

# SPACE-TIME ANALYSIS (1956-2004) OF THE DUNE SYSTEMS OF MENORCA (BALEARIC ISLANDS) WITH GEOENVIRONMENTAL VARIABLES OF USE AND MANAGEMENT

**F.X. Roig-Munar<sup>(1,2)</sup>, G.X. Pons<sup>(2)</sup>, J.A. Martín-Prieto<sup>(1,2)</sup>, A. Rodríguez-Perea<sup>(2)</sup> y M. Mir-Gual<sup>(2)</sup>**

<sup>(1)</sup> QU4TRE, consultoria ambiental

<sup>(2)</sup> Departamento de Ciències de la Terra, Universitat de les Illes Balears

Overall coastal occupation by man has been massive, rapid and acultural, giving littoralization process accelerated. Many of these occupations and transformations have led to disruption of natural mechanisms of formation and defense, preventing the proper functioning of coastal ecosystems (Brown and McLachlan, 1990), and changed the landscape dramatically, leading to changes in their natural and traditional (Pinto, 2005). This change was unexpected, as at the beginning of tourism development are not designed the coastal areas, beaches and dunes, as fragile and dynamic spaces likely to deteriorate rapidly. In this sense Nordstrom (1994) refers to the management of the coastal environment as an aberrant action, claiming that the actions taken are comprehensive and not meddling with natural processes.

In the case of Menorca the coast is the major environmental asset which is based on the economy of the island. These coastal areas are in complex systems involved on numerous factors (Martín-Prieto and Rodríguez-Perea, 1996) of different nature and magnitude, and its preservation is directly related to the possibility of natural adaptation to dynamic changes caused by agents of natural and / or human.

In the case of the dunes, these are part of a more complex system called the beach-dune system, characterized by the interaction of two distinct areas, the submerged area controlled by the marine hydrodynamics, and the field emerged, controlled by dynamic wind. These beach-dune systems represent a fragile system as a whole, because small changes can break the natural balance in each of their areas. This weakness has meant that tourist areas have been eminently modification processes, regression, and in worst cases, their disappearance, due to urbanization and lack of proper management, maintenance and preservation.

From the 70's to the present, coastal management has been marked by exploitation, by the concern to meet basic hygiene standards and the installation of certain services for leisure and recreational users, not conceiving these spaces and natural systems. The beaches and

coves were understood more as an annex to urban and tourist areas, avoiding environmental characteristics, sedimentological backup functions of the associated dune morphologies, and the fact that provide habitat for numerous plant species adapted to these environments, and essential for the maintenance and stabilization of systems (Schmitt, 1994).

In general the installation of beach services indiscriminately and randomly on the foredunes and dunes has contributed to the generation of various morphologies erosive (Alonso et al., 2002), which were the subject of restitution. These processes of alteration and degradation, which Hesp (1988, 2002) ranked morfoecologically exemplify the stages of erosion and stability and possible recovery, based this on its front dunes and this face that gives stability to the entire system. Dune systems respond to external processes and environmental factors that act directly on them. External processes are involved that determine the impact of environmental factors responsible for the slowdown in their formation processes and imbalance. These can be framed in two disturbing elements, related to environmental factors or factors related to management and use, to determine the current dynamics of each of the dune systems with visitor use and / or recreational. The pressure of human activities related to recreation and leisure, have their starting point in the recent development of coastal tourism. These can be grouped into two groups:

1. Activities that involve the destruction of the system and / or partial or total development of the system. These actions cause major imbalances and accelerated quickly.
2. The actions of management and use, which are apparently less destructive than the first, but more systematic and extensive, and encompasses many of the activities that occur on the system. Both use activities including management and installation services degrade the overall system. The areas most affected by such impacts are the most used areas, areas of beach and foredune, being also the most fragile and dynamic significance, both into the system as in the top of the beach. Be the state of these morphologies front which contribute to the stabilization or degradation of the whole system around.

## **HYPOTHESIS AND OBJECTIVES**

Because that is the island of Menorca in the Balearic Islands which has the largest number of dune systems, and where his condition is from well preserved areas poorly maintained. Because the dynamics has been given on these can be evaluated with the use of space-time variables. This allows an analysis with which to assess the geo-environmental responses of the systems, associated with its use and management measures. This result can be obtained as an evolutionary model over the periods analyzed.

The study starts from the premise that the conservation status of each of the systems in 1956 was optimal. At that time course is considered a steady state in the entire beach-dune system with a plant and morphological structure in front of dunes, classified by Hesp (2002), as stage 1, and a zonation from the beach area emerged until balanced dune areas, where the only erosion agents that could affect the system were those of natural origin, being the response of the natural and gradual recovery of these (Pye, 1982). This state of balance due to the fact that Menorca was not suffering in the years 50-60 recreational tourism pressure on its coastline.

We take as a starting studies in Menorca by Roig-Munar (2003), and the Balearics by Roig-Munar and Comas (2005), which conducted a classification analysis of beaches and coves of the islands by using variables The proposal of a classification model for its management, and a model of temporal evolution of these. This analysis was performed with field data from 2003 and 2004, obtaining a radiograph static current status of beaches in the Balearic Islands, with this methodology as a management tool for future action on each unit tested.

Therefore, the objective of this paper is an analysis of macro-scale space-time (Larson and Kraus, 1995), changes of 28 beach-dune systems Menorca (Figure 1), all of them according to different classification use, management and conservation (Table 1). These dune systems are chosen to be fragile and dynamic environment, on which you can see the trends that occur, whether erosive or recovery of stability in the form of significant morphological responses over time. Their knowledge can help establish a model on its current status and trends of the systems.

## METHODOLOGY

For the study has established the following methodology, based on the adaptation and modification of different bibliographic research methods and adapted to the conditions and realities of the island of Menorca:

1. Representative and comprehensive selection of beach-dune systems Menorca: 28 case studies (Figure 1). Son Bou system has been divided into two units (A and B (Table 1)) as the state geoenvironmental and use has been on the system during the time of analysis have been very different, and consequently units have been considered two distinct morfoecological data.
2. Determination of the periods analyzed. We have built in the periods 1956, 1975, 1983, 1995, 2000 and 2004 from aerial photographs to observe the most significant changes for each unit (Crowell et al., 1991; Valpreda and Simeoni, 2003), adding a temporal component and evolutionary analysis of the system (Garrote and Garzón, 2004).
3. They have identified and defined a representative set of 36 variables for further analysis of management, using physical and environmental parameters, to establish an evolutionary trend from 1956 to 2004 (Garcia et al., 2001, McLaughlin et al., 2002, Hesp, 1998 and 2002) and state parameters, use and management. These 36 variables (Table 2) are only qualitative, mostly discontinuous with values between 0 and 5, and are intended to characterize the state of the dune systems. Values have been assigned to each variable and each case study by photogrammetric analysis, bibliographic research, oral history of former municipal officials and management of beaches in recent years fieldwork.

These 36 variables are:

Geomorphic (19), beach system, state of the foredunes (Hesp, 2002), presence of blowouts, erosive slopes foredune, dune neomorfologías standing, channels deflation, the presence of hummocks, wind coats unbound disappearance of foredunes, historic retreat foredunes, disappearance of dunes, rock outcrops on the dunes, blowouts in the second row of the system, beach vegetation, percent cover, *Ammophila arenaria* in the system, vegetation burial, exhumation of arboreal roots, and reactivation of aeolian processes in the dune system.

Purpose (8), road density on the dune system (Voigt and Weidemann 1997; Curr et al., 2000), distance from the parking, distance from access roads, level of attendance (Roig-Munar, 2003), degree of publicizing (Blázquez and Roig-Munar, 1999), presence of urbanization on the system, waterfront, and proximity to urban centers and / or tourism.

Management (9), removal of accumulations of *Posidonia oceanica* (Roig-Munar et al., 2004a), mechanical cleaning (Roig-Munar, 2004), permanent facilities and temporary facilities on dune morphology, permanent installations and temporary facilities on foredunes (Alonso et al., 2002), of ANEI (Natural Area of Special Interest), Natural Park, and management measures, protection and recovery.

## RESULTS

Principal Components Analysis (SPSS v.12) on an array of 168 cases and 15 non-redundant variables removed 4 significant factors that explain 62.3% of the variance (Table 4), and the correlation coefficients of variables extracted from the ACP (Table 5).

The first 3 factors explain more than half of the variance (53.5%). The factor F1 (Figure 2) is highly and positively correlated with DU variables (urbanization) and PF (foredune facilities), and negatively correlated with geomorphological parameters (FR (foredune) and OD (neomorphologies)) and botanical (VP). Given that most of the 15 variables analyzed have values increasing in the sense 'presence - absence', is understood to have a significant inverse, ie the maximum values (5) correspond to the absence of the measured parameter (DU = 5 indicates no development).

Consequently, the high correlation of F1 with DU and PF is equivalent to a high correlation with the «undeveloped» and the lack of facilities in foredune morphologies. Thus, F1 is interpreted as an inverse measure of the degree of alteration of the front of the dune systems, ie as a measure of the degree of conservation or alteration, «according to the values established by Hesp (2002) - which in many cases depend on the management of credit (Brown and McLachlan, 1998, Roig-Munar, 2003, Roig-Munar et al., 2004b), or the management and control of public use on these morphologies. The alteration of the dune front, either due to their use and / or management, or natural processes can determine the status of conservation in the whole system, giving erosion based on his forehead and programming to the internal system, through deflation channels, which could be exacerbated by the lack of management or mismanagement of these spaces.

The F2 factor shows a high correlation with measures of protection (PN (natural park) and AN (NASI)) and management measures (GS). Because the variables take values reversed, this factor must be understood as an inverse indicator of the presence of actions for their conservation: F2 negative values indicate that management measures have been taken (regulation of activities, management and regulation of morphological type public use) and protection, but these protective measures, through the adoption of Autonomy of Natural Areas Law (LEN) 1 / 1991, which stated the figure of Natural Areas of Special Interest (NASI), which afforded protection to urban high percentage coast of Menorca, about half did not affect the protection of coastal resources. The factors show very weak correlations, negative correlations being F3 AN and PD, and positive EV and CV, which is interpreted as a measure of the degree of vegetation coverage of the system. F4 is negatively correlated with BF and

positively with OD, PD and VP, and F5 shows negative correlations with BF and positive CV and EV and PT.

Thus we have the components of the factors F1 and F2 factorial define a space with well-defined 4 quadrant (Figure 3), these being:

1. Undisturbed or managed systems. There is no use, protection and management of sandy coastal environment. So this is a natural phase of the system that regenerates naturally to erosion processes specific wild type (F1 and F2 positive)
2. System altered or alteration process, not management or protection processes occur and the dunes begin a trend toward the systematic degradation (F1 F2 negative and positive).
3. Systems altered, but managed, erosion processes slow down or stabilize without having the implementation of recovery methods and techniques of how eroded (negative F1 and F2) and
4. Systems undisturbed or recovered, and managed and protected (F1 F2 positive and negative).

The representation of the annual averages of the 28 dune systems on the factor space (Figure 3) indicated as from 1956 to 2000, overall, there has been a change of systems, particularly marked between 1956 and 1995. However, there is a final trajectory toward recovery situations due to the implementation of management practices that prioritize the recovery of dune morphologies. This will deduce different periods that have affected the whole beach-dune systems:

1. The period between 1956 and 1983 coincides with the entry of Menorca in the tourism market of sun and beach, and the consolidation of its occupation and resorts along its coastline, affecting this occupation dune systems. We start from an optimal situation of natural dune systems, to widespread disruption of these due to the failure to implement appropriate management measures, nor the presence of management figures, entering a dynamic that tends to the alteration and disappearance of dune forms (it follows from the steady reduction in the F1 value of annual average values of this stage.) It should be borne in mind that during 1969 it opened in its current location, the new airport of Menorca. That was a major tourist off. The number of passengers who passed through the airport has doubled in just two years. Compared to the 112,000 passengers who used the former airfield of Sant Lluís in 1968, moved to the 239,000 in 1970. During 2008, has about 1,300,000 passengers a year entries (Murray et al., 2010).
2. From 1995 to 2000, there is a tendency towards a phase of alteration of the processes of degradation of the dunes. This phase is gradually slowed down due to an increase in their management, either by the entry into force of measures of protection and / or management (thus attenuates the decrease in the values of F1).
3. The period between 2000 and 2004 can be seen a general trend towards recovery of the dunes, with a mean closer to the lower right quadrant, through the management and protection of these. The implementation of systems and methods of sustainable management and regulation of public use on these morphologies allows the stabilization of basic erosion and recovery of front and interior morphologies, foredune and

dune semiestabilizadas who had suffered reactivation processes that contribute to stabilization of the entire dune system.

It is based on an analysis of the temporal evolution of the 28 dune systems have been identified and defined four different behaviors grouped into three groups (Figure 4);

Group 1: The systems vary significantly. The annual values are moved between the two quadrants defined by the F1-F2 factorial space (top and bottom). Within this group we identified two subgroups, which remain stationary with little interannual variations (subgroup 1a), which slightly worse and are subject to management measures (subgroup 1b). We have a case of type 1b: Escorxada, and 8 cases of subgroup 1a: Trebalúger, Tamarells, Turret, S'Enclusa, Morella, Presili, Son Saura's Southern and Bot, all dune systems of type C. These systems located in NASI or Natural Park, a little publicized and pedestrian access have always been slight degradation processes for their use, and to a lesser extent by its management, often absent at the low or no tourist exploitation of these sands. Hence, variations in the factor space have been conditioned to legal protection, since the systems have similar geo-environmental conditions during the period 1956, 2004 can be described in stages 1 and 2 by Hesp (2002).

Group 2: Systems that describe a path as «C», ie that worsen over time but are subject to management measures show some recovery, noting two trends in terms of recovery acceleration of these systems to environmental response actions implemented. This recovery of dune forms by sedimentary processes of recovery can lead to a tendency toward the naturalization of the whole system, in some cases to the state of retrieval system, comparable to those of group 1 but with high levels of use and implementation of appropriate maintenance measures for proper management. Group 3: These are systems with a clear degenerative and its trend has been toward the continued degradation and even their apparent disappearance, becoming deflation surfaces with isolated relict morphologies and neocolonialism of morphologies associated with pioneer plants are eradicated in periods summer to carry out actions to adapt to the beach for tourist and recreational use. They show no signs of recovery due to lack of proper management. Nevertheless, they may be subject to management measures for the recovery of shapes.

In particular terms, system by system, there have been various developments, from dune systems that have remained stationary in its natural stage, systems that have suffered constant degradation processes to dislocation and loss practice and dune system, even those that have reverted degenerative trend towards recovery and naturalness. On average we observed highly degraded systems that have been recovered through the application of management measures particularized to each of these systems and forms. The management measures, whether they are effective and based on the natural system morphology, and not in the natural system as a result, they lead to an improvement, stabilization, recovery and rehabilitation of the form, and hence coverage plant. This is reflected in the evolution of the average values of F2-F3, showing the growth of vegetation between 1995 and 2004, coverage is increased along the eroded shapes of the system, thus showing a recovery in ways that are subsequently vegetal settled resulting in the stabilization and maintenance of the system as a whole.

Separate representation of each of the 28 systems analyzed (Figure 5) enables to trace the spatio-temporal evolution that have followed each of them directly related to its use and management, often conditioned by their degree of publicizing.

## **DISCUSSION**

The act of making functional the beach-dune coastal areas to meet the massive attendance has brought serious problems of conservation. Problems such as: neomorphologies alteration and removal of beach-dune and associated vegetation, destruction of dune formation processes, alteration and destabilization of natural beach profiles and increased erosion of aeolian transport and dune fronts by reactivating dunes semistables, loss of biodiversity, loss of beach area and volume, and their morphologies associated erosive morphologies in the first and second line lobes advancing dune, tree-burial, among others.

In the case of Menorca, where the sandy coastal area is considered the natural space where the main economic activity revolves the island due to its use and commercial exploitation, assessed this using the contingent valuation method € 33,532,156 / year (Roig-Munar and Perez-Lopez, 2007), requires the use of this space as a lasting and sustainable resource unaltered over the decades. States that the natural and environmental factors that enable the development over time and the provision of tourism services to consumers (business and / or user) to provide the greatest satisfaction to the user expectations and needs, always in line with Geo-environmental status of the systems and the declaration of Menorca Biosphere Reserve. In this sense throughout the whole coastline (beaches, coves and dunes) is the factor of production of the tourism industry in Menorca. Ensure their stay in a position to meet the demands of users required to prevent degradation processes, implement maintenance, restoration, rehabilitation and recovery.

The analysis of the temporal evolution of the dune systems of differential performance reflects three Menorca, stationary systems, systems recovered through the application of measures and management systems, and system degeneration. Of the three observed behaviors, the degenerative systems is the most interest for analysis and management, because they reflect, by erosion, the zero or more ineffective efforts that have acted on them, and steps necessary tested the latter with the trends observed between 2000 and 2004, through the application of morphological, environmental and social (Roig-Munar et al., 2006).

As in the case of the classification of beaches used for the management of sandy coast of Menorca and Balearic Islands, this analysis of time-space evolution is presented as a good tool to measure and monitor the conservation status of dune systems.

