

Assessing conservation status on coastal dunes: A multiscale approach

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ABSTRACT

Coastal dune systems are particularly fragile and threatened environments, which, however, provide fundamental ecosystem services to nearby urban areas acting for example as protective buffers against erosion. Correctly assessing their conservation status is a priority in order to manage them adequately and to plan urban development in coastal regions. In this paper we propose a practical multiscale method for the assessment of the conservation status of sandy coastal environment. The proposed method is articulated in two stages, one focusing on the landscape and the other on the plant community level. In the first phase mosaic structure and composition of the coastal landscape are analyzed using a series of indicators: natural coastal surface, richness of land cover typologies, landscape diversity and evenness, number and average size of habitat patches, and mean shape index. At a detailed scale, floristic, vegetational and structural aspects of the dune plant communities are analyzed along the main environmental gradient by measuring: spatial connectivity and richness of boundaries, species diversity, evenness and chorological index. In this work we apply and test the method in an experimental area on the Tyrrhenian coast of Italy (Latium region), comparing the conservation status of two study sites.

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1. Introduction

Sandy seashores are biologically diverse transitional systems ('ecotones') between land and water, which make up 20% of the world's coastlines (Walker et al., 2003; Van der Maarel, 2003). By occupying zones of transition between terrestrial and marine ecosystems, coastal dunes represent particularly interesting environments both from an ecological and landscape perspective.

Coastal dune systems are also particularly fragile environments and several potential dangers threaten them. Human activities in littoral areas are widespread and have been intensifying in the course of the 20th century, since historically urban zones have developed in coastal areas in most parts of the world (Cori, 1999). Factors causing disturbance are of various nature. Cattle grazing, farming, reforestation and urbanization have eliminated many stretches of internal vegetation zonation, while coast bound tourism and especially coastal erosion, endanger beach and embryo-dune communities (Brown and McLachlan, 2002; Géhu and Biondi, 1994; O'Shea and Kirkpatrick, 2000; Taveira Pinto, 2004).

Coastal regions in the past have often been inappropriately managed largely due to a lack of adequate planning. Fortunately, the

concept of coastal zone management has nowadays become generally accepted (Taveira Pinto, 2004). In fact, just as coastal dunes can be strongly affected by urban settlements, it is now recognized that healthy vegetated sandy ecosystems can provide fundamental ecosystem services to nearby urban areas, effectively acting in long term planning efforts as the best possible protective buffers against infrastructure damages due to coastal erosion (Jolicoeur and O'Carroll, 2007). However, small ecosystems often disappear in large scale studies, such as many coastal zone management plans and regional plans in general. It is therefore essential to carefully plan urban development and to monitor these environments at a more local level in order to protect and manage their entire biodiversity adequately, thus maintaining the ecosystem services they provide (Davies et al., 1995; Provoost et al., 2004).

The evaluation of the state of ecosystems at a given time and place is at the basis of any planning process for the management of natural resources. Even though the definition of conservation status has been greatly debated, it is generally recognized that its assessment can be based on the measure of biodiversity or of features used as surrogates thereof (Cabeza and Moilanen, 2001; Margules and Pressey, 2000; Yoccoz et al., 2001). In particular, vegetation, because of its specific nature, is considered a good indicator of overall biodiversity and specifically of ecosystem integrity of coastal dune environments (Araújo et al., 2002; Géhu and Biondi, 1994; Géhu and Géhu, 1980; Lopez and Fennessy, 2002).

Many methods for conservation status assessment based on vegetation analysis have been proposed both in local and regional

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contexts, but these have generally focused either on the community level or on the landscape level, independently of the spatial extent considered. Community level studies, in which species are the most common analysis unit, have used indices, such as species richness, diversity and abundance to identify conservation priorities (Balaguru et al., 2006; Greco and Petriccione, 1991; Tchouto et al., 2006), which in some cases have been associated to bioindicator species of quality (Godefroid and Koedam, 2003). Often synthetic indicators obtained with the help of some form of expert ranking have been proposed, and used to spatialize quality information over large regions (Lopez and Fennessy, 2002; Poldini and Pertot, 1989).

On the other hand, on the landscape level, where units are either patches or ecosystems, several compositional and structural metrics as well as rarity of ecosystems and cover typologies have been linked to disturbance levels and used to identify conservation and restoration priorities (Botequilha Leitão and Ahern, 2002; Langanke et al., 2007; Lausch and Herzog, 2002; Palik et al., 2000).

In coastal environments in particular, however, fewer methods have been proposed for quality and disturbance assessment of the vegetation based on biodiversity. On the plant community level, single species as bioindicators (Géhu and Biondi, 1994; Hinchliffe and Conran, 2005) or parameters, such as species richness, diversity and cover (Grunewald and Schubert, 2007; Isermann and Krisch, 1995; Vogt Andersen, 1995) have been used to evaluate dune naturalness and effects of human disturbance on coastal vegetation. The spatial pattern of dune communities has also been linked to quality and disturbance (Acosta et al., 2000, 2003). On the landscape level such indicators as patch length and boundaries, vegetation cover and other classical landscape compositional and structural indices have been used to assess the condition of dune systems and the amount of human pressure (Carranza et al., 2007; Curr et al., 2000).

However, it has long been recognized that biodiversity has a hierarchical nature, encompassing a wide spectrum of diversity components at different scales, from the species to the ecosystem and landscape level, including their processes and interactions (Primack, 2000; Whittaker, 1972; UNEP, 1992). The multiscale nature of disturbances, which tend to be spatially and temporally heterogeneous, has been increasingly accepted as well, especially because landscapes respond differentially to the spread of disturbances (Beever et al., 2006; Van der Maarel, 1993). Focusing on any single biodiversity component alone is insufficient to protect other components or correctly estimate overall conservation state (Bonn and Gaston, 2005). Higher levels in the biological hierarchy, such as habitat types and landscapes, can better integrate some of the threats to biodiversity, such as fragmentation and habitat loss, and the ecological processes that contribute to the maintenance of ecosystem function (Faith and Walker, 1996; Wessels et al., 1999). On the other hand such high organizational levels lose biological precision in the assessment of diversity and therefore it is important that lower level diversity is analyzed to some degree. A complete analysis of the conservation status of the vegetation of natural areas should not therefore be limited to a single aspect but should take into account multiple levels of biodiversity both from a compositional and structural point of view. This can be achieved in an effective and efficient way by assessing a series of selected indicators, representing the entire complexity of the vegetation system. But even though the need for such approaches is recognized (Provoost et al., 2004), very few studies have attempted a real multiscale approach in the assessment of quality for conservation and monitoring purposes (Hermy and Cornelis, 2000; Roy and Tomar, 2000), particularly in coastal environments (Espejel et al., 2004).

The purpose of this paper is therefore to propose a scientifically sound and practical method for the assessment of conservation status in sandy coastal environments, based on the multiscale concept of biodiversity, focusing on the vegetation aspect.

2. Methods

In relation with a specialized flora, plant communities of coastal dunes in various parts of the world, though single species generally vary, have much in common from the point of view of adaptations, strategies, structure, space occupation and therefore successional change and zonation (Doing, 1981; Frederiksen et al., 2006; García-Novo et al., 2004). Moreover, physical limiting factors (such as unstable substrate, wind velocity, salt spray, organic matter content, sand blast and burial, episodic overwashes, etc.) are organized along a steep environmental gradient that determines a strong sea-inland zonation of the vegetation (Frederiksen et al., 2006; Houle, 1997; Maun, 1998; Packham and Willis, 1997; Sykes and Wilson, 1988; Wilson and Sykes, 1999). The environmental requirements of coastal plant communities are very specific, so that their position in the sequence tends to be fixed (Sykes and Wilson, 1991).

The proposed method builds on these fundamental characteristics of the coastal environment. Two scales are considered: the landscape level (structure and composition) and the plant community level. At each scale the data are gathered and expressed through a series of indicators. The general method as presented here can be applied to most coastal dune environments worldwide, but sampling units and level of detail are dependent on specific regional conditions. As an example, we therefore apply and test the method in a representative area on the Tyrrhenian coast of Italy (Lazio region).

2.1. Landscape scale

At the landscape level it is first of all necessary to identify the major land cover types for landscape scale analyses (Thackrah et al., 2004). To these purposes a detailed land cover (LC) map of the coastal areas to be examined is necessary. Acosta et al. (2005) found a good correspondence between CORINE land cover classes and vegetation types on coastal dune ecosystems, therefore we propose to use this classification for habitat diversity study. It is essential that the mapping of habitats in the coastal dune environment be carried out at a detailed scale, but a preliminary study of the specific configuration of the vegetation based on available literature is necessary in order to select the appropriate level of detail (scale of the map). On these grounds the following indicators are calculated to evaluate coastal landscape.

2.1.1. Landscape composition

First of all, the coastal dune land cover mosaic is analyzed on the level of landscape composition. The abundance of each CORINE category is calculated for the coasts to be evaluated, as well as the total richness of land cover categories. In particular these parameters are highlighted for natural areas and for natural coastal land cover categories. Attention is paid to urban surface abundance as well, as an indicator of human influence and of vulnerability to human disturbance of the natural landscape (Margules and Pressey, 2000; McKinney, 2002). Finally, richness and abundance parameters of each single category can be utilized to express in a synthetic way the diversity and evenness of the entire analyzed landscape.

2.1.2. Analysis of landscape structure

In order to analyze the spatial pattern of the coastal vegetation patches we propose to calculate the following classical landscape pattern statistics: the number of patches (NUP) for all land cover categories, for natural areas and for coastal areas, their mean patch size in square meters (MPS) and their mean shape index (MSI). The way in which the surface of each category is arranged in number of patches (and therefore average patch size for each category) is related to habitat fragmentation or to heterogeneity of the spatial pattern. The shape index is a shape complexity indicator that

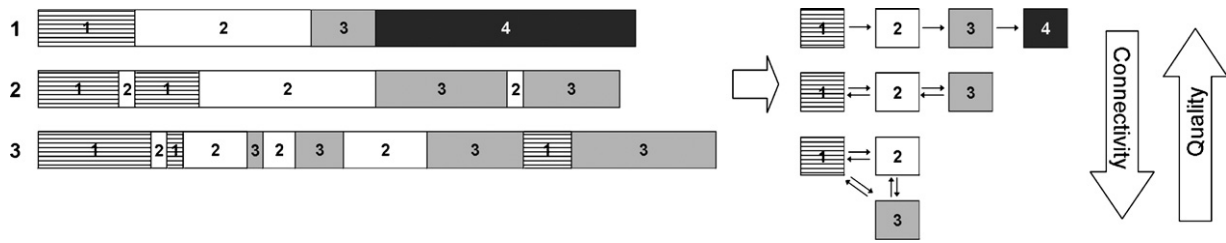


Fig. 1. Example of spatial pattern and model of connectivity in a coastal area in which hypothetically 4 total communities were found (shown here with different numbers). Case 1 is associated with the connectivity value of best structural quality while the following cases show a decrease in quality because both sea-inland and inland-sea connectivity increase. Black arrows indicate sea-inland and inland-sea directions.

usually assumes values greater than one. It equals one only for perfect isodiametric patches. In our case the MSI is calculated as a sum of each patch's perimeter divided by the square root of patch area (hectares) for each class and adjusted for circular standard (polygons), divided by the number of patches (McGarigal and Marks, 1995). For coastal environments we hypothesize that natural formations would assume stretched out forms parallel to the coastline, therefore with high MSI values, while less natural typologies or fragmented patches would assume more isodiametric or round forms.

2.2. Community scale

At the community level, as a first step it is necessary to identify the major vegetational groups of the study area. Assuming ideally a linear distribution of communities along the coastline, we propose to utilize belt transects to sample the whole spectrum of the vegetation and the zonation. These have to be laid out at regular intervals in order to cover the entire study area, perpendicular to the seashore, passing through the embryo dunes (where present)

and the main dune (seaward slope and inland slope). The percent cover of each species is estimated within each quadrat of the transect. Even in this case a preliminary study is necessary in order to select plot size under different regional configurations of the vegetation. Transect length may vary depending on dune morphology and width. Quadrats from each transect can then be organized in plots by species matrices and classified through appropriate multivariate techniques to obtain plot groups that correspond to major community types (see case study below for an example of analysis suitable for Mediterranean coastal vegetation). The floristic and vegetational data obtained in this way are then used to calculate the following indicators.

2.2.1. Analysis of the spatial pattern of the communities along the sea-inland gradient

The presence or absence of a given plant community alone yields no information about its spatial features, such as the number of patches, boundary types and links among patches. Therefore, once different community types have been identified for example by cluster analysis, we propose to evaluate the distribution pattern

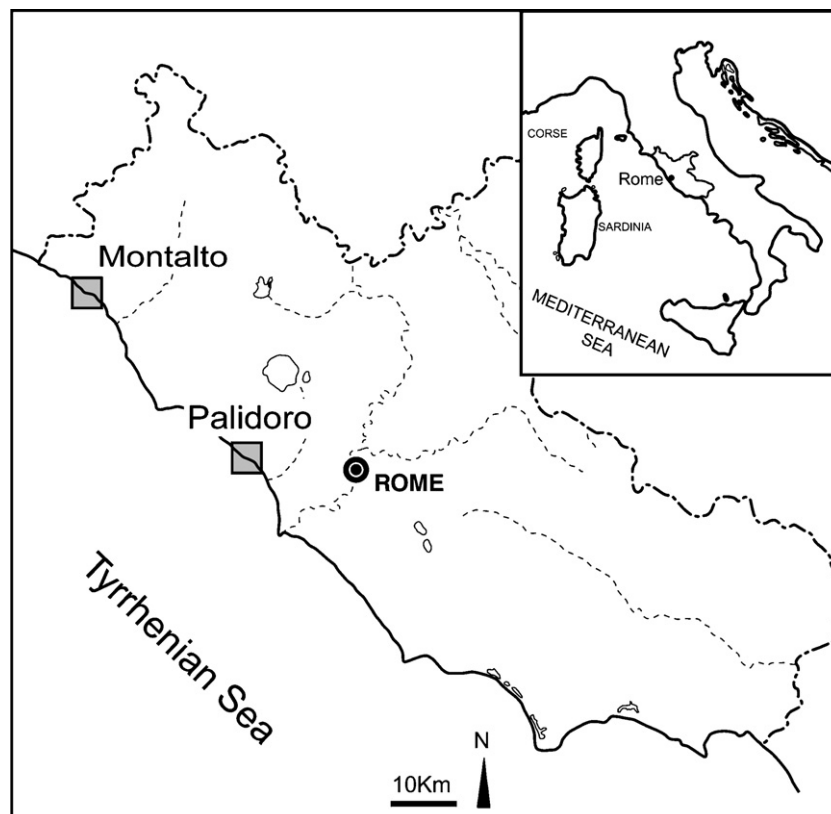


Fig. 2. Study area. The coast of Lazio is included between 42°22'32"N/11°26'46"E in the North and 41°13'20"N/13°45'43"E in the South. The grey windows indicate the location of the analyzed sites: Montalto and Palidoro.

Table 1
CORINE land cover legend expanded to the fourth level of detail.

Level 1	Level 2	Level 3	Level 4
(1) Artificial surfaces	(1.1) Urban fabric (1.2) Industrial, commercial and transport units (1.4) Artificial non-agricultural	(1.1.2) Discontinuous urban fabric (1.2.2) Road and rail networks and associated land (1.4.2) Sport and leisure facilities	
(2) Agricultural areas	(2.1) Arable land (2.3) Pastures (3.1) Forests	(2.1.1) Non-irrigated arable land (2.3.1) Pastures (3.1.1) Broad-leaved forest	(3.1.1.1) Elm formations (3.1.1.2) Igrophilous forests (3.1.1.3) <i>Eucaliptus</i> plantations (3.1.1.4) <i>Tamarix</i> plantations (3.1.1.5) Mixed woodlands (3.1.2.1) <i>Pinus</i> sp. forests
(3) Forests and semi-natural areas	(3.2) Shrub and/or herbaceous vegetation	(3.1.2) Coniferous forest (3.2.1) Natural grassland (3.2.3) Sclerophyllous vegetation	(3.2.1.1) Secondary grasslands (3.2.3.1) Coastal Juniper Macchia (3.2.3.2) Mediterranean Macchia
	(3.3) Open spaces with little or no vegetation	(3.2.4) Transitional woodland shrub (3.3.1) Beaches, dunes, and sand plains	(3.3.1.1) Bare sand with herbaceous annual beach vegetation with <i>Cakile maritima</i> and <i>Salsola kali</i> (3.3.1.2) Open psammophilous herbaceous vegetation of embryo dunes with <i>Elymus farctus</i> (3.3.1.3) Closed psammophilous herbaceous vegetation of mobile dunes with <i>Ammophila arenaria</i> (3.3.1.4) Camephitic vegetation of semistable dunes with <i>Crucianella maritima</i> (3.3.1.5) Interdune annual grasslands (3.3.1.8) Closed psammophilous herbaceous vegetation with <i>Plantago coronopus</i> and <i>Silene canescens</i> (3.3.1.9) Open psammophilous herbaceous vegetation of embryo dunes with <i>Anthemis maritima</i> and <i>Elymus farctus</i>
(4) Wetlands	(4.1) Inland wetlands	(3.3.3) Sparsely vegetated areas (4.1.1) Inland marshes	(4.1.1.1) River cane vegetation
(5) Water bodies	(5.1) Inland waters	(5.1.1) Water courses (5.1.2) Water bodies	

This table includes only the categories observed in the study area. Natural Coastal vegetation typologies are in bold.

of the communities along the sea-inland gradient according to the proposals of Acosta et al. (2000, 2003) based on the use of two structural indexes: richness of boundaries, n (Rescia et al., 1997) and gamma connectivity, γ (Forman and Godron, 1986). This method involves the projection along transects of the plant communities found (Fig. 1). Each transect is therefore characterized by a specific sequence and dimension of plant community patches. The richness of boundaries, n is obtained by counting the number of different types of boundaries along each transect. The gamma connectivity index considers additionally a patch type's position in relation to other patch types. This index, inspired by graph theory, defines the relation between patches or nodes (V) and the links among them (L). It equals the number of links present along the transect over the number of links in a planar graph with the same number of nodes: $\gamma = L/3(V-2)$, where $3(V-2)$ is the maximum possible number of links considering the number of nodes present. It ranges from 0 (no links at all) to 1 (every node is linked to every possible node). Since disturbance may cause changes in the natural sea-inland community sequence and communities typical of the seaward slope may be found on the inland slope, connectivity is calculated in the inland-sea direction in addition to the sea-inland direction. While the latter reflects the natural community sequence, the former may indicate backward steps in zonation due to disturbance.

On the landscape level when dealing with spatial patterns with numerous patches, connectivity generally tends to be positively correlated with better environmental quality (Forman, 1996). This

is usually not the case, however, in coastal dune vegetation with linear spatial community distribution. In particular, the best possible spatial structure in these environments is one in which all communities of the area are present and arranged in the correct order of the natural sequence. This situation is therefore associated with the sea-inland connectivity value of best structural quality (Fig. 1). When community types are in contact with additional communities other than the ones they are associated with in the natural sequence we observe loops in the boundary structure, giving rise to higher sea-inland connectivity values. Moreover, in these environments where we generally deal with a limited total number of communities, sea-inland connectivity values are greater for structures with fewer community types. Therefore, in coastal dune environments, high connectivity values tend to be related to loops (high sea-inland connectivity) and many backward jumps in the sequence (high inland-sea connectivity), which are indicators of heterogeneity, of high community fragmentation and often of disturbance (Fig. 1; Acosta et al., 2000).

2.2.2. Analysis of the diversity of the vegetation

Finally we suggest complementing the spatial pattern analysis by calculating a series of indicators of species diversity and vegetation quality. Firstly, we propose to estimate the diversity of the vegetation by calculating the Shannon diversity index (H) and evenness (J), which are among the most popular diversity indices in vegetation analysis (Gurevitch et al., 2002; Kent and Coker, 1996;

Magurran, 2004; Ricotta, 2007). The relation of these indices to environmental quality has been greatly discussed, but a survey of the literature shows that they are amongst the most common indices used in methods to evaluate conservation status (Kent and Coker, 1996).

Diversity indices, though, do not give any information on the quality of the species that make up the communities. To give an indication of the level of “anthropogenization” of the local flora several indices may be calculated. Since chorological information (related to geographical distribution) is generally widely available in European floristic manuals, we propose to calculate a chorological index, which relates the number of species of a chorological type that is characteristic for the examined area to the number of species of a broad distribution type or of exotic origin, which are generally introduced by humans (Cornelini et al., 1989; Greco and Petriccione, 1991). The choice of the chorological types to use in the index is strictly dependent on the studied region.

Finally, direct comparison of different coastal areas, through statistical analysis of the datasets obtained from the indices, is possible using transects as subjects.

2.3. Applicative example

The study area is located on the western coast of central Italy (Latium region; Fig. 2). Latium coasts, characterized by Mediterranean climate (Biondi and Baldoni, 1994; Blasi, 2003), are mainly composed of sandy beaches. Recent dunes (Holocene) generally occupy a narrow strip along the seashore. They are not very high (usually less than 8–10 m) and are relatively simple in structure with beaches varying in breadth from few meters to around 40 m, low embryo-dunes, generally only one mobile dune ridge, dune slacks and stabilized dunes. In natural conditions, vegetation zonation follows the sea-inland ecological gradient, ranging from annual communities on the strandline zone of the beach to Mediterranean Macchia on the inland stabilized dunes (Stanisci et al., 2004). We selected two representative areas along the northern coast of Latium as an example of coastal dunes in central Italy: the coastal area of Montalto di Castro (Viterbo) at the extreme north and the sandy beach landscape of Palidoro (Rome), that stretches from Marina di San Nicola to Passoscuro (Fig. 2). We analyzed 173 ha in the area of Montalto and 157 ha in the area of Palidoro.

In the applicative example carried out in this study, for landscape scale analyses, a detailed vector land cover map (1:5000 is an appropriate scale for coastal dune mapping in central Italy as outlined by Acosta et al., 2005) of the studied Latium coast was drawn. The mapped area extends 1 km inland and includes the holocenic dunes (Accordi and Carbone, 1988). This map was derived from panchromatic digital aerial ortho photographs (dated 2002) with 1 m definition. Land cover was manually interpreted on video, with the help of a Geographic Information System (ArcView 3.2. ESRI 2000) and of field surveys. The legend followed the CORINE land cover proposal (Anon, 1993) expanded to a fourth level of detail for natural and semi-natural areas (Acosta et al., 2005; Carranza et al., 2004).

On the community level, percent cover floristic data were recorded in contiguous 1 m × 1 m quadrats, a size commonly judged adequate considering the rapid turnover of communities and compressed zonation in Mediterranean coastal dune ecosystems and therefore chosen in order to minimize samples with different plant communities (Acosta et al., 2000, 2003; Kutiel et al., 1999). 7 transects were laid out in each sample area at 400 m intervals for a total of 14 transects. Quadrat plant cover data from each transect were classified by average-linkage clustering using chord distance as the dissimilarity index (Podani, 1993), obtaining the major community types. For the Tyrrhenian coast we calculated the chorological index as the ratio between cosmopolitan species (including additionally exotic species) and stenomediterranean species. The majority

Table 2

Landscape composition and structure indices for each coastal area examined (Montalto and Palidoro) and for both areas together.

Variable	Montalto	Palidoro	Total
Composition			
Total LC type richness	21	20	26
Natural LC type richness	15	13	18
Natural coastal LC type richness	9	7	10
Total surface (ha)	172.635	157.110	329.745
Percent natural surface	44.2	59.3	
Percent natural coastal vegetation	73.3	40.4	
Percent urban surface	8.9	17.6	
Shannon Diversity Index (<i>H</i>)	2.641	2.562	
Evenness (<i>J</i>)	0.868	0.855	
Structure			
Total number of patches	160	135	295
Number of natural patches	124	70	194
Number of natural coastal patches	105	27	132
Average natural patch size (ha)	0.83	1.43	
Average natural coastal patch size	0.88	2.01	
Mean shape index for natural patches (MSI)	2.84	2.56	
Mean shape index for natural coastal patches (MSI)	2.65	2.63	

of typical dune species on the central Italian western coast are namely strictly Mediterranean, even though some beach species show broader distributions because of their specialized habitat (Izzi et al., 2007). In this specific case exotic species alone were too few to allow for a reasonable distinction between the two areas, so cosmopolitan species in combination with these were used in the chorological index. For this pilot project we tested differences in the spatial patterns and in the quality of the vegetation between the two examined coasts comparing values of the structural indices (connectivity and richness of boundaries) and of the diversity and chorological indices through independent groups *t*-tests (Sokal and Rohlf, 1995).

A complete comparison on both spatial levels between the two study sites, on the basis of the method for conservation status assessment outlined in this paper, was thus possible.

3. Results

3.1. Landscape scale

The CORINE land cover legend was expanded to a fourth level of detail specifically for the whole 330 ha of coastal area examined, yielding a total of 26 different Land Cover Types, reported in Table 1.

The landscape level survey yielded a richness of 21 land cover types in the area of Montalto and of 20 in Palidoro (Table 2). In Montalto the natural typologies were 15, 9 of which were coastal ones, while in Palidoro only 7 natural coastal LC types were found. Of the total surface surveyed, 44% was included in natural or semi-natural categories in Montalto while in Palidoro almost 60% of the total surface fell in this category (Fig. 3; Table 2). Interestingly enough though, in Palidoro only 40% of the natural surface is represented by coastal vegetation while in Montalto the majority of the natural vegetation (more than 70%) represents primary coastal vegetation. The greater naturality of the landscape in Montalto is further underlined by the percentage of urban surface (Table 2), which is twice as much in the area of Palidoro. Moreover taking into account the proportions of each land cover category, we calculated a total Shannon diversity index slightly higher for the area of Montalto than for Palidoro. Evenness was also slightly higher for Montalto than for Palidoro (Table 2).

The analysis of the entire 330 ha resulted in the identification of a total of 295 patches, 194 of which were natural ones and 132 represented coastal vegetation patches (Table 2). The Montalto landscape

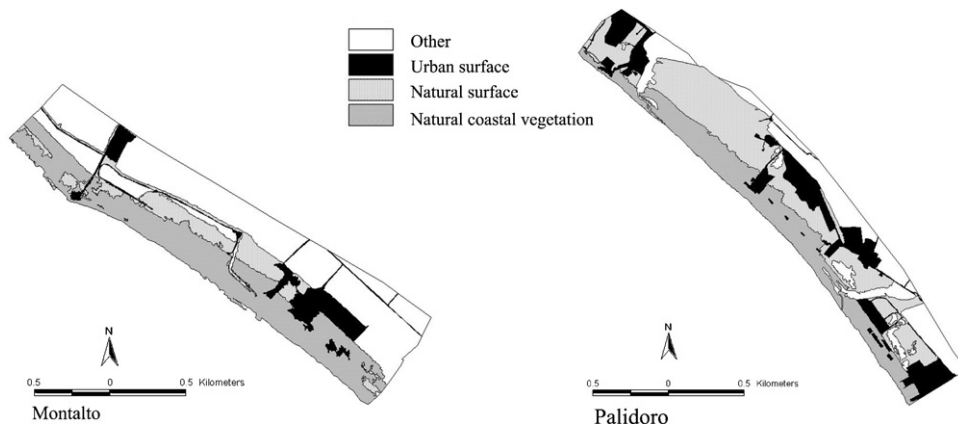


Fig. 3. Land cover maps of the analyzed coastal areas showing the diagnostic categories highlighted in Table 2 as derived from the produced IV level CORINE land cover map of the studied Latium coast. Maps, realized at a scale 1:5000, are presented here at ca. 1:30,000 scale. Natural surfaces are in grey, with coastal typologies highlighted with a darker shade of grey.

Table 3

Main plant communities found in the two coastal dune systems with their relative position along the beach-dune profile.

No.	Zone	Montalto	Palidoro
1	Beach and embryo dunes	<i>Cakile maritima</i> - <i>Salsola kali</i> community	<i>Cakile maritima</i> - <i>Elymus farctus</i> community
2	Mobile dunes	<i>Elymus farctus</i> - <i>Anthemis maritima</i> community	<i>Elymus farctus</i> - <i>Anthemis maritima</i> community
3	Interdune and backdune	<i>Silene canescens</i> - <i>Medicago litoralis</i> community	<i>Silene canescens</i> - <i>Plantago coronopus</i> community
4	Edge of fixed dune	<i>Juniperus oxicedrus</i> - <i>Cistus incanus</i> community	<i>Avena barbata</i> - <i>Bromus rigidus</i> community
5	Fixed dune	<i>Phillyrea latifolia</i> - <i>Pistacia lentiscus</i> community	

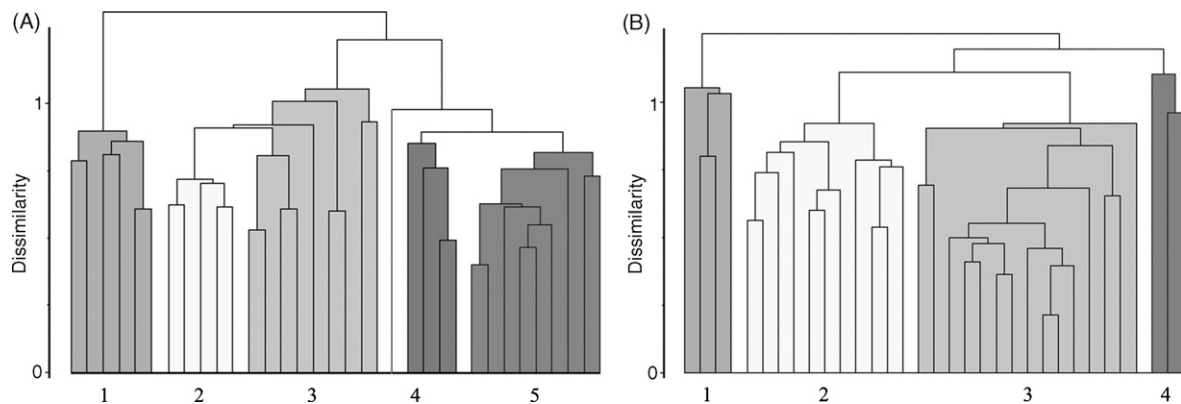


Fig. 4. Cluster analysis for the vegetation of the two examined coastal areas. 5 plant communities were identified in the coastal area of Montalto (A) and 4 communities in Palidoro (B). Numbers refer to the plant communities listed in Table 3.

was much more structured and heterogeneous from this point of view, especially considering the 105 natural coastal patches in this area (85% of the total natural patches) in contrast to only 27 natural coastal patches in Palidoro (less than 40% of the natural patches of this area). This aspect is reflected in the average size of natu-

Table 4

Indices of spatial structure and quality of the vegetation for both coastal areas examined (Montalto and Palidoro).

Variable	Montalto	Palidoro	Sig.
Spatial structure			
Richness of boundaries (<i>n</i>)	3.286	2.571	0.109
$\gamma_{\text{sea-inland}}$	0.531	0.589	0.311
$\gamma_{\text{inland-sea}}$	0.237	0.206	0.699
Quality of the vegetation			
Shannon diversity index (<i>H</i>)	3.182	2.813	0.014
Evenness (<i>J</i>)	0.884	0.835	0.017
Corological index (<i>A</i>)	0.304	0.413	0.332

Significance values refer to *t*-tests for independent groups (*df* = 12).

ral coastal patches, which is of less than a hectare for the former and more than double for the latter. On the other hand, the mean shape index does not highlight particular differences in the shape of the natural coastal patches of the two areas. This index is relatively high for both areas indicating stretched out shapes instead of isodiametric ones, as is expected for coastal vegetation. The relatively high MSI in Montalto even in face of the remarkable number of polygons suggests that in this area we are dealing with a natural heterogeneity typical for these environments, and not with a fragmented landscape as a consequence of human disturbance.

3.2. Community scale

We identified five plant communities through cluster analysis in the coastal area of Montalto and four in Palidoro (Table 3). These range from the pioneer beach communities to a well-developed Mediterranean Macchia in Montalto and to a secondary grassland substituting the shrub vegetation in Palidoro as a consequence of past human activities, passing through herbaceous psammophilous

communities affected by various degrees of disturbance along the dune profile (Fig. 4; Table 3). In the area of Palidoro plant communities of the mobile dune and of the backdune appear to be particularly altered in their floristic composition, and here the zonation ends with a secondary grassland (Table 3).

With respect to the analysis of the spatial arrangement of vegetational groups along the sea-inland gradient no significant differences emerged between the two coastal areas neither in the spatial connectivity indices, nor in richness of boundaries (Table 4). Richness of boundaries is slightly higher for the coastal area of Montalto because of the presence of a greater number of communities in this area, but the difference is not significant. Both areas seem to be subject to a considerable amount of disturbance with relatively high connectivity values in average, mainly due to heterogeneity and to the fragmentation of the communities and their repeated presence along the transects corresponding both to backward steps in the natural coastal zonation and to contact loops along the natural community sequence.

As for the quality of the vegetation, Shannon diversity index and evenness are significantly higher for the dune system of Montalto than for the coast of Palidoro (Table 4) indicating a richer and more diverse vegetation for the northern area. In particular the fairly well preserved backdune Macchia, which has been completely eliminated in the southern area as a consequence of past agricultural activities, is probably responsible for such higher diversity values.

On the other hand no significant differences emerge for the chorological index, which has relatively low values for both areas. This indicates that both areas are not particularly subject to invasion by human-favored or alien species and the strict Mediterranean character of their flora is maintained.

4. Discussion and conclusions

In face of the numerous threats endangering coastal habitats the need for monitoring and active management of these environments has emerged. Multiscale approaches are extremely useful to study small and patchily distributed ecosystems of the world, such as sand dunes, in particular if they are close to urban areas. In fact, hierarchically nested land use plans are becoming widely used because of their usefulness to stress importance of natural ecosystems for management and sustainable urban development. Analyzing coastal dunes at a broad organizational level and then, zooming them down to a finer level, can highlight more emergent properties providing valid arguments for their management and protection, also with the perspective of protecting strategic infrastructures and urban developments (Jolicœur and O'Carroll, 2007). The method proposed in this paper, by exploring two organizational levels at the extremes of the biodiversity spectrum, allowed the comparison of two local areas along the Tyrrhenian coast in a comprehensive way.

The landscape of Montalto is richer in natural coastal land cover typologies, which also cover a greater surface in this area, and is more diverse overall. The Palidoro coast, on the other hand, is much more influenced by the coastal suburbanization phenomenon (this area was also included in a region classified as one of the most critically urbanized of the northwestern Mediterranean by Cori in 1999) and the natural landscape here appears therefore more endangered in terms of alien invasions and trampling linked to human settlements (Curr et al., 2000; Kutiel et al., 1999; O'Shea and Kirkpatrick, 2000). Moreover the Montalto landscape is more structured and heterogeneous, especially when considering natural coastal land cover typologies, which in this area are arranged in numerous patches that still maintain their natural shape parallel to the coastline. The landscape of Palidoro, on the other hand is shaped by the heritage of intense agricultural activities in the

past, revealed in particular by the presence of few large polygons even in natural categories. In contrast with the wealth of literature describing effects of urban sprawling, few studies have highlighted the strong landscape modifying impacts of past agricultural activities on coastal areas, even though agricultural surfaces often occupy large percentages of the coastal landscape (as indicated for example in Italy by Carranza et al., 2004).

On the community level the analysis of the spatial pattern of the communities highlighted structural alterations in both areas. These are probably associated with disturbance due to trampling and summer coast bound tourism. Even though no statistically significant structural differences emerge between the two areas, the vegetation of Montalto still resulted significantly richer and more diverse than the one of Palidoro, underlining once more the flattening effects of the past agricultural activities and present recreational ones in the latter area. Several studies have in fact highlighted the strong negative effects of trampling and other human induced disturbances on the plant communities of coastal dunes in the Mediterranean as well as in other parts of Europe, with significant lowering of diversity values in trampled sites (Grunewald and Schubert, 2007; Kutiel et al., 1999; Vogt Andersen, 1995). Trampling and other recreation linked human activities, such as beach cleaning are rated by Brown and McLachlan (2002) among the most severe factors impacting sandy shores.

The two levels of analysis work complementarily to portray a complete picture of the naturalness of the vegetation in the two coastal areas examined. We are therefore able to recognize a better conservation state of the northern coast, while the second sample area, both because of sprawling and summer tourism associated with the proximity of the 4 million inhabitants metropolitan area of Rome (ca. 30 km south) and of intense past farming and agricultural activities, has been much more subjected to disturbance.

Our conclusion can be considered particularly trustworthy because the approach considers both the ecological processes shaping the coastal landscapes (higher organizational level) and the floristic emergencies of the sand dune communities (community level).

The method demonstrated several advantages. At the higher organizational level, the relevant data are generally widely available and relatively easily analyzed. Although the sampling process at the community scale is time-consuming, the use of transects makes it possible to include the greatest amount of diversity along the sea-inland gradient in the shortest amount of time, rendering the sampling effort the most time and cost effective possible. In contrast with many approaches for the study of conservation status or vulnerability of natural habitats, which have relied on the completion of checklists or on ratings and scorings by experts and managers (Poldini and Pertot, 1989; Regan et al., 2007; Williams et al., 2001), the direct measure of surrogate features of biodiversity at different levels in our proposal avoids the introduction of subjective judgement and bias. Moreover the method overall causes only minimal disturbance to the examined communities, even though it involves both the community and the landscape level. Nevertheless we obtained a set of different indicators on various organizational levels of the coastal environment, which are easy to determine or to calculate.

The assessment is therefore easily repeatable, allowing for straightforward comparisons among coastal areas. It may hence be used to compare the conservation status of various coastal areas and identify conservation priorities in a general region at a more detailed and local level as regular reserve design methodologies and in a fashion specifically tuned for coastal environments. Additionally this methodology, since it can be repeated in the course of the years, may be used as a basis for monitoring coastal dune ecosystems over time and for assessing the effects of management changes, when the focus needs to be specifically on the vegeta-

tion, which is often neglected or its contribution to dune health underestimated.

In conclusion, we proposed an articulated method to evaluate conservation status and disturbance levels on sandy coastal areas encompassing multiple levels of the plant biodiversity. The method summarizes coastal vegetation conservation status in an objective, standardized and repeatable way by means of several biodiversity indicators. While not all aspects studied were significantly different between sample areas examined in the applicative example, the method was articulated enough to pinpoint the overall difference in conservation status, fulfilling therefore satisfactorily its purpose.

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