THE USE OF A GIS FOR ANALYSE DUNE SYSTEMS: THE CASE OF PLATAMONA-MARRITZA (NORTHERN SARDINIA, ITALY)

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We present the product of a GIS developed to map and reconstruct the variations in the coastal dune environment in a complex geological situation like Platamona-Marritza. This GIS was created as a response to the necessity of a more co-ordinated approach to the mapping and to field studies taking place within the MIUR-COFIN 2002 Research of National Importance entitled “The aeolian deposits of the Italian coasts and the beach-dune sedimentary fluxes”. A series of specific parameters that together present a synoptic view of the dune sector under study, and show the evolutive, morphodynamic, sedimentological, vegetational and anthropic characteristics of the dunes of all Italy’s dune systems, have been included in the database. The inclusion of all these data in a GIS, that reflects the national situation, has made it possible to produce a tool that it is easy to use for a better management of the national territory.

1. INTRODUCTION

The need to have a management tool that highlights the equilibrium and evolutive trends of the Italian coastal dunes has encouraged the national scientific community to produce a GIS that can contain and compare all the cartographic, evolutive and vegetational information on the dune fields. The result has been the creation of a national georeferenced chart and associated database on an ESRI ArcGIS 8.2 platform within the recently-concluded co-ordinated research conducted in the ambit of the MIUR-COFIN 2002 project “I depositi eolici delle coste italiane ed il flusso dei sedimenti spiaggia-duna (The Aeolian deposits of the Italian coast and the beach-dune sedimentary fluxes)”. The creation of the chart in digital format, on a scale of 1:10,000, through the interpretation of overlapping photographic images taken in 1998 and made available by the Ministry for the Environment and National Territory, enabled us to synthesise the results of historical studies and insert updated reliefs, obtained from field studies, that highlight and describe the evolutive, morphodynamic, sedimentological, vegetational and anthropic characteristics of the dunes. On the basis of our experience obtained from working on the Atlas of the Italian Beaches, the only atlas presenting the erosion and anthropisation of the dunes in a symbolic form, it has been possible to create a specific legend that takes into consideration the parameters that have direct influence on the development of the dune apparatus, such as the evolutive trend of the coast, the primary factor influencing sedimentary transport and deflation surfaces, aeolian activity, intended as a factor in both the deposition of sand and erosive and transportation processes that explain the vegetational features of the beach and dune itself and whose stabilising action determines the preservation of the dune and, finally, anthropic activity, intended not only as occupation or modification but also as management and protection. The legend specifically formulated for this project has been used as the basis of the geodatabase associated with the GIS. The study of the coastal dune field of Platamona-Marritza in northwestern Sardinia, reported here, was undertaken to update and validate the morphosedimentological and vegetational data obtained from aerial photography. The activity produced an accurate topographical update of the coastline and the dune structure and delimited and determined the vegetational associations present.

2. THE DUNE FIELDS

Dunes occupy the position directly behind the subaerial beach (backshore), within the coastal sedimentary and morphological system, and obtain their nourishment by aeolian transport of sediment from the beach lying in front. The exchange of sediment with the beach is the main characteristic of the coastal dune (foredune) (Psuty, 1992), which therefore contributes to the complex and delicate processes that regulate the littoral environment and its equilibrium. Dunes have great importance in the defence of the coastline against the incursions of storms and erosion (Psuty, 1989, Arens & Wiersma, 1994) because they constitute an indispensable reserve of sediment for the dynamic equilibrium of the beach and a fundamental element in the protection of important natural coastal environments such as ponds, lagoons, and wetlands in the broadest sense of those terms. From an economic point of view dunes can be sensibly used
for tourist or recreational activities or, given their hydrological characteristics, as ideal reserves of fresh water for domestic use without compromising the growth and development of their characteristic vegetation (Zonneveld, 1992). As some of the dominant factors acting on dune dynamics are a consequence of the morpho-sedimentologic aspect of the beach, some descriptive parameters of these, such as morphodynamics, grain size and human activities, will be included in the GIS.

The efficiency of wind and wave action on the swash zone are strongly influenced by the width of the beach. So the shoreline evolution, obtained by the comparison of topographic surveys (in which we consider morphometric aspects, grain size, plant cover, direction and intensity of wind, etc.) and aerial photography, becomes very important for describing the evolution of the dune deposits and their dynamics.

Foredunes, due to their position, are undermined by storm waves, a process followed by some avalanche and retreat of their seaward slope. In periods of stasis, between the eroding storms, sand returns to the dune slope in a recovery cycle (Carter et al., 1990). Hence, foredunes are the only coastal dunes involved in an exchange of sand between the beach and dunes (Psuty, 1989). During periods of exceptional wave action or when the sedimentary budget is negative, with a consequent retreat of the coastline and a decrease in the deflation area, erosion of the innermost dunes can provide an important source of sand for the re-equilibration of the beach.

The degree of plant cover is the determinant element in the stability of foredunes. In fact, vegetation has a decisive role in the construction and stabilisation of coastal dunes. Immediately behind the swash zone, but still in the intertidal zone, the first plant species appear, increasing the roughness of the terrain, slowing the velocity of the wind and so playing a pioneering role in the deposition and fixing of the sand. These species contribute to the construction of what is conventionally called an incipient dune.

Psammophytes or sand-loving plants are adapted to an arid environment, to the extreme mobility of soil particles and wind action that transports sand and encrusts plants in salt. Generally, these plants develop long subterranean and superficial roots and stems with the special function of anchoring the plant to the sand. They are extremely adapted to the environment in which they grow. Dune ecosystems are, in fact, environments where innumerables factors exercise a limiting action on all forms of life. An easily visible phenomenon is the presence, in certain habitats, of a determined combination of populations of several species.

In a simplified scheme of the beach-dune system, consisting of beach, foredune, dune, back dune, interdunal zone and consolidated dune it is interesting to note how, morphologically, the vegetation is deposited in wedges, with the vertex towards the coastline with the taller plants at the back, protected by progressively higher advance vegetation (Figure 1).

![Figure 1: Wedge-like formation of the coastal vegetation.](image)

Wind erosion of stable fore dunes commonly starts with vegetation disruption by man (grazing, trampling, traffic, or fire). Afterwards, deflation may form blowouts, which are wind-excavated gaps in the fore dune ridge that channel sand transport landwards (Hesp, 2002).

### 3. DATA SOURCES

The principal aim of this project was the production of a thematic chart, on a scale of 1:10,000 on a GIS platform, on which to record the most important features for describing the evolution of the dune apparatuses and their state of preservation.

The objective was to consider the need to conveniently integrate the data with the GIS environment, to allows full advantage to be taken of the GIS database to effectively monitor littoral use and its effects.

Figure 2 represents the plan for the insertion of the data in the GIS database.
Figure 2: Plan for the insertion of the data in the GIS database.

The national-scale map was based on colour aerial photographs taken in 1998 and the black and white ones of an AIMA flight, made available by the Ministry for the Environment and the National Territory, and all the cartographic, sedimentological, wind-wave, anemometric and vegetational data made available by various universities and research bodies. The detailed study of the littoral of Platamona-Marritzu was based on aerial photographs taken in 1955, 1977 and 2002 and made available by the Ministry and topographic, sedimentological and vegetational reliefs carried out during our fieldwork.

All data is superimposed to facilitate spatial analysis and simulation.

4. METHODOLOGY

To visualise the aerial photography and data, ESRI ARCGis 8.2 software was used with programmes especially written for the project.

To create a single structure that can be implemented on a national scale and at the same time preserve the general congruence of the project, provision was made for a single, common national field (*Personal Geodatabase*) that can then be articulated in geographical sectors that represent the different regional work groups (*Personal Geodatabase Feature Data Set*).

In agreement with the Ministry for the Environment and National Territory it will be possible to access the cartographic contents of the “Portale Cartografico Nazionale” (National Map Portfolio), the only cartographic reference for the project, electronically.

4.1 Informative content

The three integral parts of the database are the geometrical component, the computerisation component and the meta-information. The first two, alphanumeric in nature, are normally included in a GIS, while the third, the meta-information, is a fundamental element because its incorporation in a database confirms the information inserted, describing the methods with which it was collected and summarising its possible reuse. In the specific case of this work the metadata were compiled according to the standard of the Federal Geographic Data Committee (FGDC), confirming that the data is suitable for the GIS software used and the archiving has been done in XML format.

The information describes the conditions that can be inserted and the agreed univocal definitions and ensures that every definition is synthesised in an appropriate code. The information is varied and, other than that explicitly referring to the dune apparatus, is correlated with other information that indicates the significant parameters of the coastal environment and the evaluation of the evolution of the littoral.
4.2 Methods of building a basic geographic database

The database has two fundamental features:
- Vectorialisation of all the information inserted.
- Digitalisation of the polygons, polylines and points.
- Image data processing.

Simultaneous analysis of all the features of the dune apparatus in the topographic charts and the mosaic of overlapping black and white and colour aerial photographs that must be superimposed to integrate the diverse data.

4.3 Principle fields of the database

Seven main information fields have been established in the database:

- **DUNE**: polygonal element that represents the entire dune area (incipient dune, fore dune and secondary or inactive dune).

There is provision for subdivisions according to:
- **Type** (2 classes: active and inactive, AT/NA);
- **Beach width** (3 classes: 0-20 metres, 20-60 metres, >60 metres);
- **Beach trend** (3 classes: prograding, retreating, stable);
- **Type of vegetation** (6 classes on the basis of the visually dominant types: AL = Pioneering species, AR = Shrubbery, Er = Herbaceous, ARL = Sparse shrubbery, ASS = Absence of vegetation).

- **DUNE CREST**: linear element that graphically indicates the mean trend of the crests of the active and inactive dune belts.

- **ANTHROPIC**: polygonal element that defines the extent of the urban areas, sparsely settled areas and areas of anthropic use (intended as areas used by man but without the construction of buildings) (Figure 3).

- **WORKS**: linear element that is conventionally positioned at the limit of the swash zone. It can distinguish various types of works:
  - *Artificial nourishment* (RI);
  - *Attached works* (OR);
  - *Artificial nourishment associated with attached works* (RO).

![Figure 3: An example of the sparsely settled area of Platamona.](image)

- **ANTHROPIC**: polygonal element that defines the extent of the urban areas, sparsely settled areas and areas of anthropic use (intended as areas used by man but without the construction of buildings) (Figure 3).
• BEACH USE: linear element positioned near the incipient dunes. To indicate the various uses of the front beach it is defined as:
  Activity associated with temporary occupation (TE);
  Activity associated with permanent occupation (PE).
• OPENINGS: point element positioned inside the Dune polygon near an opening towards the sea. It is possible to distinguish:
  Pathways (SE);
  Roads (SR) roads without egress;
  Natural openings (VN).
• WIND: point element that indicates the geographical location of significant meteorological stations, also those not directly monitoring the coastal area, and contains the following information:
  Name of station;
  Height above mean sea level;
  Observation period.

5. STUDY AREA

The littoral of Platamona-Marritza, situated in northern Sardinia (Figure 4) is an example of a Mediterranean coastal environment with a notably heterogeneous dune system.

The morphology of the littoral is poorly articulated and characterised by a long sandy beach (c. 17 km) fringed by a belt of longitudinal and parabolic dunes, prevalently oriented NW-SE, some of which reach a height of 32 metres [3]. The aeolian deposits extend along the entire coastal strip and it is possible to distinguish the Pleistocene aeolian sands from the Holocene and present-day ones. The oldest sandy deposits crop out, above all, along the coastline west of Marritza, where they are incorporated in a cliff several metres high. The actual dune field borders the beach for about 15 km; the longitudinal dunes, which together with the parabolic dunes form the field of Platamona, are oriented between N 110 and N 140, with a mean orientation of about N 125, clearly due to the action of the Mistral (Ozer, 1976). The hydrographic network consists of minor torrential watercourses that have a limited supply for the major part of the year and a regime essentially linked to meteoric flow.

The data from the weather station of Porto Torres indicate that the climate of Platamona is “semi-arid”, characterised by hot summers with a notable hydrological deficit, but with extremes attenuated by marine thermoregulation, a modest hydrological supply between October and January and an almost-nonexistent cold period (with a consequent reduction in winter-dormant vegetation).

Along the beach of Platamona-Marritza the most important winds influencing the dynamics of the littoral and dune system come from Quadrants I and IV, that is the Grecal and Mistral. Although the Libeccio, coming from Quadrant III, is the most frequent and intense wind, those coming from the sea have a stronger influence on the littoral dune field.
The anemological conditions remain more or less unvaried throughout the year, so that the littoral is subjected to the same winds, in the same proportions, in all seasons.

The dynamics of the wave action induced by the wind-wave climate, and specifically the dynamics influencing the transport of solid material from the southwest to the northeast, are defined in the Atlas of the Italian beaches.

5.1 Analysis of the evolution of the coastline

To determine the evolution of the coastline and the dune fields we analysed aerial photos of the Platamona-Marritza beach for the years 1955, 1977 and 2002. The 1955 image is a mosaic of 6 black and white aerial photos (scale 1:30,000), the 1977 image is a mosaic of 30 black and white aerial photos (scale 1:10,000) and the 2002 image is a mosaic of 25 colour aerial photos (scale 1:10,000). All the photographs were scanned at a resolution of 600dpi and saved as three-channel (RGB) 24-bit tagged image file format (.tiff) raster files.

Orthorectification and georeferencing of the scanner images was performed using a geographic geometry transformation programme (version 8.4 ERDAS Imagine). We used a refined model based on the Transverse Mercator projection and 32 North datum to transform the data. The control points (buildings, roads, etc.) were selected from the IGM to achieve geometric rectification and minimise the residual error between the transformation model and the reference coordinates.

After creating the three aerial photographic mosaics, the files were inserted in ESRI ARCGis 8.2 software. The different mosaics, previously georeferenced, were superimposed inside the project to analyse the evolution of the littoral.

The limits of the dune field (clearly visible in the 1955 mosaic before reforestation of the area), the coastline and the road network were determined. Recent tourist complexes, that have been constructed within the study zone, were digitalised using the 2002 mosaic and, given the notable clarity of the images, it was also possible to highlight structures on the submerged beach and the presence of beach-rock out-crops.

5.2 Campaign activities

The field studies were carried out after the selection of the most important morphological features for describing the morphosedimentological dynamics of the beach using reliefs of the submerged beach, the foredunes and the dune fields. The study, conducted from September to October 2003, consisted of surveying:

* the morphological profiles;
* the vegetation along the dune belts.

To study the state of health of the environment, recourse was made to phytosociology, the science that makes it possible to evaluate the biocenotic diversity through the identification and classification of associations (Biondi et alt., 2001). This biotest is more effective than the study of a single species to demonstrate possible anomalous stress situations as it increases the scale of observation by at least one order of magnitude.

Once all the characteristic and differential species in an association and their ecological and seasonal needs are established, it is possible to determine and evaluate the quality of the phytocenosis through, for example, the presence of an alien species in the community, the disappearance of characteristic species, the anomalous coverage of specific plant types that indicate particular ecological conditions, even anthropic interference.

In the case of a littoral with a series of dune belts, the beginning of vegetation follows a precise scheme; if we consider the dune field as divided into distinct sectors (foredunes, incipient dunes, dunes) each can be associated with different plant species. The absence of specific species or the distribution of certain associations found during the fieldwork can be considered as an indication of the erosion of the beach.

The theoretical series that should exist on this tract of the littoral is strongly influenced by the morphology of the zone: the dune field of Platamona-Marritza is a more or less elevated erosion slope that affects the secondary dunes that then behave like a primary ones, hosting Sileno-Elymetum, at the expense of Sileno-Ammophyletum, which has almost disappeared, and so creating an anomalous contact between Sileno-Elymetum and Crucianelletum or, in the worst case scenario, where the erosion is worst, between Sileno-Elymetum and Juniperetum (Figure5 where: 1: Salso lo kali-Cakiletum maritimae; 2: Sileno corsicae-Elytrigetum junceae; 3: Sileno corsicae-Ammophiletum arundinaceae; 4: Crucianello-Helichrysetum microphylli; 5: Ephedro-Helichrysetum microphylli; 6: Asparago acutifoli-Juniperetum macrocarpeae; 7: Very tolerant perennial species of Holoschoenus romanus, Juncus maritimus and Equisetum ramosissimum and reforestation with Pinus pinaster).
6. RESULTS

The creation of a GIS that considers the evolution and morphosedimentological and vegetational dynamics of dune fields on a national scale as a management tool for the coastal zone by highlighting the natural processes and the rapport between human settlement and the use of the territory has been the main objective of the national coordinated project (MIUR COFIN 2002). The formulation of a suitable legend to define the natural and anthropic situation with a finite but sufficient and exhaustive parametric index has been the basis for the construction of the geodatabase whose fields have taken into consideration all the parameters considered necessary to describe the evolution of the coastal dunes. The geodatabase has been tested to confirm that it can represent all the Italian coastal dune fields. The interpretation of the 1998 aerial photographs on a scale of 1:10,000 made available by the Ministry for the Environment and the National Territory has made it possible to formulate the first national picture of the coastal dune fields. The dune field of Platamona-Marritza (Figure 6) represents one of the test sites for the updating and validation of the photographic interpretation.

In particular, through the study of aerial photographs of different periods, topographic reliefs of the countryside, sedimentological samples and vegetational determinations the interrelationship of the database fields and the parameters of the evolutive dynamics of the dune fields has been established. It has, therefore, been possible to characterise the
general erosive situation of the coastal tract studied and, in particular the northeastern sector, the extension of the dune field that has a width varying between 500 and 1,500 metres and a NW-SE orientation, and insert the information in the appropriate geodatabase fields. The analysis of the delimitation of the plant associations has also contributed to highlighting the close relationship between the natural and anthropic evolution of the territory, from the replanting of the dunes after 1955 to their progressive anthropisation, distinguishing those sectors in which erosion of the beach is most marked with direct repercussions for the plant species (Figure 7).

The interpretation of the photographic mosaics of the various years (1955, 1977, 2002) has also revealed the progressive occupation and use of the coastal tract.

The insertion of the data in a GIS has therefore made it possible to produce an archive on the state of preservation of the coastal dunes and a user-friendly management tool which can be used to create scenarios indispensable for the correct management of the coastal tract.
References

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Biography of Nicola Corradi

Born in Imperia (IM-Italy) on 03.11.1950.
Degree in Geological Sciences (University of the Studies in Genoa).
Collaborator in the circle of the researches financed by the C.N.R. on the sedimentology, sysostratigraphy of the backdrops of the Ligurian Sea and on the dynamics of the shores.
He has participated and then coordinated several Oceanographic surveys.
From 1987 he participates to the searches and the activities of the National Project of Researches in Antarctica (PNRA), effecting several Antarctic surveys.
In 1998 and 2001 he has been named scientific coordinator of the XIV and of the XVII Oceanographic surveys of the National Program of Searches in Antarctica and he had inserted since 1996 in the programs italo-Australian international collaboration “Wega”, in the PNRA programs and in the Ocean Drilling Program (ODS).
In 1990 he participated to the realization of the Liguria maps of the “Atlas of the Italian Beaches”.
In 1991 he frequented the "European Training Course on Geographical Information System - Introduction to GIS" to learn computer science techniques applied to the Sciences of the Earth. In the same period he enters to belong to the interdisciplinary Laboratory for the territorial informative systems “LISIT” near the Consortium “Genova Ricerche”.
In 1995 he has been designated from the Department of Sciences of the Earth of the University in Genoa, as member of the Committee for the Geologic Cartography of the Region Liguria.
In 1998 he results Professor for the scientific-disciplinary, in the sector of stratigraphical geology and sedimentology.
In 2001 he participated to the vectorialisation of the “Atlas of the Italian Beaches” for Ministry for the Environment and National Territory.
He holds the following teachings (Faculty of Sciences):
- Geology
- Evolution of the coasts and the continental Basin
- Marine Geology
He has also been titular of the courses:
- Sedimentology