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Sequential Pattern in the Stabilized Dunes of Doñana Biological Reserve (SW Spain)

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ABSTRACT

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There is a spatial pattern of shrub vegetation within the stabilized dunes of the Doñana Biological Reserve consisting of a six dune-ridge/dune-slack sequence. A vegetation data set was subjected to a Split Moving Window Boundary Analysis along a 10.5 km transect. This method allows the identification of boundaries along transects and thereby different vegetation zones through the calculation of metric dissimilarities between adjacent groups of samples. The obtained dissimilarity profile shows twelve peaks, five of them corresponding to transitions to heathlands (mainly composed by *Erica scoparia* L.). Those patches of heathlands show a regular pattern, appearing at a distance of *ca.* 1,500 m away one from each other, and are related to the location of the slacks of the ancient dune systems, where the water availability is higher than in the dune ridges.

The general dune field is composed of several episodes of dune development, with the younger dune forms partially transgressing inland over the older forms. Each of the dune building episodes has created dune forms with different topographic elevations and with different depths to groundwater, which is further manifested in different patterns of heathland composition.

ADDITIONAL INDEX WORDS: *Heathlands pattern, stabilized dunes, slacks, water availability, Doñana.*

INTRODUCTION

The Doñana Biological Reserve (DBR) is the core of Doñana National Park (Figure 1). It is located on the right bank of the Guadalquivir River (SW Spain) and extends over 50,720 ha, including three morphogenetic systems: estuarine, littoral, and eolian (ZAZO, 1980; SILJESTRÖM *et al.*, 1994). Within the eolian system two geomorphologic units can be distinguished: stabilized sands and moving dunes.

Several studies have focused on the importance of geomorphology and geomorphologic processes on the vegetation composition (FERNÁNDEZ ALÉS *et al.*, 1984; JOHNSTON and NAIMAN, 1987; CORNELIUS *et al.*, 1991). In littoral dune systems those processes takes great importance due to their dynamic nature (CORDAZZO and SEELIGER, 1993; COSTA *et al.*, 1996). Vegetation development in dune systems depends on the effects of wind, drought, salt, erosion, burial, and pH change, but when the dunes are fixed by the vegetation, nutrients and water availability acquire preeminence (CRAWFORD, 1989).

The early studies about the vegetation of the stabilized dunes of Doñana showed the importance of water availability for the composition of plant communities (GONZÁLEZ BERNÁLDEZ *et al.*, 1971; RAMÍREZ DÍAZ, 1973). A model for the plant species composition based on the water table depth along a topographic gradient (dune ridge-slack) was proposed (ALLIER *et al.*, 1974). In the drier extreme of this gradient, with a water table depth greater than 3 m in summer, appears a *Juniperus phoenicea* woodland with xerophytic species, such as *Cistus libanotis, Halimium commutatum,* and *Rosmarinus officinalis*. With a water table depth of 1.5 m in summer, the heathland or hygrophytic shrub appears. This is dominated by *Erica scoparia* with some isolated individuals of the cork-oak tree *Quercus suber* (Figure 2).

This topographic model is specific to a single scale of observation (hundreds of meters). However, the results obtained from such scale have been extrapolated to larger scales (ALLIER *et al.*, 1974; AGUILAR AMAT *et al.*, 1979), identifying different plant communities to different old dune episodes. However, the processes that determine the vegetation pattern at different scales may change with the scale of study (REED *et al.*, 1993). To discern variation at the mesoscale level, the association of vegetation community and topography has been analyzed to determine spatial pattern in the heathlands in the stabilized dune systems of the Doñana Biological Reserve. A statistical analytical routine has been run incorporating plant composition and several environmental factors along an extensive transect.

STUDY AREA

The eolian systems of Doñana area comprise the dune fields, extending both inland and in the littoral. They are composed of five sequences of Holocene dunes (RODRÍGUEZ-

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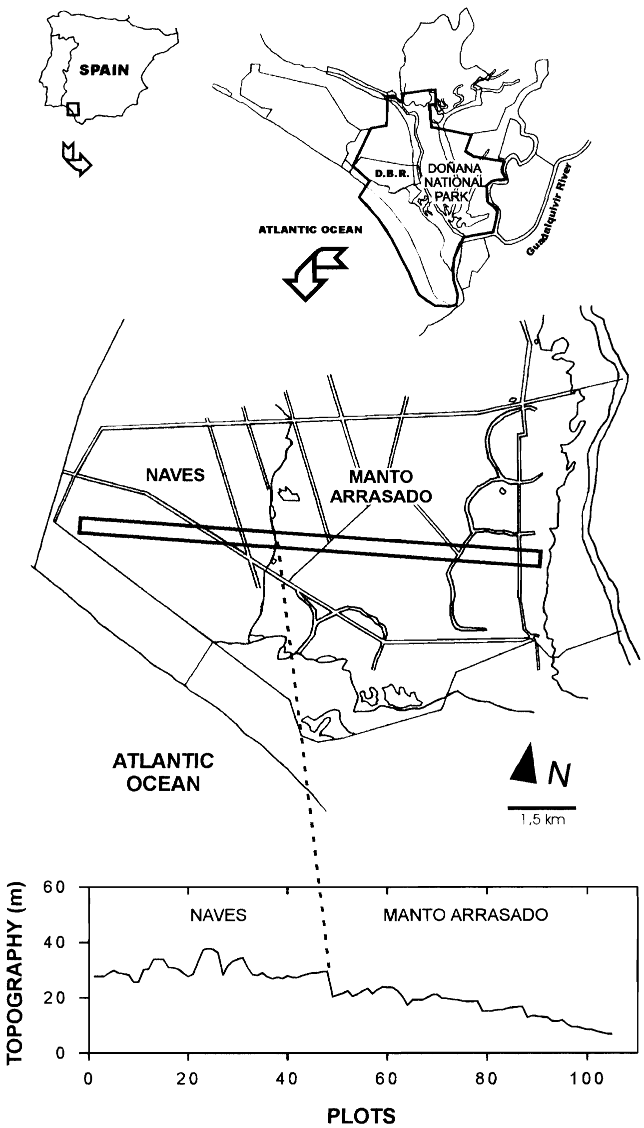

Figure 1. Doñana Biological Reserve. Location of the studied transect (10.5 km long) crossing the second (*Manto Arrasado*) and third eolian systems (*Naves*) of the stabilized dunes, and the transect topography (panel). The dashed line indicates the transition between the *Naves* and the *Manto Arrasado* dune systems.

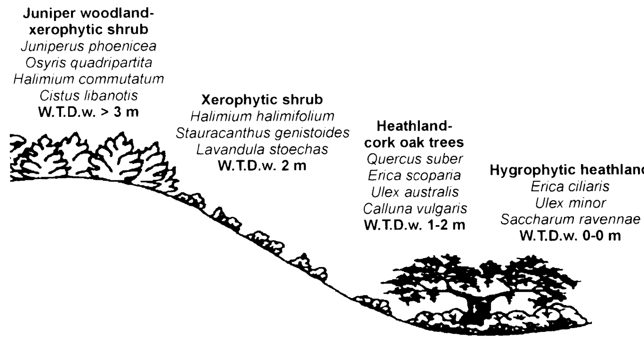

Figure 2. Model of plant composition and water availability along a topographic gradient in the stabilized dunes (modified from Allier *et al.*, 1974). Transect length: 175 m. In the higher zones, the *Juniperus phoenicea* woodland and the xerophytic shrub appear. The heathland with isolated individuals of the cork-oak trees (*Quercus suber*) appear in the lower zones. (W.T.D.w. = water table depth in winter).

RAMÍREZ *et al.*, 1996). The oldest three episodes (I, II, and III) are stable and placed inland, and were originated by west winds; the two more recent episodes (IV and V) are located at the coast, including the moving dunes, and were generated by SW winds. A transect was established which crosses the second and third eolian systems, called locally the *Manto Arrasado* and the *Naves* respectively (Figure 1).

The second eolian system has well-developed dune forms stabilized by vegetation cover. The individual dune ridges are not continuous. Periods of reactivation due to vegetation removal by anthropic management (GRANADOS CORONA *et al.*, 1988) have produced a displacement of dune forms toward the Northeast, appearing most of the slacks not welldelineated. The third eolian system is the most recent of the ancient dunes and overlaps the former, producing a marked front. This system consists of parabolic dunes fixed by vegetation, with well-delineated slacks.

Doñana has a Mediterranean type climate with some oceanic influences. Average annual rainfall is about 560 mm, with a 80% happening during the October–March period, with peaks of 90 mm for both November and December. Annual mean temperature is 16.8°C; January is the coldest month with a mean temperature of 9.9°C. Summer is dry and with high mean temperatures of 24.7° and 24.4°C for July and August, respectively. Prevailing winds come from the SW during spring and summer, drifting inland the sands of the coastal dune systems.

The soils are poorly developed due to the quarzitic nature of the substratum, and their development is the result of the interaction of hydromorphical processes and vegetation (SILJESTRÖM and CLEMENTE, 1990).

The vegetation of the Doñana stabilized sands is dominated by Mediterranean shrublands, following the destruction of the original forests (GARCÍA NOVO, 1979; GRANADOS CORONA *et al.*, 1988). Shrub composition closely follows the local topography due to different water availability. In higher and xeric zones, the shrub is composed by species from the *Cistaceae* and *Lamiaceae* families (*Cistus libanotis, Halimium commutatum, H. halimifolium, Lavandula stoechas, Rosmarinus officinalis*); in lower zones with shallower water table and occasional flooding, the shrub is dominated by the *Ericacea* family (*Erica scoparia, E. ciliaris, Calluna vulgaris*).

METHODS

The pattern of the shrub vegetation of the DBR was studied along a transect of 10.5 km, following a topographic gradient, from the *Naves* area (40 m.a.s.l.) to the grasslands close to saltmarsh border (4 m.a.s.l.) (Figure 1). Along this transect, 105 sampling points were located at 100 m intervals. At each point, a 30 m line was positioned perpendicular to the main transect and the cover of woody plants was estimated as the percent of line intercepted (GREIG-SMITH, 1983).

The Split Moving Window (SMW) Boundary Analysis (WEBSTER, 1978; WIERENGA *et al.*, 1987; LUDWIG and CORNELIUS, 1987) has been used to locate discontinuities or boundaries between soils and plant communities. This method identifies discontinuities in a multivariate data set, ordered in one dimension, by comparing sequential metric dissimilarities within the two halves of all the groups (windows) of an even-numbered size (CORNELIUS and REYNOLDS, 1991). In this case, the results refer to a window width of four sampling points using the chord distance (LEGENDRE and LEGENDRE, 1983) as the dissimilarity measure. Dissimilarity values extending above the mean plus one standard deviation were considered as a potential vegetation boundary.

The plot of species cover values versus the plots positions has been proposed as a method to detect boundaries when the algorithm failed (BRUNT and CONLEY, 1990), but here it is used only to show the change in the cover of *Erica scoparia*, the most typical species of heath communities in Doñana, along the transect.

The topography of the transect has been obtained from topographic maps scale 1:10,000 edited by the *Centro de Estudios Territoriales y Urbanos* (C.E.T.U., 1990). Water availability was represented by water table depth as a surrogate value in three heath communities along the transect (sampling points 34, 50 and 94). Three piezometers (40 mm in diameter, and 4.65, 3.00 and 2.50 m in depth respectively) were installed vertically with a hand-auger and water table records were taken monthly between March 1994 and December 1995.

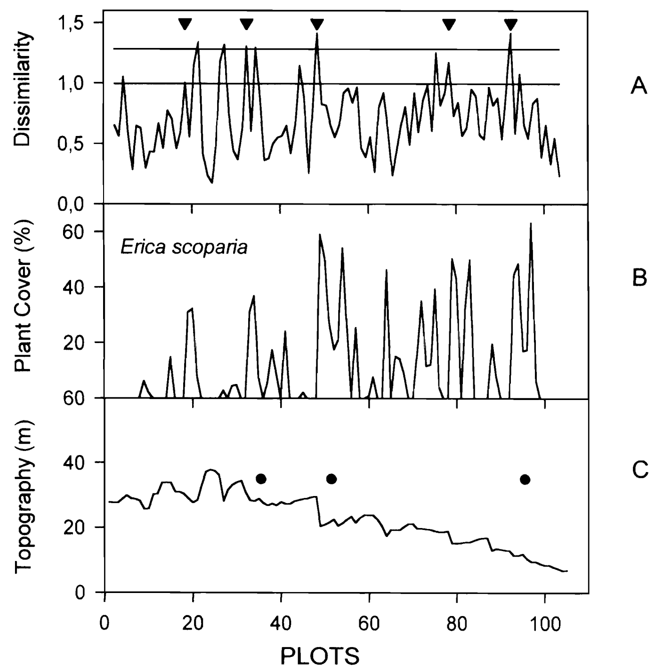

Figure 3. (A) Split Moving Window dissimilarity profile for window size four. The inverted triangles point out the transitions to heathlands. (B) Contribution of *Erica scoparia* to total plant cover per plot. (C) Transect topography (meters about sea level). The black points show the locations of the piezometers. Plot spacing is 100 m.

RESULTS

A total of 32 woody plant species were recorded along the whole transect, though only 4 species had a contribution to total cover above 7% and accounted for 55% of the plant cover. Those species were *Rosmarinus officinalis*, *Halimium halimifolium*, *Erica scoparia* and *Ulex australis*. The first two species characterize xerophytic communities, *E. scoparia* dominates the hygrophytic communities, and *U. australis* forms a transitional community (MUÑOZ REINOSO, 1997).

The dissimilarity profile for window size four (Figure 3.A) showed twelve peaks extending above the mean plus one standard deviation. Those dissimilarity peaks were compared with the contribution to total cover of the mentioned four most abundant species. Five from those twelve peaks correspond with the boundaries of hygrophytic communities as confirmed by the cover of *Erica scoparia* (Figure 3.B). The five peaks (marked with inverted triangles) appear in positions 18.5, 32.5, 48.5, 78.5 and 92.5 and are located in relatively low zones of the transect (Figure 3.C). These peaks are separated one from each other by a distance of 14–16 plots (*ca.* 1,500 m), except for the positions 48.5 and 78.5 which are 3,000 m away.

High values of *Erica scoparia* cover are related to the peaks of dissimilarity profile. However, some differences in the contribution to total cover exist between plots 1 and 48, and between plot 49 and the end of the transect. In the heathlands of the first part, the contribution of *E. scoparia* to total plant cover is always less than 40%, while in the second part is greater than 40% and may reach 60%.

The mean water table depth for the piezometers located in the sampling points 34, 50 and 94 during the sampled period were 4.49 (n = 8, s.d. = 0.122), 2.36 (n = 16, s.d. = 0.320) and 1.63 (n = 21, s.d. = 0.258) meters respectively, showing a gradient in water availability along the transect.

DISCUSSION

The results obtained agree with the small scale topographic model. According to GONZÁLEZ BERNÁLDEZ *et al.* (1971), the hygrophytic shrub community occupies the lower parts of the dune ridge-slack gradient, this is in the relative topographic lows. The heathland pattern detected is related to a sequence of dune ridges and slacks existing within the stabilized dunes (Figure 3.C) and extending across the topographic gradient from 40 to 4 m.a.s.l.. However, others dune ridge-slack sequence may exist in the stabilized dunes, out of the limits of the transect, or may have been undetected due to several reasons. The peaks produced by the heathlands appear at a distance of about 1,500 m one from each other (Figure 3.A) except for section 48.5–78.5. The lack of a peak in the position 63.5 may be due to the destruction of the ancient dune system in this area (*Manto Arrasado* means eroded sand sheet) or the transect crossing the slack through a zone relatively narrower and higher. In this zone there is not enough cover of *Erica scoparia* to be detected as a boundary by the algorithm.

Several works (ALLIER *et al.*, 1974; AGUILAR AMAT *et al.*, 1979) have distinguished three main domains of vegetation related to a topographic gradient in the stabilized sands of DBR: the xerophytic shrub in the *Naves* area, the hygrophytic shrub in the *Manto Arrasado* area, and the grasslands in the transition between the dune sands and the saltmarsh clays. This generalization, which identifies the second eolian system with the heathlands and the third system with the xerophytic shrub, interpret incorrectly the more detailed model incorporating topography (water availability) and vegetation composition. The analysis of the detailed data sets along the transect has led to the identification of a pattern in the distribution of the hygrophytic shrub (heathlands) which is not related to their absolute topographic altitude, but to the relative altitude. Therefore, the heathlands are restricted to the dune slacks within the stabilized sands.

Several episodes of dune creation and mobilization have been distinguished (VANNEY and MENANTEAU, 1979; RODRÍGUEZ RAMÍREZ *et al.*, 1996) within the stabilized sands of Doñana. The results seem to show that different dune episodes have different water availabilities, which is important to plant composition. According to RODRÍGUEZ RAMÍREZ (1996), the *Naves* eolian system is a dune system burying an older one (the *Manto Arrasado* eolian system). The average heights are 30.5 and 18.5, m.a.s.l. respectively. Different heights can explain differences in water availability between both systems and therefore differences in both total plant cover and heathland composition. For example, during the last drought (1990–95) the water table level was deeper than 4.5 m at the *Naves* and shallower than 2.5 m in the *Manto Arrasado*, which implies significant differences in water availability. Thus, the heathlands existing in the *Naves* have a total plant cover less than 80% and *Erica scoparia* (with a contribution lower than 40% of the total cover) is accompanied mainly by xerophytic shrubs. On the other hand, the plant cover of the heathlands of the *Manto Arrasado* is higher than 80% and *Erica scoparia* (with a contribution higher than 40% to the total cover) is accompanied by hygrophytic and mesic species, such as *Myrtus communis*, *Genista triacanthos*, and *Rubus ulmifolius*.

The pattern of distribution of heathlands of *Erica scoparia* shows that the geomorphology of the dune systems of Doñana, mediated through water availability, has a strong association with the vegetation at two levels: at a small scale, distinguishing dunes ridges from slacks; and at a large scale, distinguishing two different dune episodes (the *Naves* and the *Manto Arrasado*) with different topographic altitude and different heathlands composition.

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