sea, a mobile and permeable substrate (sands) and aeolian erosion (Barbour et al. 1985; Hesp 1991), the psammophilic plants are morphologically,

anatomically, phenological and physiologically adapted to a severe environmental stress, high temperatures and no available freshwater (Tüxen 1975; García-Mora et al. 1999; Costa 2001). This high specialization restrains their migration to different type of ecosystems, resulting in a large number of restrict coastal *taxa*, endemic and unique plant communities (Van Der Maarel 2003; Kim 2004; Neto et al. 2007), with high floristic originality and conservation value (Acosta et al. 2009).

Coastal landforms experience perpetual biotic and abiotic changes, natural cyclic dynamics, fluctuations in the sea level, geomorphological processes, catastrophic climatic events, sediment load budgets, accretion or erosion episodes (Tüxen 1975; Costa 2001; Soares de Carvalho et al. 2002; Psuty 2004; Lomba et al. 2009). Relationships between the beach and the dune systems’ sediment budget over time and space are the foundation for foredune development and geomorphological evolution across the beach-dune profile (Psuty and Silveira 2010). If the load capacity and resilience are exceeded, self-regulation to degradative processes may not work, resulting in sea erosion and ecosystem impoverishment (Rust and Illenberger 1996; Ferreira 2006). The role of native vegetation in the resilience and vitality of coastal social-ecological services is recognized by Feagin et al. (2010). Main ecological services performed by the psammophilic plants and communities, include important contributions to sand fixation and subsurface water retention. These communities also support important populations of terrestrial invertebrates as other coastal habitats are being lost (Howe et al. 2009), and shelter vertebrates with an active role in the propagation of some plant species, as rabbits (van Til and Koojman 2007).

In 1994, about 75 % of European Mediterranean sand dunes had already been eliminated (Salman 1994) and the destruction has not stopped since then. Recreational activities implying dune trampling, have adverse repercussion in the structure of the vegetation and in ecosystem services, such as sand fixation and prevention of superficial erosion caused by wind deflation (Araújo et al. 2002; Soares de Carvalho et al. 2002; Lomba et al. 2009).

Facing the inevitable effects of climate change, global warming, sea level rise and the intensification of catastrophic events has surges and storms (IPCC 2001; Andrade et al. 2002; Bindoff et al. 2007), coastal areas will suffer dramatic transformations even in the most optimistic future scenarios (Solomon et al. 2007). The vegetation quality is extremely important in maintaining and restoring the ecological integrity of degraded dune habitats (Kim 2004), defining the extent of the dune system, related to its state of degradation and vulnerability. The degradation of the beaches and dunes’ plant communities implies the loss of biological, ecological and landscape values. Collateral damages also may occur, like increasing soil erosion and loss, instability of coastal

geomorphological structures, transgressive sand dunes invasion landwards, sea advance and retreat of the shoreline, plus all related environmental and socio-economic issues (Araújo et al. 2002; Psuty and Silveira 2010).

The strong pressure of tourism, includes the negative impacts of land use changes (Foody 2002), namely dune destruction to facilitate construction, improvement of human access, parking cars construction, and the creation of artificialized spaces for beach recreation. All kinds of pressures are increasing, and according the IPCC (2007) including a new class of threats related to climate change, namely the progressive rise in mean air temperatures with predictable effects on the level of melting ice caps, increases in the level of the sea, and increased frequency of extreme weather events such as storms, floods and droughts. Accommodation space is a key requirement for the continued functioning of the foredune morphologies during periods of sea-level rise (Psuty and Silveira 2010). The removal of native vegetation to construct infrastructures, forest plantations of exotic species and agricultural tillage, and the proliferation of invasive alien species (Lee et al. 2000; Araújo et al. 2002; Soares de Carvalho et al. 2002; Kim 2004), are related to the depletion of biodiversity, changes in the substrate chemical composition, and absence of key species in certain communities.

In Portugal, the construction on top of the dunes and the coasts artificiality (e. g. Costa Nova, Costa da Caparica, Algarve), in addition to the frequent substitution of the native vegetation stretch by other land uses (usually starting in the grey or green dune, and continuing to the interior), has increased erosion and damaged the ecological gradients. As a result, very few good vegetated spots of natural vegetation in the "more interior dunes" are left: their vital space was occupied by construction and other human uses. In 1985 Bird reported that 70 % of the sandy shorelines in the world are eroding or having a negative sediment budget, which results in erosion and inland displacement of the shoreline. In many locations of the Portuguese coast, dramatic land use changes, such as the abandonment of agriculture, and the construction of dams that retain the sediments upstream have increased erosion. As Psuty and Silveira (2010) described, in future scenarios of sea level rise this will derail or block the coastal dunes' accommodation landwards, since there will be no available space. In fact, the ultimate vulnerability exposure factors (Wilson et al. 2005) can be the rising of sea level, and its indirect causes, specifically the economic activities that increase CO<sub>2</sub> concentration in the atmosphere contributing to global warming.

Considering the important role of vegetation in sand fixation, the knowledge of the conservation status of the Portuguese beaches and sand dunes, would be essential to develop appropriate monitoring and management plans. Yet, Baudet (2002) noticed about the *Spanish National Catalogs*, *Berne Convention* and *Habitats Directive* lists, for many

categorized *taxa*, their inclusion in threat categories was based on a subjective application of the criteria suggested by IUCN in 1980, and so far there is no information except their description, chorology, ecology and very few inventories (Baudet 2002; Saiz et al. 2003). In the case of Portugal, a *Vascular Flora Red Book Data* (that could provide information about the Portuguese psammophilic species threat status) does not even exist.

As highlighted by Acosta et al. (2009) given the sensitivity of coastal dune environments to human pressure and disturbance, the understanding of baseline diversity patterns of the community mosaic, especially in areas that still hold relatively well-preserved habitats, is a main concern. In the total of Portuguese "Nature 2000" habitats, 35 % correspond to coastal types, what is understandable due to the country's large stretch of shoreline (Neto et al. 2007). The Mediterranean formations, generally richer in species composition, include almost all the psammophilic Portuguese endemism (Neto et al. 2007) and related plant associations. In a total of 26 associations matched with the habitats of the European "Nature 2000" network, 21 occur in the South of "Ria de Aveiro", and six are classified as priority habitats for conservation.

Despite of the existence of a great number of works focused on the description of the Portuguese coastal vegetation, a generalized deficiency in public and institutional awareness about the composition, structure, distribution and importance of the psammophilic flora and vegetation, prevails. Vulnerability and resilience along the ecological gradient also varies, so management and conservation plans should take that into account. The sustainable development of touristic activities on the beach requires the integration of this information. This work aims to contribute to the construction of a more evident and systematic knowledge of these habitats.

## Study area

The study area of this work is the mainland Portuguese coast. Portugal is a Western Europe country, with 112 km to 218 km wide (direction of the parallels, approximately between 8°00' W and 6°00' W) and 561 km of maximum extension from South to North (direction of the meridians, between 37° N and 42° N) (Daveau 1995; Leal 2007). With a total area of 88 994 km<sup>2</sup> (Medeiros 2005), the continental part of the country has 1,215 km of land border with Spain, and 848 km of coastline (Leal 2007). Integrating the Iberian Peninsula, together with Spain, it comprises a geographic transition between Africa and Europe, functioning as a biogeographic bridge between the two continents, and connecting the Mediterranean Sea with central and North Europe, through the Atlantic Ocean, as shown in Fig. 1.



**Fig. 1** Study area (the Portuguese coast) in the context of the Atlantic Ocean and Mediterranean Sea. (Source: Orthophotomaps from ESRI. Maps created in a GIS Open Source Programme)

Great structural, geographic and climatic contrasts can be felt between the North and the South of Portugal. The Northern region is characterized by a rugged landscape and significant rainfall, while the south is flatter and rainier (annual precipitations usually inferior to 800 mm). The Mediterranean character of most territory is tempered by the buffer effect of the Atlantic Ocean. Due to the physical landscape characteristics, significant contrasts between the littoral and the interior of the territory also occur (Daveau 1995).

Portugal is crossed by several rivers, most starting in Spain, including, in the North, the Douro (mouth in Oporto), the Tagus (Lisbon), and the Guadiana (Vila Real de Santo Antonio, in Algarve). Important are also, in the North of Douro, the rivers Minho (mouth in Caminha), Lima, Cávado and Ave, which have great flows throughout the year. Starting in Portugal, the Vouga (flows into “Ria de Aveiro”) and the Mondego (Figueira da Foz). To the South of Tagus River, the main rivers are the Sado and the Mira. Very relevant in the ecological balance of coastal areas, are also “Ria de Aveiro”, and the estuaries of the Tagus (this estuary

is the largest opening to the Portuguese coast and the second the Iberian Peninsula), Sado, and Faro (“Ria Formosa”).

Four main type of coasts can be distinguished along the Portuguese continental coastline: low sandy beaches, cliffs, littoral wetlands (estuaries and deltas), and artificialized coasts. Beaches and sea cliffs alternate irregularly, with approximately 591 km of beaches (Andrade et al. 2002).

In general, the Portuguese coast has a tended linear configuration, resultant of the mineral nature of the rocks and the intensity of sea erosion. Especially along the Mediterranean Region, the coastline has developed according to several arches supported on cables (Carvoeiro, Roca, Espichel, Sines, Sagres and Santa Maria) (Daveau 1995; Ribeiro et al. 1987).

From the North end of the Portuguese coast to about a third of the territory (Figueira da Foz), the shore is mainly low and sandy. In areas where the nature of the rocks is of greatest hardness, like granite, shale and even limestone, the coast is usually tall and rugged, resulting in cliffs. That is the case of the coast to the North of Espinho, South Estremadura, “Costa Vicentina” (Alentejo’s southwest coast, and

western Algarve - Cape of São Vicente). In fact, most of the tallest cliffs occur where limestone is predominant, much related with the outcrop of Mesozoic rocks, such as between Nazaré and the mouth of the Tagus River, and the western Algarve coast. On the North coast, although carved in hard rocks, the line of contact with the sea is predominantly low (a narrow strip of coastal area has emerged due to the marine regression), allowing the existence of some indentations (most linked to the mouths of rivers or relevant geological formations) and some beaches. Where the sea is in contact with softer rocks, such as sandstones and clays, occur the lower coasts and most sandy beaches and dune formations, promoted by the deposition of sands in crevices (e. g. some coastal areas between Espinho and São Pedro de Moel, or in the Eastern Algarve), or along continuous formations of significant extension (like in the arch Tróia-Sines) (Ribeiro et al. 1987).

The predominant direction of sea dynamics is from NW to South. To the North of Aveiro the coast exposure is the higher, being the Algarve's coast sheltered from the predominant wave direction of NW. Significant part of the Portuguese sandy coast, has been subjected to intense erosion, especially to the north of Nazaré, due to the combined effect of the erosive waves from NW, and imbalances caused by men (e. g. land use changes with impacts in the hydrologic balance resulting in a lack of sediments to feed the beaches, "hard engineering" techniques such as the constructing of groins at the entrance of the bars, etc.). The southern coast (Algarve) shows a differentiation between the western sector of cliffs, and the eastern coast with more low sandy beaches (Fig. 2).

In terms of natural coastal ecosystems, Moreira (1984) and Costa (2001) accept three main types: beaches and dunes, marshes, and cliffs. The study area of this work is representative of the Portuguese beaches and dunes' ecosystems, along which are concentrated most of the country's more densely populated areas, with many land uses and landscape management unresolved questions, that carry intense pressures on the territory (Foody 2002; Ferreira 2006). Being the Mediterranean region a major touristic destination, steadily increasing since the 1950's and spreading to new areas like Spain and Portugal, it is also a problematic area regarding environment, nature conservation and cultural identity (Salman 1994).

## Hypothesis

This work was developed following the hypothesis that a quantifiable Euro-siberian–Mediterranean divergence in the composition of psammophilic beaches and dune communities exists, and that the vegetation psammophilic gradient, starting in the beaches and going until the more interior coastal dunes, can be identified, measured, and understood.

## Material and methods

The main types of psammophilic plant communities were studied, by consulting bibliographic fonts and analysing a large number of phytosociological inventories (relevés). All the inventories were grouped according to their floristic characteristics, and corresponding phytosociological associations. The relevés were made following the Sigmatist School of Zurich-Montpellier (Braun-Blanquet 1979; Géhu and Rivas-Martínez 1981; Rivas-Martínez 2005; Muller-Dombois and ElleMBERG 1974).

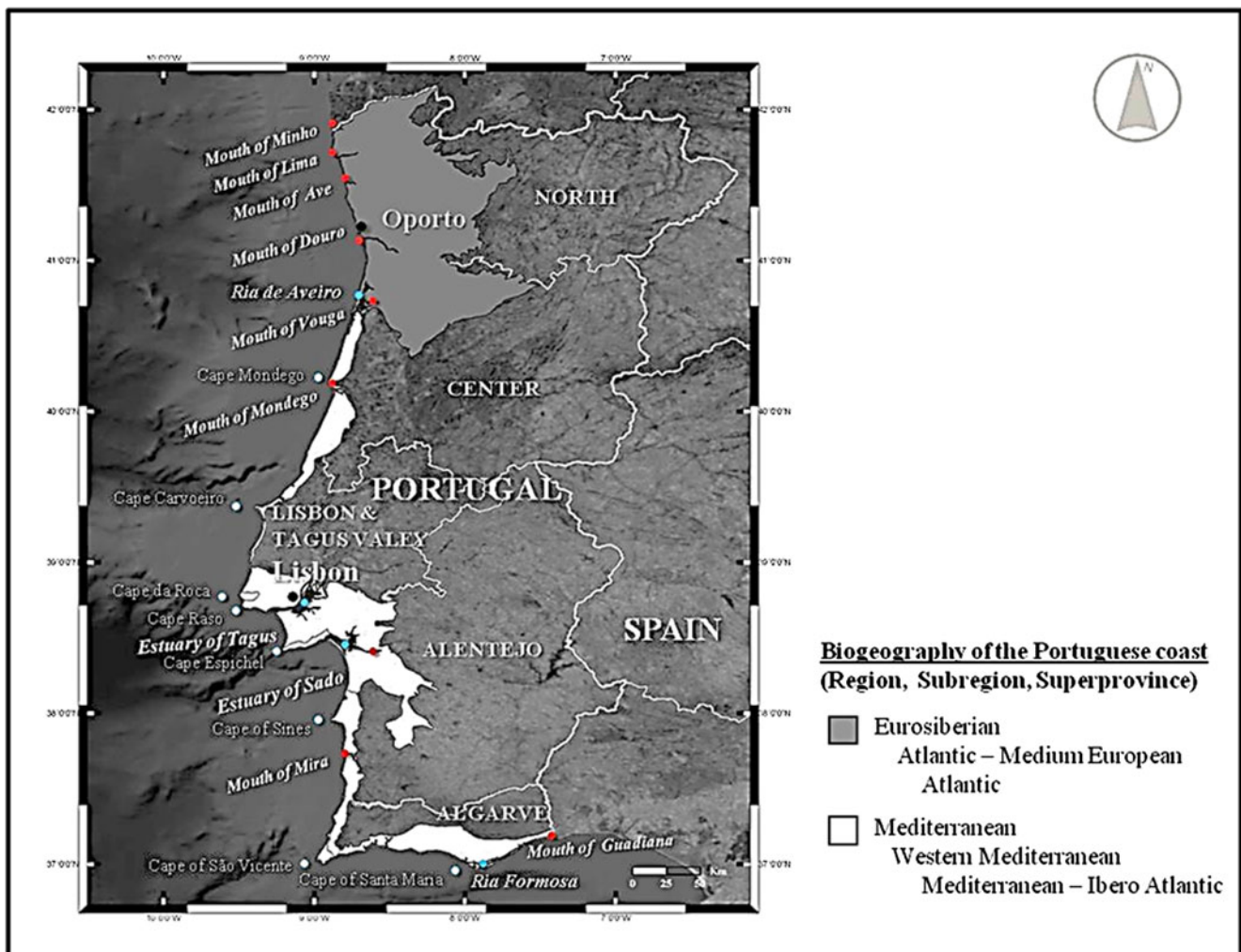
A total of 601 valid phytosociological inventories carried out during many years (1972–2009) were analysed. The sources were: for published records, Braun-Blanquet et al. (1972), Díez Garretas (1984), Costa and Lousã (1989), Rivas-Martínez et al. (1990), Neto (1993), Costa et al. (1994), Costa et al. (1997), Caldas et al. (1999), Costa et al. (2000), Neto (2002), Paiva-Ferreira and Pinto-Gomes (2002); for unpublished inventories, Pinho (2001), Lomba (2004) and Silva (2006); inventories from Lisbon to the Algarve also included original unpublished data from the authors of this work.

To obtain statistically relevant results, in the total population of possible inventories made in different locations along the Portuguese coast, only a few were randomly picked (Ruxton and Colegrave 2006). Although the data of many inventories was obtained in different years, and some spatial variation may have occurred meanwhile (e. g. geomorphological changes, accretion or progradation processes), the aim was not to study landscape dynamics, but general vegetation distribution patterns along the ecological gradient. Thus, it was accepted that trends in those patterns are a constant, and that the temporal gap would not bias the results, or the location of the analyzed inventories (since they were first randomly obtained by different authors according to their specific study aims and working areas).

The botanical nomenclature primarily follows Castroviejo et al. (1986–2007) and more recent revisions (published online), Franco (1971; 1984), Franco and Rocha-Afonso (1994; 1998; 2003), Coutinho (1939), Valdés et al. (1987), Tutin et al. (1980) and Rivas-Martínez et al. (2002). The genus *Stauracanthus* follows Díaz et al. (1990). The syntaxonomic nomenclature is according to Rivas-Martínez et al. (2001; 2002) and Rivas-Martínez (2005).

For the coastal landforms, this work uses the morphological classification of Moreira (1984) that distinguishes the vegetated sectors of the beaches and dunes in "transition medium-high beach", "high beach", "white dune", "grey dune" and "green dune".

The description of environmental factors related to the phytosociological associations' distribution, is according to the studies of Neto (1991; 1993; 1994; 2002), and their correspondence with "Nature 2000" habitats according to Neto et



**Fig. 2** Biogeographic regions, main capes, river mouths and estuaries along the continental Portuguese coast. (Sources: Biogeography adapted from Costa et al. 1998a, b. Orthophotomaps from ESRI. Maps created in a GIS Open Source Programme.)

al. (2007; 2009) and the Portuguese “Nature 2000” Sectorial Plan (“Plano Sectorial da Rede Natura 2000”) (ALFA 2006; ICNB 2006).

For each *taxa* (species and subspecies) present in the inventories, the abundance-dominance classes (Braun-Blanquet 1979) were transformed into a percentage (the mean value of each class). The individual percentages were used to calculate the mean of each inventory in relation to the total cover, and to perform the statistical analysis on floristic diversity and cover (to the total population of inventories). The analysis focused in the covers by endemic *taxa* (categorized in European, Iberian or Portuguese), and in the flora exclusivity or preference for the psammophilic substrate in which they were found.

Since vulnerability can be measured according to the intensity, impact and exposure, and also to the flora threat status (MacDougall and Loo 2002; Andelman and Willig 2003;

McKee et al. 2004), the number of threatened species and their relative threat rates were combined to indicate vulnerability (Wilson et al. 2005). To overcome the difficulties of not having a reference work, like a *Red Data Book* for the flora, it was accepted that, due to its extremophile character, all psammophilic endemic species are intrinsically threatened (although different species may suffer diverse threat levels). As proposed by Wilson et al. (2005), it is possible to infer ecological vulnerability based on the number of endemic species. In an adaptation of this premise, the cover percentages by endemic species were used. In the same context, it was considered that the exclusivity of a species in a specific substrate along the zonal gradient (in this case the species that only occur in psammophilic habitats), is a reliable indicator of the ecological vulnerability.

To understand the tendencies between the vegetation resilience and vulnerability along the different zonal sectors of the gradient, a new Index was developed and applied.

This Index was named *Extremophile Vegetation Resilience/Vulnerability Index*, and it was mainly based on the works of Freyer et al. (2000) for resilience, and Wilson et al. (2005) for vulnerability. The formula is the following:

*Extremophile Vegetation Resilience/Vulnerability Index*(Index<sub>EVR/V</sub>)

$$\text{Index}_{EVR/V} = \frac{R}{V} \ll == \gg \frac{R}{\frac{(a+b)}{4}} \ll == \gg \frac{R}{\frac{((i+j)+(k+l))}{4}}$$

In the Index<sub>EVR/V</sub>  $R$  is resilience, and  $V$  is vulnerability. The  $a$  indicates vulnerability to intensity, impact and exposure. The  $a$  is equal to  $i$  plus  $j$  ( $i$  being the intensity and impact of touristic activities, and  $j$  the exposure to coastal retreat), and  $b$  measures the vulnerability to threat, given by the sum of  $k$  and  $l$  ( $k$  refers to the endemism and  $l$  to the flora exclusivity in psammophilic substrates).

The values of  $R$ ,  $i$ ,  $j$ ,  $k$  and  $l$  vary from 1 (low), to 3 (high), with all possible intermediate decimal values (within each interval class defined according the results for the different zonal gradients). The possible classes are: low (1), low-medium (1.1–1.9), medium (2), medium-high (2.1–2.9) and high (3).

## Results

The inventories and corresponding plant associations for the geosystem “beaches and coastal dunes” (Moreira 1984) have permitted to study the flora and dominant plant communities that occur along the psammophilic gradient. Table 1 presents the floristic list of all *taxa* present in the studied inventories, by alphabetic order.

In conditions of stability, psammophilic communities occur in well-defined geomorphological and ecological gradients, mainly determined by environmental factors has sea dynamics, sea proximity, sands mobility and expressed in specific plant associations, coverage and floristic compositions. In these ecosystems the flora specialization and exclusivity to the substrate are usually high, and the different associations only contact in narrow ecotone areas (Neto et al. 2010). A general scheme of the studied dominant plant communities along the psammophilic gradient and corresponding phytosociological associations (all legally protected by the “Directiva 92/43/CEE – Anexo I” and “Decreto-Lei n° 140/99 de 24 de Abril – Anexo B-1”), in conditions of geomorphological stability, is showed in Fig. 3.

Although this general scheme can still be found almost intact in some localities, a large extension of the Portuguese coast the *geopermasigmetum* (Rivas-Martínez 2005) starting in the first vegetation strip until the grey dune, suffers a process of fragmentation, depletion and loss, related to the erosion of the medium and high beach sectors caused by and the beach downwasting. Many times is difficult to interpret

the zonal gradient, since beach species tend to “escape” to the first dune (mobile or white dunes) communities. Sometimes the process is so severe, that the mobile dunes advance inland overlapping the relatively stabilised dunes (gray dunes), and their vegetation mingle. Even the green dune can be affected. Neto et al. (2010) have showed that, along the Portuguese coast’s psammophilic communities, the medium percentage of exclusive psammophilic plant species in the gray dune is maxim at North of Aveiro, diminishing to South, and being even lowest in the Algarve. Coming from the interior, strong disturbances in the grey dune and white dune caused by human action, also damage the integrity of the plant communities and the normal sequence of the communities.

Thus, having the “normal” gradient as a reference, in cases of strong sea erosion, the presence of certain key-species from the beach and white dune sectors mixed whit impoverished grey dune communities (bioindicators), can be helpful to understand the status of the vegetation in a determined beach, and of the coastal sector itself.

### Medium-high beach transition

The first vegetation strip occurs in the medium-high beach transition area. These grasslands of succulent therophytes are characterized by low vegetation cover and reduced floristic diversity. Due to the sands instability, no perennial vegetation has the capacity to establish in this area, being the communities dominated by pioneer species (migratory annual halo nitrophilous) transported by the sea during the high tides, and deposited in the debris accumulation strip area during spring. *Taxa* displaying sea-water dispersal (García-Mora et al. 1999), like *Cakile maritima*, *Salsola kali* subsp. *kali*, and *Chamaesyce peplis* are characteristic from these communities.

In Portugal, the Euro-Siberian and Mediterranean dominant associations are separated in “Cabo da Roca” (within the influence of Serra de Sintra, Lisbon). To the North of this cape, occurs the association *Honkenyo-Euphorbietum peplis* Tüxen ex Géhu 1964, with *Honckenia peploides* and *Cakile maritima* subsp. *integrifolia*. The corresponding southern association is the *Salsola kali-Cakiletum aegyptiacae* Costa & Mansanet 1981, with *Cakile maritima* subsp. *maritima*, no *Honckenia peploides*, and higher abundance of *Salsola kali* subsp. *kali*.

Both communities are included in the European ecological network “Nature 2000” has “annual vegetation of drift lines” (or “*vegetação anual das zonas de acumulação de detritos pela maré*” in Portuguese), with the habitat code number 1210 (code EUNIS 2002: B2.1; Palearctic 2001: 17.2; Corine Land Cover: 3.3.1.). In the Portuguese coast, these communities are frequent, showing a variable conservation status, average or good in the best conserved spots, although suffering a decrease in its

**Table 1** Floristic list (601 studied inventories). For each *taxon* is indicated the position in the psammophilic gradient where the species has its optimum stage, the degree of endemism (Portuguese endemism, Iberian endemism or European endemism), and the optimum substrate (exclusive psammophilic or preferential *taxa*). Alien species are also

identified. When the species have no mention it means that they do not have a specific relation with the studied plant communities (e. g. ruderal or cosmopolite plants), are neither endemic nor alien, and/or have no ecological preference by the psammophilic substrate

Ecological optimum in the gradient	A - Alien	Degree of endemism	Optimum substrate
1- Backshore/foreshore transition area		P E - Portuguese Endemism	Ps - Psammophilic exclusive plants (restricted to beaches and sand dunes)
2- Foreshore		IbE - Iberian Endemism	
3 - White dune		EE - European Endemism	Pr - Sandy substrate preferential plants (but that also colonize other type of habitats)
4 - Grey dune			
5 - Green dune			
<hr/>			
Vascular plant <i>taxa</i>		77 - <i>Honckenya peploides</i> (L.) Ehrh - 1, 2, Pr	
1 - <i>Acacia longifolia</i> (Andrews) Willd. - A		78 - <i>Hyacintoides vicentina</i> (Hoffmanns & Link) Rothm. subsp. <i>vicentina</i> - 4, PE, Ps	
2 - <i>Aetheorhiza bulbosa</i> (L.) Cass. subsp. <i>bulbosa</i> - 4, Pr		79 - <i>Hydrocotyle bonariensis</i> Lam. - A	
3 - <i>Agrostis stolonifera</i> L. - Pr		80 - <i>Hypochoeris glabra</i> L. - 4, Pr	
4 - <i>Aira praecox</i> L. - Pr		81 - <i>Hypochoeris radicata</i> L.	
5 - <i>Allium subvillosum</i> Salzm. ex Schult. & Schult. f. - 4, Pr		82 - <i>Iberis ciliata</i> All. subsp. <i>welwitschii</i> (Boiss.) Moreno - IbE, Ps	
6 - <i>Ammophila arenaria</i> (L.) Link subsp. <i>arundinacea</i> H.Lindb.- 3, Ps		83 - <i>Iberis procumbens</i> Lange subsp. <i>procumbens</i> - 4, IbE, Ps	
7 - <i>Anagallis arvensis</i> L.		84 - <i>Jasione lusitanica</i> A.DC. [syn. <i>Jasione maritima</i> (Duby) Merino var. <i>sabularia</i> (Cout.) Sales & Hedge] - 4, PE, Ps	
8 - <i>Anagallis monelli</i> L.- 4, 5, Ps		85 - <i>Jasione montana</i> L. subsp. <i>montana</i> - 4	
9 - <i>Anchusa calcarea</i> Boiss. - 4, EE, Ps		86 - <i>Juniperus turbinata</i> Guss. subsp. <i>turbinata</i> - 4, Pr	
10 - <i>Andryala integrifolia</i> L. - Pr		87 - <i>Lagurus ovatus</i> L. - 4, 5, Pr	
11 - <i>Anthemis maritima</i> L. - 4, Ps			
12 - <i>Anthyllis vulneraria</i> L. subsp. <i>iberica</i> (W. Becker) Jalas ex Cullen - 4, EE, Pr		88 - <i>Leontodon taraxacoides</i> (Vill) Merat subsp. <i>taraxacoides</i> - 3, 4, Pr	
13 - <i>Antirrhinum majus</i> L. subsp. <i>cirrhigerum</i> (Ficalho) Franco - 5, Ps		89 - <i>Linaria lamarckii</i> Rouy - 4, PE, Ps	
14 - <i>Arctotheca calendula</i> (L.) Levyns - Ps		90 - <i>Linaria polygalifolia</i> Hofmanns. & Link subsp. <i>polygalifolia</i> - 5, IbE, Ps	
15 - <i>Armeria pungens</i> (Link) Hoffmanns. subsp. <i>major</i> (Daveau) Franco - PE, Pr		91 - <i>Lobularia maritima</i> (L.) Desv. - 4, Pr	
16 - <i>Armeria pungens</i> (Link) Hoffmanns. subsp. <i>pungens</i> - 4, EE, Ps		92 - <i>Logfia minima</i> (Sm.) Dumort.	
17 - <i>Armeria welwitschii</i> Boiss. subsp. <i>welwitschii</i> - 4, PE, Ps		93 - <i>Lolium rigidum</i> Gaudin	
18 - <i>Arrhenatherum album</i> (Vahl) Clayton		94 - <i>Lotus castellanus</i> Boiss. & Reuter - 4, Pr	
19 - <i>Artemisia campestris</i> L. subsp. <i>maritima</i> Arcang. - 4, IbE, Ps		95 - <i>Lotus creticus</i> L. - 3, Ps	
20 - <i>Bartsia trixago</i> L.		96 - <i>Lupinus angustifolius</i> L.	
21 - <i>Bromus diandrus</i> Roth		97 - <i>Malcolmia littorea</i> (L.) Br. - 4, Ps	
22 - <i>Bromus rigidus</i> Roth - Ps		98 - <i>Malcolmia ramosissima</i> (Desf.) Thell. - 4, Ps	
23 - <i>Cachrys libanotis</i> L. - 4, Ps		99 - <i>Matthiola sinuata</i> (L.) Br. - Ps	
24 - <i>Cakile maritima</i> Scop. subsp. <i>integrifolia</i> (Hornem.) Greuter & Burdet - 1, Ps- 1, Ps		100 - <i>Medicago littoralis</i> Rohde ex Loisel. - 3, Ps	
25 - <i>Cakile maritima</i> Scop. subsp. <i>maritima</i> - 1, Ps		101 - <i>Medicago marina</i> L. - 3, Ps	
26 - <i>Calendula suffruticosa</i> Vahl subsp. <i>algarbiensis</i> Boiss. Nyman - EE, Pr		102 - <i>Ononis broteriana</i> DC.	
27 - <i>Calystegia soldanella</i> (L.) R. Br. - 2, 3, Ps		103 - <i>Ononis ramosissima</i> Desf. - 4, Pr	
28 - <i>Carex arenaria</i> L. - 4, Ib, Ps		104 - <i>Ornithopus pinnatus</i> (Mill.) Druce - 4	
29 - <i>Carlina corymbosa</i> L. var. <i>major</i> [syn. <i>Carlina vulgaris</i> L.]		105 - <i>Orobanche arenaria</i> Borkh.	
30 - <i>Carpobrotus accinaciformis</i> (L.) L. Bolus - A		106 - <i>Otanthus maritimus</i> (L.) Hoffmann. & Link - 2, 3, Ps	
31 - <i>Carpobrotus edulis</i> (L.) N. E. Br. - A		107 - <i>Pancratium maritimum</i> L. - 2, 3, Ps	
32 - <i>Catapodium marinum</i> (L.) C. E. Hubb. - Pr		108 - <i>Panicum repens</i> L. - Pr	
33 - <i>Centaurea sphaerocephala</i> L. subsp. <i>polyacantha</i> (Willd.) Dostál - 4, 5, Ps		109 - <i>Parentucellia viscosa</i> (L.) Caruel	

**Table 1** (continued)

Ecological optimum in the gradient	A - Alien	Degree of endemism	Optimum substrate
1- Backshore/foreshore transition area		P E - Portuguese Endemism	Ps - Psammophilic exclusive plants (restricted to beaches and sand dunes)
2- Foreshore		IbE - Iberian Endemism	
3 - White dune		EE - European Endemism	Pr - Sandy substrate preferential plants (but that also colonize other type of habitats)
4 - Grey dune			
5 - Green dune			
34 - <i>Centaurea sphaerocephala</i> L. subsp. <i>sphaerocephala</i> – 4, 5, Ps		110 - <i>Paronychia argentea</i> Lam.	
35 - <i>Centranthus calcitrapae</i> (L.) Duf. – 4		111 - <i>Pimpinella villosa</i> Schousb. – 4, Pr	
36 - <i>Cerastium brachypetalum</i> Desp. ex Per. subsp. <i>brachypetalum</i>		112 - <i>Pinus pinaster</i> Aiton	
37 - <i>Cerastium diffusum</i> Pers. subsp. <i>diffusum</i> – 4, Pr		113 - <i>Plantago coronopus</i> L. subsp. <i>coronopus</i>	
38 - <i>Cerastium glomeratum</i> Thuill.		114 - <i>Plantago coronopus</i> L. subsp. <i>occidentalis</i> (Pigler) Franco – PE	
39 - <i>Chamaemelum mixtum</i> (L.) All.		115 - <i>Plantago macrorhiza</i> Poir. – 4, Pr	
40 - <i>Chamaesyce peplis</i> (L.) Prokh. - 1, Ps		116 - <i>Polycarpon alsinifolium</i> (Biv.) DC. – 4, Ps	
41 - <i>Cistus salvifolius</i> L. – 5		117 - <i>Polycarpon tetraphyllum</i> (L.) L. subsp. <i>diphyllum</i> (Cay.) O. Bolòs Font Quer – 4, Ps	
42 - <i>Coincya monensis</i> (L.) Greuter & Burdet subsp. <i>cheiranthos</i> (Vill.) Aedo, Leadlay & Muñoz Garm. var. <i>johnstonii</i> (Samp.) Leadlay - 3, 4, PE, Ps		118 - <i>Polygonum maritimum</i> L. – Ps	
43 - <i>Conyza canadensis</i> (L.) Cronquist		119 - <i>Pseudorhiza minuscula</i> (Pau) M. Lainz – 4, Ps	
44 - <i>Conyza sumatrensis</i> (Retz) E. Walker		120 - <i>Pseudorhiza pumila</i> (L.) Grande – 4, Ps	
45 - <i>Corema album</i> (L.) D. Don – 5, IbE, Ps		121 - <i>Pycnocomon rutifolium</i> (Vahl) Hoffmanns. & Link – Ps	
46 - <i>Corrigiola litoralis</i> L. subsp. <i>litoralis</i> – 4, Ps		122 - <i>Reichardia gaditana</i> (Willk.) Cout. – 4, Ps	
47 - <i>Corynephorus canescens</i> (L.) P. Beauv. – 4, Ps		123 - <i>Rostraria cristata</i> (L.) Tzvelev	
48 - <i>Crithmum maritimum</i> L. – 3		124 - <i>Rubia peregrina</i> L. – 5	
49 - <i>Crucianella maritima</i> L. - 4, Ps		125 - <i>Rumex bucephalophorus</i> L. subsp. <i>hispanicus</i> (Steinh.) Rech. f. – 4, IbE, Pr	
50 - <i>Cuscuta australis</i> R. Br. – A		126 - <i>Salsola kali</i> L. – 1, Ps	
51 - <i>Cuscuta campestris</i> Yunck. – A		127 - <i>Salsola vermiculata</i> L.	
52 - <i>Cutandia maritima</i> (L.) Barbey – 4, Ps		128 - <i>Santolina impressa</i> Hoffmanns. & Link - 5, PE, Ps	
53 - <i>Cynodon dactylon</i> (L.) Pers.		129 - <i>Scirpoides holoschoenus</i> (L.) Soják – Pr	
54 - <i>Cynoglossum creticum</i> Mill.		130 - <i>Scolymus hispanicus</i> L.	
55 - <i>Cyperus capitatus</i> Vand. – 3, 4, Ps		131 - <i>Scrophularia frutescens</i> L. - 4, Ps	
56 - <i>Cytisus grandiflorus</i> (Brot.) DC. subsp. <i>grandiflorus</i>		132 - <i>Sedum acre</i> L.	
57 - <i>Dactylis marina</i> Borriol – 4		133 - <i>Sedum album</i> L.	
58 - <i>Daucus carota</i> L. subsp. <i>halophilus</i> (Brot.) A. Pujadas – 4, PE		134 - <i>Sedum anglicum</i> Hudson – EE	
59 - <i>Dianthus broteri</i> Boiss. & Reut. – IbE, Ps		135 - <i>Sedum arenarium</i> Brot. - 4, IbE, Ps	
60 - <i>Echium gaditanum</i> Boiss. – 4, Ps		136 - <i>Sedum sediforme</i> (Jacq.) Pau – 4	
61 - <i>Echium tuberculatum</i> Hoffmanns. & Link – Pr		137 - <i>Senecio gallicus</i> Vill. - 4, Pr	
62 - <i>Elytrigia juncea</i> (L.) Nevski subsp. <i>juncea</i> [syn: <i>Elymus farctus</i> (Viv.) Runemark ex Melderis subsp. <i>farctus</i> ]		138 - <i>Senecio vulgaris</i> L.	
63 - <i>Elytrigia juncea</i> (L.) Nevski subsp. <i>boreoatlantica</i> (Simonet et Guin.) Hyl. – 2, Ps [syn.: <i>Elymus farctus</i> (L.) (Viv.) Runemark ex Melderis subsp. <i>boreali-atlanticus</i> (Simonet & Guinochet.) Melderis]		139 - <i>Seseli tortuosum</i> L. – 4, Ps	
64 - <i>Equisetum ramosissimum</i> Desf. – Pr		140 - <i>Silene colorata</i> Poir. – Ps	
65 - <i>Erodium cicutarium</i> (L.) L'Hér. <i>bippinatum</i> (Cav.) Tourlet – 2, 3, EE, Ps		141 - <i>Silene littorea</i> Brot. subsp. <i>littorea</i> – 4, Ps	
66 - <i>Eryngium maritimum</i> L. – 2, 3, Ps		142 - <i>Silene niceensis</i> All. - 4, Pr	
67 - <i>Euphorbia paralias</i> L. – 2, 3, Ps		143 - <i>Silene portensis</i> L. subsp. <i>portensis</i> – Pr	
68 - <i>Euphorbia portlandica</i> L. – 3, 4, Pr		144 - <i>Sonchus oleraceus</i> L.	
69 - <i>Euphorbia terracina</i> L. – 4, Pr		145 - <i>Stauracanthus spectabilis</i> Webb subsp. <i>spectabilis</i> – 5, PE, Pr	
		146 - <i>Thymus camphoratus</i> Hoffmanns & Link – PE, Ps	
		147 - <i>Thymus carnosus</i> Boiss. – 4, PE, Ps	
		148 - <i>Trifolium angustifolium</i> L.	

**Table 1** (continued)

Ecological optimum in the gradient	A - Alien	Degree of endemism	Optimum substrate
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2- Foreshore		IbE - Iberian Endemism	
3 - White dune		EE - European Endemism	Pr - Sandy substrate preferential plants (but that also colonize other type of habitats)
4 - Grey dune			
5 - Green dune			
70 - <i>Evax pygmaea</i> (L.) Brot. subsp. <i>ramosissima</i> (Mariz) R. Fern. & I. Nogueira – 4, Ps		149 - <i>Trifolium arvense</i> L. – Pr 150 - <i>Trifolium campestre</i> Schreb.	
71 - <i>Halimium calycinum</i> (L.) K. Koch – 4, P		151 - <i>Trifolium scabrum</i> L.	
72 - <i>Halimium halimifolium</i> (L.) Willk. <i>multiflorum</i> (Salzm. ex Dunal) Maire – 5, Ps		152 - <i>Tuberaria guttata</i> (L.) Fourr.	
73 - <i>Helichrysum picardii</i> Boiss. & Reut. - 4, IbE, Ps		153 - <i>Verbascum litigiosum</i> Samp. – 4, PE, Ps	
74 - <i>Herniaria ciliolata</i> Melderis subsp. <i>robusta</i> Chaudhri – 4, EE, Ps		154 - <i>Vulpia alopecuros</i> (Schousb.) Dumort. Subsp. <i>alopecurus</i> – 4, 5, Ps	
75 - <i>Herniaria maritima</i> Link – 4, PE, Ps		<u>Lichen</u>	
76 - <i>Holcus lanatus</i> L.		155 - <i>Cladonia</i> sp.- 5	

area over the last 20 years as a result of the coastline retreat and intensive use of the beaches during the summer (ALFA 2006).

#### High beach

The high beach is characterized by a sporadic penetration of the waves during winter. Two different areas can be identified in this sector: flat areas that receive sea water through a laminar flow, and may suffer wind deflation; and irregular areas, embryonic dunes or “nebkas” which are formed by a gradual sand accumulation around the plants (or other obstacles).

In the flat areas two low cover communities of perennial hemicryptophytic grasslands can be found, separated in “Cape Mondego” (Quiaios, Serra da Boa Viagem, Figueira da Foz). The Euro-Siberian community *Euphorbio paraliae-Elytrigietum boreoatlanticae* Tüxen in Br.-Bl. & Tüxen 1952 corr. Darimont, Duvigneaud & Lambinon 1962 nom. mut., is dominated by the Atlantic element *Elytrigia juncea* subsp. *boreoatlantica*, and by *Honckenia peploides*.

The Mediterranean association occurs in the South of Quiaios (since Murtinheira). *Elytrigietum junceoboreoatlantici* J. C. Costa, C. Neto, Lousã, J. Capelo & Rivas-Martínez 2004 is floristically characterized by the absence of *Honckenia peploides*, and the presence of two *Elytrigia juncea* subspecies: *Elytrigia juncea* subsp. *boreoatlantica* and *Elytrigia* subsp. *juncea* (with Mediterranean distribution). Species like *Eryngium maritimum*, *Euphorbia paralias*, *Calystegia soldanella* and *Pancratium maritimum* are also frequent.

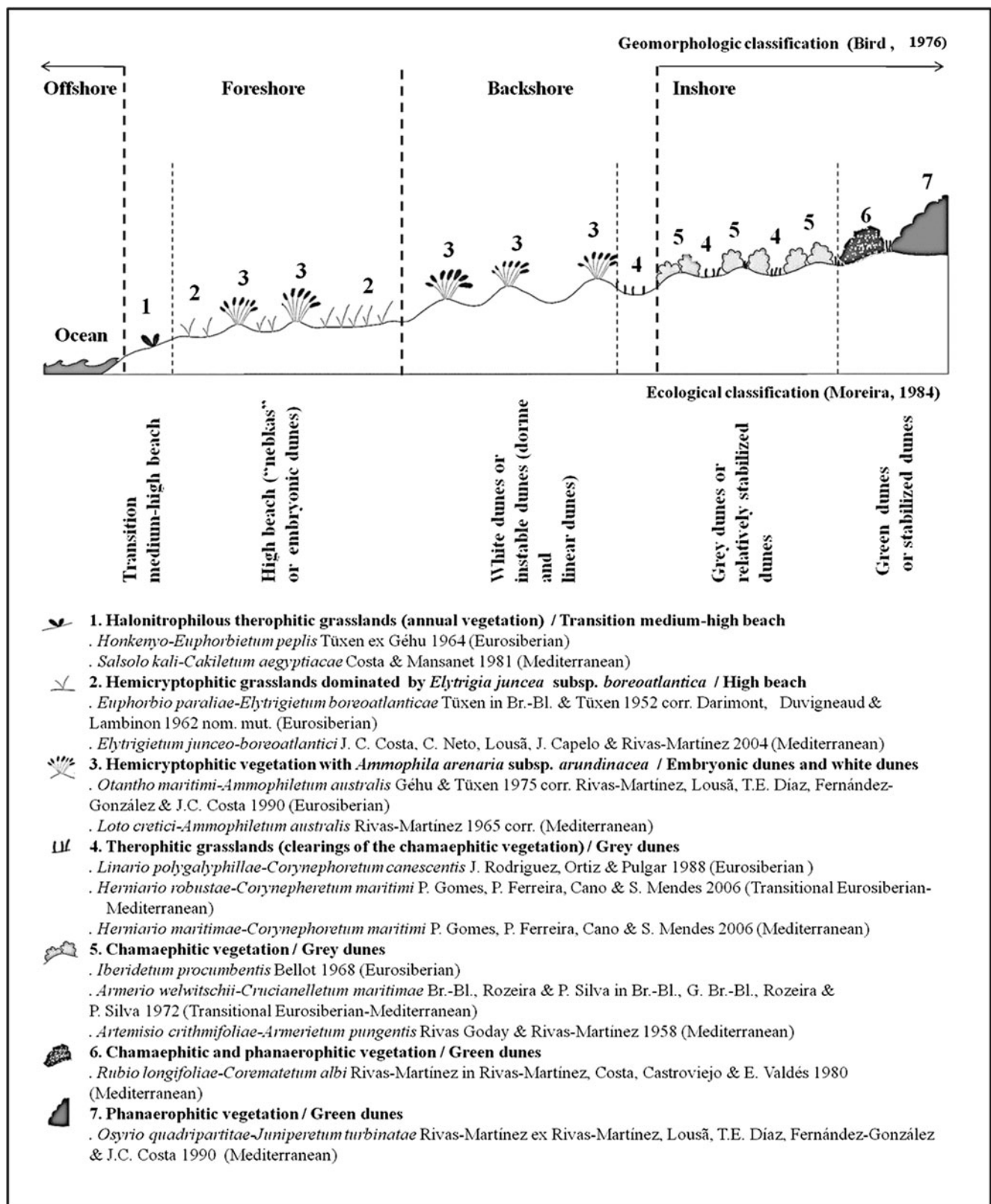
These communities are included in “Nature 2000”, with the habitat code number 2110 (EUNIS 2002: B1.3/P-16.211;

Palaearctic 2001: 16.211; Corine Land Cover: 3.3.1.), corresponding to the “mobile embryonic dunes” (or “*dunas móveis embrionárias*” in Portuguese). The high beach vegetation has suffered a decrease in its distribution area in the last two decades, showing different conservation status along the Portuguese coast. Good levels of conservation can only be found where the human pressure is low. Most areas are not well preserved. However, in some places of Ria Formosa, along the “Costa Alentejana”, and in the arch Tróia-Sines, the communities show average to good conservation status. The best yet preserved areas occur in “Dunas de São Jacinto” (despite suffering strong erosion processes) and in the Peninsula of Tróia (although the recent implementation of a major touristic project in Tróia, with strong construction pressure near the beaches and increasing in trampling, is a significant disturbing factor for the conservation of these communities) (ALFA 2006; ICNB 2006).

Colonizing species as *Ammophila arenaria* subsp. *arundinacea* and *Otanthus maritimus* constitute a barrier to the wind carried sand grains, which are deposited and tend to aggregate. The process originates micro-irregularities in the flat areas of the high beach, building the “nebkas”. The “nebkas” to the North of Quiaios are occupied by *Otanthus maritimi-Ammophiletum australis* Géhu & Tüxen 1975 corr. Rivas-Martínez, Lousã, T.E. Díaz, Fernández-González & J.C. Costa 1990, and by *Loto cretici-Ammophiletum australis* Rivas-Martínez 1965 corr. in the South.

#### White dunes

In simplified terms, the formation of a white dune (incipient frontal dune, foredune, shifting dune, primary dune or beach



**Fig. 3** Dominant plant communities in conditions of geomorphological stability, along the psammophilic gradient

ridge) is due to the coalescence of several "nebkas". In the white dune sands, air salinity is lower than that at the beach,

and the formations are oligotrophic and very dynamic (Hesp 2002), creating a succession of beach ridges and interdune

corridors. The white dune is colonized by sparse and discontinuous herbaceous vegetation dominated by *Ammophila arenaria* subsp. *arundinacea*. Perennial species as *Ammophila arenaria* subsp. *arundinacea*, have high tolerance to wind, air salinity, sands mobility, burial and oligotrophic conditions. Neto (1991) considers that this *taxon* prefers burial to maintain its vitality, having its ecological optimum in the white dune (individuals occurring in the more interior dunes usually show a decrease of vigour).

The name “white dune” comes from the low cover and the vegetation’s predominant colour. The floristic diversity is low to medium, and plant species are adapted to the constant oscillation of the topographic surface (being alternately buried and exposed). With high ecological tolerance, these species also have the capacity to quickly retreat to the interior, in conditions of sea erosion.

In Portugal, *Otantho maritimi-Ammophiletum australis* Géhu & Tüxen 1975 corr. Rivas-Martínez, Lousã, T.E. Díaz, Fernández-González & J.C. Costa 1990 possesses almost no Mediterranean elements. Communities of *Loto cretici-Ammophiletum australis* Rivas-Martínez 1965 corr. mainly differ by the dominance and abundance of *Lotus creticus*, a typically Mediterranean species that, to the North of Figueira da Foz, barely appears in “Costa Nova” (Aveiro). Chamaephytic species with a Mediterranean optimum, like *Armeria pungens* subsp. *pungens*, *Linaria lamarckii*, and *Thymus carnosus*, are frequent. However, these species are more common and abundant in stabilized sands, or where, due to erosion processes in the beach, the white dune flank facing the sea tends to be occupied by typical beach communities, promoting the mobile sands advance inland overlapping the grey dunes.

White dune communities are included in the “Nature 2000” habitat 2120 (EUNIS 2002: B1.3/P-16.212; Palearctic 2001: 16.212; Corine Land Cover: 3.3.1.), with the designation “Shifting dunes along the shoreline with *Amophila arenaria* (“white dunes”)” (or “*dunas móveis do cordão dunar com Ammophila arenaria* (“*dunas brancas*”)” in Portuguese). These communities have an important ecological role in the prevention of catastrophic events like storms, and in sands retention, since they act as the first natural barrier facing the sea (ALFA 2006; ICNB 2006).

Portuguese white dune communities present their best conservation status (as respects structure, floristic diversity and vitality), average to good, in “Dunas de São Jacinto”. However, their conservation status across the Portuguese coast is globally medium to bad in the more touristic areas, being frequent the presence of exotic species, like *Carpobrotus edulis*. The white dune is specially impacted by trampling during the summer, and in the last two decades its distribution area as suffered a serious decrease (ALFA 2006).

## Gray dunes

In the gray dunes (relatively stable dunes or secondary dunes), the sands are oligotrophic, showing smaller grains (than in the previous communities) that only move in the clearings and along the interdune corridors. Also, the soil salinity is lower than in the white dunes. The relative stabilization of the sands, allows the installation of high cover chamaephytic shrub communities very important in the process of sands stabilization. Since the sea buffer effect is weaker, daily and annual temperature ranges are higher than in the high beach and white dunes (Neto 1991; 1993; 1994), thus resulting in more extreme climatic conditions.

During spring, in the clearings of vegetation tufts dominated by hemicryptophytic and chamaephytic *taxa*, appear some non nitrophilous communities of therophytes (from *Malcolmietalia* Rivas Goday 1957).

Being oligotrophic, leached, decalcified and strongly acidified environments, the grey dune have perennial grasslands as pioneer formations in xeric areas with no previous anterior perennial vegetation background, dominated by the hemicryptophyte *Corynephorus canescens*, a caespitose and calcifuge species that sometimes forms almost monospecific and exclusive communities (Anke et al. 2002; Pinto-Gomes et al. 2006). These acidic grasslands develop in sites suffering animal (ants and rabbits) perturbation. Small-scale disturbances constitute a window of opportunity for seedling establishment in dry acidic grasslands. With the time progression, other hemicryptophytes and some chamaephytes manage to enter in these communities, diversifying their floristic composition (Anke et al. 2002) and composing specific plant associations. These communities form mosaics with the chamaephytic communities from the alliance *Helichryson picardii* (Rivas-Martínez, Costa & Izco in Rivas Martínez, Lousã, T. E. Dias, Fernández-González & J. C. Costa 1990) ex Rivas-Martínez, Fernández-González & Ioidi 1999.

In the most acidified, oligotrophic and somehow disturbed areas of the gray dunes, may develop semi nitrophilous therophytic communities. To the North of Figueira da Foz (Quiaios beach) the pioneer Euro-Siberian association *Linario polygalyphillae-Corynephorum canescens* {XE “*Linario polygalyphillae-Corynephorum canescens*” } J. Rodriguez, Ortiz & Pulgar 1988 [sin. *Jasione sabulariae-Corynephorum maritimi* A. Lomba, P. Alves & J. Honrado 2006] regularly shapes intricate mosaics with the chamaephytic communities of *Iberidetum procumbentis* Bellot 1968. The presence of the endemics *Jasione lusitanica* and *Coincya monensis* subsp. *cheiranthos* var. *johnstonii* (that only occurs to the North of Aveiro), and the absence of the *Armeria* genus, differentiates the community. The association *Herniario robustae-Corynepheretum maritimi* {XE “*Herniario robustae-Corynepheretum maritimi*” } P.

Gomes, P. Ferreira, Cano & S. Mendes 2006 [sin. *Sedo sediformis-Corynephoretum maritimae* { XE "*Sedo sediformis-Corynephoretum maritimae*" } Honrado, P. Alves, Lomba, J. Vicente, G. Silva & Napumocemo 2007] form a mosaic with the chamaeaphitic communities of *Armeria welwitschii-Crucianelletum maritimae* Br.-Bl., Rozeira & P. Silva in Br.-Bl., G. Br.-Bl., Rozeira & P. Silva 1972. This community is characterized by the presence of the Portuguese endemism, exclusive to this association, *Armeria ciliata* subsp. *welwitschii*, being a transition community between the Euro-Siberian communities from *Iberidetum procumbentis*, and the Mediterranean association *Artemisio crithmifoliae-Armerietum pungentis* Rivas Goday & Rivas-Martínez 1958, that occurs to the South of Rio Tejo. Dominated by *Armeria pungens* subsp. *pungens*, the Mediterranean association possesses important South-west Portuguese endemisms (e. g. *Linaria lamarckii*, *Thymus carnosus*, and *Herniaria maritima*), occurring together with the Mediterranean grasslands of *Herniario maritimae-Corynephoretum maritimi* { XE "*Herniario maritimae-Corynephoretum maritimi*" } P. Gomes, P. Ferreira, Cano & S. Mendes 2006 (distributed until Vila Real de Santo António, in Algarve).

For their important roles in sands retention, and as a biodiversity refuge, among other, the grey dunes are highly valuable for conservation. These communities are priority habitats in "Nature 2000" with the code \*2130 (EUNIS 2002: B1.4/P-16.223; Palearctic 2001: 16.22; Corine Land Cover: 3.3.1.), under the designation "\* Fixed dunes with herbaceous vegetation ("gray dunes")" (in Portuguese "\* *dunas fixas com vegetação herbácea* ("*dunas cinzentas*")"). Like the previous habitats, they have suffered a decline in the last two decades, having a conservation state along the Portuguese coast generally reasonable to bad. The Euro-Siberian communities to the North of Quiaios have been almost entirely substituted by agricultural uses (plantations of apple trees) (ALFA 2006). In the Algarve, due to the construction of parking lots, and the licentious access to the beaches by informal trails, the grey dune's vegetation has suffered a continued and strong disturbance, only contradicted a few years ago with the implementation of some raised footbridges. The best preserved places occur in "Dunas de São Jacinto", and in a few places along the arch Troia-Sines, namely in the area between "Lagoa de Melides" and "Lagoa de Santo André" (ALFA 2006; ICNB 2006).

#### Green dune

In the green dunes (stabilized dunes or tertiary dunes) the influence of salt spray is minimal and the sands are stabilized, showing some pedogenetic evolution. Among all the communities submitted to salt spray influence, in normal

conditions the green dunes are the most distant from the sea, a feature that allows the development of more dense and tall vegetation, demonstrated by the accumulation of humus (mull) on the soil. Together with the soil leaching, this justifies the poverty in bases and the low pH of the soil.

Unlike the previous communities, these formations are not included in the psammophilic *geopermasigmetum* (Rivas-Martínez 2005). In the Mediterranean region (in the South of Figueira da Foz, Cabo Mondego, until the Algarve), occurs an edapho-xerophytic series whose more evolved stage or climax (series' head) is constituted by the "zimbral" of *Juniperus turbinata* subsp. *turbinata* and *Osyris lanceolata* Hochst. & Steud. [syn: *Osyris quadripartita* Salzm. ex Decne.], *Osyrio quadripartitae-Juniperetum turbinatae* Rivas-Martínez ex Rivas-Martínez, Lousã, T.E. Díaz, Fernández-González & J.C. Costa 1990. Due to its capacity to create shadow and humus it can be considered a pre forest situation, confirmed by the presence of climbing phanerophytes and an herbaceous and sub-nitrophilous stratum (Neto 2002; Neto et al. 2004).

The natural edge and / or first replacing community of the "zimbral" is the "camarinhal" *Rubio longifoliae-Corematetum albi* Rivas-Martínez in Rivas-Martínez, Costa, Castroviejo & E. Valdés 1980, a shrub community, sometimes dense, dominated by chamaephytes and nanophanerophytes. Like the previous it is distributed in Portugal in the South of Figueira da Foz until Algarve, but with an irregular distribution to the North of Lisbon, where it only colonizes the dunes between Peniche and Quiaios. Often, this is a monospecific formation of the Iberian endemism *Corema album*. This community is associated to a certain level of external perturbation, that can have natural causes, anthropic or animal origins (e. g. ants and rabbits have an important role in the *Corema album* seeds dispersal) and anthropic. In areas not disturbed for a long period of time, and under favourable ecological conditions, the communities can gradually change, being occupied by species of *Osyrio quadripartitae-Juniperetum turbinatae*, and finally replaced. However the process is dynamic and the opposite also happens. In cases of extreme perturbation, both associations may disappear.

At the green dune level (continuing to the more interior dunes), for purposes of forest use, many intensive, *Pinus* sp., *Acacia* sp. and *Eucalyptus* sp. plantations have been implemented since decades (e. g. in the arch Tróia-Sines), in some cases totally substitute the natural vegetation, or seriously compromising its capacity to recover. The sands oligotrophic condition, the intrinsic difficulties in reproduction by seed of *Juniperus turbinata* subsp. *turbinata*, a characteristic of the genus *Juniperus* (Van Auken et al. 2004; Loureiro et al. 2007; Tigabu et al. 2007), and the fact that in the present climatic conditions, the species probably it is not in its optimum stage (showing almost exclusive vegetative

reproduction through the root), gives the species very low resilience. Thus, any impact strong enough to destroy entire individuals or the root system, will seriously compromise the population's recovery.

Both mentioned Mediterranean dominant green dunes' communities are priority habitats in "Nature 2000", the habitat \*2250 (EUNIS 2002: B1.6/P-16.27; Palearctic 2001: 16.27; Corine Land Cover: 3.1.1.p.p.), "\* Litoral dunes with *Juniperus* sp.", subtype 2250pt1 "Dunes and paleo-dunes with tickets of *Juniperus turbinata* subsp. *turbinata*" (in Portuguese: "\* *Dunas litorais com Juniperus spp.*", subtipo 2250pt1 "Dunas e paleodunas com matagais de *Juniperus turbinata* subsp. *turbinata*") (ALFA 2006). The stabilized dunes are often utilized for the construction of car parking, or even roads, which makes them highly vulnerable to the intensity and impact of touristic activities (*sensu* Wilson et al. 2005).

To the North of Figueira da Foz, it is not possible to talk about a similar community to the Mediterranean "zimbral"; instead, the stabilized dune is mainly occupied scrublands of heather and *Ulex* spp. from the Class *Calluno-Ulicetea* Br.-Bl. & Tüxen. 1943.

Inventories from the Mediterranean green dune communities were not analysed in the present work. However, previous works (Costa et al. 1994, 2000; Neto 2002; Neto et al. 2004), focused in the litoral *Juniperus* sp. communities, were consulted.

As respects the North-South, in the medium-high beach transition, the mean covers and the number of species are lower in the Mediterranean association, but the mean % of *taxa* that have their optimum within the studied ecosystem increases (E.: 7.1 % to E.: 30 %). There are no endemic species in this sector. In the high beach, the same trend is observed. The cover by Portuguese and Iberian endemism is higher in the Southern association. In the white dune, the results are similar; yet the numeric difference between the cover values of North and South is visibly lower. For the % of *taxa* that have their optimum within the studied ecosystem, the value is higher in the North, but slightly lower for the psammophilic species. The exclusivity is higher for the transitional communities. Iberian endemism have higher values in the North, and Portuguese endemism in the South.

Results also show that the endemic and floristic diversity increases from North to South, being the Euro-Siberian communities globally poorer than the Mediterranean. The Mediterranean communities contain the largest number of endemic species, including Portuguese endemic *taxa* with very restrict distribution, even when compared to the other sectors of the psammophilic gradient, and, in this sense, they can be considered the most threatened. Still, as regards flora exclusivity for the substrate, the value is medium.

In the chamaephitic gray dune communities, the Northern association cover values are lower than those of the

Mediterranean, although the number of species is higher. For the % of *taxa* with the ecological optimum in the gray dune ecosystem, the value is lower in the North, followed by the Mediterranean, and higher cover values in the transition association. The number of psammophilic *taxa* is lower in the North than in the South, although, again the exclusivity is higher for the transition communities. The total endemism is higher for the Mediterranean association. The transition community shows the higher cover of Iberian Endemism, and the Mediterranean communities the highest coverage by Portuguese and European Endemism.

Analysing the beach-coastal dunes gradient, the values show the progressive increase in the cover by endemic species to the interior. In this gradient, the lowest increase of cover occurs from the beach to the white dune, and an enormous rising is notorious at the grey dune level (with the maximum value of 55.83 % in the Mediterranean association). In all sectors, the values are higher for the Mediterranean associations. A gradual, but not very large, decrease of the cover by exclusive psammophilic flora is also remarkable, except in the Mediterranean white dune and grey dune shift, where a small increase occurs.

These results allowed quantifying the increase of specialization that occurs from the sea to the interior. The beach and white dune communities have total cover by psammophilic species (or near, in the case of the Mediterranean white dune communities, with 91 %); however, a low level of endemism and a high resilience does not place them among the most valuable for conservation purposes.

The chamaephitic communities of the grey dune are among the most important for conservation concerns, since they contain the largest number and cover of endemic species, including Portuguese endemism with very restrict distribution, even when compared to the other sectors of the psammophilic gradient. They also have a medium resilience (see Table 2). The green dune has an elevate value to conservation, not so much related to the endemism or substrate exclusivity, but mainly for its resilience, which is very low. These facts support the classification given to these two ecosystems as priority habitats in the "Nature 2000" network.

## Extremophile vegetation resilience/vulnerability index

### Assessing resilience and vulnerability

Facing touristic activities and other threat factors, in the sense of Wilson et al. (2005), the high beach and white dune ecosystems are highly vulnerable to intensity (magnitude, frequency and duration of the impact factors) and impacts (threat effects) on the vegetation, since is there that people stay longer time, when going to the beach. Also, it is

**Table 2** Studied dominant plant communities along the psammophilic gradient (Portuguese coast), and analysed parameters

« Nature 2000 » habitat: 1210 - Annual vegetation of drift lines [“ <i>vegetação anual das zonas de acumulação de detritos pela maré</i> ”]				
Other codes: EUNIS 2002: B2.1; Palearctic 2001: 17.2; Corine Land Cover: 3.3.1.				
Medium-high beach transition area	Association : <i>Honkenyo-Euphorbietum peplis</i> Tüxen ex Géhu 1964 – Euro-Siberian			
<i>Taxa</i>	Number of inventories: 18			
Differential: 24	M. C.: 25.78	M. sp.: 5.4		
Companion: 6, 27, 40, 49, 63, 66, 67, 77, 88, 106, 118, 126, 141	S=18.91	S=1.7		
	E.: 7.1	Ps.: 85.71	Pr.: 14.29	
	No endemisms			
Medium-high beach transition area	Association: <i>Salsolo kali-Cakiletum aegyptiacae</i> Costa & Mansanet 1981 - Mediterranean			
<i>Taxa</i>	Number of inventories: 19			
Differential: 25	M. C.: 19.11	M. sp.: 4.6		
Companion: 27, 40, 63, 66, 67, 101, 107, 118, 126	S=11.20	S=2.0		
	E.: 30	Ps.: 100		
	No endemisms			
<b>Biogeographical frontier</b> between the Eurosiberian and the Mediterranean communities, in Portugal: “Cabo da Roca” (under the influence of “ <i>Serra de Sintra</i> ”, Lisbon).				
« Nature 2000 » habitat: 2110 - Embryonic shifting dunes [“ <i>dunas móveis embrionárias</i> ”]				
Other codes: EUNIS 2002: B1.3/P-16.211; Palearctic 2001: 16.211; Corine Land Cover: 3.3.1.				
Flat areas of the high beach	Association: <i>Euphorbio paraliae-Elytrigietum boreoatlanticae</i> Tüxen in Br.-Bl. & Tüxen 1952 corr. Darimont, Duvigneaud & Lambinon 1962 nom. mut. – Euro-Siberian			
<i>Taxa</i>	Number of inventories: 72			
Characteristic & Differential: 63, 77	M. C.: 54.67	M. sp.: 5.8		
Companion: 2, 6, 8, 11, 14, 19, 24, 27, 28, 37, 42, 45, 49, 53, 55, 32, 66, 67, 40, 73, 88, 90, 95, 99, 101, 106, 107, 117, 118, 122, 126, 139, 141, 142, 153	S=30.52	S=2.9		
	E.: 16	Ps.: 84	Pr.: 16	
	PE: 0.07	IbE: 1.00	Total: 1.07	
Flat areas of the high beach	Association: <i>Elytrigietum junceo-boreoatlantici</i> J. C. Costa, C. Neto, Lousã, J. Capelo & Rivas-Martínez 2004 - Mediterranean			
<i>Taxa</i>	Number of inventories: 19			
Characteristic & Differential: 62, 63	M. C.: 41.84	M. sp.: 6.3		
Companion: 6, 11, 19, 25, 27, 31, 49, 66, 67, 40, 89, 95, 103, 106, 107, 118, 122, 126, 142	S=16.36	S=2.0		
	E.: 29	Ps.: 86	Pr.: 5	
	PE: 0.14	IbE: 1.03	Total: 1.17	
<b>Biogeographical frontier</b> between the Eurosiberian and the Mediterranean communities, in Portugal: “Cabo Mondego” (in the beach of Quiaios, influenced by “ <i>Serra da Boa Viagem</i> ”, Figueira da Foz).				
« Nature 2000 » habitat: - 2120 Shifting dunes along the shoreline with <i>Ammophila arenaria</i> (“white dunes”) [“ <i>dunas móveis do cordão dunar com Ammophila arenaria</i> (“ <i>dunas brancas</i> ”)”]				
Other codes: EUNIS 2002: B1.3/P-16.212; Palearctic 2001: 16.212; Corine Land Cover: 3.3.1.				
Primary dunes	Association: <i>Otantho maritimi-Ammophiletum australis</i> Géhu & Tüxen 1975 corr. Rivas-Martínez, Lousã, T.E. Díaz, Fernández-González & J.C. Costa 1990 – Euro-Siberian			
<i>Taxa</i>	Number of inventories: 99			
Characteristic & Differential: 6, 12, 28, 82, 88, 90	M. C.: 86.86	M. sp.: 8.1		
Companion: 2, 7, 8, 10, 13, 19, 22, 24, 25, 27, 31, 38, 42, 43, 44, 45, 47, 48, 49, 51, 52, 53, 63, 66, 67, 73, 79, 83, 87, 90, 93, 95, 97, 99, 100, 101, 106, 107, 110, 118, 120, 122, 125, 136, 137, 139, 141, 142, 144, 152, 153	S=38.23	S=4.0		
	E.: 23	Ps.: 63	Pr.: 16	
	PE: 0.01	IbE: 6.94	EE: 0.03	Total: 6.98
Primary dunes	Association: <i>Loto cretici-Ammophiletum australis</i> Rivas-Martínez 1965 corr. - Mediterranean			
<i>Taxa</i>	Number of inventories: 90			
Characteristic & Differential: 6, 15, 17, 89, 95, 115, 147	M. C.: 84.69	M. sp.: 8.7		

**Table 2** (continued)

Companion: 8, 9, 19, 23, 25, 26, 27, 30, 31, 47, 49, 54, 55, 60, 62, 63, 66, 67, 68, 73, 75, 83, 91, 97, 101, 103, 106, 107, 108, 113, 116, 118, 122, 127, 130, 131, 136, 137, 139, 141, 142, 143, 144, 148, 149, 150, 151, 153, 154, 152; 155		S=30.25	S=3.4
	E.: 19	Ps.: 67	Pr.: 15
	PE: 3.40	IbE: 0.60	EE: 0.14
			Total: 4.14
<b>Biogeographical frontier</b> between the Euro-Siberian and the Mediterranean communities, in Portugal: the frontier is not clear; a transition area occurs between Figueira da Foz and Aveiro (beach of “Costa Nova”).			
« Nature 2000 » habitat: *2130, “* Fixed coastal dunes with herbaceous vegetation (“gray dunes”)” [ “* <i>dunas fixas com vegetação herbácea (“dunas cinzentas”)</i> ” ]			
Other codes: EUNIS 2002: B1.4/P-16.223; Palearctic 2001: 16.22; Corine Land Cover: 3.3.1.			
Secondary dunes	Association: <i>Iberidetum procumbentis</i> Bellot 1968 – Euro-Siberian		
Taxa	Number of inventories: 76		
Characteristic & Differential: 12, 28, 42, 83, 84, 88, 90	M. C.: 113.37	M. sp.: 16.2	
Companion: 1, 2, 3, 6, 8, 10, 13, 14, 19, 20, 21, 22, 27, 31, 33, 35, 36, 37, 38, 39, 41, 43, 45, 46, 47, 49, 50, 57, 53, 55, 63, 65, 66, 67, 68, 70, 72, 73, 74, 76, 79, 80, 81, 85, 87, 92, 93, 96, 97, 98, 99, 100, 101, 102, 105, 106, 107, 108, 109, 110, 112, 113, 116, 117, 118, 119, 122, 123, 125, 131, 132, 133, 134, 135, 136, 137, 139, 141, 142, 143, 144, 148, 149, 150, 151, 152, 153, 154	S=37.2	S=4.3	
	E.: 43	Ps.: 28	Pr.: 16
	PE: 1.73	IbE: 32.22	EE: 1.93
			Total: 35.89
Secondary dunes	Association: <i>Armerio welwitschii-Crucianelletum maritimae</i> Br.-Bl., Rozeira & P. Silva in Br.-Bl., G. Br.-Bl., Rozeira & P. Silva 1972 - Transitional Euro-Siberian - Mediterranean		
Taxa	Number of inventories: 30		
Characteristic & Differential: 17, 83, 90, 95	M. C.: 67.23	M. sp.: 16.5	
Companion: 2, 6, 8, 9, 13, 19, 26, 27, 28, 31, 41, 45, 47, 48, 49, 55, 56, 57, 63, 65, 66, 68, 69, 71, 73, 74, 75, 86, 87, 88, 91, 97, 99, 100, 101, 103, 105, 107, 110, 116, 119, 122, 124, 131, 133, 136, 137, 139, 141, 142, 152, 153, 154	S=28.8	S=4.1	
	E.: 59	Ps.: 59	Pr.: 22
	PE: 7.33	IbE: 35.18	EE: 0.86
			Total: 43.37
<b>Biogeographical frontier</b> between the Eurosiberian and the Transitional Eurosiberian-Mediterranean communities, in Portugal: Aveiro.			
Secondary dunes	Association: <i>Artemisio crithmifoliae-Armerietum pungentis</i> Rivas Goday & Rivas-Martínez 1958 - Mediterranean		
Taxa	Number of inventories: 113		
Characteristic & Differential: 11, 16, 60, 89, 95, 115, 147	M. C.: 124.38	M. sp.: 12.48	
Companion: 2, 5, 6, 8, 9, 13, 18, 19, 23, 25, 26, 27, 29, 30, 31, 34, 38, 41, 39, 47, 48, 52, 54, 55, 57, 58, 59, 61, 66, 67, 68, 69, 73, 75, 78, 82, 87, 91, 93, 94, 97, 101, 102, 103, 106, 107, 110, 111, 113, 114, 118, 121, 125, 128, 129, 130, 131, 136, 137, 138, 139, 140, 142, 145, 146, 152, 153	S: 44.6	S: 4.5	
	E.: 49	Ps.: 59	Pr.: 25
	PE: 10.39	IbE: 33.76	EE: 11.69
			Total: 55.83
<b>Biogeographical frontier</b> between the Transitional Euro-Siberian - Mediterranean and Mediterranean communities, in Portugal: Tagus River (“ <i>Rio Tejo</i> ”, Lisboa).			

» Numbers in italic refer to plant *taxa* (see Table 1)

*M. C.* Mean covers (in %) for all studied inventories; *M. sp.* Mean number of *taxa* (for all studied inventories); *S* Population Standard Deviation; *E.* % of exclusive *taxa*, with their optimum within the studied phytosociological association; *Ps.* % of psammophilic *taxa* (restricted to beaches and sand dunes); *Pr.* % of *taxa* with preference to sandy substrate (but that also colonize other habitats); *Endemisms* (% of mean cover by endemic *taxa* in relation to the total cover); *PE.* Portuguese Endemism; *IbE.* Iberian Endemism; *EE.* European Endemism

especially in the upper sector of the backshore (high beach and white dune) that restaurants and other touristic support infrastructures, like toilets, are usually installed. Often, the white dune shows a complex of track ways related to beach access. In some locations, the medium-high beach transition areas, suffer a medium

impact of all-terrain and other vehicles. Considering the vulnerability based on coastal retreat and beach erosion, the exposure (probability of an area to be exposed to a threat for a certain time, or the time expected to be affected) of the beach is maximum, slightly diminishing in the white dune.

As regards endemism, vulnerability is low for the beach, and low to medium for the white dune. However, the flora exclusivity for the substrate along the entire zonal gradient is maximum in these areas, reflecting strong ecological adaptations, and an elevated capacity to respond to environmental disturbances. The herbaceous *taxa* that occur in these sectors are colonisers (opportunistic species or r-strategists), with strong resilience, being able to resist to negative inputs, or quickly move into new colonization areas (Freyer et al. 2000). These therophytic nitrophilous grasslands recover well after the winter storms and easily support the seasonal touristic pressure, as they have an annual life cycle. Limited to seeds during the unfavourable seasons, and being dispersed by sea hydrochory, the hemicryptophytic species that colonize the backshore and white dune, like *Elytrigia juncea* and *Ammophila arenaria* subsp. *arenaria*, are well adapted to burial, and easily advance to the interior, in situations of beach progradation.

The impact and intensity of touristic activities (Wilson et al. 2005) in the gray dune can be considered as medium. In the summer, very high surface temperatures are felt in the gray dune sands, and tourists do not stay there many times. Yet, the access to the beaches implies a certain degree of trampling. The lawless opening of paths causes habitat fragmentation and windows of opportunity to invasion by ruderal plants, namely exotic. For many years this problem was almost ignored in Portugal, until more or less two decades ago, in some places, namely in protected areas, some footbridges began to be successfully installed. Being far from the sea, the exposure to coastal retreat in the grey dune is medium, increasing however, in severe coastal erosion situations in which the white dune's transgression landwards, overlaps the grey dune.

Gray dune vegetation demonstrates low to medium resilience, since the dominant chamaephytes in those communities have slow growing rates, difficulty and delay their response to degradation. With a slower dynamic (and life cycles longer than most of white dune's plants) their capacity to quickly respond to the rise and movement of the topographic surface is weak, tending to be

gradually buried. Until a new equilibrium or progression phase is achieved, the compression and migration of plant communities to the interior, continues. Rapid erosion processes cause the increase of the direct sea influence on the white and grey dunes. In the Portuguese coast this phenomenon is frequently observed, and, in many cases, the analysed data has confirmed it. In Table 3 are showed the results for vulnerability (from the beaches until the grey dunes) based on the threat status (endemism plus flora psammophilic exclusivity).

A reference value for the Mediterranean green dunes' vulnerability, based on the endemism, would be considered as medium. Since in the green dune organic matter can accumulate in the soil, allowing the formation of acid humus (*mull*), the installation of non psammophilic species in the habitat is favoured. For this reason, the flora exclusivity for the substrate is low to medium. Comparatively to the previous ecosystems, vulnerability to coastal retreat is lower.

#### Reference values for the extremophile resilience/vulnerability index

The results found for the  $Index_{EVR/V}$  are shown in table 4. This work only presents a generic application, that can be used as a reference, but the  $Index_{EVR/V}$  can be applied according to any coastal station specific characteristics, within the defined intervals, or even in other type of habitats, with the necessary adjustments according to the major threats to the ecosystem. In this specific case, since the aim was finding reference values, for the interval classes only the intermediate values 1.5 and 2.5 were used. The value zero was considered as not applicable under the assumption that any ecosystem has some resilience and vulnerability. Thus, the final results could range from 3 (maximum resilience, and minimum vulnerability) to 0.333 (minimum resilience, and maximum vulnerability).

The differences between Euro-Siberian and Mediterranean plant communities were not considered, since these are only indicative values.

**Table 3** Vulnerability based on threat status (degree of endemism and flora psammophilic exclusivity), for the studied beach and dune sectors

Threat status indicators	Distribution	Psammophilic Sector			
		Medium - High beach transition	High beach	White dune	Grey dune
Degree of endemism (% cover)	Euro-Siberian	0	1.07	6.98	35.89
	Transition	–	–	–	43.37
	Mediterranean	0	1.17	4.14	55.83
Flora psammophilic exclusivity (Ps + Pr)	Euro-Siberian	100	100	79	44
	Transition	–	–	–	81
	Mediterranean	100	91	82	84

**Table 4** Reference values of the *Extremophile Vegetation Resilience/Vulnerability Index*, for the psammophilic vegetation of the Portuguese coast

Resilience and Vulnerability		Psammophilic Sector				
		Medium - High beach transition	High beach	White dune	Grey dune	Green dune
Resilience ( <i>sensu</i> Freyer, 2000)		High 3	High 3	Medium 2.5	Low-Medium 1.5	Low 1
Vulnerability a) Intensity, Impact, Exposure	i. Touristic activities (intensity and impact)	Medium 2	High 3	High 3	Medium 2	High 3
	j. Coastal retreat (exposure)	High 3	High 3	Medium-High 2.5	Medium 2	Low-Medium 1.5
	k. Endemicity	Low 1	Low 1	Low-Medium 1.5	High 3	Medium 2
Vulnerability b) Threat	l. Flora exclusivity in psammophilic substrate	High 3	High 3	High 3	Medium 2	Low-Medium 1.5
Total Vulnerability a) and b)		Medium 2.25	Medium 2.375	Medium 2.5	Medium 2.25	Medium 2
Final Resilience/Vulnerability		3/2.25=1.33 (positive)	3/2.375=1.26 (positive)	2.5/2.5=1	1.5/2.25=0.67 (negative)	1/2=0.5 (negative)

The  $Index_{EVR/V}$  shows a positive balance (in general medium values) for the medium-high beach transition, and high beach (although inferior). In the white dune, the vulnerability equals the resilience, reflecting a situation of equilibrium. These results are according to the annual life cycle of the medium-high beach transition plant species that complete their life cycle in a favourable season, after the summer touristic pressure, and before the winter-spring storms. The colonizers typical from this sector have a fast capacity to react and re-establish after a perturbation, being well adapted to the sands mobility.

In the grey dune the balance is negative, which is mainly related to the slowest response of the chamaephtic vegetation to environmental perturbation. In spite of that, the lowest values can be found in the green dune, because this is a extremely sensitive and low resilient ecosystem.

## Conclusions

Results have showed, in a quantified manner, the generic tendencies along the North-South coast in terms of psammophilic dominant plant communities. Also, it was possible to study in detail, the beach-interior dunes' dominant psammophilic plant communities.

When analysing the results, it became clear that the Mediterranean grey dune's communities show the highest covers by Portuguese endemism, have more biodiversity, and that is at this level that "bioindication" of sea erosion can be more clearly understood, demonstrating their special importance for conservation.

Regarding the  $Index_{EVR/V}$  the results obtained so far are interesting, but not conclude. In the future it is expected

to apply this Index to each inventory individually, to obtain precise values to all studied inventories and locations, and more accurate results, and to compare possible different situations. Eventually, to discover other differences between the Euro-Siberian and Mediterranean communities, and to adjust the present reference values for each case. In a fine scale, in the context of territorial land planning and management, namely of the beach recreational activities, it will be possible to compare several coastal sectors, and to identify the most suitable areas for the implementation of touristic support structures, or most urgent areas for actions of vegetation recovery.

It is important to reinforce that, despite the Extremophile Vegetation Resilience/Vulnerability Index was developed in the context of this specific work to study the Portuguese psammophilic gradient trends, it can be applied in the determination of vegetation conservation status, along different sectors of the coast. Like the Vulnerability, the Resilience can also be decomposed in several quantifiable parameters, relying in the communities' floristic composition, namely the life cycles of each species present in the inventories and correspondent response to disturbance. Potential research related to this work, may go in that direction.

Even though not exhaustive, this paper gives a contribution to the understanding of the psammophilic gradient in the Portuguese coasts, and can be used as a consulting source for investigation related with these ecosystems, and as a practical tool in the identification of main plant communities along the psammophilic gradient and their composition, including some differential and characteristic species. The

eventual future application of the Extremophile Vegetation Resilience/Vulnerability Index in practical situations, may also be helpful to the decision making process in the scope of Portuguese coastal land planning, and particularly in sustainable tourism activities.

## References

- ALFA - Associação Lusitana de Fitossociologia (2006) Fichas de caracterização ecológica e de gestão de habitats naturais da Rede Natura 2000. In: ICNB – Instituto da Conservação da Natureza e da Biodiversidade (2006) “Plano Sectorial da Rede Natura 2000”
- Acosta A, Carranza ML, Izzi CF (2005) Combining land cover mapping of coastal dunes with vegetation analysis. *Appl Veg Sci* 8:133–138
- Acosta A, Carranza ML, Izzi CF (2009) Are there habitats that contribute best to plant species diversity in coastal dunes? *Biodivers Conserv* 18:1087–1098
- Andelman SJ, Willig MR (2003) Present patterns and future prospects for biodiversity in the Western Hemisphere. *Ecol Lett* 6:818–824
- Andrade C, Freitas MC, Cachado C, Cardoso AC, Monteiro JH, Brito P, Rebelo L (2002) Coastal zones. In: Santos FD, Forbes K, Moita R (eds) *Climate change in Portugal. Scenarios, impacts and adaptation measures*. Gradiva, pp 173–219
- Anke J, Silke F, Wolfram B, Werner N (2002) Significance of ant and rabbit disturbances for seedling establishment in dry acidic grasslands dominated by *Corynephorus canescens*. *Phytocoenologia* 32(4):553–580
- Araújo R, Honrado J, Granja H, Pinho S, Caldas FB (2002) Vegetation complexes of coastal sand dunes as an evaluation instrument of geomorphologic changes in coastline. *Proceedings of Littoral 2002, The Changing Coast* (Porto, Portugal), pp 337–339
- Baudet ÁB (2002) *Biología de la conservación de plantas amenazadas*. Série Técnica, Ministerio de Medio Ambiente, Parques Nacionales. Madrid
- Barbour MG, De Jong TM, Pavlik BM (1985) Marine beach and dune plant communities. In: Chabot BF, Mooney HA (eds) *Physiological ecology of North American plant communities*. Chapman & Hall, New York
- Bindoff NL, Willebrand J, Artale V, Cazenave A, Gregory J, Gulev S, Hanawa K, Le Quéré C, Levitus S, Nojiri Y, Shum CK, Talley LD, Unnikrishnan A (2007) Observations: Oceanic climate change and sea level. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) *Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge
- Bird ECF (1976) *Coasts*. Australian National University Press, 2nd edition
- Braun-Blanquet J, Rozeira A, Pinto da Silva AR (1972) Résultats de deux excursions géobotaniques à travers le Portugal septentrional et moyen IV. *Equisse sur la végétation dunale*. *Agron Lusit* 33(1–4):217–234
- Braun-Blanquet J (1979) *Fitossociologia. Bases para el estudio de las comunidades vegetales*. Ed. Blume, Madrid
- Caldas FB, Honrado JJ, Paiva AP (1999) *Vegetação da Área de Paisagem Protegida do Litoral de Esposende* (Portugal). *Quercetea* 1:39
- Castroviejo S, Lainz M, López González G, Monserrat P, Muñoz Garmendia F, Paiva J, Villar L (1986–2007) *Flora Iberica*. Volumes I–VIII, X, XIV, XV, XVIII, XXI. Madrid: Real Jardín Botánico de Madrid, CSIC
- Costa JC, Aguiar C, Capelo J, Lousã M, Neto C (1998a) *Biogeografia de Portugal continental*. *Quercetea* 0:5–56
- Costa JC, Capelo J, Lousã M, Espírito Santo MD (1998b) *Sintaxonomia da vegetação halocasmofítica das falésias marítimas portuguesas* (*Crithmo-Staticetea* Br.-Bl. 1947). *Itinera Geobotanica* 11:227–247
- Costa JC, Espírito-Santo D, Lousã M (1994) The vegetation of dunes of Southwest Portugal. *Silva Lusitana* (2)1, pp 51–68
- Costa JC, Lousã M (1989) *Communautés psammophyloques et halophyloques de Ria de Alvor*. *Phytosociologie littorale et Taxonomie*. *Coll Phytosoc* XVIII:119–135, Lille
- Costa JC, Lousã M, Espírito-Santo MD (1997) *Vegetação do Parque Natural da Ria Formosa*. *Stud Bot* 15:69–157
- Costa JC, Lousã M, Capelo J, Espírito Santo MD, Sevillano JI, Arsenio P (2000) The coastal vegetation of the Portuguese divisory sector: dunes cliffs and low-scrub communities. *Finisterra* XXXV (69):69–93
- Costa JC (2001) *Tipos de vegetação e adaptações das plantas do litoral de Portugal continental*. In: *Albergaria Moreira ME, Casal Moura A, Granja HM, Noronha F* (eds) *Homenagem* (in honorio) Professor Doutor Soares de Carvalho: 283–299. Universidade do Minho, Braga
- Coutinho AX (1939) *Pereira Flora de Portugal*. *Plantas Vasculares*, 2nd edn. Livraria Bertrand, Lisboa, 938 pp
- Daveau S (1995) *Portugal Geográfico*. João Sá da Costa (ed), Lisboa, 223 p
- Díaz TE, Rivas-Martínez S, Fernández-González F (1990) *Stauracanthus Link. (Leguminosae) en la Península Ibérica*. *Itinera Geobotanica* 3:131–135
- Díez Garretas B (1984) *Datos sobre la vegetación psammofila de las costas portuguesas*. *Doc Phytosociol* 8:71–81
- Feagin RA, Wu XB, Smeins FE, Whisenant SG, Grant WE (2005) Individual versus community level processes and pattern formation in a model of sand dune plant succession. *Elsevier Ecol Model* 183(2005):435–449
- Feagin RA, Wu XB (2007) The spatial patterns of functional groups and sand dune plant community succession. *J Rangel Ecol Manag* 60:417–425
- Feagin RA, Mukherjee N, Shanker K, Baird AH, Cinner J, Kerr AM, Koedam N, Sridhar A, Arthur R, Jayatissa LP, Seen DL, Menon M, Rodriguez S, Shamsuddoha M, Dahdouh-Guebas F (2010) Shelter from the storm? Use and misuse of coastal vegetation bioshields for managing natural disasters. *Conserv Lett* 3 (2010):1–11
- Ferreira JC (2006) *Coastal zone vulnerability and risk evaluation: A tool for decision-making (an example in the Caparica Littoral - Portugal)*. SI 39 (Proceedings of the 8th International Coastal Symposium), Itajaí, SC, Brazil. *Journal of Coastal Research* pp: 1590–593
- Foody GM (2002) Status of land cover classification accuracy assessment. *Remote Sens Environ* 80:185–201
- Franco A (1971; 1984) *Nova Flora de Portugal (Continente e Açores) Volume I (LYCOPODIACEAE - UMBILIFERAE; Lisboa, 647 pag. Volume II (CLETHRACEAE - COMPOSITAE)”. Lisboa, 659 pag*
- Franco A, Rocha Afonso ML (1994; 1998; 2003) *Nova Flora de Portugal (Continente e Açores), Volume III (Fascículo I)*. 181 pag; *Volume III (Fascículo II)”, 238 pag; Volume III (Fascículo III)”, 187 pag*. Escolar Editora, Lisboa
- Frederiksen L, Kollmann J, Vestergaard P et al (2006) A multivariate approach to plant community distribution in the coastal dune zonation of NW Denmark. *Phytocoenologia* 36:321–342
- Freyer B, Reisner Y, Zuberbühler D (2000) Potential impact model to assess agricultural pressure to landscape ecological functions. *Ecol Model* 130:121–129

- García-Mora, Rosario M, Gallego-Fernández JB, García-Novo F (1999) Plant functional types in coastal foredunes in relation to environmental stress and disturbance. *J Veg Sci* 10:27–34
- Géhu JM, Rivas-Martínez S (1981) Notions fondamentales de Phytosociologie, pp 1–33. In: Cramer J (ed). *Syntaxonomie*. Vaduz, Berlin. International Symposium. IVVS
- Hesp PA (1991) Ecological processes and plant adaptations on coastal dunes. *J Arid Environ* 21:165–191
- Hesp P (2002) Foredunes and blowouts: initiation, geomorphology and dynamics. *Geomorphology* 48:245–268
- Honrado J, Vicente J, Lomba A, Alves P, Macedo JA, Henriques R, Granja H, Caldas FB (2010) Fine-scale patterns of vegetation assembly in the monitoring of changes in coastal sand-dune landscapes. *Web Ecol* 10:1–14
- Howe MA, Knight GT, Clee C (2009) The importance of coastal sand dunes for terrestrial invertebrates in Wales and the UK, with particular reference to aculeate Hymenoptera (bees, wasps & ants). *J Coast Conserv*. doi:10.1007/s11852-009-0055-x
- ICNB – Instituto da Conservação da Natureza e da Biodiversidade (2006) Plano Sectorial da Rede Natura 2000
- IPCC – Intergovernmental Panel on Climate Change (2001) Climate change 2001: The scientific basis. Working Group I Contribution, Third Assessment Report. Houghton JT, Ding Y, Griggs DJ et al (eds) Cambridge University Press
- IPCC – Intergovernmental Panel on Climate Change (2007) Climate change 2007: Impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of Working Group II to the Fourth Assessment Report (AR4). Cambridge University Press, Cambridge, UK, p 976
- Izco J (1989) El río Miño y camino en la migración de las plantas. In: *El Río Miño*. Ourense; Caixa Ourense. pp 87–97
- Kim KD (2004) Invasive plants on disturbed Korean sand dunes. *Estuarine Coastal Shelf Sci* 62(2005):353–364
- Kim D, Yu KB (2009) A conceptual model of coastal dune ecology synthesizing spatial gradients of vegetation, soil and geomorphology. *Plant Ecol* 202:135–148
- Kumler ML (1997) Critical environmental factors in dry coastal ecosystems. In: van der Maarel E (ed) *Dry coastal ecosystems*. General aspects. Elsevier, Amsterdam, pp 387–409
- Leal JLR (2007) Análise Geopolítica e Geoestratégica de Portugal. Factores Físico, Humano e Circulação. *Revista Militar*, pp 349
- Lee JK, Lee KS, Ihm BS, Kim HS, Lee SH (2000) Studies on the vegetation distribution and standing biomass at the coastal sand dune of Uido. *Basic Sci Res* 15:53–60
- Lomba ACAR (2004) A Flora e a Vegetação da Reserva Ornitológica do Mindelo (Vila do Conde). MSc, Porto University
- Lomba A, Alves P, Honrado J (2009) Endemic sand-dune vegetation from Northwest Iberian Peninsula: diversity, dynamics and significance for bioindication and monitoring of coastal landscapes. *J Coast Res*
- Loureiro J, Capelo A, Brito G, Rodriguez E, Silva S, Pinto G, Santos C (2007) Micropropagation of *Juniperus phoenicea* from adult plant explants and analysis of ploidy stability using flow cytometry. *Biol Plant* 51(1):7–14
- MacDougall A, Loo J (2002) Land use history, plant rarity, and protected area adequacy in an intensively managed forest landscape. *J Nat Conserv* 10:171–183
- McKee JK, Sciulli PW, Fooce CD, Waite TA (2004) Forecasting global biodiversity threats associated with human population growth. *Biol Conserv* 115:161–164
- Medeiros C (2005) Um Preâmbulo Geral. In: *Vários* (2005) *Geografia de Portugal: o Ambiente Físico*, Volume I, Círculo de Leitores, Rio de Mouro, pp 18–47
- Moreira MESA (1984) Glossário de termos usados em Geomorfologia do Litoral. *Estudos de Geografia das Regiões Tropicais*, 15. Centro de Estudos Geográficos. Lisboa, 1984
- Moreira MESA (1985) A evolução do litoral a partir da análise da rede hidrográfica. O exemplo da Ribeira da Comporta, Lisboa, Actas da I.ª Reunião do Quaternário Ibérico, Vol 1, pp 297–331
- Muller-Dombois, Ellemberg H (1974) Aims and methods of vegetation ecology. Wiley and Sons, N. Y, 547pp
- Neto C (1991) Os biótopos e as fitocenoses da reserva natural das dunas de S. Jacinto. Provas de Aptidão Pedagógica e Capacidade Científica, Lisboa
- Neto C (1993) A Flora e a Vegetação das Dunas de S. Jacinto. Finisterra, XXVIII, 55–56: 101–148
- Neto C (1994) O microclima das Dunas de S. Jacinto (litoral de Aveiro). *Anais do Instituto Superior de Agronomia*. Vol. XLIV, Fasc. 1º. 197–214 pp
- Neto C (2002) A Flora e a Vegetação do superdistrito Sadense (Portugal). *Guineana* 8:1–269
- Neto C, Capelo J, Costa JC (2004) Comunidades vegetais dos solos arenosos podzolizados do Sado e Costa da Galé. Uma interpretação fitossociológica dos dados paleoecológicos e geomorfológicos. *Silva Lusit* 12(2):256–262
- Neto C, Costa JC, Honrado J, Capelo J (2007) Phytosociological associations and Natura 2000 habitats of Portuguese coastal dunes. *Fitosociologia* 44(2) suppl. 1
- Neto C, Arsénio P, Costa JC (2009) Flora e Vegetação do sudoeste de Portugal continental. *Quercetea* 9:43–144
- Neto C, Martins M, Costa JC (2010) Bioindicadores of erosive dynamics in dune systems of the Portuguese coast. Résumés des communications orales et des posters. Colloque international Centenaire de la Phytosociologie, Honneur au professeur Jean\_Marie Géhu. Brest, 3–5 Novembre 2010
- Paiva-Ferreira RP, Pinto-Gomes C (2002) O interesse da Fitossociologia na Gestão e Conservação do Litoral Alentejano: Praia do Monte Velho (Santiago do Cacém). Coleção Estudos sobre o Alentejo 2, DRAOT Alentejo, Ministério das Cidades, Ordenamento do Território e Ambiente, Direcção Geral do Ambiente e do Ordenamento do Território – Alentejo
- Pinho SNN (2001) Ecomorfodinâmica de dunas holocénicas (segmento costeiro - sul). Msc, Porto University
- Pinto-Gomes C, Paiva-Ferreira R, Cano E, Mendes S (2006) Pelouse psammophiles à *Corynephorus canescens* var. *maritimus* Godr. du centre et du sud du Portugal. *Acta Bot Gallica* 153(3):341–354
- Psuty NP (2004) The coastal foredune: A morphological basis for regional coastal dune development. In: Martínez M, Psuty NP (eds) *Coastal dunes: Ecology and conservation*. Springer, Berlin, pp 11–27
- Psuty NP, Silveira TM (2010) Global climate change: an opportunity for coastal dunes?? *J Coast Conserv*. doi:10.1007/s11852-010-0089-0
- Ribeiro O (1986) Portugal. O Mediterraneo e o Atlântico. Esboço de relações geográficas. Coleção “Nova Universidade”, 4ªth edn. Livraria Sá da Costa, Lisboa, 188 pp
- Ribeiro O, Lautensach H, Daveau S (1987) Geografia de Portugal, vol I, A posição geográfica e o território. Edições João Sá da Costa, Lisboa, 334 pp
- Rivas-Martínez S (2005) Notions on dynamic-catenal phytosociology as a basis of landscape science. *Plant Biosyst* 139(2):135–144
- Rivas-Martínez S, Cantó P, Fernandez-González F, Navarro C, Pizarro JM, Sanchez-Mata D (1990) Biogeografía de la Peninsula Iberica, Islas Baleares y Canarias. Publ. Dept. Biología Vegetal, Univ. Complutense de Madrid, 2:1–5
- Rivas-Martínez S, Díaz TE, Fernandez-González F, Izco J, Loidi J, Lousã M, Penas A (2002) Vascular plant communities of Spain and Portugal. Addenda to the Syntaxonomical checklist of 2001. *Itinera Geobotanica* 15(1–2):5–922
- Rivas-Martínez S, Fernandez-González F, Loidi J, Lousã M, Penas A (2001) Syntaxonomical checklist of vascular plant communities

- of Spain and Portugal to association level. *Itinera Geobotanica* 14 (1):5–341
- Rust I, Illenberger W (1996) Coastal dunes: sensitive or not? *Landsc Urban Plan* 34:165–169
- Ruxton GD, Colegrave N (2006) *Experimental design for the life sciences*. Second Edition. Oxford University Press
- Salman A (1994) Prospects for the conservation of coastal areas, European Union for Coastal Conservation (EUCC), the Netherlands. In: Proceeding “Colloquy: Protection of Coastal areas of the Adriatic Sea”, European Nature Conservation Year 1995 and Ministry of Health and Environment of Albania. Tirana, Albania, 27–29 October 1994
- Saiz JCM, Lozano FD, Ollero HS (2003) Recent progress in conservation of threatened Spanish vascular flora: a critical review. *Biol Conserv* 113(3):419
- Silva GM (2006) *Padrões Fitogeográficos em Sistemas Dunares do Noroeste de Portugal Continental*. MSc Thesis in Landscape Ecology and Nature Conservation, Porto University
- Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (2007) *Climate change 2007: The physical science basis*. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge
- Soares de Carvalho G, Granja H, Gomes P, Loureiro E, Henriques R, Carrilho I, Costa A, Ribeiro P (2002) New data and new ideas concerning recent geomorphological changes in the NW Coastal Zone of Portugal. *Proceedings of Littoral 2002, The Changing Coast (Porto, Portugal)*, pp 399–410
- Tigabu M, Fjellström J, Odén PC, Teketay D (2007) Germination of *Juniperus procera* seeds in response to stratification and smoke treatments, and detection of insect-damaged seeds with VIS+NIR spectroscopy. *New Forest* 33:155–169
- Tutin TG et al (1964–1980) *Flora Europaea*, Vols. I–V. Cambridge University Press
- Tüxen R (1975) La côte européenne occidentale, domaine de lutte et vie. *Coll Phytosociol* 4:503–515
- Valdés B, Talavera S, Galiano EF (1987) *Flora Vascular de Andalucía Occidental*, Vols. I–II. Ketres Editora, Barcelona
- Van Auken OW, Jackson JT, Jurena PN (2004) Survival and growth of *Juniperus* seedlings in *Juniperus* woodlands. *Plant Ecol* 175:245–257
- Van Der Maarel E (2003) Some remarks on the functions of European coastal ecosystems. *Phytocoenologia* 33(2–3):187–202
- van Til M, Koojman A (2007) Rapid improvement of grey dunes after shallow sod cutting. In: Isermann M, Kiehl K (Eds) *Restoration of coastal ecosystems*. *Coastline Reports* 7: pp. 53–60
- Wilson K, Pressery RL, Newton A, Burgman M, Possingham H, Weston C (2005) Measuring and incorporating vulnerability into conservation planning. *Environ Manag* 35(5):527–543

### Internet sites

- ESRI - <http://www.esri.com/>
- ICNB “Fichas de caracterização ecológica e de gestão de habitats naturais da Rede Natura 2000” - [http://www.icn.pt/psrn2000/caract\\_habitat.htm](http://www.icn.pt/psrn2000/caract_habitat.htm)