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MANAGEMENT OF COASTAL DUNES ON THE CATALAN AND ON THE VALENCIAN COMMUNITY SHORELINES (SPAIN)

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ABSTRACT. Coastal areas constitute one of the most difficult domains to manage, due to the several human activities and natural processes concentrated in it. The case of the coastal dunes is special, since they are so fragile and any intervention on them can cause alterations in the landforms and dynamics. This work assesses the level and role of management and the morphological status of coastal dunes on the Catalan and Valencian shorelines. To that end, ten beach-dune systems from Catalan and Valencian shorelines have been studied to guess how management actions determine the morphological status of them. A set of variables, comprising management actions and morphological status, have been selected and analyzed through a Hierarchical Clustering on Principal Components (HCPC). Results show that the beach-dune systems can be gathered in 2 main groups: those where sustainable management measures were not applied and present an advanced erosive state, and the ones where sustainable management measures were applied and present a good state of conservation. The good state of conservation is related to restoring dunes applying nature-based solutions, whereas degraded morphologies appear when artificial management actions have been carried out.

Gestión de dunas costeras en las comunidades autónomas de Cataluña y Valencia (España)

RESUMEN. Las zonas costeras constituyen uno de los dominios más difíciles de gestionar debido a las numerosas actividades humanas y procesos naturales que pueden concentrarse en ellas. El caso de las dunas litorales es de especial interés dada su fragilidad y el hecho de que cualquier intervención en las mismas puede provocar alteraciones en sus geoformas y su dinámica. Este trabajo evalúa el nivel y papel de la gestión y el estado morfológico de las dunas litorales en las comunidades autónomas de Cataluña y Valencia (España). Para ello, se estudiaron diez sistemas de playa-duna para determinar en qué medida las actuaciones de gestión afectan a su estado morfológico. Se seleccionó un conjunto de variables, que comprendía acciones de manejo y estado morfológico, y se sometió a un agrupamiento jerárquico con análisis de componentes principales. Los resultados muestran que los sistemas playa-duna se pueden dividir en dos grandes grupos: uno en el que no se han aplicado medidas de gestión sostenible y se encuentran en un estado erosivo avanzado, y otro en el que sí se aplicaron medidas de gestión sostenible con un buen estado de conservación. El buen estado de conservación está relacionado con la restauración de dunas a partir de soluciones basadas en la naturaleza, mientras que las morfologías degradadas aparecen cuando se han llevado a cabo actuaciones de gestión artificial.

Key words: Beach-dune systems, coastal dunes management, dune restoration, Catalonia, Valencia.

Palabras clave: Sistemas de playa-dunas, Gestión de dunas costeras, Restauración de dunas, Cataluña, Valencia.

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1. Introduction

The coastal zone constitutes one of the most complex areas in terms of dynamics and management at a global level due to, mainly, its morpho-ecological complexity and fragility, as well as the great amount of population who lives in them (Martínez *et al.*, 2007). In terms of the Global Change, it receives major pressure in sandy coasts, where its intensive use causes serious geo-environmental problems (Defeo *et al.*, 2009).

In our case, the impact of tourism as a mass activity, implemented in Spain in the 1960s and 1970s (Yepes, 2002), has a dominant role in the environmental status of the coasts (Gómez-Pina *et al.*, 2002). Since then, coastal dunes have required an intense management activity that reconciles the land uses and the natural dynamics. The approval of the Coastal Act, in 1988, supposed the beginnings of the pretended regulation and protection of the littoral. Even so, these areas support different human and natural processes, which are objects of multiple interests that sometimes come into conflict. That is why these zones are complex and difficult to handle and this situation strongly requires the adoption of integrated coastal zone management as an indispensable resource for their management.

Attending the coastal dunes of Catalonia and Valencian Community, traditionally, and especially from the XIX century, dune management has been related to pine plantations in order to paralyze the sand to avoid burying the surrounding crops (de Ferrer, 1895). The implications of this affected the whole ecology of the system, and over its sedimentary dynamics (Frigola i Vidal, 1999). Nevertheless, the dune systems of the Costa Brava, until a decade ago, were considered simple resources associated with the tourist industry when actually they constitute very fragile natural systems with multiple values.

In this line, some decades ago, human activities related to tourism, such as urbanization, gardening and trampling, led dunes to a degraded state of conservation of coastal dunes (Brown y McLachlan, 2002; Nordstrom, 2000; Nordstrom *et al.*, 2011). Thus, during the 1990s, checklist methods for analyzing the dune systems came into wide use (Bodéré *et al.,* 1991; Davies *et al.,* 1995; García-Mora *et al.,* 2001; Laranjeira *et al.,* 1999). Recently this method was used again by other authors in arid and Mediterranean areas to assess both vulnerability and resilience of beach-dune systems (Peña-Alonso *et al.,* 2017; 2018; Ciccarelli *et al.,* 2017). Following the same methodology based on checklists, other authors have analyzed the management actions of the beach-dune environments and the degradation of dunes to relate human pressure to the status of dunes conservation (Roig-Munar *et al.,* 2006; Pintó *et al.,* 2014a; Garcia-Lozano *et al.,* 2020; Roig-Munar *et al.,* 2020).

Consequently, the foredune degradation has led to boost dune restoration projects along these sedimentary coasts. In the case of the Costa Brava, Roig-Munar *et al.* (2020) pointed out the relation between the current state of dunes and the management measures in the bays of Costa Brava. Management measures were related to good conserved and/or recovered dunes, and vice versa. An illustrative case is that of La Pletera, a system that was the object of a frustrated attempt of urbanization in the period 1956-1981. However, during the last decade management measures have been carried out

to renaturalize the system and balance it. The management of this system has allowed it to recover its dynamics and naturalness (Roig-Munar *et al.*, 2017a).

Dune systems on the Valencian shoreline present a representative and pioneer case of management, the Devesa beach, in the Albufera (lagoon) of Valencian Community. The construction of a promenade, tracks, parkings, dwellings and infrastructures destroyed its ecosystems and natural equilibrium. As a response, from 1982 several projects of dune restoration have been carried out. The measures used were the gathering of species of interests, for their cultivation and replantation, and the removing of foreign species; elimination of the promenade, tracks, parkings and all type of infrastructures, or reduction of its width; reconstruction of dune morphology through the mechanical accumulation of sand and their fixation due to the construction of palisades; and the plantation of proper species of each environment involved. In some cases, the temporary closure through sticks and ropes in the zone in the recovery process has been performed (Quintana Trenor *et al.*, 2016).

Currently, a clear trend to sustainability has been detected, since part of these systems have been the object of sustainable planning and management through soft management measures.

The objective of this work is to assess the different management strategies of dune restoration carried out across the Catalan and the Valencian shorelines and determine how this human action affects the morphological status of dunes. For this purpose, ten beaches, five from Catalonia and five from Valencian Community, have been studied in detail.

2. Study area

The beaches of Catalonia and Valencian Community are made up of a large sedimentary cell, nowadays fragmented by different artificial sediment traps (Pardo-Pascual and Sanjaume, 2019). This area has a strong coastal drift that causes transport and contributes to the distribution of sediment on the coast from the N to the S. It is a sedimentary coast composed mainly of medium and fine sandy beaches, all of which also include some stretches of gravel. Catalan and Valencian Community shorelines comprise beaches that are in town centers surrounded by a high density of buildings; others are found in residential states with a low-density built-up environment; and, to a much lesser extent, others are located beside woodland or cropland with no adjacent developed land.

In Catalonia Garcia-Lozano and Pintó (2018) counted more than 800, of which 110 host some type of dune morphologies. A regression of dune morphologies derived from the lack of criteria in their use and management is denoted, which has affected their conservation (Garcia-Lozano *et al.,* 2020). In Valencian Community there are 328 beaches (Generalitat Valenciana, 2017).

In general terms, the dune systems of Catalonia and Valencian Community assume morphological, erosive and irreversible states, according to the classification of Hesp (2002), due to the effects of natural processes such as sedimentary disruption in river basins, coastal drift and lack of management for restoration purposes (Pintó *et al.*, 2014a, 2019). Additionally, a large part of the beaches is equipped for leisure (Obiol-Menero, 2003) as Valencian and Catalan beaches constitute the basic resource of the tourism industry. Most dunes are foredunes and embryodunes in Valencian Community (Garcia-Lozano *et al*., 2018; Pintó *et al.*, 2016; Sanjaume *et al.*, 2011). This high anthropogenic pressure has also degraded the coastline and contributed to a significant coastal regression (Obiol-Menero and Pitarch-Garrido, 2011; Yepes and Medina, 2005), causing numerous artificial actions to maintain the size of the beach.

In Spain, dune systems have been part of the public domain since the adoption of the 1988 Coastal Act, which was amended in 2013. This Act protects coastal dunes and puts responsibility for its management in the hands of local and regional administrations under the supervision of the state (BOE, 2013). Ownership of the terrestrial maritime public domain therefore continues to be centralized at the state level or at the regional administration level, through territorial planning departments. In this sense,

municipalities play an important role in managing beaches, being it their responsibility to manage the seasonal facilities and keep beaches clean and free from waste, as well as making plans for their use before the start of the summer season. In spite of the above, dune systems are subjected to trampling, to their use as areas for sunbathing, to the erosive effects of civil engineering works, and to other disturbances deriving from the lack of management and planning (Gómez-Pina *et al.*, 2002). In addition, the introduction of invasive alien species (Panareda and Pintó, 2015; Pino *et al.*, 2006) threatens the conservation of dune morphologies and species and their more sensitive communities, as well as the stability of these dynamic systems.

The following ten beaches have been chosen to assess them from the point of view of level and role of management and dune conservation status.

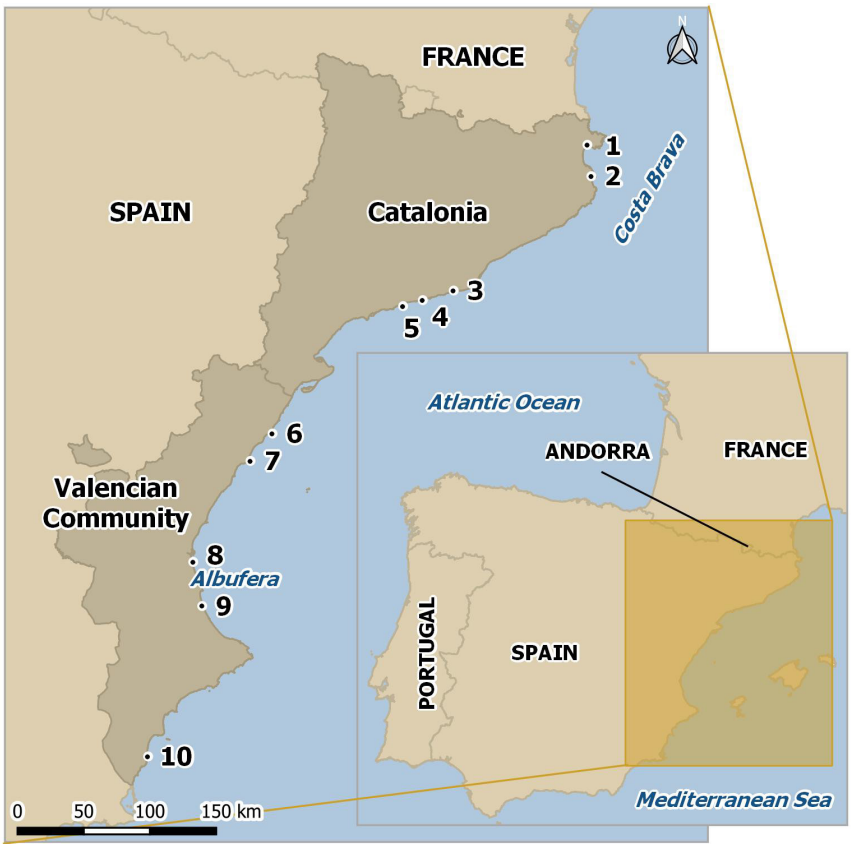

Figure 1. Beach-dune systems studied from the Catalan and the Valencian shoreline: 1. La Rovina, 2. La Pletera, 3. Castelldefels, 4. Els Muntanyans, 5. Platja Llarga, 6. Cabanes, 7. El Pinar, 8. El Saler, 9. Tavernes, 10. Guardamar.

3. Methodology

3.1. Data collecting and description of the variables

The methodology used is an adaptation of the procedure previously applied to assess the vulnerability of dune systems (Bodéré *et al.,* 1991; Davies *et al.,* 1995; García-Mora *et al.,* 2001; Laranjeira *et al.,* 1999). All these works are based on developing indices using checklist procedures, and most of the variables that feature in this analysis have been used previously in the cited studies. We identified and defined 18 variables related to the geomorphological status of dunes and human pressure activities on the beach-dune system. Following the criteria established by Bodéré *et al.* (1991), Davies *et al.* (1995), García-Mora *et al.* (2021) and Laranjeira *et al.* (1999) the variables were classified from 0 to 4, with 0 being a very negative indicator and 4 a very positive one within each parameter.

An analysis of redundancy of the 18 initial variables was carried out by means of a matrix of correlations in order to select a submatrix with nonredundant variables. From this, a matrix defined by 10 non-redundant variables (Table 1) were identified.

Table 1. Details of the 10 variables used for the management actions analysis of the studied systems.

Variables	**0**	**1**	**2**	**3**	**4**
1.Sand traps	Inefficient or absent		Stable		Efficient/ unnecessary
2. Revegetation	Inadequate or absent				Adequate or unnecessary
3. Managed paths	Not regulated	In access	On land	Suspended	Lateral
4. Dune area with restricted access	<25%	>25%	>50%	>75%	100%
5. Mechanical stockpiled sand for artificial dune build-up	Massive		Partially		Absent
6. Type of beach	Urban		Semi Urban		Natural
7. Mechanical cleaning/levelling	Causing dune scarp	Daily	Weekly	Occasionally	Absent
8. Distance from park cars to the beach	0 m	100 m	250 m	500 m	1000 m
9. Area of facilities near the foredune	>10%	<10%	>5%	<5%	0%
10. Status of foredune according to Hesp (2002) classification	Stage 5	Stage 4	Stage 3	Stage 2	Stage 1

The variables 1 to 9 correspond to human pressure and decision making and comprise a synthesis of the most important management measures carried out in the beaches studied from the 90's onward. On the contrary, variable 10 has to do with the morphological status of dunes and was obtained through the field work analysis of each of the 10 beaches during summers of 2020 and 2021. Hence, variable 10 has been considered a consequence of the variables 1 to 9 that correspond to a synthesis of the temporary evolution over decades.

Variables 1 to 9 are parameters related to the management and conservation actions, as well as the implementation of services and equipment in the beach-dune system. Specifically, we evaluated the following soft management measures: sand traps (1), revegetation (2), managed paths (3) or roped off areas (4). Some other actions have been used to measure the anthropic pressure received in the system as mechanical stockpiled sand for artificial dune build-up (5), mechanical cleaning (7), distance from park cars to the beach (8) or the temporary and permanent facilities on the foredune (9). Note that permanent facilities are those located on the foredune during all year long such as showers, whereas temporary facilities are those located during summer season such as beach bars. Finally, the type of the beach (6) has been taken into consideration for the analysis as a potential pressure to the system.

Variable 10 is the current status of the foredune according to Hesp (2002) classification. Geomorphological and ecological characteristics are the main indicators of the state of conservation and development of dunes (Hesp, 1988, 2002). That is the reason why we choose to assess the status of the foredune according to Hesp's classification in order to describe the general status of dunes conservation (Table 2). The five phases of dune degradation described by Hesp (2002) range from State 1 (the most developed natural state of the dune system comprised of a continuous, vegetation-covered foredune with seaward incipient morphologies) to State 5 (the most degraded status of the dune morphologies where small isolated hummocks are evidence of the existence of a former dune ridge currently present only discontinuously along the system). Degradation statuses 2-4 indicate the progressive advance of the erosion processes and the decrease in the vegetation cover of the dune morphologies. In our analysis, these phases have been converted into a 0-4 scale. Hesp (2002) determined that to reverse dune system

degradation certain management measures, such as revegetation and the stabilization of the beach-dune system, must be implemented.

The matrix resulting from this classification has been evaluated under the following statistical analysis.

3.2. Statistical analysis

The results of this matrix defined by the 10 non-redundant variables and 10 beach-dune systems (which means 100 cases) have been assessed by means of a Hierarchical Clustering on Principal Components (HCPC) using the *FactoMineR* package from R software. The principal component analysis (PCA) summarizes the information in a chart containing individuals (beaches) and variables. Each variable could be considered as a different dimension, but PCA reduces the dimensionality of a multivariate data to two or three principal components, and performs a cluster analysis of the results obtained from the PCA. After reducing the dimension of the data into few continuous variables containing the most important information in the data, a cluster analysis on the PCA results was performed. Hierarchical clustering is performed using the Ward's criterion on the selected principal components, which is used in hierarchical clustering because it is based on the multidimensional variance like principal component analysis.

The resulting figure shows graphically, with minimal loss of information, which variables are the principal components in a statistical analysis. According to the distribution of individuals on the chart, clusters can be established to group and describe the phenomena assessed.

4. Results

Results reveal a set of values for Catalonia and Valencian Community that define the 10 variables chosen in five beaches of each study area. In the case of Catalonia, beaches of la Pletera and els Muntanyans have the highest values, while Castelldefels and Platja Llarga have the lowest ones. That means that the first two show positive indicators both of the management measures carried out in the system and of the conservation of dune morphologies. On the contrary, the last two systems show negative indicators of management actions and conservation of dune morphologies. In the case of the Valencian Community, the highest values are in Guardamar, while the lowest ones are represented in el Pinar and el Saler. The systems that present medium values of the ten variables analyzed are la Rovina and Platja Llarga beaches, located in Catalonia, and the Cabanes and Tavernes beaches, located in the Valencian Community.

Table 2. Values of the 10 variables studied for the Catalan and the Valencian beaches.

Study area	Beach	1	2	3	4	5	6	7	8	9	10
Catalonia	La Pletera	4	4	4	4	2	4	4	4	4	3
	La Rovina	0	4	1	4	4	4	0	0	2	1
	Castelldefels	0	0	2	2	0	0	0	0	0	2
	Els Muntanyans	4	4	3	4	4	4	3	4	4	3
	Platja Llarga	0	0	0	0	4	2	0	2	0	0
Valencian Community	Cabanes	0	0	0	2	3	2	0	0	4	1
	El Pinar	0	0	1	1	0	0	0	1	1	1
	El Saler	0	0	1	3	0	0	0	1	1	1
	Tavernes	0	0	0	4	4	2	3	4	4	3
	Guardamar	4	4	2	4	3	2	2	3	4	4

The components F1 and F2 define a factorial space divided into four quadrants according to the configuration of the values expressed by the set of variables. From the HCPC the first two factors explain 77,43% of the variance. F1 is highly positively correlated with soft management measures (sand traps, revegetation and roped off areas), the lack of anthropic pressure (type of beach, mechanical cleaning, distance from park cars to the beach and the temporary and permanent facilities on the foredune) and the good status of the foredune according to Hesp (2002) classification. The factor F2 shows a high positive correlation with mechanical stockpiled sand for artificial dune build-up and to a much lesser extent with managed paths.

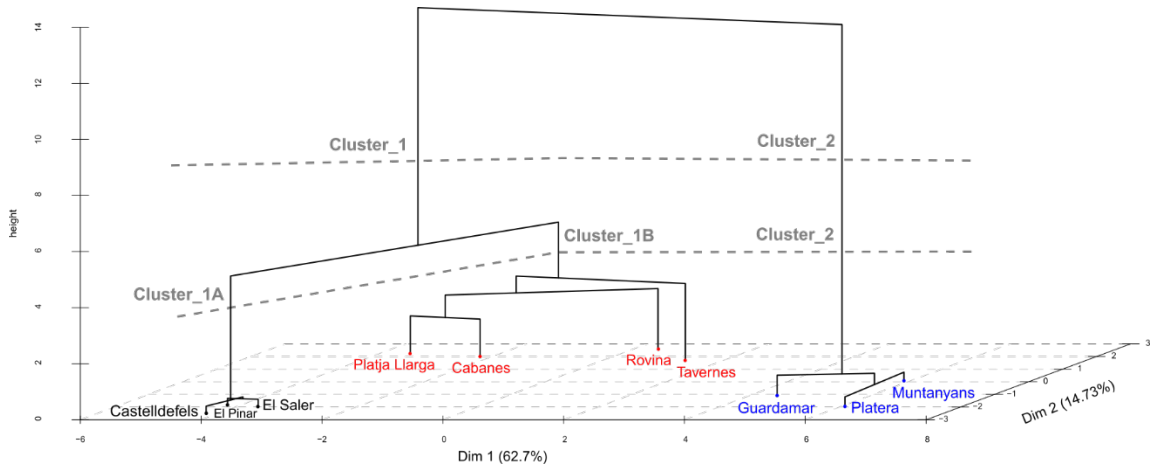

Figure 2. Dimensions and clusters resulting from the HCPC analysis.

The HCPC analysis clearly shows two beach groups: those where sustainable management measures were not applied and that present an advanced erosive state (cluster 1); and the ones where sustainable management measures were applied and that present a good state of conservation (cluster 2). Within the group of degraded systems (cluster 1), two types of beach-dune systems have been defined: those where dune construction has been carried out by mechanical stockpiled sand (cluster 1A) and those without artificial sand humps (cluster 1B).

5. Discussion

Most beaches are included in cluster 1 (7 out of 10) which means that they present degraded dunes and lack sustainable management measures. Pintó *et al.* (2014a) assessed the status of northern Catalan dunes and found highly degraded morphologies by human impacts (such as built environment, car parking and car tracks, beach raking, erosion pathways, dune breaches, invasive species and fixed dunes). Besides, Garcia-Lozano *et al.* (2020) studied 50 beach-dune systems along the Catalan coastline using management measures and the erosive state of foredunes and pointed out that most dunes were degraded and poorly (or not) managed, whereas a few ones presented a good state of conservation. The results of this research reveal that dune management on the eastern coast of the Iberian peninsula is directed to tourism demand of leisures on the upper beach and, consequently, dunes are managed accordingly.

5.1. Types of beach-dune systems

Cluster 1 makes up this group of beaches poorly managed and highly degraded. Sustainable measures of dune management are not applied here and, clearly, two types of management *status* can be distinguished: degraded dunes without management measures, and artificial dunes.

5.1.1. Artificial dunes

Cluster 1a is made up of three beaches (Castelldefels, el Pinar and el Saler illustrated in Fig. 3) where dunes were mechanically reconstructed after disappearing by stockpiled sand (Garcia-Lozano *et al.*, 2018). As an illustrative example, the case of Castelldefels beach (Fig. 3C), located in the Llobregat delta, has been chosen to develop the historical evolution of dune management of Cluster 1a.

The coastal dunes of the Llobregat delta presented sand erosion, instability of the coast of Viladecans and the N of Gavà, sedimentation in the S Gavà and Castelldefels, the construction of Port Ginesta (1985), vulnerability, loss of surface of dune landforms, high frequentation, soil contamination and proliferation of invasive vegetation (Masip *et al.,* 2009). From the 90s onward, cords of sand were artificially piled up, simulating dunes that were later revegetated (Fig. 4). Later, under the Dunas Híbridas project (2014 to 2017 according to Palacios, 2017), new dunes were mechanically performed again and reprofiled some others. Afterwards, *Ammophila arenari*a was used to revegetate dune systems by fences, while invasive vegetation was removed. It is worth highlighting that many individuals of *Ammophila arenaria* from the Dunas Híbridas project died because of the lack of sand movement on the dune ridges. The artificial sand mounds present a granulometric stratigraphy with different grain sizes throughout the vertical segment. However, the dunes of aeolian origin present an ordered stratigraphic segment, with the coarsest and most compacted grains in the lower part and the finer and looser sand in the upper part. This natural arrangement favors the movement of sand grains located in the upper part of the dunes when soft winds blow. The lack of wind dynamics in artificial dunes favors compaction that, over time, ends up being a sandy plot rather than a dynamic dune area.

Figure 3. El Saler beach (A) in summer 2021, el Pinar beach in winter 2019 (B) and Castelldefels beach (C) in spring of 2019.

Castelldefels beach illustrates this phenomenon well, as dune morphologies are compacted and aeolian dynamics scarcely affect the foredunes (Fig. 3). The high frequentation of people and the usual mechanical cleaning of the dry beach avoid developing embryodunes in the upper beach (Fig. 4: right). From a biogeographic point of view, the revegetation was questioned by Panareda and Pintó (2015) and Pintó *et al.* (2014b) that carried out an exhaustive study of the vegetal species of the delta and perceive unsatisfactory results in relation to the vegetation and dune morphology. They describe the dune restoration practice of the 90s as a beach sand garden recreation, where aesthetic and recreational criteria prevail over the natural or ecological function of the dune landscape. The dune morphologies that are recovered are integrated into the promenades with gardening criteria rather than considering dunes as natural habitats.

Figure 4. Evolution of Castelldefels beach from 2008 (left) to 2018 (right). In 2008 cords of sand were artificially piled up. In 2018 artificial dune ridges were fully covered by dune vegetation.

5.1.2. Degraded dunes without management measures

Cluster 1b groups four beaches (Platja Llarga -Fig. 5-, la Rovina, Tavernes and Cabanes). These beaches are featured by the lack of sustainable management focused on the maintenance and recovery of the dune system. The access to the beaches is abundant, both spontaneous and managed. Mechanical cleaning scarps regularly the foredune and difficult the growth of incipient dunes in the upper beach. These pathways are zones vulnerable to erosion, which generates regression of the dune system when storms are of great magnitude. For instance, the Glòria storm caused a large sediment intrusion to reach the interior of the system via its blowouts that are used as unmanaged accesses (Pintó *et al.* 2020).

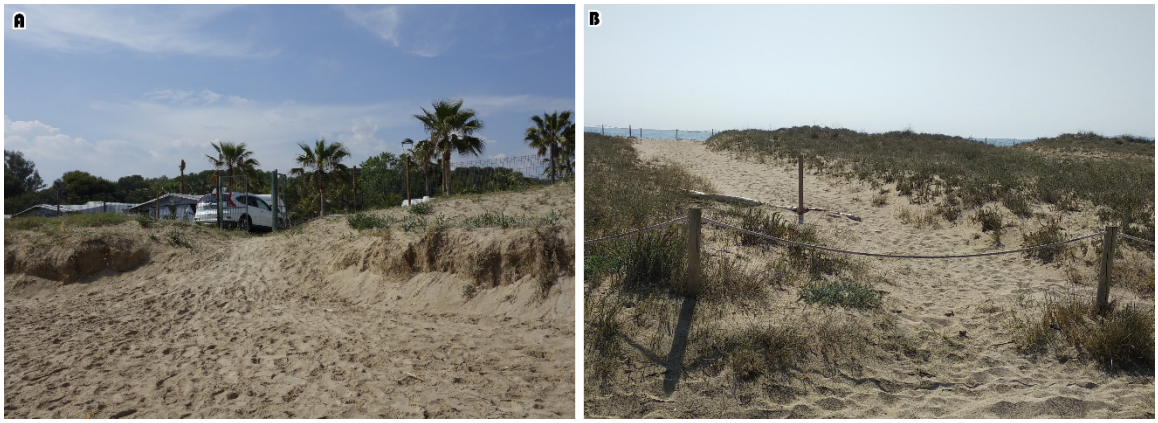

Figure 5. Pathways in Platja Llarga beach in spring 2019 (A) and la Rovina beach in spring 2021 (B). Often, campsites or parkings create unmanaged pathways that erode the foredune; whereas many times roped off dunes are not enough to avoid trampling.

5.1.3. Well-conserved dunes with sustainable management measures

Cluster 2 includes beaches well conserved from a morphological point of view where sustainable management measures were implemented (la Pletera, els Muntanyans and Guardamar) (Roig-Munar *et al.,* 2017). As la Pletera beach-dune system (Fig. 6) has been restored using soft management actions such as sand fences, managed paths, eradication of alien species, revegetation of foredune, and roped off dunes (Roig-Munar *et al.* 2020). Additionally, the deconstruction of the urban area adjacent to the dunes favored the restoration of salt marshes and the recovery of the whole coastal zone. The system evolved toward an erosive state due to the affluence of tourists. The degradation of the foredune morphologies accelerated in a regressive trend until the 2000s, due to the nonapplication of management measures for its recovery. Some sectors of the dune system disappeared and others were composed by isolated incipient dune. In the period 2009–2016 (Fig. 6), the system was subjected to sustainable management measures that allowed slow recovery of the dune system as a whole, migrating toward a state of naturalness. From 2011 onward, the first sustainable management actions were initiated through the use of sand retention fences, revegetation, managed paths, as well as the regulation of facilities on the foredune. During this period, a project of deconstruction of the abandoned area was carried out with the aim of recovering the coastal lagoons and salt marshes.

Figure 6. La Pletera beach in 2002 and in 2016.

In 2016, the system showed that it was in a balanced stage of renaturalization. The extinct line of dune morphologies in relation to the backshore was in the recovery phase; and the roped off areas were moved seaward to increase the width of the dunes. In 2019 the system presented a greater recovery of beach elevation in relation to 2010 and 2016 (Roig-Munar *et al.*, 2019), with a power of 1,63 m, with a volume of 97,185 m^3 in an analyzed area of 62,819 m^2. Therefore, this volumetric recovery reflects the clear trend towards renaturation of the emerged system.

Another interesting case to focus on is that of the Guardamar dunes (Fig. 7) in the province of Alicante (Valencian Community). Guardamar dunes have experienced the invasion of invasive alien species in the dune ridges and in the semi-fixed dunes as well as the destruction of the fixed dunes for the construction of parking areas and the degradation of dune ridges due to the transit of people and vehicles. To deal with it, actions have been taken towards the recovery of this area: the establishment of elevated gangway over the dunes for the people circulation; relocation of parking areas; restriction of access to the sensible zones, limiting the circulation of people and vehicles; restoration of the relief of the dune ridge through the placement of sand collectors across the dunes; elimination of foreign (not tree) species which have invaded the dunes, replacing them by proper species of these ecosystems; repopulation of the dune ridges with proper species and the protection of the recovered sectors; and making citizens aware of the enormous environmental value of dune ecosystems (Ministerio para la transición ecológica y el reto demográfico, 2021).

Figure 7. Guardamar beach in summer 2021

5.2. Limitations against other works

In former studies a spatio-temporal relationship between the variables were obtained, however in our case, we did not dispose of concrete data to analyze the temporal evolution for each studied variable (Roig-Munar *et al.,* 2020). Roig-Munar *et al.* (2020) studied several variables of a beach in different years, what allowed to relate the applied measures in each moment with the degradation/conservation degree of the dunes. Other studies considered the temporal evolution of the coast line, the intensity of storms or the increase in urbanization (Bodéré *et al.,* 1991; Davies *et al.,* 1995; García-Mora *et al.,* 2001; Laranjeira *et al.,* 1999), what also allows to do spatio-temporal study and comparisons with the beach-dune systems status in each moment.

Nevertheless, the present study relates the dominant management measures in each beach from the 1990s with the current geomorphological status, what can be considered a less-detailed study than others (Roig-Munar *et al.,* 2020) and it is rather an approach than a deep spatio-temporal analysis, such as those performed in other parts of the coasts, such as Catalan, Spanish or Italian coasts (Ciccarelli *et al.,* 2017; Pintó *et al.,* 2014; Garcia-Lozano *et al.,* 2020; Roig-Munar *et al.,* 2006; Peña-Alonso *et al.,* 2017; 2018). In fact, management actions carried out in a specific moment (sand stacking or massive revegetation) and their effects along the time have also been studied. Also, it has been considered if other management measures have been implemented sustained over time as for example mechanical cleaning, sand traps, roped off dunes, managed paths or the installation of services in the foredune.

Therefore, the method presented here has some limitations given that the measures considered in the studies above were not known in the 10 beaches examined, as well as the dune status for a concrete year were unknown as well. That is the reason why the present study is an approach, rather than a deep-study, based on the available data.

6. Conclusions

The checklist presented here allowed us to evaluate management techniques on dune areas of the eastern Iberian Peninsula developed coasts. The methodology is easily applicable in dunes with different morphological stages and different management and planning measures applied. Results show that the beach-dune systems can be gathered in 2 main groups: those where sustainable management measures were not applied and present an advanced erosive state (cluster 1), and the ones where sustainable management measures were applied and present a good state of conservation (cluster 2). Cluster 1 was subdivided into 2 subgroups: those beaches with artificial dunes, and those with degraded dunes without management measures. Hence, we found three types of beach-dune systems in the Catalan and the Valencian coastlines: artificial dunes, degraded dunes without management measures and well-developed dunes with sustainable management measures.

In the case of well-developed dunes with sustainable management measures, although the dune system can come from regressive stages before the applied procedures, it is shown that soft actions of an integral character allow the renaturalization of the whole complex, with natural colonization and dynamic processes that give again natural character to the system. In the cases of partial interventions throughout the system (such as degraded dunes without management measures), or interventions that favor fragmentation, their recovery is slower and subject to continuous actions. In the case of the morphologies created by means of stockpiles (artificial dunes group), these initially start from erosive stages or lack of dunes, where spaces without morphologies can be created and can be a good measure for the recovery of extinct dunes or creation of new ones, although their naturalness it is debatable and even its functionality as dynamic morphology and resilient to extraordinary storms events.

To sum up, dunes can be managed according to different objectives, the most important one has to do with the morphological criteria, which will allow for natural evolution, allowing an inherent resistance of the system as the changes associated with erosion, sedimentation or storms. This approach is more coherent with restoration if the objective is to renaturalize the dunes and make them a protection barrier for goods and services located in the shoreline. It is convenient to reach this objective through each beach adapted measures, rather than transformation practices using the artificial creation of dune surfaces.

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References

Bodéré, J.C., Cribb, R., Curr, R., Davies, P., Hallégouët, B., Meur, C., Piriou, N., Williams, A., Yoni, C., 1991. La gestion des milieux dunaires littoraux. Evolution de leur vulnérabilité à partir d'une liste de contrôle. Etude de cas dans le sud du Pays de Galles et en Bretagne occidentale. *Norois* 151 (1), 279-298.

BOE, 2013. Available at: https://www.boe.es/eli/es/l/2013/05/29/2. Last Access: 04/08/2021.

Brown, A.C., McLachlan, A. 2002. Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. Environmental Conservation 29 (01), 62-77. https://doi.org/10.1017/S037689290200005X

Ciccarelli, D., Pinna, M.S., Alquini, F., Cogoni, D., Ruocco, M., Bacchetta, G., Sarti, G., Fenu, G., 2017. Development of a coastal dune vulnerability index for Mediterranean ecosystems: a useful tool for coastal managers? *Estuarine, Coastal and Shelf Science* 187, 84-95. https://doi.org/10.1016/j.ecss.2016.12.008

Davies, P., Williams, A.T., Curr, R., 1995. Decision making in dune management: theory and practice. *Journal of Coastal Conservation* 1, 87-69. https://doi.org/10.1007/BF02835565

De Ferrer, J., 1895. P*royecto de fijación y repoblación de las dunas procedentes del golfo de Rosas*. Imprenta de Ricardo Rojas, Madrid.

Defeo, O., McLachlan, A., Schoeman, D.S., Schachler, T.A., Dugan, J., Jones, A., Lastra, M., Scapini, F., 2009. Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science* 81, 1-12. https://doi.org/10.1016/j.ecss.2008.09.022

Frigola-i-Vidal, P., 1999. Gestió actual de les dunes. Actuacions i propostes de futur. *Papers del Montgrí* 17 (Sorra i Vent. Les dunes 100 anys després.), 56-72.

Garcia-Lozano, C., Pintó, J., 2018. Current status and future restoration of coastal dune systems on the Catalan shoreline (Spain, NW Mediterranean Sea). *Journal of Coastal Conservation* 22, 519-532. https://doi.org/10.1007/s11852-017-0518-4

Garcia-Lozano, C., Pintó, J., Daunis-i-Estadella, P., 2018. Changes in coastal dune systems on the Catalan shoreline (Spain, NW Mediterranean Sea). Comparing dune landscapes between 1890 and 1960 with their current status. *Estuarine, Coastal and Shelf Science* 208, 235-247. http://doi.org/10.1016/j.ecss.2018.05.004

Garcia-Lozano, C., Pintó J., Roig-Munar, F.X., 2020. Set of indices to assess dune development and dune restoration potential in beach-dune systems on Mediterranean developed coasts. *Journal of Environmental Management* 259, 109754. https://doi.org/10.1016/j.jenvman.2019.109754

García-Mora, M.R., Gallego-Fernández, J.B., Williams, A.T., García-Novo, F., 2001. A coastal Dune Vulnerability classification. A case study of the SW Iberian Peninsula. *Journal of Coastal Research* 17, 802-811.

Generalitat Valenciana 2017. *Plan de acción territorial infraestructura verda del litoral de la Comunitat Valenciana. Dirección General de Obras Públicas, Transporte y Movilidad.* Disponible en: https://politicaterritorial.gva.es/documents/20551069/164268496/Cat%C3%A1logo+de+playas/e9a6ea3e-393c-469a-aa56-ef176cbe63d3

Gómez-Pina, G., Muñoz-Pérez, J.J., Ramírez, J.L., Ley, C., 2002. Sand dune management problems and techniques, Spain. *Journal of Coastal Research* SI 36, 325-332. https://doi.org/10.2112/1551-5036-36.sp1.325

Hesp, P. A., 1988. Surfzone, beach and foredune interactions on the Australian southeast coast. En Psuty, N. (Ed.), *Journal of Coastal Research* SI (vol. 3), 15-25.

Hesp, P.A., 2002. Foredunes and blowouts: initiation, geomorphology, and dynamics. *Geomorphology*, (48), 245-268. https://doi.org/10.1016/S0169-555X(02)00184-8

Laranjeira, M., Pereira, A., Williams, A.T., 1999. Comparison of two checklist methods for assessment of coastal dune vulnerability. *Boletín del Instituto Español de Oceanografía* 15, 259-268.

Martínez, M.L., Intralawan, A., Vázquez, G., Pérez-Maqueo, O., Sutton, P., Landgrave, R., 2007. The coasts of our world: ecological, economic and social importance. *Ecological Economics* 63, 254-272. http://dx.doi.org/10.1016/j.ecolecon.2006.10.022.

Masip, J.M., Ohlsson, B., Cartagena, S., Segalà, E. (Coords), 2009. Manual para la implantación de sistemas de gestión ambiental en los puertos deportivos. *Manuales de ecogestión* 28. Direcció General de Qualitat Ambiental (Generalitat de Catalunya).

Ministerio para la transición ecológica y el reto demográfico, 2021. Available at: https://www.miteco.gob.es/es/costas/temas/proteccion-costa/actuaciones-proteccion-costa/alicante/031161-ecosistema-dunar2.aspx#prettyPhoton. Accessed: 15/07/2021.

Nordstrom, K.F., 2000. *Beaches and Dunes of Developed Coasts.* Cambridge University Press, Cambridge.

Nordstrom, K.F., Jackson, N.L., Kraus, N.C., Kana, T.W., Bearce, R., Bocamazo, L.M., Young, D.R., de Butts, H.A., 2011. Enhancing geomorphic and biologic functions and values on backshores and dunes of developed shores: a review of opportunities and constraints. *Environmental Conservation* 38(03), 288-302. https://doi.org/10.1017/S0376892911000221

Obiol Menero, E.M., 2003. La regeneración de playas como factor clave del avance del turismo valenciano. *Cuadernos de Geografía* 73/74, 121-146.

Obiol Menero, E.M., Pitarch Garrido, M.D. 2011. El litoral turístico valenciano. Intereses y controversias en un territorio tensionado por el residencialismo. *Boletín de la Asociación de Geógrafos Españoles* 56, 177-200.

Palacios, D., 2017. *Dunas híbridas en las playas metropolitanas de Barcelona*. Presentación al congreso XIX Congreso Ecoplayas 2017, Donostia (España).

Panareda, J.M., Pintó, J., 2015. Dinámica de las plantas exóticas en los espacios dunares del delta del Llobregat (Barcelona). In: J. De la Riva, P. Ibarra, R. Montorio, M. Rodrigues (Eds). *Análisis espacial y representación geográfica: innovación y aplicación*. Universidad de Zaragoza-AGE, pp. 1793-1802, Zaragoza.

Pardo-Pascual J.E., Sanjaume E., 2019. Beaches in Valencian Coast. In: J. Morales (Ed). *The Spanish Coastal Systems*. Springer, Cham.

Peña-Alonso, C., Fraile-Jurado, P., Hernández-Calvento, L., Pérez-Chacón, E., Ariza, E., 2017. Measuring geomorphological vulnerability on beaches using a set of indicators (GVI): a tool for management. *Journal of Environmental Management* 204, 230-245. https://doi.org/10.1016/j.jenvman.2017.08.053

Peña-Alonso, C., Gallego-Fernández, J.B., Hernández-Calvento, L., Hernández-Cordero, A.I., Ariza, E., 2018. Assessing the geomorphological vulnerability of arid beach-dune systems. *Science of the Total Environment* 635, 512-525. https://doi.org/10.1016/j.scitotenv.2018.04.095

Pino, J., Seguí, J. M., Alvarez, N., 2006. Invasibility of four plant communities in the Llobregat delta (Catalonia, NE of Spain) in relation to their historical stability. *Hydrobiologia* 570 (1), 257-263. https://doi.org/10.1007/s10750-006-0189-x

Pintó, J., Martí, C., Fraguell, R.M., 2014a. Assessing current conditions of coastal dune systems of Mediterranean developed shores. *Journal of Coastal Research* 30 (4), 832-842. https://doi.org/10.2112/JCOASTRESD-13-00116.1

Pintó, J., Panareda, J. M., Martí, C., 2014b. El paisaje vegetal de las dunas del delta del Llobregat. In: R. Cámara Artigas, B. Rodríguez Pérez, J.L. Muriel Gómez (Eds). *Biogeografía de Sistemas Litorales. Dinámica y Conservación*, pp. 27-33, Universidad de Sevilla. Sevilla.

Pintó, J., Garcia-Lozano, C. 2016. Transformació històrica recent i situació actual del paisatge dunar a Catalunya. En: F. X. Roig-Munar (Ed). *Restauració i gestió de sistemas dunars. Estudi de casos,* pp. 81-99, Càtedra d'Ecosistems Litorals Mediterranis. Palafrugell.

Pintó, J., Garcia-Lozano, C., Roig-Munar, F.X., 2019. L'espai litoral. In: R. Folch, J. Peñuelas, J.D. Serrat (coord). (coord.), *Natura, ús o abús? Llibre blanc de la gestió de la natura als Països Catalans*. Institut d'Estudis Catalans.

Pintó, J., Garcia-Lozano, C., Sardá, R., Roig-Munar, F.X., Martí, C., 2020. Efectes del temporal Glòria sobre el litoral. *Treballs de la Societat Catalana de Geografia* 89, 89-109. http://revistes.iec.cat/index.php/TSCG

Quintana Trenor, A., Vizcaíno Matarredona, A., Collado Rosique, F., Benavent Olmos J.M., Soriano González, J., 2016. La Devesa de l'Albufera de Valencia: un caso de restauración dunar. In: F.X. Roig-Munar (Ed). *Restauración y gestión de sistemas dunares: estudio de casos*. Càtedra d'ecosistemes litorals mediterranis, pp. 115-135.

Roig-Munar, F.X., Martin-Prieto, J.A., Comas, E., Rodríguez-Perea, A., 2006. Space-time Analysis (1956-2004) of human use and management of the Beach-Dune Systems of Menorca (Balearic Islands, Spain) 2006. *Journal of Coastal Research* SI 48, 107-111.

Roig-Munar, F.X., Pintó, J., Vicens, J., Martín-Prieto, J.A., Ramos, S., Garcia-Lozano, C., 2017. Análisis de la evolución del sistema dunar de la Pletera (Costa Brava, Cataluña) mediante el uso de variables geomorfológicas y de gestión. *Geo-Temas* 17, 175-178.

Roig-Munar, F.X., Alturo, R., Ramos, S., Garcia-Lozano, C., Pintó, J., Martín-Prieto, J.A., Rodríguez-Perea, A., Gelabert, B., Vicent, J., 2019. Análisis evolutivo de la morfología dunar de la Pletera (Girona, Catalunya) mediante sensores LiDAR y fotográficos (2010-2018) In: R. Durán, J. Guillén, E. Simarro (Eds). *X Jornadas de Geomorfología litoral.* Castelldefels, 4 a 6 de septiembre de 2019. Libro de Ponencias. pp. 73-76.

Roig-Munar, F.X., Garcia-Lozano, C., Pintó, J., Martín-Prieto, J.A., 2020. Spatiotemporal evaluation of the geomorphological state of beach-dune systems using management criteria. *Land Degradation & Development* 31 (18), 2901-2913. https://doi.org/10.1002/ldr.3677

Sanjaume, E., Gracia, F.J., 2011. *Las dunas en España*. Sociedad Española de Geomorfología, Cádiz.

Yepes, V., 2002. La explotación de las playas. La madurez del sector turístico. *Ingeniería y territorio* 61, 72-77.

Yepes, V., Medina, J.R. 2005. Land Use Tourism Models in Spanish Coastal Areas. A Case Study of the Valencia Region. *Journal of Coastal Research* SI 49, 83-88.