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REVIEW ARTICLE

Impact of human activities on coastal vegetation – A review

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Abstract

Coastal dunes constitute complex interface ecosystems between the land and sea, providing important ecological and socio-economic services like coastal protection, recreation, regulation, food supply and biodiversity. They are characterized by high ecological diversity and also by extremely specialized and endemic species. Coastal areas, because of their position between land and sea, are attractive for many human activities. Unfortunately coastal systems have had a long history of exploitation and mismanagement.

Key words: Coastal dune systems, Iberian Peninsula, Vegetation, Human impacts, Managements

Introduction

Coastal zones constitute interface ecosystems between the land and sea (Leewis et al., 2012, Gonçalves et al., 2013; Martins et al., 2013). They exhibit complex multilevel interactions: they are under the influence of a great variety of pressures both of natural and anthropogenic origin and they display complex relationships between the physical and biological processes (Nobre and Ferreira, 2009). Besides, they are some of the most dynamic areas on Earth. In fact, a crucial feature of the coastal zones is the variability in the intensity of the multiple influences that they are subjected to. Consequently, these zones are always striving for dynamic equilibrium without almost ever achieving it (Dias, 2004).

Coastal ecosystems are among the most productive systems in the world and provide disproportionately more services relating to human well-being than most other systems, even those covering larger total areas (Millennium Ecosystem Assessment, 2005). These services include regulation (climate regulation, nutrient regulation, carbon sequestration, detoxification of polluted waters), support (shoreline stabilisation, marine life nursery functions, buffering from natural hazards), provision (supply of food, energy resources, natural products), cultural services (recreation, culture and amenity) and biodiversity (EEA, 2006, Thompson and Schlacher, 2008). As a consequence, nearly 40% of the world's population lives within 100 km of the coastline and concentrates approximately 61% of the world's total Gross Domestic product (GDP) (Millenium Ecosystem Assessment, 2005). These facts stand out the importance of coastal areas for human well-being.

However, coastal zones are extremely sensitive due to a number of reasons. One of them is the dependency of the morphology of the sea-land line and variations in its relative location on a dynamic sea-land balance (Valpreda and Simeoni, 2003). Another is the fact that coastal areas are subject to harsh environmental conditions and constitute challenging habitats to be colonized by vegetation (Maun, 2009). Plants have to manage with living in soils usually deficient in major nutrients, highly saline and generally with low water content. Besides, plants must withstand intense and almost constant winds and salt spray (Martins et al., 2013).

This study intends to provide a review of the main impacts of human activities on coastal vegetation and also of management measures that

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have been proposed to restore and/or protect these systems.

Coastal dunes

Coastal dunes systems are eolian landforms developing in coastal areas where there is a plentiful supply of appropriate sediment, a prevailing wind that carries the sand inland and vegetation capable of sand stabilization (Macedo, 2008; Maun, 2009; Acosta et al., 2013). Sand or mixed sand and rock shorelines represent around 75% of the world's ice-free coastlines (Brown, 2001 in Brown and McLachlan, 2002). As they are distributed worldwide, the climate and biomes developing on coastal dunes are very diverse, encompassing a wide range of ecological habitats (Hesp, 2002; van der Maarel 1993a in Martínez et al., 2004a). However, in spite of their wide geographical range, coastal dune ecosystems occupy a very low percentage of the terrestrial environment (Castillo and Moreno-Casasola, 1996) and, of all the coastal ecosystems sand dunes have suffered the greatest degree of human pressure (Carter, 1988).

The Spanish coast is about 8000 km in length (5000 km in the Iberian Peninsula and 3000 km on the islands), consisting of 4000 km of cliffs, 2000 km of beaches, 1400 km of coastal lowlands and 600 km of artificial coast (Dias et al., 2012). Part of the coastline faces the Atlantic Ocean and part the Mediterranean Sea. The Portuguese mainland coast is about 900 km long, with low sandy beaches and cliffs alternating irregularly (Andrade et al., 2002 in Martins et al., 2013). Beaches constitute approximately 590 km of the coastline extension (Leal, 2007 in Martins et al., 2013). From its northern end to about a third of the coastline (Figueira da Foz) the shore is essentially flat and sandy (Martins et al., 2013). To the south of this location until Cape S. Vicente cliffs alternate with lowlands with sand dunes (Dias et al., 2013). The southern coast (Algarve) shows a differentiation between the western sector, mainly composed of cliffs and the eastern sector characterized by continuous sandy beaches (Dias et al., 2013; Martins et al., 2013).

Sandy coastline ecosystems perform several important ecological functions, one of the most relevant consisting in the dissipation of incoming wave and wind energy, thus protecting and stabilizing the shoreline (Gómez-Pina et al., 2002; Gonçalves et al., 2013; Valles and Cambrollé, 2013). They also provide services very significant from the economic point of view, such as recreation, culture and amenity (Martínez et al., 2004a; Gonçalves et al., 2013). Indeed, coastal dunes are highly valuable multifunctional ecosystems that occupy a unique natural niche (Martínez et al., 2004b).

Coastal sandy environments, being situated at the interface of land and sea, are highly dynamic and plastic systems (Brown and McLachlan, 2002; Gonçalves et al., 2013; Vallés and Cambrollé, 2013). In fact, sandy shoreline ecosystems consist, in general, of three components: a surf zone, intertidal beach and dune systems (Short and Hesp, 1982), each one being colonized by different species. There is a continuous exchange of sand and biological matter between dunes, intertidal beaches and surf zones (Brown and McLachlan, 2002). The action of waves and tides mainly controls not only morphology but also species diversity, biomass and community structure (Brown and McLachlan, 2002) although species inhabiting dunes must be able to colonize an unstable substrata, to tolerate recurrent sand engulfment and sandblast (Brown and McLachlan, 2002; Fenu et al., 2012).

Biodiversity

Coastal dune ecosystems experience well marked littoral-inland gradients as regards environmental factors such as substrate coherence (which influences probability of burial by sand) and salinity, wind, salt spray and wave regime, which differ with distance from the sea and topographic sheltering (Ranwell, 1972; Guara-Requena, 1989; Acosta et al., 2009; Lortie and Cushman, 2007 in Macedo, 2008; Carranza et al., 2008; Acosta et al., 2013). These gradients act as a strong selective force, which determines the occurrence of species developing different strategies (Martínez et al., 2004b; Fenu et al., 2012). According to these gradients, structurally and floristically different vegetation types develop (Brown and McLachlan, 2002; Carranza et al., 2008), thus accounting for the coexistence of many different communities within a relatively limited area as compared with other natural ecosystems, which results in a high ecological diversity (Van der Maarel, 2003; Martínez et al., 2004b; Carranza et al., 2008, Acosta et al., 2009; Fenu et al., 2012; Acosta et al., 2013). Moreover, sandy coastal ecosystems possess extremely specialized biotic assemblages rarely shared with adjacent terrestrial ecosystems (Acosta et al., 2005; Schlacher et al., 2008; Defeo et al., 2009). Several animal groups such as arthropods, gastropods, reptiles and birds are closely associated to different habitats in the dune system (McLachlan and Brown, 2006 in Acosta et al., 2013) because of dissimilarities in food sources, protection from predators, resting sites and vegetation structure (Kritzinger and van Aarde, 1998 in Martínez et al., 2004b). Dunes support the richest thermophilic invertebrate faunas in Britain (Kirby, 1992 in Howe et al., 2010), including many of the rarer species of bees and wasps (Howe et al., 2010). Both the high biodiversity and the high level of peculiar plants and habitats constitute a crucial factor that allows rapid adjustment to environmental change (Carter, 1988; Acosta et al., 2013). All these factors contribute to a high intrinsic value of dune ecosystems (Martínez et al., 2004a; Acosta et al., 2005).

The Portuguese coast is known for the richness of its flora, due to its special biogeographic position (Braun-Blanquet et al., 1972) and also for its importance as regards conservation value. In fact, in the total of Portuguese Natura 2000 habitats, 35% correspond to coastal habitats (Martins et al., 2013). Dune vegetation possesses a high percentage of endemic plant species as a result of speciation due to environmental isolation (Neto et al., 2007). In Portugal mainland, beaches south of Tagus River are characterized by the highest degree of endemism (Neto et al., 2007). The Mediterranean habitats are generally richer as regards floristic composition than the Atlantic ones and they also include almost all the psammophilic Portuguese endemisms (Neto et al., 2007) like for example *Linaria lamarckii*, *Thymus carnosus* and *Herniaria maritima* (Martins et al., 2013).

Beach zonation

Development of the dunes mainly depends on plant cover and height, wind velocity and quantity of sand. Secondary factors such as the rate of occurrence of swash inundation, storm wave power and wind direction can also be important in determining subsequent dune dynamics (Ranwell, 1972). As a consequence of the strong environmental gradients, sand dune ecosystems consist in a succession of shore-parallel bands. At each stage of the succession the plant community alters the soil and microclimate, allowing the establishment of another group of species.

At the upper edge of the beach where only high tides and storm waves arrive and debris accumulates in spring, the first vegetation strip develops. Very few and highly specialized vascular plant species can survive here, with specific morphological and physiological traits (García-Mora et al., 1999; Acosta et al., 2009). These pioneer species must possess a high salt tolerance and features that allow the survival to sand instability and burial. Additionally they have fast reproductive strategies, which allow them to exploit the spring-summer quasi-stability of the beach. Litter brought by storms and tides is essential for the survival of these plants as it provides nutrients, moisture and shelter (Carter, 1988; Costa et al., 1994). The vegetation is ephemeral, composed mostly of annual species which regenerate and re-establish new populations in spring/summer (Acosta et al., 2009). This first plant community is characterized by low vegetation cover and reduced floristic diversity. In Continental Portugal *Salsola kali* and *Cakile maritima* are characteristic species (martins et al., 2013). These communities constitute the habitat 1210 of the European Ecological Network "Natura 2000": "Annual vegetation of drift lines" (Martins et al., 2013). In all the dune system the upper beach habitat contains a significantly small number of species, but it shows the highest rarity values and amount of endangered species (Acosta et al., 2009). In the Portuguese coast these communities have suffered a decrease over the last 20 years due to coastline retreat and intensive recreational use during summer (Martins et al., 2013). They are characterized by a variable conservation status, average or good in the best preserved areas (Martins et al., 2013).

At the very top of the beach (high beach) there is only a sporadic penetration of the waves during storms and winter (Martins et al., 2013). Perennial plant species with rural strategies are capable of colonizing this area (Carter, 1988). The aerial parts of the plants obstruct the wind and absorb the energy of windblown sand grains. Wind velocity near plants is thus reduced, and the sand is deposited around the stems (Carter, 1988; Maun, 2009). Gradually, a small dune develops around the plant. Sand trapping by these species is, however, not sufficient for big dune formation (Carter, 1988) and as a consequence, they constitute low mounds of sand, known as incipient or embryonic dunes. These dunes form habitat 2110: Mobile embryonic dunes. These are inherently species-poor and sparsely vegetated communities (Martins et al., 2013), being dominated, in continental Portugal, by two subspecies of the grass *Elytrigia juncea*: *Elytrigia juncea* subsp. *boreoatlantica* and *Elytrigia* subsp. *juncea* (Costa et al., 1994; Honrado et al., 2002; Lomba et al., 2008; Martins et al., 2013). The high beach is an extremely selective habitat for plants (Ranwell, 1972) and, as a consequence, it possesses a low diversity. However, this habitat type is of exceptional importance as an indicator of the general structural and functional 'health' of a dune system. In fact, embryonic shifting dunes are particularly vulnerable to trampling by beach users and to mechanical cleaning of beaches. In Portugal the high beach vegetation has suffered a decrease in its area, with different conservation status along the coast (Martins et al., 2013). Good conservation is observed where human pressure is low (Martins et al., 2013), although most areas are not well preserved.

Inland, perennial species with broader and denser stems constitute a major barrier to the wind and as a consequence a greater quantity of sand is deposited around their stems. As sand accumulates, dunes grow, becoming much higher than embryonic dunes. The most important characteristic of these perennial plants is their ability not only to survive but also to grow horizontally and vertically in response to sand burial (Maun, 2009). Thus, dune starts to grow in area and height over time. Although their growth is stimulated by sand deposition, there is, however, a limit for burial survival. Unless the plant is able to grow more rapidly than the rate of sand deposition, growth ceases (Carter, 1988). These communities correspond to habitat 2120: Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes"). Vegetation cover is incomplete and loose sand is subject to wind-blow. The white dunes are colonized by herbaceous vegetation dominated by *Ammophila arenaria* (Honrado et al., 2002; Lomba et al., 2008; Martins et al., 2013) and are characterized by low to medium diversity levels (Martins et al., 2013). These plant communities perform important ecological services such as the prevention of storms, since they constitute the first natural barrier against the sea (Martins et al., 2013). In continental Portuguese dunes endemic species like *Linaria lamarckii* and *Thymus carnosus* are frequent (Martins et al., 2013).

Both the embryonic and the shifting dunes with *A. arenaria* possess alow/medium diversity as regards vegetation. However, despite the low number of plant species, these habitats are characterized by high rarity and conservation values, because of the high proportion of endangered and exclusive plant taxa (Van der Maarel, 2003; Acosta et al., 2009, Martins et al., 2013). In a comprehensive study of invertebrates in UK and Wales, Howe et al. (2010) found that the most specialized dune invertebrates tend to occur in the earlier stages of dune succession, the number of specialists declining as the proportion of bare sand decreases.

Further inland the substrate becomes more and more stabilized and there is lower influence of salt spray as the result of a progressively increasing distance from the sea (Lomba et al., 2008). These conditions allow sand colonization by more species, especially shrubs that form communities of high cover value, thus the name of grey dunes (Carter, 1988; Martins et al., 2013). Grey dunes constitute a priority habitat in "Natura 2000": *2130 Fixed dunes with herbaceous vegetation. These communities are characterized by a high diversity and are very important in sand fixation (Martins et al., 2013). Most vegetation communities in grey dunes of the northwest Iberian Peninsula are characterized by endemic taxa (Lomba et al., 2008). *Jasione lusitanica* and *Coincya monensis* subsp. *cheiranthos* var. *johnstonii* are two Portuguese endemisms (Martins et al., 2013).

The different communities of the sequence described show an increase in species richness, cover, stature and biomass (Lubke, 2004; Martins et al., 2013). On the first communities vegetation is constrained by extreme abiotic conditions while on the stabilized dunes, plant communities are structured mostly due to biotic interactions (Doing, 1985).

Alterations of the zonation

Modification of this general scheme may occur because of natural factors, due to the ever-changing nature of the environment. Aeolian coastal dune systems morphology and plant species composition are the product of complex histories of alternating events of shoreline advance or retreat (González-Villanueva et al., 2013), driven by climate variables, sediment quantity and characteristics, vegetation cover, storm frequency and severity and ocean-level fluctuations (Klijn, 1990; Pye, 1993 in González-Villanueva et al., 2013). However, nowadays alteration of the vegetation zonation scheme occurs mostly due to human activities. A large extension of the Portuguese coastal sandy systems is being subjected to intense erosion processes (Martins et al., 2013) and, as a consequence, beach species tend to migrate to the mobile dunes, or even mobile dunes advance inland, overlapping stabilized dunes, thus changing the normal sequence of communities. Transgressive dune systems in the north of Portugal display a lower number of plant species in comparison to those of stable coastal systems (Macedo, 2008). Disturbances related to trangressive coastal dynamics induce dramatic changes in the composition, structure and function of plant communities by the selection of species holding particular traits (Schlacher et al., 2008). Macedo (2008) identified an increase of ruderal species and a decrease in the importance of stress-tolerant specialist species in over-disturbed foredune communities in the north of Portugal.

One of the most important aspects to realize with the coastal environment is that it is dynamic, like the forces that shape it, so it is endlessly changing. In fact, at a world level 70% of beaches are receding, 20% are stable, and only 10% are advancing (O'Riordan, 1995 in Valpreda and Simeoni, 2003). The causes of shoreline shift can be of local importance, such as a reduction of sediment input or of global importance, such as a worldwide sea level rise (Taveira Pinto, 2004; Feagin et al., 2005) and they can act at short, medium and long-term timescales (Veloso-Gomes et al., 2004; Valpreda and Simeoni, 2003).

Human activities and their impacts

The influence of humans on the coastal environment is not a modern phenomenon. In fact, it has occurred since prehistoric times (Heslenfeld et al., 2004; Nordstrom, 2000 in Schlacher et al., 2008). Iberian populations have influenced coastal regions for centuries (Dias et al., 2013). Romans caused severe environmental impacts to the vegetation cover of the Peninsula due to agriculture, deforestation and mining activities. The Muslims brought new impacts as a result of new agricultural processes and salt exploitation in estuaries and lagoons (Dias et al., 2013). After the conquest of the Peninsula by the Christians there was an increase in demographic growth, which caused growing demand for resources, especially open land for agriculture. Thus deforestation increased significantly, causing widespread erosion and reinforcing littoral drift (Dias et al., 2013). In the Aveiro region in the northwest of Portugal, in response to a huge increase in the littoral drift, the original open bay area was transformed gradually into a closed lagoon (Dias et al., 2013). The Portuguese maritime expansion required renewed shipyards and a rapid manufacture of vessels to assure the maritime trade between the mainland and recent discovered territories, which increased forest cutting in the mainland and contributed to the import of large volumes of timber from different sources (Reboredo and Pais, 2012, 2013). The same authors state that the deforestation in the mainland was mainly due to shipbuilding, since the fluctuations in the demography from the foundation of the nationality until the beginning of the XVII century were narrow, and it is well know that fuelwood consumption by inhabitants was the main energy source at that epoch.

Conversely, from the XVII onwards a demographic boom occurred in parallel with a strong decline of maritime trade, indicating that the almost total depletion of the forest cover in the mainland in the beginning of the XVIII was mainly related with human needs (fuelwood) and not vessel construction (Reboredo and Pais, 2012, 2013).

Since the XXth century the construction of dams has caused a negative sediment budget to the Portuguese coast (Martins et al., 2013), as beach particles originate mainly from inland erosion, being transported to sea via rivers (Pereira, 1996; Brown and McMachlan, 2002). These facts have resulted in erosional processes and thus inland displacement of the shoreline (Martins et al., 2013).

As coastal ecosystems provide a variety of goods and services, they have long been used for many different activities such as settlement, fishing, agriculture, afforestation, coastal defence, urban development, industrial expansion, mining and recreation (Carter, 1991 in Martínez et al., 2004a; Heslenfeld et al., 2004). However, many of these activities have accelerated remarkably in the last two centuries. All these activities generate economic profits to the human populations; yet, they result in more or less severe impacts on the coastal ecosystems (Martínez et al., 2004a). Population growth and demographic flows towards the coastline are nowadays putting pressures on these ecosystems at unprecedented scales (Brown and McLachlan, 2002; Schlacher et al., 2006, 2007a in Schlacher et al., 2008). The increase of human occupation is, in many cases, incompatible with the natural dynamics of the coastal areas (Veloso-Gomes et al., 2004) and, as a result, worldwide many coastal dune systems are in advanced stages of degradation, irreversibly altered or even lost (Martínez et al., 2004b). For example, the sandy coasts in the Mediterranean Basin are considered among the most endangered environments in Europe (van der Meulen et al., 2004; Carboni et al., 2009).

The Portuguese coastline presents a significant variety of dynamic situations (Ferreira et al., 2008 in Macedo, 2008). Some beaches are subjected to erosion processes, showing an average retreat rate of almost 4 m/year (Ferreira and Dias, 1993 in Ferreira et al., 1995). For the region around the city of Porto, in the north, shoreline retreat is estimated as a result of a reduction of sand areas and increased storminess (Ferreira et al., 2008 in Macedo, 2008). Some beaches are stable and show little evidence of erosion or accretion (Ferreira and Dias, 1993 in Ferreira et al., 1995). Nowadays, as a whole, high erosion rates seriously affect over 30% of the Portuguese coastline (Freire et al., 2009) as a consequence of several factors like the reduction of the sediment supply of the main rivers and construction too close to the shoreline (Silva et al., 2007).

Urban pressure and tourism

In Portugal the coastal area possesses a high landscape and conservation value and it is therefore no surprise that it is subjected to intense pressures (Silva et al., 2007). In fact, coastal areas are the most populated areas in the country - over 75% of the population lives on the coast. Urban, industrial and touristic areas near the coast are responsible for 85% of the GDP (CNADS, 2001). In Portugal the two largest metropolitan areas are located near the coast, concentrating 40% of the country´s total population (CNADS, 2001). As the result of bad planning and management, which allowed chaotic construction in hazard prone areas (Silva et al., 2007), coastal areas suffer from many problems. Indeed, almost every winter erosion problems occur on the western Portuguese coast due to the construction of tourist resorts close to the shoreline without suitable planning or management (Ferreira et al., 1995). In a study by the EEA (2006), among 17 European countries, mainland Portugal experienced, during 1990-2000, the largest increase (34%) in artificial areas within a 10-km strip from the coast. This rate is much higher than the increase in resident population in the same period (Freire et al., 2009).

The establishment of populations in coastal areas was, in many cases, only possible with modification of the coastal front and the building of heavy man-made structures. These infrastructures and coastal defenses, although offering more favorable conditions for economic growth, have caused magnification of coastal erosion, because important physical processes have not been taken into account (Taveira-Pinto, 2004). In fact, structures such as harbours, breakwaters, jetties and groins, which disrupt sand transport, may lead to severe erosion because they withdraw down-drift beaches of sand (Brown and McMachlan, 2002). As a result, all over the world coastal inhabitants and man-made infrastructures are facing a high-risk condition due to coastal erosion (Veloso-Gomes et al., 2004). In our present-day society, which emphasizes socio-economic criteria, this phenomenon is seen as unacceptable (Valpreda and Simeoni, 2003). Thus, management of coastal areas has traditionally focused almost exclusively on maintaining and restoring physical and geomorphological features important for coastal defence (James 2000b; Micallef and Williams 2002 in Sclacher et al., 2008).

In the 19th Century health benefits of oceanic baths were recognized (Corbin, 1989 in Dias et al., 2013; Dias, 2005; Freitas, 2010), a fact that triggered a new behaviour as regards sandy coasts, which in turn was responsible for a new and profitable economic activity: tourism. Nowadays many populations living in coastal areas depend largely on the income derived from the recreational usage of beaches and associated activities. The massification of tourism originated a boom in coastal areas demand during the 1960s and 1970s, which was responsible for the rapid and many times uncontrolled urban expansion, an example being the extensive southern coastal areas of Spain and Portugal (Dias et al., 2013). Benidorm, in Spain, increased from 5000 inhabitants in 1950, to 70,000 in 2008 and can additionally offer more than 38,000 beds (Giussani et al., 2010 in Dias et al., 2013). The resident population in Albufeira, in the South of Portugal, was 31 500 inhabitants in 2001, but peak summer population reached around 300,000 people (CNADS, 2001). In these regions many natural areas were transformed, irreversibly, into artificial coasts (Dias et al., 2013).

As a consequence of the increase of human population in coastal areas, which has often resulted in chaotic demographic expansion, some dunes systems have been completely destroyed, in the process of providing living space for buildings, residential development, tourist resorts, and recreation areas (Martínez et al., 2004b; Martins et al., 2013). Massive tourism demand has led to verticalization of the coastline (tall buildings) such as occurs in Benidorm in Spain or in Albufeira, in Portugal (Dias et al., 2013). Too often, buildings have been constructed too close to the shoreline, therefore being threatened by erosion processes (Freire et al., 2009). In Spain, the large-scale urban development carried out on the foredunes during the tourist boom of the sixties and seventies caused the destruction of many Spanish dune systems (Gómez-Pina et al., 2002). As a result of such massive dune occupation, most of the Spanish coastline started to show signs of erosive patterns, particularly in most of the tourist spots (Gómes-Pina et al., 2002). In many shorelines mere fragments of dune now remain between the high density residential and coastal amenity structures with a consequent reduction in their coastal protection role and amenity value (Curr et al., 2000).

Even when the coastal systems were spared, dunes are squeezed between sea water on the marine side and human settlements on the landward side (Feagin et al., 2005; Schlacher et al., 2008), which results in a delicate condition. In situations of rising sea level, beach erosion causes an inland movement of dune habitats but, owing to the existence of man-made barriers, species are no longer able to disperse and grow (Martinez and Psuty, 2004 in Feagin et al., 2005; Martins et al., 2013). And in fact coastal erosion actually impacts about 70% of the world´s beaches (Bird, 1985 in Feagin et al., 2005).

The Mediterranean region plays host to ca. 33% of the world's tourism industry. This high quantity of visitors, as expected, exerts a huge impact on its natural coastal resources (Curr et al., 2000). In fact, Salman observed that in 1994, approximately 75 % of European Mediterranean sand dunes had already been destroyed (Salman 1994 in Martins et al., 2013). Unfortunately destruction has continued although we are not able to quantify the remaining destruction degree of sand dunes.

In Portugal the construction on top of the dunes and the land use change in the more interior stages of the dune system have damaged the ecological gradients (Martins et al., 2013) reducing the very few good spots of natural communities in the more interior dunes.

Recreation

Recreation activities severely impact dune systems and are often responsible for the damage and even destruction of habitats (Acosta et al., 2013). Sandy beaches are the most popular areas of the seashore. In fact, more people use sandy beaches than any other type of marine or coastal habitat. As a consequence, recreation activities are tremendously concentrated (Defeo et al., 2009), which implies a high density of occupation. These activities include sunbathing, swimming and other activities such as walking, windsurfing and kite surfing (Leewis et al., 2012). Recreation activities produce various impacts on the natural environment with extreme negative effects, one of the most important being trampling by animals and humans and crushing by vehicles (Liddle and Greig-Smith, 1975; Defeo et al., 2009).

Dune vegetation is adapted to the stressful natural conditions and highly dynamic environment of sandy seashores; however, it is very vulnerable to man-made disturbances such as those connected to trampling (Liddle and Greig-Smith, 1975; Defeo et al., 2009; Acosta et al., 2013). The most obvious direct impacts of trampling on vegetation originate from the crushing and shearing of plants which decreases the fitness of certain species (Gallet and Rozé, 2001 in Acosta et al., 2013) and thus reduces biodiversity (Bonte and Hoffman, 2005 in Acosta et al., 2013; Hesp et al., 2010). On the other hand a permanent loss of vegetation cover may occur in cases of high intensity of trampling. That is, trampling intensity has a profound influence on the establishment of bare ground (Hesp et al., 2010). The destruction of plants that trap and hold sand particles exposes the underlying sand to the onshore wind, promoting the development of breaches, called blowouts. After a blowout is initiated, its margins continue to erode which results in extensive areas of open sand within what was previously a stabilized zone. Moreover, trampling destroys the complex spatial structure of the dune ecosystem that results from the strong environmental gradients (Acosta et al., 2013). As trampling is the result of heavy but usually seasonal demand at medium-high latitudes, there may be some opportunity of recovery during periods of low use. Sousa (2010) refers that during periods of low use vegetation develops in footpaths but is later destroyed by holidaymakers during high use season. Acosta et al. (2013) mention that dune vegetation, if protected from trampling, recovers fast as regards biodiversity, cover and spatial structure. The capacity for rapid recovery is a distinctive characteristic of dune plant species which are indeed adapted to high levels of disturbance. However, if certain thresholds are reached, irreversible damage can occur and then recovery is unlikely to happen (Alveirinho-Dias et al., 1994 in Curr et al., 2000).

Gheskiere et al. (2005) demonstrated, both for a Mediterranean as well as for a Baltic coastal sandy beach, that tourism related activities affect the meio-nematofauna and contribute to higher stress levels, lower species diversity of the nematode assemblages compared to nearby untouched beaches.

Off-road vehicles (motorcycles, 4 x 4 vehicles and vehicles of the buggy type) are usually used on beaches and dunes all over the world for recreation (Sclacher et al., 2008). Due to weight and type of motion, the damage caused by these vehicles is more widespread than that caused by human trampling (Westhoff 1967 in Kindermann and Gormally, 2010). The negative impacts they cause include damage of the physical properties and stability of the substrate, destruction of vegetation and disturbing, injuring or killing fauna (Brown and McLachlan, 2002; Defeo et al., 2009). Direct mortality affects not only vertebrates like turtles and birds (destruction of eggs and young) but also invertebrates such as isopods, amphipods, crabs and certain echinoderms (Brown and McLachlan, 2002; Martin et al., 2006 in Defeo et al., 2009). The passage of motorised vehicles causes severe damage, the dune system takingyears to recover.

Exotic species

The introduction of exotic vegetation on coastal dunes was, in a not distant past, a common practice along much of the world's coastlines for the purpose of stabilizing the sand substrate as is the case of *Casuarina equisetifolia* L. in the Indian Ocean and Caribbean Sea regions, *Tamarix gallica* L. in the Gulf of Mexico and *Acacia* spp. in the Mediterranean (Cronk and Fuller, 2001 in Feagin et al., 2010). Thus, nowadays, coastal sand dunes stand as some of the most threatened ecosystems due to the invasion of alien plant species (Gallego-Fernández et al., 2006). Almost always short-term stabilization of the sand was reached at the expense of long-term ecological sustainability (Feagin et al., 2010). In fact, the presence of invasive species not only alters community composition leading to a decrease in biodiversity, but also affects ecosystem functioning and structure (Gallego-Fernández et al., 2006). *Acacia* species, nitrogen-fixing plants, fill a niche that is vacant on dunes, characterized by nitrogen-poor soil (Parker et al., 1999). Nonetheless, these alien species alter soil characteristics and processes, namely soil C and N pools, which disrupt colonization by native plants (Marchante et al., 2008).

In Portugal, as happened in other parts of the world, management of coastal areas focused, for a long time, on sand fixation. In fact, in coastal areas denuded of vegetation sand was set freely in movement by the wind and was carried inland, causing serious threat to farmlands and infrastructures. Several *Acacia* tree species (*Leguminosae*) were introduced to stabilize the sand (Marchante et al., 2009). Successful colonization resulted in the growth of woodlands dominated by these exotic species, which had a consequent loss of native species diversity. On the other hand, acacia trees, covering almost the entire soil surface, brought over-stabilisation of the dunes, which resulted in the loss of bare sand patches (Marchante et al., 2009). That is, these invasive species changed the environment of the dune, which is naturally dynamic. Currently, it is documented that over-stabilised dune systems are disadvantageous (Pye et al., 2007) because they are unable to change as a consequence of fluctuations of natural forcing factors. For instance, they are incapable of supplying sand to beaches in periods of need (Lubke, 2004). The introduction of exotic plants can also be harmful to the native fauna. In India, sandy coastline in many areas has been flattened to make way for plantations with exotic species, thus destroying sea turtle nesting habitat and altering dune topography which can have serious negative impacts on coastal protection ability (Feagin et al., 2012).

Well-preserved coastal dune systems provide effective defence against the sea and at a lower cost than massive and rigid engineering interventions, although dune stabilization throughout the use of exotic species does not seem to us the proper form of management of coastal areas.

Global climate change

In addition to direct anthropogenic impacts, global climate change is expected to have intense, extensive and long-lasting consequences for the coastal systems, particularly when coastlines are retreating in response to rising sea levels (Feagin et al. 2005; Harley et al., 2006 in Schacher et al., 2008). The expected rise in sea level, if coupled with an increase in the frequency and/or intensity of storms, as predicted for some regions, is likely to lead to escalating erosion and consequent loss of habitat (Brown and McLachlan, 2002).

Pollution

Pollution is defined by the Directive 2000/60/EC of the European Parliament and of the Council of 23th October 2000 as "the direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment" (OJEC, 2000).

Coastal zones, particularly those with large population densities received large inputs of pollutants from anthropogenic origin (domestic and industrial sewages) despite airborne particulates from distant industrial sources. For example, trace metals were likely transported from the industrial sites to the area of their deposition as sulphur-bearing coatings on small anthropogenic particles. After deposition, these sulphur-bearing compounds reacted with organic matter within the sediment (Mastalerz et al., 2001). In that sense, several studies have been undertaken in different coastal world areas, in order to evaluate the PCBs, PAHs and heavy metal contamination degree of fauna, flora and substrata. For example, in Portugal mainland, estuarine sediments of Tejo River (Reboredo, 1981; Reboreda and Caçador, 2007), Sado River (Reboredo and Ribeiro, 1984; Reboredo, 1988) Ria Formosa Lagoon (Padinha et al., 2000) Ria de Aveiro Lagoon (Ramalhosa et al., 2005) and Lima River (Almeida et al., 2011), were monitored in terms of their metal content.

Also, some representative halophytic species colonizing the substrata such as *Halimione portulacoides* and *Spartina maritima* (Reboredo, 1983, 1985, 1993; Padinha et al., 2000; Reboreda and Caçador, 2007), or the former species plus *Sarcocornia fruticosa* and *Sarcocornia perennis* (Duarte et al. 2010) or even *Juncus maritimus*, *Spartina patens*, *Phragmites australis* and *Triglochin striata* (Almeida et al., 2011) were evaluated in terms of their metal content.

Although these halophytes were not representative of the dune vegetation, in some cases may live in close contact with the dune formation, which is the case of *Halimione portulacoides* colonizing a sandy environment in particular areas of Sado river estuary (Reboredo, 1988, 1992).

Thus, dunes, as interface ecosystems between land and sea, receive and suffer from a wide range of pollutants and debris, from land and/or sea origin. Figure 1 describes the most common pollutants identified in dune systems, and its main sources. Defeo et al. (2009) summarize, by a schematic diagram the variety of spatial and temporal scales of pollutants acting on sandy beach macrofaunal living communities. This conceptual model eventually can be applied to dunes systems because, according to Defeo et al. (2009), a variety of anthropogenic materials, ranging in size from molecules to large debris, can be found in dune sands impairing the physiology, survival, reproduction and behaviour of dune species.

Metals, coming from wastewater and industry tends to accumulate on fine-grained sands (reference in Defeo et al., 2009) or are carried to underwater streams by run-off, although the binding capacity of sand was weak compared with substrata with high organic and silt-clay contents (Reboredo and Pais, 1984) Fine-grained beaches usually support relatively high diversity and biomass (Defeo et al., 2009), and metal pollution may cause significant reductions both in biodiversity and in the population density of economically valuable species (references in Defeo et al., 2009), by high levels inputs or by cumulative processes.

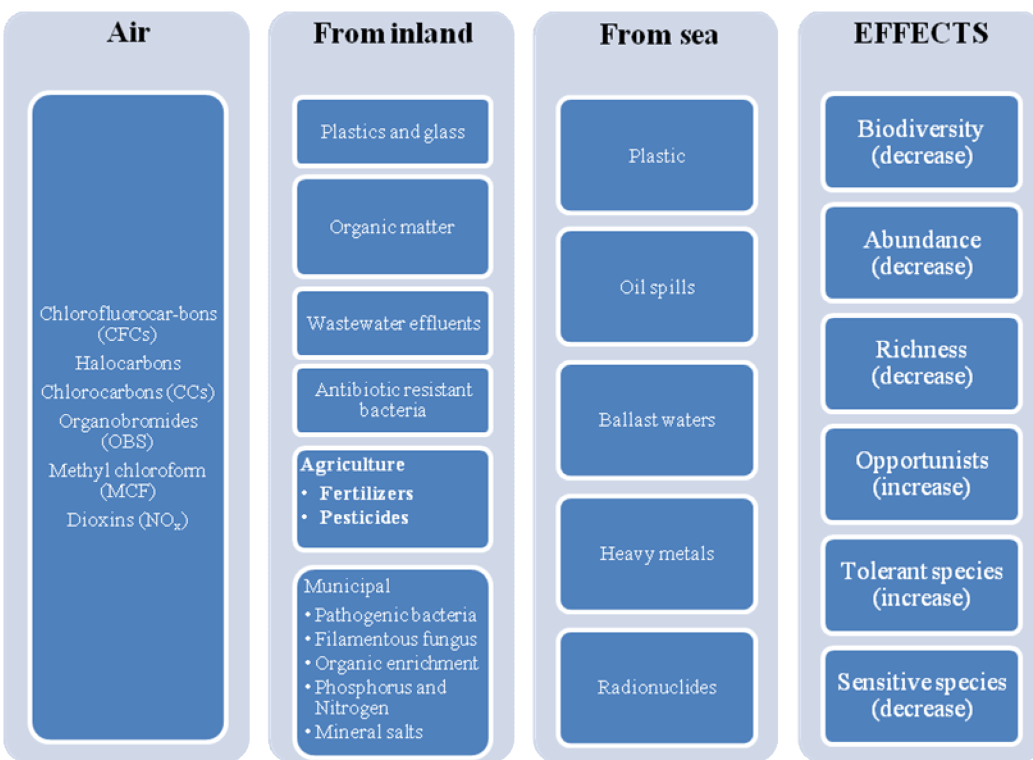

Figure 1. Most common pollutants found in dunes and their main effects in dune community systems.

Debris

Coastal areas, on one hand, receive litter coming from the sea, brought by currents and waves, and, on the other hand, litter left by beach visitants. These are known as anthropogenic marine debris (AMD).

A study from Santos et al. (2005) concerning litter composition found on beaches and dunes show that small fragments of plastics, cigarette butts, organic matter and wood compose the most abundant residues. This study showed that residues of fruits, corncob and corn leaves were the main organic matter components, whilst matches and ice cream sticks were the most representative residues of wood. A study of Madzena and Lasiak (1997) found Styrofoam as the second most important item after plastic. Cigarette butts are usually found mixed with sand and, according to Derraik (2002) referred by Santos et al. (2005), are mainly related to tourism activities.

According to Bravo et al. (2009), AMD is a ubiquitous problem, which has motivated public participation in activities such as beach surveys and clean-up campaigns. A study carried out by Bravo et al. (2009) along the Chilean coast showed that public participation in surveys and cleaning activities raised awareness and thereby contributed to an improvement of the situation. However, Bravo et al. (2009) refer that the quantities and types of AMD in beaches and coastline systems remain largely unknown.

Plastic and glass

Plastics are synthetic organic polymers, their existence being relatively recent (Gorman, 1993 in Derraik, 2002). Being lightweight, strong, durable and cheap (reference in Derraik, 2002) and with large versatility, led to a great increase in their use into all aspects of everyday life (references in Derraik, 2002) over the past decades. Plastic debris may be dispersed over long distances, because they are buoyant (Derraik, 2002; Aliani et al., 2003). They may reach the dunes by wave action, or being part of the litter deposited by beach visitants or even by wastewater effluents. Drifting plastic debris was reported by Masó et al. (2003) to be a potential vector for dispersing Harmful Algal Blooms (HAB) species.

Plastic objects dominate the visible litter on sandy beaches worldwide (references in Defeo et al., 2009; Bravo et al., 2009), constituting a danger since they may persist for centuries (references in Derraik, 2002). Plastics also constitute a potential smothering agent when swallowed by animals, nor only by swimmers like turtles and sperm whales (Stephanis et al., 2013) but also by land animals, found in dune systems.

Glass bottles have been recorded to cause wounds in humans (Santos et al., 2005) and animals crossing dune systems. Madzena and Lasiak (1997), in a study on the South African coastline, found that glass was the third most important item of the composition of the abandoned litter, both in terms of number and weight.

Organic matter

People using beaches frequently leave organic matter such as food leftovers. Dunes are often used as deposits of dog (Santos et al., 2005) and human excrements, even when there are sanitary infrastructures or waste bins in the vicinity. This organic matter causes contamination of sand with pathogenic bacteria and filamentous fungus, gives bad smell and causes aesthetic disturbances. It also constitutes a source of attraction to numerous unwanted insects like wasps and flies. The organic matter constitutes a source of enhanced nutrient inputs, especially nitrogen, which causes a change in vegetation communities, with the appearance of nitrophilous species.

Antibiotic resistant bacteria

The uncontrolled and extensive use of pharmaceutical substances mainly antibiotics in human and veterinary medicine, animal husbandry, agriculture and aquaculture has caused the increased introduction of those antimicrobial agents in the aquatic environment (references in Mudryk et al., 2010). The study of Mudryk et al. (2010) conducted at the Southern Baltic Sea coast, showed that the majority of bacteria inhabiting the sand of the studied beach were resistant to only one antibiotic out of 18 tested antibiotics in the study. This study also showed that the bacteria inhabiting the middle part of the beach and the dune were more antibiotic resistant than bacteria isolated from the seawater and the shoreline-seawater contact zone. These results also show a no significance difference in antibiotic resistance between bacteria isolated from the surface and the subsurface sand layers. The authors conclude that: a). the antibiotics are a significant selection factor and probably play an important role in regulating the composition of bacterial communities of the marine beach; b). human activities might contribute to the level of antibiotic resistant bacteria inhabiting such sites; c). the occurrence of resistant bacteria in the sand of marine beaches can possibly be treated as an alternative bioindicator of marine sand contamination influenced by anthropogenic activities and of the returning rate of resistance genes to the human population through the seawater and the marine sand beach usage.

Wastewater and sewage systems and freshwater effluents

Pathogenic bacteria and filamentous fungus can be found in beaches (Defeo et al., 2009) and sand dunes from wastewater and sewage systems by illegal discharge despite the existence of the wastewater treatment stations, as European legislation demands. This is a serious public health especially when health standards limits are exceeded which may cause beach closures (Defeo et al., 2009).

Freshwater effluents mostly charged with organic matter and mineral salts may cause a broader deterioration in the quality of the surrounding habitat (reference in Defeo et al., 2009). These effluents, arising from human activities, cause negative impacts at the survival, growth and fecundity rates (references in Defeo et al., 2009) of individuals and populations of dune species, changes in diversity and structure of the communities (reference according to Defeo et al., 2009).

Radionuclides

Radionuclides become a part of the soil, or as part of the Earth's original crust, or produced and deposited by cosmic ray interactions, or through man-made releases (EPA, 2006). Copplestone et al. (2001) examined the spatial, temporal and depth distributions of radionuclide (134Cs, 137Cs, 238Pu, 239+240Pu and 241Am) activity concentrations in the soil and in two dune plant species (*Festuca rubra* – red fescue and *Ammophila arenaria* – marram grass), in the vicinity of the British Nuclear Fuels, receiving a continuous input of entrained radionuclides, principally via sea-to-land transfer. From this study, Copplestone et al. (2001) found the greater activity concentrations in deeper regions of the soil profile, due to the leaching of radionuclides in percolating drainage water accentuated by the coarse texture, low organic matter and clay mineral content of coastal sands. The results also showed, in soil, a similar spatial distribution for all radionuclides studied, despite differences in the vegetation cover and a little evidence of any temporal changes over the study period. Copplestone et al. (2001) study found that the dominant influence of external contamination was by adherence to the plant foliage and not exclusively by root uptake. So, according to Copplestone et al. (2001) work, the transfer of radionuclides through higher trophic levels of grassland ecosystems occurs mainly by external adherence to plant foliage.

Oil pollution

Oil pollution causes a great public attention because it has a visible impact on shores, especially on bathing beaches and on aquaculture farming, and causes serious ecological and socio-economical negative impacts on coastlines reached by oil spills. They result from accidents like vessel collision, run aground ships, pipeline ruptures, petroleum shafts/platforms accidents, or during armed conflicts (i.e. Great Gulf War) (Wieczorek et al., 2007).

The oil spill reaching the coast spreads over the surface of the sediment and may go deeper in the sediment during days or weeks following the spill event (reference in Fernández-Fernández et al., 2011). Regarding the subsurface contamination two mechanisms have been described (Fernández-Fernández et al., 2011): oil penetration and oil burial. Oil penetration is driven by the percolation of oil within the sediment (Fernández-Fernández et al., 2011). This type of contamination depends on sediment texture, mean grain size and oil physical properties (viscosity), wave energy, temperature and other factors, including fungal degradation (references in Defeo et al., 2009; Fernández-Fernández et al., 2011), generating low level oiling, up to sixty centimetre in depth (Fernández-Fernández et al., 2011). In contrast, oil burial generates strong oil contamination, up to several meters in depth (Fernández-Fernández et al., 2011). The results of this study also revealed from fieldworks that the oil was still present on beaches, seven years after an oil spill.

According to Sinderman (1996) (referred by Defeo et al., 2009), sheltered beaches are usually more sensitive to pollution than exposed ones, even when sediments are fine and oil does not penetrate deeply, since they are less well flushed by wave action. Dunes in its ocean-exposed side, can suffer oil spill impact and vegetation may be used to protect coastlines against petroleum spreading to the inner regions.

The oil spill in the Gulf of Mexico was the largest accidental marine release in the petroleum era (reference in Brame et al., 2013), as a result of the explosion at the *Deepwater Horizon* drilling rig and subsequent oil spill in April of 2010 (references in Brame et al., 2013) off the coast of Louisiana (Harlow et al., 2011). The ensuing oil spill caused substantial economic and environmental damage to states on the U.S. Golf Coast (Harlow et al., 2011).

Prestige oil tanker sank off on the 19th of November 2002 off the NW coast of Spain, spilling approximately 64000 tons of heavy fuel oil (Fernández-Fernández et al., 2011), about twice the size of the Exxon Valdez spill off the Alaska in 1989, and is already the worst shipping disaster off Spain since the tanker *Aegean Sea* ran aground near La Coruña in 1992 (Junoy et al., 2005). The oil spill affected approximately 1000 km of coast belonging to Portugal, France and Spain and more than 600 sandy beaches were polluted along the Atlantic coast of Spain (Fernández-Fernández et al., 2011) having serious socio-economical impacts on shellfish farming of Rias Galegas. As a result of the Prestige oil-spill and the clean-up activities, beach populations were reduced, with *Eurydice* and *S. squamata* as the most affected taxa of the macroinfauna of the Galician sandy beaches affected by the Prestige oil-spill (Junoy et al., 2005).

Management

The coastal zone is strategically important from environmental, economic and societal points-of-view (Veloso-Gomes et al., 2008). Therefore, solving or mitigating some of its problems is of vital consideration when shaping policy for sustainable development, and needs integrated and co-ordinated management policies (Veloso-Gomes et al., 2008).

Dunes, because of their very position at the border between land and sea, are attractive for many human activities (Van der Meulen et al., 2004). Unfortunately coastal systems have had a long history of exploitation and mismanagement (Martínez et al., 2004b). The three primary ecological services coastal areas provide are defence, nature conservation and recreation. However, human activities on these systems introduce conflicting uses that hamper some of the services. Human populations and their associated activities on the coast are expected to increase in the coming decades (Brown and McLachlan, 2002; Martínez et al., 2004a), placing bigger pressure on the coastline. This increased pressure may well be mitigated by improved legislation and management practices resulting from a better understanding of coastal dune ecosystems. In the past coastal regions have often been inappropriately managed mainly due to an absence of adequate planning (Carboni et al., 2009). Even nowadays, in general, ecological aspects as well as suitable policies towards sustainability are still missing (Veloso-Gomes et al., 2004). How should coastal systems be managed so that their geomorphological and ecological characteristics are preserved and are thus able to provide the maximum of goods and services for future generations? (Feagin et al., 2010).

Management of coastal areas is undoubtedly a complex issue (Silva et al., 2007). It should be conducted in an integrated, sustainable and flexible way, so as to be able to answer to the challenges brought up by such a dynamic but sensible environment. Recently there has been a change in approach as regards dune ecosystems management: it should take into account the various aspects (physical as well as the biological, social and economic aspects) (Weinstein et al., 2007 in Macedo, 2008), the dynamic nature of the system, and operate within a long-term strategic framework at regional and national level. This strategy requires an understanding of the morphological and sedimentological features of the dune system and the knowledge of the main processes acting upon the ecosystem and prediction of future changes. Poorly planned development can increase the exposure of coastal communities to extreme events, particularly where such development is encouraged or unregulated (Feagin et al., 2010). Management should aim at maintaining the diversity and the natural dynamics of these ecosystems (Avis, 1992 in Martínez et al., 2004b).

It is known that tourism is currently a major contributor to the occupation of the coast. In Spain beach tourism is responsible for 74% of foreign tourism (Yepes, 1998 in Silva et al., 2007). Tourism is an important economic activity in Portugal, representing about 4.2% of national GDP and employing close to 5% of the workforce (Veloso-Gomes and Taveira-Pinto, 1997). The economic importance beaches have nowadays requires that recreation is included as an important component in management. Tourism was for a long time considered as a clean activity with almost no negative effects on the environment (Gheskiere et al., 2005). However, it has major impacts on coastal dune systems, which must be evaluated and monitored.

If one ecological service is over-valuated at the expense of the other services, as happens with coastal protection, it may be eventually chosen to replace dune ecosystems by heavy man-made structures (Koch et al., 2009) or in other areas to plant exotic tree species for sand stabilization. These measures may no doubt be short-sighted because they reduce or even prevent adaptive capacity of the coastal systems. Thus, over the long-term they may prove ineffective not only for the purpose they intended to tackle but also they may preclude other ecological services (Acosta et al., 2013).

In face of the numerous threats endangering coastal habitats the need for monitoring and active management of these environments has emerged (Carboni et al., 2009). Vegetation plays an essential role in determining the size, shape and stability of dune systems (Kim, 2005). In fact, vegetation quality is essential to maintain the integrity of dunes, since plants trap and stabilize sand particles against water and wind erosion. It is thus fundamental to preserve the natural vegetation cover so that coastal dune ecosystems are able to provide the full range of services (Martínez et al., 2004a). Wherever possible, the management of coastal areas should consider the succession of plant communities that occur in the dune system, from pioneer stages near the sea to the mature stages inland. These communities need to be managed as a whole, as there is a close interdependence of all the dune succession stages. Only then can the dune system adjust to erosion processes, whether natural or man-induced. Mobile dunes are part of the coastal system, with unique flora and fauna, and should be allowed to function normally which means that natural sand movements ought to be permitted (Richie, 2001 in Howe et al., 2010).

An essential aspect of management of coastal areas is thus the monitoring of vegetation changes, as vegetation composition and cover manifest the sedimentary dynamics of the system (Levin et al, 2007). To accomplish this goal reliable indicators of the condition of vegetation in coastal ecosystems must be developed (Espejel et al., 2004). The study of key species represents a suitable and an importantapproach (Gonçalves et al., 2013). Macedo (2008) suggests, based on a study performed in the northwest coast of Portugal, that, in the framework of monitoring protocols, shifts in the floristic composition of plant dune communities as regards functional traits can be used as consistent indicators of the state of coastal systems and consequently of their dynamics. Compositional shifts in phytosociological or functional spectra may be useful for the establishment of indicators of change of coastal dynamics (García-Mora et al., 1999; Lomba et al., 2008).

Conclusions

Coastal zones constitute complex interface ecosystems between the land and sea and are among the most productive systems in the world. As they provide important services and goods, they have long been used for many different human activities. However, many of these activities result in more or less severe impacts on the coastal ecosystems. Pollution, urbanization, disruption of sand transport, tourism and climate change seriously affects sandy shores. Coastal systems should be managed so that their geomorphological and ecological characteristics are preserved for future generations. This implies the existence of well-preserved coastal dune systems, since plants trap sand and stabilize the dunes. Vegetation monitoring is thus essential, which can be accomplished using consistent indicators of the state of coastal systems and consequently of their dynamics.

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