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Coastal Vegetation Zonation and Dune Morphology in Some Mediterranean Ecosystems

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ABSTRACT

ACOSTA, A.; ERCOLE, S.; STANISCI, A.; PILLAR, V.D.P., and BLASI, C., 2007. Coastal vegetation zonation and dune morphology in some Mediterranean ecosystems. *Journal of Coastal Research,* 23(6), 1518–1524. West Palm Beach (Florida), ISSN 0749-0208.

This paper describes the vegetation zonation and its relationship with dune local morphology through the application of a randomization test on some sandy ecosystems of the Italian Mediterranean coast. We postulate that the slope and the aspect of sand dunes are essential variables in the analysis of a correct plant community position along the sea–inland vegetation gradient. This study presents an analysis of coastal vegetation zonation in some of the best preserved sites of the Lazio coast (central Italy). Analysis of variance with randomization testing was performed in order to establish whether community differences are related to slope and aspect. Results from vegetation transects showed that complete community sequence is lacking in the study area. Although some community types are very common and widespread, others are rare and only restricted to areas with well-preserved dune ridges. Regarding slope/aspect, the randomization test shows that only community types located in both extremes of the vegetation zonation revealed significant differences while no differences were found for rare or heavily disturbed communities.

ADDITIONAL INDEX WORDS: *Randomization test, sandy ecosystems, central Italy, multifactor comparisons, coastal dunes.*

INTRODUCTION

Coastal dune vegetation zonation is associated with tolerance to gradients of coherence and salinity of sandy sediments, wind, salt spray, and wave inundation (Barbour and De Jong, 1977; Ranwell, 1972). In well-preserved dune ecosystems, it is assumed that typical dune vegetation zonation is closely related to the geomorphological and sedimenthological features of dune systems (Aboudha, Musila, and Van der Hangen, 2003; Carter and Wilson, 1990). Owing to this interdependence between community types and the environment, the analyses of vegetation zonation growing in dune ecosystems can only be properly understood if it is treated as a whole.

Vegetation is an important controlling factor for dune morphology, given that it impedes sand movement (Wolfe and Nickling, 1993). Many disturbance factors affect European coastal ecosystems (Van der Maarel, 2003). More specifically, coastal erosion, agriculture, urban development, and tourist pressure should be mentioned for the Italian coast (Acosta *et al.,* 2003; Géhu and Biondi, 1994a; Géhu *et al.,* 1984; Pignatti, 1993). Coastal sand dunes have been identified as being particularly susceptible to destabilization through visitor pressure, which has increased dramatically in the last 50 years (Curr *et al.,* 2000). As far as the Italian coastal dunes are concerned, they are currently undergoing a geomorphological change that, in general, leads to the modification, and in some cases to the destruction, of geoforms that support plant communities (Valpreda and Simeoni, 2003).

A better understanding of the disturbance effects induced on dune morphology and plant communities should provide a significant contribution to the ecology and conservation of coastal ecosystems. However, very few detailed studies have investigated the possible relationships between plant coenoses and local dune morphology. Several studies on Holocenic dune vegetation along the central Italian coast have described plant communities from the tide line back to fixed dunes (Acosta *et al.,* 1998, 2000; Acosta, Blasi, and Stanisci, 2000; Filesi and Ercole, 2000; Vagge and Biondi, 1999). However, no studies concerning the relationship between vegetation zonation and local morphology have been carried out on a quantitative level.

In this paper we first describe coastal vegetation zonation (major community types and spatial patterns) in some of the best preserved sites of the Lazio coast through vegetation transects. We then pose the question whether community types of the coastal zonation are associated with the slope and the aspect of sand dunes. We postulate that these two environmental variables are essential to analyse the correct community position along the sea–inland vegetation gradient. Finally, we analyse the relationship between phytocoe-

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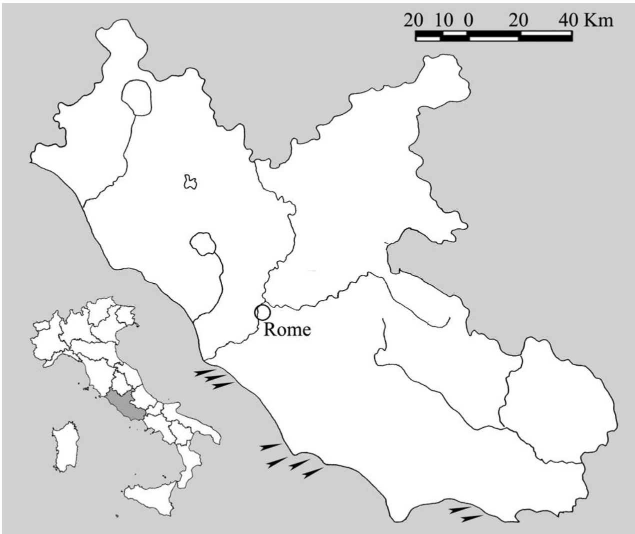

Figure 1. Study area. Location of transects is shown by an arrow.

noses and dune local morphology by applying analysis of variance through randomization testing.

MATERIALS AND METHODS

Study Area

The Lazio coast extends for more than 250 km in Central Italy along the Tyrrhenian Sea and is mainly a sedimentary coast, consisting primarily of sandy beaches. Dune coast is widespread, although some promontories and river outlets can be found. Recent Holocenic dunes generally occupy a narrow strip along the seashore, mainly in contact with ancient Pleistocenic dunes, alluvial deposits, or lacustrine deposits. Sandy beaches begin at the seashore with the stand line zone, exposed to wind and occasionally submerged during storms. There then follow some low embryo dunes and then the linear transverse dune ridges, which are usually mobile dune ridges. The final part of the gradient is represented by fixed dune ridges in the inland. Extensive dunes, with well-marked crests and depressions, are developed in only few sites of the coast, while at present several dune fronts are being eroded, both by natural processes and by human interference. Along the coast the climate is Mediterranean, varying from meso-Mediterranean dry subhumid to thermo-Mediterranean subhumid (BLASI, 1994).

Data Collection

Assuming that along the coastline plant communities are distributed in accordance with major environmental gradients, we laid out nine transects from the beach to the inland in some of the best preserved dune ecosystems of the Lazio coast (Figure 1). Transects were orthogonal to the seashore, including sites with initial plant colonization, embryo dunes, mobile dunes, and fixed dunes, up to the dune slack.

Transect length varied from 54 to 230 m depending on dune morphology and on the length of the natural vegetation strips (Figure 2), which were often heavily modified by human impact (mainly tourist pressure, urban development, agriculture, or reforestations).

Floristic variables were recorded in contiguous 1 m × 1 m quadrats (ACOSTA, BLASI, and STANISCI, 2000). The data set contains estimates of cover-abundance of plant species (116), using VAN DER MAAREL's (1979) 1–9 ordinal transform scale. Environmental data include the records of slope and aspect for each quadrat. Slope was measured in grades, and the sign indicated the aspect. As most of the Lazio dune systems are NW–SE developed (Figure 2), a positive sign indicated SW aspect (seaward side slope, looking toward the sea), while the negative sign indicated NE aspect (inland side slope).

Data Analyses

Quadrats from each transect were classified according to plant community composition by average-linkage clustering using chord distance as the dissimilarity index (PODANI, 2001). In order to identify community types, the quadrat groups derived from this classification were compared to a second classification using within-group species frequency as a measure of the relative importance.

To answer the question whether community (compositional) differences are related to slope/aspect of the community sites or not, analysis of variance with randomization testing (PILLAR and ORLOCI, 1996; PILLAR, 2004) was performed. This analysis is similar to a conventional analysis of variance, differing only in the way the probabilities are obtained, since a randomization test can supply the probabilities needed for a straightforward evaluation of the significance of group differences expressed in a sum of squares between groups statistics (Qb). In this way, two sets of variables were considered: the vegetation types (the groups being compared), derived from previous floristic clustering, and the slope/aspect, in which the sign of the slope (positive or negative) indicated the aspect. The H_0 (null hypothesis) stipulated that community types did not differ regarding slope/aspect. To avoid the effects of spatial autocorrelation and pseudo-replication, the analysis used the slope averages for each community type in each transect, and transects were taken as replicates, each with a variable number of community types. The probabilities $P(Qb^o \geq Qb)$ were generated after 1000 random permutations, which were restricted within each transect.

RESULTS AND DISCUSSION

Coastal Vegetation Zonation and Spatial Patterns

Eight distinctive community types (CT) across the dune system of the Lazio coast were identified through cluster analyses. A summary of vegetation classification is presented in Table 1. In order to analyse vegetation zonation, classification results were complemented with information regarding coastal associations (described through the phytosociological method) and the potential natural vegetation of the area published for the Lazio coast (ACOSTA *et al.*, 1998, 2000, 2003; FILESI and ERCOLE, 2000; GÉHU *et al.,* 1984; LUCCHESE and PIGNATTI, 1990; VAGGE and BIONDI, 1999).

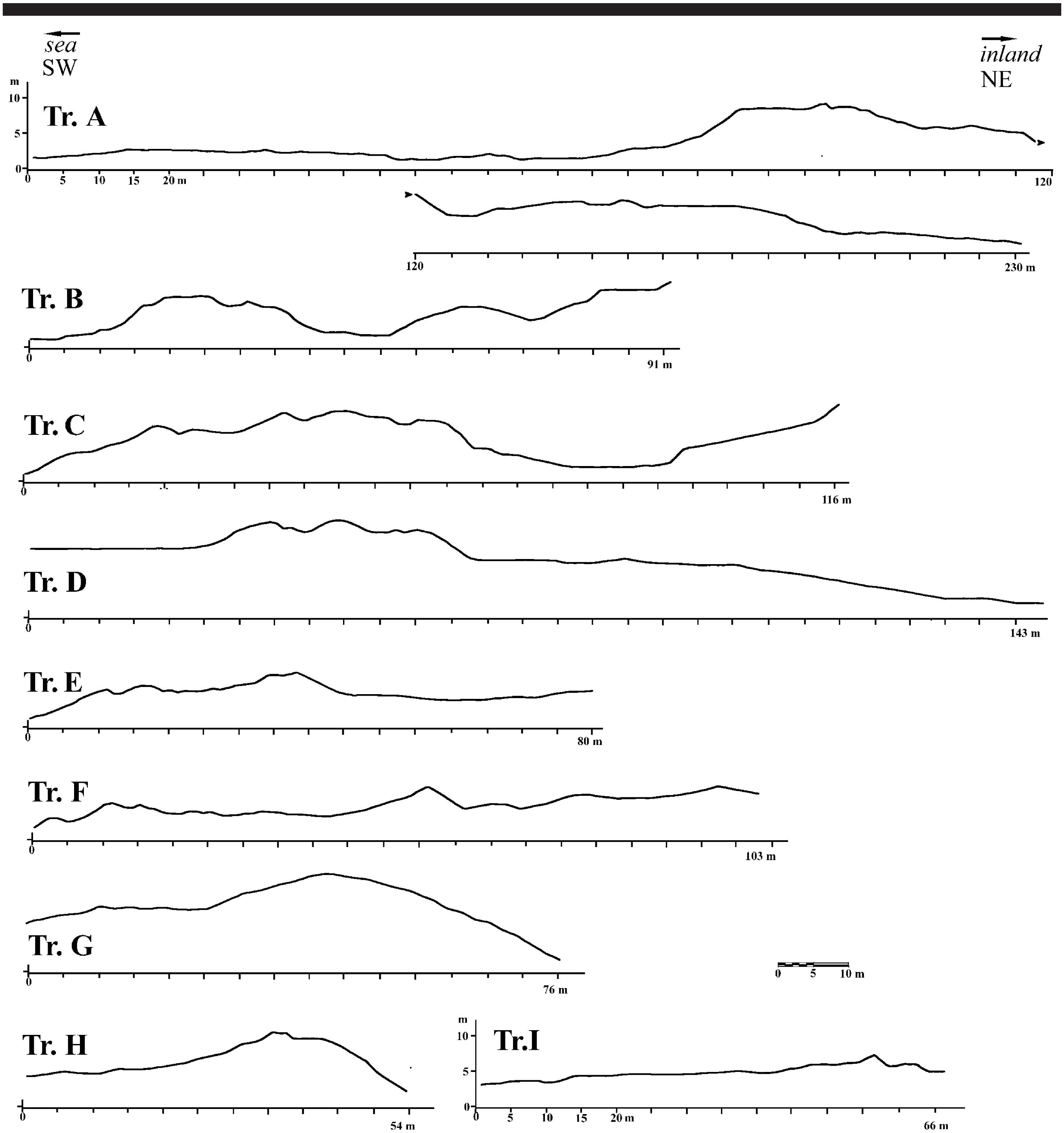

Figure 2. Profile of each transect.

Numbers indicate major community types, and the sequential order reflects the coastal vegetation zonation from annual beach communities to shrub-covered fixed dunes. Regarding herb communities, CT1 indicates annual coenoses growing on beaches (*Cakile maritima* and *Salsola kali* community), CT2 indicates embryo dune coenoses with *Elytrigia juncea* and *Sporobolus pungens* (although variants with *Otanthus maritimus* may also be found), and CT3 indicates mobile dune coenoses (*Ammophila arenaria* subsp. *australis* and *Calystegia soldanella* community). Between mobile and fixed dune ridges fragments of the *Crucianella maritima* community (CT4) can be found, but they are often substituted by replace-

Table 1. *Structure, environmental features and most representative species of each community type. Taxa nomenclature follows Anzalone (1994, 1996) and Anzalone* et al. *(1997). Last column reports information about related phytosociological associations. Syntaxa nomenclature follows the syntaxonomical scheme proposed by Stanisci* et al. *(2004) according to the Phytosociological Code (Weber, Moravec, and Theurillat, 2000).*

Community Type	Community Structure and Environment	Representative Species	Syntaxonomical Reference
CT1: *Cakile maritima* and *Salsola kali* community	Annual, nitrophilous community of the strandline zone of the beach, exposed to wind action and occasionally to breaking waves	*C. maritima, Polygonum maritimum, S. kali, Chamaesyce peplis*	*S. kali–Cakiletum aegyptiae* Costa et Manzanet 1981
CT2:*Elytrigea juncea* and *Sporobolus virginicus* community	Pioneer, perennial, and halophilous community of the low embryo dunes, dominated by dune-forming plants such as *E. juncea*	*E. juncea, S. virginicus, Echinophora spinosa, Medicago marina, Otanthus maritimus*	*Echinophoro spinosae–Elytrigietum junceae* Géhu 1988 corr. Géhu 1996
CT3: *Ammophila arenaria* subsp. *australis* and *Calystegia soldanella* community	Perennial herb community stablilized mobile dunes dominated by a rhizomatous species, *A. arenaria* subsp. *australis*	*A. arenaria* subsp. *australis, Echinophora spinosa, C. soldanella, Eryngium maritimum, Anthemis maritima*	*E. spinosae–Ammophiletum australis* (Br.-Bl. 1921) Géhu, Rivas-Martínez et Tüxen in Géhu 1975
CT4: *Crucianella maritima* and *Cyperus capitatus* community	Perennial community of the inland side of mobile dunes, dominated by chamaephytic and herbaceous species	*C. maritima, Pycnocomon rutifolium, Lotus cytisoides, Euphorbia terracina, Silene canescens, C. capitatus*	*Pycnocomo rutifolii–Crucianelletum maritimae* Géhu, Biondi, Géhu-Franck et Taffetani 1987
CT5: *Juniperus oxycedrus* subsp. *macrocarpa* and *Juniperus phoenicea* community	Pioneer juniper scrub of the seaward side of the semiconsolidated dunes and fixed dunes, exposed to wind action	*J. oxycedrus* subsp. *macrocarpa, J. phoenicea, Daucus gingidium, Lonicera implexa, Prasium majus, Dorycnium hirsutum*	*Asparago acutifolii–Juniperetum macrocarpae* (R. et R. Molinier 1955) Bolòs 1962
CT6: *Phillyrea angustifolia* and *Pistacia lentiscus* community	Evergreen Mediterranean macchia of the fixed dunes, dominated by *P. angustifolia, P. lentiscus,* and *Q. ilex* sheltered from winds	*Rhamnus alaternus, P. angustifolia, P. lentiscus, Arbutus unedo, Rubia peregrina, Asparagus acutifolius, Smilax aspera, Clematis flammula*	*Pistacio lentisci–Rhamnetum alaterni* Bolòs 1970
CT7: *Schoenus nigricans* and *Erianthus ravennae* community	Herbaceous wet community of the dune slack; in summer, the water table remained near the surface	*S. nigricans, E. ravennae, Juncus acutus, Lysimachia nummularia*	*Eriantho–Schoenetum nigricantis* (Pignatti 1953) Géhu 1984
CT8: *Quercus ilex* community	Evergreen wood of the dune slack transition, dominated by *Q. ilex*	*Q. ilex, Viburnum tinus, Phillyrea latifolia, Myrtus communis, Ruscus aculeatus, Hedera helix, Cyclamen repandum*	*Viburno tini–Quercetum ilicis* Br.-Bl. (1915) 1936

ment coenoses dominated by *Pycnocomon rutifolium* or *Ononis variegata*.

Fixed dunes are essentially shrub covered. The first type of woody coastal vegetation is represented by juniper scrub (*Juniperus oxycedrus* subsp. *macrocarpa* and *Juniperus phoenicea* community, CT5), which frequently creates a mosaic pattern when alternating with annual-grass patches. The inland facing side is progressively dominated by species that are typical of the Mediterranean macchia (*Phillyrea angustifolia* and *Pistacia lentiscus* community, CT6). It is also possible to find interdunal depressions that are colonised by wet grass coenoses (*Schoenus nigricans* and *Erianthus ravennae* community, CT7). This coastal zonation ends in the dune slack transition with *Quercus ilex* woods (CT8) and an increasing cover of caducifolious trees, which occasionally become a mixed oak woodland in the inland side of the back dune.

Spatial patterns of the eight communities along the transects are shown in Figure 3. Assuming an ideal linear distribution pattern of community types following the sea–inland vegetation gradient, we would expect communities to be arranged in sequence from CT1 to CT8 in sites where disturbance is not significant.

None of the nine transects analysed in this study contain the entire community zonation, but usually they include at least four or five different community types. In most transects community types are ordered in sequence, from lower to higher numbers, but in some cases regressions could also be found (*i.e.,* in transects B, C, E, and F), when the sequential community number is not maintained and developmental stages are in a reverse direction. These regressions were interpreted to be due to disturbance effects.

Transect A is the largest and is located on the southern side of the Tiber river with wide complex dune ecosystems. Back dunes here are extensive with interdunal depressions colonised by a wet grass community (CT7). In other areas of the Lazio coast, dune systems are narrower (*i.e.,* transect H) although with at least four different community types.

CT2 and CT3 are widespread, and they were found in most transects. However, variants with high cover values of *Anthemis maritima* and *Ononis variegata* in degraded mobile dunes are also present. The evergreen coastal macchia (CT6) is also widespread and particularly well structured in transect A. On the other hand, the pioneer juniper scrub (CT5) is less extensive and often disturbed.

The *Crucianella* community (CT4) is one of the rarest and most vulnerable coastal plant associations of the Lazio Region (Acosta *et al.,* 2003) and was frequently substituted in the study area by *Elytrigia juncea* and occasionally by *Pycnocomon rutifolium.* Finally *Quercus ilex* woodlands (CT8) are also rare because extensive forested areas have been trans-

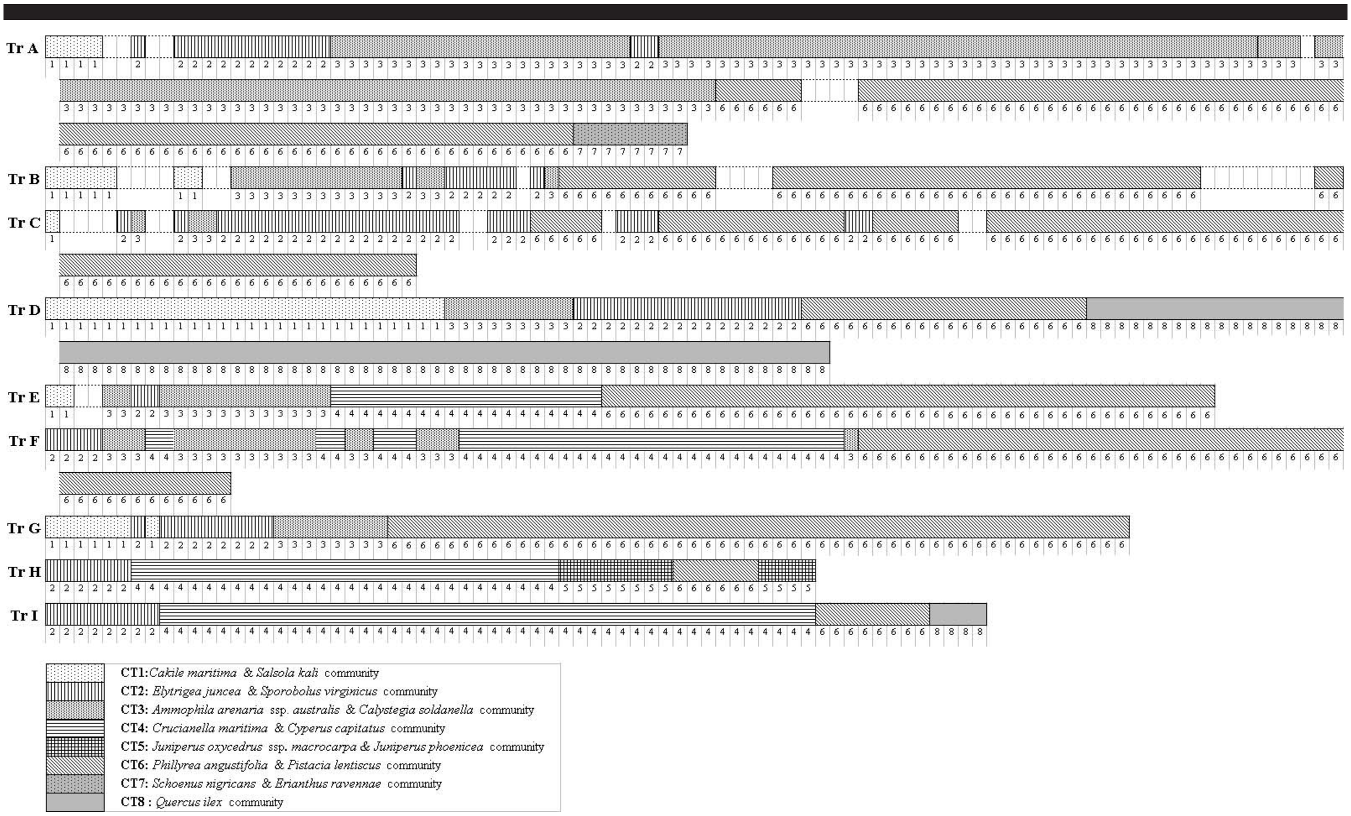

Figure 3. Spatial distribution of community types along the nine transects. Numbers indicate community types (CT).

formed into *Pinus* reforestations, arable land, or urban areas (Acosta *et al.,* 2007).

Plant Communities and Topographic Position—Dune Morphology

Randomization testing indicated significant differences in slope/aspect in the community types ($p = 0.041$). Pairwise contrasts demonstrated that slope/aspect differed significantly ($p < 0.05$) among CT1/CT6 ($p = 0.026$), CT2/CT6 ($p = 0.016$), CT3/CT6 ($p = 0.021$), CT1/CT8 ($p = 0.016$), CT2/CT8 ($p = 0.041$), and CT3/CT8 ($p = 0.023$). Thus, only community types belonging to both extremes of the coastal zonation differed regarding slope/aspect, *i.e.,* herb communities (CT1, CT2, and CT3) versus evergreen macchia and woodlands (CT6 and CT8, respectively). Both ends of vegetation zonation showed community types with contrasting structures, with floristic composition, and with plants with different ecological strategies. CT1, CT2, and CT3 typically grow on the beach and on foredunes facing the sea. Plant species are tolerant to seawater flooding, salt spray, or sand burial. Some species help consolidate and fix the mobile sands and build dune ridges. Average values of slope/aspect calculated for these communities (Figure 4) tend to be lower more inland and show positive signs (seaward slope). On the other hand, the evergreen coastal macchia (CT6) and woodlands (CT8) grow in the inland facing side of the fixed dunes, sheltered from winds and salt spray. In fact, average values of slope/aspect calculated for these communities had similar but negative records (Figure 4).

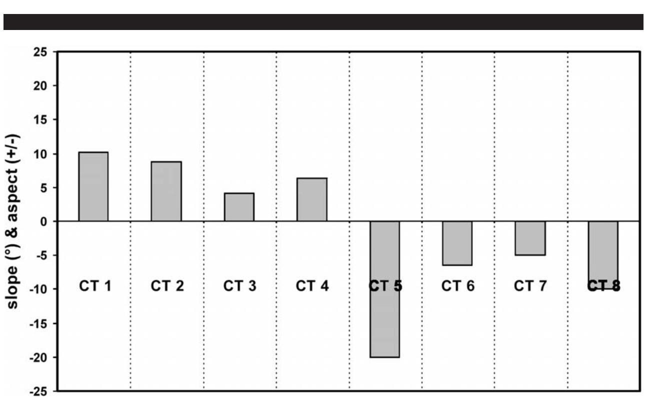

Figure 4. Slope average for each community type in the nine transects.

The other contrasts were not significant (at $\alpha < 0.05$). It should be noted that differences were not significant for the most disturbed and fragmented community types of the study area, such as the chamaephytic vegetation dominated by *Crucianella maritima* (CT4). Owing to human pressure, particularly trampling, this plant community tends to be substituted by replacement communities, such as those dominated by *Ononis variegata* or by *Pycnocomum rutifolium,* both characterized by wider ecological distribution (GÉHU and BIONDI, 1994b). Owing to the small sample size, no significant differences were found in comparisons with the juniper scrub (CT5) and wet dune slack community (CT7), both rare and highly modified by human disturbance.

CONCLUSIONS

This paper describes the vegetation zonation and its relation to local dune morphology through the application of a randomization test on some sandy ecosystems of the Mediterranean coast. Vegetation zonation encompass dunes of variable morphology and with different community types. Some communities are very common and widespread, while others are rare and restricted only to areas with well-preserved dune ridges. Although the study area includes some of the best preserved dune ecosystems of central Italy, none of the transects revealed a complete vegetation sequence.

It was supposed that coastal communities are closely related to local dune morphology. However, regarding slope and aspect, only community types located in both extremes of the vegetation zonation with contrasting structures, with floristic composition, and with plant species with different morphological and physiological traits revealed significant differences. On the other hand, no significant differences were found for rare or heavily disturbed communities. In this study, it was found that alteration of dune morphology is probably highly related to changes in coastal vegetation zonation, the fragmentation of the most widespread community types, the substitution by replacement communities, and, in the most severe cases, the disappearance of the most vulnerable plant communities.

Finally, it should be stressed that natural vegetation is essential for the conservation of dune ridges in coastal ecosystems, since dune morphology is highly dependent on the presence of particular plant communities. The results derived from this study provide some basic information for conservation management and could represent a first step in planning issues regarding coastal ecosystems.

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□ RIASSUNTO □

La ricerca riguarda alcuni ecosistemi sabbiosi delle coste del Mediterraneo per i quali è stata analizzata la zonazione vegetazionale in relazione alla morfologia delle dune, attraverso l'applicazione di un test di randomizzazione. Si postula che la pendenza e l'esposizione rappresentino le variabili essenziali per analizzare la posizione delle comunità vegetali lungo il gradiente ecologico che si sviluppa, in questi ecosistemi, dal mare verso l'entroterra. La zonazione vegetazionale viene analizzata mediante transetti eseguiti nei siti meglio conservati della costa del Lazio (Italia centrale). Su tali dati viene eseguita l'analisi della varianza, mediante test di randomizzazione, allo scopo di verificare la relazione tra le comunità e le pendenze/esposizioni per esse misurate. I risultati dei transetti di vegetazione mostrano che nell'area di studio non è mai rappresentata la sequenza fitocenotica ideale completa. Alcune comunità sono piuttosto comuni e diffuse, mentre altre sono rare e presenti solo nei siti meglio conservati. I risultati del test di randomizzazione mostrano differenze significative per le comunità localizzate agli estremi della zonazione vegetazionale, mentre le differenze non risultano significative per le comunità più rare e maggiormente disturbate.