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Proceedings of the 10th European Seminar on the Geography of Water

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Contents

Doñana active dune system: an example of a fragile equilibrium ecosystem in the Mediterranean environment

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Abstract

Doñana National Park includes one of the most spectacular active dune systems in Europe. The extension of the system (about 60 km^2) and its impressive mobile dunes create a unique landscape, which represent one of the scarce natural dune ecosystems in the Mediterranean coast. In this sense, the system is an extraordinary field laboratory for coastal dune research, especially to evaluate those processes related to environmental changes, human actions and management policies and practices. The paper includes a brief description of the system and shows the first results of our research about its evolution from 1956 to 2000.

Keywords: Coastal dunes; mobile dunes; GIS; conservation management; environmental changes

Introduction

Coastal dunes constitute valuable natural elements from many points of view; these include, among others, their ecological significance, their role as a protective agent against coastal erosion, or their relevant landscape specificity. In spite of this, coastal dunes have been destroyed and occupied by man throughout the world [3]. In a first instance, coastal dunes were considered to be especially dangerous, mainly there where they showed rapid inland advances that affected agricultural fields, inland water bodies or villages [10]. To prevent this problem we find a series of actions that have been taken against natural dunes, consisting of vegetation planting; the first well documented action is attributable to Bremontier, who developed a method for dune stabilization by pine planting in Las Landes (France) at the end of the 18th century [7]. In a second instance, the solution of tree planting was seen quite soon as a resource; many hectares of bare sand could be converted into productive forest. Therefore, even in places where coastal dune were not a problem, they were treated by planting stabilizing vegetation. Finally, during the second half of the 20th century, dunes have suffered an accelerated process of destruction due to littoral occupation by the tourist industry, intensive agricultural fields or industrial complexes. In the last decades of the 20th century, national and regional authorities started to protect the scarce coastal dunes remaining in a natural state in Europe and especially in the Mediterranean. These actions are related to numerous scientific works, which call attention to the importance of coastal dunes as agent to prevent coastal erosion and as rich ecosystems.

In this context, the founding of Doñana National Park in 1969 implies the protection, among other environments, of a unique coastal active dune system in an area close to emerging tourist and intensive agricultural sectors. As one of the scarce natural coastal dune system in Europe, Doñana active dunes represent an invaluable field laboratory for coastal dune research from ecological and geomorphological standpoints. This paper on Doñana active dunes is focused on the application of GIS techniques to morphological and dynamic characterization of the system.

Study area

As showed in figure 1, Doñana active dune system is located at one extreme of the Huelva province on the SW coast of Spain. Geologically it belongs to a series of littoral formations representing the close up of the old Guadalquivir valley. The zone is said to pertain to an oceanic Atlantic-coast Mediterranean subclimate [8]; it has 500–600 mm annual precipitation, typical summer drought, and soft mean temperatures above 10°C any month of the year. As recently delimited [4], the system is about 60 km^2 and it extends along a 26 km shoreline and 2–3 kms inland. The system is said to be active since aeolian processes are dominant above other geomorphological agents. In this sense, the system is within a greater aeolian area (500 km^2) known as the Abalario-Doñana littoral aeolian mantle (MELAD), which includes other fossil and semiactive dune units where aeolian processes are no longer dominant above pedological, erotional or mass waste processes [2].

Looking at the whole coast of Huelva, we observe a continuum of estuaries and associated marshes from the Guadiana river mouth, at the Portugal-Spain border, to the Guadalquivir river mouth at the border between Huelva and Cádiz provinces. These estuaries are closed to the sea by different littoral sand formations, among which aeolian units are normally present as foredunes or small scale dune fields where littoral spits expand wider [2]. So, what are the reasons for such a great development of aeolian formations in the Doñana area? To answer this question, factors for coastal dune development have to be considered.

Coastal dune formation factors

Littoral dunes require two main factors for their formation on any coast of world: **1) a source of sand**, and **2) wind conditions** capable of moving the sand inland. If littoral dune fields are considered, a third factor is needed: **3)** a **suitable topography** behind the beach on which dunes can develop. Vegetation is not the main requirement for coastal dune formation, as proved by many bare sand dune fields along the coasts of the world, some of which are part of coastal deserts. However, apart of these special cases in extremely arid environments, **4) vegetation** is always present in coastal dune systems and constitutes one of the key elements for their specific morphology and ecological richness.

In Doñana active dune system all the cited factors are present as revealed in the following lines.

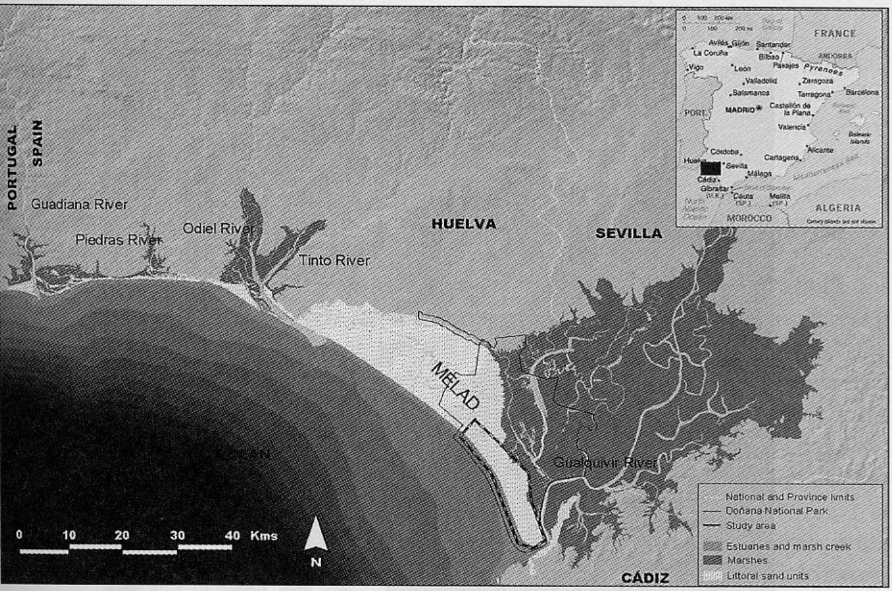

Figure 1: Localization of the study area on the coast of Huelva (SW Spain)

1. In respect to the source of sand, the system is located at the eastern extreme of the Huelva coast. This coast has constituted an entire littoral cell in which the alongshore drift has a net component to the east. Thus, Doñana's wide, accretional beaches represent a sort of sedimentary sink, where a great part of that drift arrives.

2. Over these wide beaches the wind blows strongly enough to move this sediment. The 26 km Doñana beach is aligned NW-SE, so it is an exposed coast in respect to the dominant SW winds associated with the arrival of south Atlantic depressions in winter and autumn. In summer and especially in spring, sea breezes may blow at considerable speed, high enough to blow up sand particles; the reason for this strong breeze is the great temperature differences between land and sea; wide bare sand areas reach quite high temperatures around noon, when the sea is still relative cool from the night.

3. Doñana active dunes traverse the Doñana spit. This littoral formation has been growing since 6000 years, closing the old Guadalquivir estuary. Except for the western extreme, where some old fossil dunes overlie the spit, the active dunes have developed over the spit's plain topography, which presents no important obstacles for inland migration.

4. Vegetation is present in the system from the first phase of dune formation at the back beach to the stabilization process of some inland dunes. Different aspects of vegetation are described later in the paper.

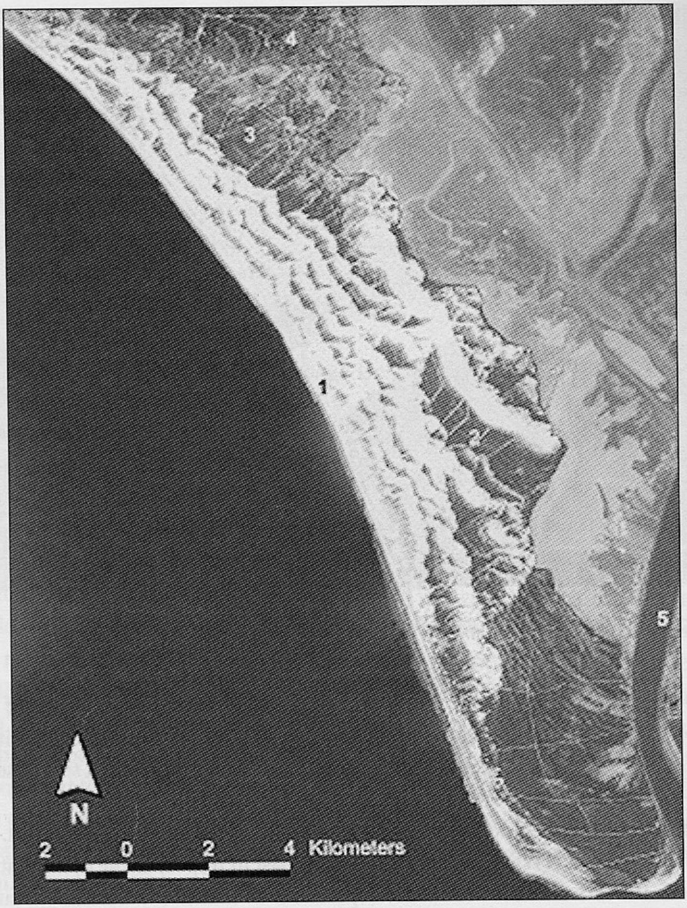

Figure 2: 1999 Orthophotograph of the Doñana active dune system 1. Dunes; 2. Slacks; 3-4 Old dunes areas; 5. Guadalquivir river.

Descripton of the dune system

Doñana active dune system, as shown on figure 2, consist of 4 or 5 parallel dune ridges (in white) separated by a series of interdune depressions (slacks). Slacks are areas of wind deflation and they represent the interval between ridge formations; the intense wind erosion is responsible for the proximity of the water layer, which at the same time explains the abundant vegetation [5].

Looking at figure 3, two different parts are distinguished in the system; the first one, corresponding to the area between letters A and B is the coastal complex, and the rest (C, D and E) is the inner complex.

Coastal dune complex

This part includes 4 different units; from the sea inland, these units are the beach, the foredune, the intermediate area and the first transgressive ridge.

The beach is obviously part of the system as it constitutes the source of sand feeding the dunes. On the back beach, pioneer vegetation species (sand catcher) such as *Eryngium maritimus, Otanhtus maritimus, Salsola kali* or *Cakile maritima* trap the sand and form the first sand mounds. However, the real dune builder plant is *Anmophila arenaria*, which is responsible for the first dune ridge formation (foredune).

The foredune (Fig. 3, A) can be a unique ridge, a set of ridges or a field of dune mounds. The dominant plant is *Anmophila arenaria*, which occupies the most exposed parts of the dune as is resistant to sand burial, wind action and salt spray. This section of dune has a steep wind side, which may be attacked by waves during storms, and a more soft lee side, where woody species (*Armeria pungens; Artemisia chitmifolia*) appear, since this is a less exposed environment. At the southeast extreme of Doñana, individuals of *Juniperus oxycedrus* can be found in this sector; this species constitutes a remnant of the old native forest destroyed by human uses of this area since the middle ages.

The intermediate area (between A and B in Fig. 3) is a sort of incipient slack. The water layer can emerge and hydrophilous plants may be present, although we rarely find the vegetation richness of true slacks. The reason for this fact is the continuous transfer of sand between foredune and the next inland unit (first transgressive ridge). This sand transfer is mainly produced through blowouts.

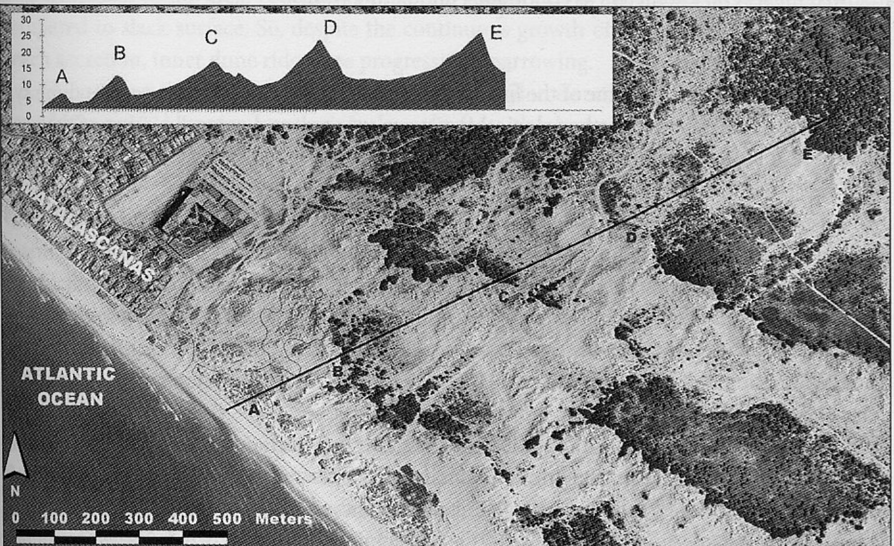

Figure 3: Doñana active dune system detail and topographic profile

The first transgressive ridge (Fig. 3, B) is a transitional unit between coastal and inner complexes and it has been frequently considered as part of the latter [4]. From our point of view, the above-mentioned sand transfer from the foredune might be assumed as a key argument for the inclusion of this unit in the coastal complex. The shape of this ridge is similar to the inner ones, which are described below.

Inner dune complex

After the first transgressive ridge, a wide slack appears that gives way to the inner complex. As shown in figure 3, the complex consists of a succession of slacks and dune ridges (C, D and E).

Slacks, locally called «*corrales*»(barnyards), are plentiful in vegetation, including different types of shrub species (*Juniperus phoenicea, Halimium halimifolium*) and tree species (*Pinus pinea*), and typical hydrophilous species when there are wet conditions (*Holoshoenus vulgaris, Erica scoparia, Calluna vulgaris...*). They show a plain topography, except for parallel undulating sand ridges (less than 1 m high) and isolated sand mounds. The first ones, called «*gusanos*» (worms), represent old positions of dune ridges fixed by vegetation. The second ones are remnant dunes that resist wind erosion due to the protection of vegetation in a particular place.

Transgressive dune ridges have a typical dune shape. The wind side has a soft, long slope from the tail to the dune crest, while the lee side level off with a short and steep slope. This dune front represents a key element that shows the advance of these mobile dunes; slip face lines can be followed for several kilometers as continuous undulating fronts.

Research findings

In this section we describe some of the first findings of our research on Doñana active dune system. Firstly, data and some methodological issues are exposed, and secondly, some of the most relevant results are commented.

Data and methodology

Basic data for the study is a set of orthophotographs from 1956, 1977 and 1999; for the 1999 orthophotograph a digital elevation model (DTM) has been built up using geomorphological criteria in the process of key element gathering (structural lines). ORTHO99 and DTM99 were used for characterization of the present state; from this set of data, dune system units were delimited and basic information was extracted, including topographic profiles (Fig. 3), slope maps, orientation maps and a series of morphometric indices for dune ridges.

The use of ORTHO56, ORTHO77 and ORTHO99 allows information extraction on the evolution of the dune system. Two main analyses were carried out: 1) the first one concerns changes occurring in the areas of dunes and slacks; by delimitation of these basic units on the three dates, areal comparison was made to see if variations in the distribution of units occurred; 2) the second one deals with dune advance rates; by photointerpretation of slip faces or dune fronts on the three dates, advance rates were calculated for the same points for the periods 1956–1977 and 1977–1999.

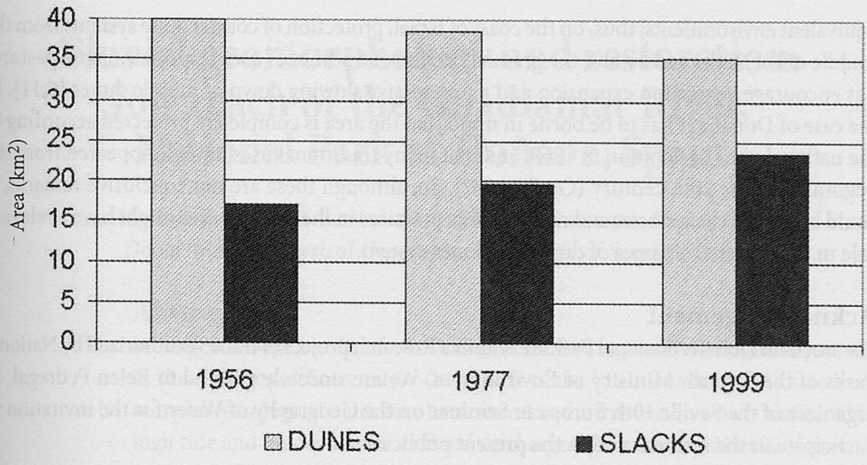

Figure 4: Superficial changes of dunes and slacks from 1956 to 1999

Results

Results of the evolution analysis are briefly presented below:

1. In respect to the areal comparison, figure 4 shows clearly the reduction of dune surfaces compared to slack surface. So, despite the continuous growth of the coastal dune complex by beach accretion, inner dune ridges are progressively narrowing.

2. Concerning the advance rates, the results show a decceleration of movement during both periods. From 1224 measurement points along slip faces, the average advance rate goes has reduced from 2.4 m/yr to 1.1 m/yr.

Conclusions

From the obtained results in the evolution analysis, some points can be brought out:

- Doñana active dune system shows an increment in vegetation cover from 1956 to 1999.
- This vegetation increment is reflected in the growing surface of slacks inward from of the inner dune ridge, which has experienced a progressive narrowing.
- Probably due to this vegetation increment, the movement of dune fronts is suffering a slowing down process.

The significance of these detected processes is not clear, nor so are the reasons for them. Results could be contradictory to data from climatology and ecology studies which show some evidence of warming in the area from the end of the 19th century [9]; this should bring more arid conditions and then a reactivation of dunes. If this warming is taking place and the system is less active, as our data shows, we may assume that there may be other reasons to explain this paradox. In this sense we have opened a line of research to study similar processes occurring in equivalent environments; thus, on the coast of Israel, protection of coastal dune systems from the middle of the 20th century and the gradual decline of traditional uses (especially cattle pasture) has encourage vegetation expansion and a progressive slowing down of mobile dunes [6,11]. In the case of Doñana it has to be borne in mind that the area is completely protected according to the national park declaration in 1969, and that many traditional uses have disappeared from the beginning of the 20th century (Ojeda, 1987). So, although these are not conclusive remarks, it could be argued that policies and management practices in the Doñana area might have a relevant role in the detected changes of the active dunes system.

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