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CORSO DI DOTTORATO
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Sistemi agroforestali, ecosistemi naturali e paesaggio

Integrated assessment of geomorphological and vegetation dynamics in a complex dunefield. Capo Comino case study (NE Sardinia, Italy).

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Wind ist der Welle
Lieblicher Buhler;
Wind mischt vom Grund aus
Schäumende Wogen.

Seele des Menschen,
Wie gleichst du dem Wasser!
Schicksal des Menschen,
Wie gleichst du dem Wind!

Gesang der Geister über den Wassern - ***J. Wolfgang von Goethe***

Il vento è dell'onda
Amante leggiadro;
e dal fondo rimescola
onde spumose.

Anima dell'uomo
come somigli all'acqua!
Destino dell'uomo
come somigli al vento!

Canto degli spiriti sopra le acque - ***J. Wolfgang von Goethe***

Wind is the wave's
Handsome suitor;
Wind stirs up from the depths
Foaming billows.

Soul of man,
How like to the water!
Fate of man,
How like to the wind!

Song of the spirits over the waters - ***J. Wolfgang von Goethe***

Abstract

The coastal environment is increasingly subject to utilization and anthropogenic disturbance. Currently a large proportion of the worldwide human population lives close to the coastline and this has led to the modification – and often the deterioration – of many previously intact coasts and ecosystems. In particular, the marketing of coastal recreation has increased drastically during the last century obliterating many natural systems. As a result, many coastal systems of the world are in advanced stages of degradation (e.g. with the elimination of native and endemic species and the introduction of the exotics, or the erosive processes induced by human modification of the natural environment, in addition to the natural erosion to which coasts are exposed (Pranzini and Rossi, 2000). In the worst cases, coastal ecosystems have been completely removed in the process of providing living space for the encroaching human population.

Dunes, beaches, coastal wetlands and salt marshes are generally considered as ecosystems at risk of loss as they are of high potential economic value or sources of biodiversity for coastal management schemes (e.g. biodiversity protection, ICZM protocols following the Barcelona protocol, 1978). The scientific investigation and understanding of natural processes in coastal ecosystems forms the basis of appropriate conservation and protection activities.

The present study investigates the development of an integrated methodology for the characterization of costal dune systems. It aims to produce a general overview of the Capo Comino landscape and its evolution to aid strategic planning decisions for enhancing the environmental sustainability of this natural system.

Focus has been given to the most relevant elements of the dunefield, such as its morphological aspect, the influence of the climate on its evolution and the distribution of vegetation.

A preliminary study of the general setting of the dunefield area allowed the development of a novel procedure for monitoring the dunes, integrating remote sensing strategies, *in-situ* measurements and data organization using geographical information systems (GIS).

The phases of this project may be summarized thus:

- Review of the existing literature

Coastal dunes have a worldwide distribution and they are characterized by a variety of forms exhibiting successional changes in geomorphology and ecological associations. The central topic for this phase of the research was the analysis of the studies focused on spatial and temporal variation in morphology, the sequences of biological succession in dune types and their adaptation to environmental stresses.

From the morphological point of view, coastal dunes are highly variable in form and dimensions and their current aspect is the consequence of stabilization and destabilization processes (Nordstrom *et al.*, 1991; Psuty, 1997, 1999; Hesp, 2004, 2006; Martinez and Psuty, 2004). The main morphological constraints for their development are related to sediment supply, wind conditions, stabilizing vegetation and human interaction. Furthermore, in

coastal environments the dichotomy between the dunes and the beach is a very significant factor.

With regard to vegetation, succession on coastal dunes has been the focus of many researches starting around a century ago (initial studies were carried out by Steinheil in 1832 and Cowles in 1899). In the present study vegetation associations and their distribution form the main topic, using the phytosociological method.

- Identification of the available information for the study area

The state of knowledge for the local study area was determined from published sources. Further data such as aerial and satellite images were evaluated and the vegetation analysis was carried out based on the existing literature that describes the main associations of Mediterranean coastal dune environments (Géhu, 1986; Géhu *et al*., 1984; Géhu and Biondi, 1994a, 1994b, 1995; Biondi 1999, 2007) and, in particular, of Sardinian coasts (Arrigoni, 1996; Bartolo *et al*., 1992; Biondi *et al*., 2001; Biondi and Bagella 2005; Filigheddu and Valsecchi, 2001).

- General setting of the study area

Investigation of the geology and geomorphology of the area, the wind-wave climate and bioclimatic indices were undertaken. Remote sensing analyses provided an essential overview of the general evolution and morphological complexity of this sector. Morphological and vegetation analyses were carried out on the two principal physionomic units of the coast: the dunefield and the beach. Results of vegetation data allowed a more precise delimitation and spatial distribution of plant associations and the characterization of two new sub-associations.

A bathymetric survey including the collection of seafloor sediment samples were also carried out for the characterization of the nearshore system.

All collected data and spatial analyses were ultimately implemented into a GIS, thereby allowing cross analysis of the information stored in the geodatabase to obtain both a qualitative and quantitative description of the landscape and the main morphological and vegetation characteristics of the environment.

- Monitoring program

The procedure integrates morphological and vegetational data - with several sedimentological considerations – in order to test a novel and readily applicable procedure for coastal dune monitoring. Three field measurement campaigns were carried out during the PhD program. This included measurements of the main geomorphological features with the integration of vegetation distribution along specific transects. Samples of the sediments of the beach and dunefield were collected in order to give further information concerning the grain sizes and the aeolic transport of sand. This research demonstrates that the dynamic processes and disturbances are well recognizable along transects. Therefore it is possible to monitor the general status of a study area using a small number of geomorphological and vegetation profiles. This integrated methodology promises a precise, effective and rapid procedure for the monitoring of coastal dunefields.

La candidata, Dott.ssa Ileana Balduzzi, durante i tre anni di Dottorato ha dimostrato impegno, grande autonomia e capacità organizzativa nel lavoro di ricerca scientifica e ottimo spirito di collaborazione con i ricercatori e docenti che hanno seguito il suo operato.
Il lavoro di ricerca da lei svolto ha permesso di raggiungere ottimi risultati scientifici, che integrano aspetti vegetazionali, geomorfologici e sedimentologici, giungendo alla messa a punto di un nuovo sistema di monitoraggio dei campi dunari.
Nei tre anni di dottorato ha completato la sua formazione scientifica partecipando ai corsi e seminari della Scuola di Dottorato, trascorrendo un periodo di 6 mesi presso la Louisiana State University (LA-USA) e partecipando a convegni nazionali e internazionali (ad alcuni dei quali ha presentato in qualità di co-autore posters e comunicazioni).
Durante il periodo di dottorato ha inoltre svolto studi e collaborazioni con il Dip.Te.Ris. dell'Università di Genova, dove ha condotto le ricerche sedimentologiche e geomorfologiche, argomento del programma di dottorato, e conseguito il titolo di Cultore della Materia in GEO/02.
Inoltre, ha fornito un prezioso e valido sostegno nelle attività didattiche del tutor (assistenza agli esami di profitto ed alle esercitazioni dei corsi di insegnamento).
In sintesi, il giudizio espresso sulla candidata non può che essere fortemente positivo.

Il Tutor
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ACTIVITIES 2009-2011

Stages and formation:

- "I processi di desertificazione come conseguenza dei cambiamenti climatici". ENEA, Santa Teresa, La Spezia (IT). 04/11/2011
- "Beach management and coastal zone management". Polo Tecnologico Magona, Marina di Cecina (IT). 14/10/2011
- "Geomorphology, dynamics and management of coastal dunes". Polo Tecnologico Magona, Marina di Cecina (IT). 29/06/2011
- Cape Cod - field survey (MA-USA). LSU – Louisiana State University. February 2011
- Stage at LSU, Louisiana State University from 7/10/2010 to 20/3/2011. Baton Rouge (LA-USA).
- Stage: "MAGIC and CARG project". From 22/2/2010 to 04/3/2010.
- Technical visit: "Cantieri di MARIMASSA". GNRAC, 14/05/2010
- Technical visit: "Cantieri del litorale di Ventimiglia e diga semigalleggiante del porto del Principato di Monaco". GNRAC. 18-19/02/2010
- "The influence of shore protection on bathing area evaluation and registration (BARE)". GNRAC, University of Florence. 24-25/05/2010, Marina di Massa (IT).
- "Training progettuale per la costa". GNRAC, University of Ferrara. 8-12/06/2009, Martinsicuro (IT).

Participation to national and international congresses:

- 45° Congress of SISV&FIP "Biodiversity Hotspots in the Mediterranean Area: species, communities and landscape level", Università di Cagliari (IT), 22-26/06/09
- GEOITALIA 2009, Rimini (IT), 9-11/09/09
- Meeting of International Association of Sedimentologists (IAS 2009), Alghero (IT), 20-22/09/2009
- 13a Conferenza Nazionale ASITA 2009 & GeoExpo Italia Fiera del Levante, Bari (IT), 1-4/12/2009
- "Strategia per la protezione della costa". GNRAC, Università di Sassari, Comune di Castelsardo, Consorzio porti turistici della Sardegna, Castelsardo (IT), 27-28-29/05/2010
- 106° Congresso Società Botanica Italiana, Genova (IT), 21-24/09/2011
- GEOITALIA 2011, Torino (IT), 19-23/09/2011

Pubblications and abstracts:

Balduzzi I., Vagge I., Corradi N., Ferrari M. (2011) - *Monitoring and management of coastal habitats: Capo Comino case study (NE Sardinia, Italy).* FIP - Global Strategy for Plant Conservation, Valencia, 13-17 settembre 2011

Balduzzi I., Vagge I.,Corradi N., Ferrari M. (2011) - *An integrated monitoring procedure of coastal dune field. The example of Capo Comino area (NE Sardinia).*SBI - 106° Congresso Nazionale, Genova, 21-24/09/2011.

Vagge I., Guido. V., Bocchi S., Balduzzi I. (2011) - *Valcuvia hay meadows and grasslands. First observations.*SBI - 106° Congresso Nazionale. Genova, 21-24/09/2011

Balduzzi I., Cavallo C.,, Corradi N., Ferrari M., Schiaffino C.F. (2011) - *Liguria pocket beaches: Bonassola case study (La Spezia, Italy).* GEOITALIA 2011, Torino, 19-23/09/2011.

Balduzzi I., Corradi N., Ferrari M., Vagge I. (2009) - *Applicazioni GIS per lo studio degli aspetti morfologico-vegetazionali del campo dunare di Capo Comino (Sardegna NE). Risultati preliminari.* – Proceedings of the "13 Conferenza Nazionale ASITA", Bari (IT), 1-4 December 2009.

Balduzzi I., Ferraris F., Firpo M. (2009) - *Applicazioni GIS allo studio di un bacino idrografico: il caso del Torrente Lemme (Alpi liguri).* – Proceedings of the "13 Conferenza Nazionale ASITA", Bari (IT), 1-4 December 2009.

Balduzzi I., Corradi N., Ferrari M., Ivaldi R. (2009) – *Seismic stratigraphy and drilling to identify submarine quarries suitable for artificial nourishment of beaches undergoing erosion: the case of Albenga-Loano (Western Liguria, Italy).* Proceedings of 27th Meeting of International Association of Sedimentologists (IAS 2009), Alghero (IT), 20-23 September 2009, p. 64 (abs).

Balduzzi I., Ferraris F., Firpo M. (2009) - *Morphometry and long profile analysis: the case study of the Lemme river (Ligurian Alps).* Proceeding of the 7th Italian Congress of Earth Sciences "GEOITALIA 2009", , 9-11 September 2009 Rimini (IT), p. 88 (abs).

Balduzzi I. (2009) – *Submarine quarry of Albenga-Loano: a sand and gravel source for beach nourishment*. Plinius 35: 7-9 (extended abstract).

Balduzzi I., Corradi N., Ferrari M., Ivaldi R. (2009) - *Transgressive submarine deposits for beach nourishment (Ligurian Sea, N.W. Mediterranean)* – 27th Meetings of Sedimentologists. Medimond International Proceedings, 49-54.

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Chapter 1
COASTAL DUNES: LITERATURE REVIEW

Coastal sand dunes are sedimentary deposits formed by the transport of sediment inland from the beach by wind action. In sediment budget terms, the beach is the source and the dunes represent the sink (Davidson-Arnott, 2010).

They range in size from small dunes less then 1 meter height and width, to massive dunefields. They may be a single vegetated ridge or small forms of a few meters in width and height alongshore in small rocky embayments, to a complex dune system that extends inland for many kilometers alongshore on sandy barrier systems or low coastal plains. All dunes are termed "aeolian" (wind formed) landforms that derives from the Greek word "Aeolus", the God of Wind (Hesp, 2000).

1.1. Coastal sand dunes, relevance and occurrence

The coastline is one of our most accessible natural assets and in particular sandy beaches and coastal dunes are taken for granted by the public.

For a long time, coastal dunes have been used for many different purposes: coastal defense, mining, housing and tourism, agriculture (Carter, 1991). In general we can resume the "natural" use of the coastal dunes as an essential store of sediment protecting the hinterland from storm erosion and potential sea level rise; with vegetation, they trap wind blown sand and stabilize beaches; they provide specialized habitats for plants, birds and animals; they represent one of the most dynamic natural ecosystems in our environment; they provide us with a range of unique landforms and ecosystems with high natural character value; they act as a filter for rainwater and groundwater, and provide a range of aquatic habitats (e.g. dune lakes)(Hesp, 2000).

The influence of humans on the coastal environment has occured for a long time. In particular, coastal habitation and recreation has increased in the last century and has led to the deterioration of many previously scenic coasts and well-preserved coastal ecosystems. Currently, a large proportion of the worldwide human population lives within 10 km of the coastline and there are many examples of the degree of modification to coastal dunes that has occured. As a result, many coastal dune systems of the world are in advanced stages of degradation, and in many cases native and endemic species have been eliminated and replaced by introduced exotics (Grootjans, 1997). Other coastal dunes have been completely removed to providing living space for humans and additional impacts associated with anthropic activities are water extraction, trampling, grass encroachment, sea-level rise and climate change.

Coastal dunes are distributed worldwide in association with sandy beach, producing a wide range of forms and dimensions related to spatial and temporal variations in sediment input and wind regime (Gimingham *et al.*, 1989; Nordstrom *et al.*, 1990; Carter *et al.*, 1992; Pye, 1993; Hesp, 2000). They occur on ocean, estuary and lake shorelines from the Arctic to the Equator (Fig. 1.1). Because they are found almost in all latitudes, the climate and biomasses developing are very different, covering ecological habitats which range from polar to tropical latitudes, and from deserts to tropical rain forests (Snead, 1982; van der Maarel, 1993; Kelletat, 1995).

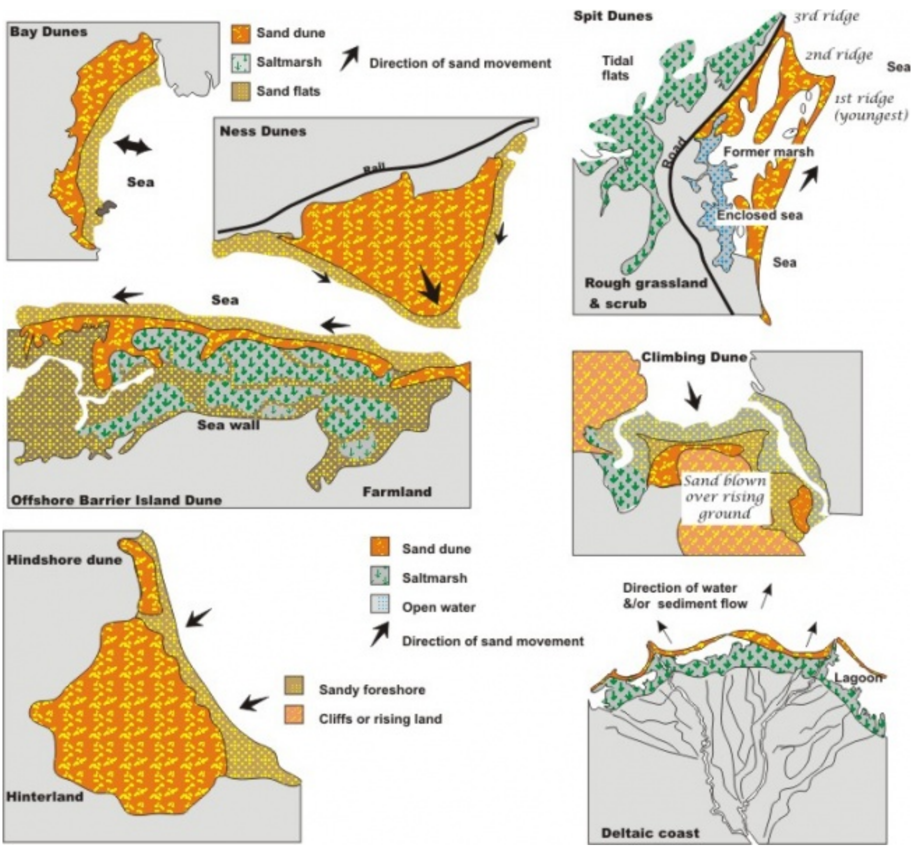


Figure 1.1 - Physical sand dunes types found along the coastline of Europe, from Ranwell and Boar (1986 - copyright J. Pat Doody).

1.2. Origins

The occurrence of dunes on the coasts appears unrelated to present climate but it is directly related to sand supply and a favorable wind regime.
Coastal dunes have formed over a variety of time scales, but most have been shaped in Holocene times from sand supplied to beaches from the sea floor (during the Late Quaternary marine transgressions) and alongshore sources (such as cliffs or glacial drift deposits) (Bird, 2000). Italian dunes can be situated in this context too.

The original sand source could be glacio-fluvial sediments, like on the Baltic Sea, Cape Cod in US, *etc.* or abundant fluvial sediments, as in Australia and the west coast of the USA.
Dune sands have similar characteristics to the beach sands from which they have been derived and generally consist of quartz, feldspar and calcareous particles, sometimes with heavy minerals.

1.3. Factors influencing dune development

Four major factors have been identified as being the most influential in dune development: effective wind direction, climatic conditions, the role of vegetation and sediment supply.
These factors have been discussed in the majority of the dune literature and authors place varying degrees of emphasis on their importance and influence.

1.3.1 Physical factors

Aeolian processes in coastal dunes

Coastal sand dunes are initiated and modified by winds and aeolian sediment transport. The most well known work about the nature of fluid processes associated with wind is by Bagnold (1941). After that one there were useful summaries by Pye (1983), Horikawa *et al.* (1986), Sarre (1987), and Nickling and Davidson-Arnott (1990).

The classic approach to wind flow and sediment movement relates sediment transport to the bed shear velocity u_* (u_* is proportional to the slope of the wind velocity profile when plotted with a logarithmic height scale, and related to the shear stress at the bed and the air density). In addition to the effect of surface roughness, wind flow direction and speed are also effected by the beach and dune topography, causing different velocity vectors along a vertical profile and the development of internal boundary layers.

The complexities on natural beaches result from the spatial and temporal variability of wind flow, the effects on rapid changes in topography which effect the wind speed and direction, physical factors such soil moisture and grain size composition, and the vegetation distribution.
Because the sediment movement is function of the shear stress velocity at the bed, initiation of sediment motion is generally related to some critical shear stress (τ). Bagnold (1941) in wind tunnel experiments found that the shear velocity at which sediment movement is initiated – called "threshold shear velocity" U_{*t} – is dependent on particle size and relative density.

In addition to the effects of grain size, other several factors may increase the threshold for movement of sediment by wind, like the presence of coating of fine sediment and organic matter, the effects of binding salts and the cohesion produced by the presence of moisture in the sand.

Concerning the modes of sand transport, aeolian sediment transport can occur as suspension, saltation and by rolling or sliding along the bed. Silt and clay particles are generally carried into the air and maintained in suspension by turbulence. Most sand transport occurs in saltation.

Coastal dunes classification

As indicated above, dune formation requires three essential factors to be fulfilled: (i) a prevailing wind above the threshold wind velocity, (ii) a supply of sand and (iii) a place in which it can accumulate. Concerning coastal zones, onshore and longshore transport supplies the sand and waves transporte it onto the beach. Differential cooling and warming between land and sea generally assures an onshore sea breeze wind in summer, regardless of the general wind circulation pattern (Goldsmith, 1978).

All those conditions vary on different beaches around the World and the sand dune formation varies according to the prevailing conditions.

Regional geomorphic studies of coastal sand dunes are quite abundant worldwide. Studies of cross-bedding and other investigations were made starting from Land (1964), Hayes (1967), Yallon (1975), etc. .

Characteristics of aeolian environments in general have been described starting from Smith (1960, 1968), Bigarella (1972), etc. .

Coastal sand dunes may be described and classified on the basis of either description (e.g. external form and internal geometry) or genetics (e.g. mode of formation).

The two main types of coastal sand dunes are (i) vegetated dunes (fixed or impeded) and (ii) non-fixed or migrating dunes.

Goldsmith (1978) devised a classification of four basic types: vegetated, artificially induced, medaño and parabolic.

Davies (1972, 1980) classified coastal dunes into primary (derived from the beach) and secondary (derived from erosion of primary dunes) types. In his scheme free dunes – including transverse, barchans, oblique ridges and precipitation ridges – were classified as primary and separated from transgressive dunes (blowouts, parabolic dunes, transgressive sand sheets). He noted that this scheme is not completely satisfactory because of the complexity that we can find worldwide.

Pye (1983) made a distinction between impeded dunes that are largely fixed in place by vegetation and transgressive dunes where vegetation is limited or absent. The term "transgressive dunes" was coined by Gardner (1955) in Australia to identify sand deposits which were actively migrating downwind and advancing over, or "transgressing" prior terrain. Actually, the term can be applied both to active and to stabilized dunes which can be moved inland over surfaces composed of forest, swamp, marsh, scrub, or bedrock, or into lagoons (Hesp and Thom, 1990).

In his model, Pye (1983) suggested five main types of transgressive dunes: transverse ridge (of which precipitation ridges – Copper, 1958- are a sub-type), barchans, transgressive sand sheets, parabolic dunes and oblique dunes.

In my work I will use the term "transgressive dunefield" more exclusively than the term described above, as suggested by Hesp and Thom (1990). Transgressive dunefield is here used to define a broad, active (when active) sand surface migrating landwards or alongshore. Note that transgressive dunefields can have various degrees of vegetation cover, and may become completetely stabilized and fully vegetated.

Beach-dune interaction

Beaches and coastal dunes are a dynamic system. The most important factor in coastal dune formation is beach width in relation to beach morphodynamics and lake levels (Davidson-Arnott and Law, 1990).

For coastal dunes the beach-dune interactions occur when onshore winds deliver beach sand to backshore dunes and when winds blow sand from the dunes to the beach, or storm waves erode sand from backshore dunes and incorporate it in the beach (Psuty, 1988). If storm waves are strong enough, the beach may be eroded and the seaward face of the foredune can be scarped. Then, as the sand is again returned to the beach by low energy waves, the eroded beach builds up, sand is blown landwards against the dune scarp and a ramp of sand eventually builds up against the eroded dune (Hesp, 2000) (Fig. 1.2).

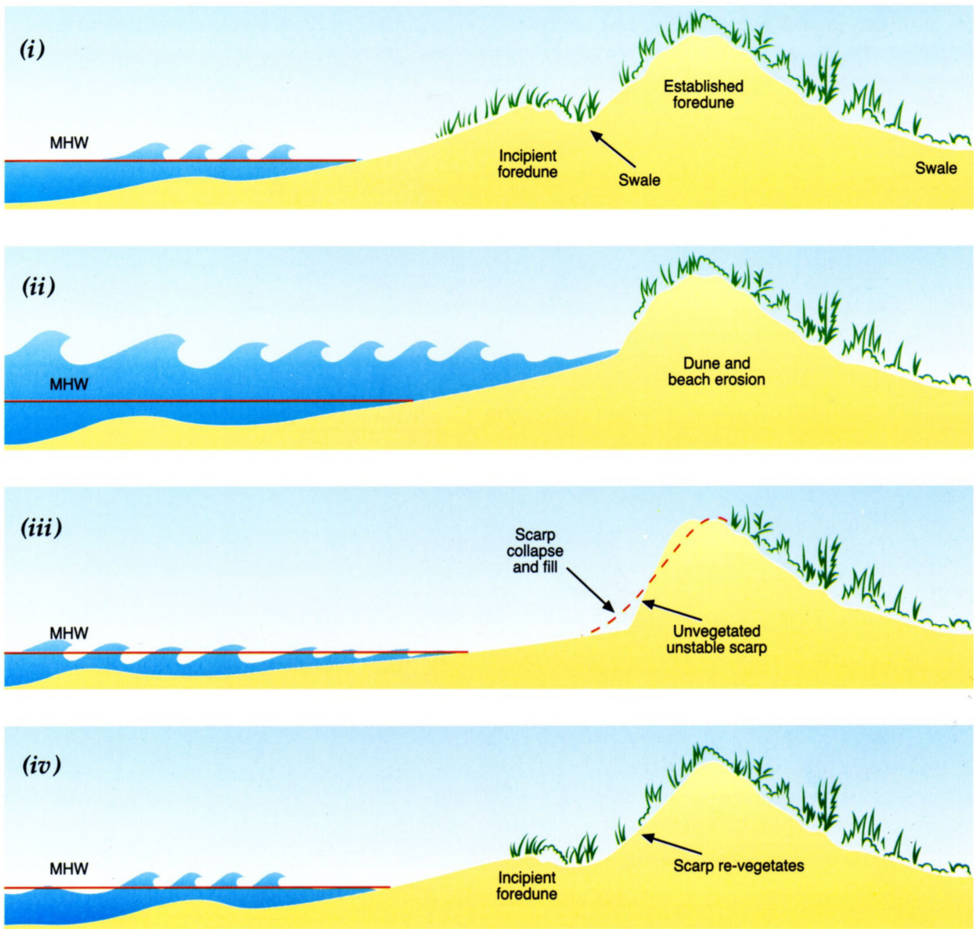


Figure 1.2 – The dynamic beach-dune system. (i) good weather; (ii) during storms the entire incipient foredune may be removed creating a scarpedforedune. Sediments moved seawards; (iii) calm weather returns and waves slowly transport sand back to the beach. The scarp is reduced by slumping and winds transport sand; (iv) over time the foredune stoss slope may re-vegetated and an incipient foredune forms (from Hesp, 2000).

The cycle of erosion and re-deposition of the dunes is quite normal and maintains the foredune as a barrier to the incursion of both sea and sand incursion.

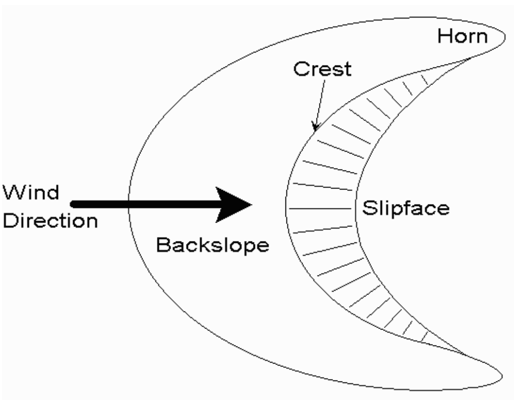
The amount of sand entrained by the wind depends on the strength of the onshore, oblique and alongshore winds and is limited by beach width. More sand can blow from the beach to a backshore dune by onshore winds arriving obliquely (Bird, 2000).

Grain size analyses show that beach sands are usually – but not always – finer and better sorted than beach sands, with positively-skewed grain-size distribution.

Types of dunes

The dune form reflects primarily patterns of wind flow and the degree of vegetation cover. Winds sweep sand from the beach to the backshore and the sand is carried until the wind velocity diminishes, the ground surface rises or vegetation is encountered.

The general anatomy of a barchans dune (Fig. 1.3) presents a simple terminology:



Backslope or stoss slope = slope of a dune which faces into the wind

Crest = sharp ridge at the top of a dune which separates the backslope from the slipface

Slipface = leeward side of the dune

Horn = the pointed end of a dune (where it is present)

Figure 1.3 - General anatomy of a barchans dune (Glossary of Physical Geography, 2011).

These morphological features may have different locations depending on the type of the dune and dune shape may be very different depending on the direction of blowing winds the response of sand movement, and the presence or absence of vegetation. It is possible to distinguish crescentic, linear, star, dome, parabolic, longitudinal (seif), reversing and complex dunes in the desert or continental dune environment, but star and longitudinal dunes are poorly represented in the coastal dune environment, where foredunes, blowouts, parabolic dunes or transgressive sheets and dunefields (which may contain barchans, tranverse dunes, barchanoids, and dome dunes, as well as a variety of other semi-vegetated dune types [e.g. nabkha, shadow dunes, remnant knobs, gegenwalle ridges, trailing ridges etc]).

Using Davies' classification and the following improvements, primary dunes are made up of foredune ridges and embryo dunes (widely defined as a "foredune system").

The foredune system consists (Fig. 1.4) of a generally continuous established foredune ridge (or few ridges) which runs parallel to the shoreline and any associated embryo dunes (also called "incipient foredune"; Hesp, 1983, 1989).

Embryo dunes may form at the toe of the seaward slope of the foredune ridge or on the backshore and separated from the foredune ridge. They represent the youngest dunes, from about few centimeters to 1-2 meters in height and width.

They form in a hostile environment for plants because of the salinity, the lack of humus and a pH of 8-9 (the alkaline pH is a consequence of the presence of shell fragments in the sand). This is also a very dry environment and the rapid drainage and exposed nature of the site make it difficult for plant growth.

On stable and eroding shorelines, embryo dunes are generally ephemeral features because of their proximity to the shore and they can be removed by wave action during storms.

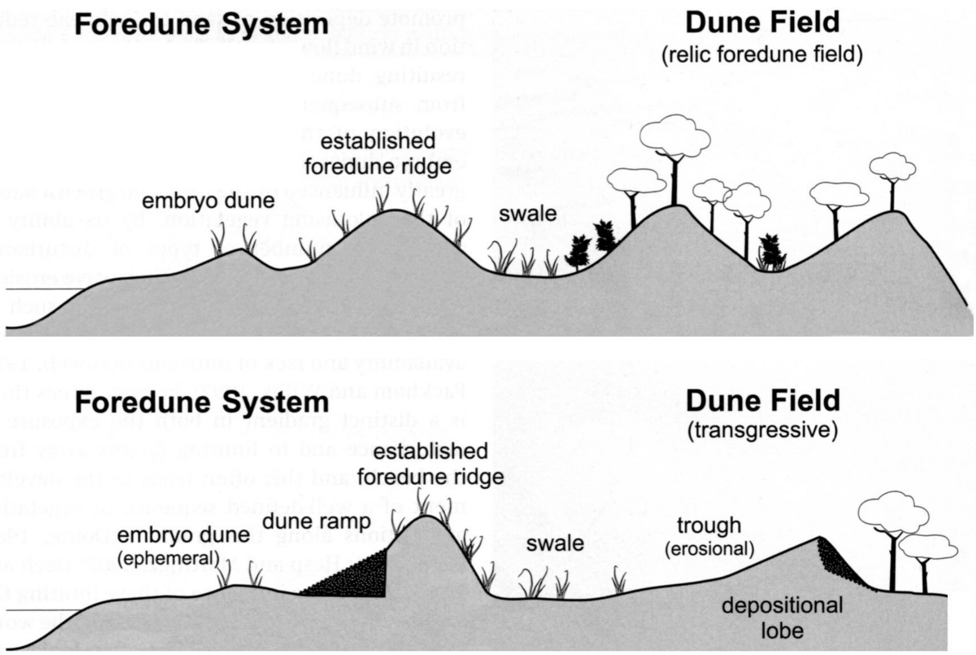


Figure 1.4 – Sketch of profile across (up) a prograding/stable beach showing the characteristics of the foredune systems with relic foredune ridges and (down) across a scarped foredune with dune ramp and active lee slope. A transgressive dunefield is localized landward (from Davidson-Arnott, 2010).

Low linear sinuous ridges result with wide empty spaces in between (Hesp, 1989). In a simple model of a foredune system where there is a beach progradation, the density of culms is low initially but it increases over time and small embryo dunes eventually coalesce into continuous ridges, developing into a new foredune.

Just shoreward of the embryo dunes are the older and slightly higher dunes called "foredunes" or "established foredunes". Foredunes are ridges of sand built up at the back of a beach, where dune grasses have colonized and are trapping blown sand. The vegetation acts as an obstacle to the wind, decreasing the velocity close to the ground and creating a sheltered environment within which blown sand is deposited (Goldsmith, 1989).

Dunes increase in height, expand horizontally and may eventually coalesce (if they began as discrete or semi-discrete nebkha), to form an established dune ridge usually parallel to the shoreline.

The time for the transition for an incipient to established ridge can vary according to the sediment supply, wind velocity, climatic conditions, composition of vegetation, plant height and density and human impact (Maun, 2009).
However, incipient and established foredunes may be vegetationally distinct, because they are colonized by different and specific species.

Scarping of the seaward margin of coastal dunes and the absence of new foredunes (or the formation of new foredunes lasting at most a few years) is very widespread around the world's coastline, as a consequence of the modern prevalence of beach erosion (Bird, 2000, EUROSION, 2004; AA.VV., 2006). Dune cliffs recede with sand collapsing on to the beach or into the sea; they may stand vertically if the sand is coherent and moist, but as it is dries it falls to a basal apron. After the formation of a dune cliff, a renewed accretion of sand may occur blowing from the beach and banked against the cliffed dune during calmer weather (Fig. 1.5).

Figure 1.5 – Erosion of foredunes in Capo Comino beach and accretion of sand blown from the beach.

The youngest dune ridge parallel to the shore is usually called “first dune ridge” or “first foredune ridge”. On some coasts there are multiple dune ridges, usually running parallel to the coastline, that have formed successively as foredunes behind a prograding sandy beach. They are characterized by elongated swales or troughs separated by ridges. Swales develop as limited depositional zones as the seaward ridges become higher due their predominance in trapping sand (Hesp, 2000).
The height and spacing of parallel foredunes is a function of the rate of sand supply to the shore, the history of the cut and fill and the effectiveness of vegetation in building the dunes.

Dune forms that are found in dunefields landward of the foredune system make up the secondary dune system, derived from erosion of primary dunes according to Davis (1972 and 1980) but blwoouts also form within foredunes.
Dunes that have been stabilized by vegetation may subsequently be eroded and re-shaped by the winds in areas where the vegetation cover has been weakened or removed, either naturally (e.g. by increasing aridity) or as the result of disturbance of human activities (Hesp and Thom, 1990; Bird, 2000). The result is the development of a variety of secondary forms from small bowl-shaped, saucer-shaped and trough-shaped blowouts (only a few tens of meters across) to large elongated parabolic dunes (hundreds of meters in length), to migrating free forms such as barchanoid ridges, transverse ridges or large sand sheets (from more than 1 kilometer in length to hundreds-thousands of square kilometers).

Mosaics of stable, vegetated dunes and unstable dunes may develop as the result of partial stabilization of drifting sand by the arrival/introduction of vegetation or as the result of the disruption of formally well-vegetated dunes (e.g. by climate change, fire, wind erosion, trampling and grazing on dunes).
In addition to blowouts and parabolic dunes there are broader transgressive mobile dunes, forming where sand blown from a beach has been retained by vegetation (Bird, 2000) or,

alternatively, where previously vegetated dunes have been disrupted by numerous blowouts until they merge into an elongated dune, spilling inland (Hesp and Thom, 1990).
Transgressive dunes are extensive on desert coasts but they are also found in humid regions where the sand supply is large enough to prevent their stabilization by vegetation (Borowca, 1990; Hesp and Thom, 1990).

Hollows in dune topography are usually occupied by dune lakes (or dune slacks), some of which may be intermittent, forming only when the water table rises after heavy rains. They are usually round or oval in shape as the result of wave and current action generated on them by wind action (Ranwell and Boar, 1986). Infilling of dune lakes may occur by blown or inwashed sand or by the formation of peat deposits. The result is a flat-floored enclave within stabilized dune topography.
The environmental conditions in the slacks differ from those of the dunes because of the coarse texture of the substrate, the proximity to the water table and the higher soil moisture.

Morphological components
At the broadest scale, we can recognize two types of morphological features: erosional features and depositional features.

Concerning erosive morphologies, these include deflation plains, slacks, deflation ridges and remnant knobs.
Deflation basin (or plains) and slacks are commonly found in migrating transgressive dunefields. They are wind-eroded deflated hollows quite elongate and they form relatively extensive flat to slightly concave surfaces.
Slacks usually evolve in the same manner but they are distinguished by the occurrence of groundwater at – or near- the surface (Tansley, 1949; Salisbury, 1952).
Along few Australian coasts, deflation basins and slacks commonly develop via a temporal sequence (Hesp and Thom, 1990).
Deflation ridges are long, elongate, coast-parallel narrow ridges due to differential rates of removal of different sized sediments. It is possible to find them covered by pumice pebbles.
Remnant knobs - also called “turret dunes” by Olson (1958) or “remainié dunes” by Guilcher (1958) - are the consequence of the non-uniform process of deflation and erosion of a pre-existing dune terrain (Figs. 1.6 and 1.7). They are sandy mounts or knobs, partially to fully vegetated, that once formed part of a particular dune type or a more continuous vegetated dunefield. The species and habit of colonizing vegetation can be a critical factor in determining knob morphology and evolution.

Figure 1.6 – Remnant knobs in Capo Comino dunefield.

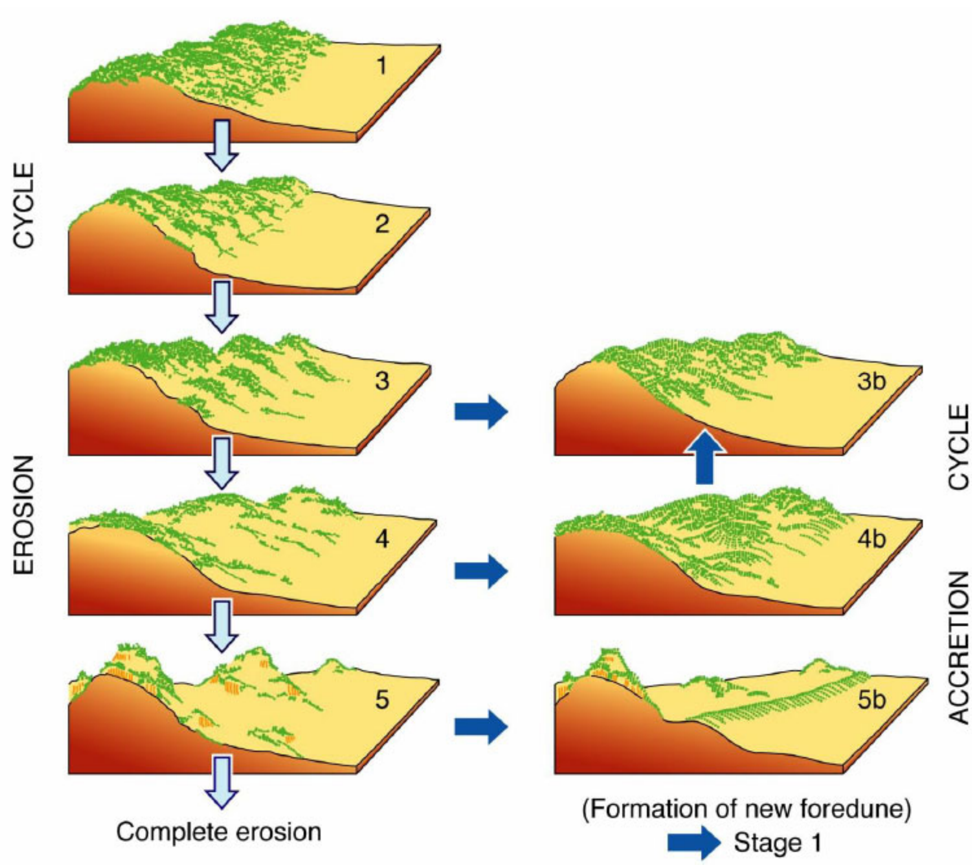


Figure 1.7 - Erosion cycle in a foredune system and formation of remnant knobs. In a following stage it is possible to have the formation of a new foredune (from Hesp 1988, 2002).

After the deflation basins/slack develop, a variety of ecological and morphological changes may take place. In regions where aggressive pioneer species are present incipient foredunes may rapidly reform on the seaward margin of deflation basins. Deflation basins may also be revegetated in a successional sequence (see §3.2), determining the formation of depositional morphologies, e.g. Gegenwalle ridges, described by Paul (1944).

Gegenwalle (literally "counter ridge") ridges are formed where pioneer plants colonize the downwind edge of an active deflation basin or slack. They are "counter" ridges because they are typically formed when the wind blows either offshore or opposite (counter) to the dominant onshore or down-dunefield winds. When this occurs, sand is transported off the dunes back onto the deflation basin and trapped in the marginal vegetation, forming a ridge. David *et al.* (1999) describe the same form as "dune track ridges".

Trailing ridges represent a depositional morphology too. They are formed by vegetation colonisation of the lateral margins of active transverse/barchanoid/parabolic dunes. Pioneer plants initially establish on the basal flank of the ridge; then they grow up and colonize the mid to upper portion of the slipface flank. As the dune continues to migrate downwind, other species colonize and stabilize the flank, while the inside portion of the newly forming ridge begins to erode. The dune migrates downwind leaving a marginal trailing ridge in its wake. Further shrubs and trees may colonize the older portions of the ridge (Hesp, 2000).

The transgressive dunefield is usually bordered on margins by the precipitation ridges (Cooper, 1958 and 1967), where sand "precipitates" or rains down into the shrub and forest margins. Such ridges are primarily formed by the classic physical processes of free sand precipitation – maybe into marginal forests. After this process, portions of this edge of marginal slope may be colonized by plants.

Various types of dunes, including coppice dunes and shadow dunes and a variety of other topographies may also develop in deflation basins and on active transgressive dunefields.

Many of the erosional and depositional morphologies presented in this paragraph are recognizable in Capo Comino dunefield.

1.3.2 Biotic factors

Plant communities of coastal dunes

As stated previously, vegetation has a basic role in coastal dune formation and development. In fact, vegetation serves both to promote deposition of sand through the reduction in wind flow near the bed and to stabilise the resulting deposit by sheltering the bed from subsequent blowing.

In coastal dune complex plan communities are a result of interaction between tolerance of plant species and sand substrate, temperature range, high wind velocities, salt spray, burial by sand and environmental heterogeneity. Species able to colonize coastal sand dunes are called "psammophile" (arenophile, a sand-loving organism).

In most dunes there is a distinct gradient in both the exposure to disturbance and to limiting factors and this leads to a well-defined sequence of vegetation associations along this gradient (Doing, 1985; Hesp, 1991; Géhu and Biondi, 1994a,b; Dech and Maun, 2005; Hesp and Martinez, 2008). This sequence often looks very similar along the worldwide coasts because of the nature of adaptation even though the plant species themselves may be different. At the same time, some species form the dominant colonising vegetation type, e.g. *Ammophila sp*. and I*pomoea sp*. .

The occurrence of plant communities in zones have been documented worldwide along sea coasts (Géhu, 1978; Doing, 1985; van deer Maarel, 1993; Doody, 1991; Thannheiser (1984); Rivez-Martinez *et al*., 1992; Biondi, 1999, 2007; Maun, 2009).

Limiting factors

In order to survive and colonize coastal dune environment, vegetation has to adapt to extreme conditions. Saltiness and sea proximity are limiting ecological factors, but most of all aridity and overheating are important for living beings survival.

Even within a dune system there is a disparity in radiative heating of different habitats that is manifested as variation in micro-environmental factors such as relative humidity, temperature, light, moisture content and wind turbulence. The major factor affecting these changes is the establishment of vegetation (Maun, 2010).

The aridity is because of the sand and its granulometric characteristics, which keeps only a scant quantity of water and for a short time. The heating is mostly related to the solar incidence radiation on the sand surface. Moreover there is a connection between those two factors: the heating favours the evaporation of the quantity of water of the soil contributing to its dryness, and the beach overheats because of this aridity.

During summer soil temperature may be very different across a beach-dune profile. Temperatures close to the shoreline are less than water temperatures (22-25°C) and air temperatures (25-30°C) because of the evaporation and its refreshing effect on the soil. Landwards across the profile soil temperatures may keep 48-50°C until more than 60°C on the dunes. This situation hampers the vegetation growth because it's impossible to find water for metabolic maintenance.

From seashore side to landwards in a dunefield there is a progressive growth in woody species because they are more exigent from an edaphic point of view and more sensitive to marine aerosols. In fact, fixed dunes' soil presents a fraction of clay and mud that is able to keep a higher quantity of water than sand soil.

In order to adapt to those ecological conditions vegetation developed several adapting strategies:

- <u>Succulence</u>

Some beach species, such as *Calystegia soldanella* and *Cakile maritima* (Fig. 1.8), are characterized by fleshy parts where it's possible to conserve small quantities of water. Succulence is peculiar to a lot of halophilic species, commonly found on dunes, lagoons and salt marshes.

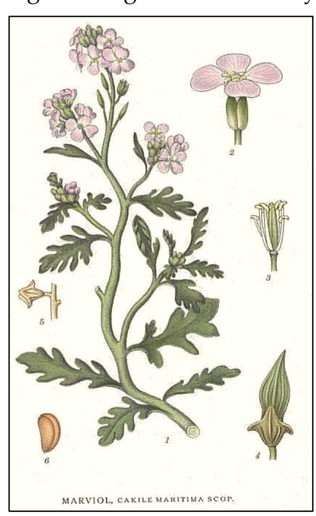


Figure 1.8 - *Cakile maritima* (Lindman C.A.M.: "Bilder ur Nordens Flora", Stockholm, 1917-1926)

In this specific situation, succulence is fundamental for determining high osmotic pressure levels able to absorb water in oversaturated salt soils.

- Hairyness

Species such as *Otanthus maritimus* and *Medicago marina* (Fig. 1.9) have leaves and stems covered by a thick hair blanket protecting from an excessive transpiration. Moreover the hairyness has a reflecting effect against solar radiation, avoiding an excessive overheating of the vegetal tissues.

Figure 1.9 – *Medicago marina* (left) and *Otanthus maritimus* (right).

- Creeping root stocks under the sand

Several species, such as *Ammophila littoralis, Cyperus kalli, Agropyron junceum* and *Sporobolus pungens* from *Graminaceae* Family, are able to avoid their root systems from the extreme temperatures of the superficial sand developing a huge buried system (Fig. 1.10). Moreover, those species present the base of the culm enveloped in a muff-like leaf sheath against overheating. This root system may reach a huge dimension and it's able to generate new entities and react against the burial of sand with a vertical growing in order to develop close to the superficial sand and to let out new shoots.
Species with root systems growing in vertical and horizontal direction are able to trap the sand blown by the wind, and to participate in dune development.
Other species present this type of root system, even if less powerful than those of the *Graminaceae* Family.

Figure 1.10 – *Agropyron junceum*'s root system. New shoots are present on the left side of the picture.

Besides them, we can mention *Eyingium maritimum, Euphorbia paralias* and *Echinophora spinosa*. *Pancratium maritimum* (Fig. 1.11) has a undergroung reserve organ, the bulb, that allows to survive to burial of sand and to easy reproduce itself by vegetative way.

Figure 1.11– *Pancratium maritimum.*

- ❑ Leathery leaves

Salsola kali, Echinophora spinosa, Crucianella maritima and *Eryngium maritimum (*Fig. 1.12) have a very thick cuticle and a scant number of stomata, concentrated in the lower part of the leaf. This strategy limits the loss of water with transpiration. For the same reason, leaves often have small dimensions or even to be transformed into prickles (the photosynthetic function is conducted by herbaceous stems.

Figure 1.12 – *Eryngium maritimum* (Otto Wilhelm Thomé: "Flora von Deutschland", Österreich und der Schweiz, 1885).

❑ Annuality

This temporal adapting strategy pertains to few species - such as *Ehphorbia peplis, Silene colorata* and *Vulpia fascicolata* – to carry out their living cycle during the winter-spring period, when temperatures are not high and the hydric ressources of the vegetation are not compromised by dryness. Moreover, rains are more frequent.
They spend the unfavourable season as a seed and they eliminate buds during the critical period of the year (Pignatti, 1994).

The study of adapting strategies of halophilic and psammophile species is one of the most interesting branches of vegetation ecologicy and the arguments presented in the previous pages are only a few concepts about it.
However, it's possible to understand the high specialization degree of those species and their value like bioindicators of the environmental conditions. As for the species, phytocenosis have a specific ecology and colonize very limited ecological niches. The changes of the limiting factors' gradient determine a succession of populations and vegetation types (Biondi and Andreucci, 1991; Maun, 2009).

The classic model of plant succession on dunes (Cowles, 1899) emphases the role of a succession of plant species in increasing stabilization of the surface through time.The model has some validity for progradational dune systems but it is now recognized that temporal evolution at any location is likely more a reflection of spatial evolution of the dune system leading to a reduction in disturbance and limiting factors (such as exposure to salt spray and moisture stress) (Géhu and Biondi, 1994b; Hesp and Martinez, 2008; Miyanishi and Johnson, 2007; Miot da Silva *et al*., 2008; Davidson-Arnott, 2010).

Theoretical succession of vegetation

Plant communities of the dune complex are a result of interaction between tolerance of plant species and sandy substrate, wind velocities, salt spray, sand accretion and environmental heterogeneity (Fig. 1.13).

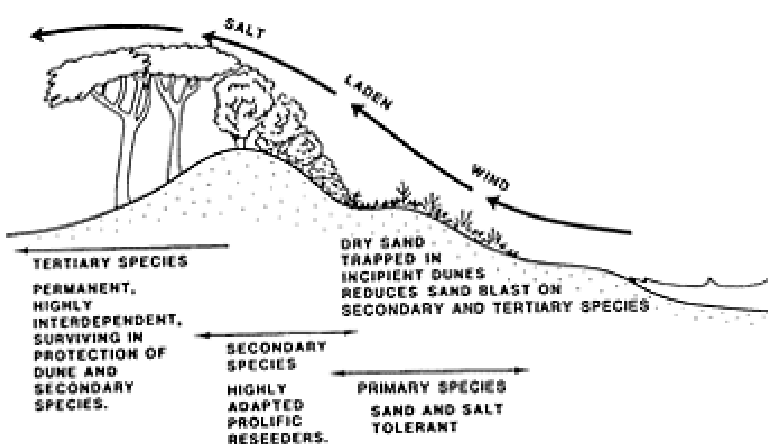


Figure 1.13 - Coastal sand dune vegetation: niches and function (Chapman, 1989).

In the different regions of the World the boundaries between vegetation zones of the dune complex may not be clearly defined because of climatic variability, geographic location, physiography of the dune system and other factors peculiar to each location (Maun, 2009).

In order to simplify the discussion, the following will be focused on Mediterranean coastal vegetation(Géhu, 1986a; Filigheddu and Valsecchi, 1992; Géhu and Biondi, 1994a; Brullo *et al.*, 2001), even if several similarities with the Atlantic vegetation and other global widespread communities are listed.

Usually from three to six different plant communities have been identified in the Mediterranean coastal area (Fig.1.14).

The vegetation communities are listed below and the vegetation is distributed in a catenal succession:

- Intertidal communities;
- Primary dunes' vegetation communities ("incipient" or "embryo" dunes in a geomorphological context);
- White dunes' vegetation communities;
- Gray dunes' vegetation communities
- Brown dunes' vegetation communities.

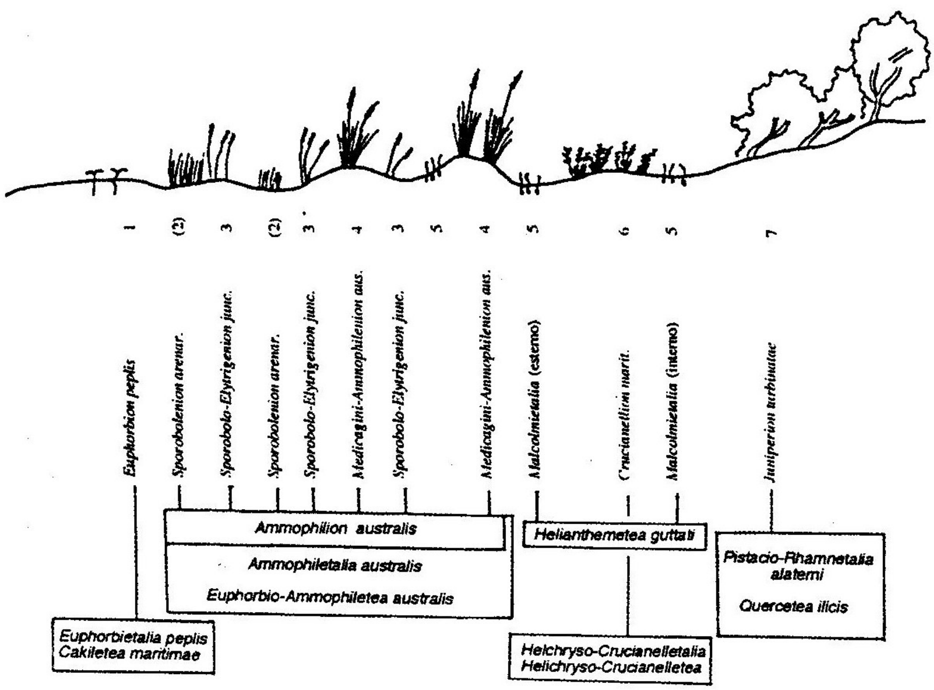


Figure 1.14 – Succession of vegetation associations in Mediterranean coastal dunes. Profile across beach-dune system (from Géhu and Biondi, 1994a).

1) Backshore zone

The first plant communities feature on the backshore zone and develop up to the high spring tide line where waves and currents leave the organic matter and the marine detritus/debris. After their decomposition, they will leave the nutrients to the soil growing the hydric retention of the substratum and permitting the living beings development. Colonizing species are annual and halo-nitrophilic plants and they need to grow with a specific range of salt and nitrate components (Watkinson and Davy, 1985; Doing, 1985; Maun, 2009). They are also called "pioneer species".

The most common species are *Cakile maritima, Salsola kali*, *Euphorbia peplis* and *Polygonum maritimum*. They are present along the entire Mediterranean coasts in a paucispecific association constituted by ephemeral and annual species and they usually start to grow from late-spring to the beginning of summer. These communities are characterized by a high fragmentariness with a very low covering index (usually only 5%).

Even if those communities are quite unstable, they are a first obstacle to the blowing sand but this zone is subjected to frequent erosion and renewal of the substratum by wind and wave action and depending on the intensity of seasonal storms and sea levels.

The pioneer species evolved several common adaptative traits that include a short-life cycle, ability to survive under harsh conditions, high fecundity, good dispersal ability, high phenotypic plasticity, seed dormancy and large seed mass (Barbour, 1978; Keddy, 1981; Peyne and Maun, 1981, 1984).

2) Embryo dunes or incipient foredunes

Above the intertidal zone the first sand accumulations appear and they are only occasionally reached by wave action and sea spray. Those first sandy domes or ridges are called "embryo dunes" or "incipient dunes" and they are colonized by few species of *Graminaceae* Family, such as *Agropyron junceum* (or *Elytrigia juncea*) (Géhu, 1986b; Géhu and Géhu-Frank, 1993). These plants are psammophile perennial species and, because of their growing method, they are able to withstand the high salinity and to trap part of the blowing sand. Moreover, they have a very low-developed sub-aereous portion and a very developed and branched buried system able to trap high quantities of sand.

In order to fight the burial of sand (up to 30 centimetres per year), *Agropyron* develops some vertical roots that stop their growth when they reach the soil surface and let out some new hardy leaves. Moreover this species is able to fight the transpiration thanks to the mechanical tissue (cuticle) of the leaves and to the presence of stomata in the leaves, covered by protecting hair.

Furthermore *Agropyro*n needs to space out its root system from the salty water-bearing stratum because of its proximity to the sea. Its strategy is a horizontal development of its root system close to the soil surface.

The covering index is discontinuous but it is possible to reach the 70% of the total covering.

Other common species in the Mediterranean region are *Echinophora spinosa, Calystegia soldanella*, *Eryngium maritimum, Medicago marina, Euphorbia paralias* and *Sporobolus pungens.*

3) White dunes (established foredune)

The next vegetation community both creates and develops on white dunes (or first foredune ridges). These ridges are already composed by free sand, strongly influenced by blowing winds that may transport the sediment landwards.

The developing of white dunes starts with a herb from the *Graminaceae* Family, called *Ammophila arenaria*. This herb is able to grow in a vertical and horizontal direction and it is a colonizing and stabilizing species but the burial of sand needs to be not very fast.

Even if *Ammophila* belongs to the same Family of *Agropyron*, there are a lot of differences between these two herbs. *Agropyron* develops isolated culms and its leaves are droopy and often close to the soil surface. *Ammophila*, instead, has some erect and hardy culms which reach up to 1 meter high and some straight leaves forming tall and thick clumps.

This special conformation is an obstacle to the blowing sand and its deposition raises the height of the dune and *Ammophila*'s stems and leaves grow in order to be not buried. So the dune height increases.

Ammophila's communities present a covering range between 50 and 80% and they are associated with other species, such as *Silene corsica*, *Eryngium maritimum, Cyperus kalli, Euphorbia paralias, Echinophora spinosa* and *Pancratium maritimum*.

4) <u>Gray dunes (fixed foredune ridges or other younger dune types)</u>

Gray dunes are constituted by the first fixed foredune ridges. In actual fact, they are gradually stabilized landwards because the blowing of sand is quite completely stopped and the erosive wind phenomena result less strong thanks to the vegetation covering (grasses and shrubs but also lichens and mosses that give to the soil a gray colour).

Ecological conditions result more favourable than in the embryo and white foredune ridges. The species of the free foredune ridges disappear and a less-specialized vegetation community appears, composed by few chamaephytic species, such as *Crucianella maritima* and *Helychrysum italicum* subsp. *microphyllum*.

These communities mainly develop on the landward slope of the foredune ridge and they are extremely vulnerable. If white dunes erode, they may be affected bysalty spray and blowing sand.

5) <u>Brown dunes (or older dune types)</u>

Brown dunes are localized in the inner sector of the dunefield, where a thin layer of acid humus gives to a brown colour to the soil. They are mainly colonized by maquis and grassland and, in a more evolutive dynamic succession, by high shrub and wooden formations.

The most advanced evolutionary stage is represented by *Juniperus turbinata*, joined to shrubs such as *Erica arborea, Arbutus unedo* and *Pistacia lentiscus* and creepy species such as *Smilax aspera* and *Rubia peregrina.*

These formations are thick and dominated by *Juniperus* that presents more than 90% of covering range.

6) <u>Slacks and interdunal areas</u>

Interdunal areas are flats, plains, basins and slacka forming between two dune ridges where the water table is also sometimes able to reach the soil surface and to form some little low-deep pools. This environment may set up a humid system, completely different from the dunes.

These pools (or wet slacks) may be seasonal and they are fed by rains too, that flow down and erode the substrate from the top to the dune base. The thinnest materials and the organic matter from plant decomposition are involved in this process. Moreover CO2-added water is lightly acid and it's able to dissolve the calcium carbonate present in sand and shells. The result is a flushing process and the interdunal areas compact themselves. Mud and clay accumulate in the soil and the water table is consequently facilitated to rise by capillarity.

Due to its proximity to the sea, the water table is characterized by salt water infiltrations. Its salinity is strictly related to seasonal variations: during the winter season, when rains are more frequent, the water is almost fresh and during summer period is almost salty because of the strong evaporation and the rising up of the brackish water. Therefore the salty superficial level grows.

After a few decades, in the interdunal areas the environment is totally different from the surrounding dunes. Concerning the vegetation species, we can find halophilic and halo-tolerant species.

These systems have a very important environmental value and they have been rapidly degrading during the last few years because of the human-induced changes.

Chapter 2
CHARACTERISTICS OF CAPO COMINO DUNEFIELD

2.1 REGIONAL SETTING

Sardinia is the second island in the Mediterranean Sea (24090 sqkm– only Sicily is bigger). The island is dominated by the Gennargentu Range (culminating at 1834 m, highest elevation in Sardinia), along with the Monte Limbara, Monte di Ala', and Monte Rasu ranges (all below 1500 m); isolated are the Sulcis-Iglesiente hills (1236 m) of South-western Sardinia, once home to a large mining district.

Plains are quite rare and reduced in extent, with the exception of the Campidano Plain from Oristano to Cagliari, which divides the main hill system from the Sulcis-Iglesiente, and the Nurra plain in the northwest (between Sassari, Alghero, and Porto Torres), which was once a mining district and quite forested, but is today mostly given to pasture.

The hydrographic basins are typical of Mediterranean regions: there are not many rivers (Flumendosa, Coghinas, Cedrino, Liscia, Temo and Tirso) but a number of torrents. Their stream lengths are quite small because mountains are very close to the coasts. They are subjected to flooding during the late fall and to a dry period during the summer (www.sardegnaterritorio.it). There are 54 artificial lakes and dams which supply water and electricity.

Sulcis proper (in the extreme Southwest) was a marshy area where malaria was still present during the 1940's. Cagliari's neighbourhood is also flat and boggy; exploitation of salt is a major industry there.

Coasts are generally rocky and tall, especially along the Eastern half; large beaches are found however on the North and North-east (Logudoro and Gallura), the South (from Teulada to Pula) and the South-west (Sulcis-Iglesiente). Apart from the Strait of Bonifacio which divides Corsica from Sardinia, the surrounding sea is quite deep at short distances from the shore.

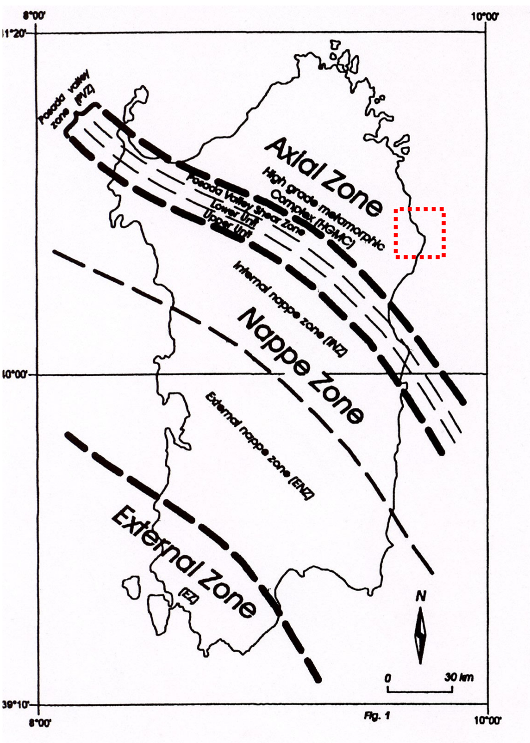
2.1.1 Geological setting

Sardinia is actually characterized by the most complete Palaeozoic succession present in Italy, called the "Sardinian basement". Its characteristic rocks formed during the Hercynian orogenesis that produced deformations, metamorphic and huge effusive and intrusive magmatic processes (Fig. 2.1 - right). The complex structural setting leads to some difficulties in reconstructing the original stratigraphic sequences.

The current position of Sardinia was determined by the anticlock-wise rotation of the Sardinia-Corsica Block (18-19 Ma ago) (Gasperi, 1995).

The tectono-metamorphic characteristics allow one identify four zones oriented in a NW-SE direction: the External Zone (Foreland), the Nappe Zone, the Posada Valley Zone and the

Axial Zone (or HGMC) (Elter and Sarria, 1989; Elter *et al.*, 1999; Carmignani *et al.*, 1994, 2001; Corsi and Elter, 2006) (Fig. 2.1 - left).



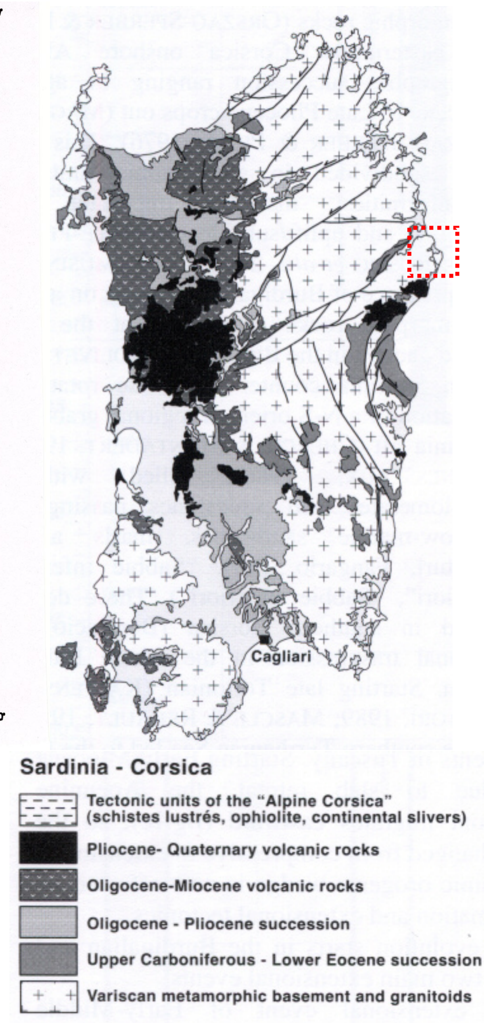


Figure 2.1– Tectono-metamorphic zones (left – Corsi and Elter, 2006) and tectonic sketch map (right - Carmignani *et al.*, 2004) of Sardinia (red rectangles: Capo Comino area).

Capo Comino is located in the Axial Zone, where the highest-grade metamorphites and the largest late-Hercynian intrusions crop out (Carmignani *et al.*, 1986; Elter *et al.*, 1999) (Fig. 2.2). The study area is characterized by the presence of two main rocks: at E, the Grt-bearing leucogranites (Upper Carboniferous-Permian plutonic complex) and at the W side of the beach by the Grt-oligoclase and Grt-Ab michaschists and paragneisses (Paleozoic) of the Hercynian metamorphic complex (with dominant amphibolite assemblages). Their contact is highlighted by the presence of a Tertiary strike-slip fault (red line in Fig. 2.2).

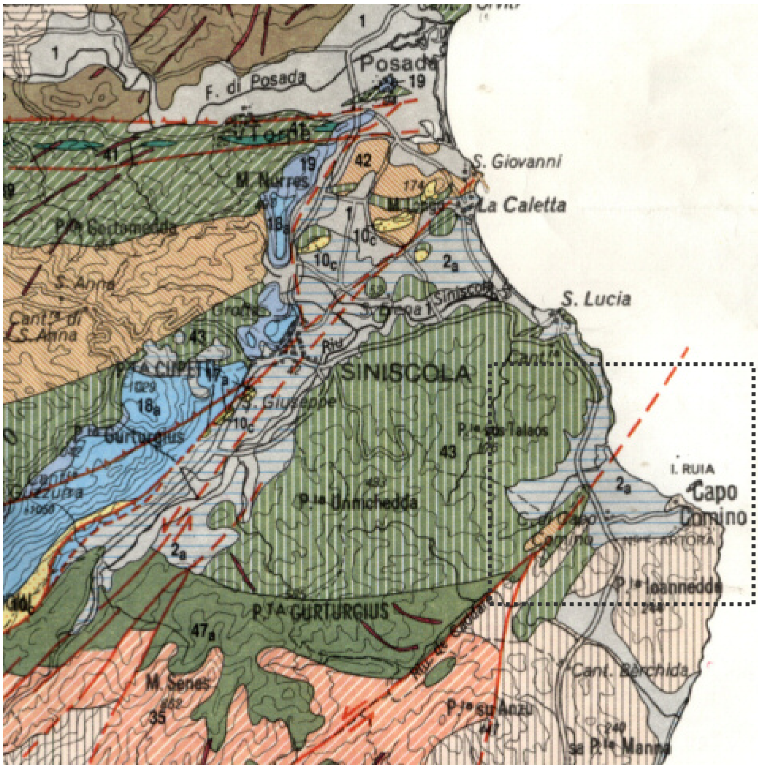


Figure 2.2 - Geological map of Capo Comino area (from “Geologic map of Sardinia”, 1996).

1: Alluvial, colluvial, aeolian and littoral gravels, sands, silts, sandy clays, travertine.
2a: Eolian sandstones (Pliocene-Pleistocene?)
10c: Continental conglomerates and sandstones (Ussana formation)
Middle Triassic p.p. – Lower Cretaceous marine and transitional succession
  18a: Carbonatic shelf deposits: dolostones and limestones
  19: Dolostones, sandy dolostones, dolomitic limestones of littoral to circalittoral environment
Upper Carboniferous-Permian plutonic complex
  26: Grt bearing leucogranites
Hercynian basement
  Intrusive complex
    35: Foliated granitoids, mostly tonalitic granodiorites and tonalites (Monte Senes)
  Hercynian migmatitic complex
    36: Leucocratic migmatites, nebulites, agmatites, gneisses, with calc-silicate lenses
  Hercynian metemorphic complex with dominant amphibolite assemblages
    42: Granodioritic orthogneiss
    43: Grt-oligoclase and Grt-Ab michaschists and paragneisses (Paleozoic)
  Greenschist and Sub-Greenschist facies Hercynian metamorphic complex
  Terrigenous sedimentary rocks of uncertain age
    47a: Metasandstones, quartzites and phyllites

Coastal deposits

Several coastal deposits related to the Quaternary eustatic oscillations were found along Sardinian coasts (Ozer, 1975, 1977a,b; Ozer and Ulzega, 1982; Carobene and Pasini, 1982; Andreucci *et al.*, 2006, 2009; Ginesu 2007, 2008).

The sea-level oscillations characterized all the Pleistocene period and in particular coastal deposits developed when Mean Sea Level was higher than the actual one. They are called "Tyrrhenian" deposits and are characterized by conglomerates and calcarenites.

Two different deposits of this age were found in the study area and they are distinguished by: (i) marine sediments: deposits laying on the alluvial terraces because of the sea ingression phenomena; and (ii) alluvial terraces (Fig. 2.3).

On the other hand, when the MSL (Mean Sea Level) was lower than the actual one (last glacial maximum), coastal zones presented wider surfaced areas, physiographic units and deflation areas were bigger and a huge volume of sediments was potentially available. Pleistocenic eolianites originated during glacial-interglacial cycles.

During the Versilian transgression (18000-8000 BP), the Pleistocenic sediments were recast and moved back to inland. The position was related to the retrograding process of coastal systems during the sea level rise.

Capo Comino coastal dunes include the Pleistocenic eolianites (Fig. 2.3) and the Holocene sand dunes. In fact, the Capo Comino area is indicated as a very high Holocene sedimentation area in the "*Carta Geomorfologica della Sardegna marina e continentale*" (scale of 1:500000, 1988). The main current deposits are sandy ridges, well-sorted and characterized by a high mineralogical maturity.

Salty soils with a silty-sand matrix are present in the study area and result from the filling of swamps at the back of dune ridges. These areas are subjected to seasonal floodings and dry periods.

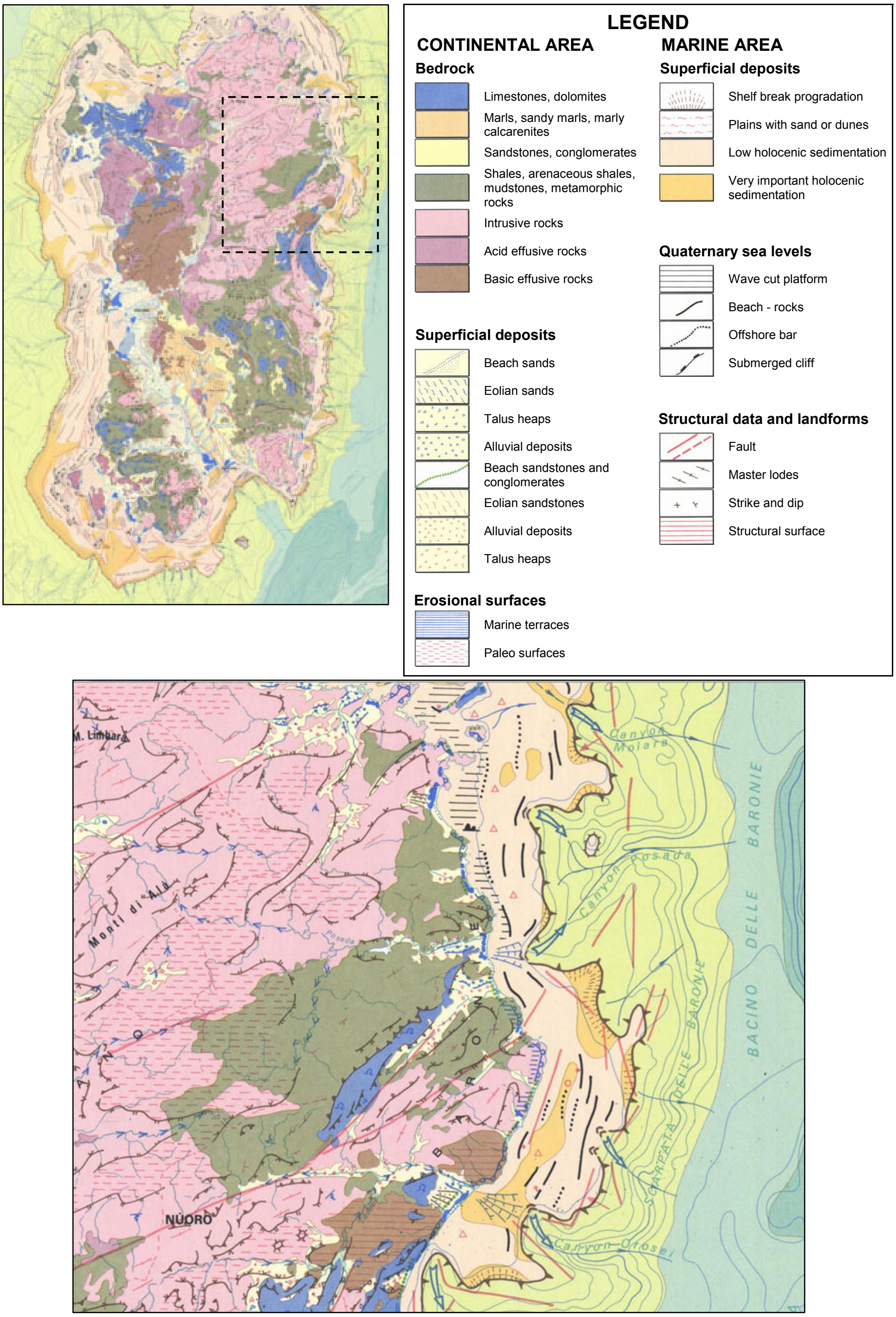


Figure 2.3 – Geomorphological features of Capo Comino area (*Carta Geomorfologica della Sardegna marina e continentale,* 1988).

2.1.2 Geographic setting

From the geographical point of view the study area is mapped in sheet 195 of the Atlas of Italian Beaches (scale of 1:100000) (Fig. 2.4). This atlas is a very useful tool for a general overview because it shows the main natural forms and dynamic processes occurring on the coasts.

Siniscola is the main built-up area (left side in Fig. 2.4) of the area, belonging to the northern *Baronia* (called "Baronia di Siniscola e Posada"). This is a mediaeval region coming from the central of Sardinia (*Barbagia* region) to the coasts.

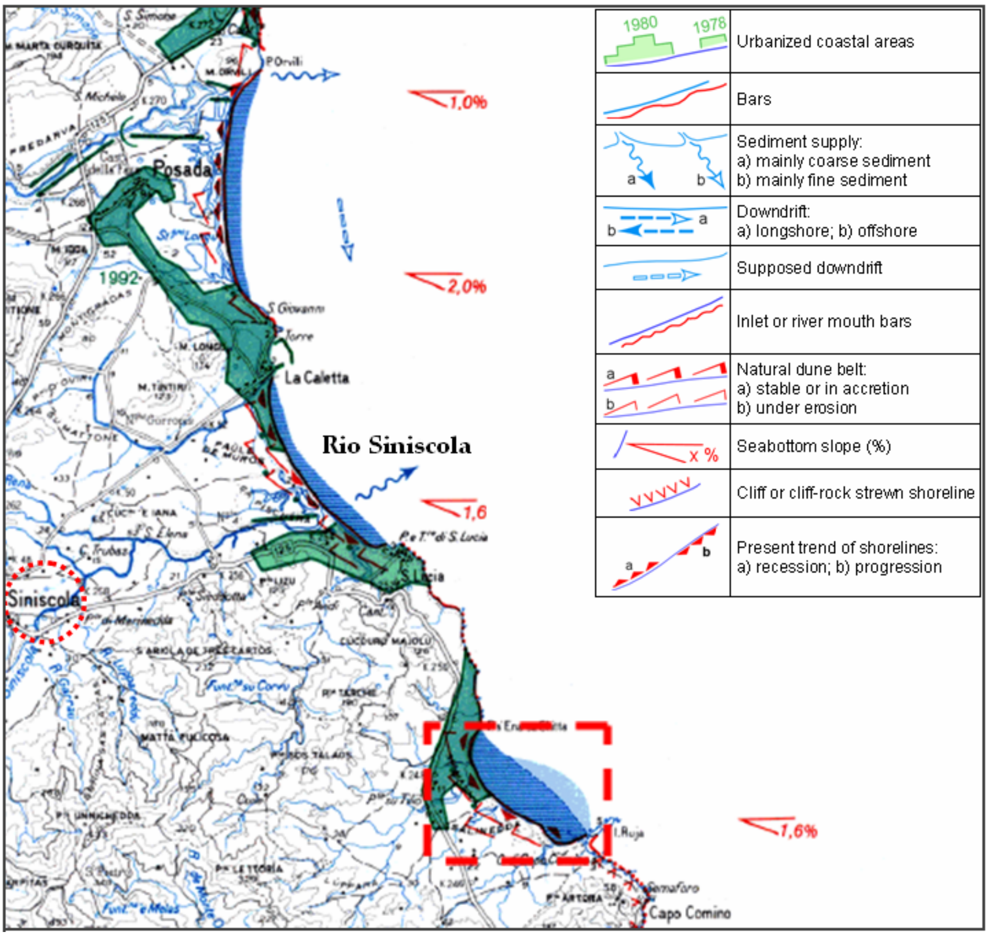


Figure 2.4 – Capo Comino area in the "Atlas of Italian Beaches" (AA.VV., 1997 - modified).

From a hydrographic point of view in this region – and in general everywhere in Sardinia - rivers and streams are characterized by an irregular flow regime. They are usually rushing during the rainy seasons and mainly dry during summer and fall.

Hydrographic basins are small and reduced, due to the mountainous and hill coastal sectors.

The main hydrographic basin is the Posada river basin (Fig. 2.5) and the study area is interested by the Siniscola stream, a very high-erosive channel, about 28.8 kilometres long getting to the coast in Santa Lucia beach, north to Capo Comino beach (Fig. 2.4). Due to its erosive characteristics, this stream is able to feed La Caletta and Capo Comino beaches during flooding periods.

Figure 2.5– Hydrographic basin of the study area (Posada river, DTM from Regione Sardegna).

The study of the region allowed the localisation of several very high-quality areas, from the environmental point of view. Between them, the ecosystems of the coastal sectors and the Monte Albo area (Fig. 2.6), a calcareous rock formation (70 square km), formed about 60 Millions years ago.

Thanks to its peculiarities and its biological richness, Monte Albo has been assigned a national biotope of botanical interest and worthy of conservation. It is also a "Biogenetic reserve of European interest".

Figure 2.6 – A picture of *Monte Albo* from Capo Comino beach (2009).

2.2 FLORA AND VEGETATION OVERVIEW

2.2.1 Phytogeographic overview

Mediterranean coastal flora is strictly related to the populations of the surrounding coasts (such as Africa and Eurasia), to the migrating phenomena from East and West and to a wide speciation activity creating the "autoctonal" elements (Pignatti, 2002).

Starting from the end of the Messinian period a few species, distributed everywhere in the Atlantic coasts, came from the West and they were distributed in the Mediterranean area. It seems that *Ammophila littoralis, Euphorbia paralias, Agropyron junceum* came onto Mediterranean coasts by this mechanism (Pignatti, 2002).

The oriental species came instead by the ancient dynamics of Tethys' basin and this vegetation is common in salted desert environments (now present in Central Asia and Orient), such as species from *Chenopodiacae, Plumbaginacae, Zigophillacae, Juncaceae* and *Graminaceae* Families.

The total number of endemic sandy species is poor; on the other hand many psammophile species are present in Mediterranean area and it is possible to suppose their origin from the divergence of coastal environments. Nevertheless, no other species belonging to the coastal sandy flora can be found in the continental systems, and at the same time it is unusual that a continental species survives close to the sea.

Therefore coastal dune and beach vegetation represents a *unicum* because of the sea influence that determines a very selective environment. Anyway, if the Mediterranean coasts present an uniformity of species and a lack of endemic species, Sardinian coasts (a Corsican ones too) present several peculiar characteristics of the flora. Moreover the entire Sardinia island presents a very high percentage of the total endemic species of Mediterranean area and this is a very interesting biogeographic aspect.

Arrigoni (1983) recognizes three fundamental genetic-historical elements for the characterization of the floristic population of Sardinia:

1) a group of floristic entities were already present at the end of Oligocene, when the Sardinian-Corsican plate started to separate from the continent. Those species belong to an ancient flora; most of them are tropical species and related to southern and western species. This process allowed the differentiation *in situ* of paleoendemic species;
2) a continental group of species came from southern regions in Sardinia and Corsica during the Messinian, most of them are halophytic species and xerophile-sclerophillic species;
3) a group of continental species arrived in Sardinia - across Corsica island - from Italian peninsula and the Provençal-Ligurian arc. This flux could be taken place during Pliocene and Pleistocene, even if there are only poor paleontological evidences.

Following the Rivas-Martinez classification (Rivas-Martinez *et al.*, 2004) Sardinia belongs to the Mediterranean Region, Western Sub-region, Italo-Tyrrhenian Domain.

Considering those assertions and the detailed analysis of Sardinian flora (and the ecological and geographic elements) Arrigoni (1983) divides Sardinia island in three sub-sectors (Fig. 2.7):

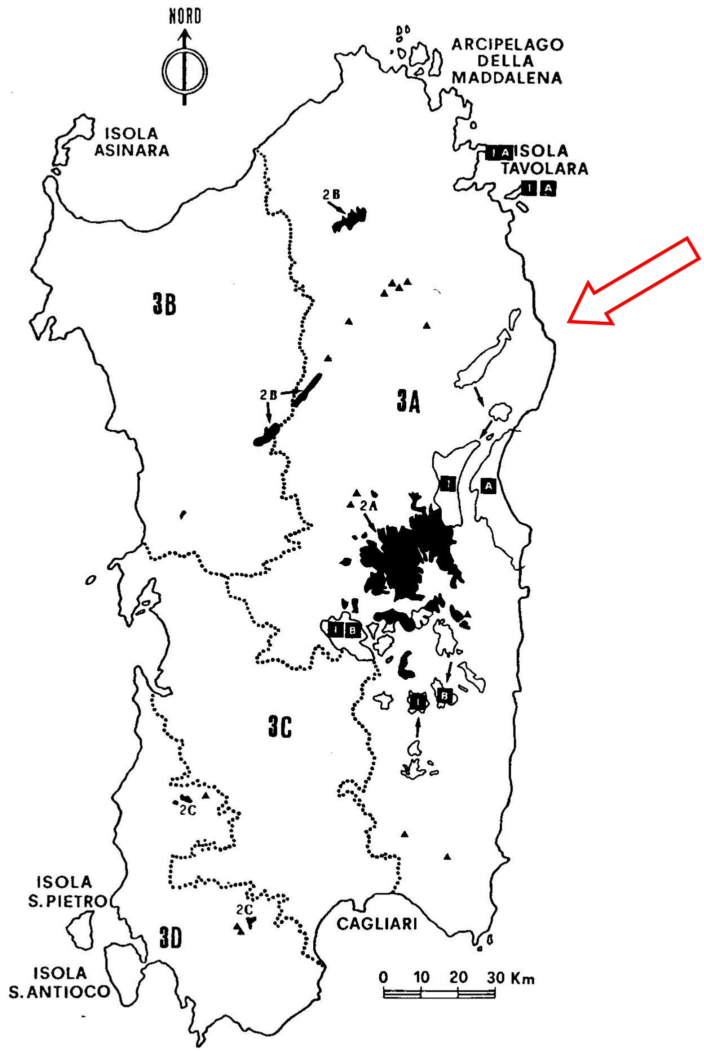


Figure 2.7 - Floristic sub-sectors of Sardinia. In black, lands higher than 1000 meters (Arrigoni, 1983).

1) Sub-sector of calcareous mountains in central-eastern Sardinia
   a) North-eastern district
   b) Tacchi's district
2) Sub-sector of siliceous mountains
   a) Gennergentu district
   b) Limbara and Maghine Mount district
3) Sub-sector of Hills and Coasts
   a) Siliceous district
   b) North-western district
   c) Campidano district
   d) South-western district

The Capo Comino area belongs to the Siliceous District of Sub-sector of Hills and Coasts, which extends from North to South on the Hercynian basement. It has many interesting species, such as *Vitex agnus-castus, Nerium oleander, Sarcopoterium spinosum, Globularia alypum, Centaurea horrida, Asplenium maritimum, Coris monspeliensis*, a huge number of exclusive endemic species (*Astragalus maritimus, Bellium crassifolium, Hyoseris taurin, etc*..) and Sardinia-Corsican endemic species (*Anchusa crispa, Erodium corsicum, Evax rotundata*).

2.2.2 Vegetation overview

Vegetation of the study area may be classified following the "*Carta delle Serie di Vegetazione della Sardegna*" - Map of vegetation series of Sardinia (2009, scale of 1:350000) (Fig. 2.8).

This map identifies the areas characterized by a single potential type of vegetation, corresponding to the environmental units of the landscape by Blasi *et al*. (2010).This classification takes into consideration the geo-lithological and bioclimatic heterogeneity.

The syndynamic approach gives the interpretation of spatial-temporal processes concerning the vegetation landscape. In this perspective, all the vegetation communities present a dynamic tendency to mature forest systems.

The study area is characterized by two geosigmeta:

1) Sardinian halophilic geosigmetum of salt marshes, ponds and coastal lagoons (*Ruppietea, Thero-Suaedetea, Saginetea maritimae, Salicornietea fruticose, Juncetea maritimi, Phragmito-Magnocaricetea* - number 27 in the map);

2) Sardinian psammophile geosigmetum of coastal dune systems (*Cakiletea, Ammophiletea, Crucianellion maritimae, Malcolmietalia, Juniperion turbinatea* - number 28 in the map).

The surrounding landscape belongs to the Thermo-mesomediterranean series of live oak (*Prasio majoris-Quercetum ilicis typicum et phillyreetosum angustifoliae* – number 11 in the map).

The classification of the study area was also done by the Ministry of the Environment, Land and Sea protection in 2010 using the "ecoregion" concept. Ecoregion is a broad and discrete ecologically homogeneous area of the Earth's surface within which natural communities and species interact with the physical characteristics of the environment (Blasi *et al.*, 2010). In Italy this classification represents a framework that is used to address national strategies for sustainability and harmonize landscape planning according to European policies (Habitats Directive, European Landscape Convention, Pan-European Biological and Landscape Diversity Strategy).

The "Ecoregion" classification led to the identification and mapping of 2 Divisions (Temperate and Mediterranean), 13 Provinces, 33 Sections and approximately 80 Sub-sections. Capo Comino area is located in Mediterranean Division, Sardinia-Corsica Block Province and Gennargentu Mountains Section.

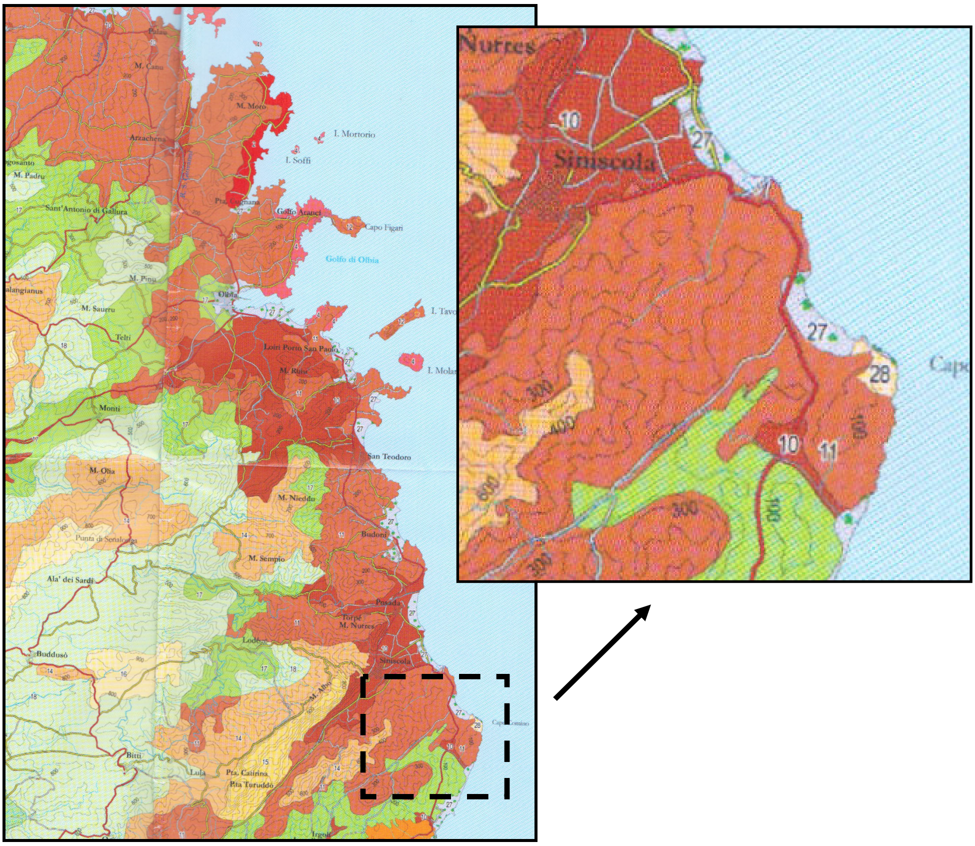


Figure 2.8 - Vegetation classification of Capo Comino area (Blasi *et al*., 2009 - modified). The legend in described in the text.

2.3 MARINE AND CLIMATE SETTINGS

The formation of a coastal sand dune system is a response to a conceptually simple, but physically complex series of processes associated with sediment transport by fluids (Sherman and Hotta, 1990). Winds and waves are the most important factors shaping the morphological evolution of coastal dunefields.

Coastal morphology is the result of a complex dynamic equilibrium of several factors. They constantly carry out their activities with imperceptible changes so it is possible to evaluate them only in a long-term period or after a catastrophic event.

Meteo-marine factors are surely the principal factors that are able to influence and define the morphological asset of the coasts. They govern the erosive and sedimentation processes and they distribute the sediment modifying the morphology of the beach and nearshore system by the longshore and the offshore transport of sediment. These factors are identified with the wind, waves and tides.

An increasing in precipitation generally causes a growing of erosive processes of the mountains and a larger sediment transport by rivers to the sea. However the coastal progradation near to the river mouth could be strongly conditioned by meteo-marine factors. During a sea storm, the transport of the "incoming" sediments is to offshore and along the coast and only during the calm-sea condition the deposition of the sediments is close to the river mouth.

As indicated in Chapter 1, coastal dunes develop at the landward side of a beach, wherever dry sand is in a sufficient supply and onshore winds above a minimum velocity occur (Hesp, 2000). Wind flow and aeolian sediment transport across dunes depend on a variety of factors and these become more difficult to measure as morphology becomes more complex and as the vegetation cover and structure varies (Hesp, 2002; Walker *et al*., 2006).

Concerning the marine regime and its influence on coastal development, waves are one of the most important elements for the determination of coastal evolutive processes and they are the principal element of the sediment distribution along the coasts. In the meteorological and marine characterization of a beach, these data are essential but we cannot affirm that we have the same marine characteristics offshore and close to the coast. In fact, the littoral could be exposed to the sea storms or waves could be deviated, as an example, by seafloor (rifraction) and/or by the presence of an obstacle (diffraction).

All these factors have to be taken into consideration for the analysis of the study area.

2.3.1 Materials

Several wind databases were analyzed during this research. Data were used for the meteorological and bioclimatic classification and the wind regime analysis, in order to determine the potential sediment transport and the wind regime on dune orientation and evolution.

Data were collected from four weather stations (Fig. 2.9): Capo Bellavista (39°56'N 9°43'E, 156 m above sea level) and Olbia (40°54'N 9°31'E, 13 m above sea level) in the east coast, Alghero (40°38'N 8°17'E, 23 m above sea level) in the west coast, and Cagliari (39°15'N 9°03'E, 1 m above sea level) in the south coast.

Figure 2.9 - Location of the four weather stations, with yellow markers. Capo Comino area is in red rectangle.

For a general view of the wind regime data from Alghero, Cagliari and Olbia stations (from the World Meteorological Organization databases) were analyzed, covering a period from 1973 to 1993. The observations about speed and direction are hourly measured.

For a more accurate analysis two databases from Capo Bellavista weather station were used, from the Network of the Air Force Meteorological Service.

The first one is the "Atlante Climatico d'Italia" (http://clima.meteoam.it/atlanteClimatico.php), with a 4 daily measured data from 1971 to 2000.

The second one is a complete raw dataset by the "Aeronautica Militare Italiana - Servizio Meteorologico" (AMI), period from 2000 to 2010. It contains SYNOP and SYREP data, with a three-time per hour frequency. Wind data are taken with an eight-time per day frequency.

Concerning the wave climate, several data from different sources were examined.

The first one is a report by courtesy of the "Istituto Idrografico della Marina Militare" (Italian Hydrographic Institute), referring to Capo Bellavista (39° 56′ N, 9° 43′ E) and Capo Figari (41°00′ N, 09°39′ E) weather stations.

Capo Bellavista station is the closest weather station to Capo Comino area and, fortunately, the exposure of Capo Comino beach is very similar to Capo Bellavista coast. In fact, it is characterized by an open exposition of winds blowing from the 1st and 2nd quadrants (e.g. coming from N, E and S).

Data from each station may be considered valid from the statistical point of view.

Results were supported by the analysis of data from the Capo Comino buoy (40° 31' 59.99" N, 9° 55' 0.1" E) of RON (*Rete ondametrica Nazionale* - Italian Ondametric Buoy Network). This buoy was located in 2002.

Data are available online (www.idromare.it), starting from January 2004 to September 2005, when the buoy was disused.

The study of seafloor, especially of the nearshore, was effectuated by geophysical and sedimentological analyses. These data were gathered during a field survey in 2009 (§3.3).

2.3.2 TEMPERATURE AND PRECIPITATION

On clear summer days the temperature of the surface layer of sand may reach above 60°C, mainly because sand is a poor conductor of heat (Maun, 2009). However, immediately below the sand surface, temperature declines rapidly producing very steep lapse rates (Baldwin and Maun, 1983). Moreover, in the evening the thin hot surface layer of sand cools rapidly because the low thermal conductivity of sandy soil doesn't allow the replenishment of heat from lower layers of soil. High temperatures increase energy absorption by leaves and strand plants usually avoid overheating by rolling the leaves, waxy surfaces, vertical orientation and hairy leaves, thereby also avoiding moisture stress (Maun, 2009).

Sandy soils have high porosity and after a rain most of the water in drained away because of the low capacity of sand to retain water. Evaporation in open dune systems also removes substantial quantities of water.

Due to these physical and biotic factors water potentials in coastal dune systems are highly related to temperatures and precipitations.

2.3.2.1 Results

In the following tables (Tabs. 2.1 and 2.2), the mean temperature and precipitation during the periods 1977-2000 and 2000-2010 are presented.

Mean annual temperatures are between 14 and 26°C.

The highest temperatures are reached during the summer season (30-32°C in June-July-August), with a long dry period due to the Azores and Saharans Highs (Anticyclones).

During spring (March-April-May), mean temperatures are between 12 and 17°C, with temporary and sporadic disturbances due to cold air irruptions. Fall presents mild temperatures (15-22°C) too.

The total mean precipitation (400-500 mm/year) is modest.

In general two rainy periods are present: spring and fall, spaced out by a dry period (summer) when N and N-E winds bring long fair periods.

The wettest months are October, November and December and the driest June, July and August. During the others months, there are few occasional showers.

	Tmax (°C)	*Tmin (°C)*	*P (mm)*	*T (°C)*
Jan	13.5	8.0	35.4	10.8
Feb	13.9	7.9	40.5	10.9
Mar	15.2	8.8	34.3	12
Apr	17.4	10.5	29.8	14
May	21.1	14.0	23.9	17.6
Jun	25.4	17.8	12.8	21.6
Jul	28.5	20.8	5.5	24.7
Aug	29.3	21.5	11.9	25.4
Sep	26.2	18.8	46.8	22.5
Oct	21.9	15.4	59.5	18.6
Nov	17.4	11.7	62	14.5
Dec	14.7	9.2	57.2	11.9

Table 2.1 – Mean temperatures and precipitations during 1971-2000. Capo Bellavista weather station (data from *Atlante Climatico d'Italia*, 2009)

	Tmax (°C)	*Tmin (°C)*	*P (mm)*	*T (°C)*
Jan	13.99	7.91	43.07	10.67
Feb	14.23	7.60	24.87	10.45
Mar	16.97	9.66	33.00	12.79
Apr	19.24	11.66	49.97	14.83
May	23.11	15.22	28.28	18.57
Jun	27.71	19.08	8.06	23.36
Jul	31.17	22.07	2.46	25.88
Aug	31.65	22.54	9.93	25.92
Sep	27.50	19.13	36.26	22.58
Oct	23.67	16.31	59.31	19.39
Nov	18.58	12.13	57.81	15.29
Dec	15.05	8.95	74.22	11.76

Table 2.2 – Mean temperatures and precipitations during 2000-2010. Capo Bellavista weather station (data from AMI).

2.3.3 WIND ANALYSIS

2.3.3.1 WIND ROSES

Method

It is a matter of common observation that the wind is not steady so it is necessary to know the probability density distribution of the wind speed. The wind distribution may be described by two parameters: the mean wind speed, and the 'shape' parameter, which is a measurement of the width of the distribution. This approach is useful since it allows both the wind speed and its distribution to be described in a concise fashion.

In the following paragraphs, winds will be mainly analyzed by the production of wind roses.

Wind rose gives a very succinct view of how wind speed and direction are distributed in a particular location. It is presented in a circular format - with a polar coordinate system - and shows the frequencies and the speeds of winds blowing from a particular direction. The directions of the rose with the longest spoke show the wind direction with the greatest frequency.

Wind roses from AMI are represented with 8 cardinal directions such as North (N), NE, E, *etc*; wind roses calculated from the raw database of AMI use 16 cardinal directions, such as such as North (N), NNE, NE, *etc*. Wind direction was designed taking an interval of 45° centred on the cardinal provenance point.

Wind regime classification is useful for identifying the aeolian influence in desert and coastal dune environments. Also, dune types generally occur in conjunction with specific wind regimes (e.g. parabolic dunes usually develop with narrow unimodal and bimodal wind regimes (Freyberger and Dean, 1979)).

Freyberg and Dean (1979) identify five commonly occurring wind regimes: narrow unimodal, wide unimodal, acute bimodal, obtuse bimodal, and complex.

A narrow unimodal wind regime is characterized by having 90% or more of the drift potentials in adjacent directions or within 45° on the compass. A wide unimodal wind regime consists of two peak drift potential within a singular directional quadrant, but it has a distribution of 45° or greater. An acute bimodal wind distribution consists of two modes forming an angle less than 90°; accordingly an obtuse bimodal wind distribution has two modes forming an angle greater than 90°. A complex wind regime is characterized by having a wind distribution with three or more nodes or with "poorly defined nodes" (Freyberger and Dean, 1979).

The wind speed intervals for Alghero, Olbia and Cagliari stations are calculated using the Beaufort scale, with value expressed in knots. Data from Capo Bellavista station were analyzed using both knots and meters per second values.

A seasonal and hourly analysis of wind distribution and frequency from 1971 to 2000 (AMI data) have been done and seasonal, monthly and hourly analysis for data between 2000 and 2010. The software for 2000-2010 data is courtesy of Lakes Environmental Software (WR-PLOT).

Results and discussion

The general view of distribution of winds in Sardinia is given by Olbia, Alghero and Cagliari's data analysis (Fig. 2.10). In general, extreme events have a maximum of wind speed of 28-33 knots but storms with a wind speed of 22-27 knots and 17-21 knots are more common. It's common known that the strongest events in the island are conditioned by NW winds ("Maestrale" in Italian, "Mistral" in French).

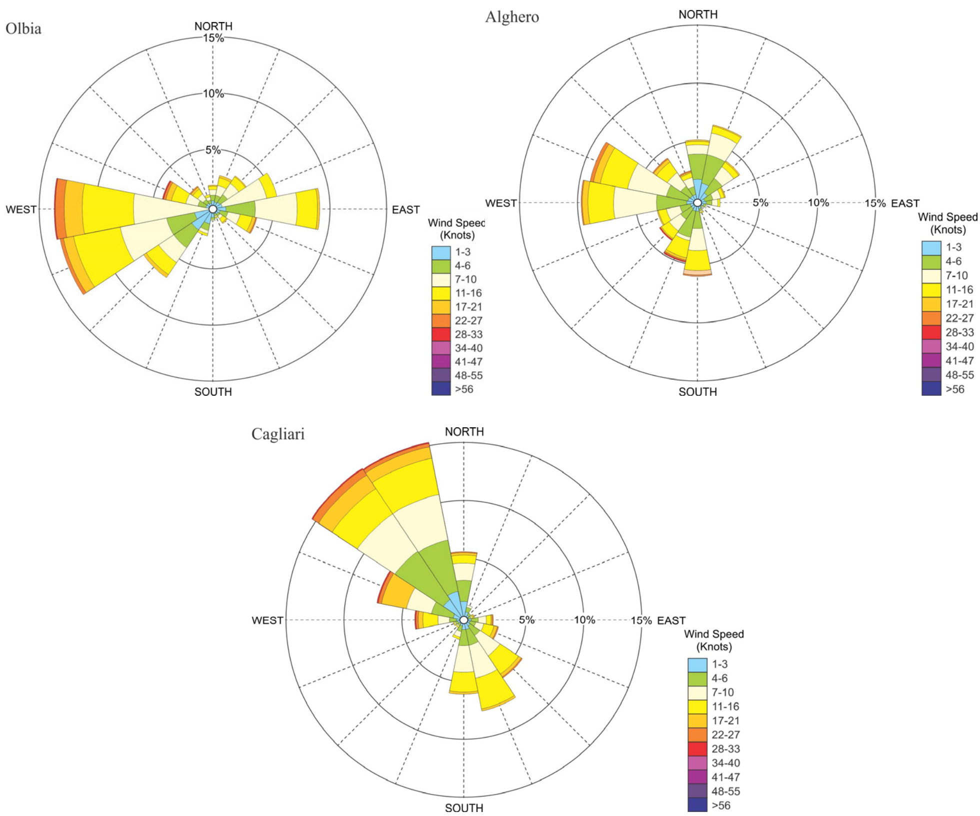


Figure 2.10 – Wind roses of Olbia, Alghero and Cagliari stations; wind speeds in knots.

Olbia's wind rose presents the highest percentage of strong events from the W and WSW (winds coming from inland) – about 4.2% from WSW and 4.5% from W in the 11-16 knots class; 0.9% from WSW and 1.6% from W in the 17-21 knots class.
A second important sector is the E sector where we can find a high frequency in the 7-10 knots and 11-16 knots classes (about 3.7% in the 7-10 knots class and 1.8% in the 11-16 knots class).
The strongest events (22-27 knots class and 28-33 knots class) usually come only from the WSW-W-WNW sector.
Alghero weather station in located in the west coast of Sardinia. Meteorological conditions are very different from the east coast and wind rose shows a spread distribution of the frequency. Strongest events (28-33 and 22-27 knots class, moderate gale and strong breeze

using Beaufort classification) come from a sector of about 170° degrees (winds coming from S to NNW). Moderate winds - 11-16 and 17-21 class knots classes - are usually from W (2.2% and 0.5%) / WNW (2.4% and 0.6%) and S (1.7% and 0.4%) / SSW (1.5% and 0.2%). Considering SW and WSW sectors, they present a relevant frequency of winds but always with an half of percentage comparing to the previous ones.

Cagliari weather station in located in the south of Sardinia. Strongest events come from the W-NNW sector (a sector of 90° of winds coming from inland) as 17-21 knots winds.
Moderate winds (11-16 knots class) have a bi-modal distribution: a first sector is always the W-NNW and a second is the E-S sector.

Capo Bellavista weather station is the closest station to Capo Comino area. Its data allowed me a more accurate analysis of wind conditions. The first important aspect is the possibility of evaluate about 30 years of data (as suggested by the WMO) and the second one the availability of a complete dataset for the last decade (2000-2010).

1971-2000 period

The anemometric diagrams - for the period of reference from 1971 and 2000 - are ordered by season as follows (Figs. 2.11, 2.12, 2.13 and 2.14). Classes are: 1-10 knots (white shape), 10-20 knots (red shape) and >20 knots (blue shape).

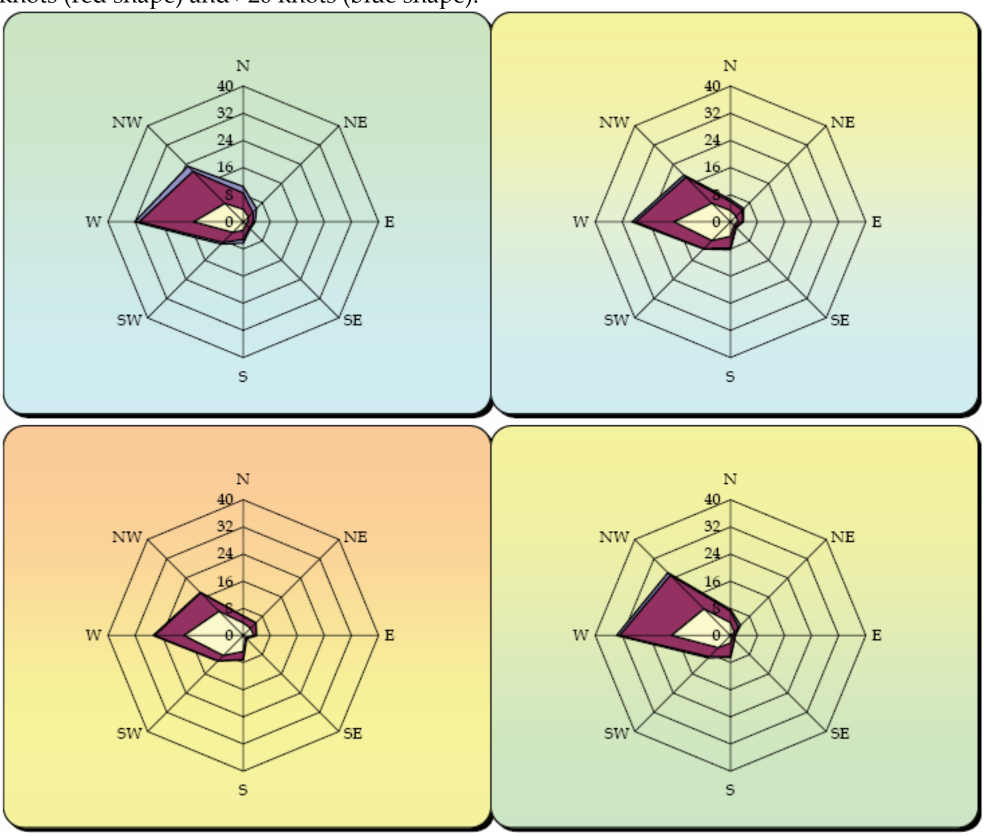


Figure 2.11 - Percentage frequency of occurrence at 00am for winter (7% wind calm), spring (13% wind calm), summer (21% wind calm) and fall (9% wind calm) (from *Atlante Bioclimatico d'Italia*, 2009).

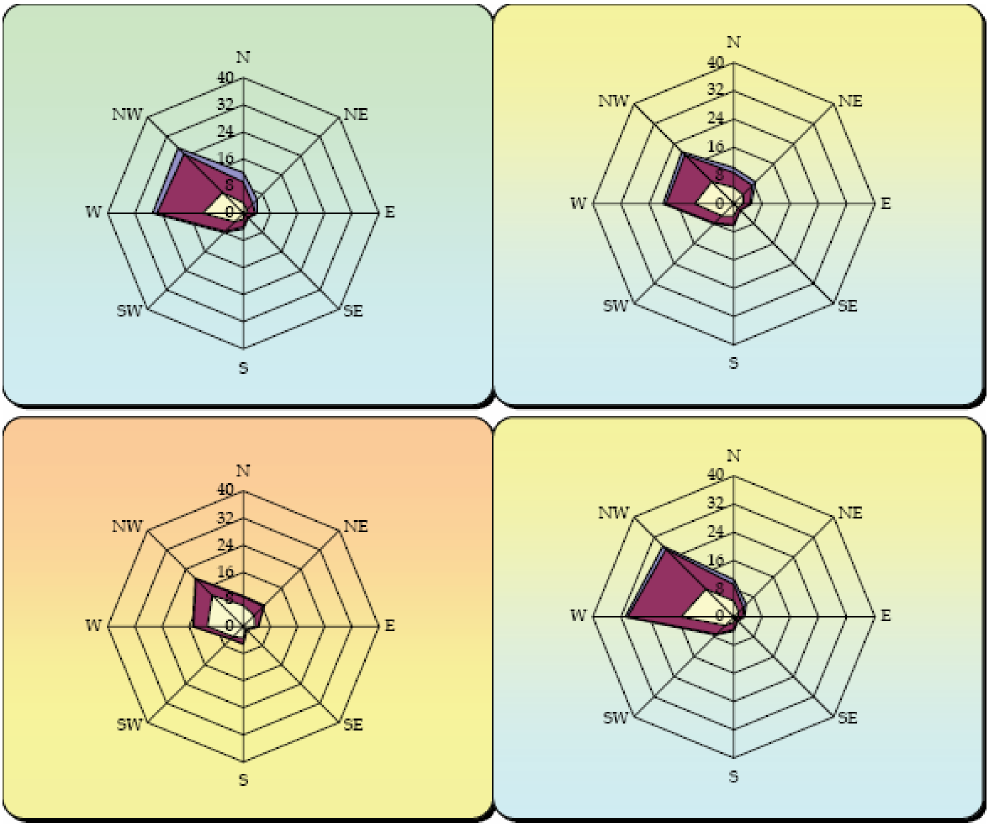


Figure 2.12 - Percentage frequency of occurrence at 06am for winter (9% wind calm), spring (18% wind calm), summer (30% wind calm) and fall (9% wind calm) (from *Atlante Bioclimatico d'Italia*, 2009).

Wind roses in figures 2.11 and 2.12 are quite similar. During the night (0am and 6am) winds blowing from the 4th quadrant are the main ones and there is a high component blowing from west.
Frequencies are mainly comprises between 10 and 20 knots; only during summer the 1-10 knots frequency is the main one.
The result shows a stronger influence of the hourly period of the observation during the day compared to the seasonal importance.

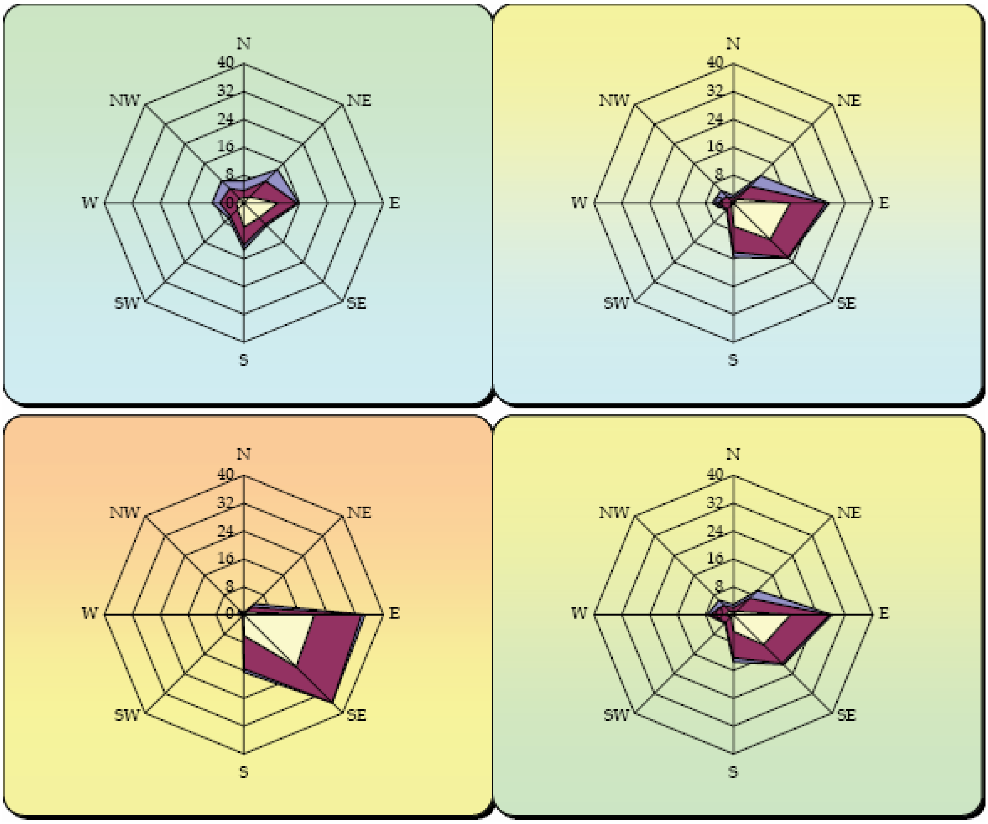


Figure 2.13 - Percentage frequency of occurrence at 12am for winter (17% wind calm), spring (7% wind calm), summer (4% wind calm) and fall (7% wind calm) (from *Atlante Bioclimatico d'Italia*, 2009).

Wind roses in figure 2.13 are very different from the previous ones.
At 12am, winds mainly blow from the 2nd quadrant and the highest component is from east.
Frequencies are mainly comprises between 1 to 10 knots and 10-20 knots but during winter there is a high component of frequencies >20 knots from 4th and 1st quadrants.
The >20 knots frequencies are also important during spring and fall too, but with a lower intensity.
Winds with frequencies between 1-10 knots are quite important too, in particular during summer.

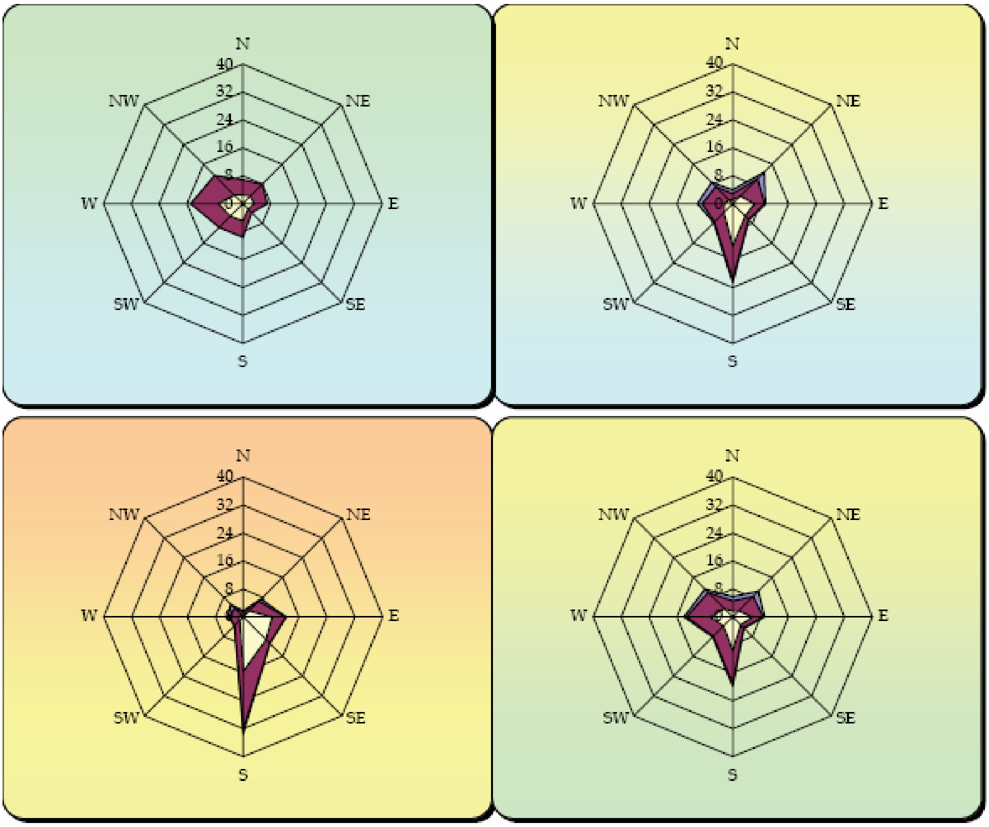


Figure 2.14 - Percentage frequency of occurrence at 6pm for winter (15% wind calm), spring (18% wind calm), summer (21% wind calm) and fall (16% wind calm) (from *Atlante Bioclimatico d'Italia*, 2009).

Figure 2.14 presents the results about 6pm data analysis.
Wind roses have a strong influence from the season, with a similar wind rose for spring, summer and fall but a very different for winter.
During the afternoon, winds are completely different from the rest of the day, with a strong influence of winds blowing from the south.
Frequencies are mainly comprises between 10 and 20 knots but during spring and fall there is a component of frequencies >20 knots coming from 4^{th} and 1^{st} quadrants.
Winds with frequencies between 1-10 knots are quite important too, in particular during summer.
The anomaly is represented by winter rose. South winds are not important and the main influencing winds are from west (such as for figures 2.11 and 2.12), from the 3^{rd} and 4^{th} quadrants.

2000-2010 period

Data referred to 2000-2010 (Fig. 2.15) show the total wind distribution presenting a high percentage of events coming from W-WNW-NW sectors and from S sector. The wind rose data indicate an obtuse bimodal distribution.

Strong wind speeds (34-41 knots) are only coming from N-NNE and from WNW.

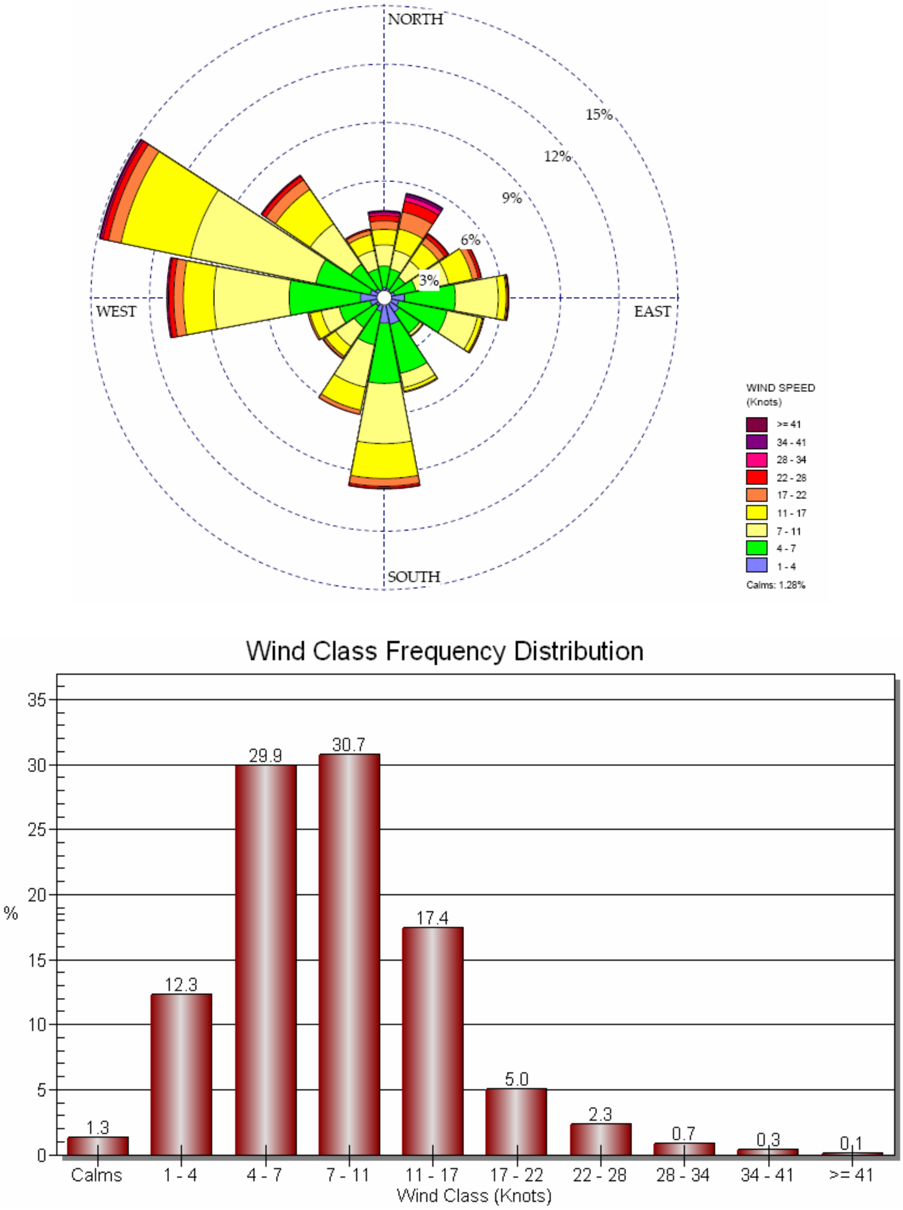


Figure 2.15 - Wind rose of 2000-2010 and wind class frequency distribution.

Concerning the frequency distribution, the most frequent wind classes are 4-7 and 7-11 knots.

Winds from the 1st and 2nd quadrants (N-E-S) are full of humidity because of they blow on the sea surface and any obstacles stop them. Between them, the most important are Grecale (NE) and Sirocco (SE) winds.
Winds from the 3rd and 4th quadrants (S-W-N) are partially slowed down by Monte Albo at the east side and Punta Artora at south, and most of all they are channelled by the local topography into preferential directions (Fig. 2.16).

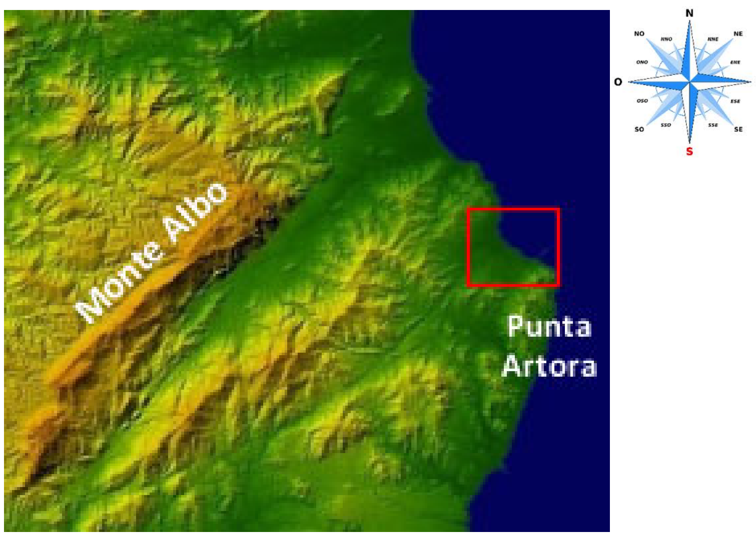


Figure 2.16 – Capo Comino area (red rectangle) in a DTM from 3D-CTR (3D-Technical Regional Chart).

Seasonal wind roses

Periodicity plays a prominent lead for the meteorological characterization of Sardinian coasts. In fact, wind roses are strongly influenced by the seasonal patterns. Furthermore, the sediment transport is slowed down by the weather conditions (e.g. rain, ice, snow) and the high humidity level of the soil.

In the Capo Comino area, during cold seasons snowfalls are extraordinary events but rains may be frequent and they may influence the sediment transport.
Figures 2.18 and 2.19 shows the seasonal wind roses and table 2.3 summarizes few generic data. The legend is presented in figure 2.17.

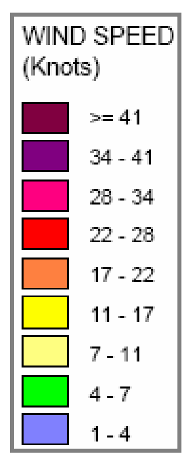


Figure 2.17 – Legend of wind roses.

Season	Average speed (knots)	Total counts (number)	Calms (%)
Winter	9.84	15050	1.48
Spring	8.05	15944	1.08
Summer	7.09	16092	1.49
Fall	9.14	16094	1.09

Table 2.3 - Statistical data about seasonal wind roses.

During fall (A) and winter (B), wind distributions are similar, and the wind distribution trend is narrow unimodal, especially for the fall period. In general, wind roses are comparable to that presented in figure 2.15. On the other hand spring (C) and summer (D) wind distributions are very different. During the spring, the most prominent component of the wind regime is the consistency of the S and WNW. The onshore winds have a good frequency too (E and SE). The northern winds, instead, have a lower frequency compared to the cold season ones'. The resulting distribution is a complex wind regime.
Summer wind rose presents a complex wind regime too, with strong intensities coming from N-NNE-NE and a wide distribution of wind regime.

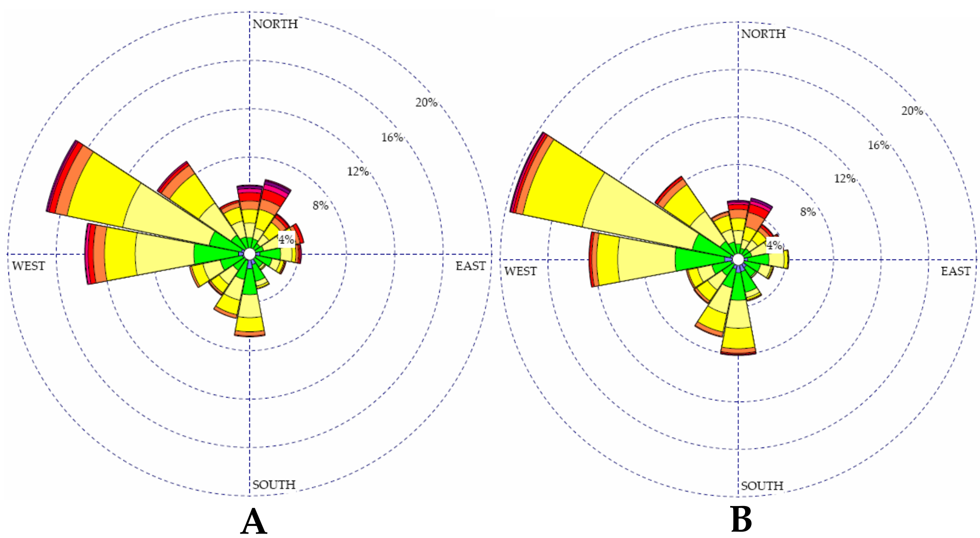
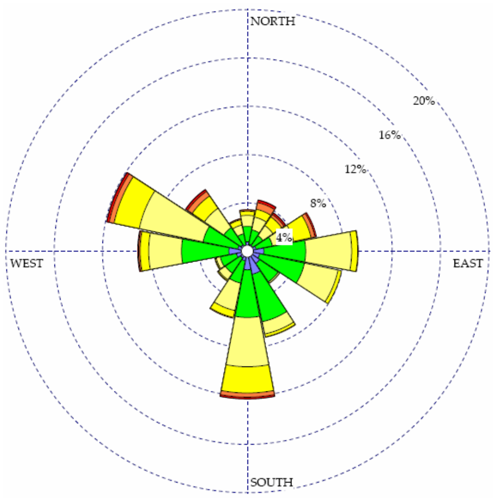
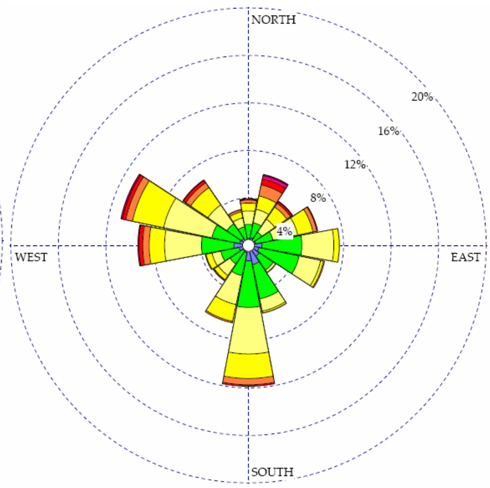


Figure 2.18 – Seasonal wind roses (2000-2010): fall (A), winter (B).



C



D

Figure 2.19 – Seasonal wind roses (2000-2010): spring (C), summer (D).

<u>Hourly seasonal wind roses</u>

The seasonal observations do not provide a detailed representation of the regional wind regime. Weather station recorded wind speed and wind direction measurements four times per day. Therefore it presents a more accurate portrait of the wind regime.

Wind regime changes very much not only depending on the season but also during the day, because of the difference in pressure generating the wind may occur for a lot of different factors (e.g. local winds along lake and ocean shores are the result of the temperature differences between land and water, which cause a pressure difference and wind).

In coastal regions, the local topography and the proximity to the sea influence the wind regime. For example, land surfaces warm and cool more rapidly than do water surfaces; therefore, land is warmer than the sea during the day; wind blows from the cool water to warm land—the sea breeze, so called because it blows from the sea. At night, the wind reverses, blows from cool land to warmer water, and creates a land breeze. Land and sea breezes develop only when the overall pressure gradient is weak. Wind with a stronger pressure gradient mixes the air so rapidly that local temperature and pressure gradients do not develop along the shoreline.

Figures 2.20, 2.21, 2.22 and 2.23 present the hourly seasonal wind roses. Their statistical data are presented in tables 2.4, 2.5, 2.6 and 2.7.

Wind roses indicate a high variance in wind distribution depending on the season but also on the daily hour of measurements. This wide modal distribution of winds reflects on the transport of the sand, producing a general drift direction of the dunefield but also a lot of local morphologies.

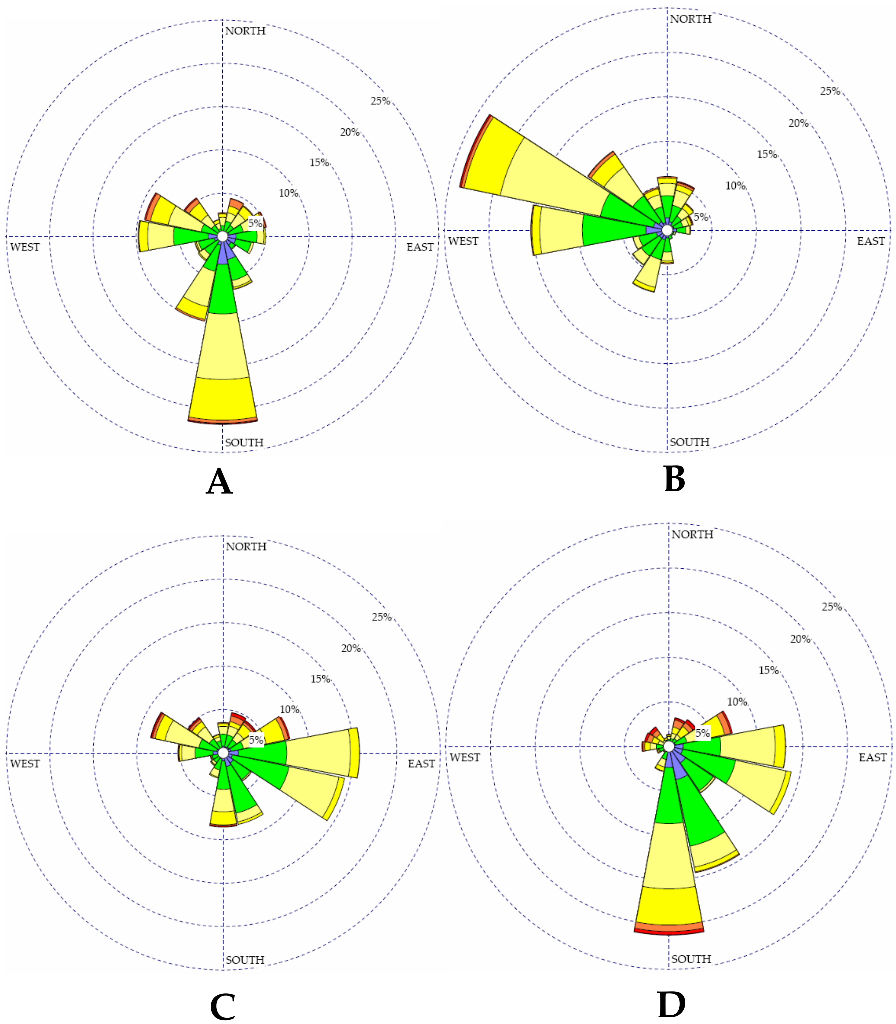


Figure 2.20 – Wind roses of summer period (2000-2010): 00am (A), 06am (B), 12am(C), 06pm (D) (legend in Fig. 2.17)

Hour	Average speed (knots)	Total counts (number)	Calms (%)
00-06 am	6.72	6038	2.05
06-12 am	7.03	6034	1.46
12 am – 06pm	7.59	6040	0.99
06 pm – 00am	7.14	4020	1.84

Table 2.4 - Statistical data about wind roses - summer.

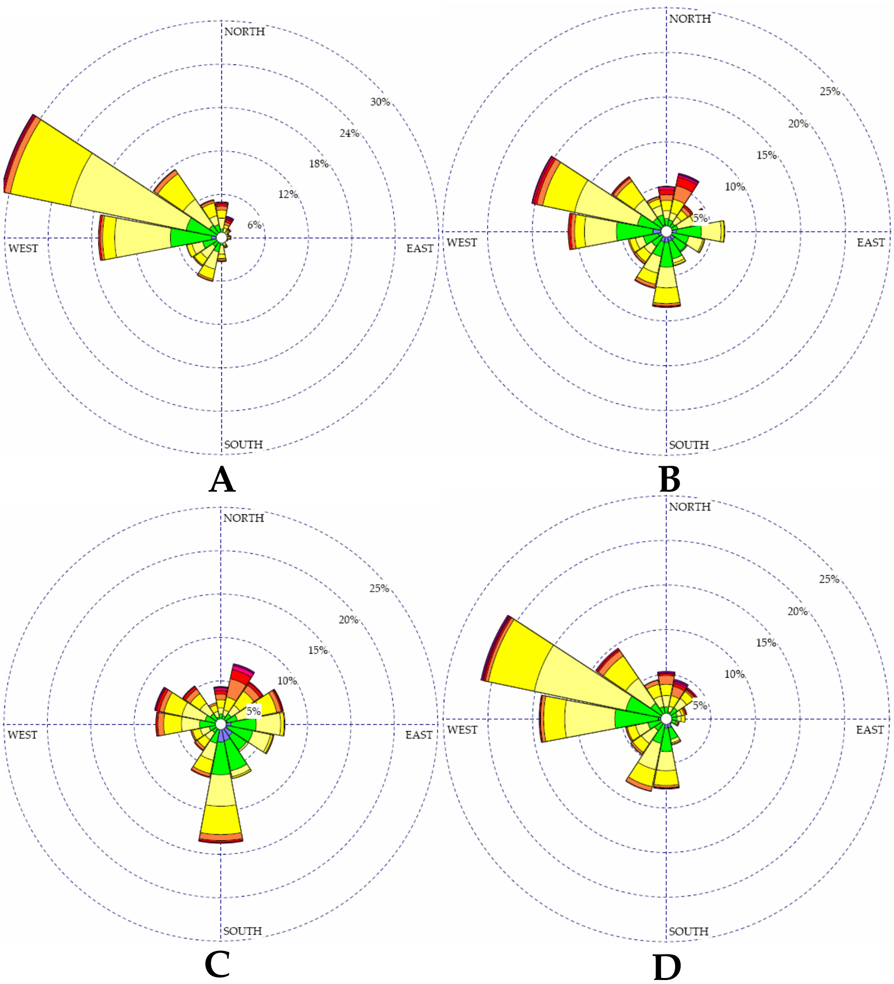


Figure 2.21 – Wind roses of fall period (2000-2010): 00am (A), 06am (B), 12am(C), 06pm (D) (legend in Fig. 2.17).

Hour	Average speed (knots)	Total counts (number)	Calms (%)
00-06 am	9.23	5990	0.97
06-12 am	8.85	5946	1.01
12 am – 06pm	9.42	5960	1.17
06 pm – 00am	9.15	3994	1.15

Table 2.5 - Statistical data about wind roses - fall.

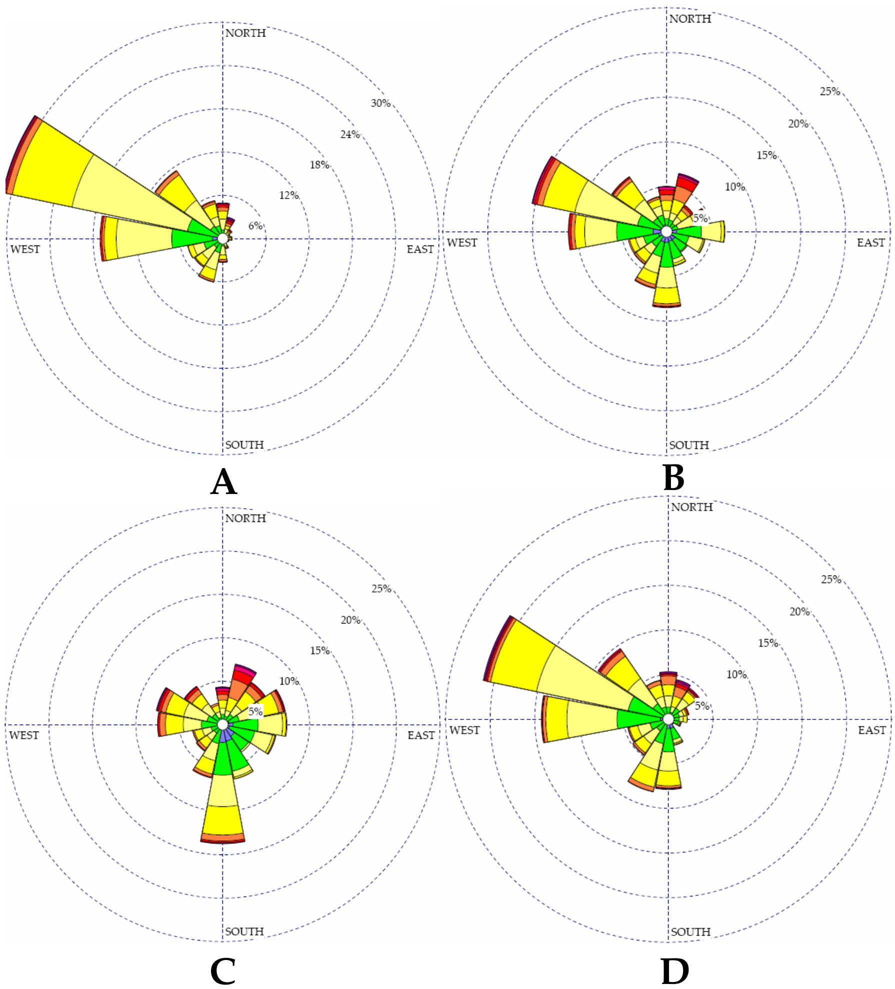


Figure 2.22 – Wind roses of winter period (2000-2010): 00am (A), 06am (B), 12am(C), 06pm (D) (legend in Fig. 2.17).

Hour	Average speed (knots)	Total counts (number)	Calms (%)
00-06 am	9.89	2836	1.23
06-12 am	9.66	2831	1.45
12 am – 06pm	10.12	2831	1.52
06 pm – 00am	9.74	1880	1.54

Table 2.6 - Statistical data about wind roses - winter.

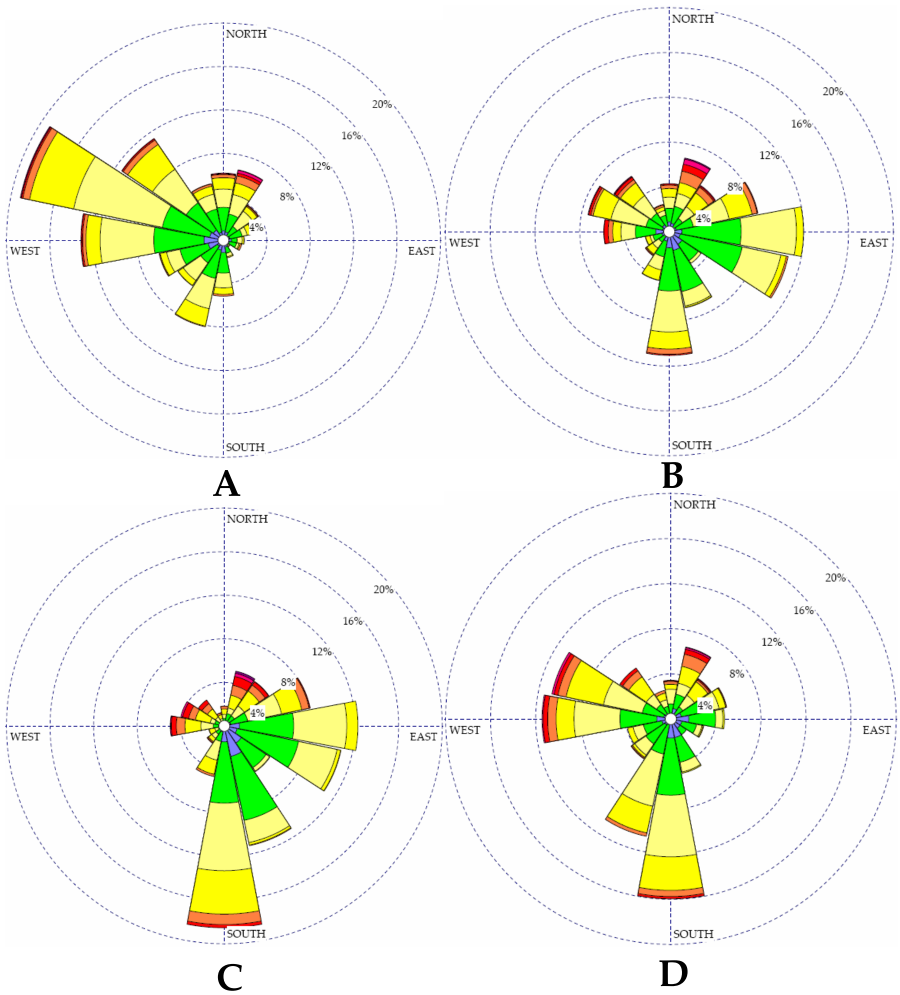


Figure 2.23 – Wind roses of spring period (2000-2010): 00am (A), 06am (B), 12am(C), 06pm (D) (legend in Fig. 2.17).

Hour	Average speed (knots)	Total counts (number)	Calms (%)
00-06 am	7.72	3014	1.23
06-12 am	7.90	3013	0.9
12 am – 06pm	8.57	3024	0.93
06 pm – 00am	8.13	2017	1.49

Table 2.7 - Statistical data about wind roses during spring.

2.3.3.2 SAND ROSES

Method

One of the most accessible methods for estimating the potential for sand transport by wind is the use of meteorological measurements.

Various different formulae have been proposing for estimating the transport potential (Bagnold, 1941, 1953; Skidmore, 1965; Skidmore and Woodruff, 1968; Hsu, 1973; Fryberger, 1978, 1979; Freyberger and Dean, 1979) and Fryberger formulae has been one of the most adopted during the past decades (Thomas, 1984; Goudie and Thomas, 1985; Castel, 1988; Havholm and Kocurek, 1988; Sweet *et al.*, 1988; Le Roux, 1990; Sweet, 1992; Wal and McManus, 1993; Lee *et al*., 1994; Nickling and Wolfe, 1994; Mush *et al*., 1995).

Essentially the "Fryberger model" uses standardized wind data to estimate regional aeolian sediment drift potential (DP), evaluating relative rates of sand transport over a fixed time period. In addition, Fryberger developed classification schemes with witch to describe wind environments based on wind energy and directional variability, and demonstrated the wide applicability of the technique (Fryberger 1979; Fryberger and Ahlbrandt, 1979; Freyberger and Dean, 1979; Freyberger *et al.*, 1984; Fryberger *et al.*, 1992).

Freyberger method has two fundamental principles: (i) when considering the role of wind regimes in geomorphology, only those winds exceeding the threshold velocity for sand transport are of importance; (ii) stronger winds are more effective in transporting sand than weaker winds.

He started with the modification of Lettau and Lettau equation (1978) for sand drift and he developed a weighting factor for velocity classes in which strong winds are given higher weightings and weaker winds lower weightings, such as:

$$q \propto V^2(V-V_t)$$

where V is wind velocity at 10m height, V_t is the impact threshold wind velocity at 10m, and q is the rate of sand transport.

The method calculates the appropriate weightings for each velocity category categorizing them by direction and speed. The value of $V^2(V-V_t)$ is divided by 100 to lower the magnitude of the weighting factors and simplify the plotting of sand roses.

The weighting factors for all categories are then combined to estimate the potential sand drift based on the percentage frequency of observations of sand-transporting wind in each category:

$$Q \propto V^2(V-V_t)\ t$$

where $V^2(V-V_t)$ is the weighting factor, Q is the rate of sand drift and t is time wind blew expressed as a percentage.

This result is known as drift potential (DP) and it's expressed as numbers of "vector units" (for the full method see Fryberger 1978; Freyberger and Dean, 1979), and the resulting values are independent of the unit in which the wind data were expressed (Fryberger *et al.*, 1984; Thomas, 1984; Sweet, 1992; Kar, 1993).

The Lettau and Lettau (1978) equation for sand drift yields a rate in m^3 m-width^{-1} yr^{-1}. This equation and Fryberger's equation can be related establishing that DP values can be converted to approximate volumes of sand transport by assuming an appropriate bulk density for quartz sand. Fryberger (1978, 1979a, 1979b) and Fryberger and Ahlbrandt (1979) produced graphs showing the relationship between DP and rate of sand transport in m^3 m-width^{-1} yr^{-1} for two presumed threshold drag velocities V_t (V_t^* = 160 mm/s and V_t^* = 190 mm/s). These graphs were used to convert values of DP to rates of sand transport (Fryberger, 1979; Cooke *et al.*, 1993).

This method is widely used and understood but it presents a number of limitations which effectively restrict the use of the indices to relative estimates of potential sand transport (Fryberger, 1978; Fryberger and Ahlbrandt, 1979; Fryberger and Dean, 1979; Bullard, 1997; Pearce and Walker, 2005).

In particular, the method for calculating weighting factors is dependent upon the specific units of wind velocity, because the midpoint of each velocity category is used as the starting point for each calculation. So weighting factors based on velocities measured in knots have different magnitudes from those based on velocities measured in other units, for example meter per second (Tab. 2.8).

Summary velocity category (knots)	**Velocity category nearest equivalent (m/s)**	**Weighting factor $V^2(V-V_t)/100$ (knots)**	**Weighting factor $V^2(V-V_t)/100$ (m/s)**
11-16	6.5-7	2.7	0.353
17-21	9-10	25.3	3.182
22-27	12-13	75.0	10.196
28-33	15-16	172.1	22.885
34-40	18-19	342.3	51.430

Table 2.8 – Weighting factors for each velocity category (modified from Bullard, 1997).

However, the unit of measurement is important if the results are interpreted using Fryberger's classification of wind-energy environments, which uses velocities expressed in knots. In fact, Fryberger (1979a) calculated that the average annual amount of wind energy (DP) in sand seas ranged from 80 to 489 vector units and he categorized the wind regime of various desert environments using total DP and the ratio of RDP/DP (which categorizes the directional variability of the wind regime) (Tab. 2.9).

In recognition of the use of metric units, two variation of Fryberger's weighting equation were produced by Carson and McLean (1986) and Kalma *et al.* (1988), using km/h and m/s respectively. Neither of these studies recalibrated the wind-velocity classification produced by Fryberger.

Values of drift potential calculated using wind speed in knots	**Values of drift potential calculated using wind speed in m/s**	**Wind-energy environment**
< 200	< 27	Low-energy environment
200-400	27-54	Intermediate-energy environment
> 400	> 54	High-energy environment

Table 2.9 - Recalibration of Fryberger's (1979a) classification of wind-energy environments (Bullard, 1997).

Bullard (1997) indicated that values of DP should be compared with Fryberger's classification of wind-energy environments only if the wind velocities were expressed in knots. In a recent work, Pearce and Walker (2005) indicated systematic frequency and magnitude biases in the model.
These biases result from: (i) variations in wind direction sector range – which effects frequency bin size for determining percent occurrence of transporting winds – and (ii) use of wind speed class mid-point values over more statistically representative values (mean, median, etc) or minimally classified (whole knot) wind speeds in the magnitude weighting factor for DP calculations.
Frequency biases resulting from wind data aggregation into direction sectors of varying size produces statistically significant discrepancies in DP and RDP (resultant drift potential) estimates.
Magnitude biases result from the use of the wind speed class mid-point values instead of other statistically representative measures of wind speed in DP calculations. The estimation of RDP estimation may be more significant in complex wind regimes and/or in environments with more frequent high-magnitude winds from the cardinal directions.
Given the increased availability of more precise unclassified data, most of these systematic frequency-magnitude biases can be avoided. Pearce and Walker (2005) recommend on reducing inaccuracies imposed by these biases (i) using to-the-degree wind data where available and categorizing into 16 equal 22.5° direction sectors, (ii) using either wind speed class statistical mean values or minimally classified whole knot values in DP calculations and (iii) recognizing that converting 36-point (10s of degrees) data to 16 direction classes may introduce a frequency bias toward the cardinal directions and will cause inaccuracies in DP and RDP estimates of an amount that depends on the wind regime.

Data expressed in knots for the AMI database and the *Atlante Bioclimatico d'Italia* tables were analyzed. The following paragraphs summarize the results concerning 2000-2010 data because no many differences came out from the comparison with 1971-2000 results.

Results

Table 2.10 summarizes the results of RDP (Resultant Drift Potential) expressed in vector units (v.u), of RDD (Resultant Drift Direction) expressed in degrees and of RDP/DP rate. The last column lists the percentage of calms (speed <1 knot) in the study period.

2000-2010	RDP (v.u.)	RDD (°N)	RDP/DP	Calms (%)
Total	500.02	164	0.48	1.28
Spring	494.26	159	0.48	1.16
Summer	107.8	144	0.28	1.49
Fall	342.20	157	0.4	0.99
Winter	1113.23	171	0.57	1.41

Table 2.10 – Results of RDP, RDD and RDP/DP for all data and for seasonal periods.

After the mathematical procedure for calculating the transport vectors, sand roses may be draw.
In figure 2.24 DP's percentage vectors are represented by black lines in each quadrant (values in percentage) and the RDP vector is represented by the red line. Sand rose is calculated from all data collected between 2000 and 2010.
The prevailing sedimentary transport results from NNW to SSE, with an angle of 164°N. The RDP value is 500.02 vector units.

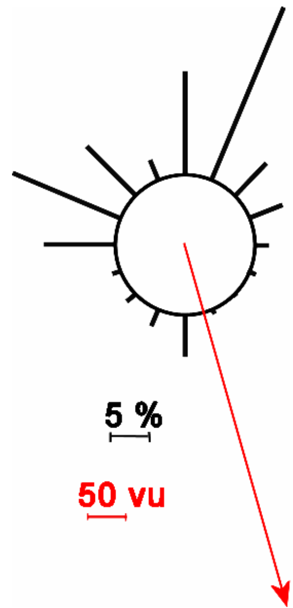
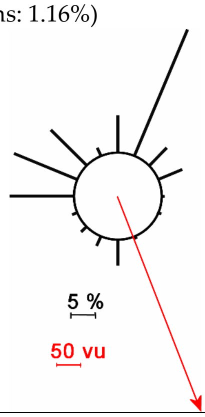
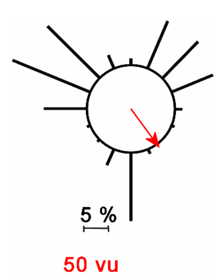
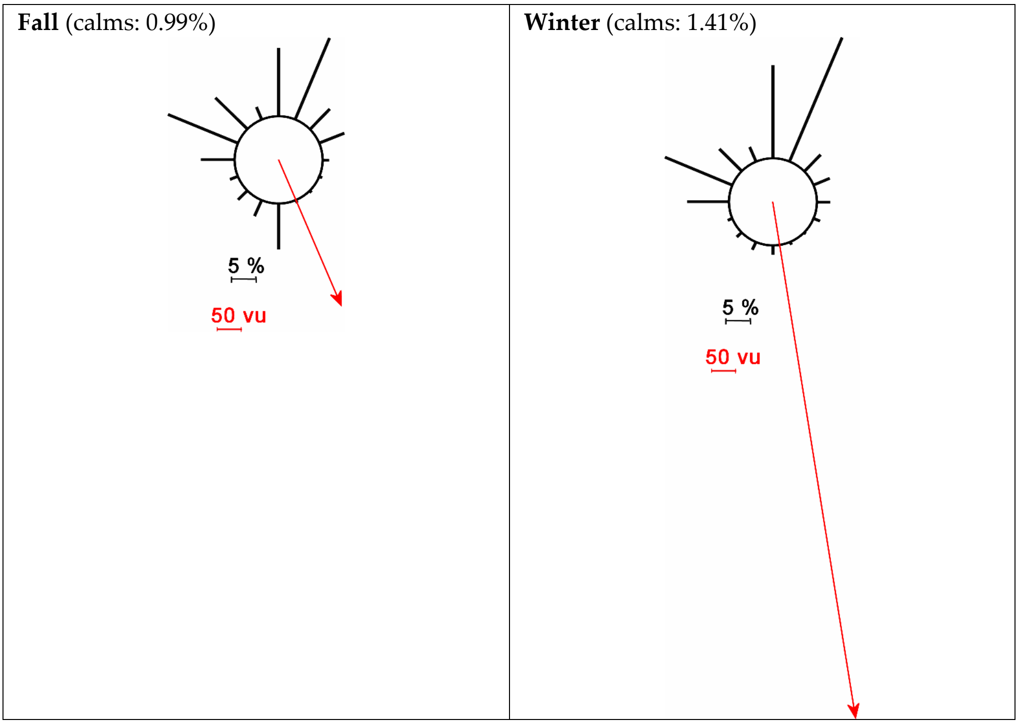


Figure 2.24 – Sand rose, period 2000-2010 (calms: 1.28%).

Figure 2.25 shows the sand roses calculated for each season.
They take in consideration the influence of the periodicity, in particular of precipitations and other climatic factors able to slow down the sand transport.
As seen in §2.3.2, in general precipitation is not abundant. In Sardinia, in fact, the mean annual precipitation is modest. Rains are infrequent but very strong storms are quite usual and they are not regularly distributed during the year. They are mostly diffused during spring and they are in short supply during winter and totally absent during summer when a dry-climate period establishes because of the Azores High (also known as North Atlantic Subtropical High/Anticyclone or the Bermuda-Azores High) or Saharian Highs. The first one is a large subtropical semi-permanent centre of high atmospheric pressure, not very hot compared to the Saharian ones'. It is frequent in the Italian peninsula during summer.

Spring (calms: 1.16%)	**Summer** (calms: 1.49%)
	



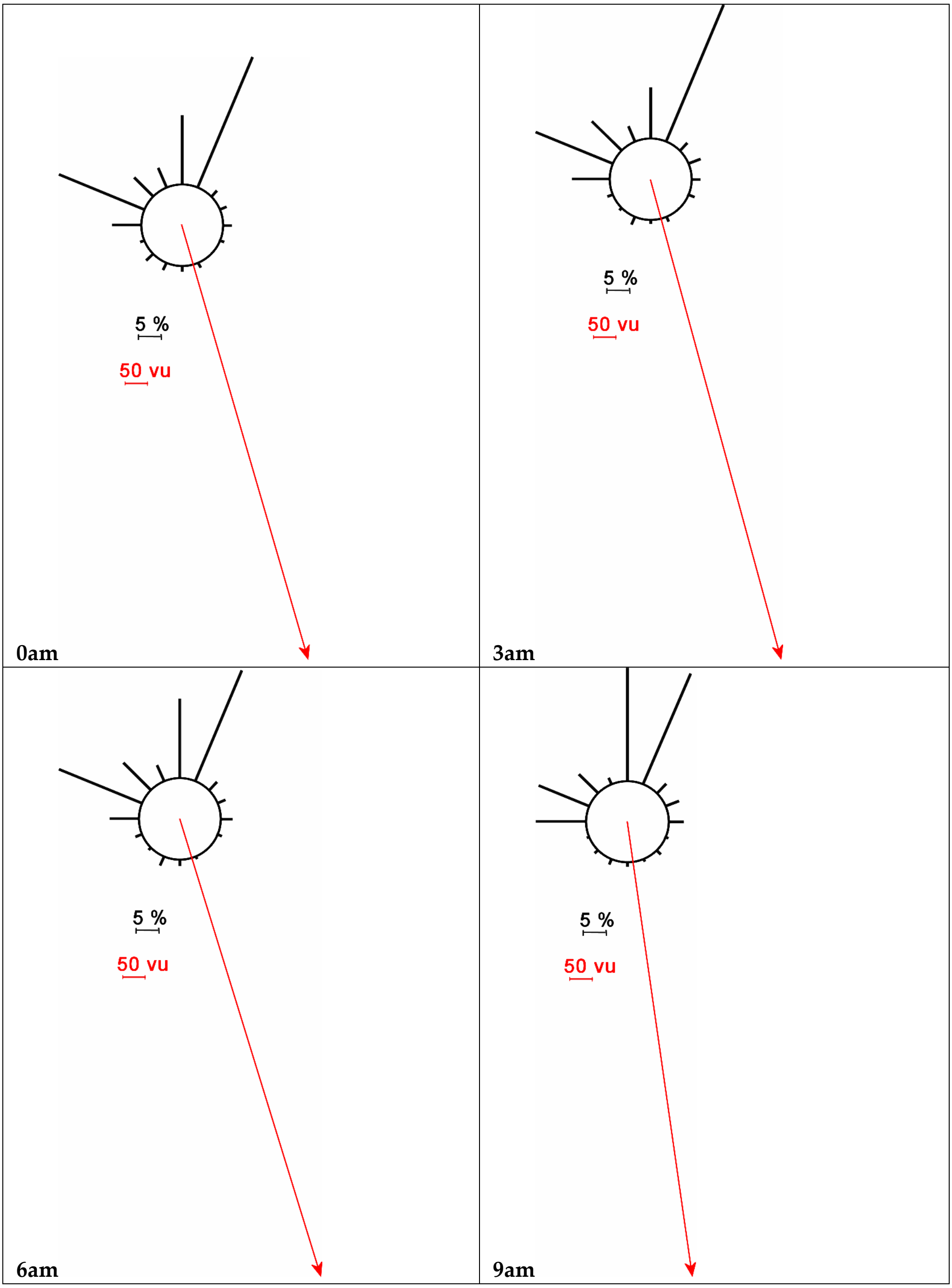
B

Figure 2.25 – Seasonal sand roses. Data from 2000 to 2010.

The net sedimentary transport results from NNW to SSE, with an angle varying from 144° to 171°N.

RDD's vectors indicates that the highest rate of sediment transport is during winter (1113.23 v.u.) according with the high frequencies of strong winds in the wind roses, then followed by the spring period (494.26 v.u.).

The analysis of the components for the transport is further complicated if the hourly data are considerated. In fact, the directions of the transport result strongly influenced by local climatic factors, such as sea and land breezes (Figs. 2.26, 2.27, 2.28 and 2.29). These winds are the main drivers of local morphologies. In fact, forms develop along different angles – sometimes opposite – compared to the general migration of the dunefield (detailed information in § 3.1).



A

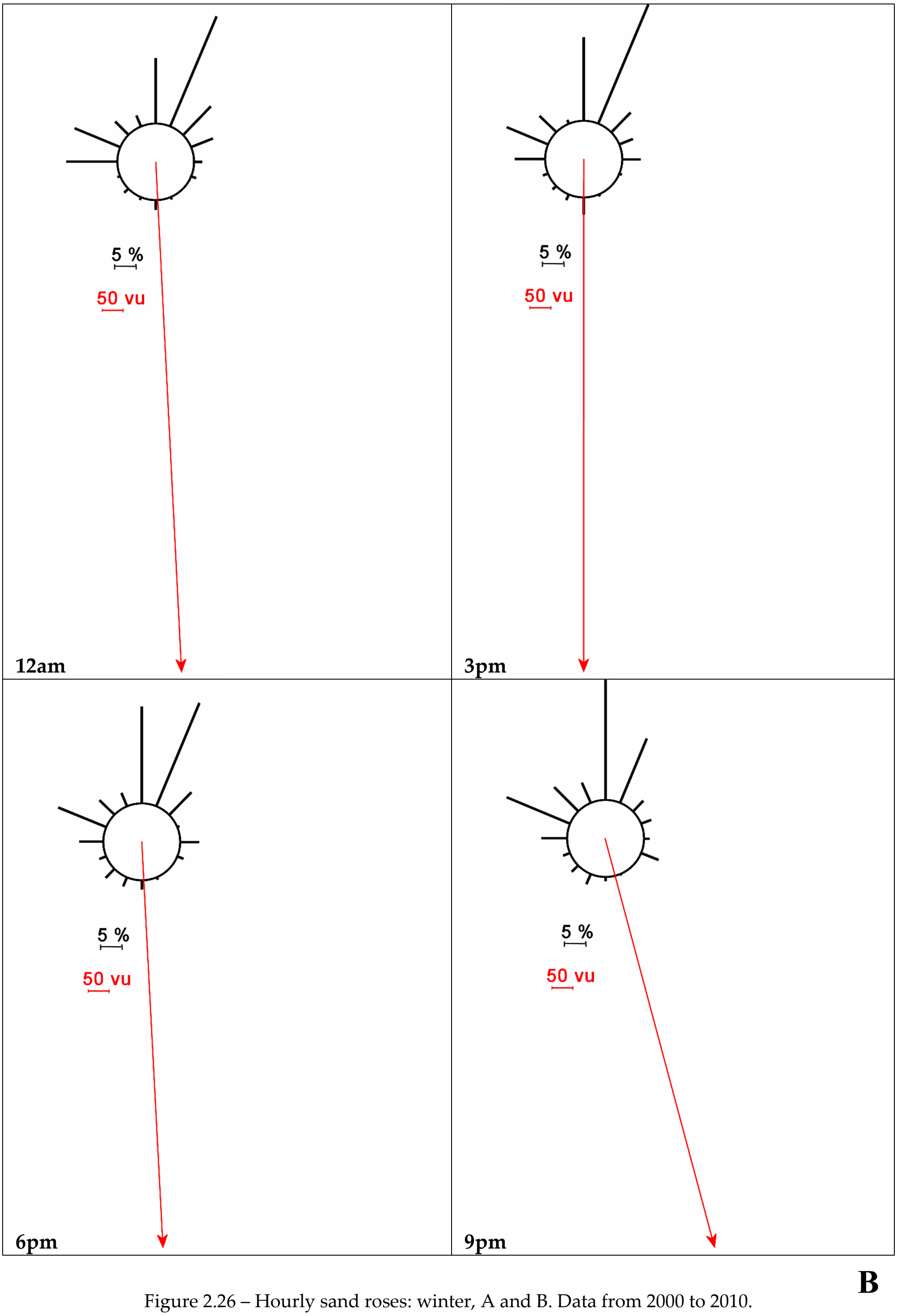


Figure 2.26 – Hourly sand roses: winter, A and B. Data from 2000 to 2010.

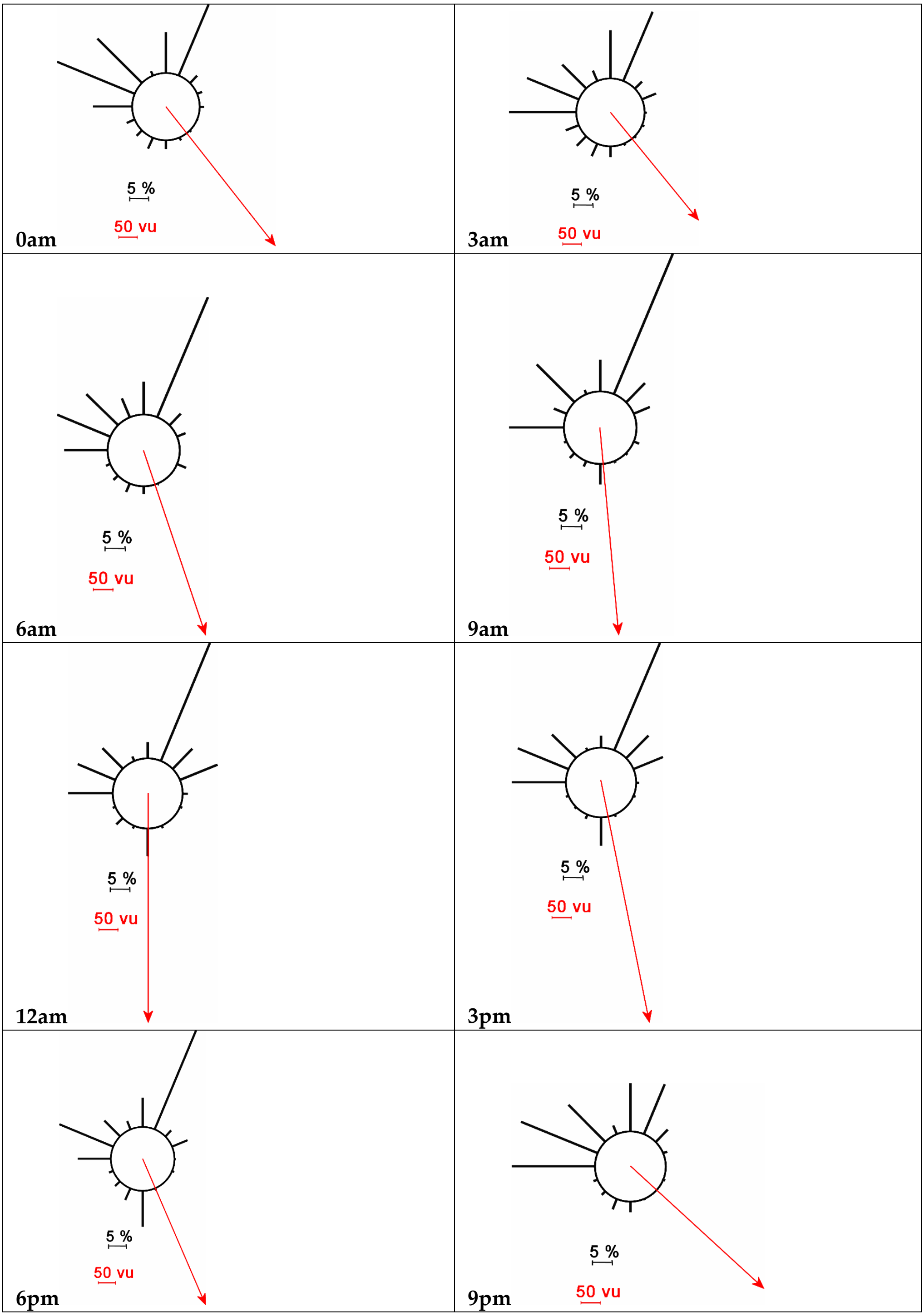


Figure 2.27 – Hourly sand roses: spring. Data from 2000 to 2010.

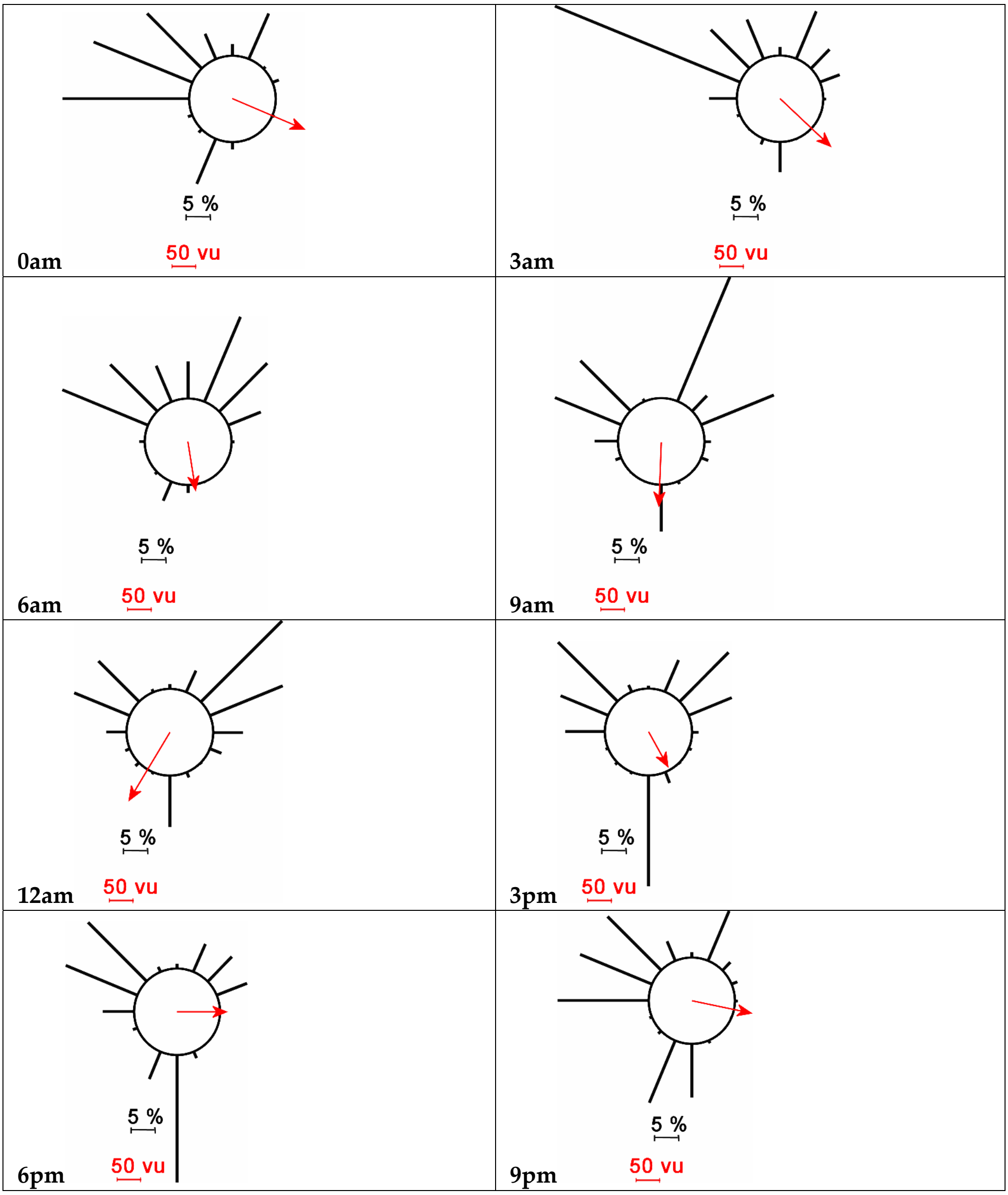


Figure 2.28 – Hourly sand roses: summer. Data from 2000 to 2010.

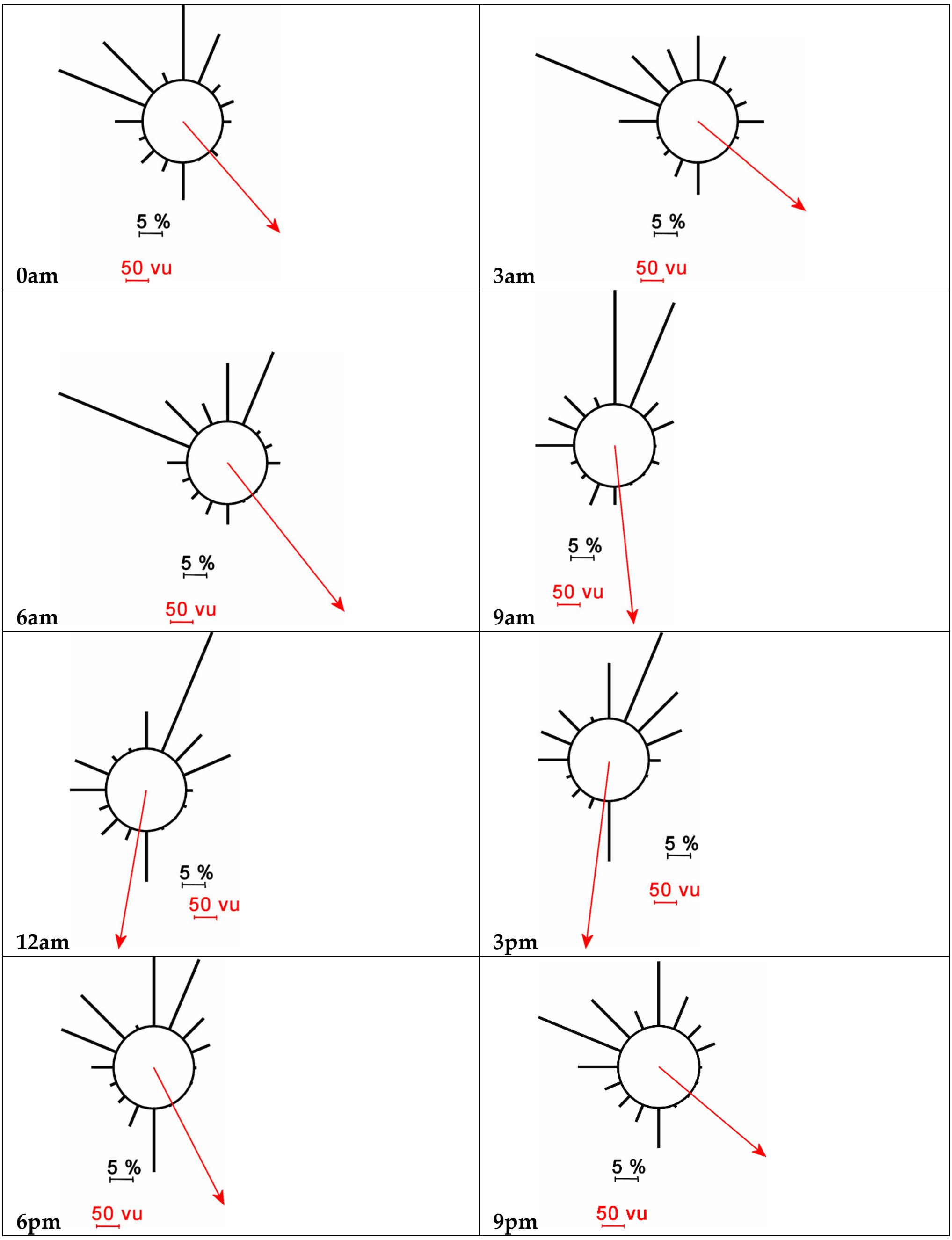


Figure 2.29 – Hourly sand roses: fall. Data from 2000 to 2010.

Discussion

Sand roses analysis is fundamental in order to understand the real direction of the sediment transport. In fact, if we take in consideration the wind blowing action and the relation with the grain size of the sediment, results show the strong influence of specific speed classes able to move the sand.
Figure 2.30 merges a radar graph of the wind rose (blue shape - figure 2.15) and a sand rose (black lines and red vector – figure 2.24).
DP's values of the sand roses are wind frequency data weighed up on mean grain size of the the sediment. So units of measurements are different and defined in the figure: percentage for frequencies of the winds (wind rose), vector units for the vector of sediment transport (red line) and percentage for DP's values (black lines).

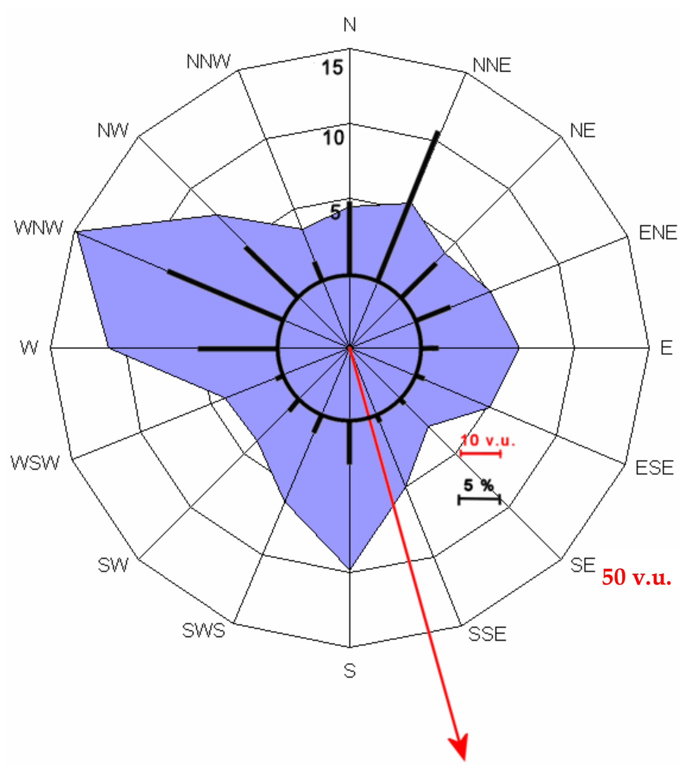


Figure 2.30- Merge of sand and wind roses. Period 2000-2010.

The figure indicates that, even if the highest-frequency winds blow from NW,WNW,W and S, if the threshold velocity of sediment transport is considered the main prominent winds for the sand movement are from NW, WNW, W and NNE.
Winds blowing from S have not a sufficient speed in order to exceed the threshold velocity of sand burial. So they don't contribute to the vector of the sediment transport.
NNE winds seem to be not very important in the wind rose because they low frequency but, instead, the resultant DP value is very high. This is because of the high speeds of the winds blowing from this sector.

The resultant vector is, in fact, with an angle of 164°N, with a high component from WNW and NNE.
The results of the potential sediment transport have a good approximation and they highlight the real movement of the dunefield.
Good explanations concerning the local morphologies may be done thanks to the seasonal and hourly transport analyses.

2.3.4 MARINE SETTING

2.3.4.1 Method

Meteo-marine data from the Italian Hydrographic Institute (IIM) were used for a generic overview of the study area.

Data from the Ondametric Buoy Network (RON), instead, were analyzed for a detailed study of Capo Comino beach.

The buoy collected few synthetic parameters:

- Hs (metres) height of the significant spectral wave;
- Tp (seconds) peak period;
- Tm (seconds) average period;
- Dm (N degrees) average motion direction;

and spectral parameters per frequency band:

- density of energy
- motion direction
- directional dispersion (spread)
- asymmetry (skewness)
- kurtosis

In order to define the marine influence on Capo Comino beach, following wind regime classification, the main exposure sector is defined by two tangent lines leading from two extreme geomorphological elements (e.g. heads, promontories) with a confluence or vertex on the beach. This angle represents the sector of the maximum incoming sea storms and it is very important in order to understand the geographical size of the fetch. The meaning of "fetch" in length of unobstructed open sea surface across which the wind can transfer its energy and generate waves (from "Glossary of Coastal terminology").

It's important to note that wave height, fetch and length of the wind are linked and they proportionally interact. Waves are much high as fetch is wide and as the atmospheric disturbance is durable.

2.3.4.2 Results

The main exposure sector is between 355°N and 120°N, with a geographic fetch of about 260 kilometers (centred on the Lazio coast).

The northern limit of this sector is about 240 Km long if I consider the *Arcipelago Toscano* (Tuscany) and about 385 km long if I consider the Versilian coasts (and the presence of Isola d'Elba is non influential on winds). The eastern tangent vector arrives to the Calabrian coasts and it's about 510 km long.

Results of the IIM report are presented below.

Data from the weather station of Capo Bellavista collected 18 years of observations; data from Capo Figari have about 23 years of observations.

Figures 2.31 and 2.32 present the results of the mean frequencies of the conditions of the sea, calculated for 4 intervals of Beaufort scale: 0-1, 2-3, 4-5, 6-8.

Values of the mean monthly and annual frequencies of wave height are indicated in the following histograms for each interval.
The histogram in figure 2.31 highlights that the more significant frequencies are in the 2-3 interval. They exceed the 60% in both the weather stations. The 6-8 interval, instead, has a frequency of 5% and it represents very strong sea storms occurring only during December and January, during the cold season.

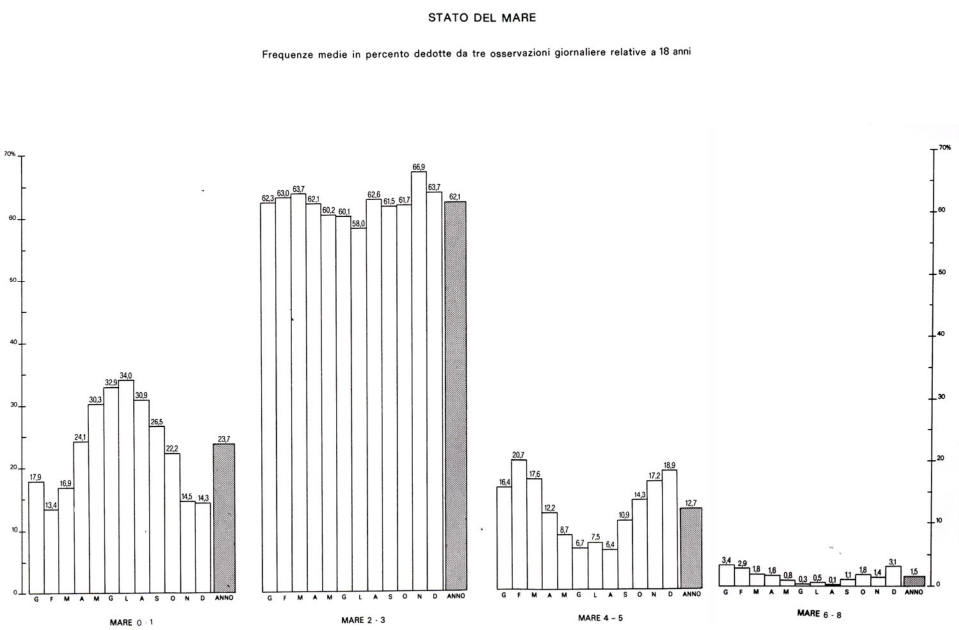


Figure 2.31 – Frequencies of the sea conditions for Capo Bellavista weather station (from IIM).

The histogram in figure 2.32 is related to Capo Figari weather station. In this case too, the main frequencies are from 2-3 interval, and the values exceed the 60% for all the year, excluding the month of July (only 49% of frequency). Frequencies of 4-5 interval are worthy of consideration because they reach the 30% in January and the 29.8% in February.

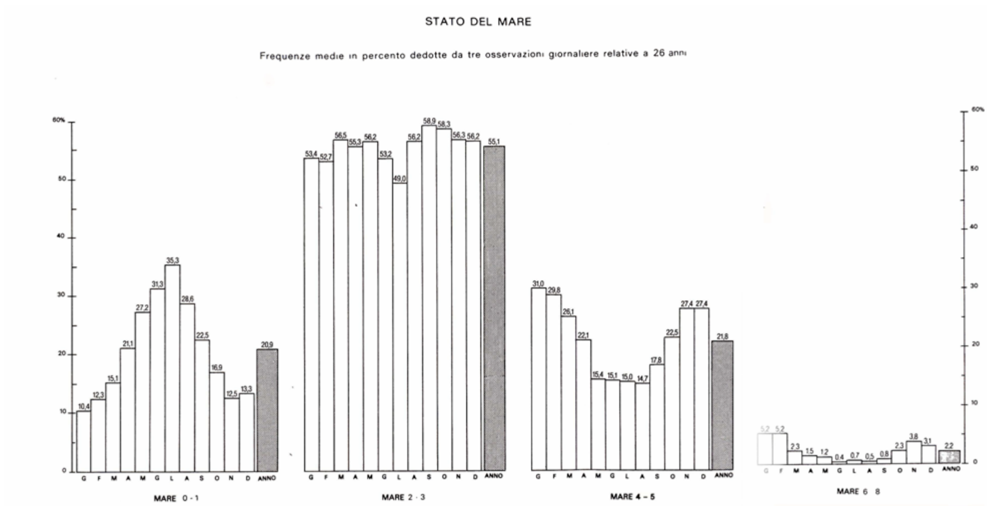


Figure 2.32 – Frequencies of the sea conditions for Capo Figari weather station (from IIM).

With regard to the source of sea storms (Fig. 2.33) (6-8 interval of Beaufort scale), the main ones usually come from the NE (Grecale wind). The secondary source is from the SE (Sirocco) but the frequencies are much lower than the first one.

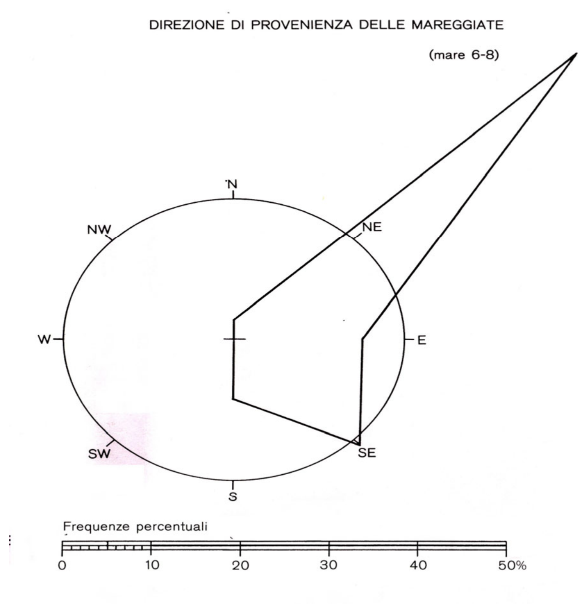


Figure 2.33 – Source of sea storms for Capo Bellavista weather station (6-8 interval of Beaufort scale; from IIM).

Data from Capo Comino buoy (Fig. 2.34) were collected from 2002 to 2005. Usually the statistical analysis of 3 years of observations is not valuable for a correct interpretation but these data were used in order to validate and confirm the previous analysis of Capo Bellavista and Capo Figari weather stations.
The radar graph supports the presence of a bimodal distribution of the frequencies.

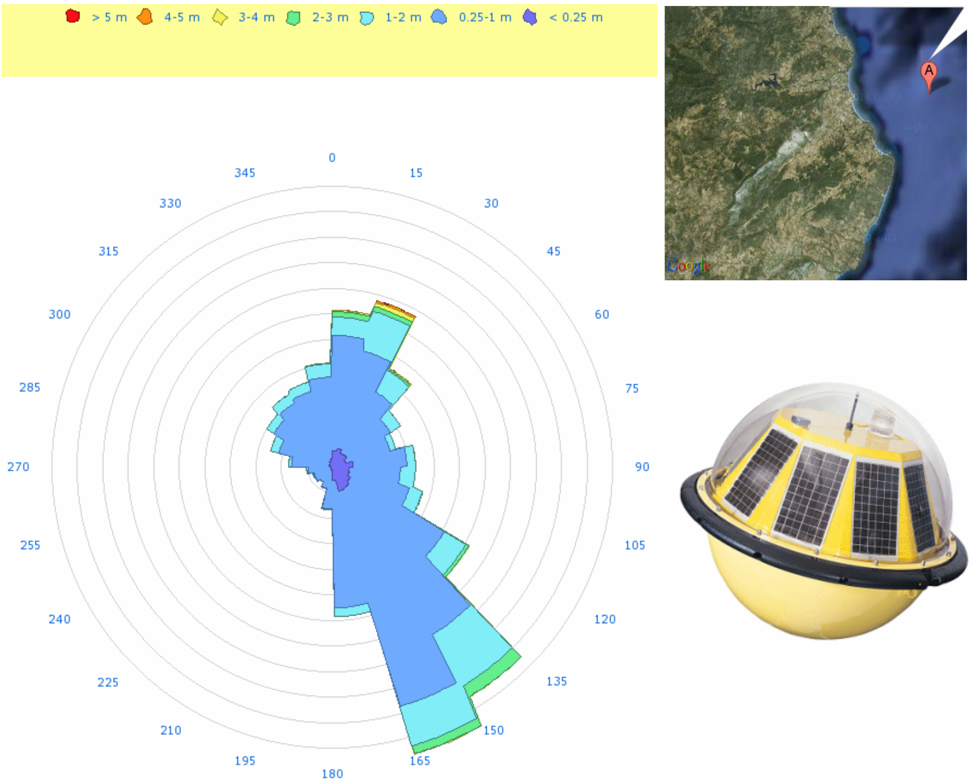


Figure 2.34 – Mean direction and wave height from Capo Comino buoy and its localisation (by APAT, *Servizio Mareografico*, www.idromare.it).

The main frequencies are from SSE-ESE but the highest values of sea storms are from NE-NNE (Grecale wind), even if the frequencies of the events are lower compared to the Sirocco. However Sirocco storms are sheltered by Capo Comino headland so the waves coming from 120°N to 180°N cannot occur with strong intensities on the beach.
Then data (a total of 4354 surveys) were divided into 5 intervals (between 0° and 180°N) depending on the source direction. Results are summarized in table 2.11.

Interval	Mean Hs (m)	Max Hs (m)
0°-22°	0.9	4.45
22,5°-67,5°	0.9	3.80
67,5°-112,5°	0.7	3.44
112,5°-157,5°	0.8	3.44
157,5°-180°	0.7	2.50

Table 2.11 – Mean and maximum significant wave heights.

Frequencies were also classified by the different intervals of the wave height (Fig. 2.35). Results confirm data presented in figure 2.31 and 2.32, where the more frequent values are between 0 and 1 m (about 80%).
The energy of the wave (equivalent to the offshore wave) is defined by the height, the period and the source.
The results are: Hs = 0.73 meters, Tp = 8 seconds, source = 150°N.

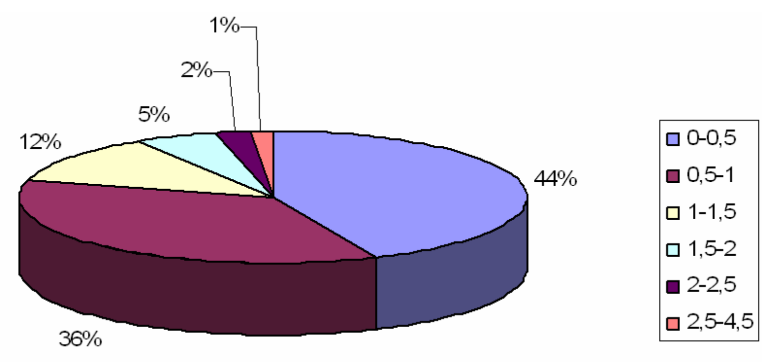


Figure 2.35 – Frequency of wave-height intervals (classes expressed in meters).

2.4 BIOCLIMATIC ANALYSIS

The distribution of the vegetation is strictly related to the climate settings and surface and sub-surface moisture. At first, it is necessary to distinguish the climatology – science that studies the climate conditions – and the bioclimatology, considering the effects that climate has on the biosphere and, in particular, on living beings.

In order to understand the distribution of the vegetation species on the Earth, it is necessary to better define the climate relating to the land extension of a species or a community. So we can distinguish the macroclimate, the mesoclimate and the microclimate.

Macroclimate is the climate of a relatively large geographic area, depending on the geographic situation (latitude and longitude influence the solar radiation on the Earth), the distance to oceans and the orography (altitude). It corresponds to the De Martonne's Regional Climate Value and to the Geiger's *Groβklima*. As an example, the Mediterranean climate is a macroclimate.

Mesoclimate is the variation of a regional macroclimate subjected to local influences, mainly depending on topographic factors. We can also call it "local climate" or "topoclimate". As an example, in a valley the climate of a slope exposed to the north is different from that exposed to the south.

The term microclimate is referred to any climatic condition in a relatively small area, within a few metres or less above and below the Earth's surface and within canopies of vegetation. That is the climate referring to a well defined spatial level.

Microclimatic conditions depend on such factors as temperature, humidity, wind and turbulence, dew, frost, heat balance, and evaporation. As an example, the effect of soil type on microclimates is considerable.

An important definition is about the "bioclimate". It is the description of the climate, and as it influences and is influenced by biological life beings, above all the vegetation.

Pignatti (1995) suggests that it's important to distinguish among the climate factors, the cosmic and geographic elements, and other ones such as insolation, precipitation and temperature. Indeed, using the combination of these factors it's possible to find on the Earth surface several climatic factors and elements that produce very different climate types.

2.4.1 Materials

Climate might be very different if we consider the range of variation of the meteorological elements. Maybe if we reduce the number of these factors considering only temperature and precipitation (that are in general the most indicative elements), a number of local situations are present on the Earth's surface. Thus, it is necessary to realize a logical classification system by "climatic types" that helps us to synthesize and define differences and similarities.

In order to characterize the climate of Capo Comino area, monthly and annual data were analysed from 1977 to 2010 (data source: "Atlante Climatico d'Italia", http://www.meteoam.it) and from 2000 to 2010 (SYREP and SYNOP data from Aereonautica Militare Italiana, Servizio Metereologico).

The weather station is localized at Capo Bellavista (coordinates 39°56′N 9°43′E, 156 meters above mean sea level) and data from 1977 to 2010 were available.

Several bioclimatic indexes very common in literature were calculated in order to classify the climate of this area. Microsoft Excel and the online software (www.globalbioclimatics.org) developed by Rivas-Martinez were used.

2.4.2 Methods and results

Bioclimate is defined by climate indexes. They elaborate meteorological data comparing the different biocenosis of the study area. Biological populations are considered such as expression of specific climate (Biondi, 1985). In order to classify the climate, several indexes and formulae were proposed. They are related to climate factors and they define the principal characteristics with a particular reference to geographic area or vegetation distribution on Earth's surface (Pignatti, 1995).
In the following pages a few climatic indexes will be analyzed, considering the most significant presented in literature.
Starting from the pluviometric values, the "pluviofactor" by Lang (1915, 1920) is simply to calculate: $I = P/T$
where P=annual precipitation in mm and T=mean temperature in °C. Ranges are: $I > 160$ Humid, $160 < I < 100$ Humid-temperate, $100 < I < 60$ Dry-temperate, $60 < I < 40$ Half-arid, $I < 40$ Arid
I value of Capo Bellavista station is 24, typical of Mediterranean climate.
De Martonne (1923) modified Lang's formula : $I=P/(T+10)$
and the ranges are: $0< I < 5$ Desert climate, $5< I <15$ Arid (steppes), $15< I <20$ Half-arid (and Mediterranean –like climate), $20< I <30$ Sub-humid, $30< I <60$ Humid, $I > 60$ Iper-humid.
The ecological value of this index is not quite far from the Lang's index and we can find four intervals: $I < 5$: desertic vegetation; $5 < I < 10$: steppe; $10 < I < 20$: grassland, $I > 20$: forest vegetation.
The calculated value for the study area is 15.5.
The most famous climatic classification was proposed by Wladimir Köppen in 1918, and then modified several times. It considers mean annual and monthly temperature and precipitation. The climatic regimes are characterized referring to the vegetation distribution.
Köppen identified five climatic groups:

- Megathermic-humid climate: mean temperature is always above 15°C;
- Arid climate: hot deserts with mean annual temperature above 18°C and mean temperature of the hottest months above 26°C; cold deserts with mean temperature of the coldest months sometimes below to -30°C;
- Exothermic climate: mean temperature of the coldest month is between 2 and 15°C;
- Microthermic climate: mean temperature of the hottest month is below 10°C and the mean temperature of the coldest month is below 2°C;
- Nival climate: mean temperature of the hottest month is below 10°C with a huge annual temperature range (Pignatti, 1998).

Köppen defined the value of <30 mm to identify an arid month. This value represents the sufficient amount of precipitation in order to maintain a rapid evapotranspiration on a naked soil (Daget, 1977). Considering data presented in tables 2.1 and 2.2, indexes defined an arid climate for the study area, in particular to a Mediterranean climate - Csa subtype.

Rivas-Martinez classification

Bioclimatic classification by Rivas-Martinez (Rivas-Martinez *et al.*, 2004) results very effective in the phytoclimate characterization of Spain peninsula and of the Earth, in general. It proposes 5 macrobioclimates (tropical, Mediterranean, temperate, boreal and polar) and 27 bioclimates. In European continent tropical macrobioclimate is not present.

The variation of thermic and ombrothermic values distinguished several bioclimatic types: the thermotype and the ombrotype (Fig. 2.36).

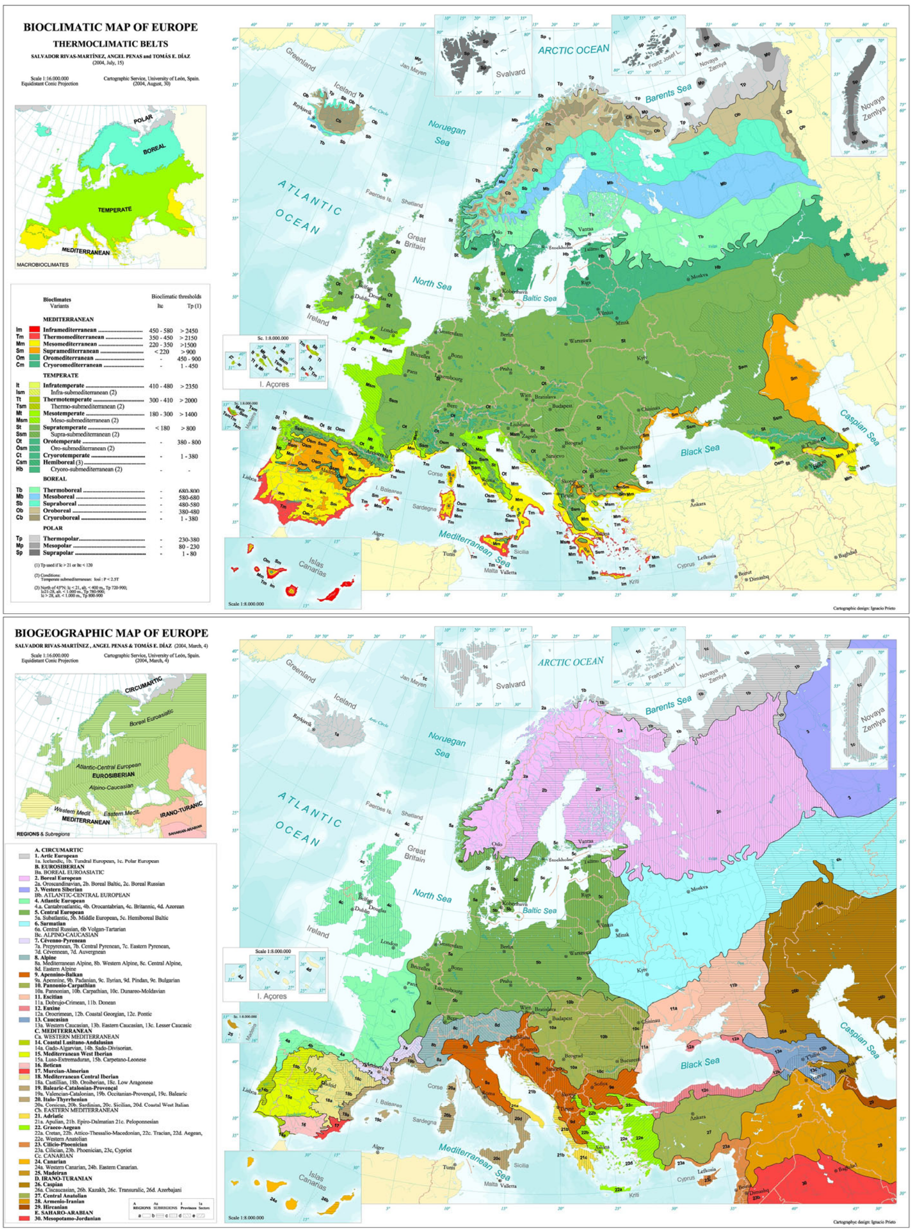


Figure 2.36 – Bioclimatic classification of Europe: thermoclimatic belts (up) and biogeographic maps.

Capo Comino area was classified as West Mediterranean, Italo-Tyrrhenian climate and Thermomediterranean belt.
In his bioclimatic approach, Rivas-Martinez proposed the calculation of several indexes. Considering the location and the characteristics of the study area, the following ones were anlyzed:

<u>Continentality Index - Ic</u> (yearly thermic interval).
Ic = Tmax - Tmin
The number (in Celsius degrees) expresses the range between the average temperatures of the warmest (Tmax) and coldest (Tmin) months of the year. It expresses the annual oscillation of the temperature, attenuated by the proximity to lakes, oceans, *etc* .
The simple continentality index-types (number of 3) and subtypes are: hyperperoceanic (0-11) [extremely hyperperoceanic (0-3), euhyperperoceanic (3-7), barely hyperperoceanic (7-11)], oceanic (11-21) [euoceanic (11-18), semicontinental (18-21)], and continental [subcontinental (21-28), eucontinental (28-45) and hypercontinental (45-65)].

<u>Ombrothermic Index - Io</u>
Io = (Pp/Tp) 10.
Ten times the quotient resulting value between the yearly positive precipitation in mm (Pp: Yearly Positive Precipitation. In mm, total average precipitation of those months whose average temperature is higher than 0ºC) and the yearly positive temperature (Tp: Yearly Positive Temperature. In tenths of degrees Celsius, sum of the monthly average temperature of those months whose average temperature is higher than 0ºC.)
0,1< Io< 2 Mediterranean climate, 2<Io<3,8 Temperate climate.

<u>Ombrothermic Index of summer (driest three-month) – Ios_3</u>
$Ios_3 = Pp_3/Tps_3$
The quotient resulting value between the sum of the precipitation of the driest three months (Tr_3) and the average temperatures of that period. (Tr_3: June, July and August in the Northern Hemisphere; December, January and February in Southern Hemisphere).
It is possible to calculate the value for the driest bi-month (Ios_2) and the driest month (Ios_1).

<u>Thermicity Index - It</u>
It = (T + m + M) 10.
= ten times the sum of T (yearly average temperature), m (average minimum temperature of the coldest month of the year), M (average maximum temperature of the coldest month of the year).
Coldest month of the year: the one which has the lowest monthly average temperature (Tmin). This index takes in consideration the coldest temperature, limiting factor to plants and vegetation communities.

<u>Compensated Thermicity Index - Itc</u>
Itc = It ± C.
It's the sum of Thermicity Index and a Compensation Value (C) (Rivas-Martinez, 1994; 2002). In the extra-tropical zones of the World (northern and southern 27ºN and 27ºS parallels, respectively), the Compensated Thermicity Index is designed to equilibrate the

cold "excess" that occurs during winter in the continental climates, or the excessively mild winter in the marked oceanic territories, so that these index values can be significantly compared.
If the Continentality Index (Ic) lies between 9 and 18, the Itc value is considered equal to the It value, that means that there is no modification. In the other hand, if the Continentality Index does not reach, or surpass, the mentioned values, it is needed to compensate the Thermicity Index adding or subtracting a figure called Compensation Value (C).

The results of the bioclimatic indexes are presented in Figs. 2.37 and 2.38.
Considering Rivas-Martinez classification, the study area is characterized by a Mediterranean Pluvioseasonal - Oceanic macroclimate and an Upper Thermomediterranean Low Dry bioclimatic belt.
Mean annual temperature is above 18°C.
The simple continentality index (Ic) is about 15 (Oceanic/euoceanic bioclima) and the annual ombrothermic index (Io) is about 2 (Mediterranean climate).

```
----------------------- BIOCLIMATIC INDEX AND DIAGNOSIS -----------------------
       Thermicity index................................(It):   385
       Compensated thermicity index....................(Itc):  385
       Simple continentality index.....................(Ic):    14.6
       Diurnality index................................(Id):     7.8
       Annual ombrothermic index.......................(Io):     2.05
       Monthly estival ombrothermic index............(Ios1):    0.22
       Bimonthly estival ombrothermic index..........(Ios2):    0.35
       Threemonthly estival ombrothermic index.......(Ios3):    0.42
       Fourmonthly estival ombrothermic index........(Ios4):    0.61
       Annual ombro-evaporation index.................(Ioe):    0.49
       Annual positive temperature.....................(Tp):  2045
       Annual negative temperature.....................(Tn):     0
       Estival temperature.............................(Ts):   717
       Positive precipitation..........................(Pp):   420
```

N°of Years	P>4T	P:2T a 4T	P: T a 2T	P<T	T<=0
	2	6	1	3	0

```
Latitudinal Belt...: Eutemperate
Continentality.....: Oceanic - High Euoceanic
Bioclimate.........: MEDITERRANEAN PLUVISEASONAL-OCEANIC
Bioclimatic Belt...: UPPER THERMOMEDITERRANEAN LOW DRY
```

Figure 2.37 – Bioclimatic indexes of Capo Bellavista. Data from 1977 to 2000.

```
----------------------- BIOCLIMATIC INDEX AND DIAGNOSIS -----------------------
        Thermicity index................................(It):   395
        Compensated thermicity index...................(Itc):   395
        Simple continentality index.....................(Ic):    15.5
        Diurnality index................................(Id):     9.1
        Annual ombrothermic index.......................(Io):     2.02
        Monthly estival ombrothermic index............(Ios1):     0.1
        Bimonthly estival ombrothermic index..........(Ios2):     0.24
        Threemonthly estival ombrothermic index.......(Ios3):     0.27
        Fourmonthly estival ombrothermic index........(Ios4):     0.52
        Annual ombro-evaporation index.................(Ioe):     0.47
        Annual positive temperature.....................(Tp):  2115
        Annual negative temperature.....................(Tn):     0
        Estival temperature.............................(Ts):   752
        Positive precipitation..........................(Pp):   427
```

N°of	P>4T	P:2T a 4T	P: T a 2T	P<T	T<=0
Years	2	5	2	3	0

```
Latitudinal Belt...: Eutemperate
Continentality.....: Oceanic - Low Euoceanic
Bioclimate.........: MEDITERRANEAN PLUVISEASONAL-OCEANIC
Bioclimatic Belt...: UPPER THERMOMEDITERRANEAN LOW DRY
```

Figure 2.38 – Bioclimatic indexes of Capo Bellavista. Data from 2000 to 2010.

Ombrothermic diagrams

Pluviothermic and ombrothermic diagrams were proposed by Bagnouls and Gaussen (1957) and subsequently modified by Walter and Leith (1960).

They are commonly used in phytogeography analysis because of the simple consultation.

The monthly mean values of temperature and precipitation are referred to a Cartesian coordinate system in y axis (ordinate) with a scale 1P=2T ; months are represented on x axis (abscissa).

Authors defined the dry period when the precipitation line is lower than the double value of temperature. In the graphic, the dry period is the area formed by the superposition of the two curves.

Using this criterium, we can define four pluviometric classes:

- oceanic and marine: precipitations are distributed for the whole year;
- continental: the highest rain period is during the summer and the lowest during the winter;
- equinoctial: minimum during summer, maximum during winter;
- mediterranean: minimum during summer and maximum during winter.

Ombrothermic diagrams are represented in the following two charts (Figs. 2.39 and 2.40.) and the study area belongs to the "Mediterranean" pluviometric class.

Mediterranean climate is characterized by at least two months of dryness during summer season and the minimum winter temperature never goes below 0°C. Those conditions are completely verified in the study area.

Precipitations are huge during winter and spring period (lined area) and the dry season goes from May to September (gray area). The minimum hydric contribution is during July and August.

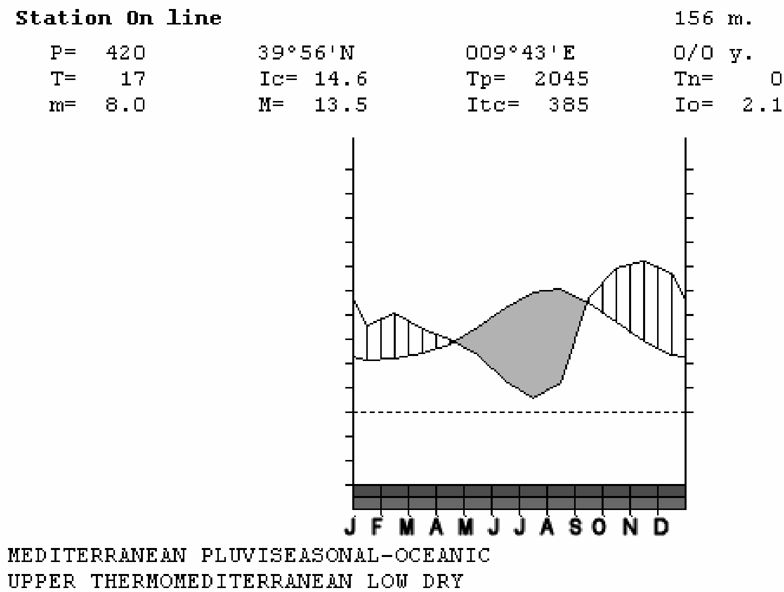


Figure 2.39 – Ombrothermic diagram. Data from 1977 to 2000.

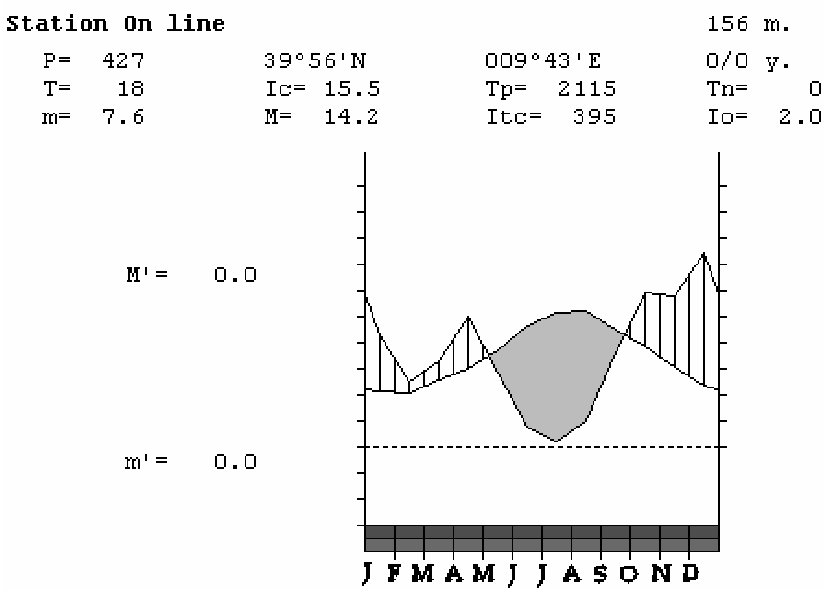


Figure 2.40 – Ombrothermic diagram. Data from 2000 to 2010.

Water balance
Several climatic indexes considering the evapotranspiration value were introduced by Thornthwaite (1948, 1953 and 1957) and then modified by Mather (1978, 1979). The evapotranspiration is a very important condition for vegetation survivor and he distinguished the "real evapotranspiration" (ETR) and the "potential evapotranspiration" (ETP). The first one (ETR) is the quantity of water that effectively evaporates considering the soil and climate characteristics, directly from the soil and by the absorption and transpiration of plants. ETP is the quantity of water that could evaporate from the soil, directly or not, by the absorption and the transpiration of plants, without the depletion of water reserve and in specific pedological and climatic conditions. Thus the potential evapotranspiration represents an ideal condition with constant humidity of the soil and an optimal situation for plants survivor. The knowledge of this constraints is very important from the bioclimatic and ecological point of view.
With regard to Capo Bellavista meteorological station, the following indexes were calculated using pluviometric and temperature data:

- potential evapotranspiration (PE);
- variation of water reserve (VR);
- water reserve (R);
- real evapotranspiration (RE);
- water deficit (DF);
- humidity coefficient (HC).

Results are indicated in figures 2.41 and 2.42.
Water superavit (SP) and drainage (DR) values were not calculated because no information was present about the study area (e.g. type of soils).
Figures 2.41 and 2.42 show the maximum values of the potential evapotranspiration (PE); they occur from June to September, during the dry period. The tables assert that during the spring season the variation of the reserve is negative that means that the hydric resources are used to fight the deficit and there is no more accumulation of water. Reserve of water is zero from June to October; deficit is positive during the same period.
Data concerning the precipitations (Fig. 2.42) affirm that during the last ten years there was a light difference in the monthly values, with an increasing of the rain in December-January and the variation of the reserve. It started to be negative from March, with lower values in February and November too.

Using the real evapotranspiration index, the potential evapotranspiration index and the precipitation values it is possible to realize the Hydric Balance chart by Thornthwaite.
Data from meteorological station were elaborated and results are showed in figure 2.43 and 2.44. It is possible to recognize a high deficit area (white area), covering the period from June to October. The reserve use period (square-drawn area) goes from March to June, corresponding to the increasing values of evapotranspiration. The imbibition period is from October to February, when the quantity of water is higher than the capacity of the soil evapotranspiration and there is a growing accumulation of water in the soil up to the saturation.

WATER INDEX CARD Station On line

Altitude: 156 m. Latitude: 39°56'N

(C°/mm)	T	PE	P	VR	R	RE	DF	SP	DR	HC
Jan	10.8	23	35	12	67	23	0	0	0	0.5
Feb	10.9	23	41	17	84	23	0	0	0	0.7
Mar	12.0	34	34	0	84	34	0	0	0	0.0
Apr	14.0	48	30	-18	66	48	0	0	0	-0.4
May	17.6	81	24	-57	9	81	0	0	0	-0.7
Jun	21.6	117	13	-9	0	22	96	0	0	-0.9
Jul	24.7	151	6	0	0	6	145	0	0	-1.0
Aug	25.4	147	12	0	0	12	135	0	0	-0.9
Sep	22.5	105	47	0	0	47	58	0	0	-0.6
Oct	18.6	69	60	0	0	60	10	0	0	-0.1
Nov	14.5	38	62	24	24	38	0	0	0	0.6
Dec	11.9	26	57	31	54	26	0	0	0	1.2
Year	17.0	864	420	*	*	420	444	0	0	0.0

T = Average temperature
PE = Potential evapotranspiration
P = Precipitation
VR = Variation of the reserve
R = Reserve
RE = Real evapotranspiration
DF = Deficit
SP = Superavit
DR = Drainage
HC = Humidity coeficient

Figure 2.41 – Water index chart. Period 1971-2000.

WATER INDEX CARD Station On line

Altitude: 156 m. Latitude: 39°56'N

(C°/mm)	T	PE	P	VR	R	RE	DF	SP	DR	HC
Jan	10.7	21	43	22	90	21	0	0	0	1.1
Feb	10.5	20	25	5	95	20	0	0	0	0.2
Mar	12.8	36	33	-3	92	36	0	0	0	-0.1
Apr	14.8	51	50	-1	91	51	0	0	0	-0.0
May	18.6	86	28	-58	32	86	0	0	0	-0.7
Jun	23.4	133	8	-32	0	41	93	0	0	-0.9
Jul	25.9	164	2	0	0	2	161	0	0	-1.0
Aug	25.9	152	10	0	0	10	143	0	0	-0.9
Sep	22.6	104	36	0	0	36	68	0	0	-0.7
Oct	19.4	72	59	0	0	59	13	0	0	-0.2
Nov	15.3	40	58	17	17	40	0	0	0	0.4
Dec	11.8	24	74	50	67	24	0	0	0	2.1
Year	17.6	905	427	*	*	427	477	0	0	0.0

T = Average temperature
PE = Potential evapotranspiration
P = Precipitation
VR = Variation of the reserve
R = Reserve
RE = Real evapotranspiration
DF = Deficit
SP = Superavit
DR = Drainage
HC = Humidity coeficient

Figure 2.42 – Water index chart. Period 2000-2010.

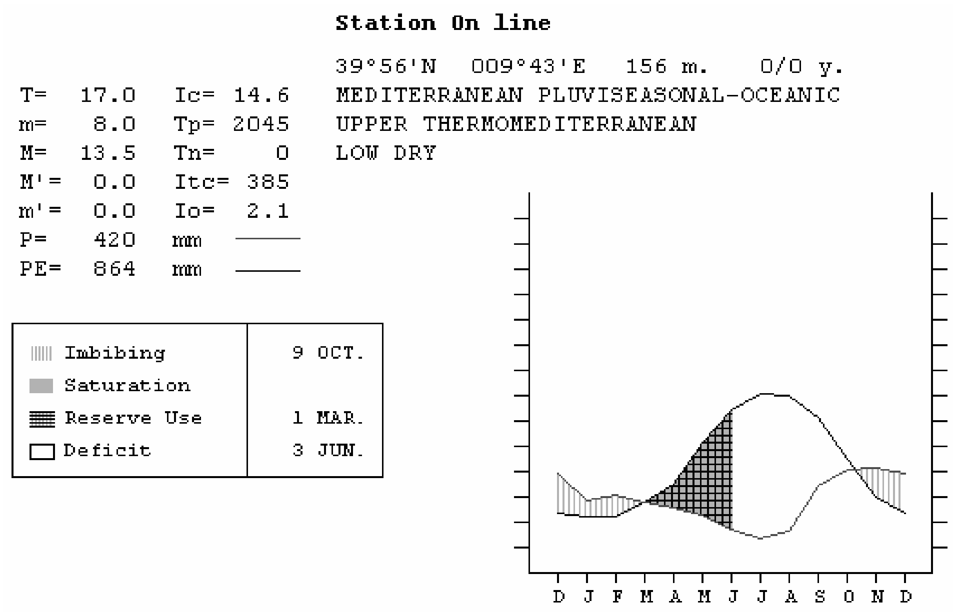


Figure 2.43 – Hydric balance chart. Period 1971-2000.

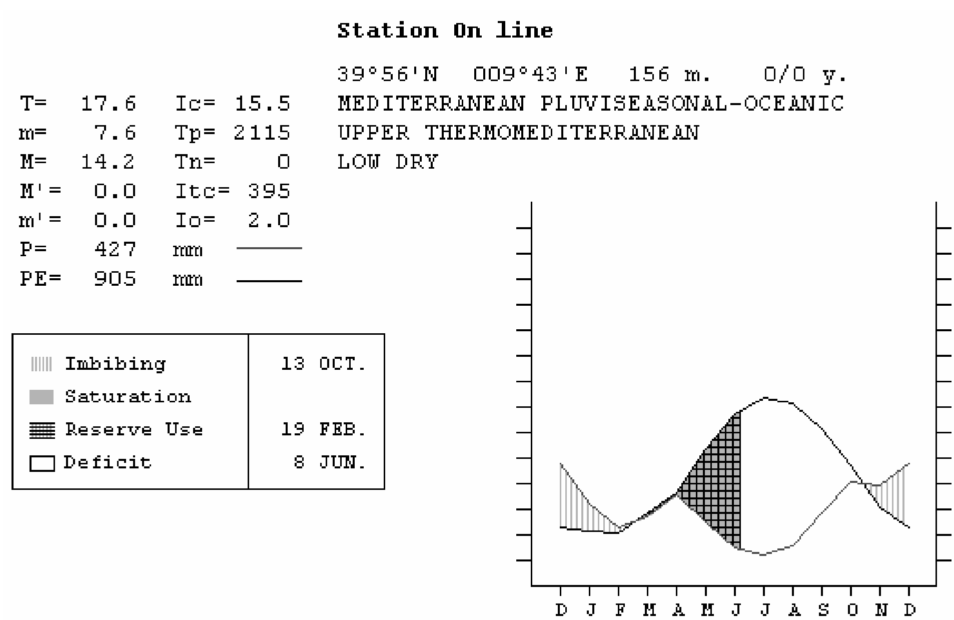


Figure 2.44 – Hydric balance chart. Period 2000-2010.

2.5 Conclusions

Capo Comino dunefield is located in a coastal area characterized by metamorphites and late-Hercynian intrusions outcrops. Current dunes include Pleistocenic eolianites and Holocene sand dunes.

With regard to the vegetation, the study area is characterized by two geosigmeta: the Sardinian halophilic geosigmetum of salt marshes, ponds and coastal lagoons and the Sardinian psammophile geosigmetum of coastal dune systems.

The climatic analysis is referred to Capo Bellavista meteorological station and covers the period from 1971 to 2010.
The study area presents a huge period of hydric deficit, starting from June to October.
Mean annual temperature is above 18°C. The hottest months are July and August, with temperature above 31°C; the coldest ones are January and February with temperature below 11°C. Precipitation is strongest from October to December and there is a dry period covering the entire summer season.

Bioclimatic indexes highlight a Mediterranean Pluvioseasonal - Oceanic macroclimate and an Upper Thermomediterranean Low Dry bioclimatic belt.
The annual ombrothermic index (Io) is about 2 and represent a typical Mediterranean climate. The Water Index and the Hydric Balance charts confirm the high hydric deficit period during summer.

The wind data analyses indicate a high variance in wind distribution depending on the season but also on the daily hour of measurement. This wide modal distribution of winds reflects on the transport of the sand, producing a general drift direction but also a lot of local morphologies.
Sand roses analysis well defines the real direction of sediment transport The mean sedimentary transport results from NNW to SSE (angle of 164°N).
The direction of the transport results strongly influenced by local climatic factors, such as sea and land breezes. These winds are the main drivers of local morphologies.

The biggest sea storms (6-8 interval of Beaufort scale) usually come from the NE (Grecale wind). The main wave-frequencies are from SSE-ESE but Sirocco waves are moderated by Capo Comino headland so waves coming from 120-180°N cannot occur with strong intensities on the beach.

Chapter 3
DATA COLLECTION AND PROCESSING

3.1 GEOMORPHOLOGICAL ANALYSIS

Coastal geomorphology is a branch of geomorphology in which the focus is on the form (morphology) of landforms (geo) in the coastal zone which in the very general sense extends from the landwardmost landforms formed by coastal processes to potentially the deep ocean.. It overlaps with other applied sciences such as geology, meteorology, oceanography, coastal engineering and biology (Davidson-Arnott, 2010).

One of the first publications concerning dune dynamics was by Bagnold in 1941 and it focus on dunes in arid environments. The most part of the following studies refer to it.
Recently, due to the increasing impact of the human activities on the coasts, the understanding of the functioning of the system reached a strong relevance.
The actual aim is to make predictions at large spatial and temporal scales but this is not so simple if we take into consideration the potential impacts of global climate change and if we assume that coastal systems vary greatly in their dynamic range and in their response to changing controls. Concepts of systems interrelationships, feedback paths, dynamic equilibrium and thresholds have been part of geomorphology for the past 40 years (Pye and Psoar, 1990). The researches have been concentrating on evolutive models, most of them based on morphodynamic criteria (Short and Hesp, 1982) or sedimentary budgets (Psuty, 1992). The new approaches take into consideration field measurements too (Bauer *et al*., 1990; Robertson-Rintoul, 1990; Doody, 2001, 2008).
In Italy, few projects were carried out, especially on dune dynamics and protection. In 2003, the Ministry of the Universities and Technologic and Scientific Researches advanced a biennial project concerning the study of Italian coastal dunefields (AA.VV., 2006; Balduzzi *et al*., 2006)).

Results of the geomorphological analysis are discussed in the following paragraphs.
The first one – *Geomorphology of the Capo Comino dunefield* – analyzes the main geomorphological features found in the dunefield and their evolution during 1954-2006.
The second one – *Geomorphological maps* – presents the maps and results of the spatial analysis of the features. The paragraph *"Migration rate"* compares the values of migration between different sectors of the dunefield. The paragraph - *Sedimentary transport and geomorphological features* – shows the relations between the transport directions (from different winds) and the local geomorphological features. The last paragraph describes the *Evolutionary model of the dunefield*.

3.1.1 Methods
Geomorphological analysis of Capo Comino dunefield was carried out by air photographs (1954, 1977, and 2006) and field surveys (2009-2011).

1954 air photos are from Royal Air Force archives (2 photos, scale of about 1:30.000), 1977 (4 photos, scale of 1:10.000) and 2006 air photos (2 photos, scale of 1:10.000) are from Regione Sardegna archives. In order to integrate the photo analysis, a 1 meter resolution DTM from a LiDAR survey (2008, Regione Sardegna) was analyzed.
Remote sensing analysis was carried out using a stereoscope in order to obtain a 3D vision of the dunefield. Photos were georeferenced by ERDAS Imagine software and a mosaic of pictures was imported in GIS software (ESRI ARCGis 9.3). For convenience of representation, the study area was characterized by morphological units and a specific legend was improved.
Field surveys were carried out from 2009 to 2011, in order to validate data concerning the current morphology of the dunefield.

3.1.2 Results

3.1.2.1 Geomorphology of the Capo Comino dunefield

Capo Comino dunefield is developed along a 3.5 km beach. It may be classified as a transgressive dunefield complex and it is composed by two different portions (Fig. 3.1).

Figure 3.1 – Geomorphological complexes in Capo Comino dunefield.

The first one, the foredune complex, extends along the rear of the beach. It is characterized by a foredune-blowout complex (green area in figure 3.1). The landward extension is almost constant, especially in the northern and southern sectors. The edge in the central sector is characterized by an overlapping onto the inner system. In the south-eastern sector of the dunefield foredunes are characterized by a wide arboreal covering, interrupted by natural and human-induced gaps. It is often affected by wave scarping (Fig. 3.2) and the orientation of the crests is largely influenced by onshore winds.
The second complex, with a maximum of 450 meters width, forms a transgressive dunefield complex (yellow area in figure 3.1). It is characterized by parabolic dunes moving from NW to SE.

Figure 3.2 - Foredunes under erosion.

The dunefield is characterized by the presence of a significant number of blowouts (Fig. 3.3). Few of these blowouts were present in the 1954 air photos and it's possible to show the evolution and the increase of the surface area.
In the northern sector blowouts are mainly oriented along a NE-SW direction, following the transport vector of onshore winds (see Figs. 2.28 and 2.29).
In the central sector, the orientation of the axis changes and the main directions are mostly from NW to SE, following the main wind transport direction (winds blowing from the 4th quadrant).
Blowouts are present in the transgressive dunefield complex in a number of "anomalous" situations too. In fact, in the central-southern sector blowouts are oriented along several

directions which should seem quite casual if compared to the main transport direction. In actual fact, instead, they are influenced by the local topography and they develop along some directions, not directly associated to particular and frequent winds. A few blowouts are effected by human influences (pathways, dirty roads, e*tc.*) too and their development is random, not related to particular winds.

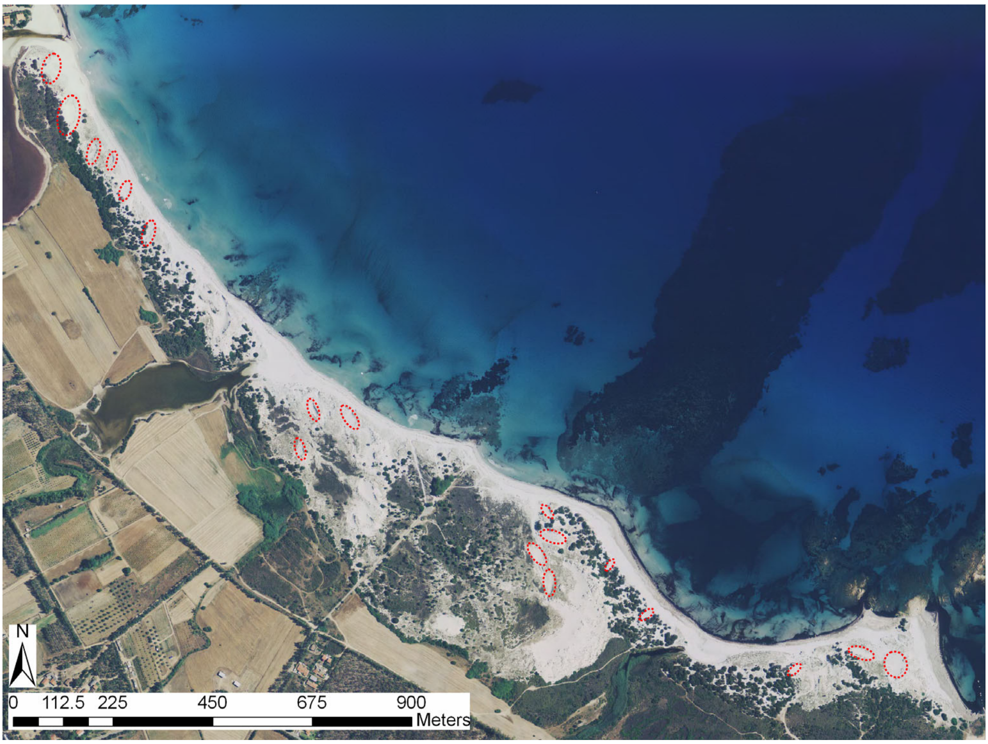


Figure 3.3 – Blowouts in Capo Comino dunefield in 2006 (Regione Sardegna) (red circles).

Concerning the inner transgressive system, its evolution is influenced by winds from the 4th quadrant, as shown by the evolutionary analysis (see §3.3.5). The main morphological forms are parabolic dunes, with differing degrees of development

In the central sector they evolve into a digitated parabolic complex, as a consequence of a stabilizing process (Fig. 3.4).

Figure 3.4 – Digitate parabolic dunes in the North-central sector of the transgressive system.

It's possible to identify several deflation basins in the dunefield, and broken up by Gegenwalle ridges (Fig. 3.5). These relict forms are colonized by vegetational associations composed by herbaceous and arboreal species. They originate from the process of sand trapping at the base of the large mobile parabolic dunes by colonies of vegetation, mostly marram grass. The migration of the dune leaves behind a series of arcuate, low dune ridges, called "counter ridges" or "Gegenwalle ridges" (Paul, 1944).

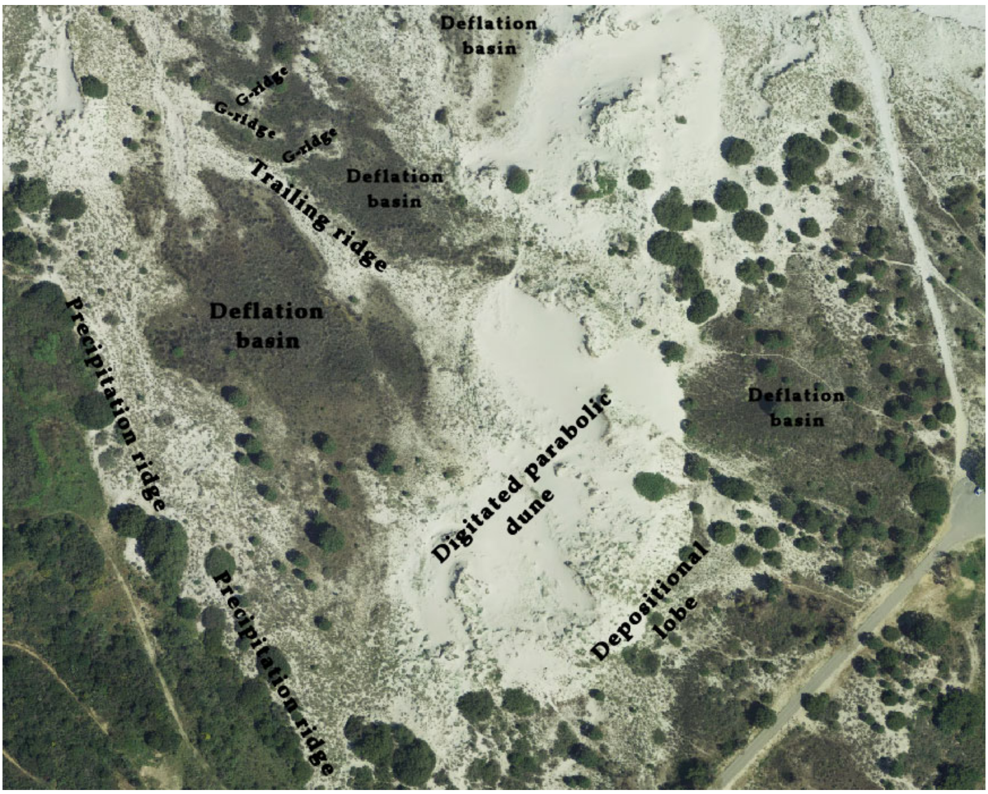


Figure 3.5 – Geomorphological forms in Capo Comino dunefield (2006 air photos, Regione Sardegna). Zoom of deflation basins and Gegenwalle ridges.

Trailing ridges (Fig. 3.6) are present along the entire transgressive system and their main orientations are about 335°N in the northern-central sector and 290°N in the southern-central sector. They are higher ridges colonized by herbaceous vegetation and represent the relict arms of the migrating parabolic dune.
A broad sand area is present close to the edge of the south-central sector of the transgressive system (Fig. 3.7). It is characterized by a few parabolic dunes, covering a 180 degree wide sector. These dunes are interdigitated forming a wide stoss slope, leaning about 45 degrees. Their depositional lobes are characterized by wide crests and very steep slip faces.

Figure 3.6 - A trailing ridge between two deflation basins in the central sector of Capo Comino dunefield.

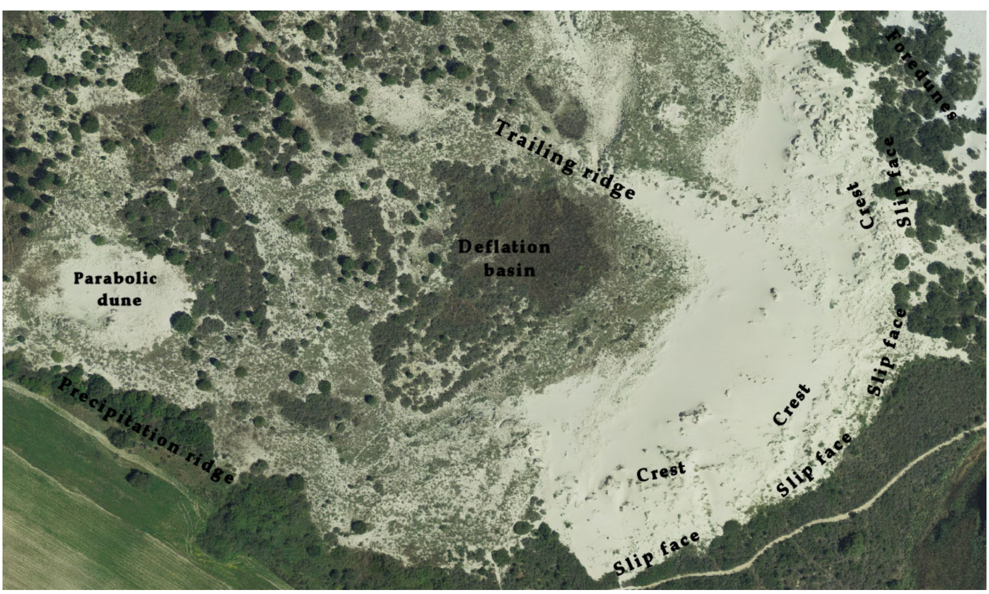


Figure 3.7 – Geomorphological forms in Capo Comino dunefield, south-central sector (2006 air photos, Regione Sardegna).

The landward edge of the dunefield is defined by a precipitation ridge, colonized by vegetation (Fig. 3.8). It is about 5-6 meters high, if compared to the cultivated fields of the backdune.

Figure 3.8 - Precipitation ridge and the vegetation cover.

Historical analysis

Air photos of 1954 show a dunefield with a low vegetation cover. In the inner sector many of bare areas are present.

The photos do not have a good resolution so it's quite difficult to identify all the morphological forms. Anyway it's is possible to highlight the presence of elongate parabolic dunes, developing from NNW to SSE in the seaward and from NW to SE in the inner sector of the dunefield.

In the south, the transgressive system ends with a wide deflation area, where it is possible to recognize a few parabolic dunes in the northern sector and a transgressive dune complex in the southern one. It's possible to draw crest lines and the main slip faces (Fig. 3.9).

Deflation basins are mainly localized in the central sector and characterized by hygrophilic vegetation (herbaceous vegetation and few shrubs).

During the '50, the edge of the dunefield has been affected by the planting of perennial woody plant, in particular by *Pinus p.* species.

In the last decades most of those trees disappeared because of fires but few of them are actually present on the dunefield, especially in the central sector (e.g. aligned pines along the street going to the beach).
Cultivated areas were present next to the dunefield but not very close to the precipitation ridges. Shrub vegetation colonized the sector between the precipitation ridge and the cultivated fields.

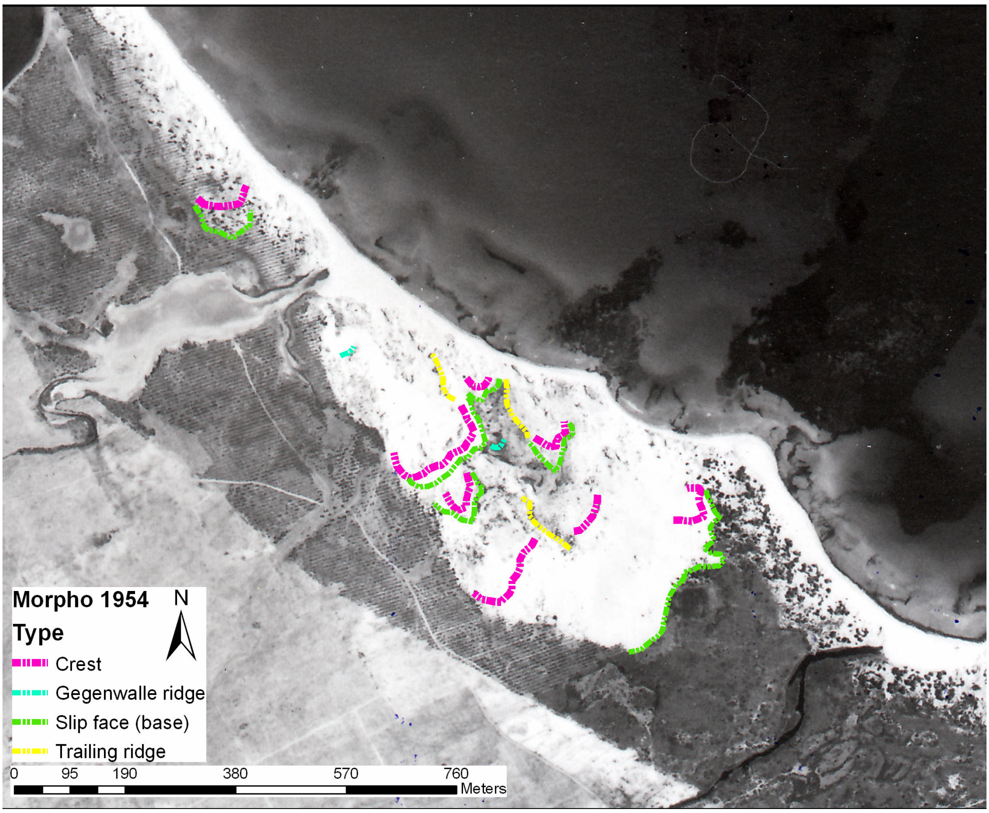


Figure 3.9 – Geomorphological forms in 1954 (air photos from Regione Sardegna).

In 1977 (Fig. 3.10) the dunefield evolved compared to the situation in 1954. The main change is represented by the more obvious development of the parabolic dunes, the migration of the parabolic dunes, and the formation of more defined parabolic forms in the south-central sector (1).
The migration of the crests and slip faces of the wide sandy area is clear, and the consequent cannibalizing process of the foredunes (2).
A new parabolic dune (probably originated from a blowout) is present in the north-central sector, with a W-E migrating direction.
Deflation basins are characterized by a thick herbaceous covering.

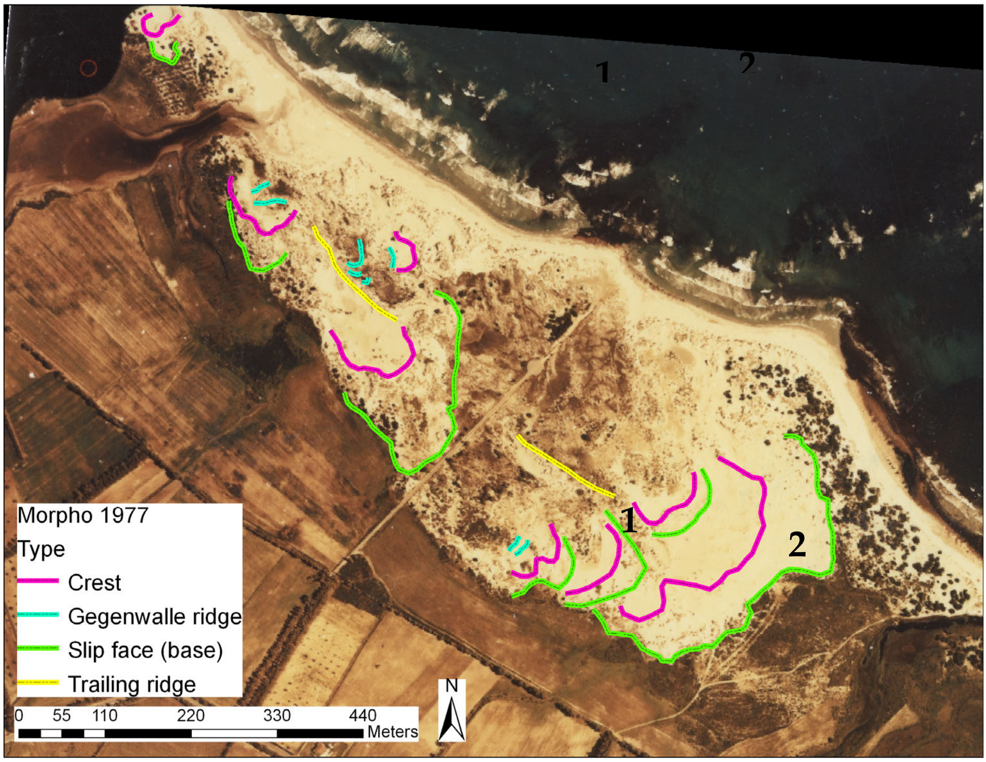


Figure 3.10 – Geomorphological forms in 1977 (air photos from Regione Sardegna).

The migration of the features has continued over time and the position of the morphological forms in shown in figure 3.11.
The vegetation covering is widely present in the dunefield, from herbaceous to arboreal species, not only in the foredunes but also in the transgressive system too.
The migration of the wide parabolic complex in the south-central sector has almost reached the river bed (1) and a wide deflation basin formed at the base of the parabolic dunes (2), characterized by many Gegenwalle ridges.
It's possible to recognize a digitate parabolic system in the north-central sector (3) and to note the evolution of the WE parabolic dune, detected in 1977 photos.

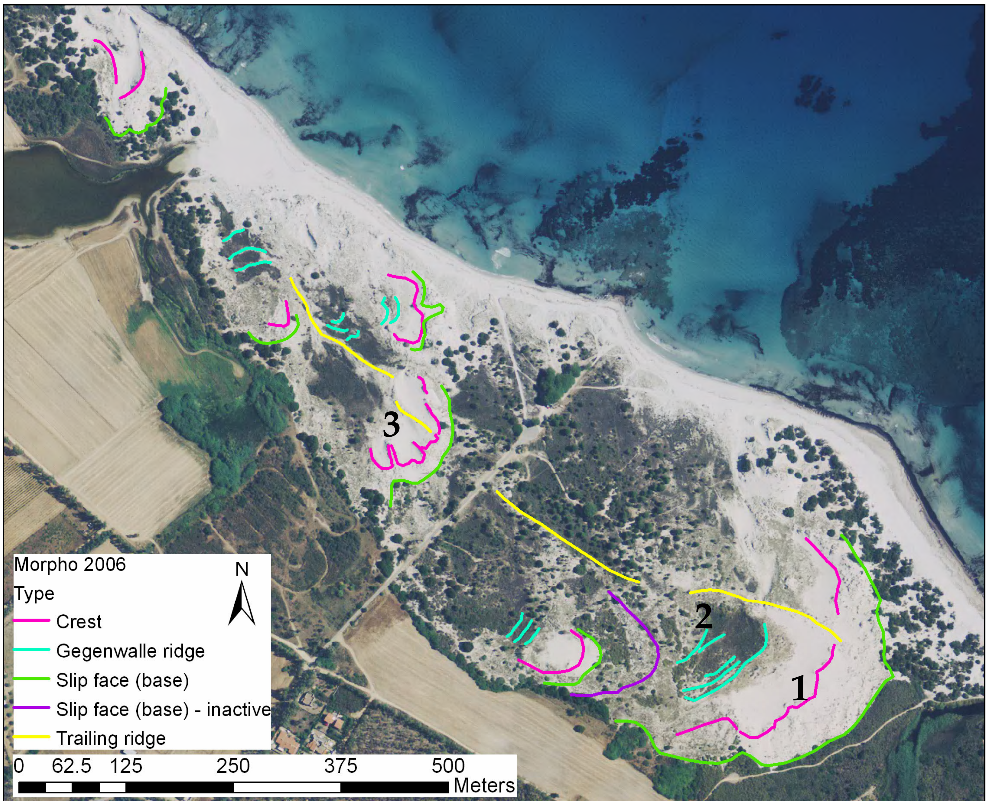


Figure 3.11 – Geomorphological forms in 2006 (air photos by Regione Sardegna).

3.1.2.2 Geomorphological maps

Geomorphological maps have been created from the analysis of air photos. They give an overall view of the presence and the areal distribution of the landscape units.
Types of morphological features have been divided into different categories, each presented by a colour. Their definition have been discussed in chapter 1 and §3.3.1.
The legend considers the main geomorphological features of the coastal dunefield and it is presented in figure 3.12.

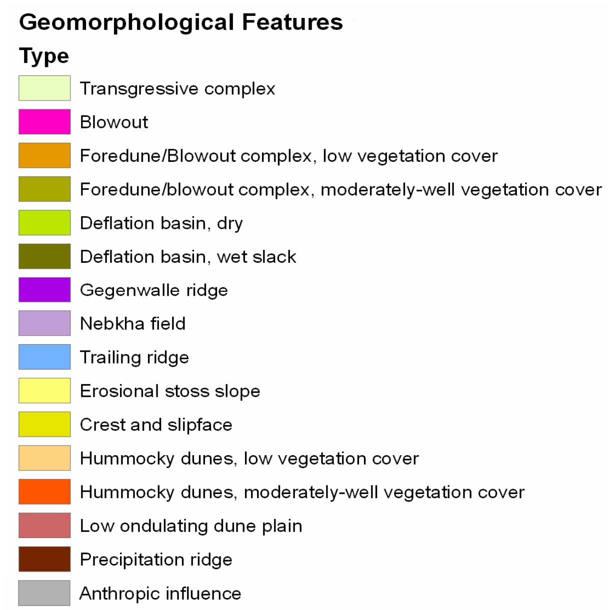


Figure 3.12 – Legend of the geomorphological maps.

For each morphological unit a shapefile has been created and areas and shape-lengths have been calculated.
The projection details of the cartography are shown in table 3.1.

Projection	Datum
Monte_Mario_Italy_1 Projection: Transverse Mercator False Easting: 1500000.000000 False Northing: 0.000000 Central Meridian: 9.000000 Scale Factor: 0.999600 Latitude Of Origin: 0.000000 Linear Unit: Meter	GCS_Monte_Mario Datum: D_Monte_Mario

Table 3.1 – Projection and datum details of the cartography.

Maps of 1954, 1977 and 2006 are presented in figures 3.13 and 3.14.

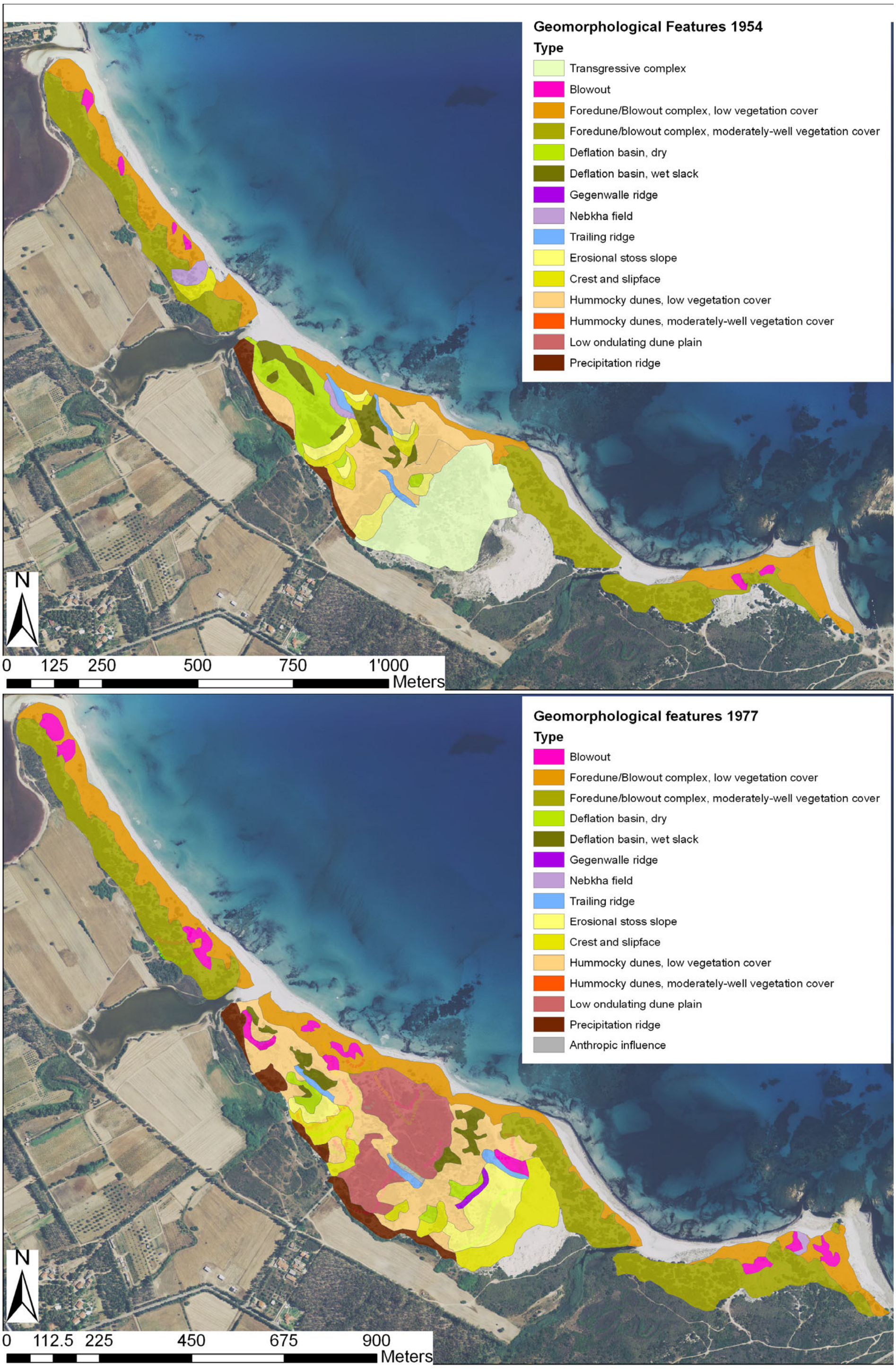


Figure 3.13 – Geomorphological maps. Elaboration of 1954 (up) and 1977 (dowm) air photos (2006 air photos, Regione Sardegna).

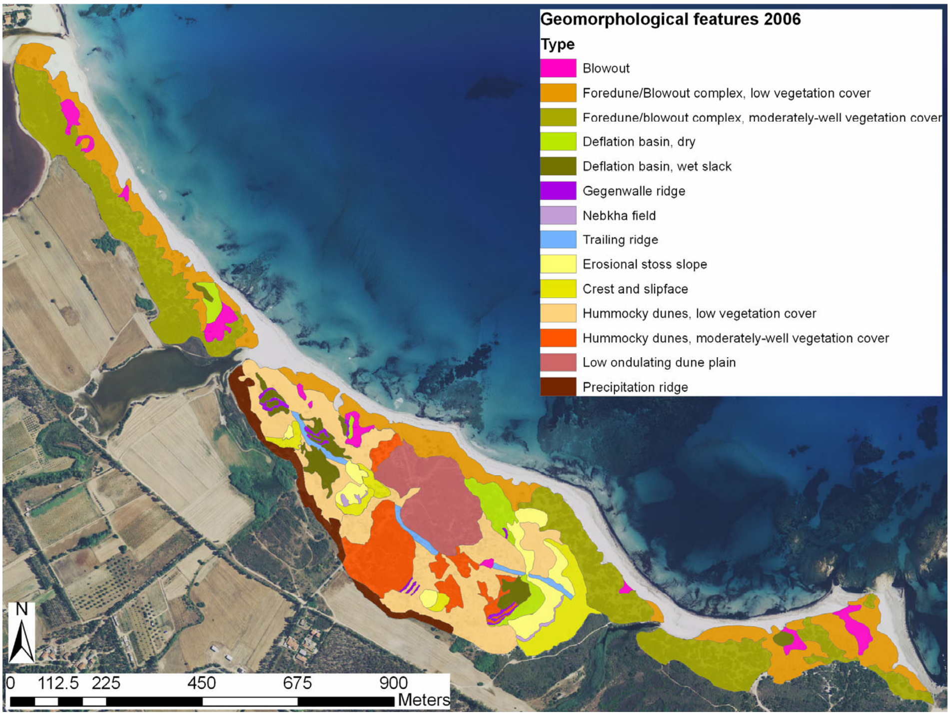


Figure 3.14 – Geomorphological map. Elaboration of 2006 (bottom) air photos (2006 air photos, Regione Sardegna).

Using the GIS spatial analyst, several analysis have been done.
Concerning the evolutionary analysis, the previous paragraphs describe the historical changes of the dunefield, considering the movement of the forms and the increasing vegetation covering. Figure 3.15 represents the qualitative summery of these observation.
In order to consider the quantitative changes of the surfaces' units, we should need to take in consideration some important conditions: the total area of the dunefield increased about 7 hectares from 1954 to 2006; few morphological types changed during the time (e.g. transgressive unit was classified only in 1954 photos); air photos from RAF (1954) have not a very good quality and the classification of the vegetation covering has been very difficult.
In general, the vegetation covering increases stabilizing the dunes (e.g. Hd-i linearly increases from 1954 to 2006) and the coverage area of migrating forms increases too (e.g. Gg, Tr and P-R) (Fig. 3.16).
The natural vegetation succession changes the coverage of few categories (e.g. L-d into Hd-i and Hd-ii) (Fig. 3.17).
Concerning the Dac and Das values, they are not representative in the quantitative point of view because of the evolution of the transgressive complex (1954) into a parabolic complex (1977-2006) and the total changing of these categories in the legend.

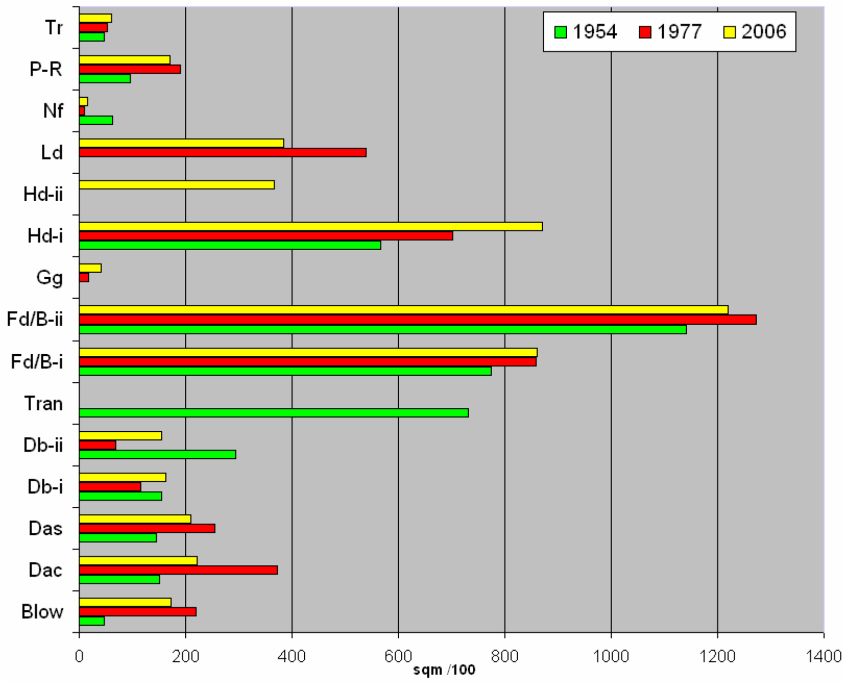


Figure 3.15 – Coverage for each geomorphological type (1954, 1977 and 2006; units in sqm*10^{-2}). (Blow: blowout; Dac: Crest and slipface; Das: Erosional stoss slope; Db-i: Deflation basin, dry; Db-ii: Deflation basin, wet slack; Tran: Transgressive complex (1954) Fd/B-i: Foredune/blowout complex, low vegetation cover Fd/B-ii: Foredune/blowout complex, moderately-well vegetation cover; Gg: Gegenwalle ridge; Hd-i: Hummocky dunes, low vegetation cover Hd-ii: Hummocky dunes, moderately-well vegetation cover; Ld: Low-ondulating dune plain; Nf: Nebkha field; P-R: Precipitation ridge; Tr: Trailing ridge).

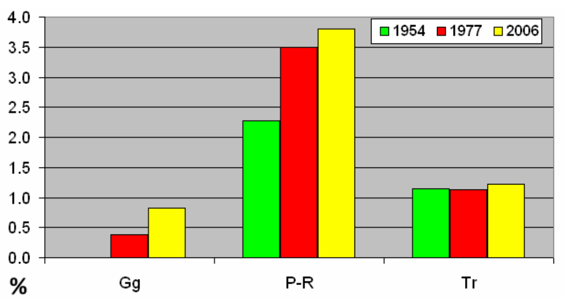


Figure 3.16 – Increase of Gg, P-R and Tr covering surface from 1954 to 2006.

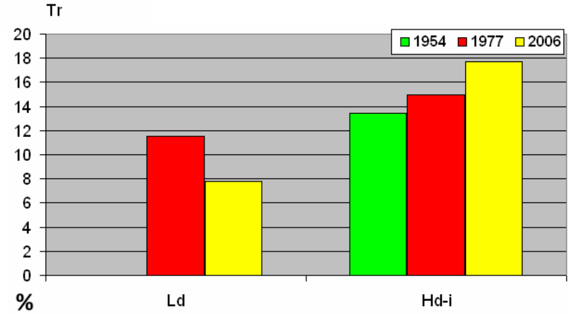


Figure 3.17 – Increasing of Hd decreasing of Ld covering surfaces and from 1954 to 2006.

3.1.2.3 Migration rate

The migration rate of the morphological features has been determined by the comparison between 1954, 1977 and 2006 photos.

Figure 3.18 shows the migration of the transgressive dune complex along the direction NW-SE for about 110 meters between 1954 and 1977 and about 84 meters between 1977 and 2006. Therefore in the south-central sector the migration rate is 4.7 m y^{-1} and 2.9 m y^{-1} for each observation period.

The south-eastern sector of the dunefield displays a lower migration rate: about 3.85 m y^{-1} from 1954 to 1977. The 1977-2006 period has been quite stable and the edges of the dunefield didn't move.

The values of the migration rate are comparable to those presented in the international literature (Pye, 1982; Story, 1982; Anthonsen and Jensen, 1996; David e*t al.* 1999; Wolfe and Lemmen, 1999; Bailey and Bristow, 2004; Marin, *et al.*, 2004; Hugenholtz and Wolfe 2005, 2006).

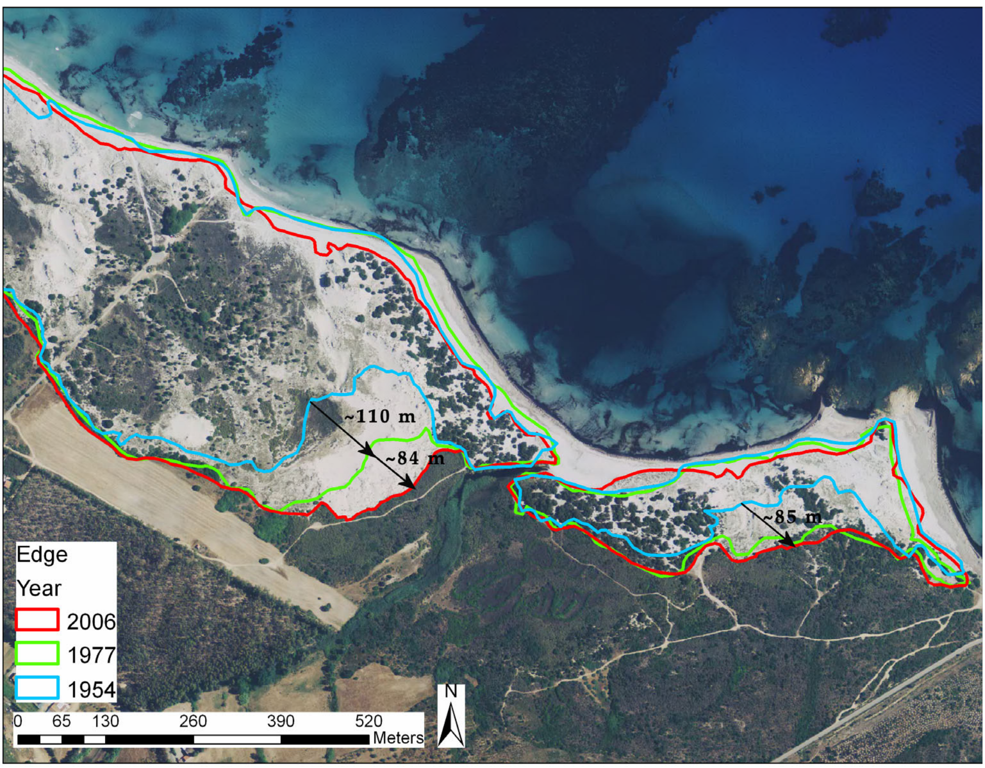


Figure 3.18 – Migration of the southern sector of the dunefield during 52 years (1954-2006). Black arrows: mean direction of movement; values in meters.

To the exception of the natural migration of the morphological forms, there are no big variations in the shape of the dunefield in the seaward sector, probably due to the general stability of the coastline.

The only evident variations are in the southern-central area, where the *Juniperus* plants of the foredunes decrease in number, probably because of the salt sprays and the immediate vicinity to the coastline. A further reason is the natural migration of parabolic dunes to SE. They are cannibalizing the old foredune ridges with *Juniperus* vegetation.
Concerning the morphological types of the inner sector, the migration of the crests, slipfaces and the evolution of the Gegenwalle and trailing ridges are quite evident.
Figure 3.19 highlights the evolution of the forms from 1954 to 1977. Black arrows indicate the real migration of slip faces and crest during 23 years.

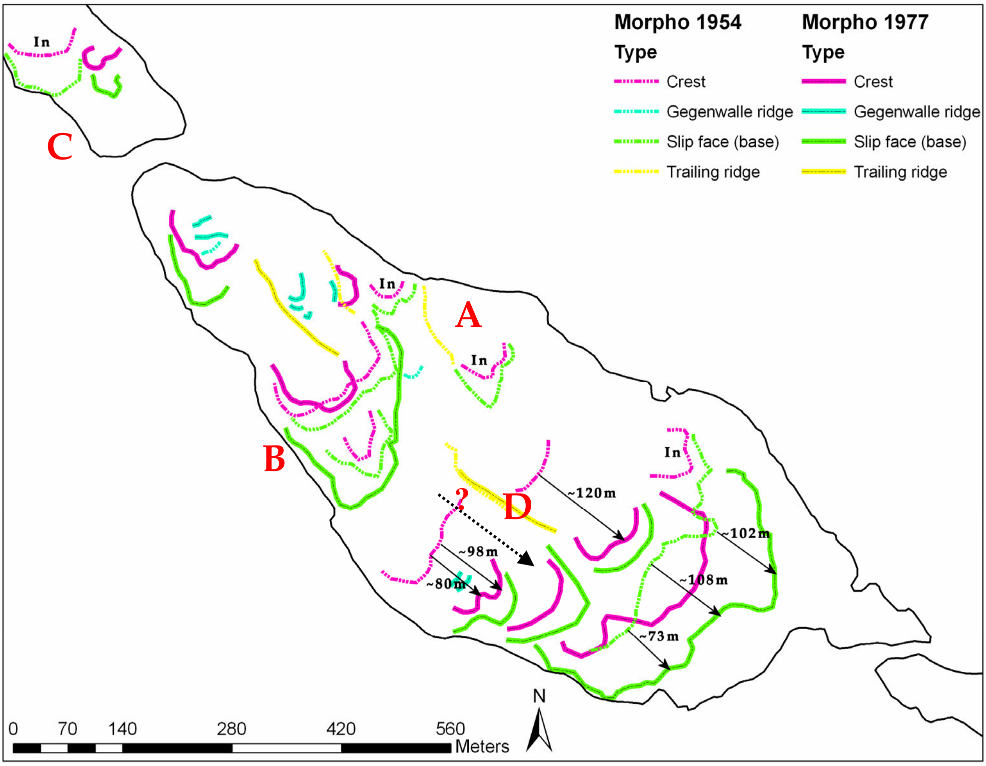


Figure 3.19 – Medium-term analysis, 1954-1977 (black arrows: direction of movement and approximate measurement in meters; In= inactive forms in 1977).

A few forms of 1954 are inactive in 1977 (and so relict), such the parabolic dunes in the seaward sector (A) and the parabolic dune in the central sector (B). In 1977 it has been included in the slipface of the younger and following dune.
In addition a new dune, oriented W-E, has been formed.
In the northern sector a new parabolic dune originated, probably from a blowout, and a 1954 dune became inactive (C).
The migration of the dune (D) in the southern-central sector was about 90 meters but it's not clear if it evolved in the first or in the second parabolic dune.
The resulting migration rate is about 3.9 and 5.2 m y^{-1} in the central sector and 3.7 and 4.7 my^{-1} in the transverse/parabolic dune sector.

The evolution of the dunefield from 1977 and 2006 is shown in figure 3.20.
The migration rate is unchanged compared to the previous one, with mean values from 1.3 my^{-1} in the northern sector to 1.6 - 2.2 m y^{-1} in the northern-central sector and 1.7 - 3 m y^{-1} in the southern-central sector.

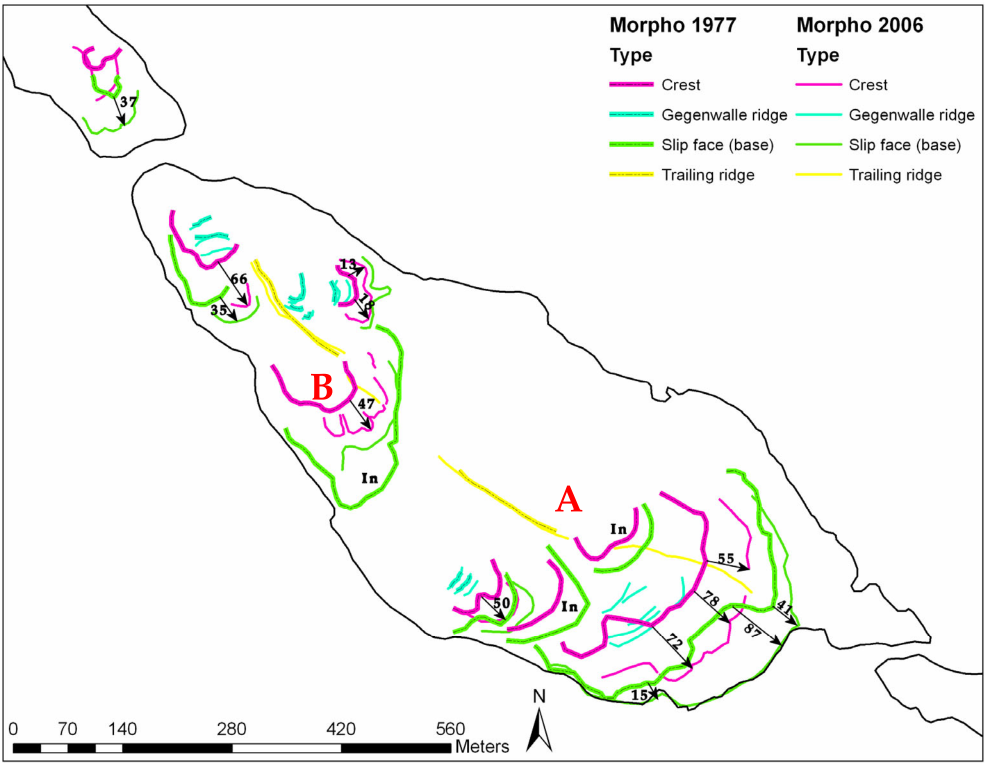


Figure 3.20 – Medium-term analysis, 1977-2006 (black arrows: direction of movement and approximate measurement in meters; In= inactive forms in 2006).

The morphological forms resulting are almost identical to those in 1977, and the only changing is the shift along the vector of winds blow.
In the southern sector a new trailing ridge formed (A), separating two wide parabolic dunes. They are oriented SW-NE and NNW-SSE. It's very easy to identify Gegenwalle ridges in the 2006 pictures. They formed because of the fast migration of the stoss- slope and the evolution of a wide deflation basin.
The big slipface in the northern-central sector is inactive in 2006 and a new slipface formed in the digitate parabolic dune system (B).

The long-term analysis map (Fig. 3.21) summarizes the two previous maps.
It allows obtaining the mean migration rates of morphological forms: 3.75 - 1.8 m y^{-1} in the southern-central sector and 2.5 – 0.9 m y^{-1} in the northern-central sector.

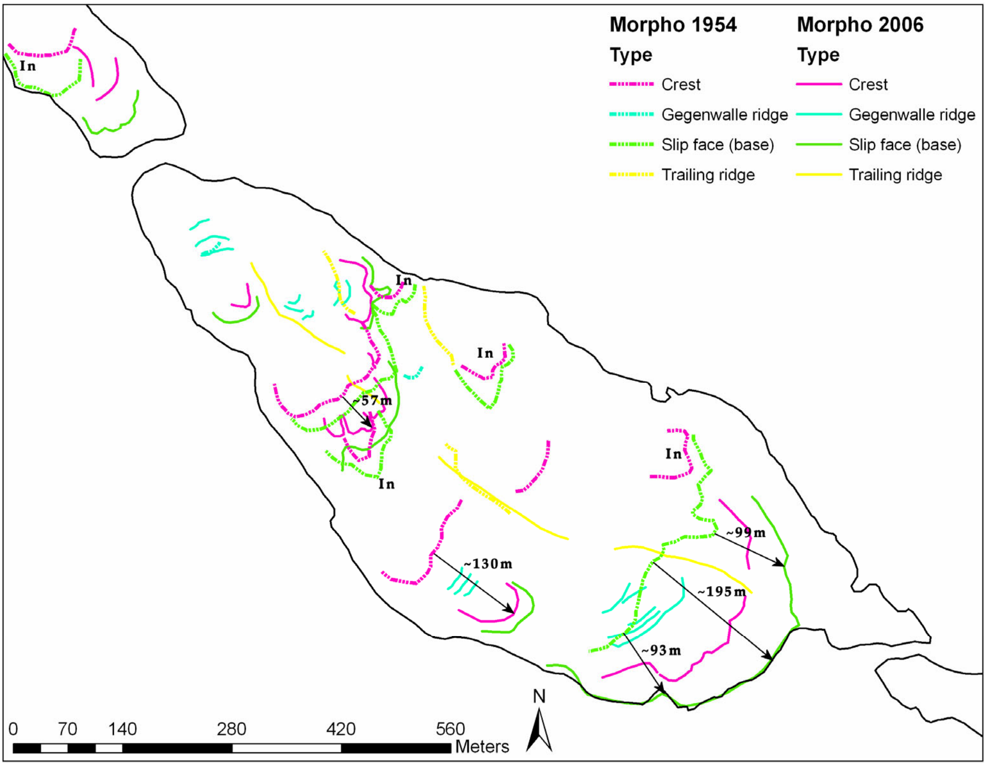


Figure 3.21 – Long-term analysis, 1954-2006 (black arrows: direction of movement and measurement in meters; In= inactive forms in 1977).

The migration rates of the transgression of the dunefield decreased from 1954 to 2006.
The mean value changed from 4.7 to 2.9 m y^{-1} and it's probably due to the decreasing sediment supply and the stabilization of the forms by vegetation.

3.1.2.4 Sedimentary transport and geomorphological response

Many geomorphological forms exist in the dunefield. Most of them follow the main vectors of the predominant winds (chapter 2).
In general the transgression of the dunes has a well-defined direction along the main transport vector but it's possible to find many geomorphological features that develop along secondary transport vectors.
In actual fact, the dunefield is relatively open to winds from all quarters so small blowouts develop with orientation associated with the many different directions of winds. As an example, breezes have a limited period but a continuous frequency during the year and they are strong enough to influence the local morphologies so several blowouts develop along a direction that is very different from the main one and sometimes their axis are quite perpendicular to the principal transport direction.
Fig. 3.22 is the summery of the geomorphological aspects presented in §3.3.1. Comparing the morphological features (Fig. 3.22) and the sand roses (Fig. 3.23), the correspondences between the winds and the development of the forms may be examined.

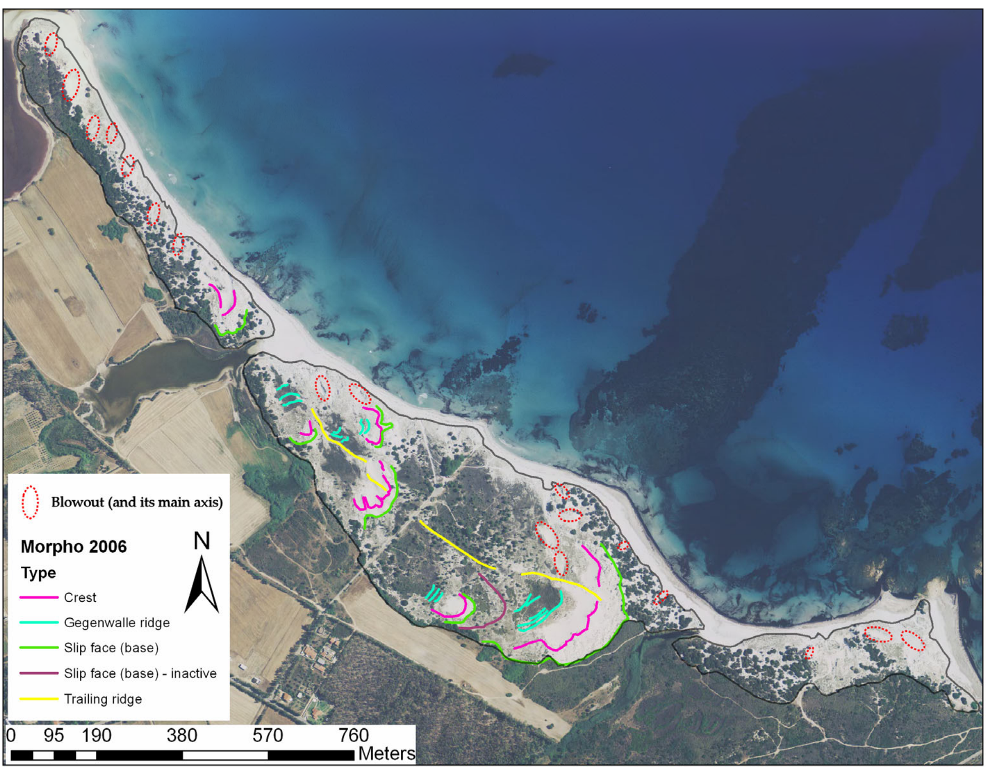


Figure 3.22 – Main dune morphologies in Capo Comino dunefield (2006 air photos, Regione Sardegna).

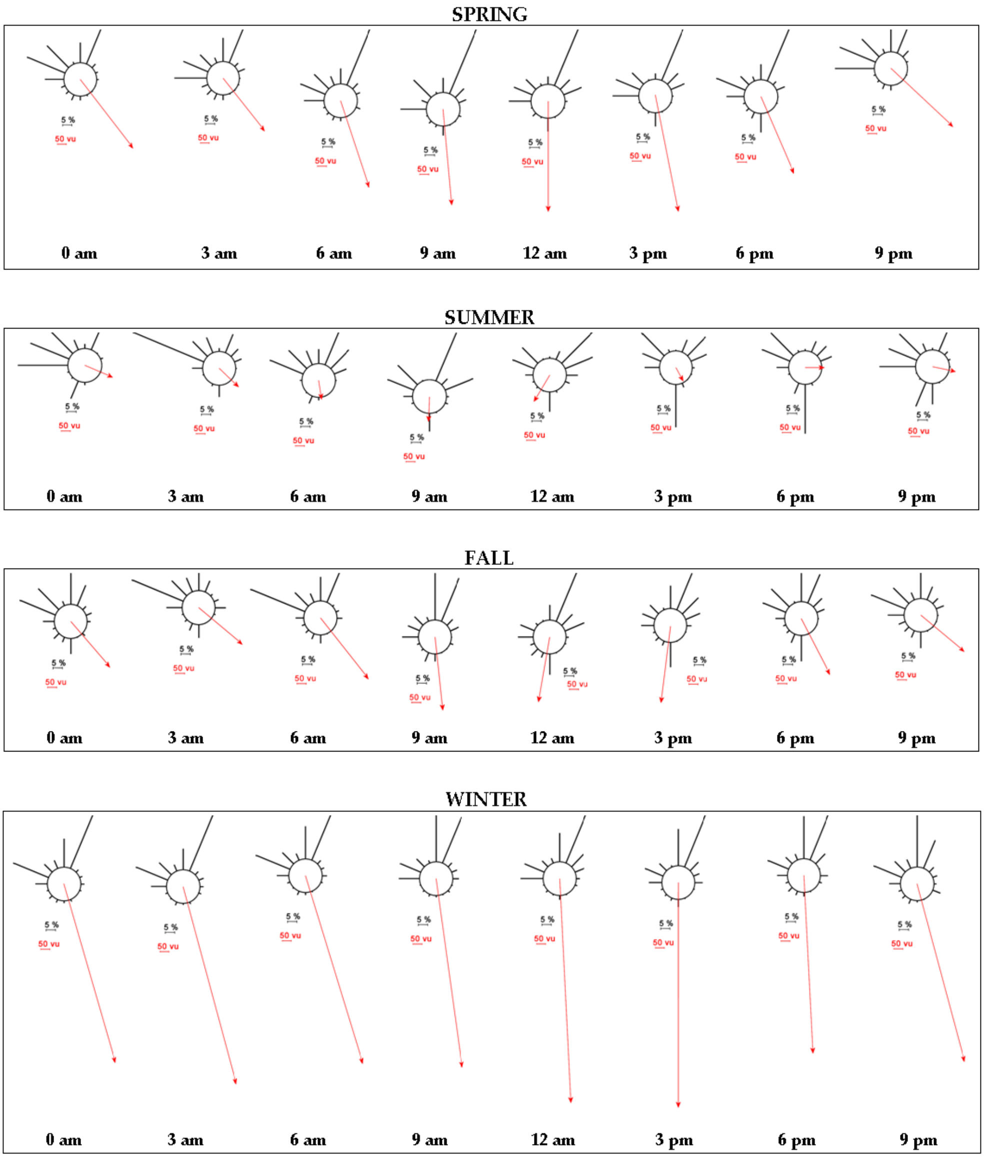
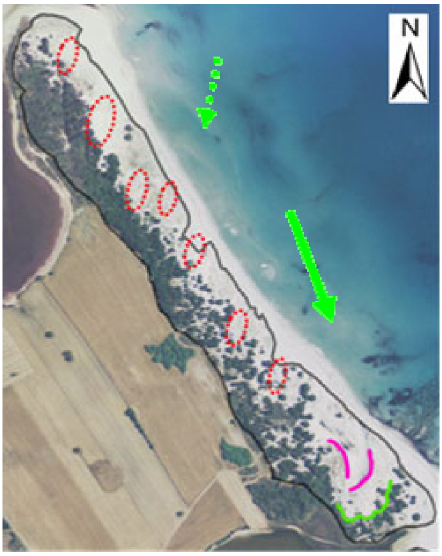


Figure 3.23 – Seasonal and hourly sand roses, drawn for the 2000-2010 period (see § 2.3.3.2).

The northern sector (Fig. 3.24) is strongly dominated by the onshore winds, coming from the 1st quadrant. Those winds influence the formation of blowouts and the main axis of their evolution.



The foredune is also characterized by an active area at the bottom of the picture. This sector is influenced by the main wind direction, very strong during the winter season, but also important during the year.

Figure 3.24 – Northern sector of the foredune system. Green arrows: main transport direction (dotted arrow: from onshore winds).

The central sector of the dunefield (Fig. 3.25) presents a very complex morphology. In fact, the relict foredune system and the transgressive/parabolic system merge in the sector close to the seashore.

The human influence is strong too, with a large pathway system, which cuts the local morphologies and sometimes produces preferential ways of sand burial.

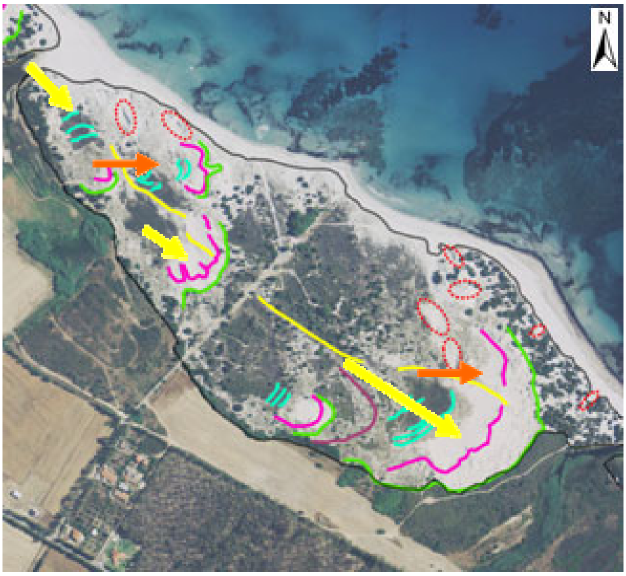


Figure 3.25 – Central sector of the dunefield. Orange and yellow arrows: main transport directions.

There are two main directions influencing the central sector: the first one (yellow arrows) derives from the 4th quadrant winds and determines the main transport direction.

The second main component (orange arrows) is from West. It influences the movement of few parabolic dunes, “pushing” them to the coastline. In the southern sector, the deposition lobe of the parabolic dune is cannibalizing the foredune system (and the *Juniperus* species).

The transport in the south-eastern sector of the dunefield (Fig. 3.26) is influenced by the onshore winds in the foredune complex (cyan arrow) and by the main transport direction, such as in the northern sector (yellow arrow).

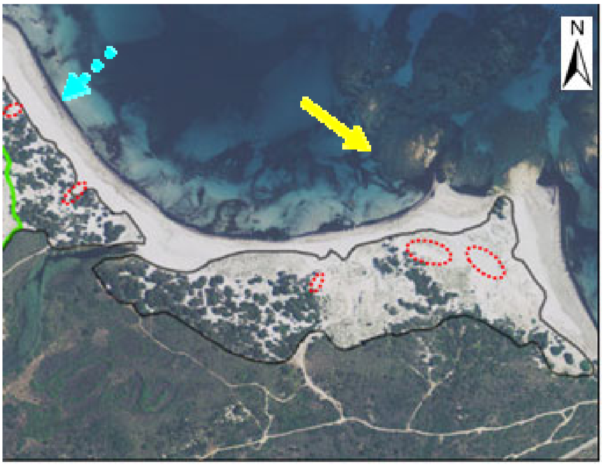


Figure 3.26 – South-eastern sector of the dunefield. Cyan arrow: transport direction from the onshore winds; yellow arrow: main transport direction.

3.1.2.5 Evolutionary model of the Capo Comino dunefield

As indicated above, the Capo Comino dunefield is composed by two different dynamic complexes.
Foredunes (Fig. 3.27) are constituted by a series of sandy ridges, developing parallel to the shoreline. Their dynamic is mainly influenced by onshore winds.
Foredunes in Capo Comino develop along a profile such as that presented in figure 3.27, because of the general stability of the coastline (or it could be better the low erosion degree).
In a theoretical profile (Bird, 1972; Hesp, 2002), embryo dunes form on the backshore and they constitute the first aeolian deposits. The following sandy ridges (more than one in a stable/accretion system) are the foredune ridges, characterized by a greater diversity of vegetation, stability and possibly incipient soil development. Indeed, the inner foredune ridges may be colonized by mosses and lichens. They give a relative stability to the sand.
Some hollows may form between the foredune ridges, and they are also called "interdunal depressions". They can be filled by water forming wetlands or slacks, if the water table level is close to the soil surface.
The inner ridges, protected from the sea ingression, are stabilized by the vegetation. Surviving conditions are here less hazardous compared to the first foredune ridges and the vegetation may develop into shrub and woody communities.

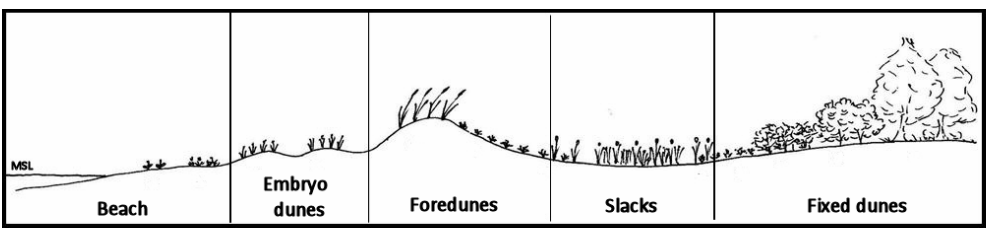


Figure 3.27 – Theoretical profile of foredunes (from Balduzzi *et al.*, 2009 modified).

The transgressive complex of Capo Comino dunefield is composed by parabolic dunes, more or less stabilized by the vegetation depending of the sector.
In general, three main units may be recognized, migrating from NW to SE (Fig. 3.28). Parabolic dunes (2) result strongly stabilized by vegetation of the central sector.

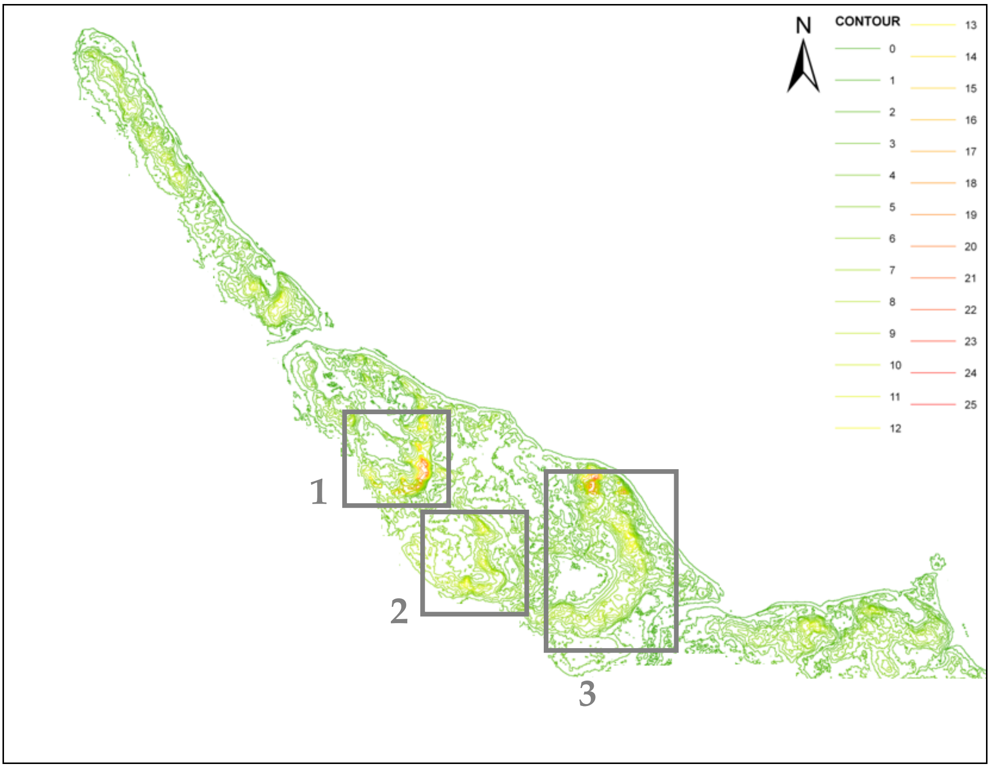


Figure 3.28 – Elaboration of the DTM (1 meter resolution). The main parabolic dunes are located in the rectangles (elevation in meter).

Parabolic dunes are composed by different geomorphological features. The main ones are a deflation basin, a depositional lobe and two lateral trailing ridges (Fig. 3.29).

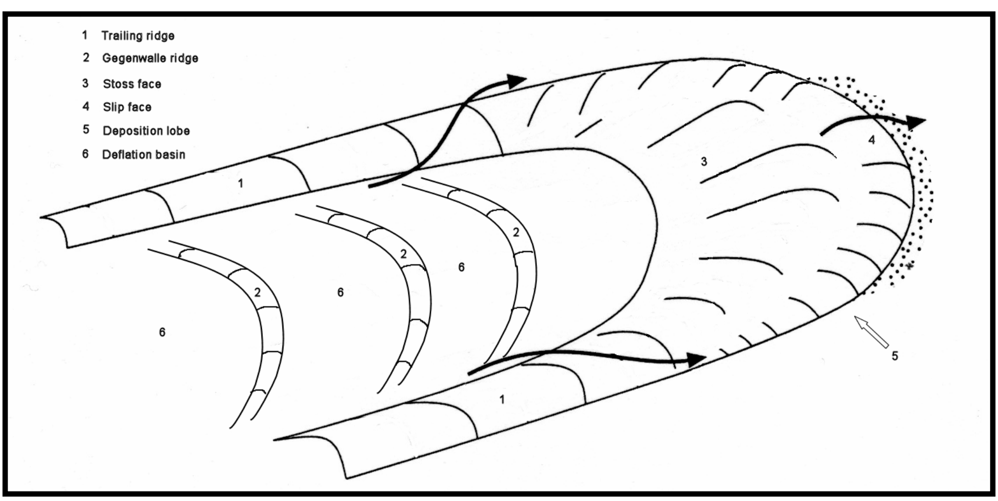


Figure 3.29 – Morphological features of a parabolic dune.

The sedimentary transport is up the axis of the deflation basin, across the depositional lobe - erosion on the stoss-slope and deposition on the crest and slip-face - but on the inner slopes of the trailing ridges too. Thus they may be considered dynamic forms.
Therefore the oldest and most evolved forms are far from the deposition lobe, where the vegetation is not affected by sand burial. The oldest parts of the trailing ridges too are quite stable and completely vegetated.
In the deflation basin, several relict and active features may be found (Gegenwalle ridges). They are higher than the basin and characterized by different types of vegetation depending on their position and age in the deflation basin.

From an evolutionary point of view (Fig. 3.30), Capo Comino dunefield went through a stabilization of the wide deflation plains in the last century.
The most important stabilization phase took place from 1954 to 1977 when the dynamic forms had a general change. In particular, the central seaward sectors - initially characterized by several very dynamic parabolic dunes – were stabilized into hummocky dunes with herbaceous and shrub vegetation.
The transgressive complex of 1954 has been changed into a transgressive/parabolic dune complex where a median trailing ridge has developed.
Foredunes in the southern sector changed with an increase of the dunefield area (about 85 meters of migration, NW-SE orientation).
During 1977-2006 the dunefield has been modified even further along the edges of the southern sector with the increase of the deflation areas and the formation of wide (about 55-60 meters wide) and high (about 12-14 meters above MSL) crests and slip-faces.
The transgressive-parabolic dune complex of 1977 has evolved into a parabolic dune complex. The migration of crests and slip-faces and the formation of the median trailing ridge have continued.
The central sector actually becomes more stable with the main parabolic dunes evolving into digitate parabolic dunes.
The southern sector of foredunes is quite stable, exception to the increasing of the blowouts' area.

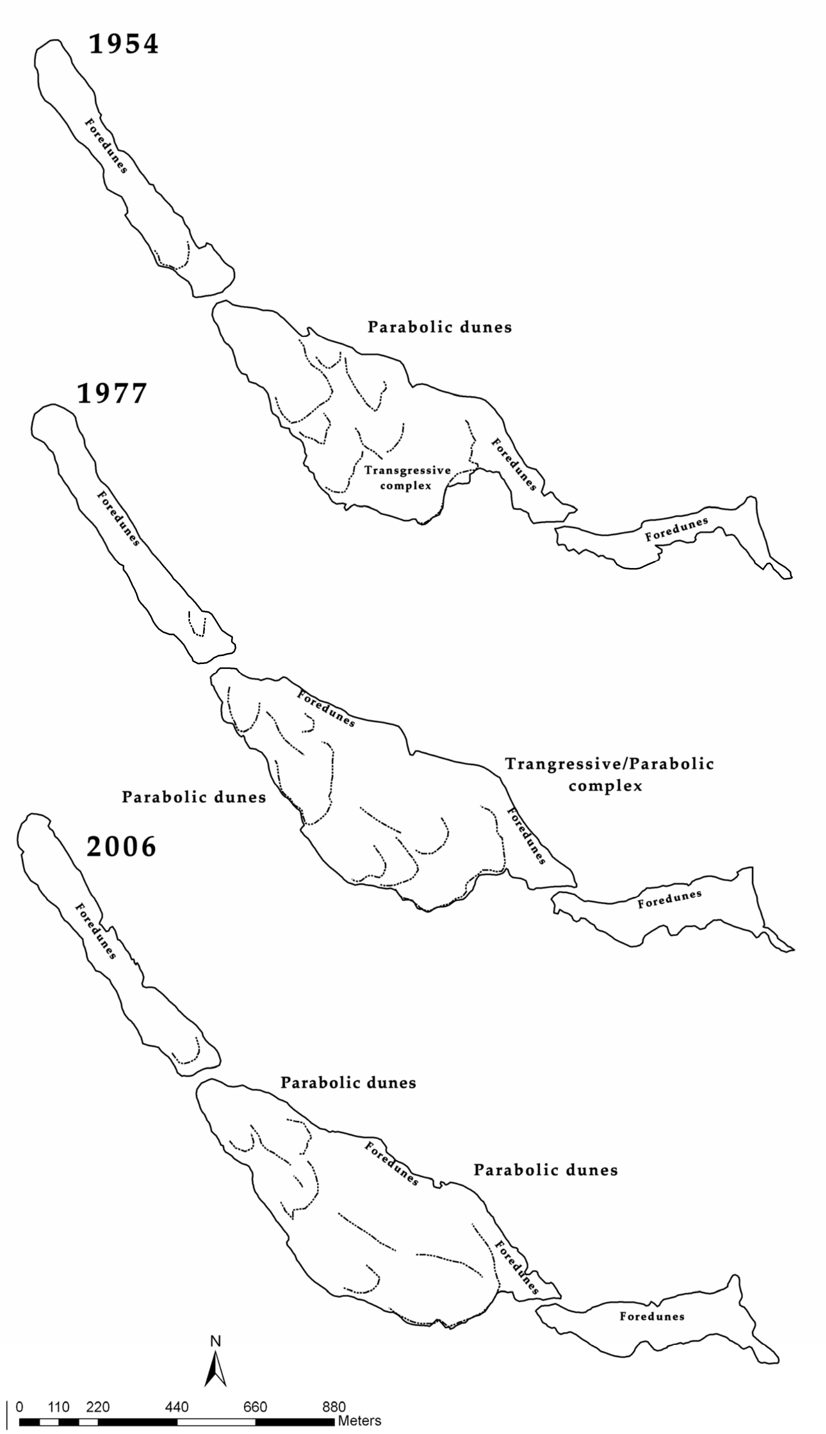


Figure 3.30 – Evolutionary model of the Capo Comino dunefield (1954-2006).

3.2 FLORA AND VEGETATION ANALYSES

This chapter presents the study of the vegetation of the Capo Comino area using qualitative and quantitative approaches. The simplest method is based on the observation of the landscape and it allows the interpretation of the ecosystem considering the different species. Species are the first components of a generic group - the vegetal population - and they are defined as the complex of elements able to crossbreed and generate a fertile generation (Pignatti, 1994). The group of species constitutes the flora of the habitat. The word flora defines the complexity of species (and subspecies) occupying a specific area on the Earth's surface, with no limits about the dimension. The area should be geographically limited and ecologically well characterized. Therefore if the vegetal population is characterized by the distinction and the count of its principal elements (the species) this method brings to the important concept of "floristic diversity" and Italy is the richest European country considering the number of present species (Pignatti, 1994).

The second method uses the concept of vegetation. The word vegetation encompasses the group of phytocenosis of a specific environment. Phytocenosis is a vegetal grouping with a relatively uniform floristic composition and it is different from the surrounding groupings (Mariotti and Margiocco, 2002). Therefore if the main characteristic of the flora is to be essentially a qualitative concept (taxonomic rank), the main attributes of the vegetation, instead, are quantitative and structural characteristics, strictly related to climatic and edaphic conditions.

Concerning the study of coastal dunes, they are found in all latitudes so the climates to which they are exposed and their biomasses may be very different. They cover ecological habitats which range from polar to tropical latitudes and from desert to tropical rain forests (Snead, 1972; van der Maarel 1993; Kelletat, 1995). Vegetation study started from a detailed bibliographic review. The oldest known study on the vegetation of coastal dunes was performed in 1835 by Steinheil (van der Maarel, 1993). A lot of more recent books focus on coastal dunes (van der Meulen *et al.*, 1991; Carter *et al.*, 1992; van der Maarel, 1993; Garcia-Novo *et al.*, 1997; Packham and Willis, 1997; Wiedemann *et al.*, 1999; Hesp, 2000) with a particular emphasis on the mid-latitude dunal systems. A recent book by Martinez and Psuty (2004) incorporate contributions concerning both tropical and temperate latitudes with studies on geomorphology, community dynamics, biotic interactions, ecophysiology and environmental conservation. A lot of vegetation researches were carried out in Mediterranean area (Braun-Blanquet J. 1933, 1952; Géhu, 1986; Géhu *et al.*, 1984; Géhu and Biondi, 1994a,b; Géhu and Biondi, 1995) and in particular in Sardinia and Corsica (Bartolo *et al.*, 1989; Filigheddu and Valsecchi, 1992; Biondi *et al.*, 2001; Biondi and Bagella, 2005;). A detailed floristic work has been conducted by Arrigoni (1996) in Capo Comino area.

During this research floristic studies were carried out by the observation of the vegetation species and the identification of their form and characteristics (§3.2.1). Afterwards the species were counted and classified and it has been possible to estimate the floristic richness considering the characteristic elements and their position in the environment. Section 3.2.2 shows the results concerning the vegetation analysis referring to the vegetal life forms and their competition for the space and the nutrients. The concluding paragraphs will present the distribution of the vegetation communities on the study area with particular reference to the foredune and transgressive systems. A vegetation map graphically summarizes the results of the vegetation distribution on the entire dunefield.

3.2.1 FLORA

3.2.1.1 Method

The study and the estimation of the vegetation species has been carried out by floristic investigations during the field surveys.
Every species has been determined using the ”Flora d'Italia” book by Pignatti (1982, 2002) and the floristic list has been integrated with bibliographic information. Afterwards flora has been studied by quali-quantitative analyses, the definition of the biological and chorological spectra and the estimate of the bioindication values.

Biological forms

The comparison of floras of two study areas presents several constraints because the floristic correlation usually brings to a total divergence due to the high number of variables. So it’s better to attribute the species to a specific category and to group them in order to obtain good results (Pignatti, 1995).
Species may be group by systematic criteria or by morphic and distribution affinities taking in consideration their adaptation and their ecological factors. Indeed, plants - living in the same environmental conditions - present similar life cycles and morphologies even if they are located far away from each other.
One of the first approaches to provide a comprehensive system of plant life-forms classification is to consider their adaptation to the unfavourable conditions. Humboldt (1886) for the first time formulated the concept in which he considered the location of perennating buds or organs. Raunkiaer (1934) used it as descriptive tool for classifying plant life-forms based on the position and degree of protection of the renewing buds, which are responsible of the renewal of the plant’s aerial body when the favourable season comes. Raunkiaer’s system has an actual validity.
According to his system, plant species can be grouped into five main classes (called “biological forms”): phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes. The percentage of various life-form classes is called “biological spectrum”.
Biological forms are categories or morphological types that may be recognized with well-defined and limited variations for each vegetal group, independently of their taxonomic affiliation.
The entities belonging to the same species are usually attributed to the same biological form but in different environmental conditions they may show a different adaptation. So Authors sometimes didn’t present concordant biological forms.
In this work biological forms by Pignatti (1982, 2005) were used, coming from Raunkiaer’s studies and splitted up into sub-forms using Braun-Blanquet’s (1932) and Negri’s (1964) criteria. They are divided into:

- therophytes: perennial plants surviving the unfavourable season as seeds and complete their life-cycle during favourable seasons. E.g. many desert plants are by necessity therophytes.
  They are divided in: Tcaesp (caespitose); Trept (reptans); Tscap (scapose); Tros (rosulate); Tpar (parasitic).

- geophytes: plants with underground buds (contained in bulbs or rhizomes). Every year the subaerial part of the plant dies after the seed dispersion.
  They are divided in: Grad (budded roots); Gbulb (with bulbs); Grhiz (with rhizomes); Gpar (parasitic).
- hydrophytes: annual aquatic plants with submerged buds. They are divided in: Irad (radicans); Inat (natans).
- hemicryptophytes: grasses with buds located on the soil surface, protected by dead leaves (or similar) or by snow. They are common in temperate regions. They are divided in: Hcaesp (caespitose); Hrept (reptans); Hscap (scapose); Hros (rosulate); Hbienn (biennial); Hscand (scandens).
- chamaephytes: plants (most of them are very low shrubs) with aerial buds at 30 cm maximum above the soil surface and surrounding by leaves and branches. They are divided in: Chsuffr (sub-fruticose); Chscap (scapose); Chsucc (succulent); Chrept (reptans); Chpulv (pulvinate); Chtall (tallophytic); Chfrut (fruticose).
- phanerophytes: woody plants (arboreal plants, shrubs, lianas) with buds up to 30 cm above the soil surface. Buds are surrounded by leaves. They are common in equatorial and humid tropical areas. They are divided in: NP (nano, less than 2m); Pcaesp (caespitose): Pscap (arboreal); Plian (lianas); Psucc (succulent); Pep (epiphytes); Prept (reptans).
- helophytes: plants with submerged base and emerged buds. He (submerged).

Biological spectra may be different depending on the method. When the analysis is carried out with a list of species, every species has the same weight in the biological spectrum. This result is called “floristic biological spectrum” (Raunkiaer, 1934; Costa *et al*., 2007).
However when the number of individuals, instead of species, of each life form is counted, each class can be weighted by its density giving rise to the “vegetation biological spectrum”. This spectrum indicates phenomena relative to the vegetation rather than to the flora (Batalha and Martins, 2002).

Chorological elements

Every species owns a specific area representing the area where it spontaneously lives (Pignatti, 1995). This “area” is dynamic and linked to both ecological factors (actual, such as climatic factors limiting the plant distribution) and historical factors (evolutive and historical-geological factors).
Very different plants (from a systematic point of view) can live in coinciding distribution areas and Earth’s surface has been divided into different geographic regions following floristic criteria. This classification by “geographic elements” identifies and qualifies different groups of plants.
Comparing the areas of different species, it’s possible to note that specific models repeat themselves, so to identify different types of areas, called “chorotypes” or “chorological elements”.
Series of chorotypes may be distinguished for the same distribution (geographic elements) or the genetic element. Sometimes these two elements concur, especially for those species owing a limited area of distribution that fits with the area where the species first originated (endemic species). When the species is not endemic, the individuation of the genetic element is difficult and doubtful. So the geographic element represents a more concrete factor

because it is related to the actual distribution of the species and the mainly repeated chorotypes are called "phytogeographic elements".
Considering the location of the area, the chorological elements (referred to Pignatti 1982, 2005) may be classified in:

- Endemic (Endem): these species are present only in a specific study area;
- Sub-endemic (Subendem): these species have a limited area, e.g. a region (such as Italy);
- Steno-Mediterranean (Stenomedit): these species have a limited area (e.g. warm Mediterranean coasts for the Olive tree area);
- Euri-Mediterranean (Eurimedit): the area is centred on Mediterranean coasts but species can be located in Central Europe too (e.g. Grape area);
- Mountain Mediterranean (Medit-Mont): Steno- and Euri-Mediterranean species in mountain areas. They are divided in sub-elements: North Medi-Mont, where the limits are represented by southern coasts of Europe, Spain and Greece; East Medit-Mont, where the limits are located in the western Mediterranean sea, from Balkans to Turkey and Egypt; South Medit-Mont, where limits are the Northern Africa coasts, from Morocco to Egypt; West Medit-Mont, where limits are located in the western Mediterranean sea, from Liguria to Spain and Algeria; North-west Medit-Mont, where limits are areas from Liguria to Spain; South-west Medi-Mont, where limits are coasts from Morocco to Tunisia and Sicily; North-east Medit-Mont, where limits are areas from Balkans to Turkey; South-east Medit-Mont, where limits are done by a wide area from Cyrenaica to Egypt and Syria.
- Eurasian (Eurasiat): species of the Eurasian continent or from one of its sectors but in a temperate climate. They are divided in: Paleotemperate, with eurasian species *latu senso* living in North Africa too; Eurasian, with eurasian species *strictu senso* common from Europe to Japan; South-european– South-siberian, species from warm areas of Europe and the dry belt of South-Siberia; Pontic, species living around Black Sea; European-Caucasian, species of Europe and Caucasus; European, species of Europe; Central-European, species in temperate Europe, from France to Ukraine; N-Europe, species in Northern Europe; SE-Europe, species of Carpatian-Danubian regions.
- Atlantic (Atlant): species of the Atlantic coasts of Europe. They are divided in: W-Europe, from Scandinavia to Iberian Peninsula; Sub-Atlantic, from Central Europe with a sub-oceanic climate; Mediterranean-Atlantic (Steno), from Atlantic to Mediterranean coasts; Anfi-Atlantic, from coasts of two sides of the Atlantic Ocean (North America and Europe); Mediterranean-Atlantic (Euri), from Mediterranean to Atlantic (Steno) coasts but able to live in the continental regions too.
- Orophile South-European (Orof S-Europ): species of the mountains of S-Europe. They are divided in: Orophile S-Europe, from SE; Orophile SW-Europe, from SW; Alpine Endemic, species distributed in the Alps; Orophile-European, species of the European mountains, mainly in the southern chains; Orophile-Central European, species on the Alps, Jura, Carpathians and sometimes the southern chains.
- Boreal (Bor): species living in the boreal altitudes. They are divided in: Circumboreal, with species distributed in cold and cold-temperate regions of Europe, Asia and North America; Euro-Siberian, with species of cold and cold-temperate regions of Eurasia; Arctic-Alpine (Circumboreal), species of Arctic

regions of Eurasia and North America and in high mountains of the temperate belt; Arctic-Alpine (Eurasian), species of Arctic regions of Eurasia and high mountains of temperate belt; Arctic-Alpine (European), species of Arctic Europe, Alps and high mountains of S-Europe; Arctic-Alpine (Euro-American), species of Scandinavia, North America and high mountains of temperate regions.

- Pantropical (Pantrop): species distributed in the tropical belt of Eurasia, Africa and America.
- Saharian-sindic (Saharo-Sind), with species distributed in dry regions from N-Africa to India.
- Mediterranean-Turanian (Medit-Turan): with species from the desert and sub-desert regions from the Mediterranean basin to Central Asia.
- Sub-cosmopolitan (Subcosmop), with species worldwide distributed, but with few gaps.
- Cosmopolitan (Cosmop), with species worldwide distributed.
- Sub-tropical (Subtrop), with species distributed in the tropical and warm-temperate belts.
- Adventive, exotic species brought by humans. For convenience, they are in the macro-element called Exotic.

Bioindication values by Ellenberg

In natural conditions plants grow in a specific area only if this place is congenial to their ecological needs. So, if a plant is present in an area we can suppose its ecological characteristics.

Bioindication values constitute the numeric evaluation of the influence of the main ecological factors in determining the characteristics of the area. This evaluation is quite subjective but it takes in consideration few objective elements: geographic and topographic distribution, experimental measurements and comparison with other species. The synthesis of this estimate is represented by a number.

Ellenberg published in 1974 the catalog of the German flora and it gave for each species a definition (by numeric values) concerning the main ecological factors. In that time, the value of the plants and vegetal communities as ecological bioindicators was already known (e.g. Braun-Blanquet, 1928) but the limit of the Authors (Oberdorfer, 1964) was to only observe the correlation between the environmental conditions and the distribution of the species. Ellenberg's proposition was to choose six key ecological factors (light, temperature, continentality, water, pH, nutrients) and to weight the importance of each factor in order to understand the plant-life conditions (Pignatti, 2005).

The novelty was to use the very wide knowledge concerning the geographic and topographic distribution of the species and to apply it.

The method of bioindication (*Zeigerwerte*) by Ellenberg (1974, 1979 and 1992) is based on strict criteria but it is very simple to understand and apply. For each species of German flora, the behavior referred to the six ecological factors is summarized in a numeric scale:

- L (light): values from 1 to 9. Distribution of the species related to the relative light intensity (the natural environmental intensity of the light during the season of the maximum leaf development).

- T (temperature): values from 1 to 9. The value is referred to the annual mean temperatures in the area of the species.
- C (continentality): values from 1 to 9. Geographic distribution of the species following the continentality index.
- U (humidity or water resources): values from 1 to 12. Distribution of the species following the humidity soil index (from very dry to moderately-humid, from marshy area to floating vegetation).
- N (nutrients): values from 1 to 9. Distribution of the species related to the nutrient resources on the soil during the vegetative season.
- R (pH): values from 1 to 9. Distribution of the species related to the pH index of the soil or its calcareous content.
- S (saltiness): values from 1 to 3. Distribution related to the salt concentration of the soil or water.

The bioindication values may be applied to species, floras, communities, vegetation complexes and then analyzed by statistical methods. In fact, a radar graph (called "ecogram") can be drawn, and it constitutes a real fingerprint of the study area. So it's immediately possible to compare different ecosystems (Pignatti, 2005).

Afterwards an analogous classification was proposed by Landolt in 1977. He drew on Ellenberg's indexes and he added two more values: humus and volume of pores.

These studies didn't assert on Italian researches because of the higher number of Italian species, compared to the German ones. Only close to the borders Landolt's indexes have been used and several researches have been performed.

Starting from 1993, Pignatti's group has been effectuating several field surveys in order to calibrate the bioindication values in Italy.

In this chapter Ellenberg's indexes will be used, with few modifications of the values proposed by Pignatti (2005).

3.2.1.2 Results

Considering the bibliographic data (Arrigoni, 1996) and floristic-vegetation surveys on the field, results of the floristic study are presented in the following pages with several biological, chorological and ecological considerations.

a) <u>Floristic list</u>

The floristic list presents the species found in Capo Comino area. They are grouped by Family, in alphabetical order. Each element reports its biological and chorological attributes (from *Flora d'Italia* by Pignatti 1982, 2002).

Few species presented in the list have not been directly observed on the field, but they have been got from Arrigoni's paper (1996). They are marked by a star.

Species are 183 distributed in 28 Families. Between them, the most represented are *Graminaceae, Compositae, Leguminosae, Liliaceae, Chenopodiaceae, Juncaceae, Caryophyllaceae* and *Cyperaceae.* This observation is in concert with the phytogeographic, environmental and climatic characteristics of the study area.

<u>Araceae</u>	
* *Arisarum vulgare* Targ.-Tozz.	G rhiz, Stenomedit.
<u>Asclepiadaceae</u>	
Gomphocarpus fruticosus (L.) Aiton fil.	P caesp; Avv.
<u>Cactaceae</u>	
Opuntia ficus-indica (L.) Miller	P succ; Avv.
<u>Campanulaceae</u>	
* *Laurentia gasparrinii* (Tineo) Strobl	T scap; W-Stenomedit.
<u>Caprifoliaceae</u>	
Lonicera implexa Aiton	P lian (SV);Stenomedit.
<u>Caryophyllaceae</u>	
* *Polycarpon tetraphyllum* L.	T scap; Eurimedit.
Silene colorata Poiret	T scap; Stenomedit.
Silene corsica DC	H scap; Endem.
Silene gallica L.	T scap; Eurimedit.
Silene nicaeensis All.	T scap; Stenomedit.
* *Spergularia marina* (L.) Griseb.	T scap; Subcosmop.
<u>Chenopodiaceae</u>	
Arthrocnemum macrostachion (Moric.) Moris	Ch succ; Stenomedit.
Arthrocnemum fruticosum (L.) Moq.	Ch succ; Eurimed.

Atriplex latifolia Wahlenb.	T scap; Circumb.
Atriplex littoralis L.	T scap; Eurasiat.
Halimione portulacoides (L.) Aellen	Ch suffr; Circumbor.
Salicornia patula Duval-Jouve	T scap; Stenomedit.
Salicornia europeae L.	T scap; W-Europ. (Atl.)
Salsola soda L.	T scap; Paleotemp.
Salsola kali L.	T scap.; Paleotemp.
Suaeda maritima (L.) Dumort.	T scap; Cosmop.
<u>Cistaceae</u>	
Cistus albidus L.	NP; W-Stenomedit.
Cistus monspeliensis L.	NP; Stenomedit-Macaron.
Cistus salvifolius L.	NP; Stenomedit.
Halimium halimifolium (L.) Willk.	NP; W-Stenomedit.
<u>Compositae</u>	
Aetheorrhiza bulbosa (L.) Cass.	G bulb; Stenomedit.
Anthemis maritima L.	H scap; W-Medit.-Mont.
Aster squamatus (Sprengel) Hieron.	T scap; Avv.
Aster tripolium L.	H bienne; Eurasiat.
Carlina corymbosa L.	H scap; Stenomedit.
Chondrilla juncea L.	H scap; S-Europ.- S-Sib.
Cichorium intybus L.	H scap; Cosmop.
Galactites tomentosa Moench	H bienne; Stenomedit.
Gnaphalium luteo-album L.	T scap ; Subcosmop.
* *Hedypnois cretica* (L.) Willd.	T scap; Stenomedit.
Helichrysum italicum (Roth) Don subsp. *microphyllum* (Willd.) Nyman	Chsuffr; W.-Medit.
**Hypochoeris achyrophorus* L.	T scap; Stenomedit.
Inula crithmoides L.	Ch suffr; Alof. SW-Europ.
Inula viscosa (L.) Aiton	H scap; Eurimedit.
Lactuca saligna L.	T scap; Eurimedit.-Turan.
**Leontodon leysseri* (Wallr.) Beck	T scap; Eurimedit.
Matricaria chamomilla L.	T scap ; Subcosmop.
Oglifa gallica (L.) Chrtek et Holub	T scap; Eurimedit.
Otanthus maritimus (L.) Hoffmgg. et Link	Ch suffr; Stenomedit.-Atl.
Pulicaria odora (L.) Rchb.	H scap; Eurimedit.
Rhagadiolus stellatus (L.) Willd.	T scap; Eurimedit.
Reichardia picroides (L.) Roth	H scap; Stenomedit.
Sonchus maritimus L.	H ros; Eurimedit.
Sonchus oleraceus L.	T scap; Subcosmop.
* *Sonchus tenerrimus* L.	T scap; Stenomedit.
Urospermum dalechampii (L.) Schmidt	H scap; Eurimedit.
* *Urospermum picroides* (L.) Schmidt	T scap; Eurimedit.

<u>Convolvulaceae</u>	
Calystegia soldanella (L.) R. Br.	G rhiz; Cosmop.-litorale
Convolvulus althaeoides L.	H scand; Stenomedit.
<u>Cruciferae</u>	
Cakile maritima Scop.	T scap; Medit.Atl. (Euri)
Lobularia maritima (L.) Desv.	H scap; Stenomedit.
Malcolmia ramosissima (Desf.) Thell.	T scap; W-Medit.
<u>Cupressaceae</u>	
Juniperus turbinata (Guss.) Nym.	P caesp; Stenomedit.
<u>Cyperaceae</u>	
Bolboschoenus maritimus (L.) Palla	G rhiz; Cosmop.
Carex distachya Desf.	H caesp; Stenomedit.
* *Carex flacca* Schreber	G rhiz; Europ.
Cyperus kalli (Forsskal) Murb.	G rhiz; Stenomedit.
Cyperus longus L.	He; Paleotemp.
Holoschoenus romanus (L.) Fritsch	G rhiz; Stenomedit.
Schoenus nigricans L.	H caesp;Subcosmop.
<u>Ericaceae</u>	
Arbutus unedo L.	P caesp; Stenomedit.
Erica arborea L.	P caesp; Stenomedit.
<u>Euphorbiaceae</u>	
Euphorbia paralias L.	Ch frut; Eurimedit.
Euphorbia peplis L.	T rept; Eurimedit.
Euphorbia terracina L.	T scap; Stenomedit
Ricinus communis L.	T scap; Paleotrop.
<u>Fagaceae</u>	
Quercus ilex L.	P scap; Stenomedit.
Quercus suber L.	P scap; W-Medit.(Euri)
<u>Frankeniaceae</u>	
**Frankenia hirsuta* L.	Ch suffr; Stenomedit.
<u>Gentianaceae</u>	
Blackstonia perfoliata (L.) Hudson	T scap; Eurimedit.
Centaurium tenuiflorum (Hoffmgg. et Link) Fritsch	T scap; Paleotemp.
<u>Graminaceae</u>	
Ammophila littoralis (Beauv.) Rothm.	G rhiz; Eurimedit.
Agropyron elongatum (Host) Beauv.	H caesp; Eurimedit.
Agropyron junceum (L.) Beauv.	G rhiz; Eurimedit.

Agropyron pungens (Pers.) R. et S.	G rhiz; Eurimedit.
Agropyron repens (L.) Beauv.	G rhiz; Circumbor.
Agrostis stolonifera L.	H rept; Circumbor.
Brachypodium ramosum (L.) R. et S.	H caesp; W-Stenomedit.
**Briza maxima* L.	T scap; Paleo-Subtrop.
Briza minor L.	T scap; Subcosmop.
Bromus rigidus Roth.	T scap; Subtrop.
Catapodium marinum (L.) Hubbard	T scap; Medit.Atl.
Cutandia divaricata (Desf.) Bentham	T scap; SW-Stenomedit.
Cutandia maritima (L.) Richter	T scap; Stenomedit.
Cynodon dactylon (L.) Pers.	G rhiz; Cosmop.
Cynosurus echinatus L.	T scap; Eurimedit.
Cymbopogon hirtus (L.) Janchen	H caesp; Paleotrop.
Dactylis glomerata L.	H caesp; Paleotemp.
Hordeum maritimum With.	Tscap;W-Eurimedit-Subatl.
Imperata cylindrica (L.) Beauv.	G rhiz; Termocosmop.
Lagurus ovatus L.	T scap; Eurimedit.
Oryzopsis miliacea (L.) Asch. et Sch.	H caesp; Stenomedit.
Phragmites australis (Cav.) Trin.	G rhiz; Subcosmop.
* *Polypogon maritimus* Willd.	T scap; Stenomedit.
Spartina juncea (Michx.) Willd.	G rhiz; Anfi Atl.
Sporobolus pungens (Schreber) Kunth	G rhiz; Subtrop.
Vulpia membranacea (L.) Link	T caesp; Medit.Atl.
Juncaceae	
Juncus acutus L.	H caesp; Eurimedit.
Juncus articulatus L.	G rhiz; Circumbor.
Juncus bufonius L.	T caesp; Cosmop.
* *Juncus capitatus* Weigel	T scap; Medit.Atl.(Euri)
Juncus maritimus Lam.	G rhiz; Subcosmop.
Juncus subulatus Forsskal	G rhiz; S-Medit.
Juncaginaceae	
Triglochin bulbosum L.	
subsp. *barrelieri* (Loisel.) Rouy	G bulb; Endem.
Labiatae	
Lavandula stoechas L.	NP; Stenomedit.
Mentha pulegium L.	H scap; Subcosmop.
Leguminosae	
Calicotome villosa (Poiret) Link	P caesp; Stenomedit.
Dorycnium pentaphyllum Scop.	H scap; W-Medit.
subsp. *suffruticosum* (Vill.) Rouy	
Dorycnium rectum (L.) Ser.	H scap; Stenomedit.
Lotus cytisoides L.	Ch suffr; Stenomedit.

Lotus tenuis W. et K.	H scap ; Paleotemp.
Medicago litoralis Rohde	T scap; Eurimedit.
Medicago marina L.	Ch rept; Eurimedit.
* *Medicago truncatula* Gaertner	T scap; Stenomedit.
Ononis reclinata L.	T scap; E-Medit.-Turan.
Ononis natrix L.	H caesp; Eurimedit.
subsp. *ramosissima* (Desf.) Batt. et Trab.	
Ononis variegata L.	T scap; Stenomedit
**Ornithopus compressus* L.	T scap; Eurimedit.
* *Scorpiurus muricatus* L.	T scap; Eurimedit.
Trifolium angustifolium L.	T scap; Eurimedit.
Trifolium arvense L.	T scap; Paleotemp.
Trifolium campestre Schreber	T scap; Paleotemp.
Trifolium glomeratum L.	T scap; Eurimedit.
<u>Liliaceae</u>	
**Allium commutatum* Guss.	G bulb; E-Stenomedit.
Allium subhirsutum L.	G bulb; Stenomedit.
Asparagus acutifolius L.	NP; Stenomedit.
Asparagus albus L.	NP; W-Stenomedit.
Asphodelus microcarpus Salzm. et Viv.	G rhiz; Stenomedit.
Pancratium maritimum L.	G bulb; Stenomedit.
Ruscus aculeatus L.	Ch frut; Eurimedit.
Smilax aspera L.	NP; Subtrop.
Urginea maritima (L.) Baker	G bulb; Stenomedit.
<u>Linaceae</u>	
Linum bienne Miller	H bienne; Eurimedit.
Linum strictum L.	T scap; Stenomedit.
* *Linum trigynum* L.	T scap; Eurimedit.
<u>Lythraceae</u>	
* *Lythrum hyssopifolia* L.	T scap; Subcosmop.
<u>Malvaceae</u>	
* *Malva alcea* L.	H scap; Centro-Europ.
<u>Myrtaceae</u>	
Eucalyptus globulus Labill.	P scap; Colt.
Myrtus communis L.	P caesp; Stenomedit.
<u>Oleaceae</u>	
Nerium oleander L.	P caesp; S-Stenomedit.
Olea europaea L.	P caesp; Stenomedit.
Phillyrea angustifolia L.	P caesp; W-Stenomedit.
Pistacia lentiscus L.	P caesp; S-Stenomedit.

<u>Orchidaceae</u>	
Spiranthes spiralis (L.) Koch	G rhiz; Europ.-Cauc.
<u>Orobanchaceae</u>	
Orobanche minor Sm.	T par; Subcosmop.
Orobanche ramosa L.	T par; Paleotemp.
<u>Palmae</u>	
Chamaerops humilis L.	P scap; W-Stenomedit.
<u>Pinaceae</u>	
Pinus pinea L.	P scap; Eurimedit.
<u>Plantaginaceae</u>	
Plantago coronopus L.	T scap;Eurimedit.
Plantago lanceolata L.	H ros; Cosmop.
<u>Plumbaginaceae</u>	
* *Limonium contortirameum* (Mabille) Arrig. et Diana	H ros; Endem.
Limonium virgatum (Willd.) Fourr.	H ros; Eurimedit.
<u>Polygonaceae</u>	
Fallopia convolvulus (L.) Holub	T scap; Circumbor.
Polygonum maritimum L.	H rept; Subcosmop.
* *Rumex bucephalophorus* L.	T scap;Eurimedit.-Macaron.
<u>Primulaceae</u>	
Anagallis arvensis L.	T rept; Subcosmop.
Anagallis parviflora Hoffmgg. et Link	T rept; W-Stenomedit.
<u>Ranunculaceae</u>	
Clematis cirrhosa L.	P lian; Stenomedit.
Clematis flammula L.	P lian; Eurimedit.
<u>Rhamnaceae</u>	
Rhamnus alaternus L.	P caesp; Eurimedit.
<u>Rosaceae</u>	
Rubus ulmifolius Schott	NP; Eurimedit.
Potentilla reptans L.	H ros; Paleotemp.
<u>Rubiaceae</u>	
Crucianella maritima L.	Ch suffr; Stenomedit.
Rubia peregrina L.	P lian; Stenomedit.

<u>Santalaceae</u>	
Osyris alba L.	NP; Eurimedit.
* *Thesium humile* Vahl	T scap; Medit.Atl.(Steno)
<u>Scrophulariaceae</u>	
* *Bellardia trixago* (L.) All.	T scap; Eurimedit.
* *Kickxia cirrhosa* (L.) Fritsch	T scap; Stenomedit.
* *Kickxia commutata* (Bernh.) Fritsch	H rept; Stenomedit.
<u>Tamaricaceae</u>	
Tamarix gallica L.	P caesp; W-Stenomedit.
<u>Thymelaeaceae</u>	
Daphne gnidium L.	P caesp; Stenomedit.
<u>Typhaceae</u>	
Typha angustifolia L.	G rhiz; Circumb.
<u>Umbelliferae</u>	
Daucus carota L.	
subsp. *maximus* (Desf.) Ball	H bienn; Eurimedit.
Echinophora spinosa L.	H scap; Eurimedit.
Eryngium maritimum L.	G rhiz; Medit-Atl.(Steno)
* *Oenanthe silaifolia* Bieb.	H scap; Medit-Atl.(Euri)
Pseudorlaya pumila (L.) Grande	T scap; Stenomedit.
<u>Verbenaceae</u>	
Vitex agnus-castus L.	P caesp; Medit.-Turan.

b) <u>Biological spectrum</u>

Result concerning the biological spectrum is presented below.

Figure 3.31 shows the total biological spectrum of the species of the study area.

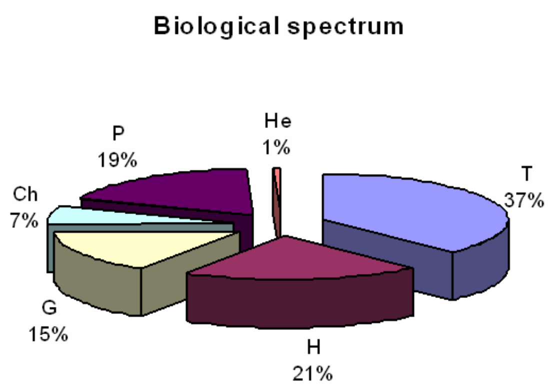


Figure 3.31 - Biological spectrum of Capo Comino area.

It shows a dominance of therophytic species, mainly *scapose* and *caespitose*, such as in coastal Mediterranean environments.

Hemicryptophytes (mainly H *scapose*) have a good percentage too (21%). Geophytes reach 15% and between them Grhiz are the main ones with psammophile species (*Ammophila littoralis*, *Agropyron junceum*, *Sporobolus pungens* and *Spartina juncea*).

The 19% is represented by therophytic species (mainly shrubs) and 7% by chamaephytes. The last ones are located on the established dunes.

Helophytes are only less than 1% and represented by *Cyperus longus.*

c) <u>Chorological spectrum</u>

The phytogeographic characteristics shown in the general chorological spectrum (Fig. 3.32) highlights the marked Mediterranean features of the study area.

The chorological spectrum indicates the dominance of Mediterranean species (Steno-Medit. 36%, Euri-Medit. 27%), in concert with the phytogeographic and bioclimatic characteristics of the study area.

The species presenting a Mediterranean and Atlantic distribution are 4% and European species are 10% of the total distribution.

Sub-cosmopolitan and cosmopolitan species are represented by 11% , mainly related to the anthropic influence.

Endemic species are 2% (*Silene corsica*, *Limonium contortirameum* and *Triglochin bulbosum* subsp. *Barrelieri*).

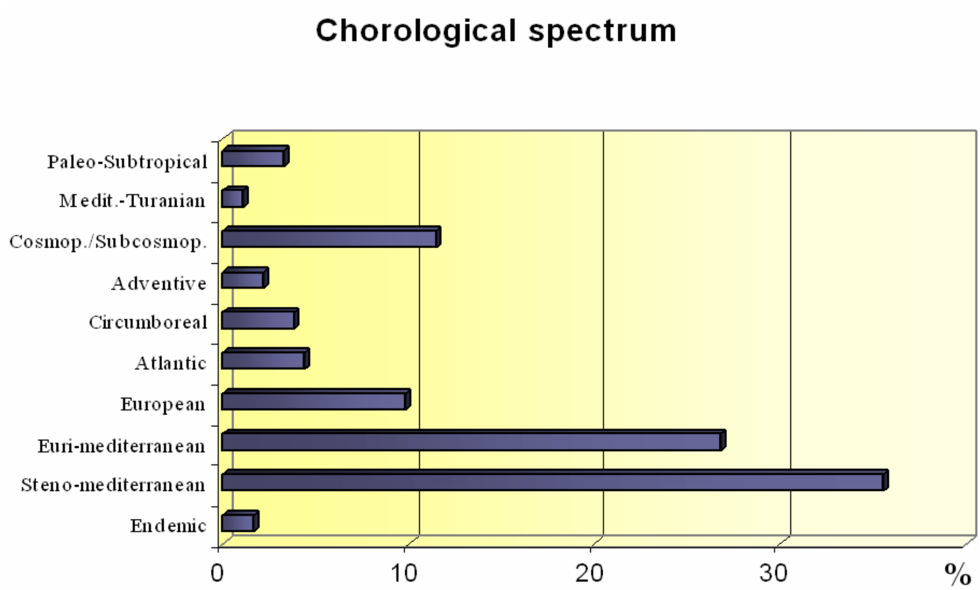


Figure 3.32 – Chorological spectrum of the study area.

Between the adventive species (2%) *Gomphocarpus fruticosus* and *Aster squamatus* are represent in Capo Comino area.
Gomphocarpus fruticosus, called "false cotton", is a shrub coming from South-Africa. It has been cultivated in order to obtain textile fibers. This species is actually spontaneous on pebble-sandy soils of Sardinia, Sicily, Calabria and Puglia. The main characteristic is its fruit, a fusiform boll (1x5cm), with sub-spiny prickles. It contains seeds.
Aster squamatus is an arboreal species, presenting branchy trunk and 0.8 meters high. Several little flower heads are present at the edge of the branches. Flowers are purple. It is common to find this species in the uncultivated fields, mainly humid and in tropical environments.

d) <u>Ecogram of Ellenberg's indexes</u>
Results of Ellenberg's bioindication values are presented. The ecogram of the vegetation of the study area is shown in figure 3.33. In general, the radar graph indicates high values of L (light) and T (temperature), as expected for Mediterranean vegetation.
The high S index (scale of the values from 1 to 3) confirms the general discrete halo-tolerance of the species.
The low values of U (Humidity) and C (continentality index) confirm a coastal dry environment.

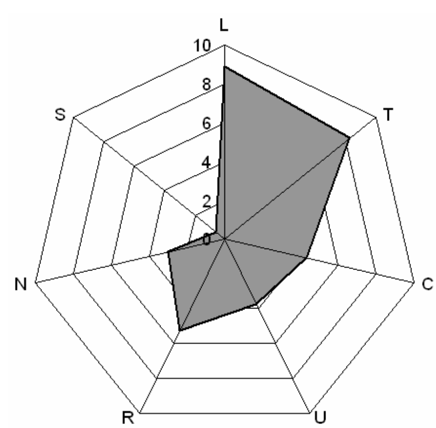


Figure 3.33 – Ecogram of the vegetation in Capo Comino area.

3.2.2 VEGETATION ANALYSIS

3.2.2.1 Method

The study of the vegetation has been carried out by the phytosociological method. The term "phytosociology" was coined in 1896 by Józef Paczoski but only with J. Braun-Blanquet (1915, 1928, 1932, 1964) the new method was experimented.
The phytosociological method investigates the vegetal associations of the plants and their relationships with the surrounding environment.
The fundamental unit is the association, defined as "plant groupings more or less stable and in equilibrium with the environment, and characterized by a specific floristic composition. The presence of exclusive elements (characteristic species) shows a special and self-governing ecology" (Braun-Blanquet, 1915). This is a conceptual model of a phytocenosis.
A vegetal community is constituted by single species, related by complex relationships of competition and cohabitation. Their groupings are not casual and result from different factors: climate, geological substrate, geomorphology, edaphic conditions and human factors.
The associations are defined by the statistically repeated combination of plants and these groupings build a dynamic relationship between them.
The phytosociological method is surely the most efficient and effective approach in order to investigate the relationship between the vegetation and the environmental parameters. This procedure rests on the assumption that in the same ecological conditions the phytocenosis are represented by the same combination of species. So, it's possible to define the different typologies by the floristic analysis and few quantitative observations.
The study of the vegetation bases on the phytosociological relevés by Braun-Blanquet's method (1964). They are carried out with the aim of collecting detailed information about homogeneous samples of vegetation. The relevé (or survey) has the advantage of a rapid procedure, allowing the comparison of the vegetation if few areas. The aim of this correlation is the evaluation of possible floristic variability related to ecological factors.
The procedure establishes that during a survey data concerning the station point have to be noted: name of the place, topographic references, altitude (in meters above MSL), exposure/orientation, mean inclination of the surface, geolithologic substrate. Then the structure of the vegetation: height, coverage of the different layers (arboreal, shrub, herbaceous and eventually moss layer) and total coverage of the vegetation.
The second step is to write the floristic list. It is convenient to start with the species in a small area, such as 1 sqm, and then to consider a homogeneous twice, three-time, *etc* areas just until no more new species will be found.
A relevé have to be carried out in a homogeneous area with the same floristic composition and social relationships (called "basic population"). The choice of the population is partially independent from the floristic composition but the structural, geomorphological and landscape factors have a strong importance.
Every species is listed with its abundance, the dominance and the association degree, using standard scales. The abundance is referred to the thickness; the covering value is evaluated with the abundance in an abundance/dominance scale; the association degree is related to the way of aggregation of the plants.

The dominance/abundance scale by Braun-Blanquet (1964) is composed by 7 values:
- 5: covering value > 75%;
- 4: covering value between 50 and 75%;
- 3: covering value between 25 and 50%;
- 2: covering value between 5 and 25%;
- 1: covering value between 1 and 5%;
- r: very rare species, only few isolated plants. They have small covering value.

The association degree is expressed by:
- 5: high association degree, with the formation of "pure" populations;
- 4: formation of colonies on at least the 50% of the area;
- 3: small colonies;
- 2: small groupings;
- 1: isolated plants.

After the field survey, the relevés can be compared. The phytosociological relevés of Capo Comino area (118 relevés) have been grouped in a raw table.

Then relevés have been compared, ordered and classified by the multivariate analysis (MATEDIT software) (Burba *et al.*, 1992). The software uses a bidirectional matrix (rows are species and columns are relevés). In order to compare the relevés, data have to be transformed using the Van Der Maarel scale (1979) where r =1, + =2, 1=3, 2=5, 3=7, 4=8, 5=9 and the absence of a plant corresponds to 0.

The results are usually represented as dendograms and relevés are grouped following their similarity degree.

Every group can characterize a vegetation type. The different types are then related to a syntaxonomic scheme following gerarchic units. The association is the basic categories and than upper and lower syntaxonomic categories are considered.

Considering the similarity indexes of the dendogram, final tables can be filled in. These tables present the characteristic species of the association, several species that are characteristic of the alliance and eventually joined with those of the upper unit, and other species defined by accidental species with very low frequency or indifferent species (they can be found in other groupings, without a particular ecological link).

Each table with more than 6 relevés presents the "frequency class" for each species (or "presence class"). The standard classes are:

I: species in 1-20% of relevés;

II: species in 21-40% of relevés

III: species in 41-60% of relevés

IV: species in 61-80% of relevés

V: species in 81-100% of relevés

The frequency class bring to a better analysis of the distribution of each species and to several considerations about the homogeneity of the distribution.

The "covering index" (Braun-Blanquet, 1925) has been calculated for each table. It considers the abundance/dominance value for every relevé and it takes in consideration the corresponding covering degree using its central value (Tab. 3.2).

Abundance-Dominance scale (value)	Covering degree (%)	Central value (number)
5	75-100	87.5
4	50-75	62.5
3	25-50	37.5
2	5-25	12.5
1	1-5	2.5
+	<1	0.1

Table 3.2– Central values for each abundance-dominance value.

The covering index is the sum of the central values (corresponding to the abundance/dominance value) multiplied by 100 and divided by the total number of the relevés of the table.
Using the covering index, the vegetation biological spectrum and the ecological ecogram for each association have been calculated. They help to a better understanding of the distribution and ecology of the associations.
Concerning the distribution of the associations, it has been possible to create a vegetation map of the study area, using a DTM (1 meter resolution) and collecting data about the distribution of each association during the field surveys. A specific legend has been created and this information has been analysed by GIS software (ARCGis 9.3).
The distribution of the vegetation associations has been also considered by two profiles, located in the central sector of the dunefield. These transects well explain the dynamic or catenal successions of the associations along the morphological forms.

3.2.2.2 Results

a) <u>Vegetation associations</u>

The vegetation analysis has been carried out in the dunefield and in the retrodunal systems. The results bring to the classification of several different vegetal communities and to the evaluation of their biological and ecological aspects too.

Starting from the nearshore zone, the first vegetal community is represented by *Posidonia oceanica* ((L.) Delile, 1813) meadows.

This marine phanerogame is endemic of Mediterranean Sea and presents hypogeal roots and rhizomes. They can grow along both the horizontal and the vertical directions, fighting the silting up by marine currents and wave action. They create underwater meadows, called "matte", and constituted by a tangle of roots, dead and alive rhizomes mixed with very compact sediments.

The presence of the *Posidonia o.* meadow plays a leading role from the ecological point of view, not only for living beings (biological impact) but also for waves and marine currents mitigation (physical impact). In addition, leaves and dead parts of the plants periodically deposit on the shore and constitute *banquettes*. These deposits partially protect the beach from the erosive action of wave-motion (Lenzini *et al.*, 1989, 1992; Biondi, 1999).

Deposits on the shoreline may be considerable, more than 1.5 meters high. In Capo Comino area they are mainly present in the southern part of the beach (due to the coastal drift) and they are very high close to Iscra Ruja. However these deposits, not appreciated by the tourists, are taken away from the beach causing damage to the natural system.

With regard to the beach-dune environments and the retrodunal areas, vegetation associations are presented in the following pages.

Beach-dune system

Data have been analyzed by cluster analysis in order to find the similarities between the relevés and to obtain different groups of vegetation.
The analysis of specific groupings and the similarity indexes of the dendogram (Fig. 3.34) bring to recognize 11 associations. They are listed and presented in the following pages.

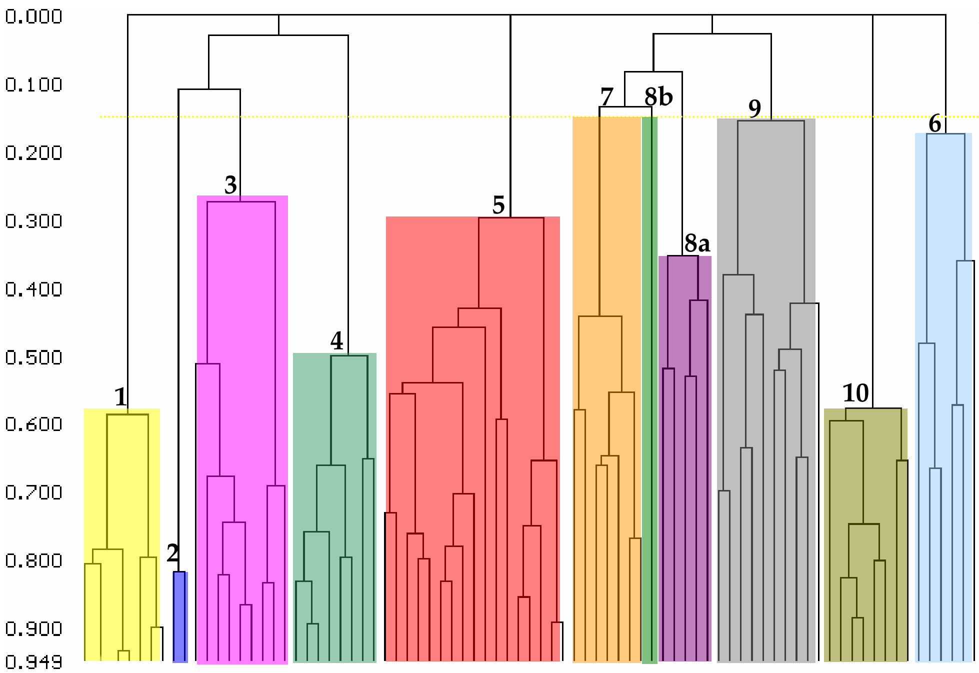


Figure 3.34 – Dendogram of the relevés on the dunefield
(1: SaCa; 2: Sa; 3:SiEl; 4:SiAm; 5: CrHe; 6:SiOn; 7:OlJu; 8a:ErAr; 8b: PiCa; 9:CiHa; 10: ImSc).

1) <u>*Salsolo kali-Cakiletum maritimae* association</u>

Annual and halo-nitrophilic species form a therophitic (Fig. 3.35) community constituting the *Salsolo kali - Cakiletum maritimae* association. This association is distributed in Mediterranean and Atlantic areas (Brullo *et al.*, 2001) and it has been found in the study area (Tab. 3.3).
Considering an ideal profile from sea to inland, this association is localized in the on the beach, after the aphitoic zone (Fig. 3.36). So these communities are also called "seashore communities" and they colonize the upper beach, where waves and currents leave the organic matter. When the organic matter decomposes, it releases nutrients and riches the sand substrate allowing to the plants the colonisation of this sector of the beach.

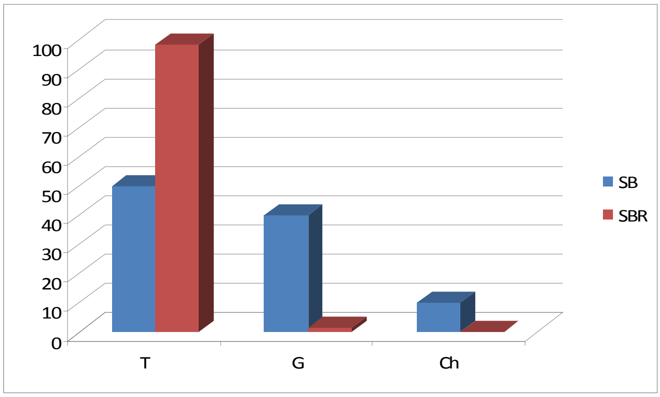


Figure 3.35 – Biological spectrum of *Salsolo kali – Cakiletum maritimae* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Figure 3.36 - *Salsolo-cakiletum* association of the upper beach, in the central (right) and southern (left) sectors of Capo Comino area.

Salsolo kali-Cakiletum maritimae Costa & Mansanet, 1981 corr. Rivas-Martìnez *et al*., 1992

Rel. (n)	**10**	**72**	**94**	**30**	**38**	**78**	**79**	**111**		
Area (sqm)	10	30	12	20	15	30	30	30		
Coverage (%)	30	35	60	25	30	60	70	65		Freq.
Species (n)	3	3	2	5	4	8	5	6	Pres.	class
Charact. and diff. species of ass.										
Cakile maritima Scop.	2.2	3.3	3.4	2.2	2.2	4.4	4.4	4.4	8	V
Salsola kali L.	1.2	2.2	2.2	2.2	2.3	2.3	2.2	2.3	8	V
Charact. and diff. species of upper units										
Euphorbia peplis L.	-	-	-	-	-	1.1	+	-	2	II
Atriplex latifolia Wahlenb.	-	-	-	-	-	-	1.1	+	2	II
Other species										
Eryngium maritimum L.	+	+	-	+	+	+.2	-	+	6	IV
Agropyron junceum (L.) Beauv.	-	-	-	+	-	+	+	+	4	III
Calystegia soldanella (L.) R. Br.	-	-	-	+	+	+	-	-	3	II
Euphorbia paralias L.	-	-	-	-	-	+	-	-	1	I
Silene colorata Poiret	-	-	-	-	-	+	-	-	1	I
Sporobolus pungens (Schreber) Kunth	-	-	-	-	-	-	-	+	1	I

Table 3.3 – Relevés of *Salsolo kali – Cakiletum maritimae* association in Capo Comino dunefield.

2) *Sporoboletum arenarii* sub-association *elymetosum farcti*

The association *Sporoboletum arenarii* is usually present where the beach has a flat profile due to the sea ingression. It is mainly constituted by geophytes(Fig. 3.37).
The sub-association *elymetosum farcti* is present in Capo Comino area (Tab. 3.4).
It was firstly described for Corsica (Géhu and Biondi, 1994 a) and then Sardinia coasts (Biondi *et al*., 2001) and it highlights the erosive process of the shoreline. This association may be in contact with *Salsolo-Cakiletum* of the beach and/or with the *Sileno – Elytrigetum* of the embryo dunes.

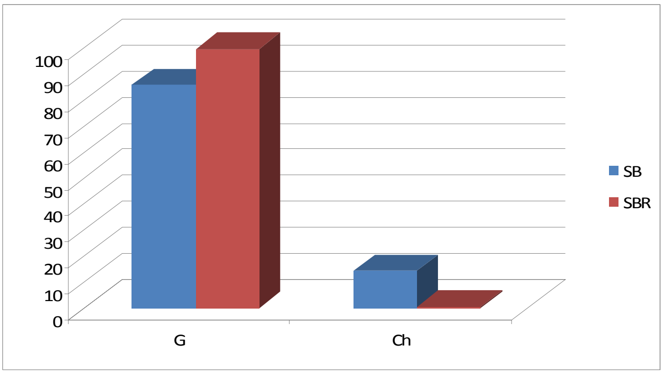


Figure 3.37 – Biological spectrum of *Sporoboletum arenarii elymetosum farcti* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Sporoboletum arenarii (Arénes 1924) Géhu & Biondi, 1994
elymetosum farcti Géhu & Biondi, 1994

Rel. (n)	**58**	**56**	
Area (sqm)	20	20	Pres.
Coverage (%)	60	60	
Species (n)	5	6	
Charact. and diff. species of ass.			
Sporobolus pungens (Schreber) Kunth	3.4	4.4	2
Agropyron junceum (L.) Beauv.	+	+	2
Charact. and diff. species of upper units			
Eryngium maritimum L.	1.1	+	2
Pancratium maritimum L.	+	+	2
Ammophila littoralis (Beauv.) Rothm.	+	-	1
Other species			
Aetheorrhiza bulbosa (L.) Cass.	-	+	1
Lotus cytisoides L.	-	+	1

Table 3.4 - Relevés of *Sporoboletum arenarii* subass. *elymetosum farcti* in Capo Comino dunefield.

3) *Sileno corsicae – Elytrigetum junceae* association

Sileno corsicae-Elytrigetum junceae association (Tab. 3.5) is endemic of Sardinia and Corsica coasts. The association is characterized by *Silene corsica* and *Agropyron junceum (= Elytrigia juncea* (L.) Nevski). It colonizes the embryo dunes of the upper beach and in Capo Comino area it is disfigured by erosion and human-induced processes, such as trampling and seasonal cleaning works (Fig. 3.38)
This association is mainly constituted by geophytic species (Fig. 3.39).
Two species, *Pancratiun maritimum* and *Cyperus kalli*, are very common in this community - above all in Relevé 13 - and they represent a "buried" association (Géhu and Biondi, 1994 b). The last surveys of table 3.5 (rel. 68-69) suggest the presence of *Crucianella maritima.* This situation is common where *Sileno–Elytrigetum* is colonizing the established ridges (especially the backslope) after the deposition of blown sand.

Figure 3.38 – Picture of *Sileno corsicae-Elytrigetum junceae* association on the first dune ridge (at the back-front, *Ammophila arenaria* belonging to the following association).

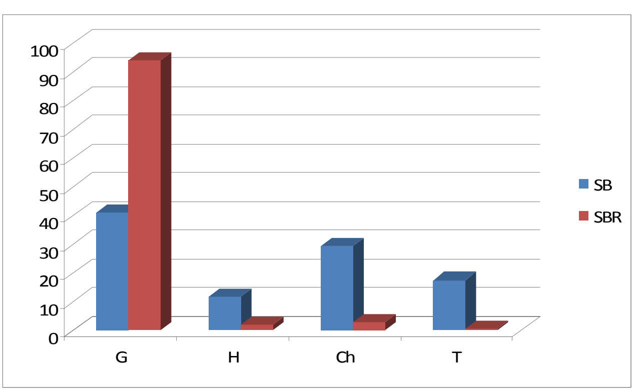


Figure 3.39 – Biological spectrum of *Sileno corsicae – Elytrigetum junceae* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Sileno corsicae-Elytrigetum junceae (Malcuit 1926) Bartolo, Brullo, De Marco, Dinelli, Signorello & Spampinato, 1992 corr. Géhu, 1996

Rel. (n)	**9**	**13**	**52**	**14**	**68**	**69**		
Exposure	-	-	-	E	-	-		
Slope (degree)	-	-	-	15	-	-		Freq.
Area (sqm)	25	20	30	20	60	40	Pres.	class
Coverage (%)	60	60	70	65	75	80		
Species (n)	7	9	6	9	13	8		
Charact. and diff. species of ass.								
Agropyron junceum (L.) Beauv.	3.3	3.3	3.3	3.3	4.4	4.4	6	V
Silene corsica DC	-	+.2	-	-	+.2	-	2	II
Charact. and diff. species of upper units								
Eryngium maritimum L.	2.2	2.1	2.2	3.2	2.3	2.2	6	V
Pancratium maritimum L.	+	2.2	1.2	+	1.1	1.1	6	V
Cyperus kalli (Forsskal) Murb.	-	2.1	+	+	+	1.1	5	V
Echinophora spinosa L.	+	-	-	1.1	1.2	1.1	4	IV
Ammophila littoralis (Beauv.) Rothm.	-	+	-	-	+.2	1.2	3	III
Medicago marina L.	-	-	-	+.2	+	1.2	3	III
Otanthus maritimus (L.) Hoffmgg. et Link	-	1.3	-	+	-	-	2	II
Sporobolus pungens (Schreber) Kunth	1.2	-	-	-	-	-	1	I
Calystegia soldanella (L.) R. Br.	+	-	-	-	-	-	1	I
Euphorbia paralias L.	-	+	-	-	-	-	1	I
Other species								
Crucianella maritima L.	-	+	+.2	+.2	1.2	1.2	5	V
Cakile maritima Scop.	+	-	+	+	+	-	4	IV
Salsola kali L.	-	-	-	-	+	-	1	I
Lotus cytisoides L.	-	-	-	-	+	-	1	I
Silene colorata Poiret	-	-	-	-	+	-	1	I

Table 3.5 - Relevés of *Sileno corsicae-Elytrigetum junceae* association in Capo Comino dunefield.

4) *Sileno corsicae - Ammophiletum arundinaceae* association

Sileno corsicae-Ammophiletum arundinaceae association (Tab. 3.6) is endemic of Sardinia and Corse coasts. This association is located on white dunes, where sediments are inconsistent and mobile with a high growing degree (especially the vertical one) because of sand burial. They are colonized and built up by *Ammophila arenaria*.
Sileno-Ammophiletum is mainly constituted by geophytic species, but the biological spectrum of Capo Comino area (Fig. 3.40) shows the presence of chamaephytes, mainly represented by *Crucianella maritima*. This species has been found in catenal succession at the backslope of the first dune ridges.
This association is close to the shoreline in few sectors of Capo Comino because of the erosion of the embryo dunes and it has gradually deconstructing. In the inner sector, instead, this association characterizes the crests of parabolic dunes and the younger Gegenwalle ridges, at the base of the stoss-slope (Fig. 3.41).

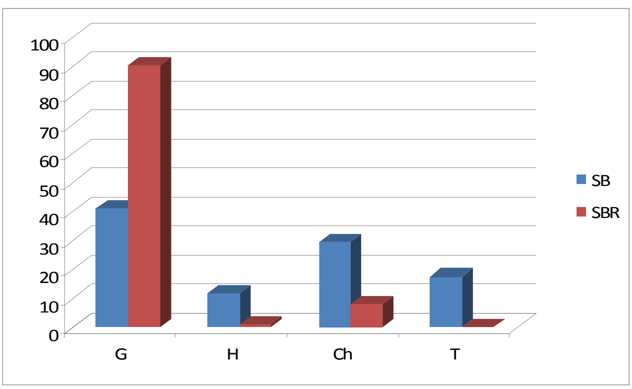


Figure 3.40 – Biological spectrum of *Sileno corsicae-Ammophiletum arundinaceae* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Figure 3.41 – *Sileno-Ammophiletum* association under erosion in the first ridge of foredunes (left) and at the top of the parabolic dunes in the central sector (right).

Sileno corsicae-Ammophiletum arundinaceae Bartolo, Brullo, De Marco, Dinelli, Signorello & Spampinato, 1992

Rel. (n)	**12**	**44**	**95**	**112**	**43**	**26**	**83**	**74**		
Exposure	N	-	E		-	-				
Slope (degree)	30	-	60		-	-				Freq.
Area (sqm)	25	40	40	50	30	40	50	25	Pres.	class
Coverage (%)	70	80	65	80	60	50	90	75		
Species (n)	7	7	8	9	4	8	8	8		
Charact. and diff. species of ass.										
Ammophila littoralis (Beauv.) Rothm.	4.4	4.4	4.3	4.4	4.4	3.3	4.4	3.3	8	V
Silene corsica DC	-	+	+	-	-	+	+.2	-	4	III
Charact. and diff. species of upper units										
Eryngium maritimum L.	2.2	1.2	1.2	1.2	1.2	1.2	1.1	3.3	8	V
Euphorbia paralias L.	+	+.2	+.2	1.1	-	1.1	-	+	6	IV
Cyperus kalli (Forsskal) Murb.	1.1	+	1.2	1.1	-	-	-	+.2	5	IV
Pancratium maritimum L.	+	-	-	+	-	-	1.1	1.2	4	III
Echinophora spinosa L.	+	-	+.2	-	-	-	+	1.2	4	III
Agropyron junceum (L.) Beauv.	-	+.2	+	-	-	-	2.3	2.3	4	III
Medicago marina L.	-	-	-	-	1.2	+	-	-	2	II
Calystegia soldanella (L.) R. Br.	-	-	-	+.2	-	-	-	-	1	I
Other species										
Crucianella maritima L.	+.2	+	2.2	1.1	1.2	1.2	-	2.2	7	V
Inula crithmoides L.	-	-	-	-	-	-	+.2	-	1	I
Pseudorlaya pumila (L.) Grande	-	-	-	-	-	-	+	-	1	I
Lotus cytisoides L.	-	-	-	1.2	-	-	-	-	1	I
Imperata cylindrica (L.) Beauv.	-	-	-	+.2	-	-	-	-	1	I
Cakile maritima Scop.	-	-	-	-	-	+	-	-	1	I
Silene colorata Poiret	-	-	-	-	-	+	-	-	1	I

Table 3.6 – Relevés of *Sileno corsicae - Ammophiletum arundinaceae* association in Capo Comino dunefield.

5) *Crucianello-Helichrysetum microphylli* association

Crucianello-Helichrysetum microphylli association is mainly constituted by chamaephytic vegetation (Fig. 3.42). This association was found in other sectors of the island (Bartolo *et al.*, 1989, 1992; Mossa, 1989, 1992; Brullo *et al.*, 2001).
The common species in Capo Comino area are *Crucianella maritima* and *Helichrysum italicum* subsp. *microphyllum* (Tab. 3.7). They are located on fixed and stable sand dunes occurring on the landward side of white dunes. These dunes are called "gray dunes" because of the presence of mosses and lichens which give the characteristic gray color.
In Capo Comino *Crucianello-Helichrysetum* association gets rich of *Imperata cylindrica* and defines the new *imperatosum cylindricae* sub-association. It happens when the garigue gets close to the interdunal wetlands (Fig. 3.43).
Table 3.7 shows the presence of species of *Ammophiletea* class on the foredunes. This highlights the strong erosion of the first dune ridge because of erosive process. In fact, *Crucianello-Helichrysetum* association is unprotected by salt spray and the sand burial is forming deposits of new embryo dunes on older gray dunes. Above all relevés 90 and 77 show the presence of *Agropyron junceum* and the decreasing presence of *Crucianella maritima* and *Helichrysum italicum,* more sensitive to salt spray.

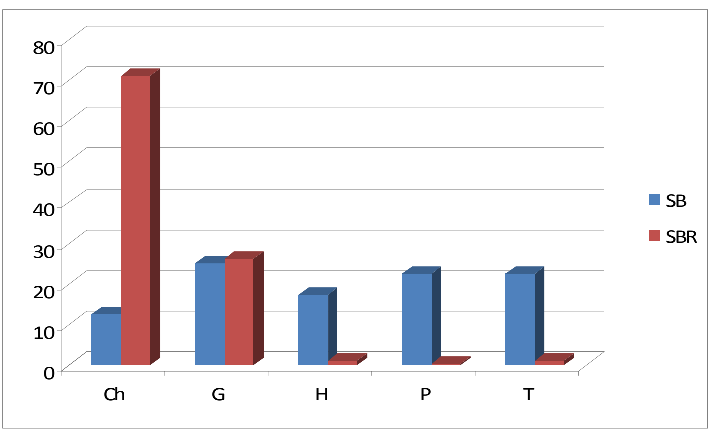


Figure 3.42 – Biological spectrum of *Crucianello - Helichrysetum microphylli* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Figure 3.43 – *Crucianello-Helichrysetu*m in the inner ridges (top and right) and the transition to the sub-association *imperatosum cylindricae* (bottom).

Crucianello-Helychrysetum microphylli Bartolo, Brullo, De Marco, Dinelli, Signorello & Spampinato, 1992																						
imperatosum cylindricae new subass. (holosintypus n. 32)																						
Rel. (n)	**90**	**77**	**73**	**1**	**15**	**67**	**70**	**11**	**85**	**93**	**8**	**42**	**18**	**96**	**45**	**19**	**25**	**33**	**32***	**34**		
Exposure	E	N	-	-	-	-	-	-	-	E	E	S	N	-	-	-	SSE	-	-	-		
Slope (degree)	20	25	-	-	-	-	-	-	-	10	15	5	35	-	-	-	8	-	-	-	Freq.	
Area (sqm)	50	80	100	50	50	80	50	30	60	40	20	30	20	80	50	15	40	30	30	40		Pres. class
Coverage (%)	80	70	70	85	75	75	75	75	85	70	60	80	50	80	85	80	90	50	80	80		
Species (n)	10	10	13	14	16	9	14	11	7	10	13	7	7	12	10	8	7	5	7	8		
Charact. and diff. species of ass.																						
Crucianella maritima L.	3.3	3.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	3.3	4.5	5.5	3.3	4.5	5.5	5.5	5.5	3.3	3.4	3.4	20	V
Helichrysum italicum (Roth) Don	+	+	1.2	3.4	2.3	2.2	+.2	2.3	+.2	3.4	1.2	1.2	1.2	3.3	1.2	2.3	1.2	1.2	3.4	3.3	20	V
subsp. *microphyllum* (Willd.) Nyman																						
Diff. species of subass. *imperatosum cylindricae*																						
Imperata cylindrica (L.) Beauv.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2	1.2	2.3	2.3	4.4	4.4	6	II
Charact. and diff. species of upper units																						
Ononis natrix L. subsp. *ramosissima* (I	-	-	+.2	1.2	-	-	+	-	-	1.2	+	-	-	-	-	-	-	-	-	-	5	II
Charact. and diff. species of *Ammophiletea* class																						
Medicago marina L.	-	-	-	+	+.2	-	+	+	-	-	1.1	1.1	1.2	-	+	+	1.2	1.2	2.2	1.2	13	IV
Eryngium maritimum L.	2.2	3.3	1.2	-	+	+.2	1.1	-	+	-	1.1	+	-	-	1.1	-	-	+	-	-	11	III
Pancratium maritimum L.	3.2	2.2	3.3	+	+	1.1	1.1	2.1	1.2	1.1	+	-	-	-	-	-	-	-	-	-	11	III
Cyperus kalli (Forsskal) Murb.	1.3	2.3	2.2	+	1.1	1.1	+	+	-	-	1.1	-	-	-	+	-	-	-	-	-	10	III
Agropyron junceum (L.) Beauv.	3.3	3.4	2.2	2.1	1.1	2.2	2.2	1.2	+.2	1.2	-	-	-	-	-	-	-	-	-	-	10	III
Ammophila littoralis (Beauv.) Rothm.	+.2	-	1.2	+.2	-	-	+.2	-	1.2	-	1.2	+.2	-	-	1.2	-	-	-	-	-	8	III
Echinophora spinosa L.	1.2	1.2	+	1.1	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	6	II
Silene corsica DC	1.2	-	1.2	-	-	-	+.2	+.2	-	1.2	-	-	-	-	-	-	-	-	-	-	5	II
Euphorbia paralias L.	-	+	-	-	-	-	-	-	-	-	1.1	+	-	-	-	-	-	-	-	-	3	I
Calystegia soldanella (L.) R. Br.	-	-	2.2	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	2	I
Other species																						
Lagurus ovatus L.	-	-	-	+	+	-	+	+	-	-	+	+	-	+.2	+	+	+	-	+	+	12	III
Silene colorata Poiret	-	-	-	+	+	+	+	+	-	+	+.2	-	1.1	-	+	+	+	-	-	-	11	III
Lotus cytisoides L.	1.2	1.1	1.2	-	-	1.2	1.2	1.2	1.2	1.2	-	-	-	1.2	-	-	-	-	-	-	9	III
Urospermum dalechampii (L.) Schmid	-	-	-	+	+	-	-	-	-	-	-	-	-		-	+	-	-	-	-	4	I
Pseudorlaya pumila (L.) Grande	-	-	-	+	+	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	4	I
Juniperus turbinata (Guss.) Nym.	-	-	-	-	-	-	-	-	-	-	-	-	+	1.2	-	-	-	-	-	+.2	3	I
Osyris alba L.	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	3	I
Holoschoenus romanus (L.) Fritsch	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	2	I
Aetheorrhiza bulbosa (L.) Cass.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	2	I
Pinus pinea L.	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	2	I
Clematis cirrhosa L.	-	-	-	-	-	-	-	-	-	-	+	-	-	1.2	-	-	-	-	-	-	2	I
Vulpia membranacea (L.) Link	-	-	-	-	-	-	-	-	-	+	-	-	-	1.1	-	-	-	-	-	-	2	I
Accidental species	1	1	1	1	3	-	-	-	-	1	-	-	1	-	1	-	-	-	-	2		

Table 3.7 – Relevés of *Crucianello - Helichrysetum microphylli* and *imperatosum cylindricae* subass. *nova* (holosintypus n° R32) in Capo Comino dunefield. List of accidental species in annex VII.

6) *Sileno nicaensis-Ononidetum variegatae* association

Therophytic meadows (Fig. 3.44) are common as mosaic pattern with *Crucianellion* and *Ammophilion.*
The main species are *Ononis variegata, Silene nicaeenisis, Silene colorata* and *Cutandia maritima*.
They constitute the *Sileno nicaensis-Ononidetum variegatae* association described by Géhu and Biondi (1994) for Corsica coasts.
The last surveys in table 3.8 (rel. 80, 82) show the dominance of *Vulpia membranacea*.
This species is usually present where soil is affected by nitrophyl alteration.
Agropyron junceum, instead, was always present in the relevés and highlights the huge sand transport to inland.

Figure 3.44 – Pictures of *Sileno nicaensis-Ononidetum variegatae* association. *Ononis variegata* with its yellow flowers (up) and *Silene nicaeensis* (left).

Sileno nicaensis-Ononidetum variegatae (Géhu *et al* . 1987) Géhu & Biondi, 1994

Rel. (n)	**81**	**88**	**91**	**92**	**80**	**82**	
Area (sqm)	25	10	40	10	8	30	
Coverage (%)	85	50	50	40	85	85	
Species (n)	10	8	11	10	7	17	Pres.
Charact. and diff. species of ass.							
Ononis variegata L.	4.5	3.4	3.4	3.3	1.1	+	6
Silene nicaeensis All.	-	1.2	+	+	-	+	4
Anthemis maritima L.	-	-	-	-	-	+	1
Charact. and diff. species of upper units							
Silene colorata Poiret	+	+	1.1	-	2.2	1.1	5
Vulpia membranacea (L.) Link	-	1.2	1.1	+.2	3.3	4.4	5
Cutandia maritima (L.) Richter	+.2	2.2	-	-	4.4	+	4
Lagurus ovatus L.	-	-	-	+	1.2	+.2	3
Pseudorlaya pumila (L.) Grande	-	-	1.2	+	-	-	2
Rumex bucephalophorus L.	-	-	+.2	-	-	1.1	2
Bromus rigidus roth subsp. *ambigens* (Jordan) Pign.	-	-	-	-	-	2.2	1
Other species							
Agropyron junceum (L.) Beauv.	1.2	+.2	+.2	+.2	+.2	1.2	6
Medicago marina L.	+	1.2	+	-	+.2	1.2	5
Pancratium maritimum L.	1.1	-	+	+	-	+	4
Lotus cytisoides L.	-	+	1.2	2.2	-	+.2	4
Eryngium maritimum L.	+	-	-	+	-	-	2
Cyperus kalli (Forsskal) Murb.	-	-	-	1.1	-	1.1	2
Silene corsica DC	1.2	-	-	-	-	-	1
Cakile maritima Scop.	+	-	-	-	-	-	1
Echinophora spinosa L.	+	-	-	-	-	-	1
Sporobolus pungens (Schreber) Kunth	-	-	+	-	-	-	1
Rhagadiolus stellatus (L.) Willd.	-	-	-	-	-	1.2	1
Crucianella maritima L.	-	-	-	-	-	+.2	1
Helichrysum italicum (Roth) Don subsp. *microphyllum (* Willd.) Nyman	-	-	-	-	-	+.2	1

Table 3.8– Relevés of *Sileno nicaensis-Ononidetum variegatae* association in Capo Comino dunefield.

7) *Oleo sylvestris-Juniperetum turbinatae* association

The most evolved stage of the associations in Capo Comino dunefield is represented by the presence of *Juniperus turbinata, Erica arborea, Arbutus unedo, Pistacia lentiscus, Smilax aspera* and *Rubia peregrina* (Fig. 3.45). Those species are mainly phanerophytes (Fig. 3.46).

Figure 3.45 – *Oleo sylvestris-Juniperetum turbinatae* association in Capo Comino dunefield, central (left) and southern sector (right).

These formations are located on brown dunes, characterized by the presence of soils with a typical brown color. They compose thick formations with usually more than 90% of coverage and they are related to *Oleo sylvestris-Juniperetum turbinatae* association (Tab. 3.9). An impoverish aspect of this association has been found in the southern-central sector of the beach, where sea storms and the erosive process exposed it directly to salt sprays.

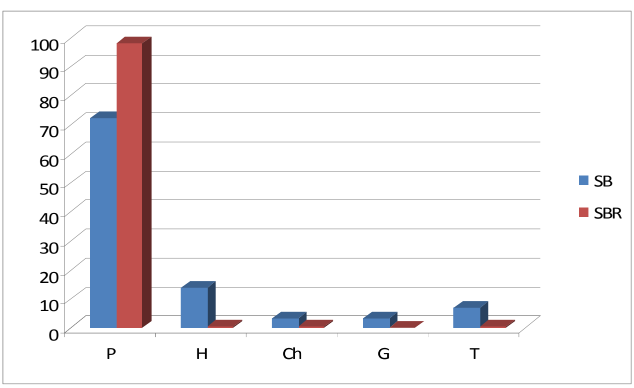


Figure 3.46 – Biological spectrum of *Oleo sylvestris-Juniperetum turbinatae* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Oleo sylvestris-Juniperetum turbinatae
Arrigoni *et al*., 1985 corr. Biondi & Mossa, 1992

Rel. (n)	**2**	**24**	**7**	**60**	**27**	**75**	**89**		
Exposure	-	-	-	-	-	-	-		
Slope (degree)	-	5	-	-	-	-	-		Freq.
Area (sqm)	10	80	60	80	50	50	60	Pres.	class
Coverage (%)	100	100	100	100	95	98	95		
Vegetation height (m)	2.5	6	3	6	5	6	5.5		
Species (n)	5	12	15	17	11	13	13		
Charact. and diff. species of ass.									
Juniperus turbinata (Guss.) Nym.	5.5	5.5	5.5	5.5	5.5	5.5	5.5	7	V
Olea europaea L. var. *sylvestris*	-	+	-	-	-	-	+	2	II
Charact. and diff. species of upper units									
Rubia peregrina L.	2.1	1.2	1.2	1.2	1.2	1.2	2.2	7	V
Pistacia lentiscus L.	+	-	1.1	2.3	1.2	1.2	1.2	6	V
Asparagus acutifolius L.	-	+.2	1.1	1.1	1.1	+.2	1.1	6	V
Arbutus unedo L.	-	2.2	1.2	1.2	1.2	1.1	-	5	IV
Quercus ilex L.	+	+	+.2	-	-	+	-	4	III
Smilax aspera L.	-	-	1.2	2.2	-	1.1	2.2	4	III
Ruscus aculeatus L.	-	-	1.1	1.2	+.2	-	-	3	III
Clematis cirrhosa L.	-	-	+.2	-	-	1.2	1.2	3	III
Erica arborea L.	-	1.2	-	+	-	-	-	2	II
Myrtus communis L.	-	+	-	+.2	-	-	-	2	II
Phillyrea angustifolia L.	-	-	+	1.2	-	-	-	2	II
Rhamnus alaternus L.	-	-	-	-	-	+.2	2.3	2	II
Carex distachya Desf.	-	-	+.2	-	-	-	-	1	I
Other species									
Lagurus ovatus L.	+	+	+	-	-	+	+	5	IV
Daphne gnidium L.	-	+	-	-	+	+.2	+	4	III
Oryzopsis miliacea (L.) Asch. et Sch.	-	+.2	+	+.2	-	-	-	3	III
Halimium halimifolium (L.) Willk.	-	-	-	1.2	+	+	-	3	III
Cistus albidus L.	-	-	-	+	1.1	-	+.2	3	III
Osyris alba L.	-	-	-	1.2	+	-	+	3	III
Calicotome villosa (Poiret) Link	-	+	-	+	-	-	-	2	II
Cistus salvifolius L.	-	-	-	-	-	+.2	+	2	II
Lavandula stoechas L.	-	-	-	+	-	-	-	1	I
Brachypodium ramosum (L.) R. et S.	-	-	+.2	-	-	-	-	1	I
Nerium oleander L.	-	1.1	-	-	-	-	-	1	I
Lobularia maritima (L.) Desv.	-	-	+	-	-	-	-	1	I
Cyperus kalli (Forsskal) Murb.	-	-	-	1.2	-	-	-	1	I
Ononis reclinata L.	-	-	-	-	+	-	-	1	I

Table 3.9 – Relevés of *Oleo sylvestris-Juniperetum turbinatae* association in Capo Comino dunefield.

8) *Pistacio lentisci-Calicotometum villosae* and *Erico-Arbutetum* associations

Shrubs of *Pistacia lentiscus* and *Calicotome villosa* are dynamically related to *Oleo-Juniperetum* and they represent a less evolved stage.
The dynamic link with *Oleo-Juniperetum* is highlight by the presence of *Juniperus t*. in the floristic list of the association *Pistacio lentisci-Calicotometum villosae* (Tab. 3.10). This association was first described by Biondi *et al.* (2001) for Nurra region (N-Sardinia). *Erica arborea* and *Arbutus unedo* often become dominant species and the vegetation shows an arboreal structure. These phytocenosis (rel. 39 in Tab. 3.10) form the *Erico-Arbutetum* association.
Those two associations are mainly composed by phanerophytic species (Figs. 3.47 and 3.48).

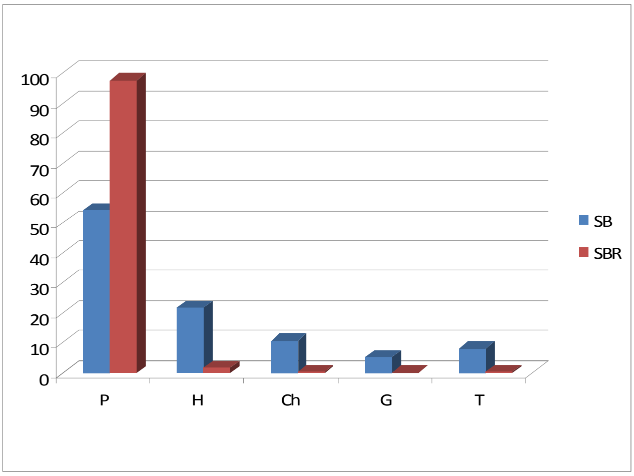


Figure 3.47 – Biological spectrum of *Pistacio lentisci-Calicotometum villosae* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

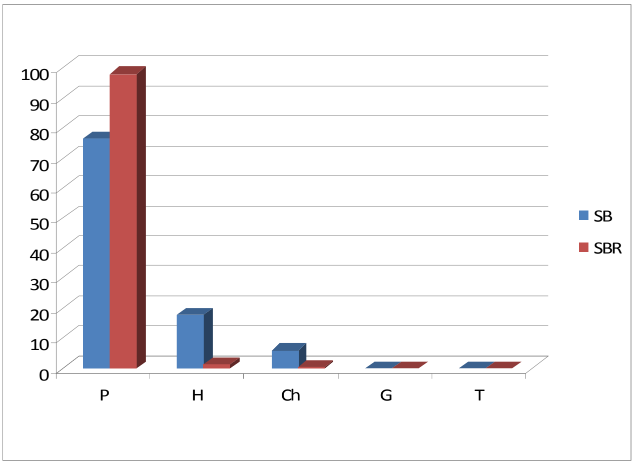


Figure 3.48 – Biological spectrum of *Erico-Arbutetum* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Erico-Arbutetum unedonis Molinier, 1937
Pistacio lentisci-Calicotometum villosae Biondi, Filigheddu & Farris, 2001

Rel. (n)	**39**	**23**	**36**	**3**	**29**	**86**	
Exposure	-	S	-	S	-	-	
Slope (degree)	-	15	-	10	-	-	
Area (sqm)	40	50	30	40	50	40	Pres.
Coverage (%)	100	100	100	100	100	100	
Vegetation height (m)	2	1.7	1.7	1.5	1.6	1.5	
Species (n)	17	13	16	13	15	6	
Charact. and diff. species of ass. *Erico-Arbutetum*							
Arbutus unedo L.	4.4	+.2	-	+	-	-	3
Erica arborea L.	2.2	+.2	-	-	-	-	2
Charact. and diff. species of ass. *Pistacio-Calicotometum*							
Pistacia lentiscus L.	1.2	3.3	4.4	5.5	4.4	5.5	6
Calicotome villosa (Poiret) Link	+	3.3	-	-	2.3	+	4
Charact. and diff. species of upper units							
Juniperus turbinata (Guss.) Nym.	+.2	+	1.2	1.1	2.3	+	6
Rubia peregrina L.	1.2	1.2	2.2	2.2	+	-	5
Asparagus acutifolius L.	1.1	1.1	1.1	1.1	1.1	-	5
Daphne gnidium L.	+	1.2	+	1.2	1.2	-	5
Myrtus communis L.	1.2	1.2	2.3	-	-	-	3
Phillyrea angustifolia L.	2.3	2.2	3.3	-	-	-	3
Clematis cirrhosa L.	-	-	1.2	2.3	-	2.3	3
Carex distachya Desf.	-	-	1.2	-	1.2	-	2
Quercus ilex L.	-	-	-	1.1	+	-	2
Smilax aspera L.	+.2	-	-	-	-	-	1
Olea europaea L.	-	-	-	-	+	-	1
Other species							
Halimium halimifolium (L.) Willk.	+	+	-	1.2	-	-	3
Oryzopsis miliacea (L.) Asch. et Sch.	-	-	+.2	+.2	+.2	-	3
Cistus albidus L.	-	-	+.2	+	-	-	2
Brachypodium ramosum (L.) R. et S.	+	+.2	-	-	-	-	2
Helichrysum italicum (Roth) Don subsp. *microphyllum* (Willd.) Nyman	+	-	-	+	-	-	2
Accidental species	3	1	5	1	5	2	

Table 3.10– Relevés of *Pistacio lentisci-Calicotometum villosae* and *Erico-Arbutetum* associations in Capo Comino dunefield. List of accidental species in annex VII.

9) *Cisto salvifolii-Halimietum halimifolii* association

The presence of species belonging to *Cistaceae* Family represents a degraded stage of the previous associations. This situation is mainly related to sectors affected by fires and the main actual species are *Halimion halimifolium*, *Cistus salvifolius*, *Cistus albidus*, *Cistus monspeliensis* and *Lavandula stoechas* (Fig. 3.49).
They form the *Cisto salvifolii-Halimietum halimifolii* (Tab. 3.11) association, described by Géhu and Biondi (1994a), maily composed by phanerophytes (Fig. 3.50).

Figure 3.49 – Pictures of *Cisto salvifolii-Halimietum halimifolii* association.

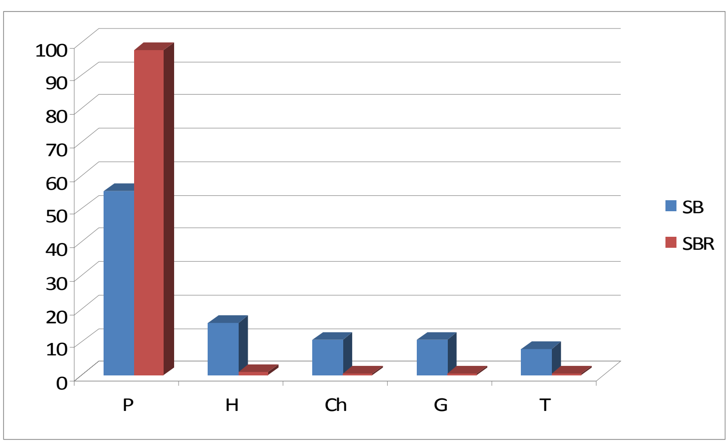


Figure 3.50 – Biological spectrum of *Cisto salvifolii-Halimietum halimifolii* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Cisto salvifolii-Halimietum halimifolii Géhu & Biondi, 1994

Rel. (n)	**4**	**100**	**85**	**87**	**41**	**6**	**101**	**21**	**22**	**17**		
Area (sqm)	45	60	50	80	50	35	70	30	50	40		Freq.
Coverage (%)	100	100	98	97	100	100	90	100	100	100	Pres.	class
Vegetation height (m)	1.5	1.6	1.6	1.5	1.6	1.5	1.5	1.6	1.5	1.5		
Species (n)	17	15	8	11	10	17	10	16	15	13		
Charact. and diff. species of ass.												
Halimium halimifolium (L.) Willk.	3.3	4.4	4.4	5.5	5.5	1.2	4.5	5.5	1.2	1.2	10	V
Cistus salvifolius L.	+.2	+	+.2	2.3	+	4.4	2.3	2.3	5.5	5.5	10	V
Charact. and diff. species of upper units												
Daphne gnidium L.	-	+.2	-	-	1.1	1.1	1.2	+	2.2	1.1	7	IV
Cistus albidus L.	-	1.2	1.2	-	-	+	-	+	+.2	+	6	III
Helichrysum italicum (Roth) Don subsp. *microphyllum* (Willd.) Nyman	-	-	+.2	+.2	-	-	+	+.2	+.2	+.2	6	III
Dorycnium pentaphyllum Scop. subsp. *suffruticosum* (Vill.) Rouy	-	-	-	+	-	+	-	-	-	+	3	II
Osyris alba L.	1.2	-	-	-	-	-	-	-	-	-	1	I
Cistus monspeliensis L.	-	-	-	-	-	2.3	-	-	-	-	1	I
Lavandula stoechas L.	-	-	-	-	-	-	-	-	-	+.2	1	I
Other species												
Juniperus turbinata (Guss.) Nym.	+.2	1.2	-	1.1	1.1	+.2	1.2	+	+	+	9	V
Clematis cirrhosa L.	1.2	1.1	3.3	2.3	-	1.1	1.2	+.2	+	-	8	IV
Calicotome villosa (Poiret) Link	2.2	3.3	-	-	-	3.3	3.3	1.2	2.2	+	7	IV
Rubia peregrina L.	2.2	1.2	1.2	2.2	2.2	1.2	-	1.2	-	-	7	IV
Pistacia lentiscus L.	2.3	+.2	1.2	-	-	+	-	1.2	1.2	-	6	III
Asparagus acutifolius L.	1.1	1.1	-	-	1.2	1.1	1.1	-	+	-	6	III
Inula viscosa (L.) Aiton	-	-	-	-	-	1.2	-	+	1.2	+	4	II
Daucus carota L. subsp. *maximus* (Desf.) Ba	-	+	-	-	-	+.2	-	+	+	-	4	II
Schoenus nigricans L.	-	-	-	-	-	-	-	+.2	+	1.2	3	II
Juncus maritimus Lam.	-	-	-	-	+	-	-	+.2	+.2	-	3	II
Lagurus ovatus L.	-	+	-	-	+	+	-	-	-	-	2	I
Arbutus unedo L.	1.2	-	-	1.2	-	-	-	-	-	-	2	I
Myrtus communis L.	+	1.2	-	-	-	-	-	-	-	-	2	I
Briza minor L.	2.2	+	-	-	-	-	-	-	-	-	2	I
Quercus ilex L.	+	-	-	-	-	+	-	-	-	-	2	I
Nerium oleander L.	-	-	-	-	-	-	-	1.1	2.2	-	2	I
Crucianella maritima L.	-	-	-	+.2	+	-	-	-	-	-	2	I
Accidental species	2	1	1	2	1	1	2	-	-	2		

Table 3.11 – Relevés of *Cisto salvifolii-Halimietum halimifolii* association in Capo Comino dunefield. List of accidental species in annex VII.

10) *Imperato cylindricae-Schoenetum nigricantis* association

The association *Imperato cylindricae-Schoenetum nigricantis* (Tab. 3.12) is composed by hygrophilic species, such as *Imperata cylindrica, Schoenus nigricans, Juncus maritimus, Juncus acutus*, and by heliophilic pioneer species of *Quercetalia ilicis* association (Arrigoni, 1996).
Imperata c. and *Schoenus n.* are the dominant species and they form thick vegetation. They have been used by Arrigoni (1996) for the definition of *Imperato–Schoenetum* association.
This association is located in the interdunal areas, where the water table can reach the soil surface and form low-deep pools, fed by rains too. Moreover rainwater flows from the top of the dune and bring sediments to the lower pools. Usually sediments are fine and they are mixed with the organic matter coming from the vegetal decomposition. This placer mining process induces the slow droop and the compaction of the soil. Silt and clay may accumulate and, subsequently, the water table has more possibility to go up due to the capillarity. However the water table is characterized by the infiltration of salt water and it is salty. Its saltiness is strictly related to seasonal variability; during winter rains are heavy but during summer - when no rains occur and there is a huge evaporation – the water is salty.
After several decades, humid habitats form between dune ridges and they distinguish themselves from the surrounding environments (Figs. 3.51 and 3.52).

Figure 3.51 – *Imperato cylindricae-Schoenetum nigricantis* association close to Capo Comino beach.

A new sub-association - *nerietosum oleandri* - has been described in Capo Comino area, characterized by *Nerium oleander.* This association is mainly present in those sectors where the soil surface is characterized by outcrops.


Figure 3.52 – Pictures of *Imperato cylindricae-Schoenetum nigricantis* association in inner sectors.

The floristic biological spectrum shows the distribution in each type of biological form. The vegetation biological spectrum, instead, emphasizes the dominance of hemicryptophytes and geophytes (Fig. 3.53).

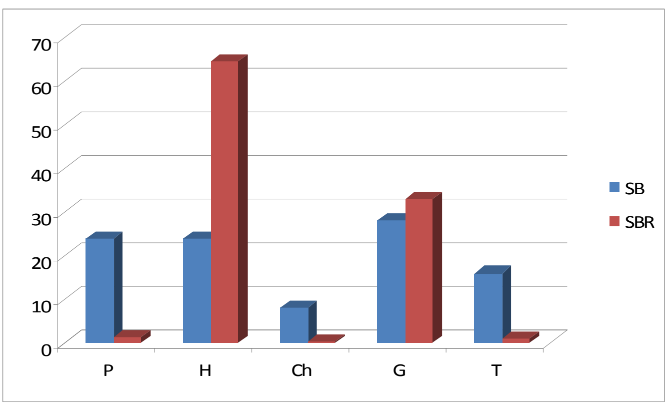


Figure 3.53 – Biological spectrum of *Imperato cylindricae-Schoenetum nigricantis* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Imperato cylindricae-Schoenetum nigricantis Arrigoni, 1996
nerietosum oleandri new subass. (holosintypus n 104)

Rel. (n)	**16**	**20**	**104***	**105**	**106**	**109**	**107**	**37**		
Area (sqm)	100	80	60	50	100	80	50	50		Freq.
Coverage (%)	95	98	100	100	95	100	80	95	Pres.	class
Species (n)	13	7	12	13	11	11	5	10		
Charact. and diff. species of ass.										
Imperata cylindrica (L.) Beauv.	3.4	3.4	2.3	3.3	4.4	3.4	1.2	3.3	8	V
Schoenus nigricans L.	5.5	5.5	5.5	5.5	5.5	5.5	4.4	3.3	8	V
Diff. species of subass. *nerietosum oleandri*										
Nerium oleander L.	1.1	1.1	+.2	1.1	+	-	-	-	5	IV
Vitex agnus-castus L.	-	-	1.1	-	+	-	-	-	2	II
Charact. and diff. species of upper units										
Juncus maritimus Lam.	+.2	+	2.2	2.2	2.2	1.1	1.2	2.3	8	V
Holoschoenus romanus (L.) Fritsch	1.2	1.2	+.2	1.2	1.2	1.2	+.2	+	8	V
Centaurium tenuiflorum (Hoffmgg. et Link) Frit	-	-	-	+	+	+	-	-	3	II
Limonium virgatum (Willd.) Fourr.	+	-	-	-	-	-	-	1.2	2	II
Juncus articulatus L.	-	-	+.2	-	-	-	-	-	1	I
Inula crithmoides L.	-	-	-	-	-	-	-	1.1	1	I
Other species										
Inula viscosa (L.) Aiton	-	2.2	1.2	2.2	1.1	1.2	1.2	1.1	7	V
Blackstonia perfoliata (L.) Hudson	1.1	+	+	+	+	+	-	-	6	IV
Gnaphalium luteo-album L.	-	-	+	+	+	+	-	-	4	III
Agrostis stolonifera L.	-	-	1.2	2.3	1.2	+.2	-	-	4	III
Daucus carota L. subsp. *maximus* (Desf.) Ball	1.1	-	-	+	-	+	-	-	3	II
Plantago coronopus L.	+	-	-	-	-	-	-	1.2	2	II
Pistacia lentiscus L.	+	-	-	-	-	+	-	-	2	II
Lotus tenuis W. et K.	-	-	+.2	+.2	-	-	-	-	2	II
Juniperus turbinata (Guss.) Nym.	+	-	-	-	-	-	-	-	1	I
Erica arborea L.	+	-	-	-	-	-	-	-	1	I
Spiranthes spiralis (L.) Koch	1.1	-	-	-	-	-	-	-	1	I
Sporobolus pungens (Schreber) Kunth	-	-	-	-	-	-	-	+.2	1	I
Medicago marina L.	-	-	-	-	-	-	-	+	1	I
Rubus ulmifolius Schott	-	-	+.2	-	-	-	-	-	1	I
Typha angustifolia L.	-	-	-	1.1	-	-	-	-	1	I

Table 3.12 – Relevés of *Imperato cylindricae-Schoenetum nigricantis* association in Capo Comino dunefield.

Retrodunal areas

Retrodunal areas are characterized by a stream (*Rio Locontenu*) which flows in the southern sector of the study area, a central salt marsh (*Salinedda*) and a bigger and perennial salt marsh (*Salina*) in the northern sector of the study area. So hygrophilic phytocenosis can develop in those sectors and they are mainly represented by annual halophytes, perennial hemicryptophytes and chamaephytes.
These phytocenosis are common in other sectors of Sardinia and Corsica, and in Mediterranean coasts (Arrigoni, 1996; Biondi *et al.*, 2001; Biondi *et al.*, 2004; Biondi, 1992; Géhu et al., 1984; Géhu & Biondi, 1994; Vagge and Biondi, 1999).

1) <u>Annual halophilic vegetation</u>

Several annual pioneer species colonizing dry soils during the summer (during winter these soils are submerged by water) have been found at the banks of salt marshes and between the perennial halophilic vegetation. In particular, *Salicornia patula* and *Suaeda maritima* have been found in the study area and they constitute the *Suaedo maritimae-Salicornietum patulae* association (Tab. 3.13). This is a therophytic association (Fig. 3.54).

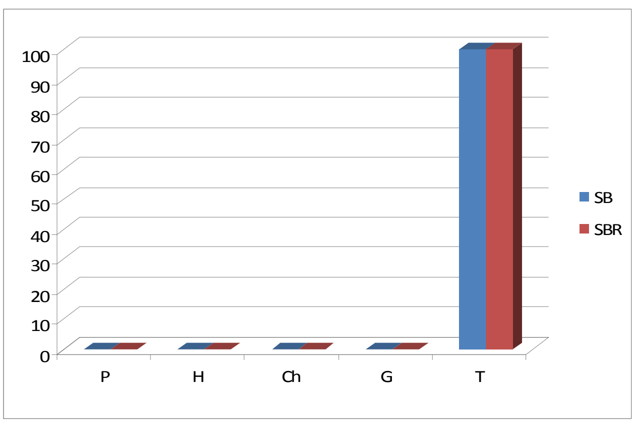


Figure 3.54 – Biological spectrum of *Suaedo maritimae-Salicornietum patulae* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

These communities have been mainly found on higher soils compared to other annual species so on substrates drying faster than the surrounding ones and usually more salted (Biondi *et al*., 2001 Biondi *et al*., 2004; Biondi, 1992).

Suaedo maritimae-Salicornietum patulae

(Brullo & Furnari, 1976) Gèhu & Géhu-Franck, 1984

Rel. (n)	**63**
Area (sqm)	10
Coverage (%)	80
Species (n)	3
Charact. and diff. species of ass.	
Salicornia patula Duval-Jouve	4.4
Suaeda maritima (L.) Dumort.	1.2
Charact. and diff. species of upper units	
Salsola soda L.	+

Table 3.13 – Relevés of *Suaedo maritimae-Salicornietum patulae* association in Capo Comino retrodunal areas.

Salsoletum sodae is a therophytic association (Fig. 3.55) found in Capo Comino area. It is a paucispecific association (Tab. 3.14) that develops in contact with chamaephytic halophilic associations. They are mainly located on organic soils periodically submerged by water.

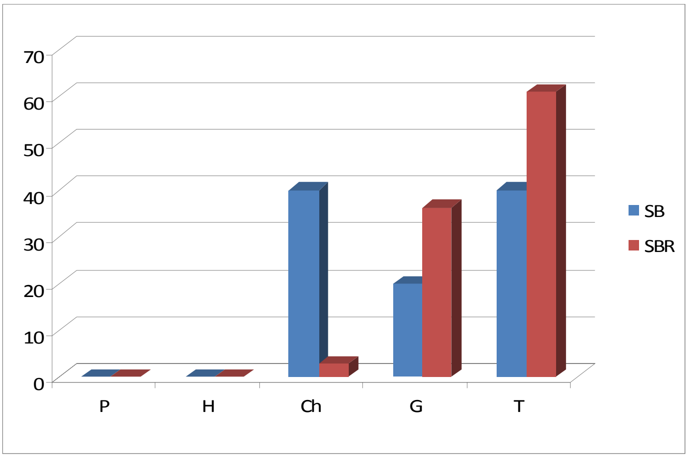


Figure 3.55 – Biological spectrum of *Salsoletum sodae* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Salsoletum sodae Pignatti, 1953

Rel. (n)	**50**
Area (sqm)	10
Coverage (%)	85
Species (n)	5
Charact. and diff. species of ass. and upper units	
Salsola soda L.	4.4
Other species	
Agropyron repens (L.) Beauv.	3.3
Arthrocnemum fruticosum (L.) Moq.	1.2
Aster squamatus (Sprengel) Hieron.	+
Halimione portulacoides (L.) Aellen	+.2

Table 3.14 – Relevés of *Salsoletum sodae* association in Capo Comino retrodunal areas.

The *Salicornietum emerici* association (Tab. 3.15), instead, has been found in the salt marshes of La Caletta and it is probably present in Capo Comino too. The biological spectrum shows the dominance of therophytic species (Fig. 3.56).
This association is characterized by annual monospecific species, developing on substrates submerged by sea water and partially humid during summer (Biondi *et al.*, 2001). They are usually in contact with the chamaephytic formations of *Arthrocnemum macrostachion*.

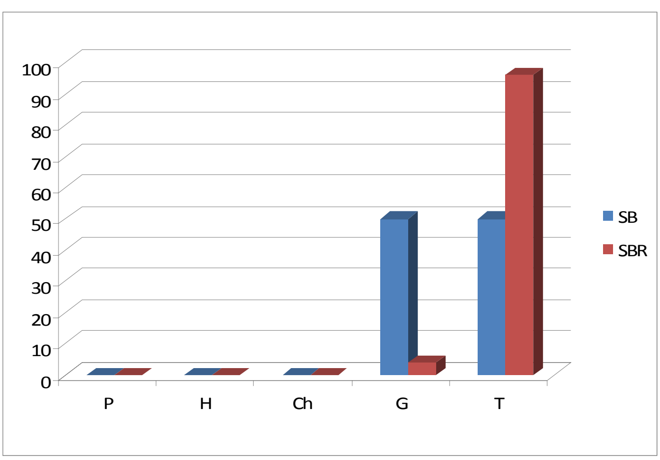


Figure 3.56 – Biological spectrum of *Salicornietum emerici* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Salicornietum emerici (O.de Vòlos, 1962)

Brullo & Furnari, 1976

Rel. (n)	**64**
Area (sqm)	20
Coverage (%)	80
Species (n)	5
Charact. and diff. species of ass. and upper units	
Salicornia emerici Duval-Jouve	4.5
Other species	
Bolboschoenus maritimus (L.) Palla	1.2

Table 3.15 – Relevés of *Salicornietum emerici* association in Capo Comino retrodunal areas.

2) <u>Perennial geophytes and hemicryptophytes</u>

Several different communities have been found on humid soils, usually submerged by water They may form halophile or halo-tollerant communites depending on the edaphic salt rate. *Scirpo-Juncetum subulati* (Tab. 3.16) is a paucispecific and halophilic association characterized by *Juncus subulatus.* In Capo Comino area it is present the sub-association *sarcocornietosum fruticosae* indicating more saltiness (due to a long dry summer period) and defined by the presence of *Arthrocnemum fruticosum*. It is characterized by geophytic and chamaephytic species (Fig. 3.57).

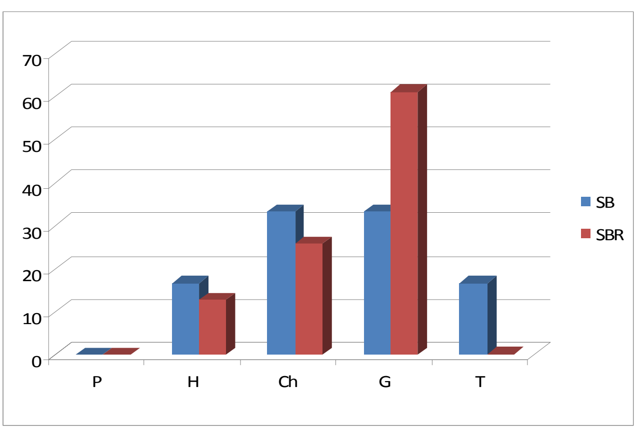


Figure 3.57 – Biological spectrum of *Scirpo-Juncetum* sub-ass. *subulati sarcocornietosum fruticosa; relevés* of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Scirpo-Juncetum subulati Géhu, Biondi, Géhu-Frank & Costa, 1992
sarcocornietum fruticosae Géhu, Biondi, Géhu-Frank & Costa, 1992

Rel. (n)	**49**	**53**	
Area (sqm)	30	30	
Coverage (%)	100	100	
Species (n)	5	4	Pres.
Charact. and diff. species of ass. and upper units			
Juncus subulatus Forsskal	5.5	5.5	2
Diff. species of subass. *sarcocornietum fruticosae*			
Arthrocnemum fruticosum (L.) Moq.	+.2	3.4	2
Other species			
Juncus maritimus Lam.	1.2	+	2
Agropyron elongatum (Host) Beauv.	3.4	-	1
Halimione portulacoides (L.) Aellen	3.4	-	1
Atriplex littoralis L.	-	+.2	1

Table 3.16 – Relevés of *Scirpo-Juncetum subulati* sub-association *sarcocornietosum fruticosa* in Capo Comino retrodunal areas.

Inulo-Juncetum maritimi association (Tab. 3.17) has been found at the banks of the salt marshes on sandy humid substrates. It is characterized by geophytic and chamaephytic species (Fig. 3.58) and this association is usually in contact with surrounding halophilic-chamaephytic associations (these last are located on higher soils).
Inula crithmoides and *Juncus maritimus* are the characteristic and differential species of this association. The *Arthrocnemum fruticosum* variant indicates less humid (or completely dry) stations during summer.

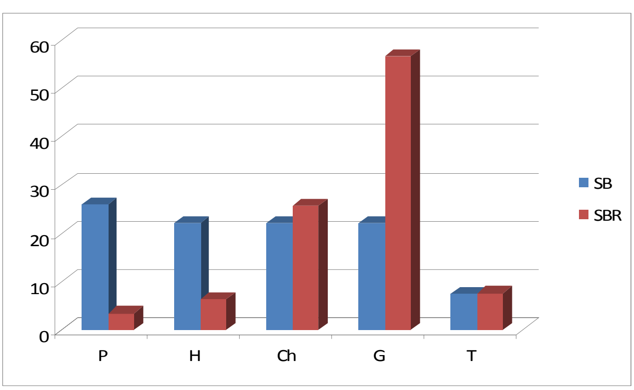


Figure 3.58 – Biological spectrum of *Inulo-Juncetum maritimi* association; *relevés* of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Inulo-Juncetum maritimi Brullo in Brullo, De sanctis, Furnari, Longhitano & Ronsisvalle, 1988

Rel. (n)	**28**	**35**	**103**	**54**	**47**	
Area (sqm)	30	30	30	30	50	
Coverage (%)	100	100	100	100	100	
Vegetation height (m)	1.2	1.3	1.2	1.3	1.2	
Species (n)	10	11	6	8	8	Pres.
Charact. and diff. species of ass.						
Juncus maritimus Lam.	4.4	4.4	3.3	5.5	4.5	5
Inula crithmoides L.	3.4	1.2	+	+	1.2	5
***Arthrocnemum fruticosum* var.**						
Arthrocnemum fruticosum (L.) Moq.	-	-	-	+.2	3.3	2
Charact. and diff. species of upper units						
Aster squamatus (Sprengel) Hieron.	3.3	-	-	1.1	1.2	3
Atriplex littoralis L.	+	-	-	1.2	1.2	3
Halimione portulacoides (L.) Aellen	-	-	-	2.2	4.4	2
Limonium virgatum (Willd.) Fourr.	1.1	-	-	-	-	1
Imperata cylindrica (L.) Beauv.	1.2	-	-	-	-	1
Holoschoenus romanus (L.) Fritsch	-	3.3	-	-	-	1
Arthrocnemum macrostachion (Moric.) Moris	-	-	-	1.2	-	1
Aster tripolium L.	-	-	-	-	2.3	1
Bolboschoenus maritimus (L.) Palla	-	-	-	-	+	1
Other species						
Sporobolus pungens (Schreber) Kunth	+	-	-	+.2	-	2
Daucus carota L. subsp. *maximus* (Desf.) Ball	-	1.2	1.2	-	-	2
Halimium halimifolium (L.) Willk.	2.3	-	-	-	-	1
Agropyron junceum (L.) Beauv.	1.1	-	-	-	-	1
Polygonum maritimum L.	1.1	-	-	-	-	1
Pistacia lentiscus L.	-	+	-	-	-	1
Nerium oleander L.	-	1.1	-	-	-	1
Medicago marina L.	-	+	-	-	-	1
Rubia peregrina L.	-	1.2	-	-	-	1
Daphne gnidium L.	-	+	-	-	-	1
Clematis flammula L.	-	+.2	-	-	-	1
Helichrysum italicum (Roth) Don subsp. *microphyllum* (Willd.) Nyman	-	+	-	-	-	1
Inula viscosa (L.) Aiton	-	-	2.2	-	-	1
Gomphocarpus fruticosus (L.) Aiton fil.	-	-	+	-	-	1
Lotus tenuis W. et K.	-	-	+	-	-	1

Table 3.17 – Relevés of *Inulo-Juncetum maritimi* association in Capo Comino retrodunal areas.

Juncus acutus is in contact with the previous association but usually on higher and dry substrates (Fig. 3.59). It characterizes the *Limonio virgati-Juncetum acuti* association (Tab. 3.18). The characteristic species are hemicryptophytes (Fig. 3.60).

Figure 3.59 – Picture of *Salinedda* banks in the central retrodunal area (2009).

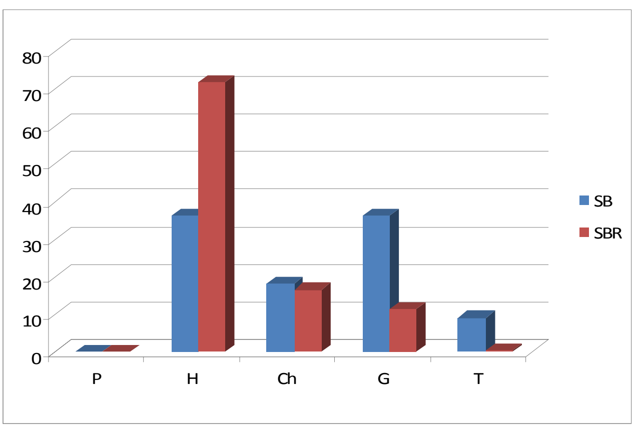


Figure 3.60 – Biological spectrum of *Limonio virgati-Juncetum acuti* association; *relevés* of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Arrigoni (1996) described the sporadic presence of *Holoschoenetum romani* association; it was found on compact substrates, characterized by humid soils and full of carbonates. This association has not been described in the vegetation relevés of this research.

Limonio virgati-Juncetum acuti

Brullo & Di Martino ex Brullo & Furnari, 1976

Rel. n.	**48**
Area sqm	40
Coverage %	100
Species n.	10
Charact. and diff. species of ass.	
Juncus acutus L.	4.5
Limonium virgatum (Willd.) Fourr.	1.2
Charact. and diff. species of upper units	
Agropyron elongatum (Host) Beauv.	4.4
Juncus maritimus Lam.	1.2
Inula crithmoides L.	2.3
Halimione portulacoides (L.) Aellen	2.2
Aster tripolium L.	1.2
Agropyron repens (L.) Beauv.	1.2
Other species	
Sporobolus pungens (Schreber) Kunth	2.3
Lagurus ovatus L.	+
Aetheorrhiza bulbosa (L.) Cass.	+

Table 3.18 – Relevé of *Limonio virgati-Juncetum acuti* association in Capo Comino retrodunal areas.

Sometimes species such as *Spartina juncea*, *Juncus acutus*, *Juncus maritimus* and *Schoenus nigricans* have been also found close to salt marshes on humid and compact substrates, rich of silt and clay. These soils are usually submerged by the river (Fig. 3.61).

Spartina juncea is a Grhiz and it has Mediterranean and Atlantic distribution (Fig. 3.62). It was first described in Sardinia by Valsecchi (1962) but it is considered a quite rare species.

The species found in Capo Comino area are characteristic of the thermophytic *Junco maritimi-Spartinetum juncei* association (Tab. 3.19). This association has been described in S'Ena Arrubia marsh (Filigheddu *et al*., 2000).

Figure 3.61 – Pictures of *Salinedda*'s river mouth and inner banks.

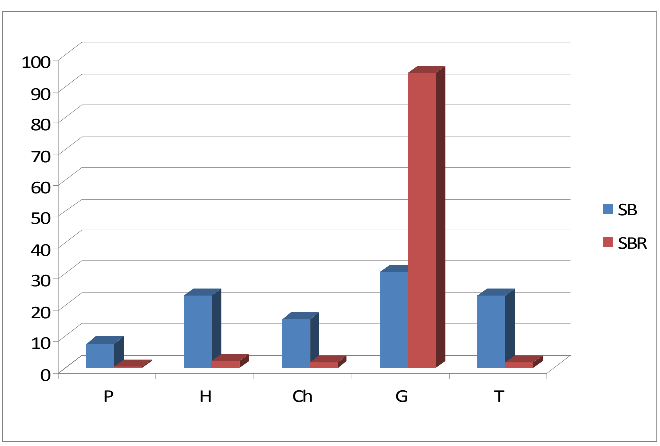


Figure 3.62 – Biological spectrum of *Junco maritimi-Spartinetum juncei* association; *relevés* of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Junco maritimi-Spartinetum junceae O. de Bolos, 1962

Rel. (n)	**59**	**46**	
Area (sqm)	50	30	
Coverage (%)	100	100	
Species (n)	6	10	Pres.
Charact. and diff. species of ass.			
Spartina juncea (Michx.) Willd.	5.5	5.5	2
Juncus maritimus Lam.	1.2	1.2	2
Charact. and diff.species of upper units			
Juncus acutus L.	+	+.2	2
Schoenus nigricans L.	1.2	-	1
Inula crithmoides L.	-	1.2	1
Aster squamatus (Sprengel) Hieron.	-	1.2	1
Halimione portulacoides (L.) Aellen	-	+	1
Atriplex littoralis L.	-	+	1
Aster tripolium L.	-	+	1
Other species			
Phragmites australis (Cav.) Trin.	+	-	1
Pistacia lentiscus L.	+	-	1
Sporobolus pungens (Schreber) Kunth	-	+.2	1
Salsola soda L.	-	+	1

Table 3.19 – Relevés of *Junco maritimi-Spartinetum junceae* association in Capo Comino retrodunal areas.

3) Perennial chamaephytic vegetation

Perennial halophilic associations are present on the banks of salt marshes. They are usually in contact with halophilic herbaceous formations - annual and perennial – and they are distributed following the saltiness rate (Biondi *et al.*, 2001; Biondi and Zuccarello, 2000; Andreucci *et al.*, 1998).
In Capo Comino area, and in most part of the Sardinian coasts, the formation characterized by *Arthrocnemum fruticosum* is present and it colonizes the middle-lower layers of salt marshes. These areas are submerged during summer too.
The association is *Puccinellio festuciformis-Sarcocornietum fruticosae* (Tab. 3.20) and it is composed by hemicryptophytic, chamaephytic and geophytic species.
Furthermore, the sub-association *juncetosum subulati* has been found in low dips usually submerged during winter but dry during summer.
The main species is *Arthrocnemum fruticosum*, succulent chamaephytic species (Fig. 3.63).

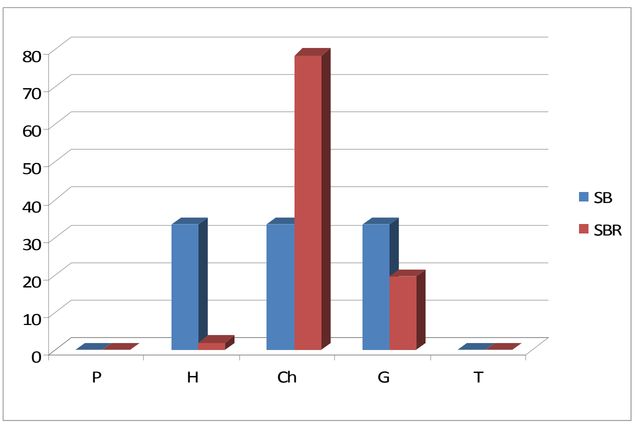


Figure 3.63 – Biological spectrum of *Puccinellio festuciformis-Sarcocornietum fruticosae* sub-association *juncetosum subulati*; *relevés* of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Puccinellio festuciformis-Sarcocornietum fruticosae [Br.-Bl. (1928) 1952] Géhu,1976
juncetosum subulati Géhu & Biondi, 1994

Rel. (n)	**55**	**51**	
Area (sqm)	15	30	
Coverage (%)	70	90	
Species (n)	5	7	Pres.
Charact. and diff. species of ass.			
Arthrocnemum fruticosum (L.) Moq.	4.4	5.5	2
Charact. and diff. species of subass. *juncetosum subulati*			
Juncus subulatus Forsskal	-	+.2	1
Charact. and diff. species of upper units			
Juncus acutus L.	1.2	+	2
Halimione portulacoides (L.) Aellen	+	1.2	2
Limonium virgatum (Willd.) Fourr.	+	-	1
Agropyron elongatum (Host) Beauv.	-	+	1
Juncus maritimus Lam.	-	+	1
Arthrocnemum macrostachion (Moric.) Moris	-	+	1
Other species			
Sporobolus pungens (Schreber) Kunth	3.3	-	1

Table 3.20 – Relevés of *Puccinellio festuciformis-Sarcocornietum fruticosae* sub-association *juncetosum subulati* in Capo Comino retrodunal areas.

Two chamaephytic halophilic associations have been found in La Caletta marshes and they probably should be in Capo Comino too. The first one is characterized by *Arthrocnemum macrostachion* and colonizes the middle-high salt dips (dry during summer). Its association is *Puccinellio convolutae-Arthrocnemetum macrostachyi* (Tab. 3.21).

The second one shows a lower halophylia (higher position compared to the previous one) and it is characterized by *Halimione portulacoides.* Its association is *Puccinellio festuciformis-Halimionetum portulacoidis* (Tab. 3.21).

The main species of these associations are *Arthrocnemum fruticosum* and *A. macrostachion,* two succulent chamaephytes (Fig. 3.64 and 3.65).

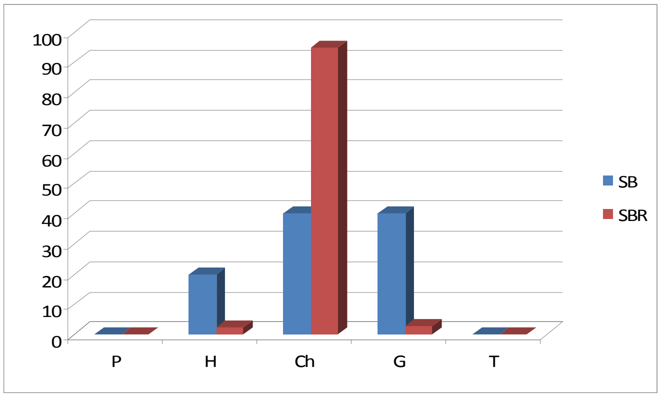


Figure 3.64 – Biological spectrum of *Puccinellio convolutae-Arthrocnemetum macrostachyi* association; *relevés* of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

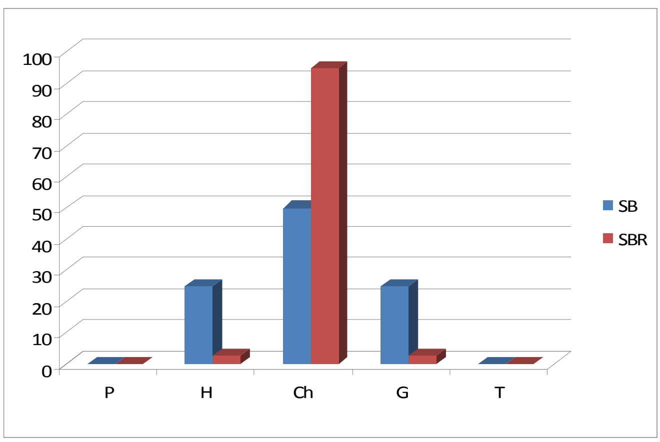


Figure 3.65 – Biological spectrum of *Puccinellio festuciformis-Halimionetum portulacoidis* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Puccinellio convolutae-Arthrocnemetum macrostachyi
[Br.-Bl. (1928) 1933] Géhu ex Gèhu, Costa, Scoppola, Biondi, Marchiori, Peris, Géhu-Franck, Caniglia & Veri 1984
Puccinellio festuciformis-Halimionetum portlacoidis
Gèhu, Biondi, Géhu-Franck & Costa 1992

Rel. (n)	**65**	**66**	
Area (sqm)	30	20	
Coverage (%)	100	100	
Species (n)	5	4	Pres.
Charact. and diff. species of *Puccinellio-Arthrocnemetum macrostachyi*			
Arthrocnemum macrostachion (Moric.) Moris	5.5	-	1
Charact. and diff. species of *Puccinellio-Halimionetum portlacoidis*			
Halimione portulacoides (L.) Aellen	2.2	5.5	2
Charact. and diff. species of upper units			
Limonium narbonens Miller	1.2	1.2	2
Other species			
Juncus subulatus Forsskal	1.2	1.2	1
Juncus maritimus Lam.	+	-	1
Inula crithmoides L.	-	+	1

Table 3.21 – Relevés of *Puccinellio convolutae-Arthrocnemetum macrostachyi* and *Puccinellio festuciformis-Halimionetum portulacoidis* in Capo Comino retrodunal areas.

4) Other types of vegetation

In the southern sector of the dunefield, close to Rio Locontenu river mouth, a thick population of *Phragmites australis* var. *maxima* is present (Fig. 3.66). This species is 5-6 meters high and it is surrounded by *Juncus maritimus*, *Bolboschoenus maritimus, Schoenus nigricans, Holoschoenus romanus, Agrostis stolonifera* and several other species.
This phytocenosis has very similar ecological, floristic and station conditions to Valencia coasts where *Typho angustifoliae-Phragmithetum maximi* association has been first described (Costa *et al.*, 1986).
This association has been found in Capo Comino too (Tab. 3.22) and it is mainly composed by geophytic species (Fig. 3.67).

Figure 3.66 – Pictures of *Rio Locontenu*. The river mouth and its vegetation.

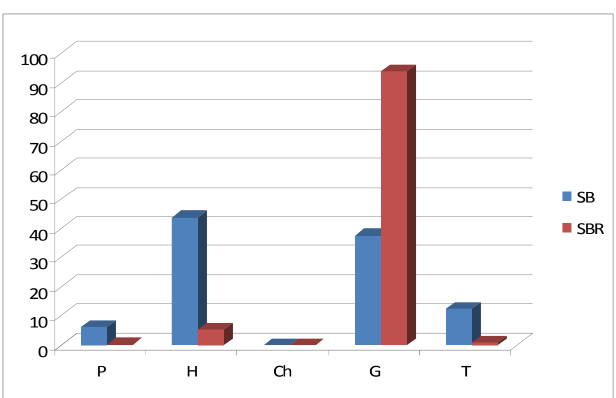


Figure 3.67 – Biological spectrum of *Typho angustifoliae-Phragmithetum maximi* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Typho angustifoliae-Phragmithetum maximi Costa, Boira, Peris & Stubing, 1986

Rel. (n)	**57**	**102**	**61**	
Area (sqm)	40	40	40	
Coverage (%)	100	100	100	
Vegetation height (m)	4.5	5	5	
Species (n)	11	7	10	Pres.
Charact. and diff. species of ass.				
Phragmites australis (Cav.) Trin. var. *maxima*	5.5	5.5	5.5	3
Typha angustifolia L.	-	+.2	-	1
Charact. and diff. species of upper units				
Juncus maritimus Lam.	4.5	2.2	2.3	3
Bolboschoenus maritimus (L.) Palla	1.2	+	3.3	3
Schoenus nigricans L.	2.3	+	+	3
Holoschoenus romanus (L.) Fritsch	+.2	-	+	2
Aster squamatus (Sprengel) Hieron.	-	-	+	1
Juncus acutus L.	-	-	+	1
Agropyron pungens (Pers.) R. et S.	-	-	1.2	1
Other species				
Agrostis stolonifera L.	+.2	+.2	1.2	3
Inula viscosa (L.) Aiton	+.2	+	-	2
Plantago lanceolata L.	+	-	-	1
Sonchus maritimus L.	+	-	-	1
Dorycnium rectum (L.) Ser.	+	-	-	1
Fallopia convolvulus (L.) Holub	1.2	-	-	1
Vitex agnus-castus L.	-	-	+	1

Table 3.22 – Relevés of *Typho angustifoliae-Phragmithetum maximi* association in Capo Comino retrodunal areas.

A shrub phytocenosis has been found close to the *Typho-Phragmithetum* association. It is characterized by hygrophilic species, mainly phanerophytic (Fig. 3.68), such as *Vitex agnus-castus, Myrtus communis* and *Rubus ulmifolius.* Herbaceous species are present too, such as *Holoschoenus romanus, Phragmites australis, Juncus maritimus* and *Agrostis stolonifera.*
These species compose the *Rubo ulmifolii-Viticetum agni-casti* association (Tab. 3.23), first described by Paradis (2006).
This association is present at the base of the precipitation ridges (landward edge of dunefield) and the beginning of the cultivated and uncultivated fields (Fig. 3.69).

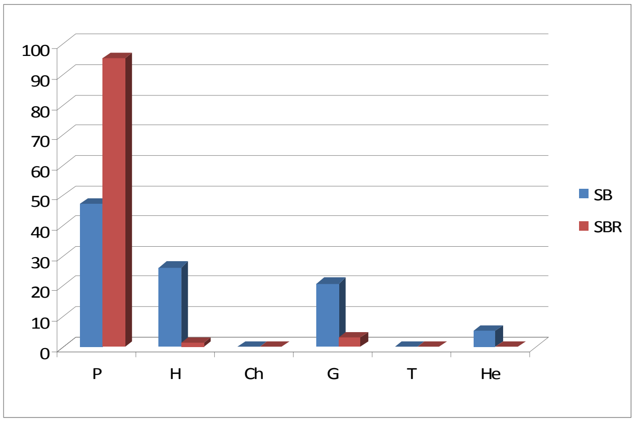


Figure 3.68 – Biological spectrum of *Rubo ulmifolii-Viticetum agni-casti* association; relevés of Capo Comino area (SB: floristic biological spectrum; SBR: vegetation biological spectrum).

Figure 3.69 – Retrodunal area at the base of the precipitation ridge.

Rubo ulmifolii-Viticetum agni-casti Paradis 2006

Rel. (n)	**31**	**40**	**76**	**62**	
Area (sqm)	40	80	8	40	
Coverage (%)	100	100	100	100	
Vegetation height (m)	1.6	1.7	2.5	1.6	
Species (n)	12	14	8	12	Pres.
Charact. and diff. species of ass. and upper units					
Vitex agnus-castus L.	3.3	5.5	5.5	5.5	4
Rubus ulmifolius Schott	4.4	4.4	1.1	3.4	4
Other species					
Myrtus communis L.	3.3	3.3	2.2	4.4	4
Holoschoenus romanus (L.) Fritsch	+	+	+.2	2.2	4
Smilax aspera L.	1.3	+.2	-	4.5	3
Inula viscosa (L.) Aiton	1.3	+	-	-	2
Daucus carota L. subsp. *maximus* (Desf.) Ball	+	+	-	-	2
Rubia peregrina L.	+	2.2	-	-	2
Clematis cirrhosa L.	+	+	-	-	2
Asparagus acutifolius L.	+	-	-	+	2
Pistacia lentiscus L.	-	1.2	+.2	-	2
Juncus maritimus Lam.	-	+	-	+	2
Gomphocarpus fruticosus (L.) Aiton fil.	-	+	-	+	2
Osyris alba L.	1.2	-	-	-	1
Oryzopsis miliacea (L.) Asch. et Sch.	1.2	-	-	-	1
Phillyrea angustifolia L.	-	+	-	-	1
Juniperus turbinata (Guss.) Nym.	-	+	-	-	1
Clematis flammula L.	-	-	-	+.2	1
Phragmites australis (Cav.) Trin.	-	-	-	1.2	1
Agrostis stolonifera L.	-	-	-	1.2	1
Cistus salvifolius L.	-	-	-	+	1
Cyperus longus L.	-	-	1.2	-	1
Matricaria chamomilla L.	-	-	+	-	1
Potentilla reptans L.	-	-	+	-	1

Table 3.23 – Relevés of *Rubo ulmifolii-Viticetum agni-casti* association in Capo Comino retrodunal areas.

Cultivated and uncultivated fields are located between the salt marshes. They are the substitution of the potential *Quercus ilex* forest.

The progressive neglect of the fields is due to the sand burial (Fig. 3.70). Few years ago these fields have still been cultivated but now the most part of them (in particular those that are closer to the dunefield) are abandoned.

The sand is transported from the dunes to inland by blowing winds, and it is consequent upon the natural migration of the dunefield.

The uncultivated fields are colonized by annual herbaceous species (Fig. 3.71).

The main species of the fields are *Matricaria chamomilla, Lolium temulentum, Cynosurus echinatus, Coleostephus myconis, Bromus hordeaceus* and *Bromus gussonei*.

These fields are periodically mown at the beginning of the summer.

Figure 3.70– Picture of an uncultivated field. Grasses has been mown down. A lot of blown sand is present on the soil.

Figure 3.71 – Picture of an uncultivated field in the retrodunal areas.

b) Ecological considerations about vegetation associations

The distribution of vegetal associations is strictly related to their ecological needs and their ecology is well represented by Ellenberg's ecograms.
The analysis of the ecograms for each vegetation association is a proper representation of the characteristic of the different life forms.
The climatic factors are not influential on the vegetation ecograms because we are considering a small scale of analysis (a dunefield) and the associations live in the same environment. So, continentality, temperature, light present almost the same values for each association.
The edaphic conditions, instead, are the most important factors influencing the ecological values of the associations because they are related to their position in the study area.
As an example, concerning the associations present on the dunefield (Figs. 3.72 and 3.73), SK, Sa, SE and SA ecograms show the highest tolerance to saltiness. In fact, these associations have been mainly found on the first dune ridges close to the shoreline where salt sprays influence the vegetation survival.
Species forming SK association need a lot of nutrients. In fact, they colonize the upper beach where the organic matter - coming from the sea during storms - has been decomposed in the sandy substrate.
The remaining associations present a very low halo-tolerance. In fact, they have been found far from the shoreline where dune ridges are characterized by "gray" or "brown" soils.
IS ecogram is the only one that presents a high value of humidity. In fact, the vegetation of the dunefield is characteristic of dry environments. Species of IS association, instead, are typical of humid environments and they have been found in the interdunal low dips, close to the water table.
PH values (R index) are mainly acid for the inland associations, only IS has a basic one's. The associations of the first foredune ridges present neutral values (in fact, soils are not present there, only incoherent sand is present!).

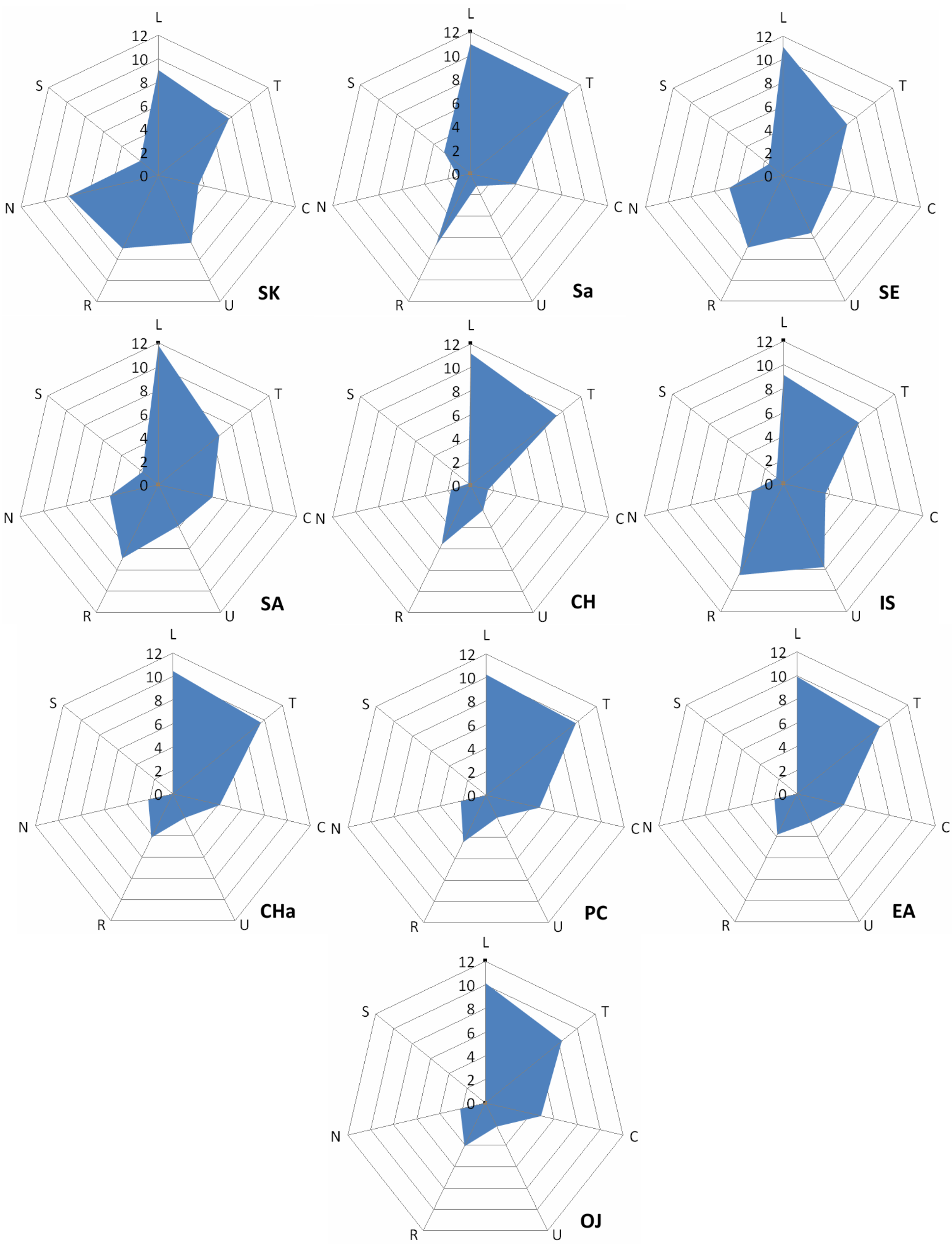


Figure 3.72 – Ecograms of the vegetation associations of the dunefield.
(SK: *Salsolo kali-Cakiletum maritimae*; Sa: *Sporoboletum arenarii elymetosum farcti*; SE: *Sileno corsicae-Elytrigetum junceae*; SA; *Sileno corsicae-Ammophiletum arundinaceae*; CH: *Crucianello-Helychrysetum microphylli*; IS: *Imperato cylindricae-Schoeneto nigricantis*; CHa: *Cisto salvifolii-Halimietum halimifolii*; PC: *Pistacio lentisci-Calicotometum villosae*; EA: *Erico-Arbutetum unedonis*; OJ: *Oleo sylvestris-Juniperetum turbinatae*).

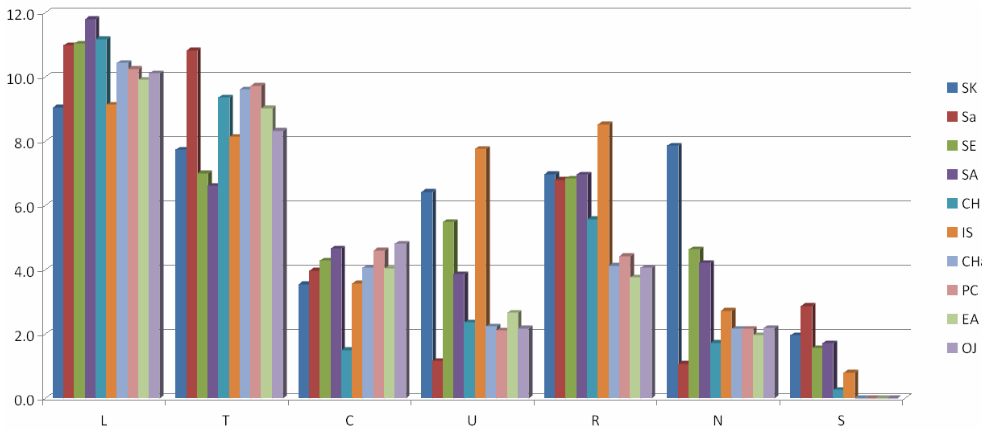


Figure 3.73 – Comparison between Ellenberg's indexes for each vegetation association of the dunefield.

With regard to the retrodunal vegetation associations (Figs. 3.74 and 3.75), the most part of the associations presents a strong resistance to the saltiness and high values of humidity. Indeed, the main environments of retrodunal areas are represented by salt marshes (*Salinedda* and *Salina*) and river banks.

It's important to note the high values of N of the annual halophilic associations and the presence of a favorable acid-neutral soil.

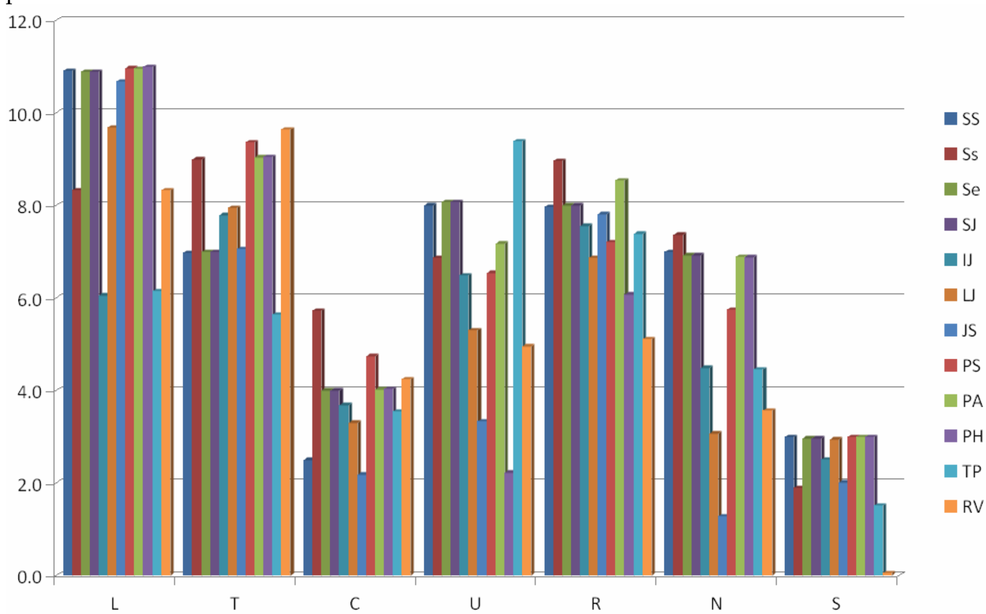


Figure 3.74 – Comparison between Ellenberg's indexes for each vegetation association of retrodunal areas.

(SS: *Suaedo maritimae-Salicornietum patulae*; Ss: *Salsoletum sodae*; Se: *Salicornietum emerici*; SJ: *Scirpo-Juncetum subulati*; IJ: *Inulo-Juncetum maritimi*; LJ: *Limonio virgati-Juncetum acuti*; JS: *Junco maritimi-Spartinetum junceae*; PS: *Puccinellio festuciformis-Sarcocornietum fruticosae*; PA: *Puccinellio convolutae-Arthrocnemetum macrostachyi*; PH: *Puccinellio festuciformis-Halimionetum portlacoidis*; TP: *Typho angustifoliae-Phragmithetum maximi*; RV: *Rubo ulmifolii-Viticetum agni-casti*).

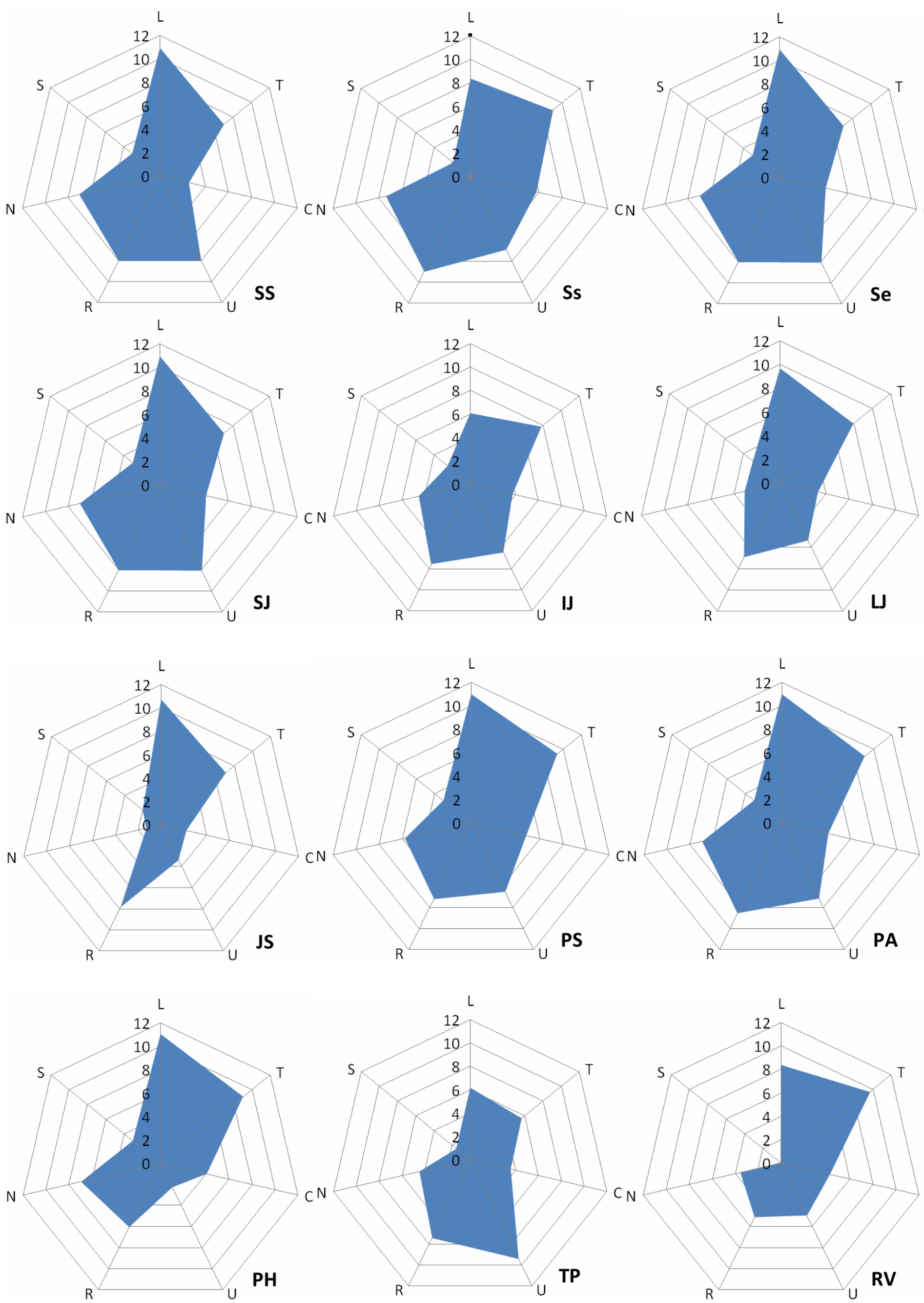


Figure 3.75 – Ecograms of the vegetation associations of the retrodunal areas (the acronyms are explained in Fig. 3.74).

c) <u>Vegetation map</u>

The description of the vegetation association of the dunefield and the analysis of a Digital Terrain Model (1 meter resolution, by courtesy of Regione Sardegna) allowed the compilation of the vegetation map of Capo Comino dunefield.
This represents an indispensable tool for the ecological study of the landscape.
The vegetation map shows the extent and the spatial patterns of the actual vegetation types. They have been identified considering their homogeneous specific composition at the scale of the map.
A geographical information system by ESRI (ARCGis 9.3) gave the technical support to its creation and a specific legend has been designed in order to consider all the vegetation association of the dunefield.
The parcels describing the coverage and the fragmentation of the vegetation associations can be measured (area, perimeter, area/perimeter rate, etc). So it is possible to give information about the habitats, their distribution, their qualities and conservation.
Furthermore the vegetation map is a basic tool in order to define the edges of the sectors that should be subjected to specific management. As an example, it is possible to immediately define the distribution of those habitats that have been included in the Habitat Directive (92/43/CEE) and to plan monitoring and management actions in order to protect their biodiversity.
Figure 3.76 highlights the influence of the local morphologies on the vegetation association and the complexity of their distribution, in particular in those sectors where the transition between the foredunes and the transgressive complex is present.
In general, associations of embryo and white dunes of the foredune complex are distributed along prevailing onshore wind direction (winds blowing from the 1st quadrant). In several sectors SiEl and – especially – SiAm associations disappear and CrHe association is present in the first dune ridge, directly facing to the seashore. Most of those associations result deconstructed and highly buried. Sometimes they are completely overlaid by new embryo dunes' associations.
The erosive forms, such as blowouts, are very frequent on the foredunes. They characterize nude soils (SAND) where the sedimentary transport has been reactivated and the vegetation associations have been disappeared.
In the inner foredunes, instead, the presence of shrub and arboreal associations is sometimes interrupted by anthropic paths.
Concerning the inner sectors, mainly related to the dynamic of the transgressive complex and the evolution of parabolic dunes, the vegetation is distributed in a specific model (see following paragraph) but it is interrupted by paths and roads.
The presence of a lot of *Pinus* plants has to related to the reforestation actions occurred in the last century ('50).
PiCa maquis – usually present after fires - is located close to the main roads and in the outer sectors of the dunefield (especially close to the river mouth).
The anthropic influence is surely a stressful factor of the natural environment. As an example, paths often develop out of the main tracks following the easiest way across the dune and they produce some preferential "ways" where the blowing sand may be transported to inland.

The associations and groupings presented in figure 3.76 are listed below:

Salsolo kali-Cakiletum maritimae (SaCa)
Sporopoletum arenarii (SpAr)
Sileno corsicae-Elytrigetum junceae (SiEl)
Sileno corsicae-Ammophiletum arundinaceae (SA)
Crucianello-Helichrysetum microphylli (CrHe)
Crucianello-Helichrysetum microphylli imperatosum cylindricae (CrHeI)
Imperato cylindricae-Schoenetum nigricantis (ImSc)
Pistacio lentisci-Calicotometum villosae (PiCa)
Oleo sylvestris-Juniperetum turbinatae (OlJu)
Sand with Sileno corsicae-Elytrigetum junceae (Sand+SiEl)
Imperata cilindrica population (Im)
Pinus pinea population (Pi)
Halo-hygrophilic phytocenosis (HaHy)

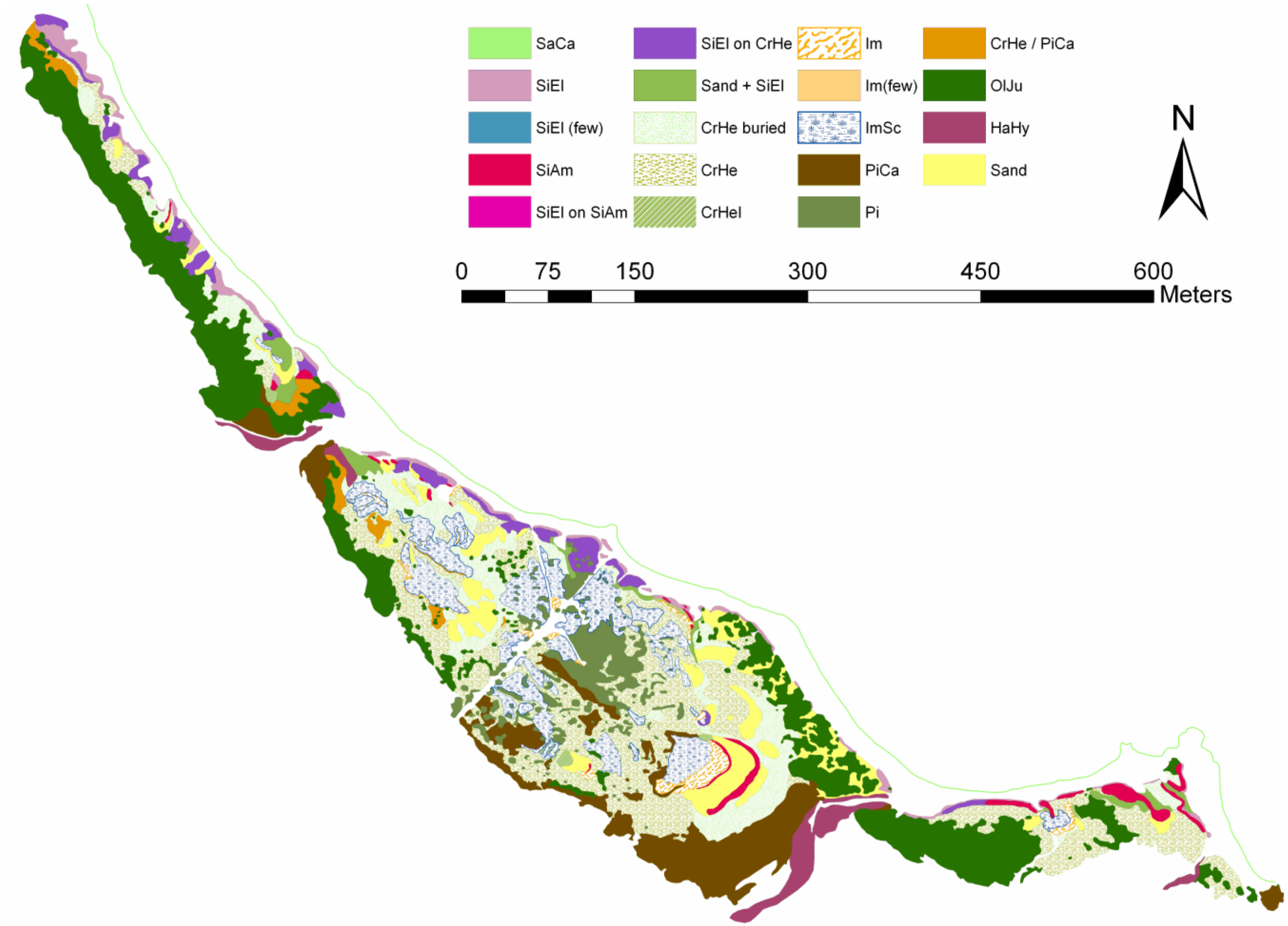


Figure 3.76 – Vegetation map of the Capo Comino dunefield.

d) Models of vegetation distribution on the dunefield

The distribution of vegetal association is related to their position in the dunefield and their dynamic is strictly related to the evolution of the study area.

Even little changes can bring to substantial alterations on the quality and distribution of the phytocenosis. As an example, extreme events – such as floodings and sea storms – can erode the first dune ridges and their phytocenosis. The following reconstructing process brings to a new colonization by pioneer species.

Foredune system is located in the seaward sector and it presents a theoretical profile of vegetation distribution (Fig. 3.77). As already discussed, foredunes are built up at the back of beaches where vegetation or other obstructions trap the blown sand. They become higher and wider as sand accretion continues.

Vegetation plays a dominant role in determining the size, the shape and the stability of foredunes. In fact, the aerial part of the vegetation obstructs the wind and absorbs wind energy so sand transport can be interrupted. Plants continue to grow more rapidly than the rate of deposition and the sand deposition determines the increase of the width and height of the dune.

Vegetation associations are distributed following the ecological valence of the specific species and communities. They distribute starting from halophilic and nitrophilic associations located close to the shoreline and become as less halo-tolerant and more evolved in the inner sectors.

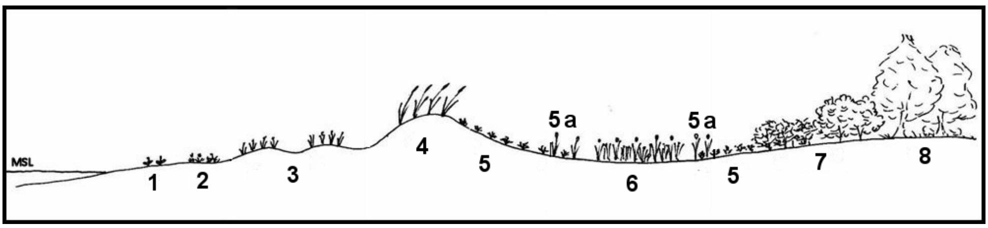


Figure 3.77 – Foredunes profile and distribution of the vegetation associations.
1 *Salsolo kali-Cakiletum maritimae* (SaCa), 2 *Sporopoletum arenarii* (SpAr), 3 *Sileno corsicae-Elytrigetum junceae* (SiEl), 4 *Sileno corsicae-Ammophiletum arundinaceae* (SiAm), 5 *Crucianello-Helichrysetum microphylli* (CrHe), *5a Crucianello-Helichrysetum microphylli imperatosum cylindricae* (CrHeI), 6 *Imperato cylindricae-Schoenetum nigricantis* (ImSc), 7 *Pistacio lentisci-Calicotometum villosae* (PiCa), 8 *Oleo sylvestris-Juniperetum turbinatae* (OlJu).

With regard to the inner transgressive sectors, the vegetation associations are in general distributed following the scheme in figure 3.78. This specific case represents the distribution in a parabolic dune.

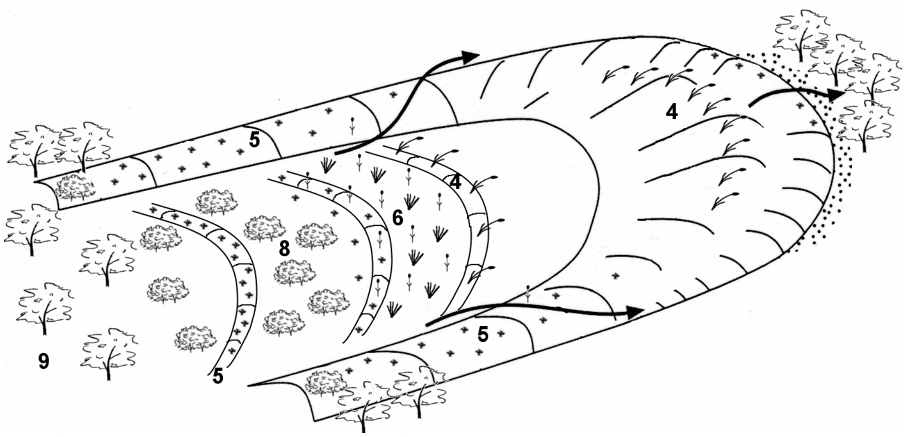


Figure 3.78 - Distribution of the vegetation associations in the inner parabolic dunes.
4 *Sileno corsicae-Ammophiletum arundinaceae* (SiAm), 5 *Crucianello-Helichrysetum microphylli* (CrHe),, 6 *Imperato cylindricae-Schoenetum nigricantis* (ImSc), 8 *Pistacio lentisci-Calicotometum villosae* (PiCa), 9 *Oleo sylvestris-Juniperetum turbinatae* (OlJu).

The profile along the main sedimentary transport (Fig. 3.79) shows the presence of *Sileno – Ammophiletum* association on the top of the depositional lobe (crest of the dune) where sediments are free and incoherent. It is also present at the base of the stoss slope, colonizing the first relict ridge of the deflation basin (Gegenwalle ridge).
Crucianello-Helichrysetum association is distributed on the older Gegenwalle ridges of the deflation basin but also on the lateral trailing ridges (see Fig. 3.78). This association gets rich of *Imperata c*. (forming the new sub-ass. *Crucianello-Helichrysetum microphylli imperatosum cylindricae*) where the garigue is close to dips (slacks).
Slacks are characterized by *Imperato cylindricae-Schoenetum nigricantis* association.

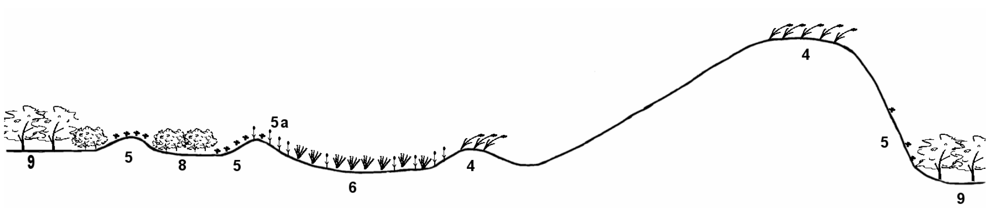


Figure 3.79 - Profile of the vegetation distribution along the prevailing wind direction on parabolic dunes.
4 *Sileno corsicae-Ammophiletum arundinaceae* (SiAm), 5 *Crucianello-Helichrysetum microphylli* (CrHe), 5a *Crucianello-Helichrysetum microphylli imperatosum cylindricae* (CrHeI), 6 *Imperato cylindricae-Schoenetum nigricantis* (ImSc), 8 *Pistacio lentisci-Calicotometum villosae* (PiCa), 9 *Oleo sylvestris-Juniperetum turbinatae* (OlJu).

Several phytocenosis referred to the *Pistacio lentisci-Calicotometum villosae* association are present in the central sector of the transgressive complex. The most evolved communities are represented by *Oleo sylvestris-Juniperetum turbinatae* association.

This type of profile is well recognizable in Capo Comino area. In fact, the morphological and vegetation analysis of two transects localized in the inner sector of the dunefield are presented. They have been examined along the sedimentary transport direction (Fig. 3.80).

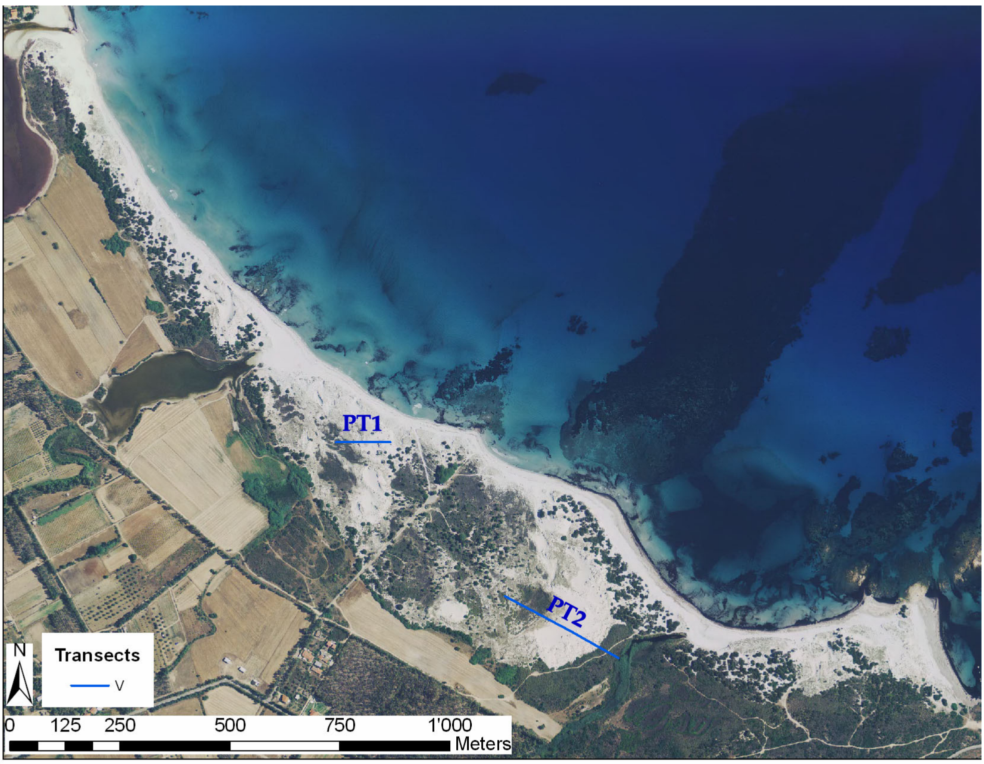


Figure 3.80 – Morphological and vegetation profiles along the direction of sedimentary transport.

PT1 transect is located in the northern-central sector. Its station point is on the crest of a parabolic dune developing from WNW to ESE. This direction is quite anomalous compared to the main migration of the complex but it is related to secondary winds (see §2.3.3 and §3.1.2). Several blowouts are present, mainly oriented NW-SE and W-E and the interpretation of this sector is complicated because of the transition between foredunes and the inner transgressive complex.

PT1 profile (Fig. 3.85) is strongly influenced by foredunes ridges, as demonstrated by the presence of *Agropyron j.* . This species, in fact, is typical of embryo dunes and it is has been found along this transect due to its proximity to the shore. Along PT1, *Agropyron j.* has been found at the base of the stoss slope where the incoherent sand builds up the younger Gegenwalle ridge (Ggw).

The older Gegenwalle ridges are well-recognizable in figure 3.81. They are characterized by *Crucianello-Helichrysetum* association.

Imperato-Schoenetum association is present in low dips between the older Gegenwalle ridges.

Figure 3.81 - Picture and location of PT1 profile (red line).

PT2 profile (Fig. 3.86) is located in the south-central sector, where the maximum rate of transgression was registered (§3.1.2). This sector is characterized by the highest dunes of the area (Fig. 3.82).
PT2 profile is quite similar to PT1 profile but *Agropyron j.* is not present because the line is located too far from the beach. The younger Ggw (Fig. 3.83) is colonized by *Ammophila arenaria* (also present on the dune crest) and the older Ggw ridges present *Imperata c*. and *Crucianello-Helichrysetum* association. The more evolved stages are characterized by *Pistacio-Calicotometum* and *Oleo -Juniperetum* associations. Only few old *Juniperus* trees are present in the central sector. Pines, instead, are abundant.

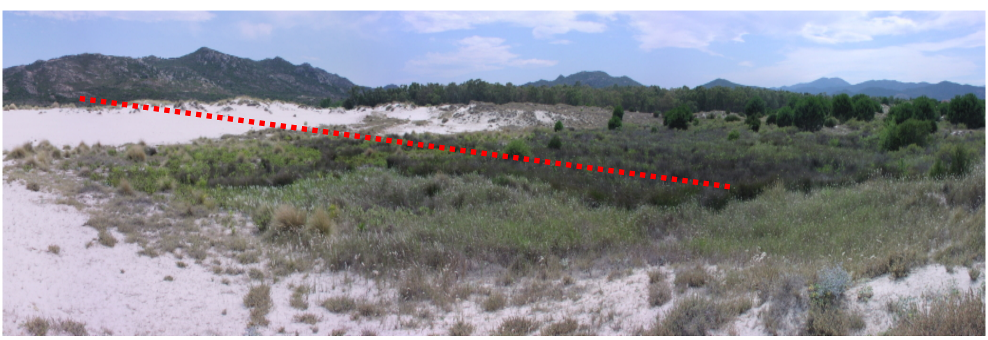


Figure 3.82 - Picture and location of PT2 profile (profile: red line; station points are located at the left side).

In the other side of PT2 transect, going down along the slipface of the dune, *Crucianello-Helichrysetum* association is present at the base of the slope. Then shrubs of CiHa (their presence is characteristic after a bushfire) are located in the flat basin. The mature stage of the succession is represented by the occasional presence of *Oleo-Juniperetum* association (maybe few trees of *Juniperus* survived from the fire). The last association found along the profile – TyPh - is in a catenal succession with the previous ones but it colonizes the river banks (Fig. 3.84).

Figure 3.83 - Picture from the station point (SP2) of PT2 profile. *Ammophila a*. is on the younger Gegenwalle ridge. At the backward, pines are close to the main road.

Figure 3.84 - Picture from the first station point (SP1) of PT2 profile. It's easy to recognize shrubs of CiHa and then phragmites in the backward.

The legend of PT1 and PT2 transects is presented in annex I.

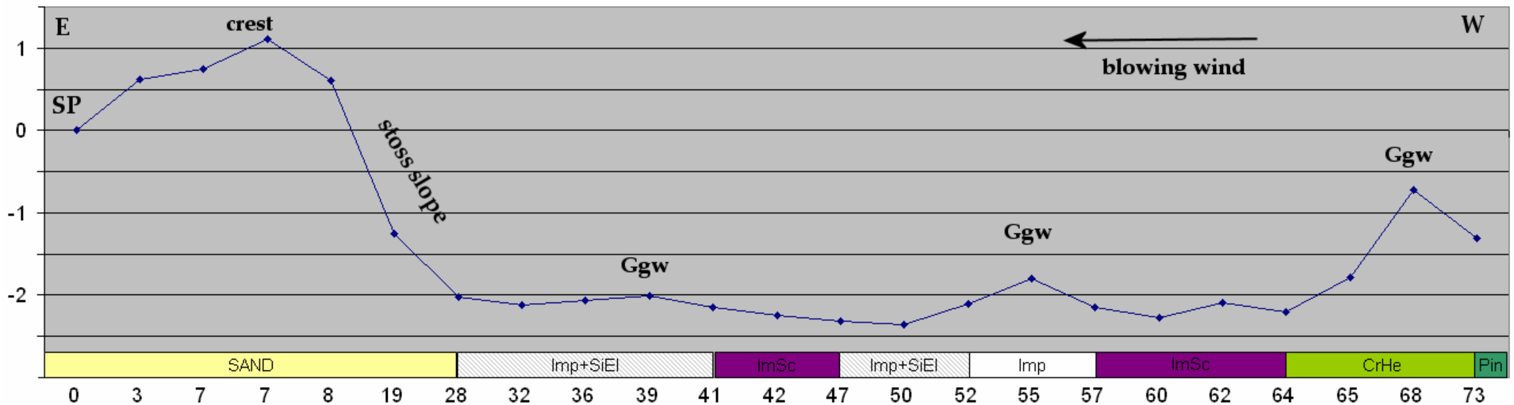


Figure 3.85 – PT1 profile along the sedimentary transport direction (x and y-scale in meters; x-scale is stretched; point 0 is referred to SP).

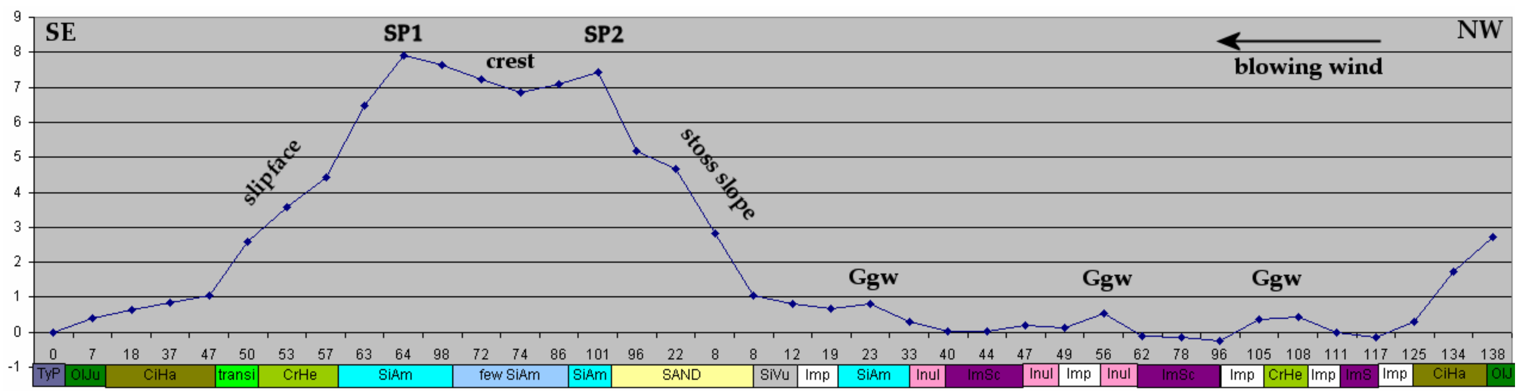


Figure 3.86 – PT2 profile along the sedimentary transport direction (x and y-scale in meters; x-scale is stretched; point 0 is referred to river bank.

e) <u>Syntaxonomic scheme</u>

Vegetation associations are grouped in the syntaxonomic scheme. It refers to papers cited in the previous paragraphs and to papers about the classification of European vegetation (Biondi, 1999; Biondi *et al.*, 2001; Biondi *et al.* 2004; Brullo *et al.*, 2001; Filigheddu *et al*, 2000; Rivas-Martinez *et al.* 2002).
The associations are referred to synthaxa of upper orders (alliances, orders, classes and eventually sub-alliances and sub-orders) and several annotations concerning the ecology integrate the following scheme.

CAKILETEA MARITIMAE Tüxen & Preising ex Br.-Bl. & Tüxen 1952
Therophytic and halo-nitrophilic species. Substrates with a lot of organic matter.
CAKILETALIA INTEGRIFOLIAE Tüxen in Br.-Bl. &Tüxen 1952 corr. Rivas-Martìnez, Costa & Loidi 1992
Annual and halo-nitrophilic species, distributed in Mediterranean, Cantabrian-Atlantic and Pontic areas.
Cakilion maritimae Pignatti 1953
Halo-nitrophilic species of sandy beaches.
Salsolo kali-Cakiletum maritimae Costa & Mansanet 1981 corr. Rivas-Martìnez *et al*. 1992

AMMOPHILETEA AUSTRALIS Br.-Bl. & Tüxen ex Westhoff, Dijk & Passchier 1946
Perennial and pioneer vegetation of coastal sandy dunes with Mediterranean and Mediterranean-atlantic distribution.
AMMOPHILETALIA Br.-Bl. 1933
Herbaceous and perennial vegetation, constituted by hemicryptophytes and geophytes, mainly located on embryo and mobile dunes. Mediterranean distribution.
Ammophilion australis *Br.-Bl. 1921 corr. Rivas-Martínez, Costa & Izco in Rivas-Martínez,* Lousa, T.E. Díaz, Fernández-González & J.C. Costa 1990
Perennial vegetation of embryo and mobile dunes. Mediterranean distribution.
Sporobolo arenarii-Elytrigenion junceae Géhu 1988 corr. Géhu 1996
Sileno corsicae-Elytrigetum junceae (Malcuit 1926) Bartolo, Brullo, De Marco, Dinelli, Signorello & Spampinato 1992 corr. Géhu 1996
Medicagini marini-Ammophilenion australis (Br.-Bl. 1921) Rivas-Martinez & Géhu 1980 em. Géhu & Biondi 1994
Sileno corsicae-Ammophiletum arundinaceae Bartolo, Brullo, De Marco, Dinelli, Signorello & Spampinato 1992
Sporobolion arenarii (Géhu & Géhu-Franck ex Géhu & Biondi 1994) Rivas-Martinez, Fernàndez-Gonzàlez, Loidi, Losa & Penas 2001
Pioneer and perennial species with halo-subnitrophilic preferences. Flat areas with salty or organic substrates.
Sporobolenion arenarii Géhu 1988
Sporoboletum arenarii (Arénes 1924) Géhu & Biondi 1994
elymetosum farcti Géhu & Biondi 1994

HELIANTHEMETEA GUTTATI (Br.-Bl. in Br.-Bl., Roussine & Nègre 1952) Rivas Goday & Rivas-Martinez 1963 em. Rivas-Martinez 1978
Therophytic and thermo-xerophilicspecies.

MALCOLMIETALIA Rivas Goday 1958
Annual psammophile vegetation. Mediterranean and Mediterranean-atlantic distribution.

Alkanno-Maresion nanae Rivas Goday ex Rivas Goday & Rivas-Martinez 1963 corr. Diez-Garretta, Asensi & Gavila 2001
Therophytic and psammophile vegetation. Natural environments.

Sileno nicaensis-Ononidetum variegatae (Géhu et al. 1987) Géhu & Biondi 1994

MOLINIO CAERULEAE-ARRHENATHERETEA ELATIORIS Tüxen 1937
Herbaceous vegetation, perennial and/or hygrophilic species. Deep and steady-humid soils, with periodic floods.

HOLOSCHOENETALIA Br.-Bl. ex Tchou 1948
Hygrophilic herbaceous species on humid soils. Mediterranean distribution.

Molinio-Holoschoenion Br.-Bl. ex Tchou 1948
Thermo and Supra-mediterranean vegetation on very basic and humid soils.

Holoschoenetum romani Br.-Bl. (1931) 1952

PHRAGMITO-MAGNOCARICETEA Klika in Klika & Novàk 1941
Halophilic species, partially submerged in low-deep, stagnant or low-flowing waters.

SCRIPETALIA COMPACTI Hejny in Holub, Hejny, Moravec & Neuhäusl 1967 corr. Rivas-Martìnez, Costa, Castroviejo & E. Valdés 1980
Vegetation mainly constituted by rushes and grasses. Stagnant salt waters.

Scirpion compacti Dahl & Hadac 1941 corr. Rivas-Martìnez, Costa, Castroviejo & E. Valdés 1980
Vegetation mainly constituted by rushes and grasses. Dry substrates during summer.

Scirpo-Juncetum subulati Géhu, Biondi, Géhu-Frank & Costa 1992

sarcocornietum fruticosae Géhu, Biondi, Géhu-Frank & Costa 1992

PHRAGMITETALIA Koch 1926 em. Pignatti 1954
Vegetation mainly composed by grasses.

Phragmition communis Koch 1926
Vegetation mainly composed by high grasses on humid soils.

Typho angustifoliae-Phragmithetum maximi Costa, Boira, Peris & Stubing 1986

JUNCETEA MARITIMI Br.-Bl. in Br.-Bl. & Roussine & Nègre 1952
Salt meadows. Dominance of hemicryptophytes.

JUNCETALIA MARITIMI Br.-Bl. ex Horvatic 1934
Hemicryptophytes in Mediterranean and Med.-Atlantic areas. Humid soils periodically submerged.

Juncion maritimi Br.-Bl. ex Horvatic 1934
Salt meadows and rushes. Humid soils. Mediterranean distribution.

Inulo-Juncetum maritimi Brullo in Brullo, De sanctis, Furnari, Longhitano & Ronsisvalle 1988

Limonio virgati-Juncetum acuti Brullo & Di Martino ex Brullo & Furnari 1976

Junco maritimi-Spartinetum junceae O. de Bolos 1962

Plantaginion crassifoliae Br.-Bl. in Br.-Bl., Roussine & Négre 1958
Vegetation of slacks and lagoons. Sandy/pebbly compact substrates, humid only during winter.
Imperato cylindricae-Schoenetum nigrigantis Arrigoni 1996
nerietosum oleandri subass. nova

SALICORNIETEA FRUTICOSAE Br.-Bl. & Tüxen ex A. & O. Bolòs 1950
Salt substrates., Med.-Atlantic and Saharan-Indian distribution.
SALICORNIETALIA FRUTICOSAE Br.-Bl. 1933
Salt substrates. Dominance of chamaephytes and/or succulent dwarf-phanerophytes. Mediterranean distribution.
Salicornion fruticosae Br.-Bl. 1933
Erect glassworts on higher layer of slacks and lagoons. Humid and fresh soils.
Puccinellio festuciformis-Sarcocornietum fruticosae [Br.-Bl. (1928) 1952] Géhu 1976
juncetosum subulati Géhu & Biondi 1994
Puccinellio festuciformis-Halimionetum portlacoidis Gèhu, Biondi, Géhu-Franck & Costa 1992
Arthrocnemion glauci Rivas-Martìnez & Costa 1984
Highest levels of slacks and lagoons. Dry soils during summer.
Puccinellio convolutae-Arthrocnemetum macrostachyi [Br.-Bl. (1928) 1933] Géhu ex Gèhu, Costa, Scoppola, Biondi, Marchiori, Peris, Géhu-Franck, Caniglia & Veri 1984
THERO-SUADETEA Rivas-Martìnez 1972
Annual glassworts of salt dips. Sandy-clay soils sometimes submerged.
THERO-SALICORNIETALIA Tüxen in Tüxen & Oberdorfer ex Gèhu & Géhu-Franck 1984
Annual glassworts of salt dips. European distribution.
Salicornion patulae Géhu & Géhu-Franck 1984
Annual, halophilic and pioneer glassworts. Mediterranean coasts.
Suaedo maritimae-Salicornietum patulae (Brullo & Furnari 1976) Gèhu & Géhu-Franck 1984
Salicornietum emerici (O. de Vòlos 1962) Brullo & Furnari 1976
THERO-SUADETALIA Br.-Bl. & O. de Bolos 1958
Annual halo-nitrophilic species developing on organic matter coming from the sea and released on the banks of lagoons and salt dips.
Thero-Suaedion Br.-Bl. in Br.-Bl., Roussine & Négre 1958
Salsoletum sodae Pignatti 1953

HELICHRYSO -CRUCIANELLETEA MARITIMAE Gèhu, Rivas-Martìnez & R. Tüxen 1973 in Géhu 1975
Chamaephytic vegetation. Landward side of dunes and on established dune ridges, sub-halophytes of rocky coasts. Mediterranean and Atlantic distribution.
CRUCIANELLETALIA MARITIMAE Sissingh 1974
Chamaephytic vegetation of the inner established/or not dunes. Mediterranean and Atlantic-Cantabrian distribution.
Crucianellion maritimae Rivas-Goday & Rivas-Martìnez 1963
Chamaephytes on fixed dune ridges. W-Mediterranean distribution.

Crucianello-Helichrysetum microphylli Bartolo, Brullo, De Marco, Dinelli, Signorello & Spampinato 1992
imperatosum cylindricae subass. nova

CISTO-LAVANDULETEA Br.-Bl. In Br.-Bl., Molinier & Wagner 1940
Xerophilic and heliophilic species; chamaephytes and dwarf-phanerophytes of garigue. Siliceous and low-evolved soils. Mediterranean distribution.

LAVANDULETALIA STOECHADIS Br.-Bl. In Br.-Bl., Molinier & Wagner 1940 em. Rivas-Martìnez 1968
Chamaephytes and dwarf-phanerophytes of garigue. Central-W Mediterranean distribution.

Coremation albi Rothmaler 1943
[*Stauracantho genistoidis-Halimion halimifolii* Rivas-Martínez 1979 (syntax. syn.)]
Garigue of established dunes and paleo-dunes.

Cisto salvifolii-Halimietum halimifolii Géhu & Biondi 1994

NERIO-TAMARICETEA Br.-Bl. & O. Bolòs 1958
Lake and riparian woods and shrubs. Mediterranean, Saharian-Arabic distribution. Temporally submerged by sea water during high tides.

TAMARICETALIA Br.-Bl. & O. Bolòs 1958 em. Izco, Fernández-González & A. Molina 1984
Arboreal and shrub vegetation. River banks, river mouths and lake basins. Mediterranean coasts.

Rubo ulmifolii-Nerion oleandri O. Bolòs 1985
Shrub vegetation. Pebbly or sandy soils.

Rubo ulmifolii-Viticetum agni-casti Paradis 2006

3.3 MORPHO-SEDIMENTOLOGICAL SURVEYS OF THE NEARSHORE-BEACH SYSTEM

The morphological and sedimentological characteristics of the beach will be analyzed in the following pages. The aim of this literature review is to set the importance of the study of the beach-nearshore system in order to better understand the synergy between this transition environment and the coastal dune environment in term of sediment supply and natural protection.

In the international literature several papers described the importance of the beach-dune interaction and Authors parameterized their models (Sherman and Bauer, 1993, Davidson-Arnott, 2010; Delgado-Fernandez and Davidson-Arnott, 2011).

Several basic concepts are described in the folowing pages, mainly concerning factors that influence coastal modifications and the description of the elements for a beach analysis. These concepts will be useful during the discussion of the results.

3.3.1 Literature review

3.3.1.1 ***Coastline and coastal modifications***

Several Authors approached to the study of coastal processes, considering the most different points of view (e.g. geological and geomorphological approaches, study of the physical processes, landscape planning, etc.). In fact, many factors occur on coasts and on their evolution. Between them, Davies (1972) recognized three broad groups: (i) *physical factors of the lands* - geological structure (plate tectonics, mountain ranges, continental shelf width, relief,..), the local geology (local structures, rocky type) the geomorphic processes (river valleys, deltas, sediment supply) and the isostatic sea level change (tectonic isostacy, glacial isostacy) -, (ii) *physical factors of the sea* - eustatic sea level change (glacial eustacy, geoidal changes), wave climate (water body size, orientation of the coast, wind and storm climatology), tides (tidal range, tidal type, tidal currents), ice effects (shorefast ice, winter ice cover), local erosion and deposition (coastal erosion, transport and deposition processes) – and (iii) *biological effects* (mangroves, salt marshes, coral reefs, sea grass beds, coastal dune vegetation).

In medium/short-term time, modification of the coast takes place through the erosion, transport and deposition of material that is either eroded by waves and currents or brought to the coast, e.g. by rivers or cliffs (Cambers, 1976; Cowell and Thom, 1994; Short, 1999; Bird, 2000; Davidson-Arnott, 2010).

Estimation of long-term sediment transport is often carried out as part of the determination of the littoral sediment budget for a section of coastline. The littoral sediment budget (Fig. 3.87) is an accounting technique in which the volume (or mass) of all sediment inputs and outputs to and from the beach and nearshore zone are assessed for a section or reach of the shoreline (Rosati, 2005).

The main sediment sources to coastal systems are longshore transport into area, input from rivers, wind transport onto beach, erosion of sea cliffs, onshore transport, beach

nourishment and sand from dune erosion. Inputs from rivers are probably the most important source, followed by cliff erosion and by biogenic actions (only in the tropics).
Instead, the main sediment losses from nearshore coastal systems are longshore transport out of area, wind transport away from beach, offshore transport, abrasion and sand mining (Komar, 1998; Short, 1999; Davidson-Arnott, 2010).

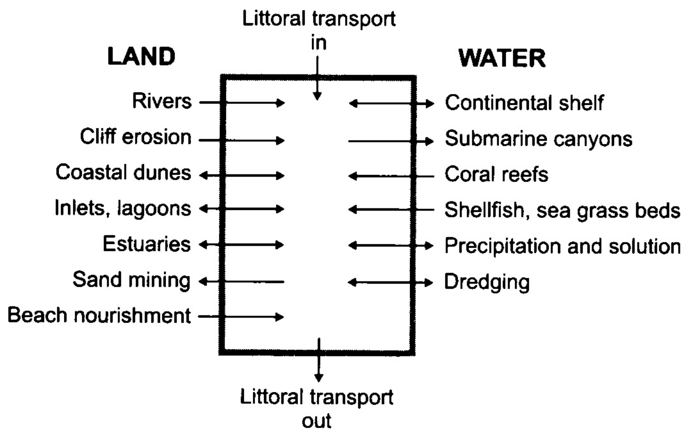


Figure 3.87 - Littoral sediment balance (from Davidson-Arnott, 2010).

The shore parallel boundaries of the area within witch the budget is calculated are usually defined by the landward and the offshore limits of the sediment transport by wave action (called "closure depth") (Hallemeyer, 1981; Komar, 1998; Mangor, 2004; Pranzini, 2004).
Ideally, if the budget along a stretch of coast is positive (inputs exceed outputs), the deposition process prevails against the erosion and the shore could prograde. If the balance is negative, the beach erosion will occur. Nevertheless, quantification of the sediment budget for a stretch of coast is not easy because of the high number of variables to measure or estimate, above all the estimate of sediment inputs. It's very important to take in consideration that estimating methods may occur in subjective errors (of the operators and of the application of the methods) and sometimes is not so possible to compare results achieved from different methods (Pranzini and Wetzel, 2008).

An ideal estimation is done in a section of coast that contains a source (or few sources) of sediment, a well-defined zone of alongshore sediment transport and a downdrift zone where sediment is either deposited or is lost offshore. This sector is normally called "littoral cell" and a related concept is that of the "coastal sediment compartment" (Davies, 1974), which is used on highly embayed coasts. However there can be exchange of sediment between adjacent littoral cells and the boundaries may be quite fuzzy. The identification of cells units and directions of net longshore sediment transport are the starting point for collecting information on inputs and outputs and the determining of a littoral sediment budget. In particular cases (e.g. pocket beaches) large headlands or other "obstacles" are present, confining sediment movement to the area between the headlands and isolating the embayments from the rest of the coast (Yasso, 1965; O'Rourke and Le Blond, 1972; Pranzini, 2004).

Some coastline changes are the result of human activities, such as the commercial demand of big ports or defense structures (e.g. groynes, breakwaters) against the sea ingression. Other important human modifications occurred because of the "land claim" (the making of new ground by enclosing or filling nearshore areas) (French, 1997); several examples between the number of worldwide cases are represented by Monaco and Genova in Europe, Tokyo Bay and Hong Kong in Asia and "Palm Islands" in United Arab Emirates.

Concerning the sediment size, fine sediments (silt and clay size range) generally tend to be placed in suspension and diffuse to the nearshore water column. Then they are settled out of suspension in deep water or brought into estuaries, bays and lagoons where they are deposited in quiet water.

Coarser particles are exchanged between the inner nearshore and surf zones and the beach and transported alongshore in appreciable quantities. Usually the shore normal transport (net transport of sediment onshore or offshore) and the longshore transport of sediment (processes tending to move sediments alongshore) occur simultaneously.

Unidirectional currents in the nearshore and surf zone are generally not strong enough to erode and transport coarse sediments directly (except in few location of the surf zone, e.g. rip channels) and sediments are set in motion by the oscillatory current (associated with waves) and the vortices (associated to wave breaking). The longshore sediment transport in the beach and nearshore zone is instead extremely effective and it results from three sets of processes: (i) beach drifting on the swash slope, driven primarily by oblique wave action; (ii) transport by wave-generated longshore currents; (iii) transport seaward of the breaker zone by wind-driven and tidal currents (Short, 1999; Bird, 2000; Davis and Fitzgerald, 2004).

The direction of the net longshore sediment transport may be manifested from the presence of natural features (like spits, bay mouth barriers and barrier islands) and the interference with this transport is the cause of many human-induced problems involving locally enhanced erosion and sedimentation. Longshore sediment transport is also important in determining local beach sediment budgets and in the definition of littoral cells (Bird, 2000; Pranzini, 2004; Reeve *et al*., 2004).

In order to understand the longshore sediment transport is important to analyze the beach drifting and the surf zone transport. Beach drifting results from wave run-up on the beach foreshore (swash slope) where waves approach at an oblique angle to the local beach orientation. The swash occurs at the angle of wave approach but the return flow is influenced by gravity and tends to return straight down the slope. Sediments are transported in the direction of wave advance in a series of saw tooth motions (Fig. 3.88). The relative volume of sediment moved along the beach varies considerably depending on wave conditions and beach form and the sediment size range (Short, 1999; Davidson-Arnott, 2010).

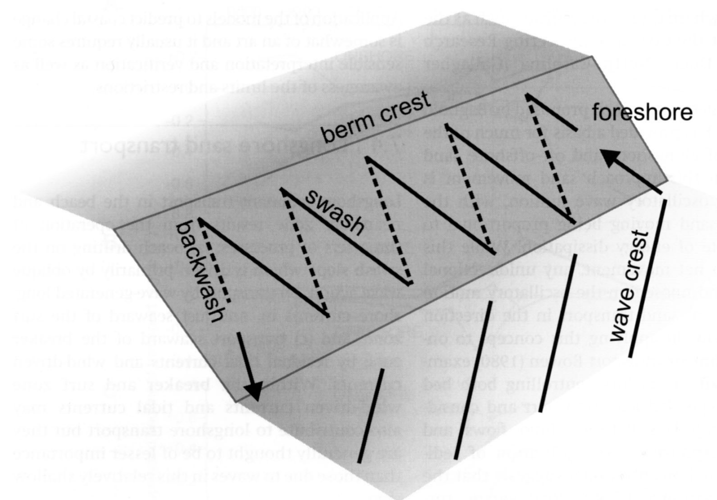


Figure 3.88 – Schematic process of longshore transport (from Davidson-Arnott, 2010).

Sediment is set in motion by the wave oscillatory motion and by turbulent vortices generated by wave breaking and then transported alongshore by longshore currents generated by waves, winds or tides (Transk, 1955; Carter, 1988; Komar, 1998).
Considering the littoral drift system based on wave refraction models and local wave climatic statistics, the magnitude and net direction of transport along the coast could be predict by models (Cowell *et al*., 2003 a, b; Mangor, 2004; Brøker and Mangor, 2006).

3.3.1.2 Beach types

The gradient of the beach and the nearshore is important in influencing both the amount of wave energy reaching the beach and the configuration of the beach itself. The analysis of the characteristics of Australian beaches has led to an important classification of beaches that is now applied worldwide (Wrigth *et al*., 1979; Short, 1999). Anyway, it's important to take in consideration the differences between the oceanic and Mediterranean coasts. In general the main characteristics of these models may be extrapolated.

Considering the model in figure 3.89, the beach may go through different dynamic stages related to specific energy conditions.
There are two end members: "dissipative" and "reflective" beaches. A dissipative beach has a gentle gradient in the shallow subtidal and intertidal areas, where wave energy is gradually dissipated. At the other hand, reflective beaches have relatively steep gradients and a significant amount of energy is reflected back toward open water. The main characteristic is the presence or not of sand bars. Dissipative beaches tend to have multiple bars that cause the wake breaking and the energy dissipation gradually to the shoreline. Intermediate beaches also have nearshore bars but they may low areas that permit

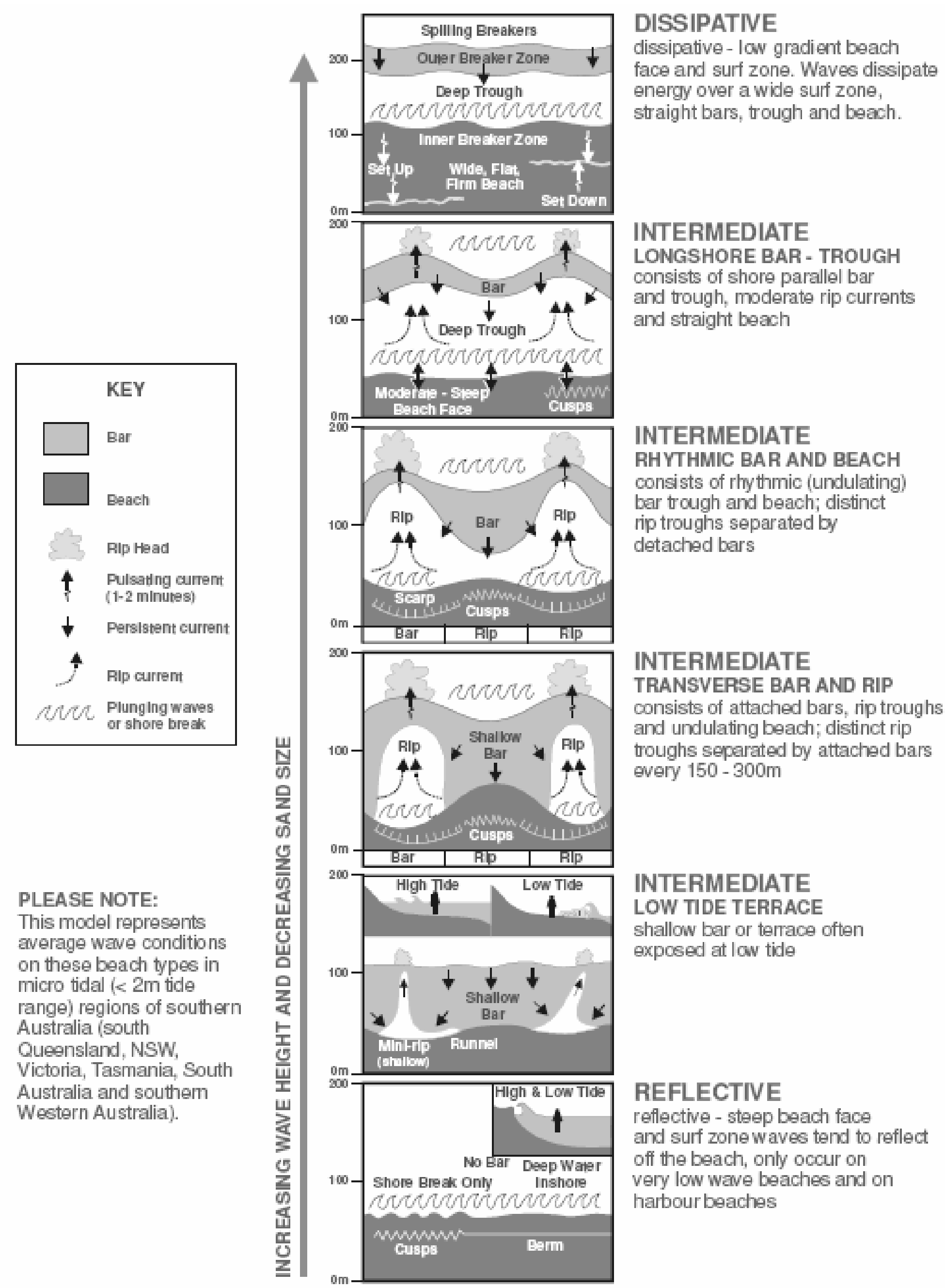


Figure 3.89 – Diagram of the beach and nearshore configurations, from highly reflective to dissipative beaches (NSW-Dep. Land and Conservation, 2001 adapted from Short and Wright, 1983)

the development of rip channels and rip currents. Reflective beaches generally do not have bars because of their steep gradients. Only a little wave energy is lost as waves move across the nearshore so it's common to display erosive conditions.
Anyway, the determining factor for this classification is the amount of wave energy reaching the beach. Nevertheless in addition to the wave energy (Hb: wave height and T: wave period), beach systems are strongly dependent upon two more factors: the spring tide range (TR) and the sediment size (Ws, fall velocity).
All these parameters can be quantified using the dimensionless fall velocity (Ω=Hb/T Ws) (Short, 1999) or the relative tide range (RTR=TR/Hb) (Short, 1999) and each beach state has a characteristic morphodynamic regime.

3.3.1.3 ***Morphology of beach and nearshore systems***
Beach and nearshore systems are the most dynamic of coastal systems and there is a continuous exchange of sediment between the two, driven by alternations of storms and fair weather conditions (Komar, 1975; Davis, 1982; Davis and Fitzgerald, 2004).
Beaches consist in an accumulation of unconsolidated sediments ranging from fine sand to large cobbles which have been transported and deposited by waves and currents. We can characterize the whole zone over which sediment transport by waves occurs as the "littoral zone" and it incorporates the nearshore zone between the low tide line and the offshore limit of wave action on the bed (submarine beach or nearshore system) and the primary beach- or subaerial beach (zone from the landward limit of wave action during storms to the low tide limit) (Schwartz, 1982; Bird, 2000; Pranzini, 2004).

Those systems can be subdivided into three sub-systems along a profile normal to the shoreline (Fig. 3.90): (i) outer shoreface extending offshore to the wave base, dominated by oscillatory motion generated by shoaling waves, tidal currents and wind-driven circulation; (ii) inner shoreface extending roughly from mlw (mean level water) to seaward of the outer breaker zone; (iii) beach system, extending from mean low water to the landward limit of wave action.

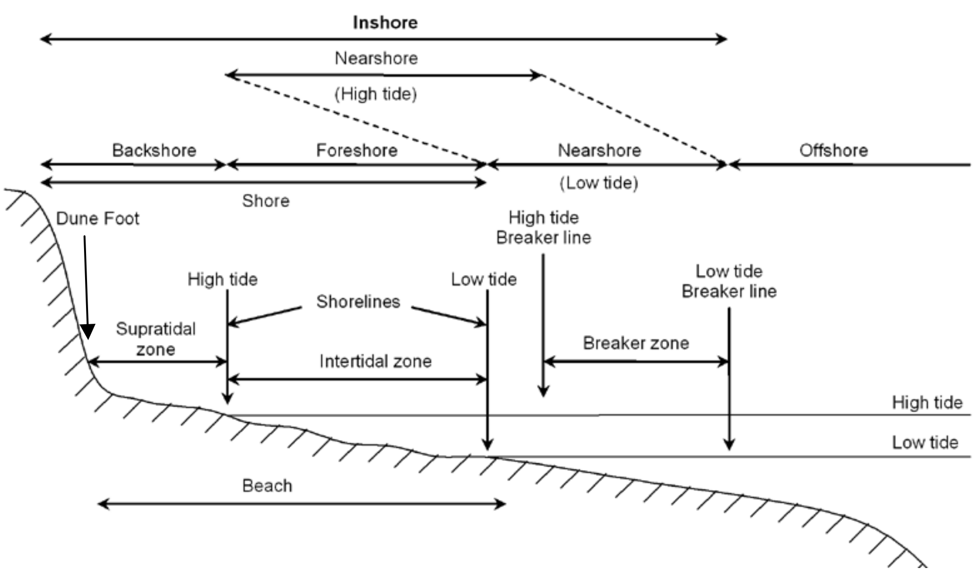


Figure 3.90 – Coastal terminology (from Bird, 2000 - modified).

Observations show that beaches – especially sandy beaches – are highly dynamic in form and there is a considerable feedback between the processes controlling sediment transport and the characteristic forms at the micro-scale (ripples, dunes) and meso-scale (bars and troughs, swash slope forms) (Davis and Fitzgerald, 2004; Mangor, 2004; Davidson-Arnott, 2010).

The measurement of morphological forms and changes (accretion or erosion) are necessary if we want to analyze the morphodynamic of the beach.

Over many decades the standard technique for measuring the beach and the shallow profile uses the measure of height and distance along profiles set up normal to the shore and surveying out to the limit of wading (Evans, 1940; King and Williams, 1949; Davis *et al.*, 1972). Morphological changes along profiles can be measured by repeated surveys and by surveying a number of closely spaced profiles the data could be aggregated to produce a contour map (Davis and Fox, 1972; Greenwood and Davidson-Arnott, 1975).

Actually, surveys are routinely done with a theodolite (or other topographic instruments) and a differential GPS, permitting a rapid acquisition of detailed surveys. Data from an echo sounder can be recorded simultaneously.

In the past decade the use of airborne LiDAR to map extensive sections of beach and dune systems has increased dramatically (Zhang *et al.*, 2005; Robertson *et al.*, 2007) with the simultaneous use of instruments to measure ground topography and underwater topography. The output of these data is incorporated into software (contouring and/or Geographic Information Systems softwares) which can produce digital elevation models (Pranzini and Wetzel, 2008). Continuous monitoring over few years provides the survey of profile changes during the time and it enhances our knowledge about coastal modifications and short-time development.

3.3.1.4 *Beach-nearshore sediments and slopes*

We can recognize three types of beaches based on sediment size: (i) sand beaches; (ii) gravel beaches composed of pebbles and/or cobbles and (iii) mixed sediment beaches, composed by sand and pebbles or sand and cobbles. (Davidson-Arnott, 2010). The sediment range for each class varies considering the different classifications presented in international literature.

The composition and size of the sediment reflects the source material and the processes of sorting and the dynamics of sediment erosion, transport and deposition are greatly influenced by the density and shape of the particles making up the beach.

If we don't take in consideration other control factors – e.g. bedrock influence - it has been long recognized that particle size is an important control on the slope of the beach, both subaerial and submerged (Davis and Fitzgerald, 2004) – e.g. on very fine sand beaches (0.1-0.2 mm) the subaerial slope is always gentle because of the infiltration is low and berm development is consequently limited.

On sandy beaches the nearshore slope is comparatively gentle and there is a considerable exchange of sediment between the subaerial beach and the nearshore. Wave asymmetry and the sorting process tend to move coarse sediments landward toward the step while finer sediments are preferentially transported offshore above the bed in the undertow or rip currents (Horn, 1993). Thus, seaward of the breaker zone grain size tends to decrease and there is a gradual decrease in the bed slope.

In the breaker and surf zones grain size variations reflect topographical controls. Sediments on the crest and seaward slope of the bars are generally well-sorted while sediments at the base of the trough are more poorly sorted. Relatively coarse sediments are found in rip channels (Greenwood and Davidson-Arnott, 1972; Wang and Davies, 1998).

3.3.1.5 *Sandy beach profile and plan view*

Repeated surveys along a profile generally show that there is a considerable variability in the shallow water and on the subaerial beach. The zone between the maximum bed elevation and the minimum bed elevation is termed "sweep zone" and it represents the reworking area by wave action.

Observations and measurements indicate that sand is transported continuously in suspension, as bed load and collectively through migration of sand bars. The existence of characteristic profile shore suggests that there is a dynamic equilibrium between the forces controlling sand movement and that it should be possible to predict profile form and changes from some relatively simple combination of parameters. The Dean "equilibrium profile" (Dean, 1991, 1997) is used extensively in the engineering literature, particularly as input to predicting the form of nourished beach profiles but it takes in count of only one grain size. Several studies suggest a compound profile (Inman *et al*., 1993; Stive *et al*., 1995) taking in count the different grain sizes along the profile or the response at different scale times.

In plan view beaches can be convex, straight or concave. Convex beaches are mostly common around the distal ends of sand spits and on deltas but much of the time beaches develop on a high relief coast and are located in some embayments between headlands or anchored downdrift of a promontory, assuming a concave form. Straight beaches are common on coastal plains where the underlying bedrock ceases to influence them and the form becomes controlled by alongshore and on-offshore sediment transport.

Wave refraction and transport gradients are not the only controls on beach planform. In many cases forms evolve from headlands that reflect the underlying bedrock control or other different features. Waves engraving on these beaches may form zeta bay beaches (Silvester and Hsu, 1993) or parabolic beaches (Hsu *et al*., 1987; Silvester and Hsu 1993, 1997). A particular case is done by pocket beaches (or embayed beaches) where shoreline may rotate depending on the direction of incoming waves and several other factors, such as the seasonality and periodic variations (Short and Masselink, 1999).

3.3.1.6 *Beach- nearshore evolution: scale of analysis*

The study of beach-nearshore evolution is generally considered at four different temporal scales (Davidson-Arnott, 2010):

- instantaneous (seconds to minutes): measurement of fluid transport and sediment transport processes;
- short-term (hours to day): measurements over a short-time period and incident wave field, water levels and morphology changes;
- annual (monthly to yearly changes): seasonal or annual changes in morphology reflect the intensity and the characteristics of incident waves and winds;

- decadal (period of 10-50 years): changes reflect variation in storm intensities, patterns of longshore migration of sand waves, changes in beach and dune sediment budget.

This research focuses on long-term analysis (decadal study) and it is mainly related to coastline evolution. Annual changes are measured using the morphological study of beach profiles.

3.3.2. Materials and methods

The study of the coastline evolution was carried out by air photos interpretation (1954, 1977 and 2006 air photos by the courtesy of Regione Sardegna). Photos were georeferenced by ARCGis 9.3 in order to compare different shorelines.

From 2009 to 2011, eight beach profiles were measured and samples from the beach step, the swash zone, the ordinary berm, the storm berm and the base of the dune have been collected.

Morphological profiles were carried out by a theodolite (Sokkia SET6 ETS model) and a D-GPS (Trimble AG132 model). Their location is presented in figure 3.91.

Transects ran perpendicularly to the shoreline. Every morphological key point was noted and georeferenced. Then data were normalized along the distance (x-axis) in order to compare profiles collected during three years.

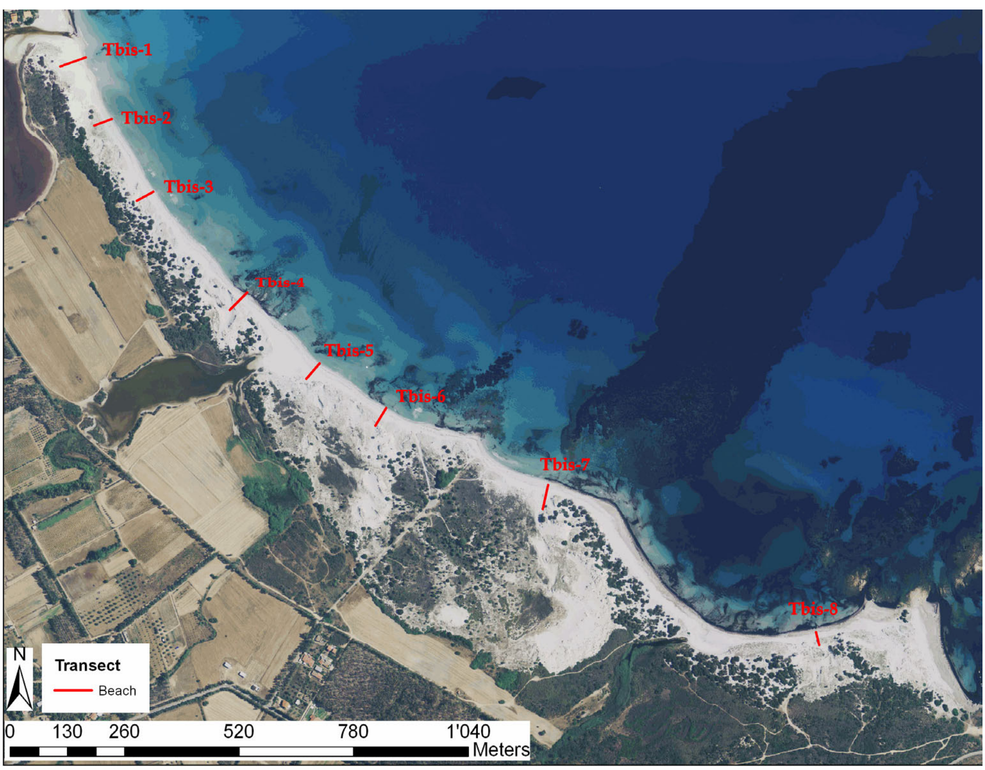


Figure 3.91 – Location of the morpho-sedimentological transects in Capo Comino beach (2006 air photos, Regione Sardegna).

In order to define the morphology of the nearshore zone a bathymetric survey (ODOM HYDROTRAC model, 200k Hz, 1cm resolution) was realized in 2009 and 48 samples from the seafloor were contemporary collected using a Van Veen grab (0.5 m^3).
Geophysical lines were regularly spaced each 50 meters. Samples were collected at -2/-4/-8/-16 meters depth every two lines (Fig. 3.92).
Data were processed and a final bathymetric model was elaborated by interpolation (Golden Software SURFER).

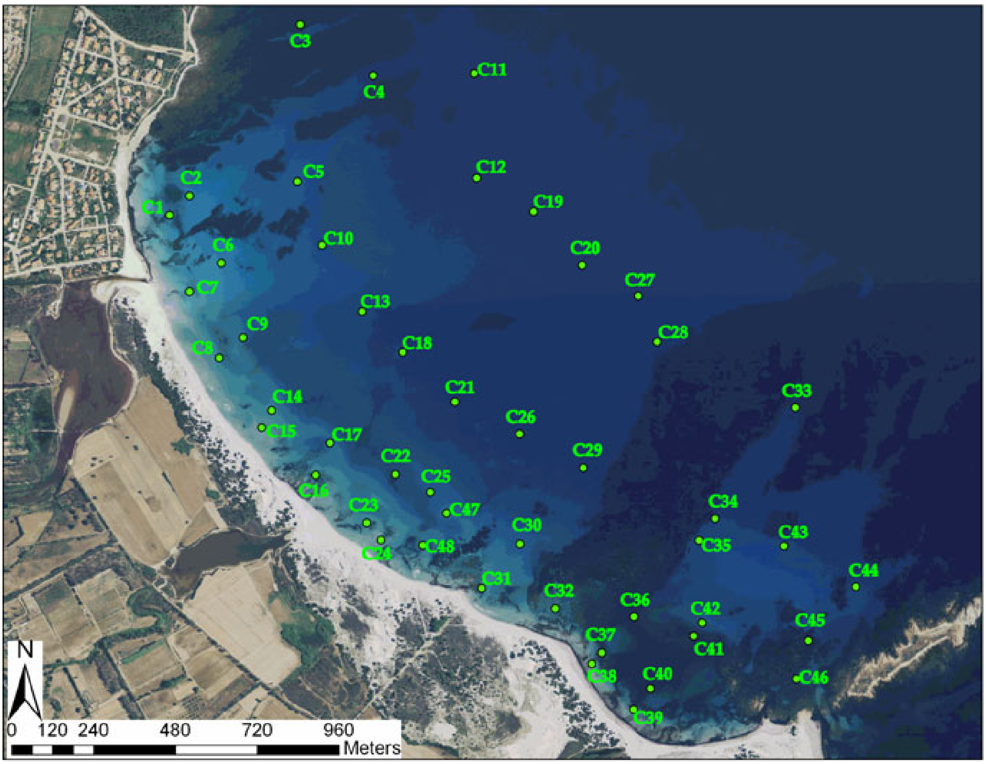


Figure 3.92 – Samples collected in the nearshore system (2006 air photos, Regione Sardegna).

Several samples from the dunefield were collected and analyzed too (results will show in §4.2). Total samples are 175 and they were analyzed in a sedimentological laboratory (Dip.Te.Ris. – University of Genova, Italy).

The first step of the methodology plans to put half-sample in a dryer (at 104°C) and to weight it after 24 hours. Then the sample has to be washed in order to eliminate the salt (because salt may be compromise the analysis due to its high cohesiveness with the particles) and put again in the dryer for 24 hours. After a second weighing, the sample may be analyzed by sieves.
The result of sieving procedure is the repartition of the sample in the granulometric classes and various statistical parameters – that describe the nature of the population of particles in the sample – may be calculated.

Statistical values are usually calculated starting from the histograms and frequency curves of distribution. The distribution of grain sizes typically follows or approaches a log-normal distribution.

Between the common statistical parameters, mean grain size (Folk and Ward, 1957), mode and median, sorting index (Trask, 1932), deviation (Krumbein, 1934), standard deviation (Folk and Ward, 1957), skewness (Folk and Ward, 1957) and kurtosis (Folk and Ward, 1957) have been considered. Most of them are very common parameters in statistical analysis (such as mean, mode, median and deviation). Concerning the sorting index, well-sorted sediment present most of the grains about of the same size, whereas poorly sorted sediment has a wide range in article sizes. Skewness is the measure of the asymmetry of the distribution of the population (positive values: the tail of the distribution curve on the right side is longer than the left side and the bulk of the values lie to the left of the mean; negative values: the tail on the left side of the probability density function is longer than the right side and the bulk of the values -possibly including the median- lie to the right of the mean).
Kurtosis is the measure of the "peakedness" of the distribution curve of the sediment and defines in how many grain size classes the sample is distributed.
These parameters suggest the presence of coarser or finer tails in the sediment distribution and wide/narrow distribution curves. Several values are expressed in *phi* (phi=-log2(mm)) or mm, following the formula of each statistical parameter.
Complete lists of sedimentological indexes are in annexes II (2009 samples), III (2010 samples), IV (2011 samples) and V (2009 samples collected from seafloor).

3.3.3 Results

a) <u>Coastline evolution</u>

A marked longshore drift direction from North to South characterizes this coastal sector (see Fig. 2.4). The coastal development of Capo Comino beach is influenced by the presence of two headlands and this process can be explained in term of wave refraction. In particular the presence of the southern headland provides some shelter from S-ESE waves and gives rise to the development of a zeta bay beach.

The underlying bedrock control is reflected in the shape of the beach too. Indeed, outcrops and boulder deposits are present in the northern, in the central and southern sectors (Fig. 3.93). Shoreline is strongly influenced by them (see §3.1.2) and we can recognize three main cells: a northern cell that is the longest (about 2.5 km) and quite linear, a central cell - about 900 meters long with a light embayment - and a third cell (from Iscra Ruja to the end of the beach) about 300 meters long.

Figure 3.93 - Outcrops in Capo Comino beach, northern (left) and central (right) sectors.

With regard to the evolution of the beach, the northern sector (Fig. 3.94) is affected by erosional processes and critical situations are more evident if we consider the impact of the sea storms on the built-up area (S’Ena sa Chitta village). In reality – as we will see later - the shoreline was relatively stable in the long-term period and dangers were more related to the proximity of the houses to the beach.

Figure 3.94 - Northern sector and buildings close to the beach (May 2010).

The evolutive analysis of the beach between 1954 and 2006 (Figs. 3.95, 3.96 and 3.97) identified the relative stability of the shoreline. The northern and the central sectors of the beach (Fig. 3.98) were interested by erosion but this process brought to a retrogradation of the beach of several meters. It retrograded -10/-15 meters and -40 meters respectively.
In 1977 coastline seemed to prograde in the northern sector (Fig. 3.97) but this result was due to the anomalous conditions of the air photos' shooting. Indeed, 1977 photos were over-exposed in that sector and the presence of breaking waves during a storm caused hard time on detecting the shoreline. Thus this element cannot be taken in consideration (green dotted line) for the shoreline evolutive analysis.

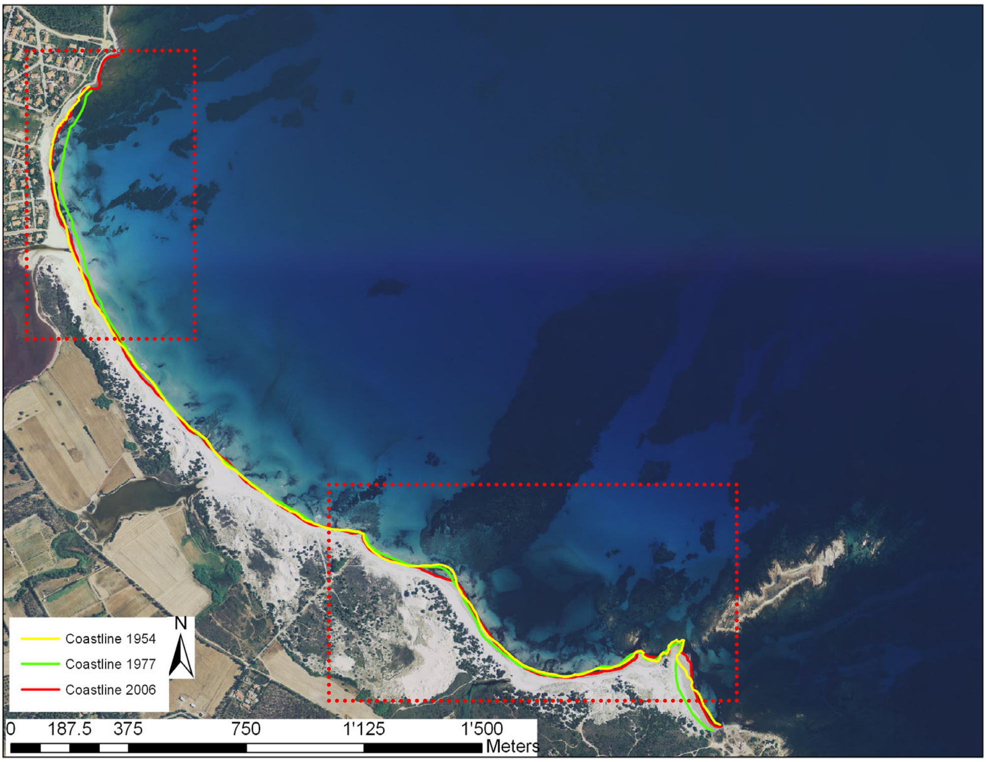


Figure 3.95 - Coastline evolution in Capo Comino beach (1954-2006). Red rectangles: location of Figs. 3.96 and 3.97.

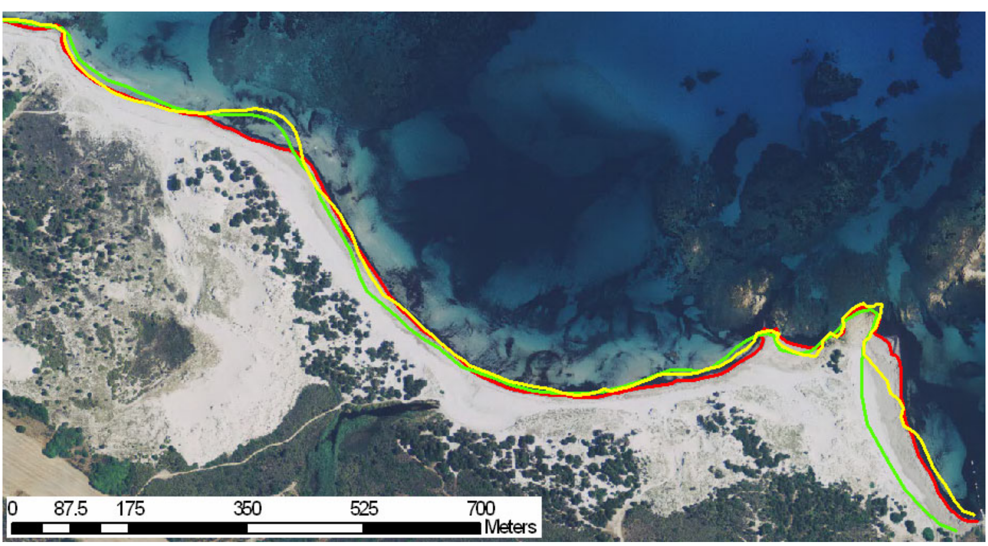


Figure 3.96 - Coastline evolution in Capo Comino beach (1954-2006), southern sector: the erosion in the central sector and the huge *banquette* in the south-eastern cell.

Figure 3.97 - Coastline evolution in Capo Comino beach (1954-2006), northern sector.

Figure 3.98 - Pictures of northern (up) and central beach (down).

The south-eastern sector (third cell), instead, is sheltered by Iscra Ruja and the cape. It's common to find huge deposits of *Posidonia oceanica* on the beach (forming *banquettes*) and the beach wide can considerably increase (Fig. 3.96 – the deposit is more than 50 meters wide).

These deposits were generally found also in the northern and central sectors of the beach (Fig. 3.99) but volumes were smaller.

Figure 3.99 – Deposits of *banquette* in central sector of the beach.

The nature of these deposits is almost ephemeral because they can move back to the water during a sea storm or follow the coastal drift. They also can be buried by sand coming from the sea and it's common in Capo Comino to walk on a "fluffy beach".
In Capo Comino these deposits are usually taken away during the summer because of the touristic activities. They are carried off by mechanical vehicles, especially in the northern and central beach that are more attended by people.
The south-eastern sector, instead, is only periodically interested by the cleaning operations (usually every two years by the Public Administration of Siniscola) (Fig. 3.100 – before and after cleaning actions).
The importance of the *banquettes* is largely known in the international literature due to the contribution to beach protection but, most of all, for the natural restoration of coasts (Boudouresque *et al.*, 2006) .

Figure 3.100 - South-eastern beach with (up, 2009) and without (down, 2011) seagrass deposits.

b) <u>Bathymetric and sedimentological maps</u>

Considering the light changes of the coastline in the long-term period, only one bathymetric survey (June 2009) was carried out in order to highlight the morphology of the nearshore zone. More surveys should show up the morphological changes at small scale (such as the bars' migration) but this information should affect in the least the analysis of the interaction between the nearshore-beach system and the dunefield.
Therefore, starting from data collected in 2009, the results of the analysis of the bathymetric lines may be summarized in figure 3.101. The map shows a gentle slope of the nearshore zone, with a mean value of 2.2% (1.01 degrees) for -5m depth and 1.6% (0.725 degrees) for -10m depth in the central sector.

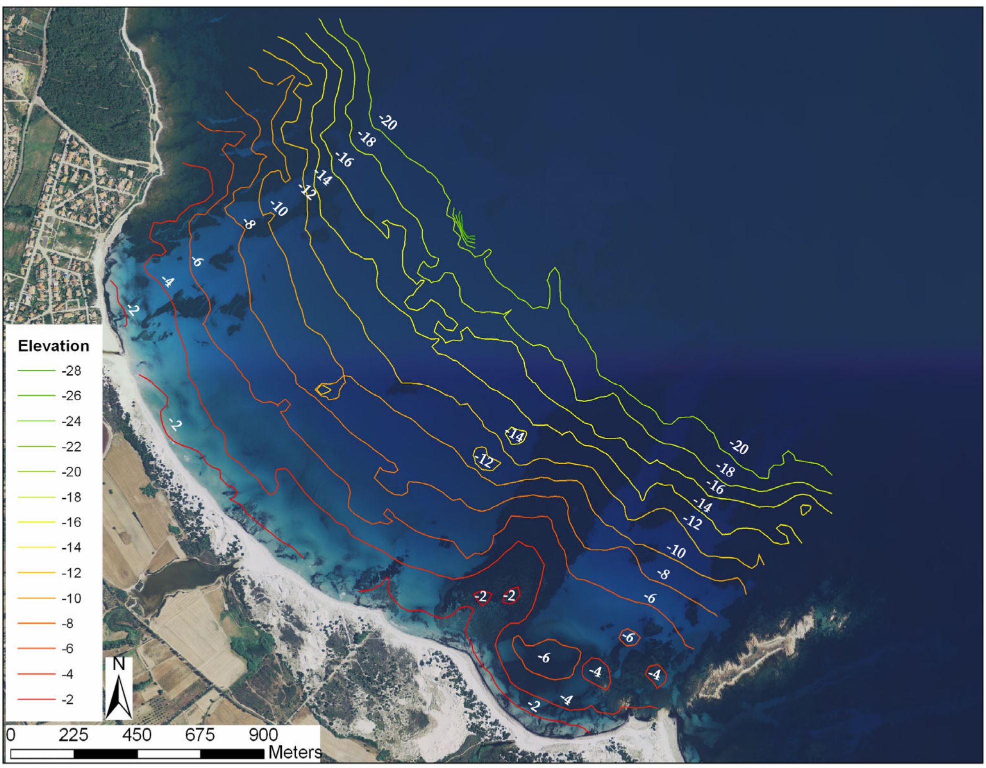


Figure 3.101 - Bathymetric map of the nearshore zone of Capo Comino (2006 air photos, Regione Sardegna).

This gentle slope allows the wave breaking and a gradually energy dissipation along the nearshore zone. The external sectors are influenced by the northern headland and by Iscra Ruja (the little rock island).
Isolines are almost straight and the discontinuities are related to the presence of outcrops and bedrock (Fig. 3.102). In fact, the southern-central sector is characterized by convexity of the lines, indicating higher seafloor compared to the surrounding areas.
In the central sector, instead, the concavity of the lines (red dotted line in Fig. 3.102) suggests the presence of a channel, deeper than the surrounding areas.

These assertations were confirmed by the analyses of sedimentological samples.

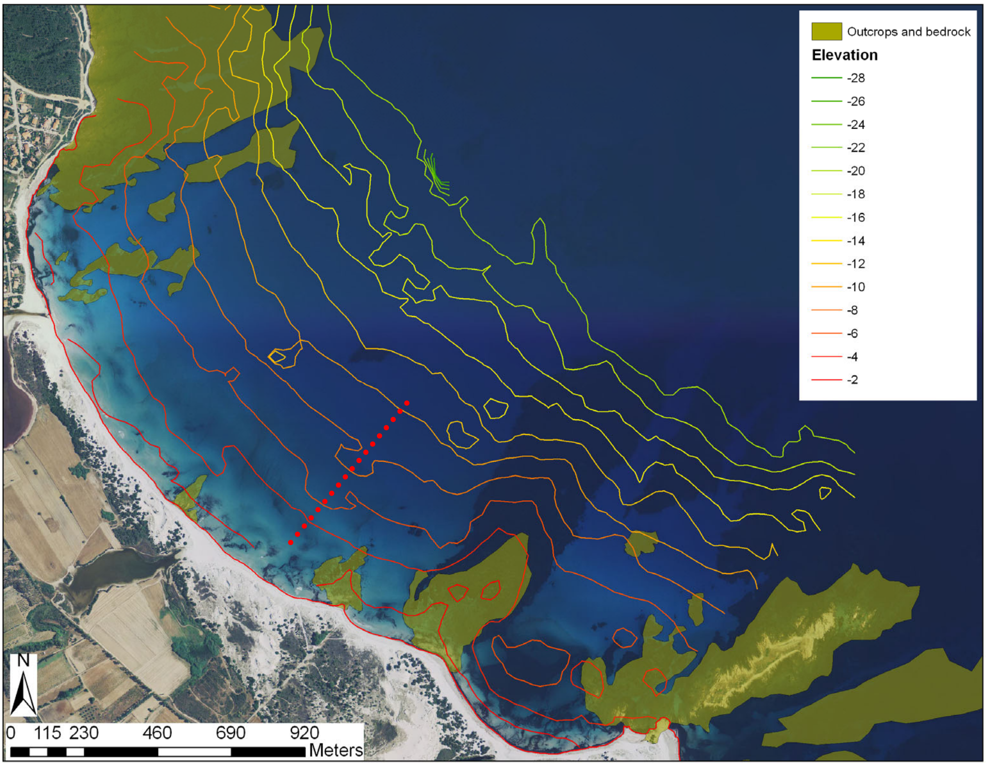


Figure 3.102 – Bathymetric map of the influence of the bedrock and outcrops.

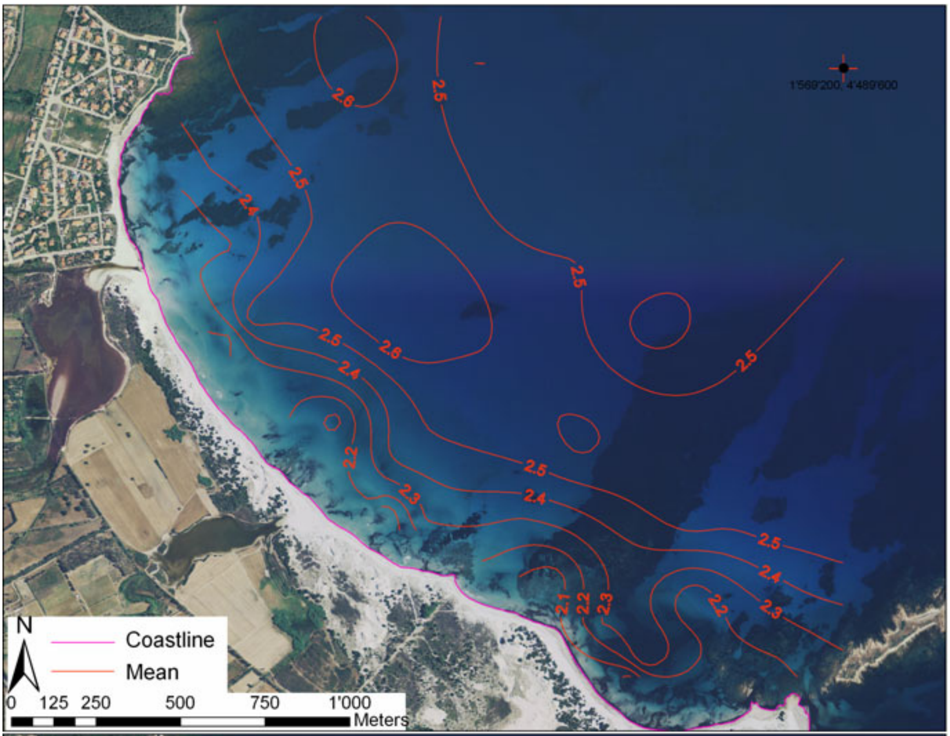
Sedimentological indexes were calculated for each sample in order to produce maps of their distribution in the area (Figs. 3.103 and 3.104).

Table 3.24 summarizes the mean, maximum and minimum values of the sedimentological indexes.

	Mean	Max / sample	Min / sample
Mode (Phi)	2.42	2.74 / 13 -17	2.06 / 32
Mean (Folk and Ward, 1957) (Phi)	2.37	2.69 / 13-18	1.98 / 39
Median (Phi)	2.38	2.71 / 13	2.01 / 39
Sorting Index (So) (Trask, 1932) (mm)	1.21	1.29 / 39	1.05 / 33
Deviation (Krumbein, 1934) (mm)	0.04	0.06 / 39	0.01 / 33
Inclus.Graph.**St. Deviation** (Folk and Ward,1957) (Phi)	0.43	0.56 / 11	0.04 / 14
Inclus.Graph. **Skewness** (Folk and Ward, 1957) (Phi)	-0.07	0.09 / 45	-0.29 / 33
Graphic **Kurtosis** (Folk and Ward 1957) (Phi)	1.18	2.01 / 33	0.87 / 32

Table 3.24 - Mean, min and max values for each sedimentological index.

The mean of the grain sizes is 2.37 phi (about 0.2 mm), belonging to the "fine sand" class (Wenthworth-Krumbein classification). The min/max values, instead, refer the sediments to a range varying from medium to fine sand classes.
Sediments were generally well-sorted and values of asymmetry were usually negative but few values were positive (related to finer grain size composition). The finest samples were usually located in the external nearshore (the influence of wave energy is very low and it influences the sediment distribution on the seafloor only during storms) or where sediments might be trapped into pockets (e.g. close to the outcrops).
The distribution of the samples allowed defining the location of the morphological forms of the nearshore. Figs. 3.103 and 3.104 well describe the presence of a bar, parallel to the shoreline (between -10 and -12 meters depth), cut off by a deeper channel (rip channel). The presence of a bar detached from the shoreline (or several bars too) is common in dissipative-intermediate beaches. Bars can move in relation to different wave energies and position in the nearshore zone.
In Fig. 3.103 the bar is well defined and it is located in the central nearshore (value 2.55 of the mean and 2.65 of the mode).
Figure 3.104, instead, clearly shows the presence of an erosive morphological form in the central sector of the nearshore (rip channel).



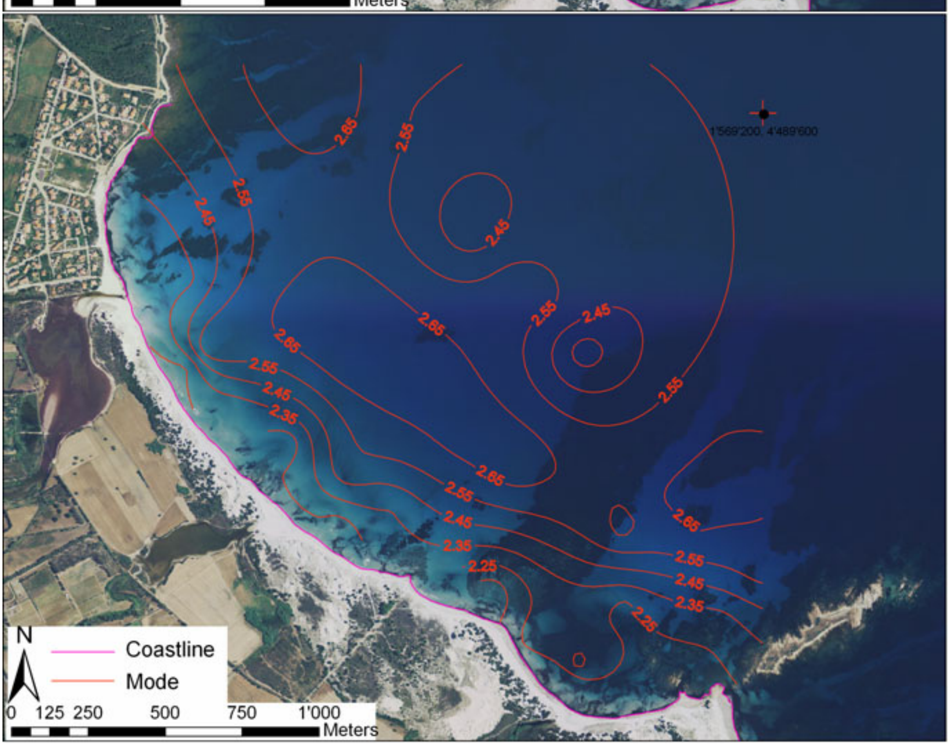


Figure 3.103 – Sedimentological maps: mean of the grain size (top) and mode (bottom).

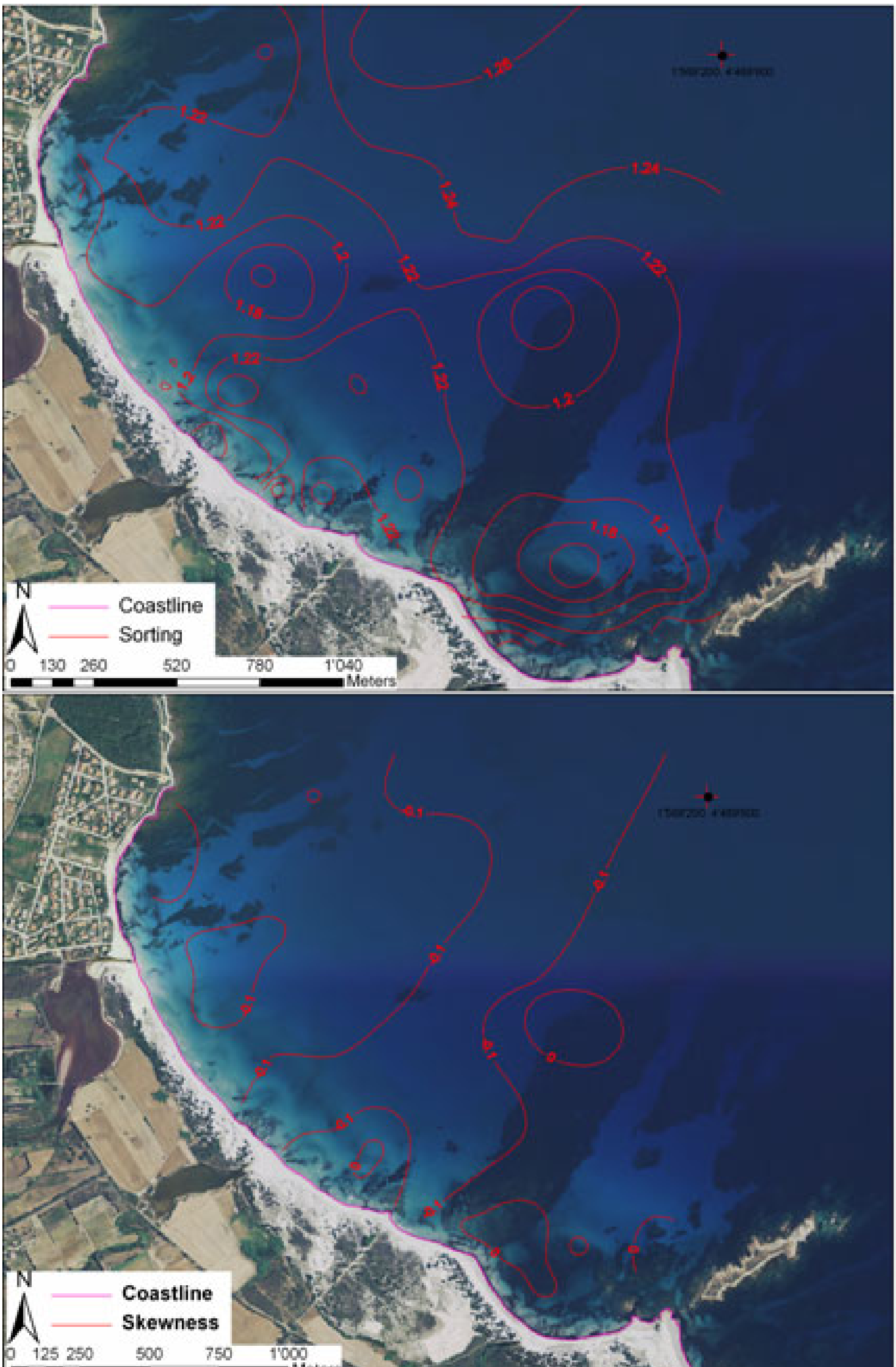


Figure 3.104 – Sedimentological maps: sorting (top) and skewness (bottom).

c) <u>Morphological beach profiles and sedimentological characterization</u>

Results concerning the morphological profiles and the samples collected on the beach are described. Sometimes samples were not collected because of the temporary presence of *banquettes* along the beach, especially during 2010 survey.
X and Y-axes of morphological profiles are expressed in meters.
In the ample graphs x-axes are in meters and y-axes are in percentage (frequency %).

<u>T1bis profile</u>
Profile T1bis was located in the northern sector of the beach (Fig. 3.105), close to the river mouth of the biggest salt marsh (*Salina*) of Capo Comino area. The morphological profile is presented in figure 3.107. The SP (station point) was situated on the top of the first established dune ridge, surrounded by *Juniperus* trees.

Figure 3.105 - View of T1bis profile from South (2010).

This sector of the beach was strongly influenced by the presence of the salt marsh (it is usually annual, no dry period occurs). Sometimes it was affected by floodings and these events were able to erode the first dune ridge close to the river mouth (Fig. 3.106).

Figure 3.106 - View of *Salina*'s mouth after a flooding (2005). The first established dune ridge and embryo dunes were eroded.

During the monitoring period, T1bis profile showed several changes. First of all, between 2009 and 2010 a sea storm probably occurred eroding the base of the embryo dune and forming an erosive scarp. The embryo dune also appeared flatter in 2010-2011 lines compared to 2009 profile.
Between 2010 and 2011 the upper sector of the profile didn't change so much, except to the volume of sand accumulated at the base of the ridge (sand buried from the beach to inland).

Concerning the sedimentological analyses, figure 3.108 summarizes the results.
Samples of beach step (BS), swash zone (MSL), ordinary berm (BO) and dune foot (DF) were collected along the morphological profile.
2009 and 2010 DF-samples were very similar, with a leptokurtic distribution of the curve in two main classes corresponding to 1.5 and 2 phi. These values of grain size confirmed the aeolian nature of these sediments that accumulated at the base of the established dune ridge.
BO-samples presented a leptokurtic curve distribution too. Sediments were very homogeneous and in 2009 and 2011 the most part of them (about 45%) belonged to 1.5 phi class. In 2010, instead, the sediment was more distributed into two classes.
BS and MSL-samples presented a wider distribution of the grain size classes. In particular they were characterized by the presence of coarser tails.
Most part of the coarser sediments was referred to shells and little pebbles coming from the erosion of outcrops.

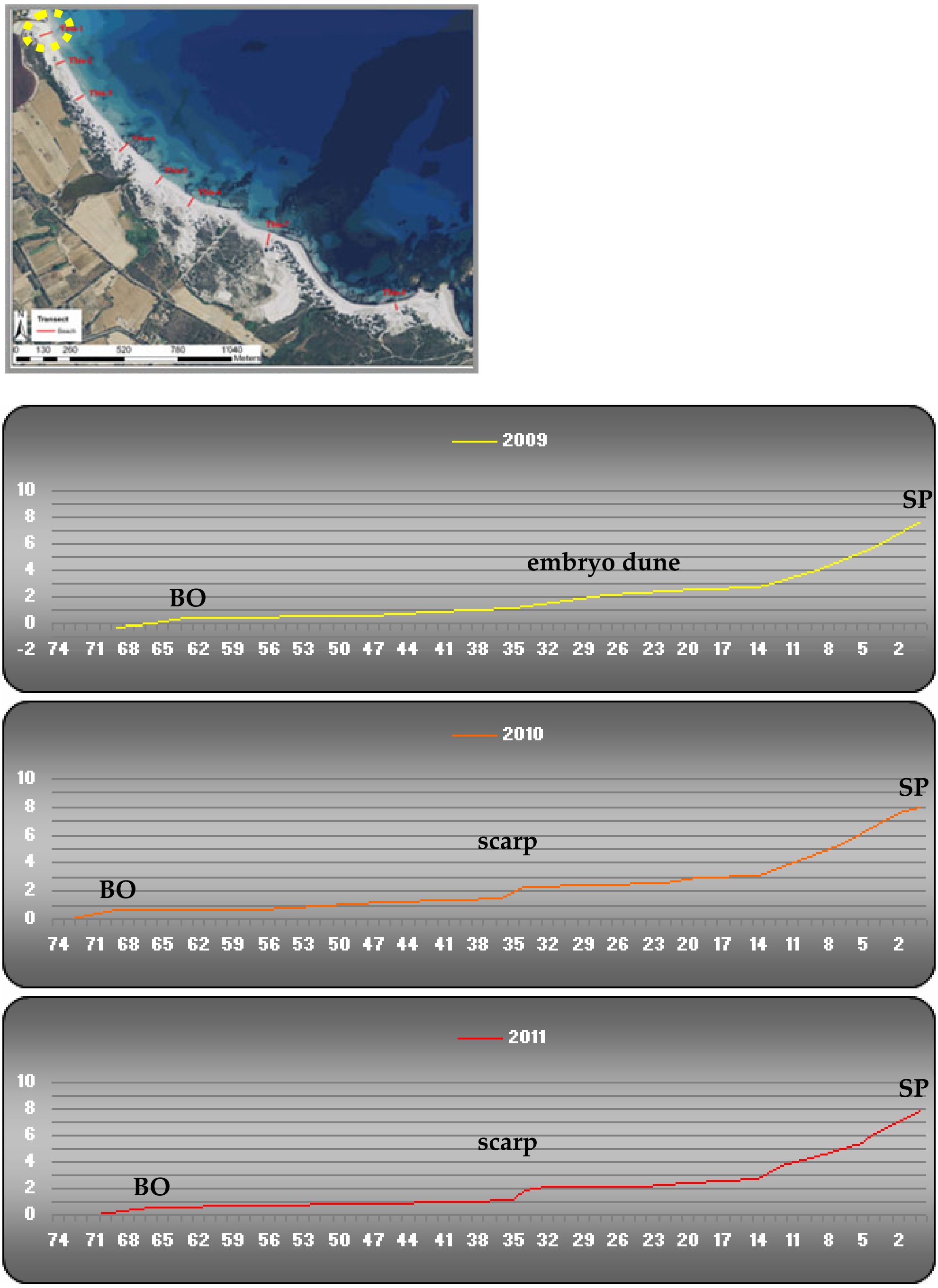


Figure 3.107– T1bis profile in 2009-2010-2011 and its location in Capo Comino beach (up); x-y axes in meters.

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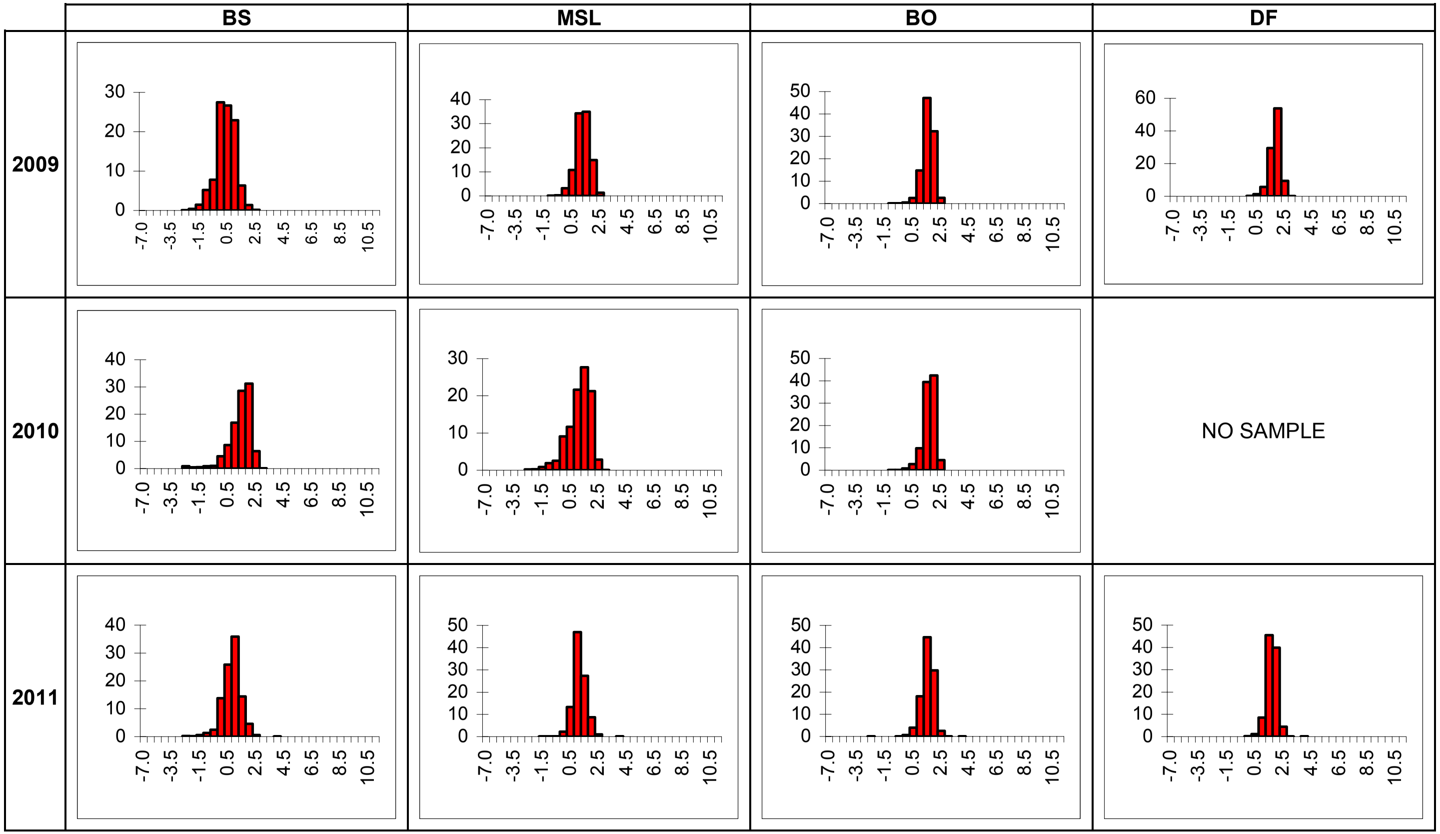
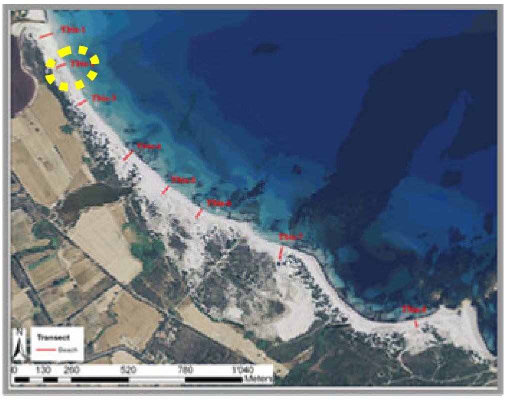


Figure 3.108 – Samples collected along profile T1bis in 2009-2010-2011 (x-axis: phi; y-axis: %). BS: beach step; MSL: mean sea level; BO: ordinary berm; DF: dune foot.

T2bis profile



T2bis profile (Fig. 3.109) remained unchanged between 2009 and 2011.
The first dune ridge (located at about 46 meters from the SP) didn't change its morphology but the transport of the sand by winds changed its vegetation (during field observations species more common in established foredunes disappeared and new pioneer species were colonizing the relict foredune).

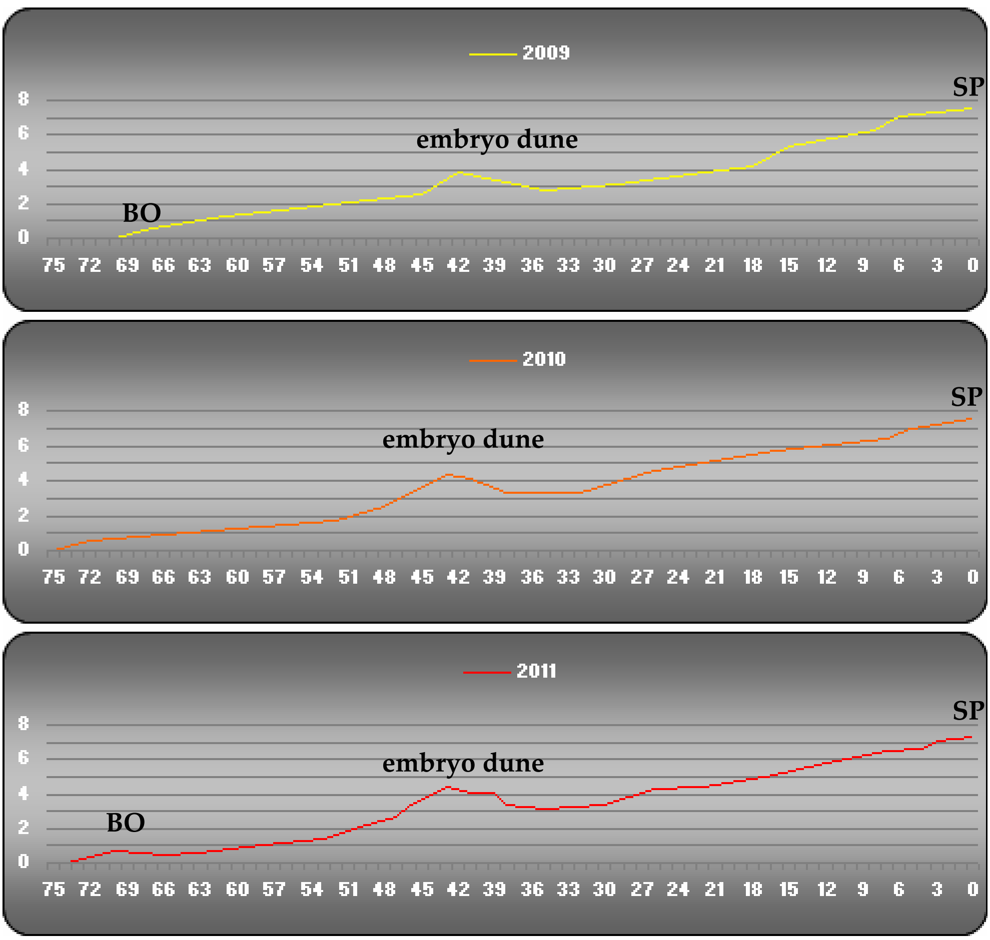


Figure 3.109 – T2bis profile in 2009-2010-2011 and its location in Capo Comino beach (up); x-y axes in meters.

The general profile was gentle with a lot of sand accumulation between the first (relict) dune ridge and the top of the second one (where SP is located).
This profile didn't show evidences of erosive events, such as storm berms.
In 2010, shoreline was characterized by deposits of *banquette*. It was impossible to define the position of the berm. Moreover no samples were collected during that survey.
BO and DF-samples presented a leptokurtic distribution and well-sorted sediments.
MSL and BS-samples had a wider distribution, but the mean grain size was always in the fine sand class. A tail of coarser sediments was characterized by shells.
Figure 3.110 shows the BS-sample (up) and the DF-sample (down) of 2011.
Figure 3.111 presents the sediments collected along T2bis transect over the monitoring period.

Figure 3.110 – BS-sample (up) and DF-sample of T2bis transect (2011). To note the coarser grain size of the beach step (little pebbles and shells) and the fine dans composing the dune foot sample.

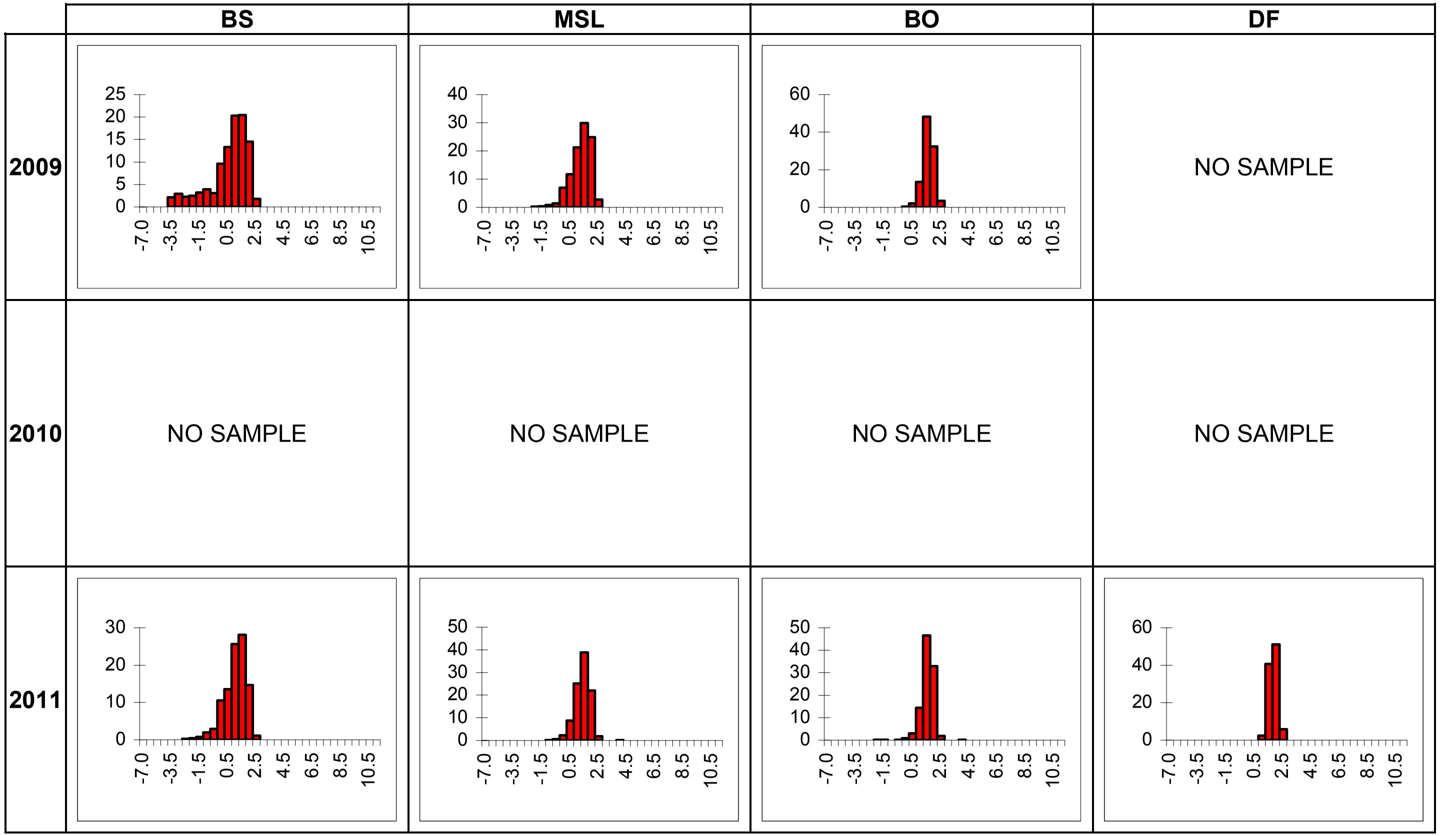
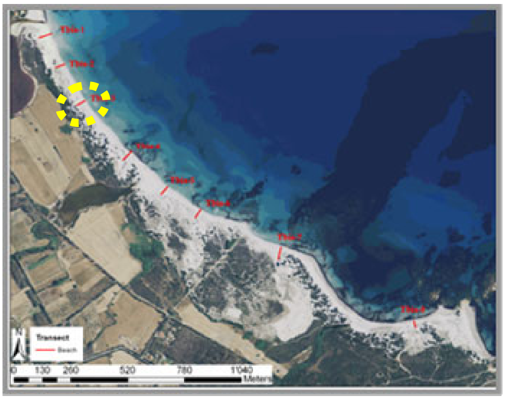


Figure 3.111 – Samples collected along profile T2bis in 2009-2010-2011 (x-axis: phi; y-axis: %). BS: beach step; MSL: mean sea level; BO: ordinary berm; DF: dune foot.

T3bis profile



T3bis profile (Fig. 3.112) showed an erosive phase in 2009, with the formation of a scarp in the embryo dune. The embryo dune was not totally eroded and then winds were able to reconstruct its morphology.
Indeed, in 2011 no erosive forms were noted on the profile and the embryo dune presented again the previous morphological profile.
The analysis of the sediments (Fig. 3.113) brought to the same conclusions obtained for T1bis and T2bis transects.

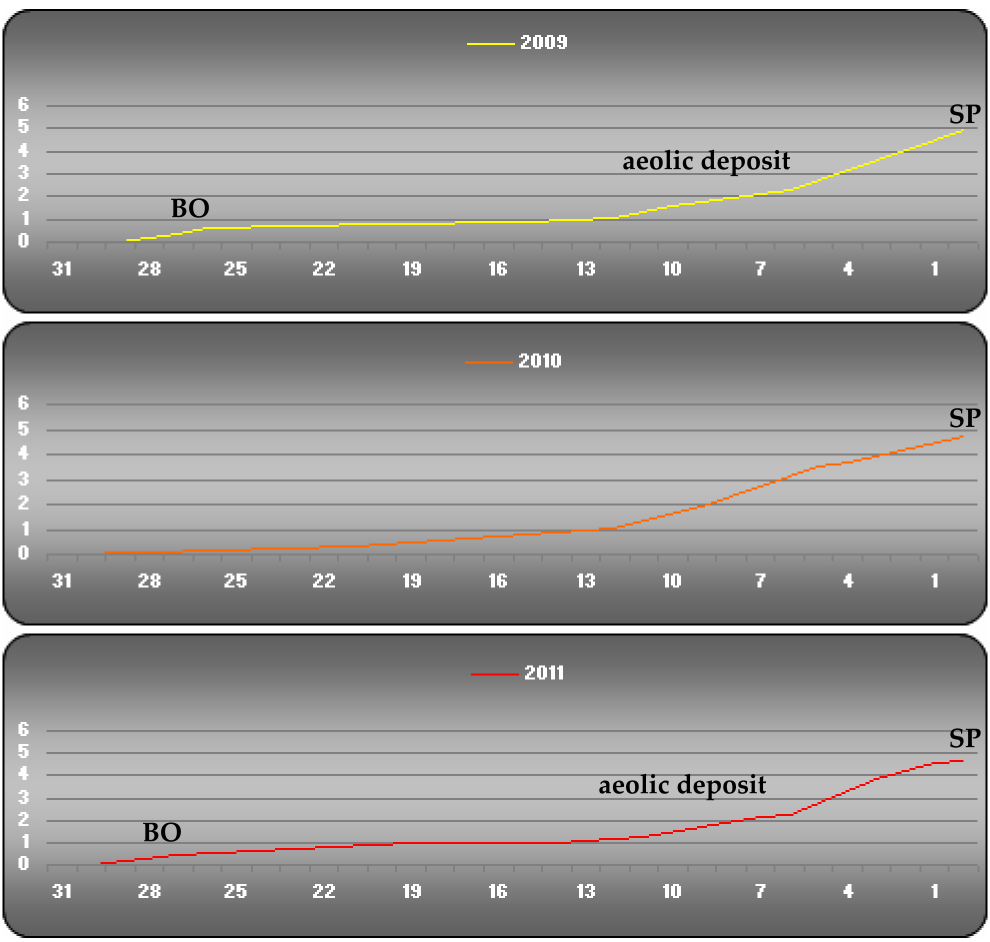


Figure 3.112 – T3bis profile in 2009-2010-2011 and its location in Capo Comino beach (up). X and Y-axes in meters.

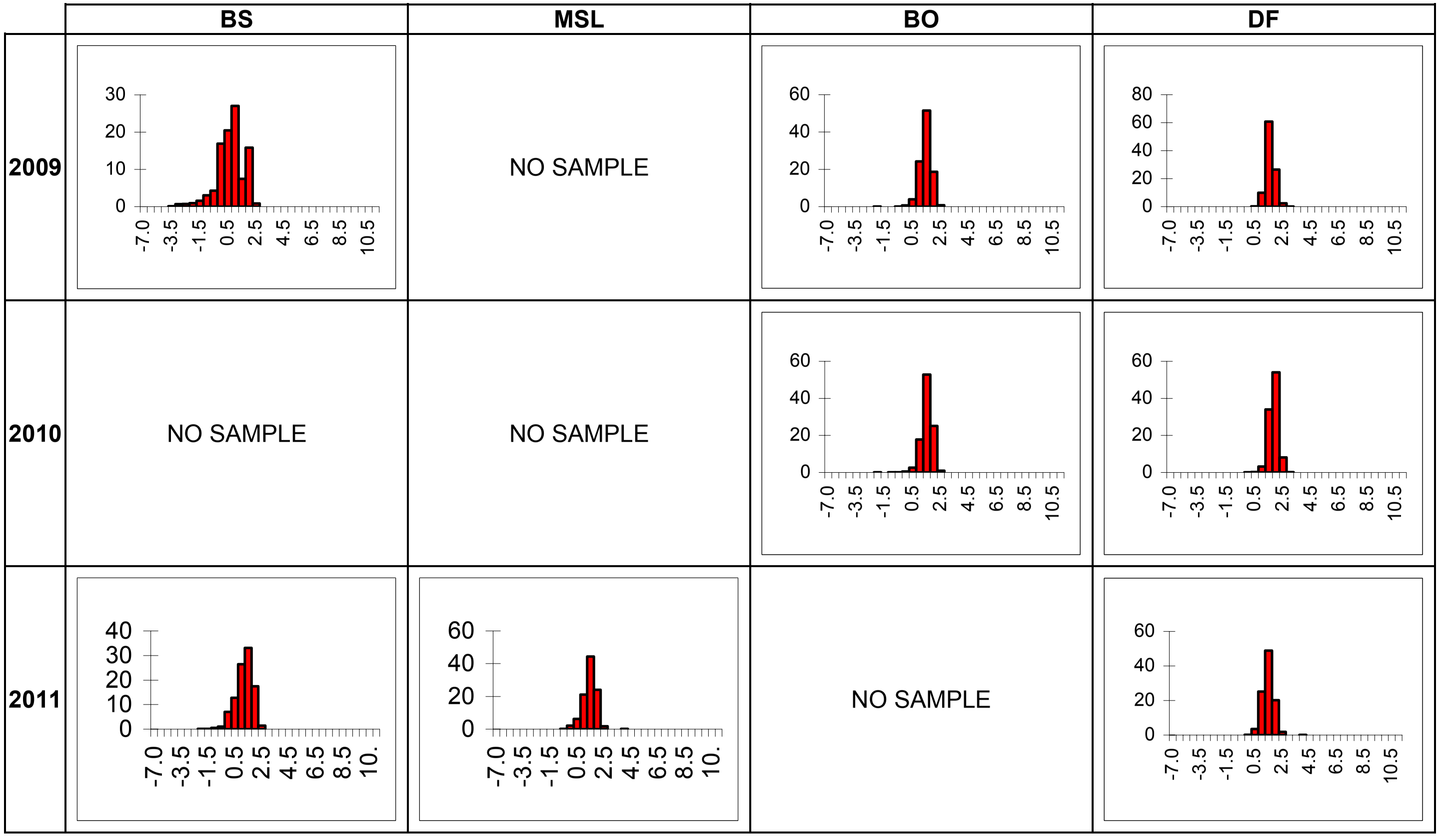
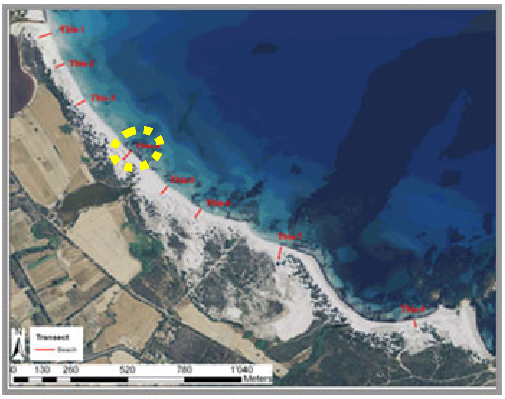


Figure 3.113 – Samples collected along profile T3bis in 2009-2010-2011 (x-axis: phi; y-axis: %). BS: beach step; MSL: mean sea level; BO: ordinary berm; DF: dune foot.

T4bis profile



T4bis profile (Fig. 3.114) was characterized by a steep beach profile with a slope of 12.5% (about 5.7°).

Along this profile was common to find a series of two-three storm berms attested by the presence of shells and wooden debris.

The station point was located on the top of the first established foredune and it was affected by sand burial (Fig. 3.115). This sand came from a blowout, developing from NNW to SSE.

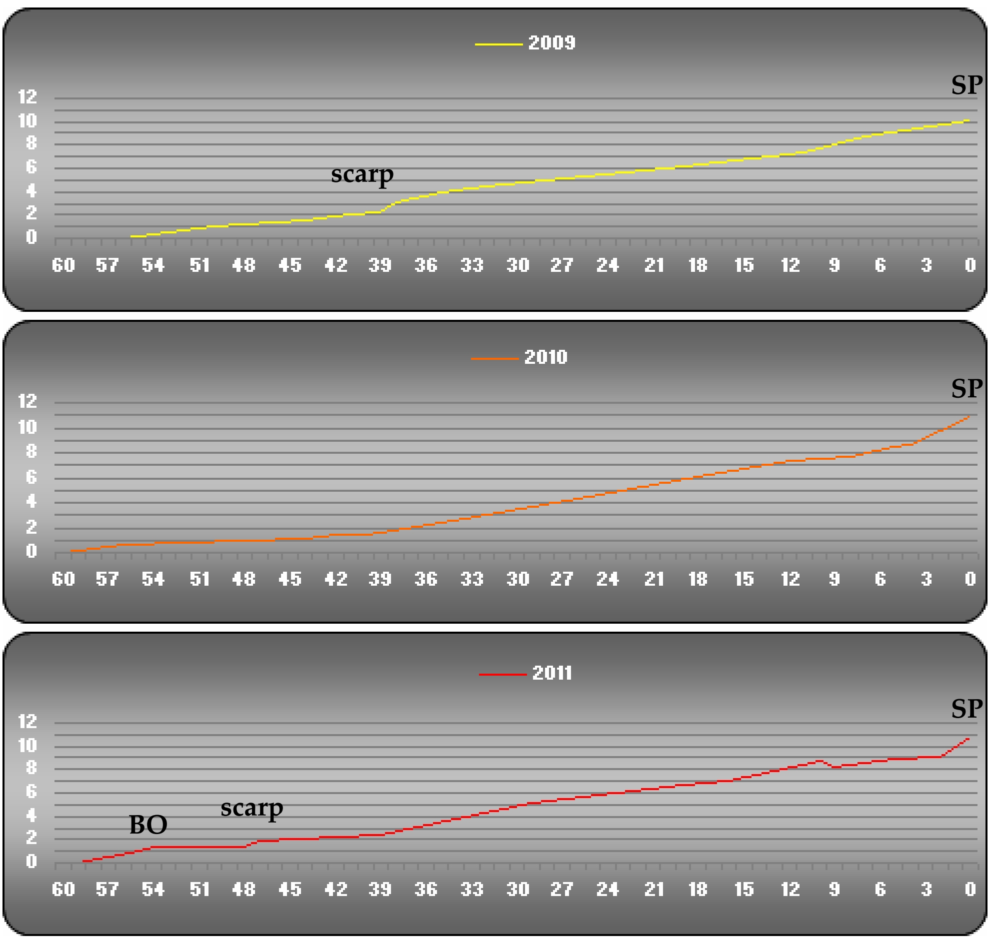


Figure 3.114 – T4bis profile in 2009-2010-2011 and its location in Capo Comino beach (up); x-y axes in meters.

The shoreline was stable, but a light accretion interested this sector of the beach in 2010 (a *banquette* was present mixed with sand). In reality, the surrounding areas were affected by sea ingression (Fig. 3.116).

The sand eroded from the dunes was probably distributed again on the beach after the storms.

Figure 3.115 – View of the T4bis station point from the beach. A huge sand deposit at the middle slope is buried the vegetation of the dune ridge (2010).

Figure 3.116 – Sea ingression in the central sector. View from T4bis station point (2011).

Samples were collected in 2009 and 2011. In 2010, a huge *banquette* was on the beach and samples were not collected (Fig. 3.117).

The sediment distribution was similar to the results of T1-T2-T3bis transects and confirmed the sedimentological considerations expressed for the previous profiles.

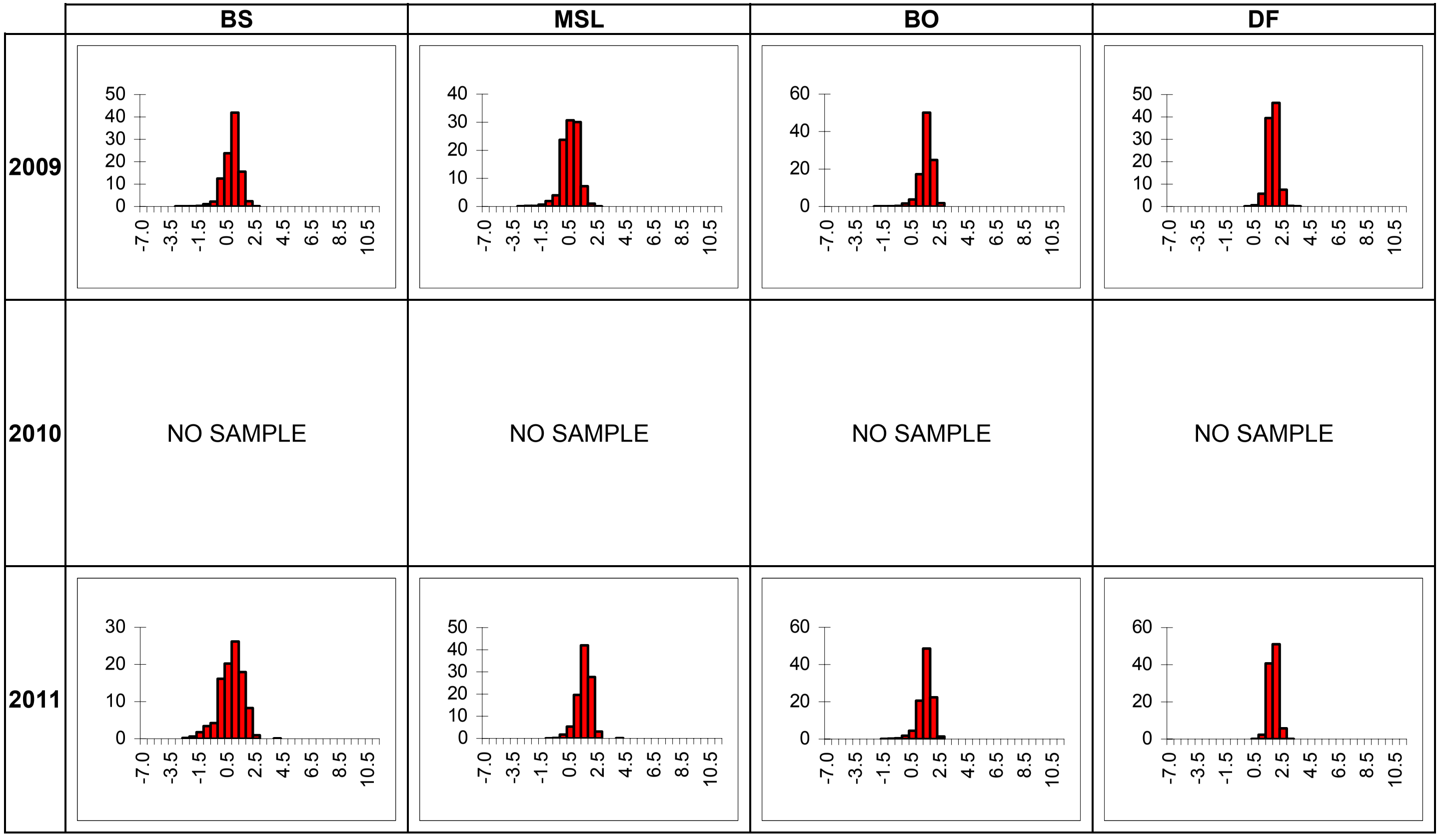
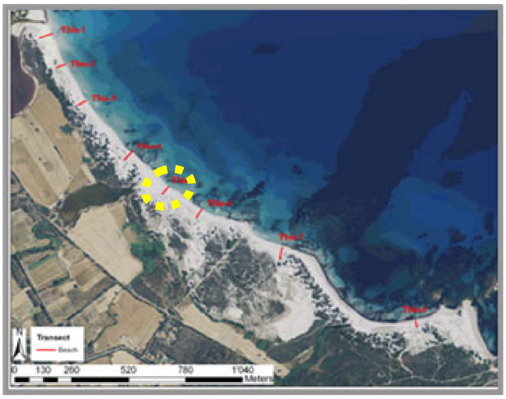


Figure 3.117 – Samples collected along profile T4bis in 2009-2010-2011 (x-axis: phi; y-axis: %). BS: beach step; MSL: mean sea level; BO: ordinary berm; DF: dune foot.

T5bis profile



T5bis profile (Fig. 3.118) was located in the central sector of the beach, close to *Salinedda* (the central salt marsh).
This profile was strongly influenced by the river mouth position (Fig. 3.119). In fact, during the past three years, the contribution of sediments from the river caused the shoreline migration and the modification of the profile along the beach.

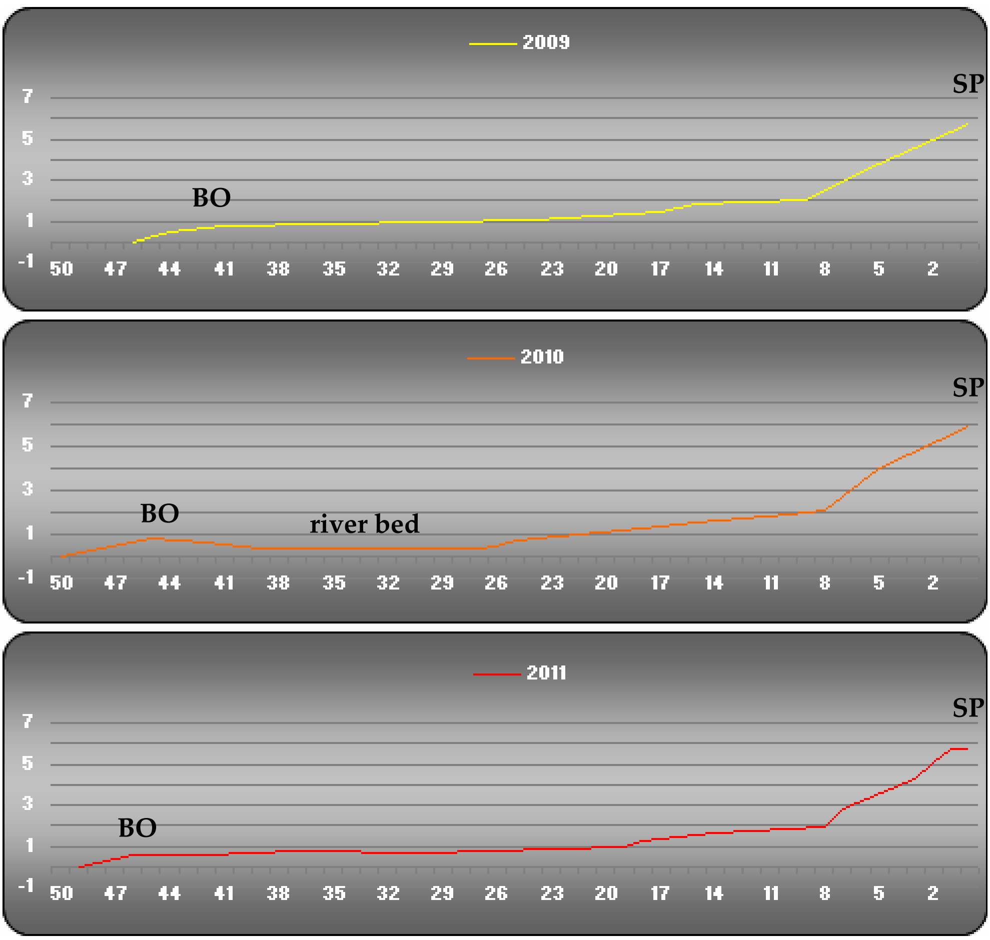


Figure 3.118 – T5bis profile in 2009-2010-2011 and its location in Capo Comino beach (up); x-y axes in meters.

Compared to the 2009 situation, in 2010 the profile showed a wider deflation area of the beach and the shoreline aggraded about 3 meters. The profile was also characterized by the presence of the river bed that crossed the topographic line (about 15 meters wide).
No embryo dunes were found in this sector of the beach during the surveys, probably due to the presence of the river mouth. Anyway sand could accumulate at the base of the established dune ridge and pioneer vegetal species were found there.
But these deposits are really ephemeral because they are related to the migration of the river bed that could completely erode them.

Figure 3.119– River mouth of Salinedda. View from T5bis profile station point (2011).

Sediment samples were collected (Fig. 3.120). Results showed the general trend of the previous samples.
BO and DF-samples presented a leptokurtic curve, with the distribution in two main classes. The exception was represented by 2009 and 2011 BO-samples that were characterized by a wider distribution of sediments.
BS and MSL-samples were heterogeneous with a high component of shells and little pebbles.

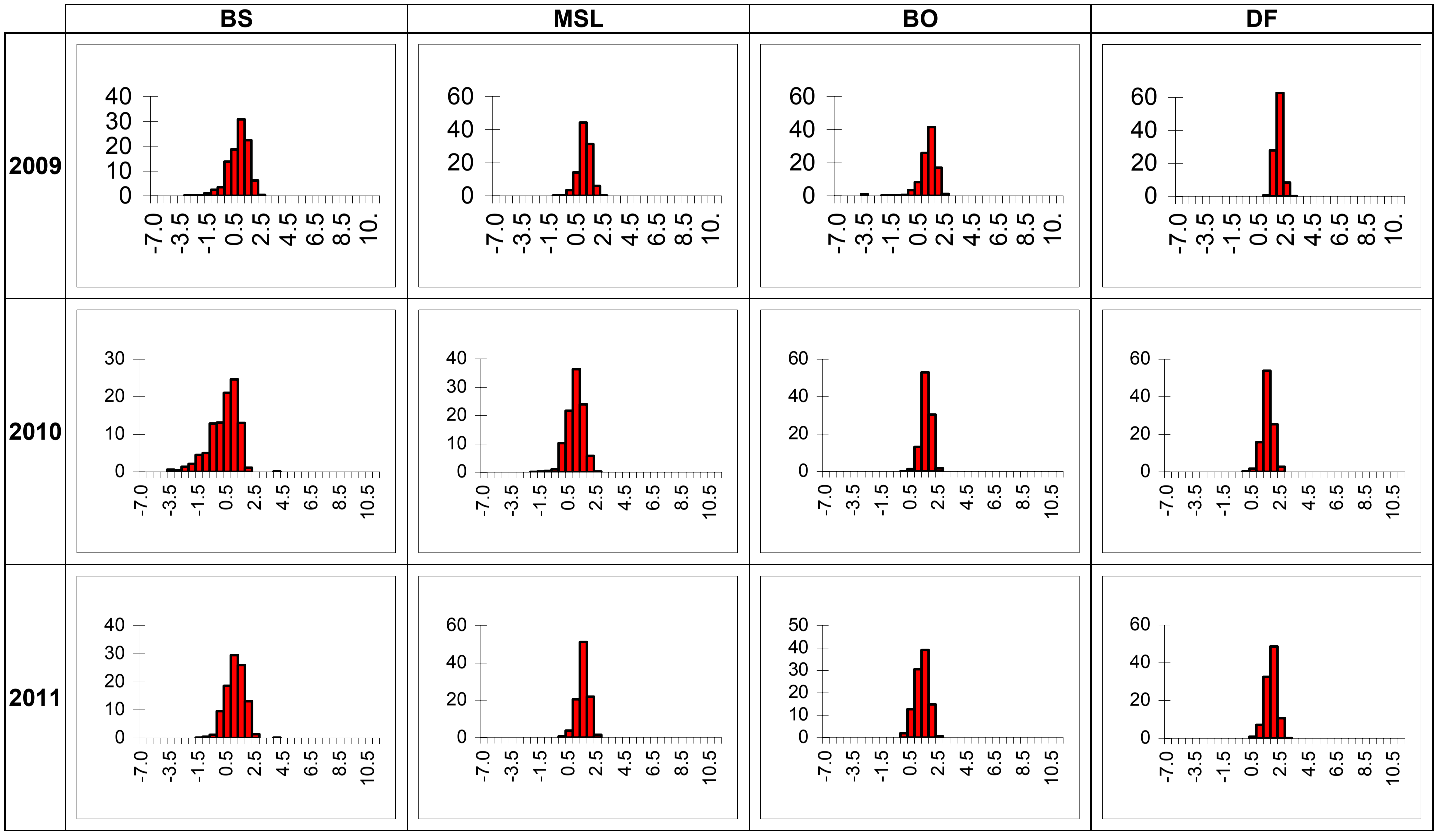
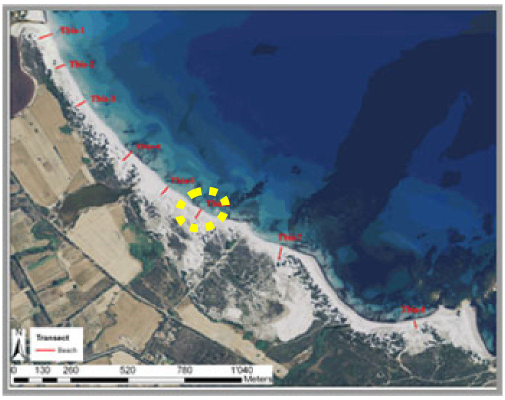


Figure 3.120 – Samples collected along profile T5bis in 2009-2010-2011 (x-axis: phi; y-axis: %). BS: beach step; MSL: mean sea level; BO: ordinary berm; DF: dune foot.

T6bis profile



The wide of the beach along T6bis profile (Fig. 3.121) was about 30 meters.
The shoreline was stable during the monitoring period.
A huge sector was occupied by embryo dunes that didn't show changes during the monitoring period.
Changes were more evident in the area between the embryo dunes and the established dune ridge where an anthropic path has lowered and changed the morphology of the profile.

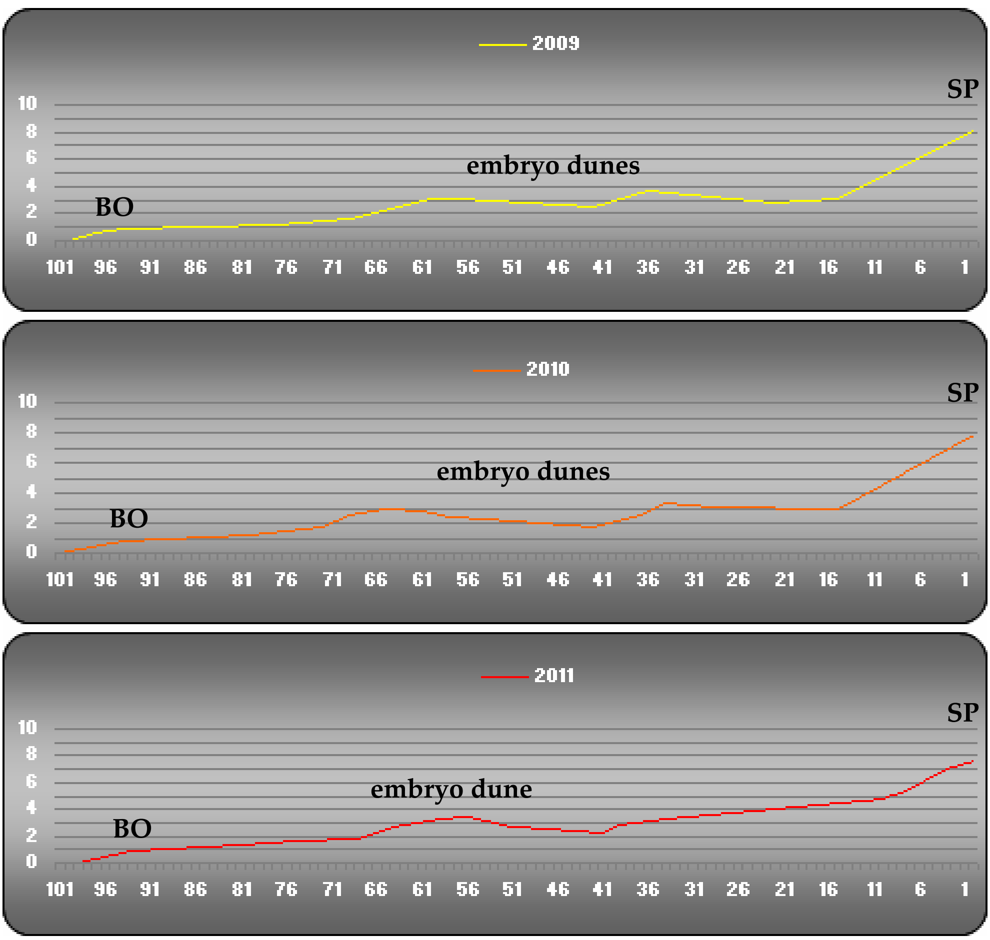


Figure 3.121 – T6bis profile in 2009-2010-2011 and its location in Capo Comino beach (up); x-y axes in meters.

In this sector no evidences of sea storms were noted.

Figure 3.122 – Tongue of a blowout developing from W to E.

This profile was affected by sand transport. Sediment came from inland and it was related to a tongue of blowout developing from W to E (Fig. 3.122). The tongue has climbed the established foredune ridge from the backslope to the shoreface.

Samples were collected and results are shown in figure 3.123.

BO and DF-samples were characteristic of aeolian sediment transport, with a general distribution in two classes of grain size.

BS and MSL-samples were heterogeneous and characterized by the presence of shells and little pebbles.

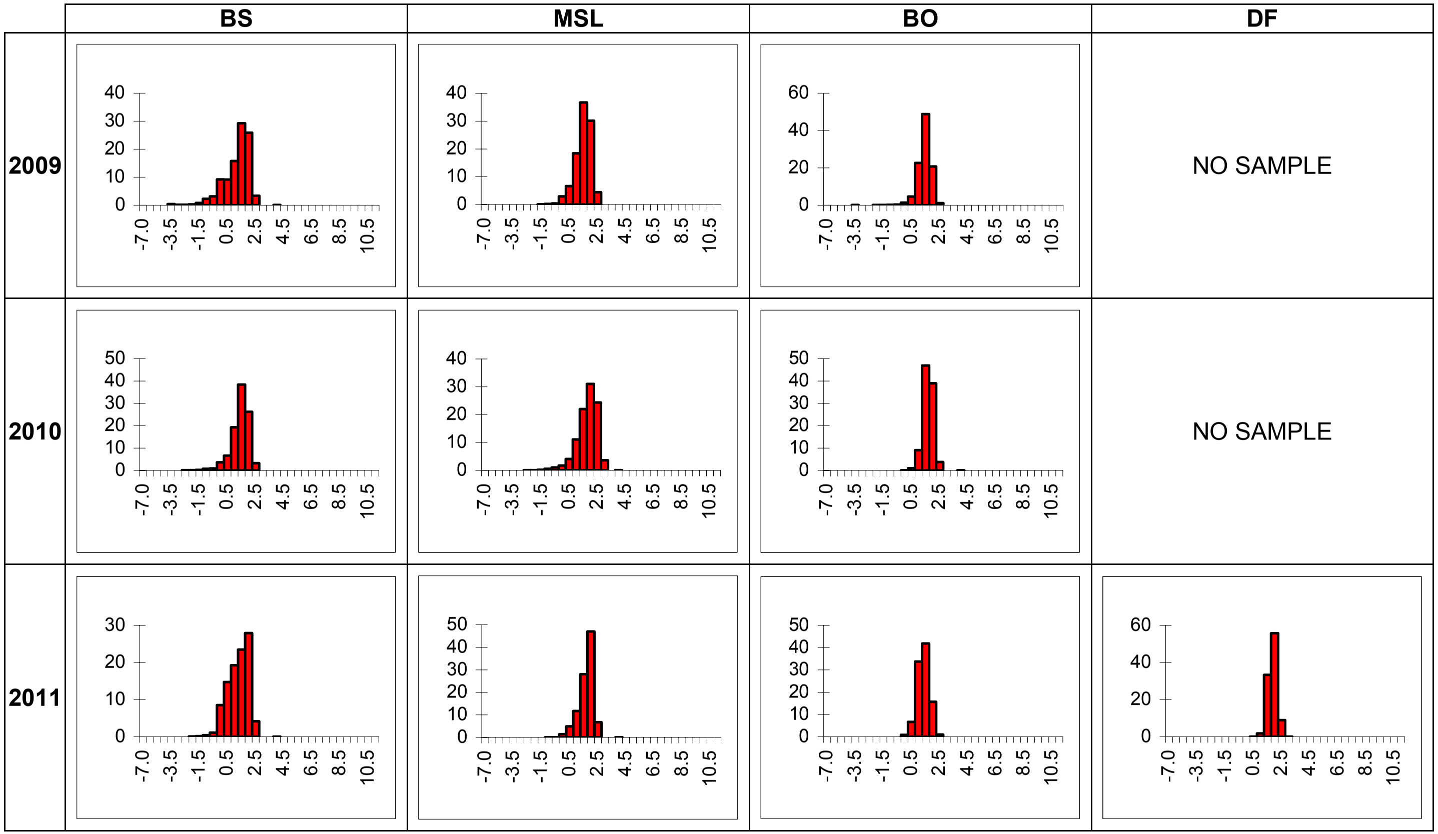
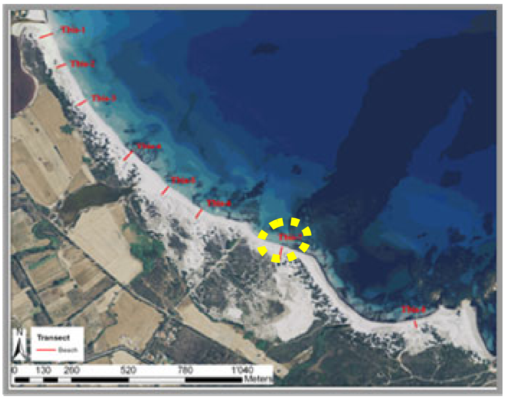


Figure 3.123 – Samples collected along profile T6bis in 2009-2010-2011 (x-axis: phi; y-axis: %). BS: beach step; MSL: mean sea level; BO: ordinary berm; DF: dune foot.

T7bis profile



T7bis profile (Fig. 3.124) was located in the central sector of the beach, where the oldest establishes foredunes with *Juniperus* trees were directly close to the sea and affected by storm waves (Fig. 3.125).
After a quite flat beach, a very steep slope defined the limit with the dune system (slope value is about 37° or 82%). This slope represented the scarp eroded by sea storm and several plant roots were completely exposed.

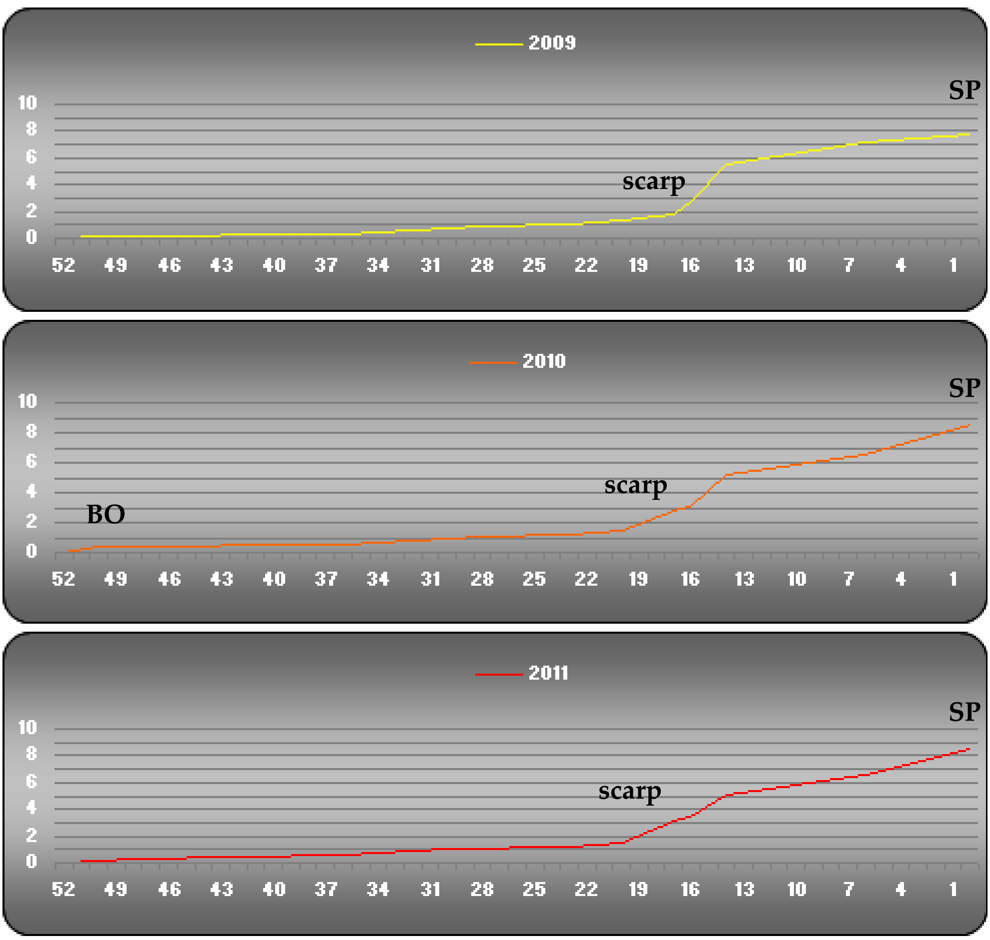


Figure 3.124 – T7bis profile in 2009-2010-2011 and its location in Capo Comino beach (up); x-y axes in meters.

This sector was characterized by the highest rate of erosion, of about -40 meters from 1954 to 2006. But in the short-term analysis (2009-2011) the morphological profile was quite the same. The only relevant change was the presence of a sand deposit at the base of the dune scarp in 2010-2011. This deposit was related to sand burial, as demonstrated by the analysis of the samples.

Figure 3.125 – Beach view close to T7bis. *Juniperus* trees are affected by salt spray and the base of the dune is sometimes eroded by waves.

The distributions of the grain size were generally represented by leptokurtic curves (Fig. 3.126).

DF-samples (most of all in 2010 and 2011) were characteristic of aeolian sediments.

BS and MSL-samples, instead, were more heterogeneous with coarse tails.

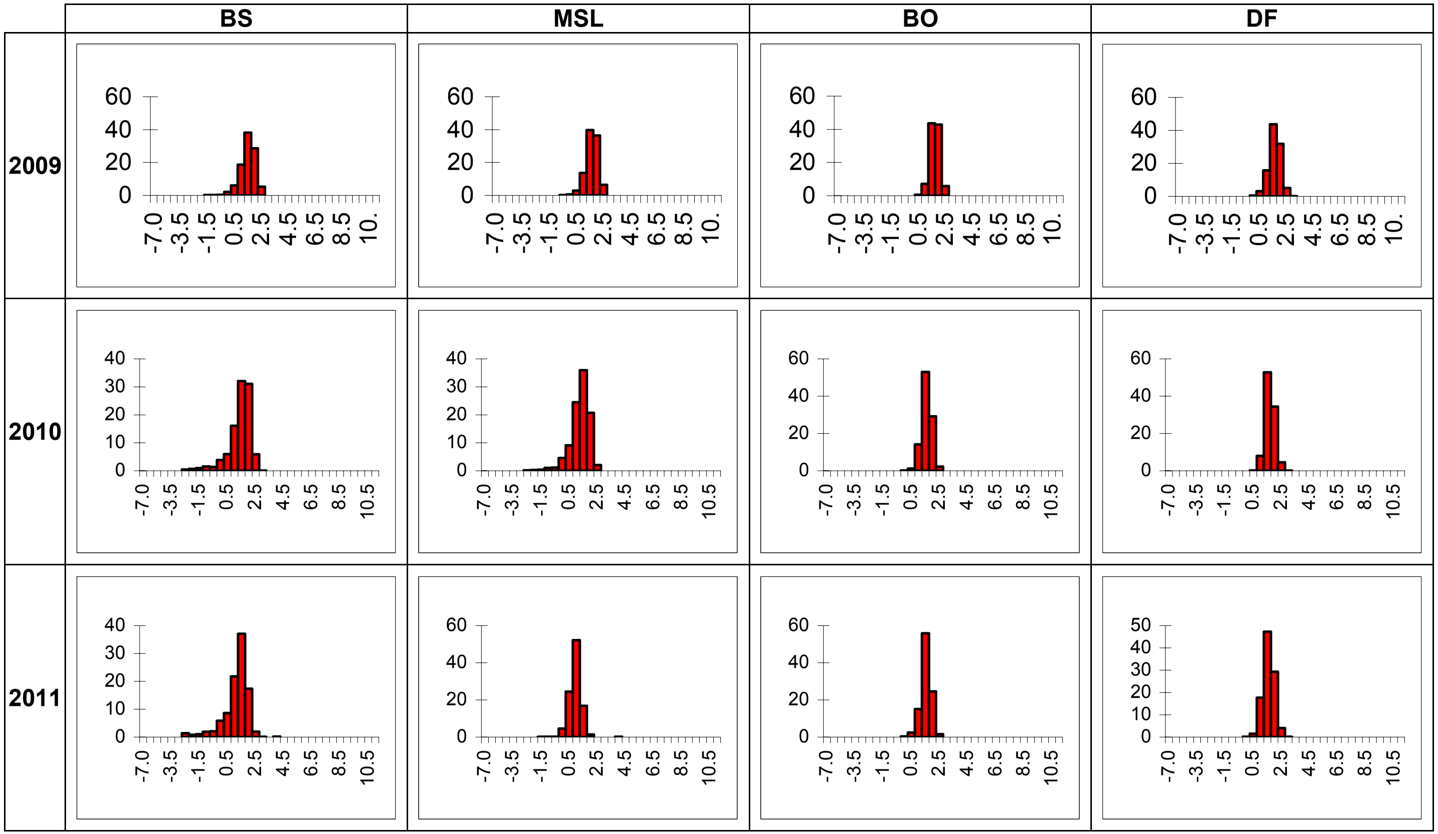
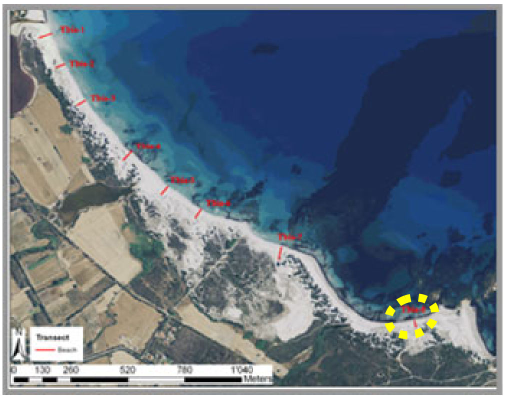


Figure 3.126 – Samples collected along profile T7bis in 2009-2010-2011 (x-axis: phi; y-axis: %). BS: beach step; MSL: mean sea level; BO: ordinary berm; DF: dune foot.

T8bis profile



T8bis profile (Fig. 3.127) was located in the south-eastern sector of the beach. The nearshore was characterized by the presence of a lot of outcrops and a huge *banquette* was present during the entire monitoring period (Fig. 3.128).
The longshore drift favors the sand accumulation on this sector of the beach and, even if the beach wide is only 20 meters, the shoreline resulted stable during the time and the slope was always gentle (about 3°).

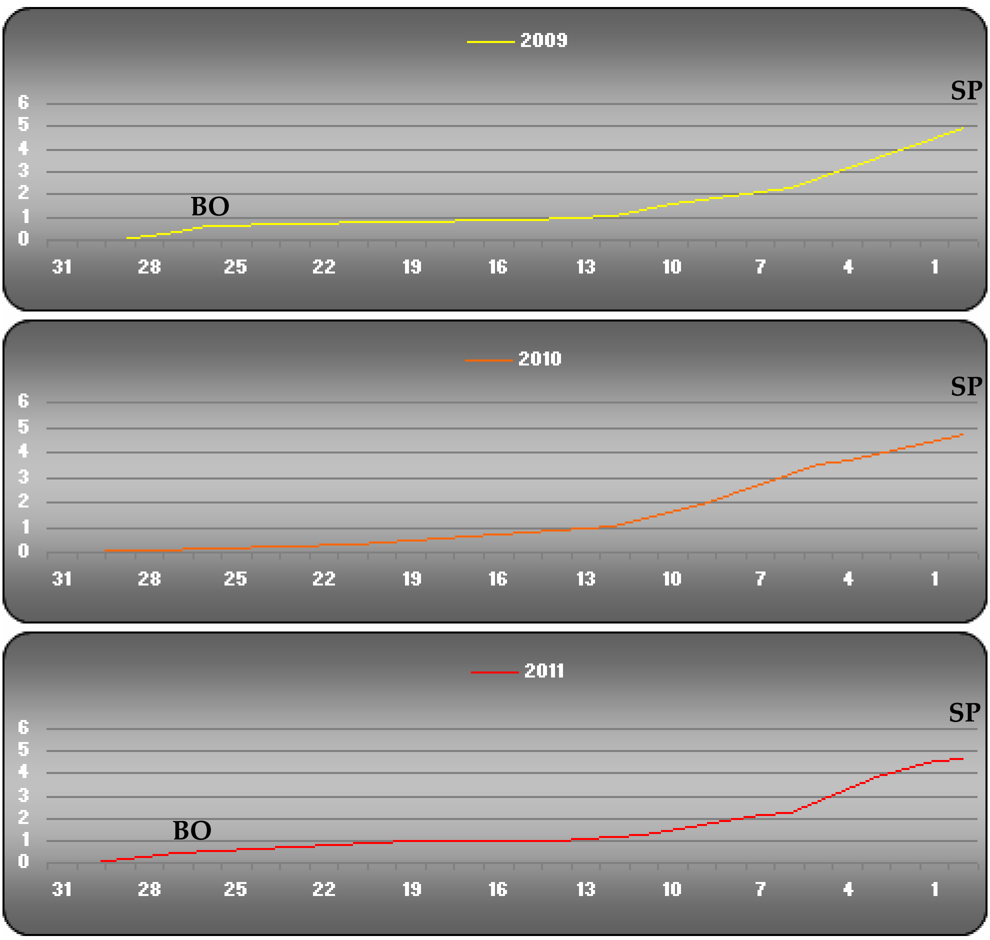


Figure 3.127 – T8bis profile in 2009-2010-2011 and its location in Capo Comino beach (up); x and y-axes in meters.

Embryo dunes were present only at the base of the established dune ridge, where sand was accumulating by winds.

Figure 3.128 – Beach view close to T8bis. Huge *banquette* in 2011.

Sediments distribution is shown in figure 3.129.
Coarse sediments were present only in BS-samples. MSL, BO and DF-samples were characterized by homogeneous sediments. They were well-sorted and presented a leptokurtic curve of distribution.

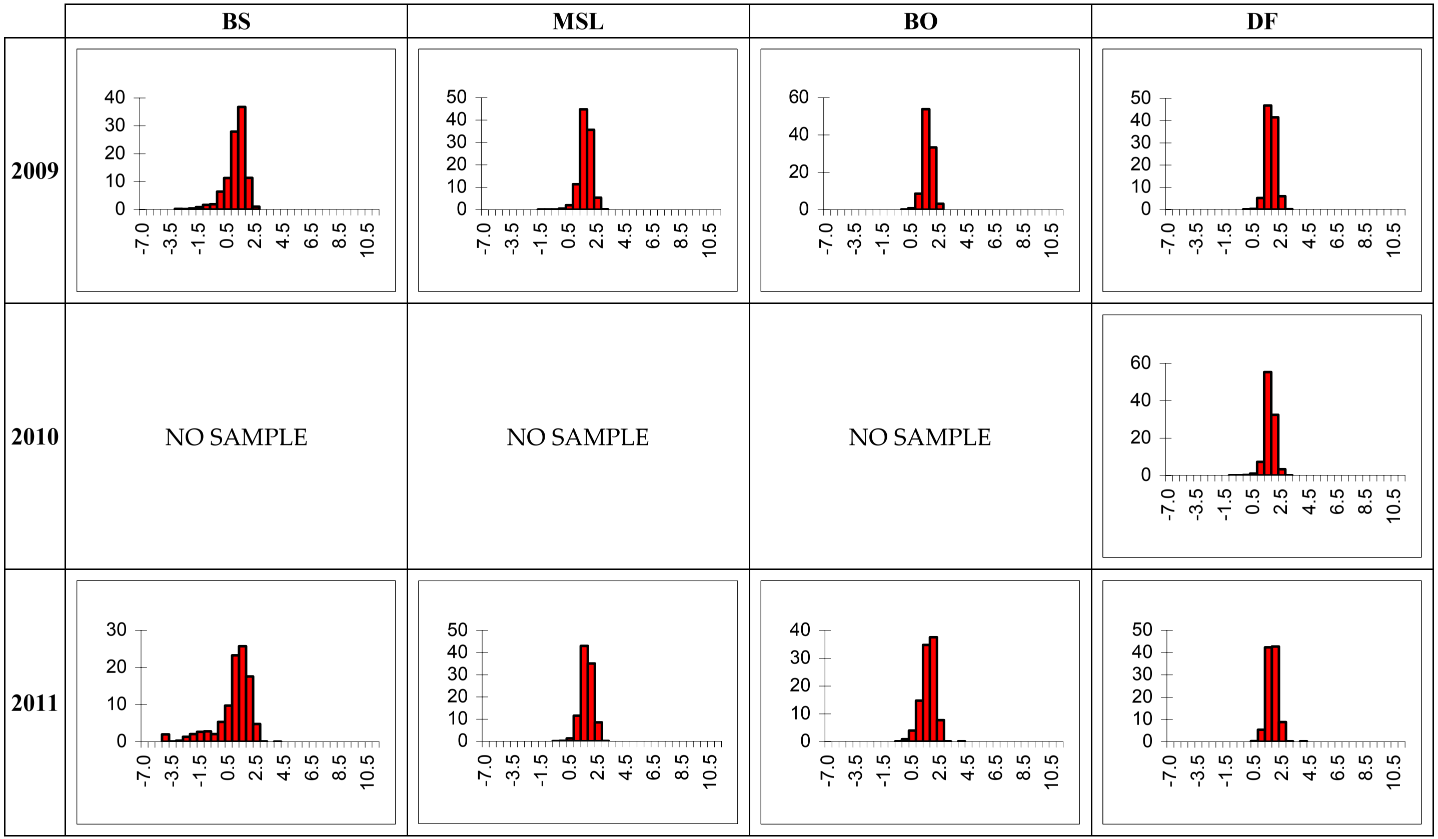


Figure 3.129 – Samples collected along profile T8bis in 2009-2010-2011 (x-axis: phi; y-axis: %). BS: beach step; MSL: mean sea level; BO: ordinary berm; DF: dune foot.

3.3.4 Discussion

The geophysical survey of the nearshore zone allowed creating the detailed bathymetric map of Capo Comino and samples defined the distribution of the sediment on the seafloor. The integration of those data with the analysis of the coastline highlighted the intermediate-dissipative profile of this sandy beach. Indeed, the presence of a gentle slope and bars allow the wave energy dissipation in the nearshore zone (Fig. 3.130).

Figure 3.130 – Wave spilling in Capo Comino beach (June 2010).

The morphology of beach profiles showed several changes during the monitoring period. First of all, between 2009 and 2010 a sea storm probably occurred eroding the base of the embryo dunes and it formed an erosive scarp, in particular in the northern sector of the beach. But the fast dynamic of the beach-dune system allowed the reconstruction of aeolian deposits between 2010 and 2011. This was demonstrated by the presence of new or partially-reconstructed embryo dunes.

The beach usually presented the typical morphological forms (e.g. berms, scarps), except for those sectors where mechanical vehicles were used for the beach cleaning operations and "produced" a flat beach profile.

Beach slope was usually gentler in the northern and central-southern sector (with values of about 6-7%). The sector of T3bis and T4bis, instead, presented higher slope values between 10 and 12%.

In general, due to the low erosive rate of the shoreline over the long term (1954-2006), the beach may be considered relatively stable. The morphological profile analysis (2009-2011) determined that the principal changes were related to periodic sea storms that were able to erode the embryo dunes and sometimes the first established dune ridge. Monitoring of profiles also revealed that the dynamic of the beach and the wind action can rapidly reconstruct the morphological forms just eroded.

A very interesting subject should be the study of the influence of the flooding events on the beach. These events are relatively common in this beach, due to the presence of two salt marshes and a river mouth. Floodings, in fact, may bring a lot of new sediment to the beach and, at the same time, erode dune ridges that surround the banks. Several evidences of these events were noted on the field.

Concerning the sediments, samples never presented a bimodal distribution (sometimes it may happen where there is mixing of population, such as for combination of different minerals and sand sources). The distribution of the grain sizes was always unimodal.

In particular, samples collected from the dune foot always presented a leptokurtic curve with the distribution of grain sizes in two main classes. This is mainly related to the aeolian transport from the shore to inland.

Samples collected from the ordinary berms resulted homogeneous and well-sorted. MSL samples were, instead, more heterogeneous. This anomalous situation (we should expect heterogeneous sediments on the berm and well-sorted sediment on the foreshore due to the run-up) was probably due to the general uniformity of the grain sizes.

BS samples were heterogeneous with coarser tails because of a lot of shells and little pebbles (coming from the eroded outcrops) were found.

The comparison of the indexes well explains the sediment drift along the beach (Figs. 3.131 and 3.132).

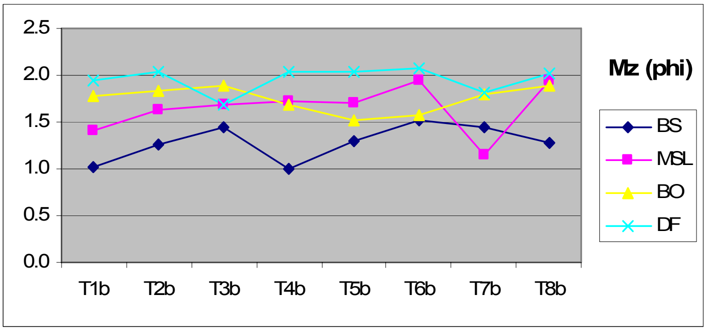


Figure 3.131 – Comparison between the mean grain size of 2011 samples (x-axis: sample; y-axis: value in phi).

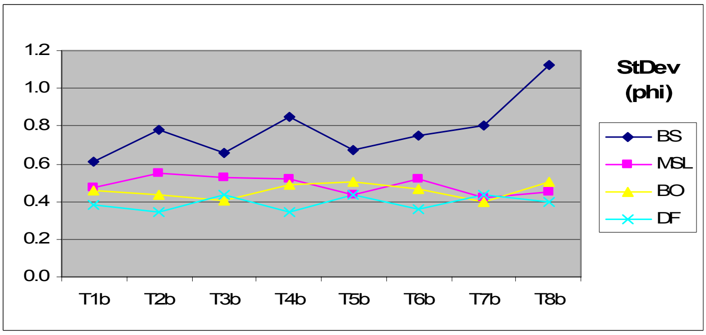


Figure 3.132 – Comparison between the standard deviation of 2011 samples (x-axis: sample; y-axis: value in phi).

Figure 3.131 shows the textural characteristics of samples collected in 2011 along the Capo Comino beach.

Mz-distribution presented a general decreasing of the sediment grain sizes from north to south. T4bis and T5bis were exceptions because they were located close to the right and left sides of the river mouth.
This distribution was well indicated by BS-values distribution. It presented a decreasing value of the mean grain size from T1bis to T3bis. T4bis value was anomalous (influenced by *Salinedda*'s river mouth and the presence of many outcrops close to the shoreline).
Therefore the N-S drift was confirmed by the decreasing of T1-2-3bis and T4-5-6bis values.
A similar distribution was well shown by MSL-Mz values. The general trend highlighted the presence of finer sediments from North to South. T7bis samples was anomalous and characterized by coarser sediment and it interrupted the decreasing trend.
BO-Mz values were well-sorted and homogeneous. Values of T4bis and T5bis were anomlous and influenced by *Salinedda's* river mouth.
DF-Mz values showed a regular grain size distribution and they were related only to wind action. The grain size changes correspond to topographic variations of the first foredune ridge that may influence the wind speed and the sand deposition (e.g. blowouts, gaps).
Standard deviation values (Fig. 3.132) showed a general homogeneity of sediments. MSL-BO-DF values mainly corresponded to leptokurtic distribution. BS-values, instead, highlighted a more heterogenity of sediments because they were characterized by shells/pebbles that usually give a coarser tail to curve of distribution.
Over three years, the general trend of sedimentological indexes was confirmed.
As an example, figure 3.133 compares mean grain sizes (Mz) of 2009, 2010 and 2011.

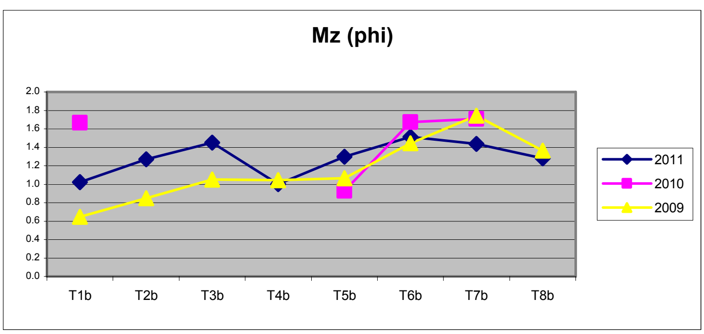


Figure 3.133 – Mean grain size distribution in 2009-2010-2011 (x-axis: sample; y-axis: value in phi).

Sediments in 2011 and 2009 followed a decresing distribution (except for T4bis). In 2010 no many samples were collected because of a *banquette* that was present along the beach. Therefore, it was impossible to compared it with the previous ones.
In general, the distribution of sediments in 2009 showed a less variability compared to 2011, with the decresing of grain sizes from north to south. The first sector (T1bis, T2bis, T3bis) was characterized by coarser sediments compared to 2011 but they presented a similar trend of distribution. This difference in size could be explained by a higher apport of sediments from *Salina* in 2009. The distribution of the samples also highlighted the influence of the river mouths and it confirmed a general longshore drift from north to south.

Chapter 4
THE MONITORING PROCEDURE

This chapter will focus on the development of a monitoring procedure.
The aim of this work is to integrate morphological and vegetational data – with several sedimentological considerations – in order to test a novel and rapid procedure for coastal dune monitoring.

Traditionally, it is usual to collect data at every fixed point along transects, such as every 1-2 meters. The method presented in the following paragraphs may be rapidly applied because during field surveys only key points were surveyed.
The results of the studies concerning the morphology of the dunefield (§3.1) and the vegetation (§3.2) have been widely explained previously. The analysis of the study areas indicated that they are both mutually dependent and affect each other.

The objective of this monitoring plan is to document the distribution of the plant life forms, their dynamics and responses to disturbances, and to identify those factors that are potentially responsible for both long-term and short-term changes. In particular, the morphological changes of the dunefield (primary due to sand transport) and the influence of climatic events (such as sea storms, floodings, *etc.*) have been considered.

4.1 Method

In general a monitoring plan consists of collecting qualitative and quantitative data related to a study area over time. By performing a standardized sampling method on a monthly, seasonal or yearly basis, a researcher can determine the status of the environment and may develop management steps to conserve the natural system.

The monitoring procedure used during this research is a response to this main question: "How can the response of this coastal dune environment to disturbances and natural changes be rapidly measured, using a multidisciplinary approach?". This is a difficult question to answer, but the study of the area by remote sensing and the analysis of the wind climate suggested that this coastal environment presents a morphological complexity that reflects a complexity in vegetation distribution. Therefore the location of several permanent monitoring stations and the analysis of the changes over a broad area (from the shore to inland) were carried out.

The procedure uses the "transect" as unit of measurement. Transect may give a complete set of information along a specific line concerning all the parameters of the environment. The same sampling method along the same transects ensures an accurate and comparable collection of data. Thus eight permanent transects were set up in the field (Fig. 4.1) and the SP (station point) locations were controlled every year by a D-GPS.
Regular photographs from fixed points were particularly useful to relocate station points from year to year.

The direction of each transect was associated with the prevailing wind influencing that specific sector. This direction was identified following the development of the main morphological features.

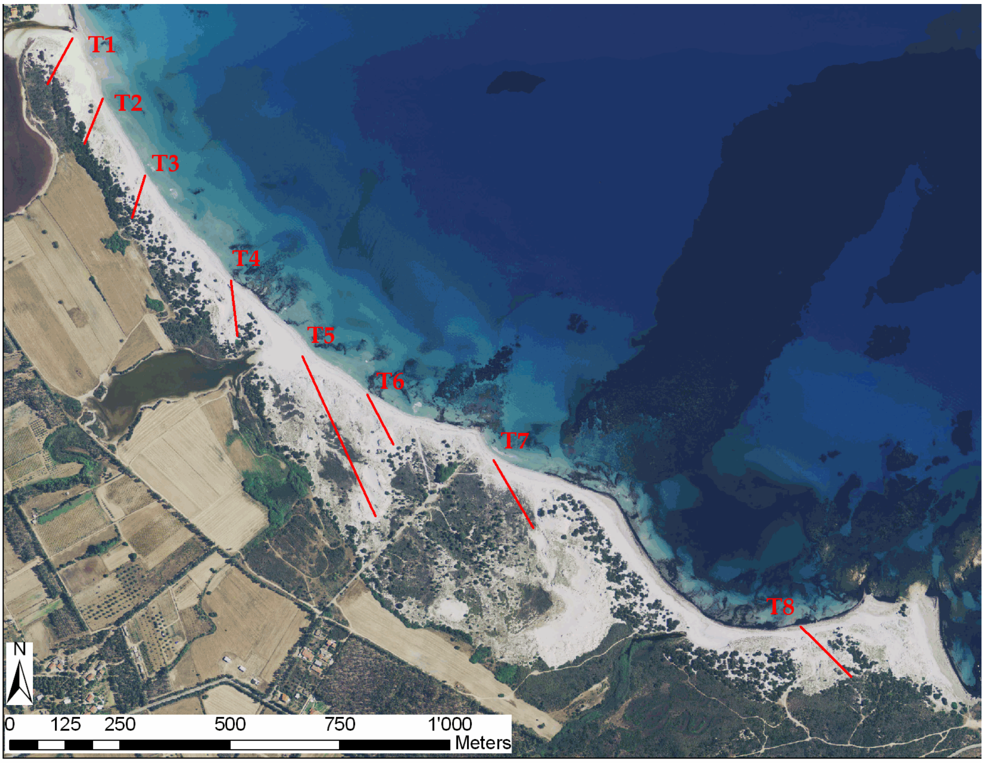


Figure 4.1 - Localization of the morphological and vegetation transects (2006 air photo, Regione Sardegna).

The multidisciplinary approach derives from the concurrent morphological and vegetation data collection and from the research of the common response to the same environmental change.

Topographical measurements were taken from 2009 to 2011 using a theodolite and a D-GPS. Data concerning the distribution of the vegetation associations and morphological features were collected annually. This linear method is well suited to the vegetation structure and the simple identification of the association is faster than measurements on quadrats.

Then data were processed in the laboratory. Transects were compared in a Microsoft Excel file with a macro specifically created for this purpose.

The x-axis of each line was normalized because the collected data were not at a specific distance each year. Y-axes and x-axes are expressed in meters.

The coordinates of the station points of each profile are indicated in annex VI.

In order to draw a profile and to associate the vegetation data, the name of each association is indicated with an abbreviation. The legend and the list of these abbreviations are presented in table 4.1.

	SaCa	*Salsolo kali-Cakiletum maritimae*
	few SiEl	presence of few plants of *Sileno corsicae-Elytrigetum junceae*
	SiEl	*Sileno corsicae-Elytrigetum junceae*
	few SiAm	presence of few plants of *Sileno corsicae-Ammophiletum a.*
	SiAm	*Sileno corsicae-Ammophiletum arundinaceae*
	SiEl on SiAm	*Sileno c.-Elytrigetum j.* on *Sileno c.-Ammophiletum a.*
	CrHe	*Crucianello-Helichrysetum microphylli*
	buried CrHe	*Crucianello-Helichrysetum microphylli* buried by sand
	SiEl on CrHe	*Sileno c.-Elytrigetum j.* on *Crucianello-Helichrysetum m.*
	SiAm on CrHe	*Sileno c.-Ammophiletum a.*on *Crucianello-Helichrysetum m.*
	ImSc	*Imperato cylindricae-Schoenetum nigricantis*
	buried ImSc	buried *Imperato cylindricae-Schoenetum nigricantis*
	PiCa / CiHa	*Pistacio lentisci-Calicotometum v.* or *Cisto salvifolii-Halimietum h.*
	transit	transition from PiCa/CiHa to OlJu
	OlJu / pinus	*Oleo sylvestris-Juniperetum turbinatae* or *Pinus pinea* population
	TyPh	*Typho angustifoliae-Phragmithetum maximi*

	SAND	sand
	Imp	*Imperata cilindrica* population
	Imp + SiEl	*Imperata cilindrica* with *Sileno corsicae-Elytrigetum junceae*
	SiOn	*Sileno nicaensis-Ononidetum variegatae*
	Inul	*Inula viscosa* population
	Imp + CrHe	*Crucianello-Helichrysetum m.* subass. *imperatosum cilindricae*

Table 4.1 – Legend and abbreviations of vegetation associations.

4.2 Results

<u>T1 transect</u>

The first transect (Fig. 4.5) was located in the northern sector of the beach, along the foredune-blowout complex. The profile was oriented 9°N. It was about 160 meters long and the general topography didn't change during the monitoring period, except to the upper beach sector.

The topography was characterized by a flat deflation area (from the shoreline to the upper beach) (Fig. 4.2) of about 85 meters wide, strongly influenced by the presence of *Salina*'s river mouth of (the northern salt marsh).

A "real" embryo dune was not present in 2009 and an erosive scarp indicated a previous erosive event. But the presence of SiEl association indicated that these pioneer species were colonizing the sand substrate and were starting to accumulate the sand and build the embryo dune (present in 2010 and 2011). In fact, in 2010-2011 an embryo dune with SiEl association was present.

Figure 4.2 - Seaward side of T1 transect (2011).

After the deflation area, the profile continued with the first established foredune ridge where the CrHe association was overlaid by the SiEl association in 2009 and a buried CrHe was present close to the crest (station point). In 2010 and 2011 the buried CrHe has disappeared.

The crest of the dune and the landward sectors of the profile (Fig. 4.3) were characterized by the presence of CrHe association, then by maquis of PiCa and OlJu associations. The inner section didn't change during the monitoring period.

Figure 4.3 - Landward view of the dunes close to T1 transect (2011).

Several samples (Fig. 4.4) were collected along the profile in 2009.
Their location is shown in figure 4.5.
All these samples presented an unimodal distribution.
Samples A-B-C-D are homogeneous and mainly distributed in two classes (1.5-2.0 phi). This distribution suggests the aeolian nature of these sediments. Sample E, instead, presented a wider distribution of the curve. It was collected close to the station point, where CrHe association was present in 2009. This type of community, developing in low pillows, may keep coarser fractions of sediments.

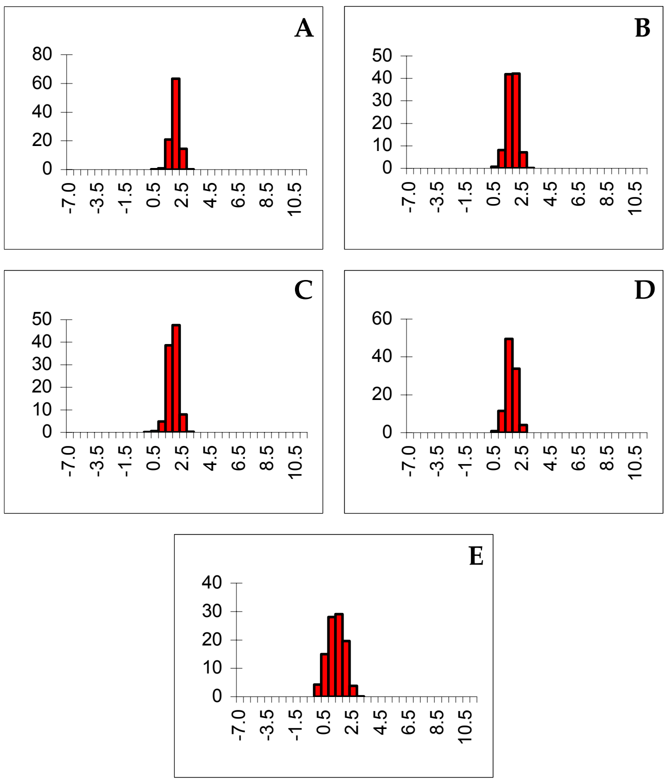


Figure 4.4 – Samples collected along T1 transect in 2009. (A: before SiEl association; B: SiEl association; C: SiEl-on-CrHe association; D: buried CrHe; E: CrHe association).

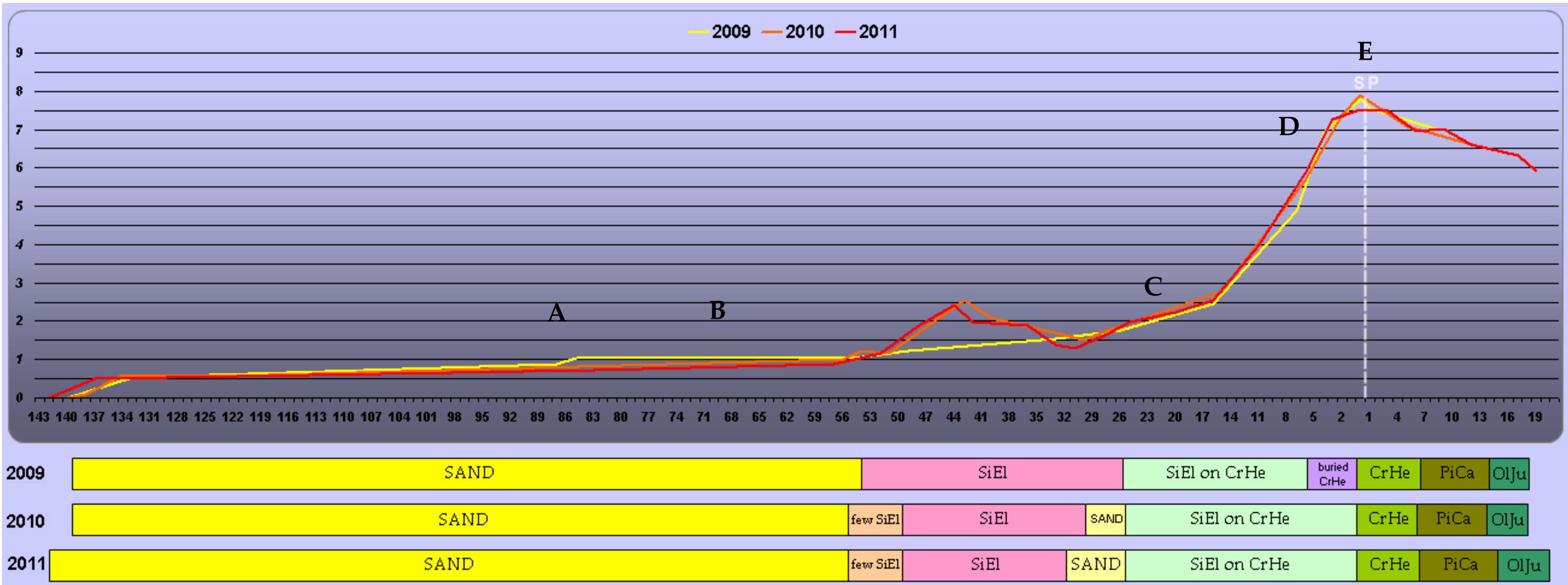


Figure 4.5 – T1 transect in 2009, 2010 and 2011 (x and y-axes are in meters; SP: station point).

T2 transect

The second transect (Fig. 4.9) was about 150 meters long and oriented 9°N, following the direction of onshore prevailing winds (Fig. 4.6).

The deflation area of the beach was about 40 meters wide and the foot of the first ridge was colonized by SiEl in 2009. This ridge was characterized by the presence of few *Ammophila a*. plants mixed with a buried CrHe association. In 2010 these species disappeared from the front of the ridge, probably due to an erosive event that changed the morphological profile too (the volume of the sand deposit have been decreased). In 2010 *Ammophila a*. plants were found only at the top of the ridge but overlaid by SiEl association (SiEl-on-SiAm).

In 2011 SiEl association and SiEl-on-CrHe were present on the ridge. *Ammophila a*. was totally disappeared.

Figure 4.6 - Seaward side of T2 transect (2010).

In 2009 a buried CrHe association was noted at the back of the first ridge (Fig. 4.7) but it gradually disappeared.

The second ridge was characterized by a CrHe association that in 2011 was totally buried, probably due to the sand transport by onshore winds.

Figure 4.7 - Landward side of T2 transect (2010).

Samples collected along T2 transect are presented below (Fig. 4.8; the location in figure 4.9).

Samples A-B, collected on the embryo dune, presented the characteristics of aeolian sediments with a homogeneous distribution in two prevailing classes.

Sample C presented coarser component, coming from the falling down of sediments from the instable dune crest. Indeed, blowout is an erosive form that deeps and increases its surface. The edges of a trough blowout are usually instable so it is possible to find coarse sediment close to edges. It is also possible to find less-sorted and heterogeneous sediments in the inner surface of the blowout and they represent coarser residual grain sizes.
Sample D was located at the crest of the dune ridge, where the CrHe association has been gradually buried by sand transport. In fact, the distribution of its sediments suggests a higher component from aeolian processes.

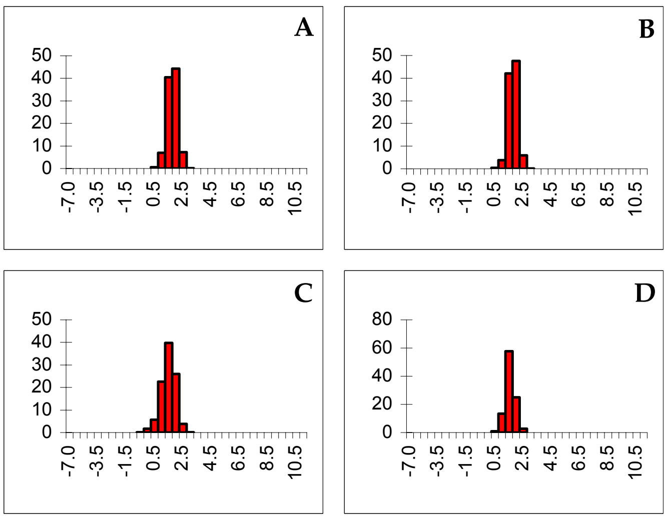


Figure 4.8 – Samples collected along T2 transect in 2009. (A: SiEl association; B: CrHe association; C: blowout with few SiEl; D: buried CrHe).

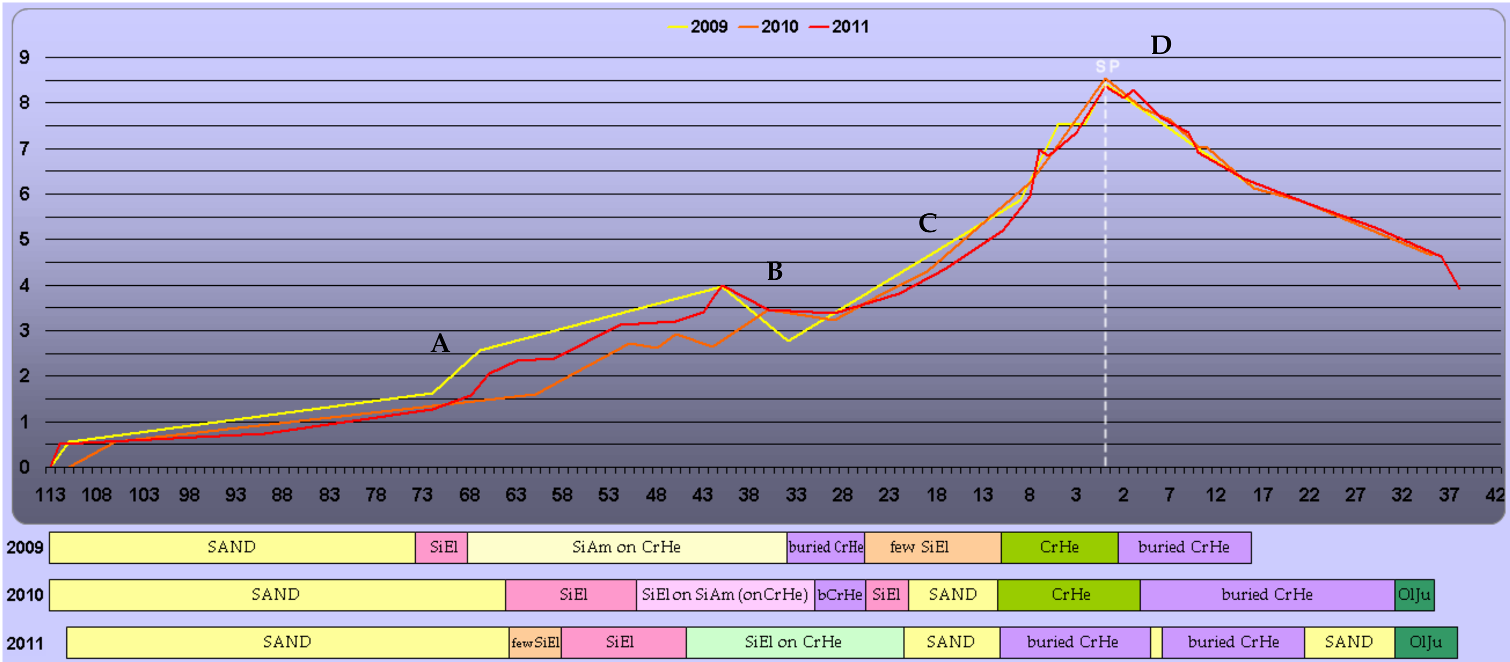


Figure 4.9 – T2 transect in 2009, 2010 and 2011 (x and y-axes are in meters; SP: station point).

T3 transect

This transect (Fig. 4.13) was oriented 6°N, following the prevailing wind direction. It was about 100 meters long and the deflation area was about 40 meters wide.

The profile and the distribution of the vegetation were quite similar to transect T2 (Fig. 4.10).

The SiAm association was present on the first dune ridge in 2009, and it overlapped on an old CrHe association. The evolution of the vegetation on this ridge followed the same dynamic presented in the previous profile. In fact, in 2010 SiAm has been noted with a high component of SiEl association because of the sand burial. In 2011, instead, the last plants of *Ammophila a*. disappeared and only SiEl association was present with the last components of the old CrHe association.

Figure 4.10 - Seaward side of T3 transect (2010).

The increasing transport of sand was confirmed by the presence of a buried CrHe between the two ridges in 2009-2011. Behind the station point, the profile didn't change from 2009 to 2011. It shows the presence of CrHe on the crest, followed by a buried CrHe and the presence of an anthropic path (SAND) (Fig. 4.11).

Samples collected along T3 transect are presented in figure 4.12 (the location in Fig. 4.13).

These three samples presented the characteristics of sediments transported by winds, with homogeneous distribution in two prevailing classes. This evidence confirms the previous observations concerning the evolution of this transect and the process of sand transport to inland.

Figure 4.11 - Landward view of dunes close to T3 (2010). To note the presence of a lot of blown sand.

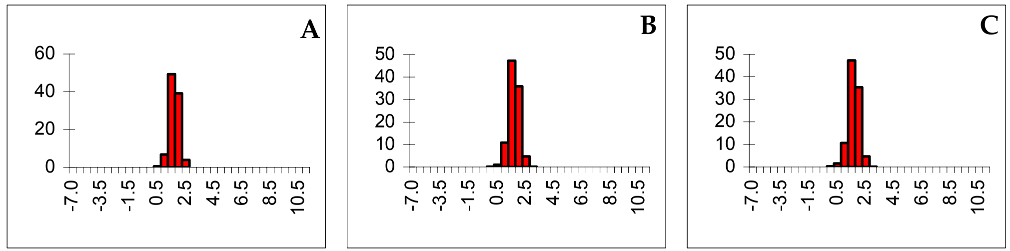


Figure 4.12 – Samples collected along T3 transect in 2009. (A: first dune foot, no vegetation; B: SiAm on CrHe; C: buried CrHe).

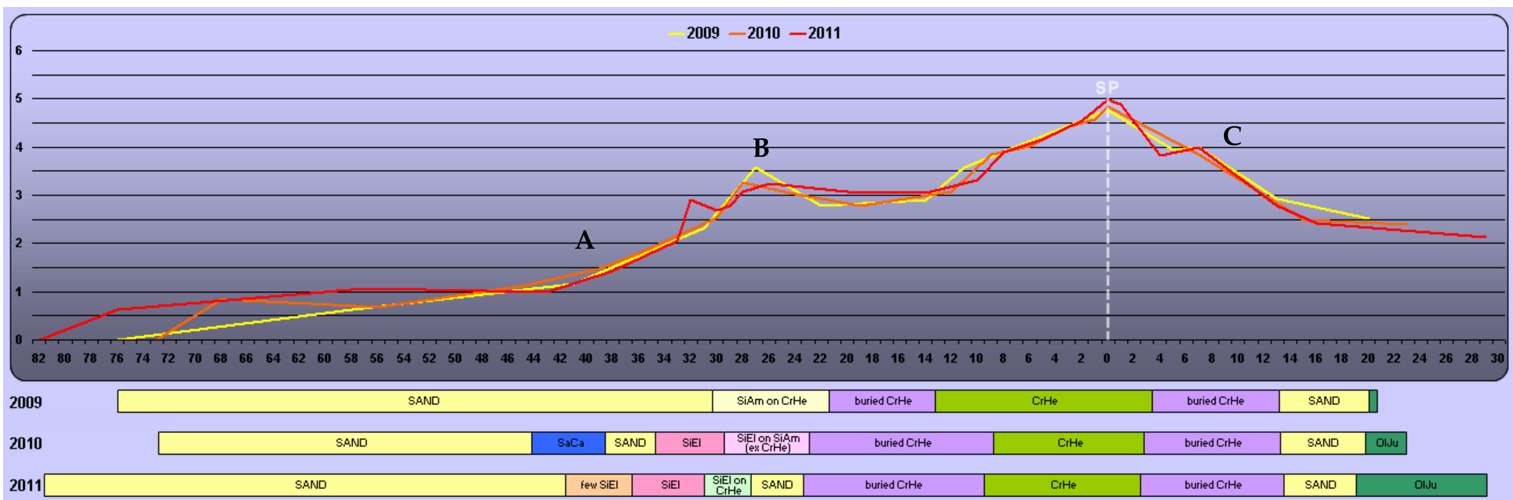


Figure 4.13 – T3 transect in 2009, 2010 and 2011 (x and y-axes are in meters; SP: station point).

T4 transect

T4 profile (Fig. 4.18) was located close to the *Salinedda* river mouth, in the transition sector between the foredunes and the parabolic dunes.
This sector was characterized by a wide deflation area and it was common to find evidences of sea storms (Fig. 4.14). This is confirmed by the presence of SaCa association in 2009 profile between the first and the second ridge.


Figure 4.14 – Evidences of sea ingression, close to T4 transect (2011).

T4 transect was about 170 meters long and it was oriented 358°N.
The profile was subjected to essential change in the seaward sector (Fig. 4.15). In 2009 a huge dune ridge (about 4 meters high) was present.
The vegetation was characterized by a SiEl-on-CrHe association.
In 2010 this ridge was eroded by a sea storm and only a 2 meters high dune ridge remained, with the remaining plants of SiEl-on-CrHe. In 2011 this deposit totally disappeared.
The aeolian deflation provided to sand transport to inland and SiEl association was able to colonize the base of the stoss slope in 2009 (present in 2010 too). In 2011 few initial species were increased and SiEl association was noted.


Figure 4.15 - Seaward side of T4 transect (2011).

In 2009 the station-point area was characterized by a buried CrHe (because of remnant knobs were present). In 2011 the presence of SiEl predominated on CrHe association.

The high transport rate of the sand was confirmed by the presence of SiEL-on-CrHe in the backslope of the dune, starting from 2009 to 2011 (Fig. 4.16).
The OlJu association was identified at the end of the profile.

Figure 4.16 - Landward view close to T4 (2011). To note the presence of a lot of blown sand and a steep slope at the leeside of the dune.

Samples were collected along T4 transect in 2009 and results are shown in figure 4.17 (the location is presented in Fig. 4.18).
Sediments of A-B-D samples had a comparable distribution, with the prevalence of two main classes (2-1.5 phi). These sediments confirmed the high sedimentary sand transport to inland.
Sample C was collected in the lower area between the first and the second dune ridge. It presents a coarser tail due to debris coming from the sea during storms. The presence of SaCa association (2009) in this sector confirmed this observation.
Sample E was characterized by a high frequency of 1.5 phi class. It was collected on the leeface (slipface) of the second dune ridge and it is a typical aeolian sediment, such as demonstrated by the presence of a buried CrHe association.

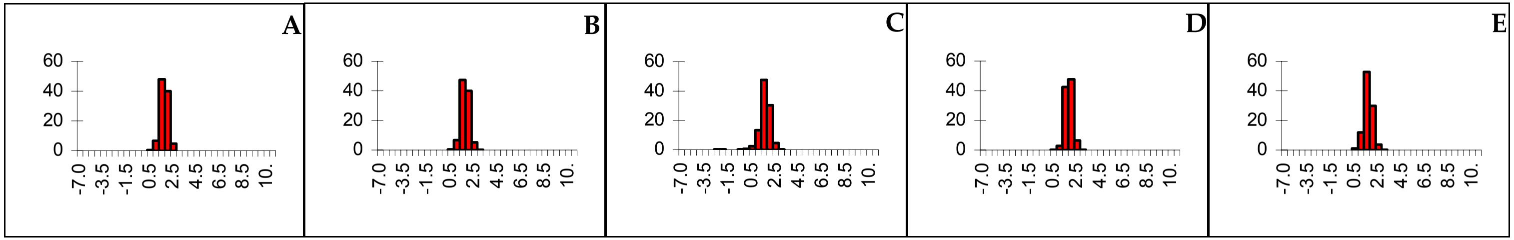


Figure 4.17 – Samples collected along T4 transect in 2009. (A: first dune foot, no vegetation; B: SiEl on CrHe; C: SaCa; D: sand/stoss-lope; E: slipface with buried CrHe).

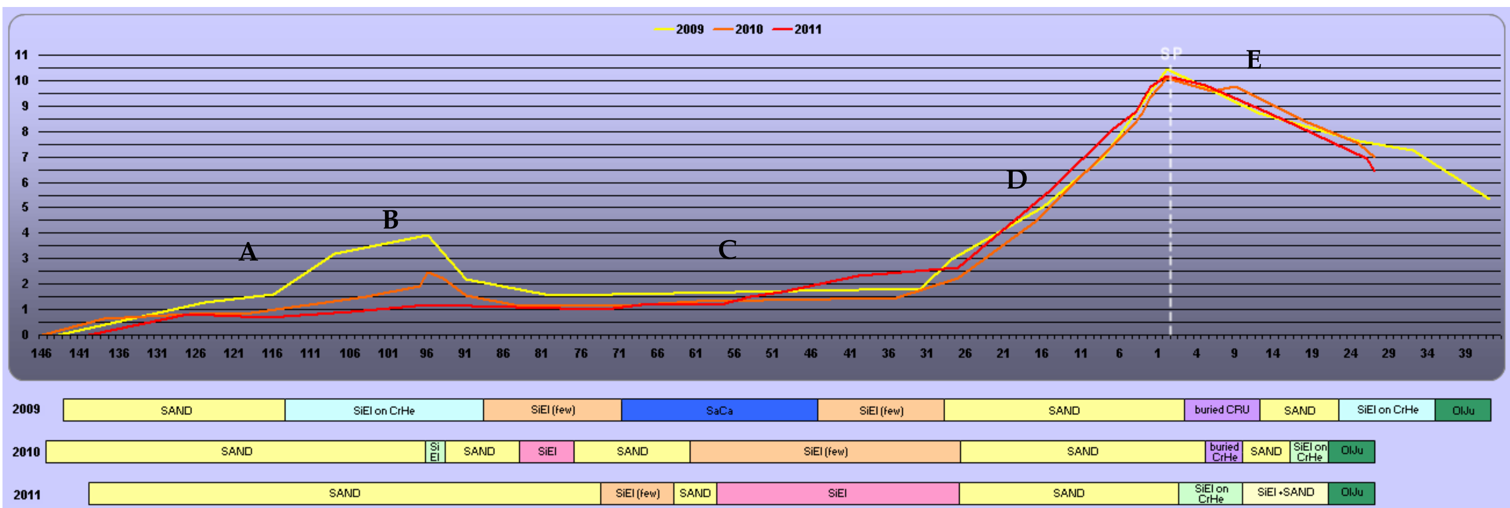


Figure 4.18 – T4 transect in 2009, 2010 and 2011 (x and y-axes are in meters; SP: station point).

T5 transect

This profile was located in the north-central sector of Capo Comino dunefield. It presented a very complex profile due to the transition between a narrow foredune/blowout complex and the inner parabolic dunes.
It was about 380 meters long and oriented 355°N. The entire profile is shown in figure 4.22 but the figure has been divided in three parts in order to better point out the morphological and vegetation features.
The seaward sector of this transect (Fig. 4.19) was strongly influenced by *Salinedda* river mouth.

Figure 4.19 – Picture from T5 station point (2011).

Figure 4.23 shows the first part of the profile. The migration of the river bed during three years of observations is well represented. As a consequence, the deflation area of the beach might change a lot depending on the river mouth position.
In 2009 SaCa association was noted as evidence of debris deposit on the middle beach. The first association was represented by SiEl that colonized the upper beach in 2009, 2010 and 2011.
The dune foot, instead, registered the presence of SiAm association forming a low deposit (about 1 meter high in 2010 and 1.5 meters high in 2010-2011).
In 2009 the inner slope of the first dune ridge was occupied by SiEl-on-CrHe; then it disappeared in 2010-2011, and the presence of SiAm association was noted on the crest of the first dune ridge, where SP was located.
The landward of the transect (Fig. 4.20) was very complex.
The second sector (Fig. 4.24) was influenced by the presence of the tongue of a surrounding blowout. In fact the presence of SiEl association and sand was due to blowing sand coming from the seaward sector (where the blowout originated) (see Fig. 4.20).
The following associations represented the response of the vegetation to the morphological changes because of the presence of this blowout. In fact, CrHe association was buried and its extension (buried CrHe) was increased during three year, following the dynamic of the increasing blowout.
A CrHe association was noted on the top of the blowout.

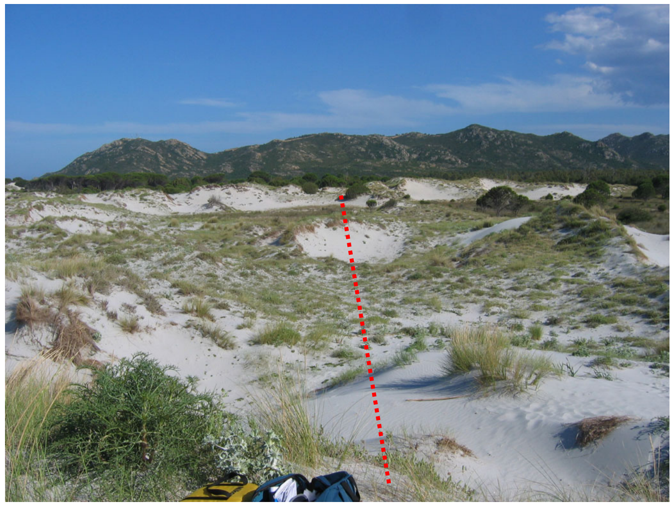


Figure 4.20 – Landward side from T5 station point. To note the presence of the tongue of blowout in the foreground and of second blowout developing along the line.
At the backfront, the digitated parabolic dune complex.

Figure 4.25 shows the end of T5 transect. This sector belonged to the central parabolic dunes complex and it was characterized by the presence of a wide and low deflation basin. The prevailing association was ImSc.

Two higher ridges interrupted the basin and they corresponded to Gegenwalle ridges. CrHe association was identified of them.

A younger Gegenwalle ridge characterized the base of the stoss slope of the parabolic dune and *Imperata c.* was noted on it.

The stoss slope (erosive form) and the crest (sand deposition on it) were characterized by sand.

A buried CrHe was identified at the backslope of the dune.

Three samples were collected along T5 transect and the histograms are presented in figure 4.21 (the location is shown in Figs. 4.24 and 4.25).

Sample A, collected on the first dune ridge, and sample B, collected on the buried CrHe, presented the typical characteristics of aeolian sediments with a homogeneous distribution in two classes (2.0-1.5 phi).

Sample C (collected on the stoss slope) had coarser components, coming from the falling down of sediments from the dune crest.

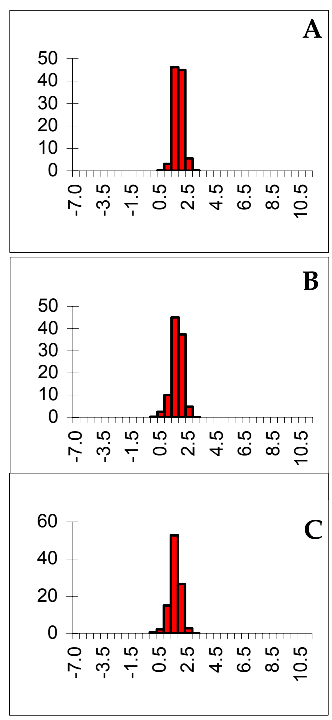


Figure 4.21 – Samples collected along T5 transect in 2009. (A: SiAm; B: buried CrHe; C: sand).

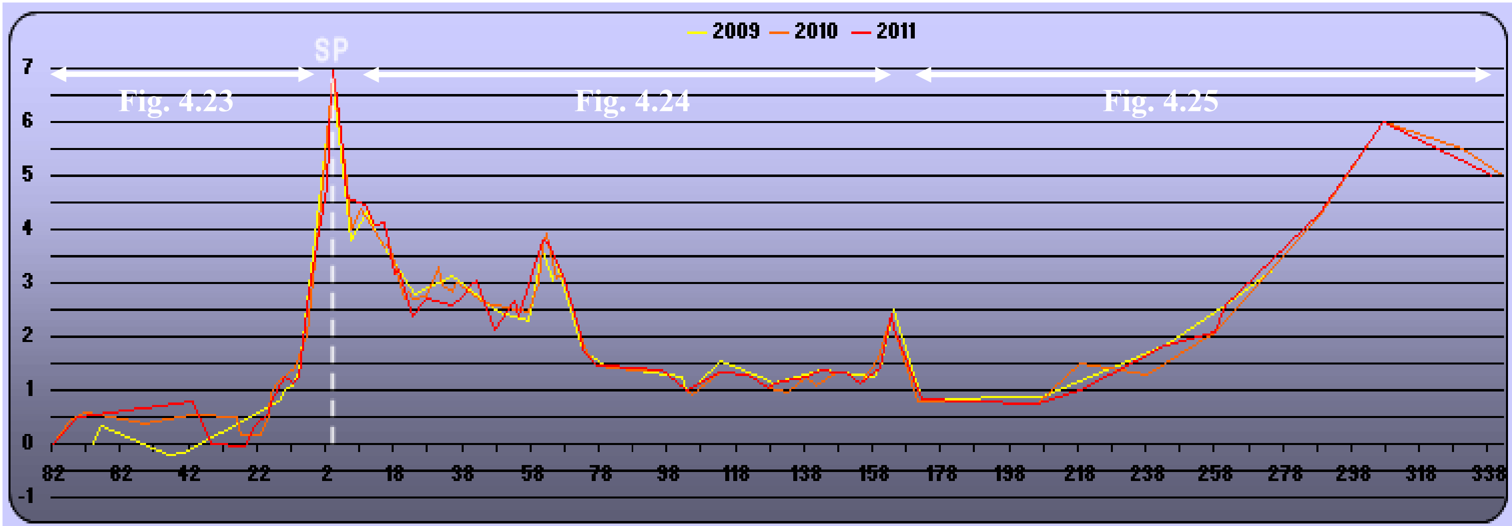


Figure 4.22 – T5 transect in 2009, 2010 and 2011 (SP. station point). It has been divided into figures 4.23, 4.24 and 4.25 (x and y-axes are in meters; SP: station point).

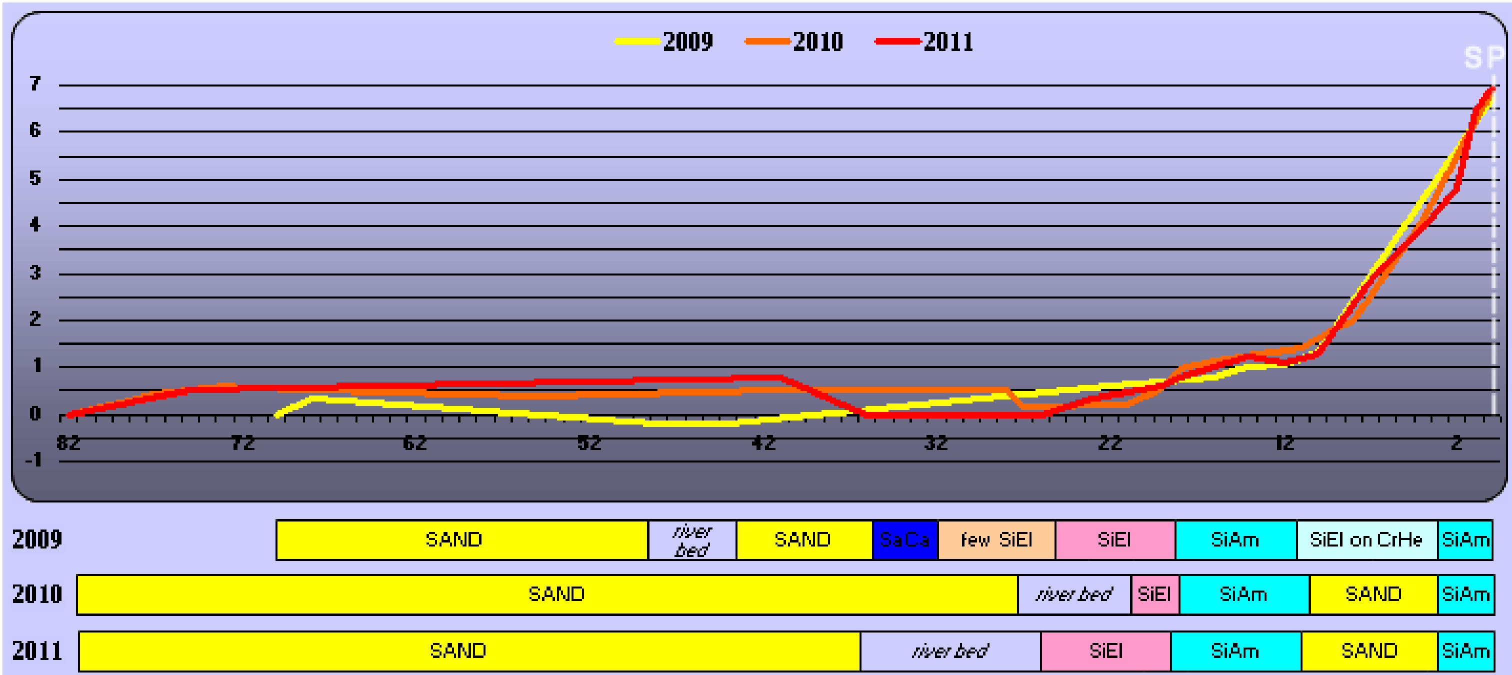


Figure 4.23 – First sector of T5 transect in 2009, 2010 and 2011 (x and y-axes are in meters; SP: station point).

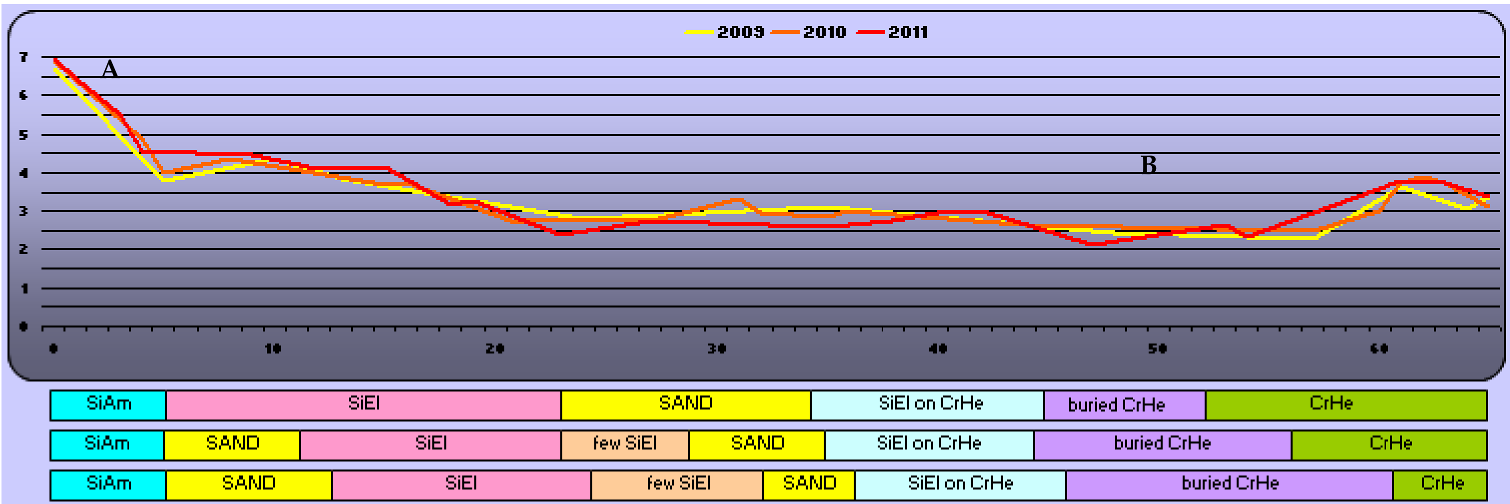


Figure 4.24 – Second sector of T5 transect in 2009, 2010 and 2011 (x and y-axes are in meters).

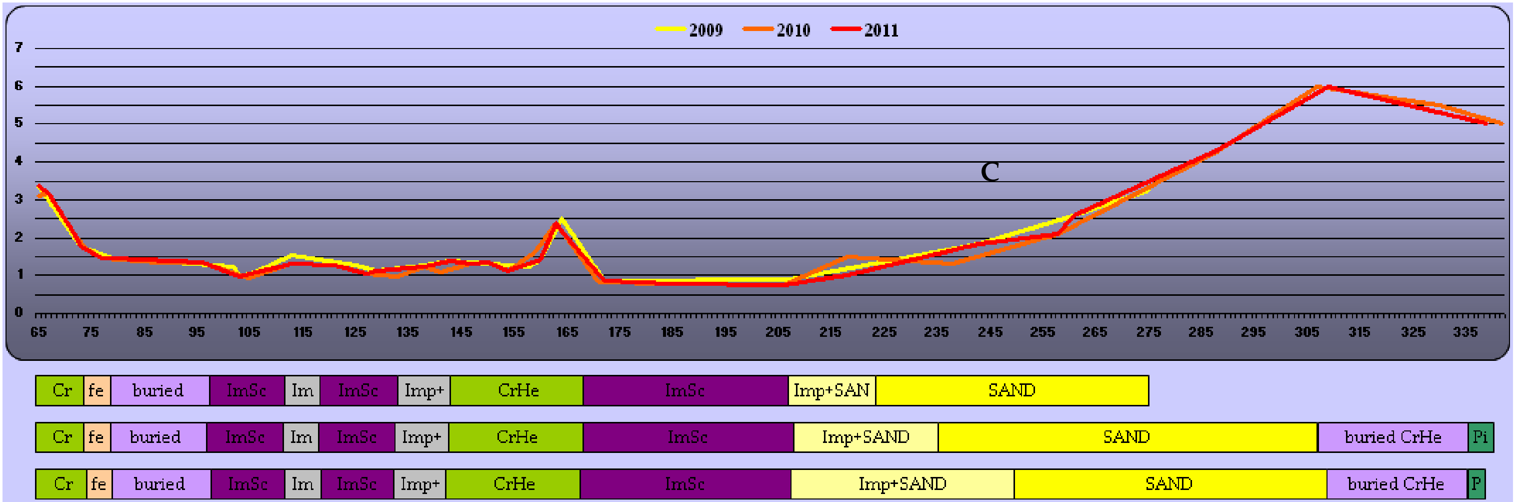


Figure 4.25 – Third sector of T5 transect in 2009, 2010 and 2011 (x and y-axes are in meters).

T6 transect

T6 transect (Fig. 4.28) was located in the central sector of the dunefield. As T5 transect, it was characterized by the transition between the foredunes and the parabolic dune system. The profile was about 120 meter long with an orientation of 352°N.
In 2009 the general topography of this section presented two main ridges. The first one was characterized by SiEl association at the base, and by SiAm-on-CrHe immediately before the higher deposit. This ridge could be considered the first foredune ridge and the crest was occupied by SiAm association (Fig. 4.26). A buried CrHe association colonized the backslope, just to the middle of the seaward slope of the second ridge. An anthropic path interrupted the distribution of the vegetation.

Figure 4.26 – View of the first dune ridge of T6 transect with *Ammophila arenaria* (2009).

In 2010 T6 transect didn't change so much, except to the first dune ridge where the previous SiAm-on-CrHe association was substituted by SiEl-on-SiAm because of the aeolic transport. The sand transport to inland was noted because of the presence of SiEl-on-CrHe in the backslope too.
In 2011 T6 showed an increasing of the deflation area of the beach. The SiEl association, already present in 2009, was migrated seaward and the previous location was occupied by SiAm, forming a new dune ridge.
Samples of sediment were collected in 2009. The histograms are presented in figure 4.27 (the location is on Fig. 4.28).
They presented a leptokurtic distribution of grain sizes. Samples A-B-D had a prevailing class distribution (2.0 phi). Sediment of sample C was mainly distributed between 1.5 and 2 phi.
They all represented aeolian sediments, confirming the strong transport of sand to inland.

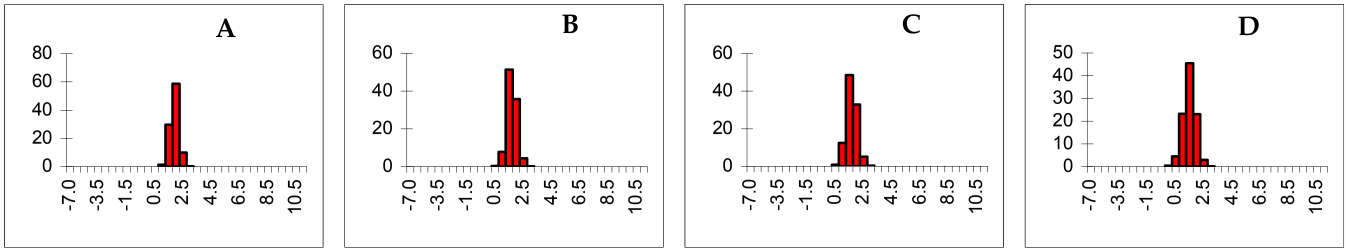


Figure 4.27 – Samples collected along T6 transect in 2009. (A: first dune foot, no vegetation; B: SiAm on CrHe; C: SiAm; D: buried CrHe).

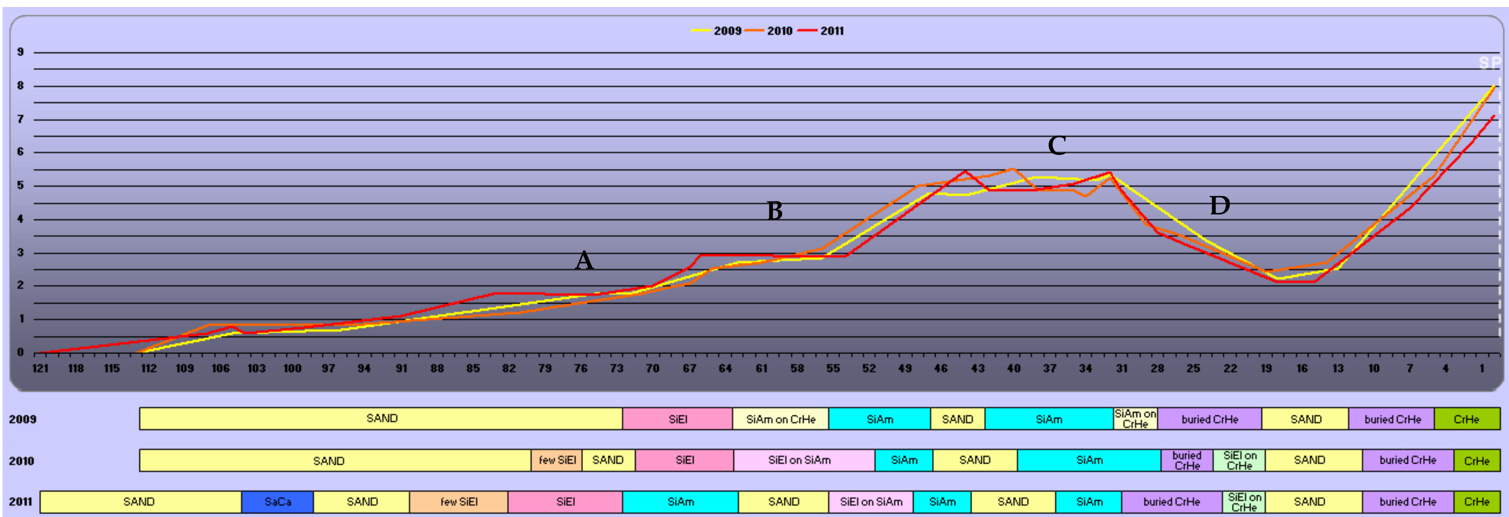


Figure 4.28 – T6 transect in 2009, 2010 and 2011 (x and y-axes are in meters; SP: station point).

T7 transect

T7 profile was located in the southern-central sector, where the highest dunes of the dunefield were present.
It was about 350 meters long and oriented 352°N.
The first dune ridge (Fig. 4.30) represented the seaward sector of the foredune/blowout complex. It was colonized by SiEl association at the base and SiAm on the top, with several differences. In 2009 SiAm was overlaid by the older CrHe association (SiAm-on-CrHe); in 2010 and 2011 this association was mixed with SiEl (SiEl-on-SiAm). The backslope of the ridge was colonized by CrHe, affecting by sand burial.
The profile continued along a deflation basin, characterized by ImSc association (and interrupted by Gegenwalle ridges with CrHe association and *Imperata c.* population)
In 2009 few plants of *Ammophila a*. were present on the remnant knob at the base of the blowout (Fig. 4.29) but in 2010-2011 they disappeared, due to the falling down of the knob.
The presence of a following buried CrHe association along the line represented the remnant knobs on the external edge of the blowout.
The axis of the blowout was characterized by sand.

Figure 4.29 – View of the T7 transect from its station point (2011).

On the crest of the blowout (station point) a buried CrHe association was noted. In 2011 the light erosion of the crest brought to the lost of several plants of CrHe.

No sedimentological samples were collected in 2009 along this transect.

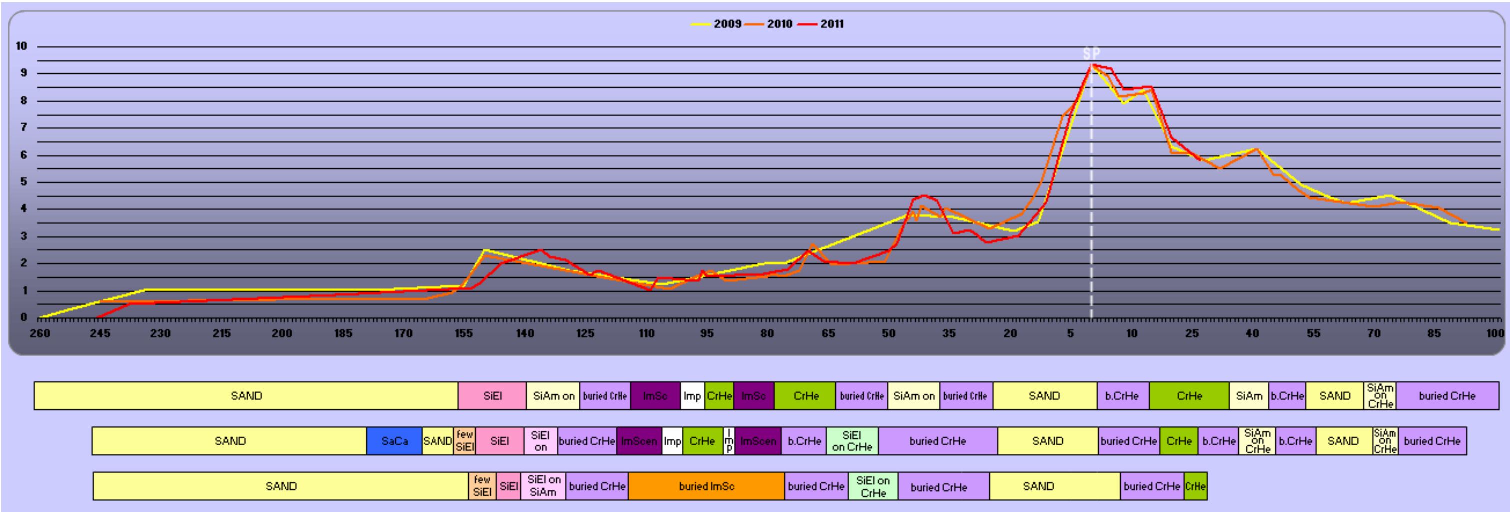


Figure 4.30 – T7 transect in 2009, 2010 and 2011 (x and y-axes are in meters; SP: station point).

T8 transect

T8 profile (Fig. 4.34) was located in the south-eastern sector of the dunefield, close to Iscra Ruja (little rocky island).
This sector was characterized by the presence of a foredune/blowout system and a lot of outcrops were present along the beach (Fig. 4.31).
T8 transect was oriented 348°N and it was about 130 meters long.

Figure 4.31 – View of the beach from T8 station point. Outcrops were present in the beach and in the nearshore zone. To note the *banquette* along the shoreline (2009).

The beach was about 25 meters wide but the beach might change a lot due to huge deposits of *banquette* (see §3.1). The dune foot and the seaward slope were colonized by SiEl association. On the top of the dune ridge, where T8 station point was located, SiAm association was present over three years.
The morphological profile of T8 transect was almost unchanged during the monitoring period but in this specific case several observations concerning the vegetation suggested important changing processes.
First of all, the vegetation of the first crest has gradually changed: in 2009 SiAm was overlaid by the older CrHe association (SiAm-on-CrHe) and in 2011 the pioneer association of SiEl overlaid the SiAm association (SiEl-onSiAm). The transport of sand was also confirmed by the presence of SiEl-on-SiAm and buried CrHe in the backslope of the foredune.
The profile was then characterized by the presence of a lower area (Fig. 4.32), occupied by ImSc and a lot of *Imperata cylindrica* at the external edges of the basin.
A blowout was present at the end of the line. CrHe was present at the base of the erosive slope and a buried CrHe at the top.

Figure 4.32 – Landward side of T8 transect. Picture from station point location.

Sediment samples were collected along the profile in 2009 (Fig. 4.33).

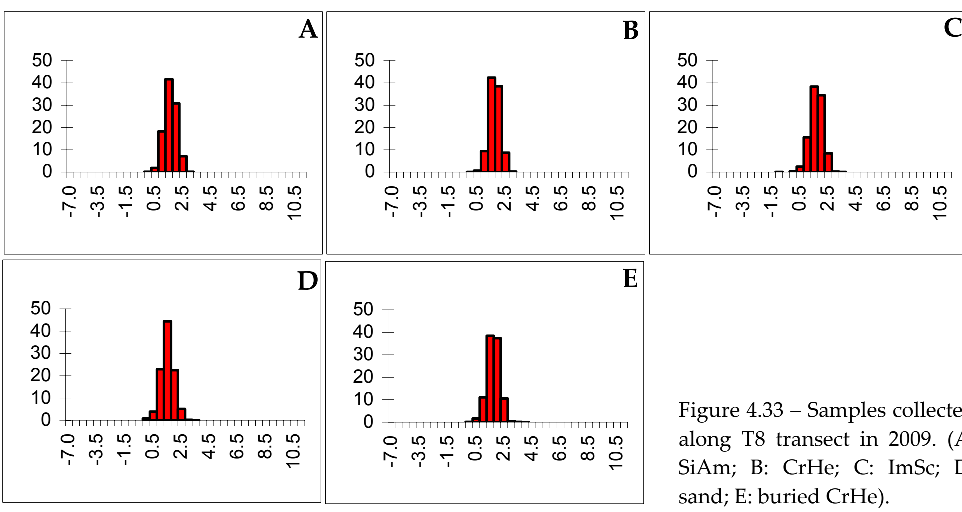


Figure 4.33 – Samples collected along T8 transect in 2009. (A: SiAm; B: CrHe; C: ImSc; D: sand; E: buried CrHe).

The location of the samples is shown in Fig. 4.34.

Samples A-B-C-E were homogeneous and they are representative of the aeolic sand transport to inland. Indeed, in 2009 CrHe association was affected by sand burial (e.g. sample B. There was CrHe association in 2009 and then buried CrHe in 2011).

Sample D was collected at the erosive slope of the blowout and it indicated heterogeneous sediment, probably due to the falling down of sediments from the top. During the monitoring period this side of the blowout presented an increasing deeper profile because of erosive process.

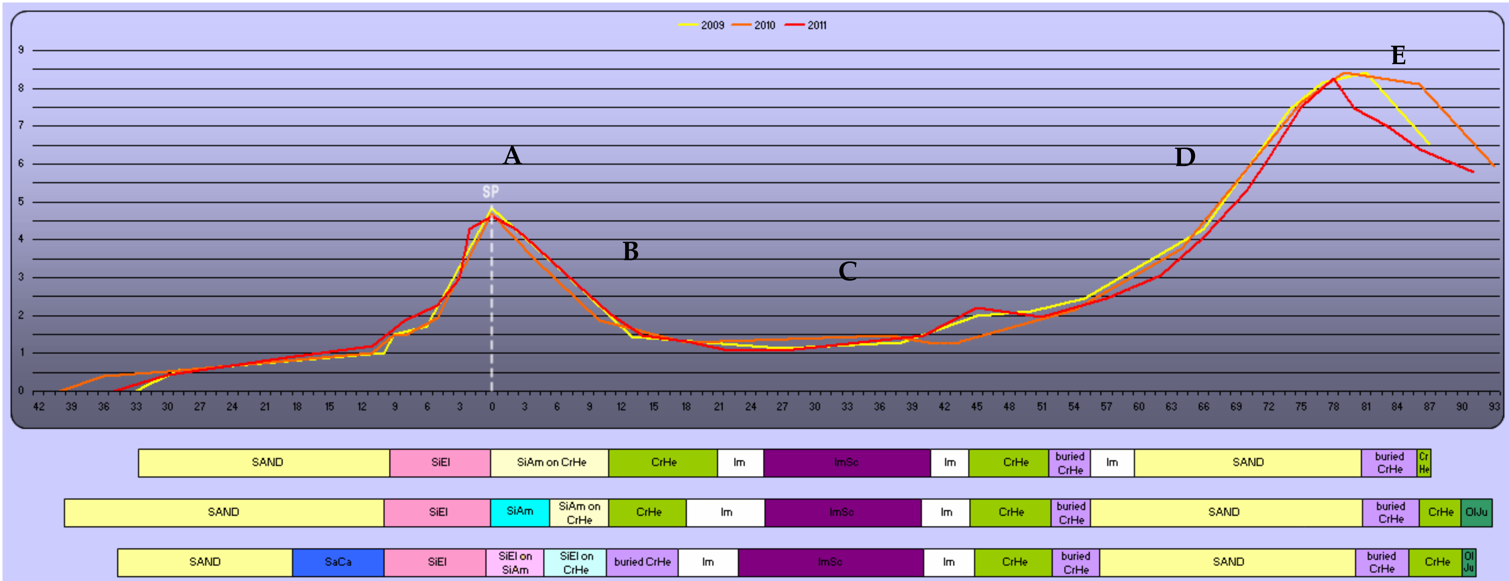


Figure 4.34 – T8 transect in 2009, 2010 and 2011 (x and y-axes are in meters; SP: station point).

Chapter 5
CONCLUSIONS AND DISCUSSION

The aim of the research is to develop a novel, integrated methodology for the description of complex dunefields, using the example of the Capo Comino dunefield. The Capo Comino study area is a highly complex environment regulated by disturbance. Indeed, this dunefield develops along a 3.5 km beach (oriented NW-SE) and is composed of two different dynamic systems: the foredune/blowout complex (close to the shore) and the transgressive complex (landward sectors), mainly characterized by parabolic dunes. These two systems were studied using a multidisciplinary approach integrating geomorphological and vegetation studies in order to consider all the factors affecting the dynamics and evolution of the dunes.

The geomorphological study was initially conducted *via* the analysis of air photos (1954-1977-2006) that afforded a general view of the distribution of landscape units. The historical analysis allowed definition of the rate of migration of the transgressive complex (approximately 3.75 m y^{-1}) including detail concerning the changes in the coastal system during this period. The morphological evolution of the Capo Comino dunefield underwent stabilization of the wide deflation plains characterizing the coast during the last century. In particular, the central seaward sectors - initially characterized by several dynamic parabolic dunes – were stabilized into hummocky dunes. The inner transgressive complex changed into a transgressive/parabolic dune complex where a median trailing ridge developed. Then the inner central sector evolved into a parabolic dune complex.

Sand rose analysis is fundamental in order to understand the direction of sediment transport. Indeed, taking into consideration the winds and the relation with the grain size of the sediment, the prevailing sedimentary transport was found to occur from NNW to SSE during winter and spring. This was also strongly influenced by local climatic factors, such as sea and land breezes that are the main factors effecting local morphologies. The northern sector, in contrast, was strongly dominated by onshore winds (NE winds) that influenced the formation and evolution of blowouts.

Seaward sectors were also affected by sea storms. The strongest disturbances were imposed by NE-NNE winds (the Gregale wind), whilst Sirocco storms (SSE winds) were moderated by Capo Comino headland.

The integration of these data with the analysis of coastline evolution highlights the intermediate-dissipative profile of this sandy beach. Indeed, the geophysical survey of the nearshore zone shows a gentle slope of the seafloor and the presence of bars.

In general, due to the low erosive rate of the shoreline over the long term (1954-2006), the beach may be considered relatively stable. The morphological beach analysis (2009-2011) determined that the principal changes were related to periodic sea storms that were able to erode the embryo dunes and sometimes the first established dune ridge. Monitoring of profiles also revealed that the dynamics of the beach in concert with wind action can rapidly reconstruct the morphological forms that had just been eroded.

With regard to the floristic study and the biological, chorological and ecological results, the Capo Comino study area exhibits typical characteristics of Mediterranean coastal environments.

The study of the vegetation was carried out using the phytosociological method both in the dunefield and in the retrodunal systems. Results allow classification of several different plant communities and also the evaluation of their biological and ecological aspects. The analysis determined 11 vegetation associations on the dunefield and 12 associations in retrodunal areas.
The construction of the vegetation map of the Capo Comino dunefield allowed rapid understanding of the distribution of these vegetation associations. This distribution is strictly related to the ecological needs and position within the study area. Indeed, vegetation associations are distributed following the ecological valence of characteristic species and of the surrounding community. Indeed, in the dunefield halophilic and nitrophilic associations were located close to the shoreline and associations became as less halo-tolerant and relatively evolved in the inner sectors.

In general coastal dunefields experience the effects of natural and anthropic constraints and react relatively rapidly to these disturbances. Even minor changes can impose substantial alterations to the quality and distribution of the phytocenoses.

Extreme events (such as floodings and sea storms), rather, can erode the first dune ridges and their phytocenoses and the following reconstructing process results in fresh colonization by pioneer species. In order to better understand these processes and to predict landscape evolution, monitoring plans are crucial in order to improve ICZM protocols. The aim is to restore and protect these natural environments and to plan appropriate management. Indeed, when solely the vegetation of the study area is considered it is possible to list several protected habitats (following EU Habitats Directive 92/43/CEE and the Natura2000 habitats directive). Between them, the "mobile pioneer dunes" habitats - adopted in version EUR15 of Natura 2000 and equivalent to the *Sileno corsicae-Elytrigetum junceae* association - are characteristic of the embryo dunes of Capo Comino, with a highly dynamic response to environmental stresses. The "shifting dunes along the shoreline with *Ammophila arenaria"* (white dunes – code 2120) are present in the central and southern sector of the dunefield, close to the shoreline and on the top of the highest dune of the transgressive complex. The *"Crucianellion maritimae* fixed beach dunes" habitat (code 2210) characterizes the entire dunefield, and it is particularly well-developed and preserved in the central inner sector. The "coastal dunes with *Juniperus spp"* habitat (code 2250) is present in the foredune/blowout complex.

However this area is only partially included in a SIC (Site of Community Interest - SIC-ITB020012) and a monitoring and management plan is a necessary step in order to protect local biodiversity. Therefore, the ultimate aim of this research has been to perform a novel monitoring procedure. The methodology involves planning an initial and essential analysis by remote sensing followed by field work collection of sedimentological, morphological and vegetational data along several transects, systematically repeated. Rapid execution is achieved by the collection of only key points along the profiles. The multidisciplinary approach derives from the concurrent morphological and vegetational data collection and data concerning responses to environmental change.

Three years of monitoring detail the fast dynamics of the dune system and the strong synergy between this and the beach. Indeed, the most dynamic sectors were located seaward and they were mainly affected by sea storms. Changes were rapid, especially with regard to vegetation distribution. Indeed, despite a short monitoring period it was possible to note erosional-reconstruction processes and the presence of new or partially-reconstructed embryo dunes.

The inner sectors, rather, showed a strong dynamic, mainly related to winds and sediment transport. Erosive forms – such as blowouts – create denuded soils resulting in the disappearance of the associations. They also influence the vegetation distribution in the surrounding areas.

The results demonstrate that it is therefore possible to monitor a study area using a small number of transects. The integrated procedure is precise and effective and its execution is faster compared to the monitoring of the entire dunefield.

With regard to the Capo Comino area, the natural characteristics of this site deserve full consideration from the public administration. A continuous monitoring plan and a solid management approach are key to the improvement of ICZM protocols because of their contribution to the conservation and the preservation of coastal sandy ecosystems.

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ANNEXES

I) Legend of associations and groupings – §3.2.2 and Chapter 4

	SaCa	*Salsolo kali-Cakiletum maritimae*
	few SiEl	presence of few plants of *Sileno corsicae-Elytrigetum junceae*
	SiEl	*Sileno corsicae-Elytrigetum junceae*
	few SiAm	presence of few plants of *Sileno corsicae-Ammophiletum a.*
	SiAm	*Sileno corsicae-Ammophiletum arundinaceae*
	SiEl on SiAm	*Sileno c.-Elytrigetum j.* on *Sileno c.-Ammophiletum a.*
	CrHe	*Crucianello-Helichrysetum microphylli*
	buried CrHe	*Crucianello-Helichrysetum microphylli* buried by sand
	SiEl on CrHe	*Sileno c.-Elytrigetum j.* on *Crucianello-Helichrysetum m.*
	SiAm on CrHe	*Sileno c.-Ammophiletum a.* on *Crucianello-Helichrysetum m.*
	ImSc	*Imperato cylindricae-Schoenetum nigricantis*
	buried ImSc	buried *Imperato cylindricae-Schoenetum nigricantis*
	PiCa / CiHa	*Pistacio lentisci-Calicotometum v.* or *Cisto salvifolii-Halimietum h.*
	transit	transition from PiCa/CiHa to OlJu
	OlJu / pinus	*Oleo sylvestris-Juniperetum turbinatae* or *Pinus pinea* population
	TyPh	*Typho angustifoliae-Phragmithetum maximi*

	SAND	sand
	Imp	*Imperata cilindrica* population
	Imp + SiEl	*Imperata cilindrica* with *Sileno corsicae-Elytrigetum junceae*
	SiOn	*Sileno nicaensis-Ononidetum variegatae*
	Inul	*Inula viscosa* population
	Imp + CrHe	*Crucianello-Helichrysetum m.* subass. *imperatosum cilindricae*

II) Samples 2009

Sample	Mode (Phi)	Mean - MZ (Phi)	Median (Phi)	Sorting Index (mm)	Deviation (mm)	Inclus. Graphic St. Deviation	Inclus. Graphic Skewness	Graphic Kurtosis
T1_1	2.232	2.174	2.199	1.142	0.029	0.350	-0.062	1.321
T1_2	2.005	1.981	1.992	1.230	0.053	0.414	-0.056	0.959
T1_3	2.092	2.024	2.053	1.221	0.050	0.388	-0.051	0.893
T1_4	1.848	1.897	1.861	1.217	0.053	0.396	0.039	0.961
T1_5	1.541	1.528	1.534	1.358	0.108	0.622	-0.029	0.907
T1bis_1	0.480	0.646	0.620	1.390	0.215	0.689	-0.023	1.047
T1bis_2	1.512	1.511	1.509	1.284	0.090	0.523	-0.029	1.031
T1bis_3	1.837	1.836	1.818	1.221	0.056	0.425	-0.014	0.997
T1bis_4	2.177	2.055	2.109	1.213	0.047	0.417	-0.174	1.052
T2_1	2.047	1.997	2.018	1.227	0.052	0.408	-0.075	0.948
T2_2	2.058	2.010	2.033	1.213	0.049	0.353	-0.039	0.790
T2_3	1.771	1.712	1.724	1.283	0.076	0.534	-0.082	0.987
T2_4	1.782	1.836	1.786	1.179	0.047	0.378	0.111	1.135
T2bis	1.510	0.847	1.155	1.698	0.277	1.397	-0.425	1.306
T2bis_2	1.811	1.523	1.605	1.399	0.116	0.712	-0.218	0.970
T2bis_3	1.837	1.870	1.832	1.219	0.055	0.409	0.031	0.997
T3_1	1.898	1.939	1.919	1.213	0.051	0.369	0.014	0.875
T3_2	1.875	1.913	1.886	1.223	0.054	0.401	0.008	0.944
T3_5	1.871	1.910	1.880	1.224	0.054	0.406	0.007	0.962
T3bis_1	1.125	1.052	1.019	1.461	0.204	0.963	-0.060	1.205
T3bis_3	1.721	1.656	1.680	1.204	0.059	0.425	-0.034	1.044
T3bis_4	1.793	1.854	1.804	1.174	0.045	0.358	0.128	1.089
T4_1	1.913	1.950	1.935	1.216	0.051	0.371	0.001	0.862
T4_2	1.918	1.955	1.942	1.218	0.051	0.378	0.007	0.877
T4_3	1.826	1.855	1.824	1.224	0.056	0.434	0.018	1.025
T4_4	2.057	2.020	2.041	1.211	0.048	0.356	-0.017	0.819
T4_5	1.814	1.873	1.826	1.205	0.052	0.393	0.079	1.021
T4bis	1.204	1.044	1.102	1.292	0.127	0.550	-0.152	1.032
T4bis_2	0.951	0.767	0.787	1.341	0.174	0.599	-0.065	0.967
T4bis_3	1.777	1.734	1.743	1.197	0.053	0.470	-0.080	1.241
T4bis_4	1.754	1.731	1.731	1.187	0.051	0.430	0.000	1.142
T4bis_5	2.075	2.013	2.038	1.224	0.051	0.398	-0.066	0.923
T5_1	1.979	1.997	2.006	1.211	0.049	0.345	0.006	0.772
T5_2	1.905	1.919	1.900	1.228	0.055	0.413	-0.037	0.964
T5_3	1.790	1.813	1.782	1.197	0.051	0.411	0.041	1.096
T5bis_1	1.296	1.065	1.142	1.411	0.166	0.747	-0.185	1.024
T5bis_2	1.349	1.356	1.337	1.235	0.082	0.465	0.012	1.051
T5bis_3	1.689	1.561	1.598	1.284	0.087	0.567	-0.176	1.164
T5bis_4	1.814	1.839	1.808	1.214	0.054	0.417	0.029	1.019
T5bis_5	2.196	2.111	2.152	1.158	0.034	0.341	-0.112	1.091
T6_1	2.187	2.101	2.142	1.179	0.038	0.361	-0.088	1.027
T6_2	1.862	1.924	1.891	1.211	0.051	0.375	0.057	0.906
T6_4	1.743	1.709	1.714	1.235	0.065	0.467	0.000	0.978
T6_6	1.843	1.899	1.860	1.222	0.055	0.410	0.058	0.981
T6bis_1	1.895	1.442	1.626	1.471	0.138	0.872	-0.360	1.042
T6bis_2	1.862	1.730	1.766	1.301	0.079	0.576	-0.168	1.026
T6bis_3	1.735	1.665	1.687	1.221	0.063	0.478	-0.096	1.135
T6bis_5	1.568	1.614	1.598	1.275	0.081	0.501	0.048	0.954
T7bis_1	1.830	1.743	1.768	1.286	0.074	0.567	-0.128	1.063
T7bis_2	1.938	1.894	1.895	1.250	0.060	0.465	-0.053	0.991
T7bis_3	1.985	1.974	1.981	1.223	0.052	0.390	-0.064	0.902
T7bis_4	1.845	1.838	1.830	1.239	0.059	0.457	-0.024	0.979
T8_1	1.836	1.846	1.836	1.251	0.062	0.482	0.027	0.994
T8_2	1.942	1.971	1.964	1.238	0.055	0.436	0.004	0.995
T8_3	1.922	1.893	1.897	1.262	0.063	0.491	-0.016	0.998
T8_4	1.742	1.731	1.727	1.244	0.066	0.487	0.034	0.996
T8_5	1.976	1.978	1.979	1.257	0.059	0.474	-0.021	1.025
T8bis_1	1.623	1.363	1.477	1.308	0.102	0.676	-0.284	1.251
T8bis_2	1.887	1.910	1.885	1.232	0.056	0.425	-0.004	0.987
T8bis_3	1.838	1.897	1.857	1.203	0.050	0.375	0.068	0.964
T8bis_4	1.937	1.976	1.970	1.217	0.051	0.367	0.047	0.830

III) Samples 2010

Sample	Mode (Phi)	Mean - MZ (Phi)	Median (Phi)	Sorting Index (mm)	Deviation (mm)	Inclus. Graphic St. Deviation	Inclus. Graphic Skewness	Graphic Kurtosis
T1_BS	2.048	1.677	1.760	1.397	0.105	0.721	-0.251	1.051
T1_MSL	1.737	1.410	1.522	1.444	0.137	0.805	-0.252	1.010
T1_BO	2.036	1.941	1.955	1.237	0.056	0.424	-0.151	0.960
T1_SB	1.904	1.875	1.869	1.239	0.058	0.435	-0.057	0.949
T1_DF	2.136	2.026	2.069	1.224	0.050	0.418	-0.151	1.000
T3_BS	1.906	1.938	1.921	1.216	0.052	0.379	-0.011	0.900
T3_BO	1.773	1.754	1.749	1.186	0.050	0.419	-0.009	1.137
T3_DF	2.152	2.059	2.100	1.203	0.045	0.367	-0.083	0.900
T5_BS	1.660	0.928	1.213	1.460	0.200	0.734	-0.675	0.925
T5_MSL	1.270	1.181	1.201	1.324	0.125	0.591	-0.074	0.981
T5_BO	1.813	1.851	1.809	1.199	0.051	0.386	0.059	1.038
T5_DF	1.780	1.807	1.774	1.191	0.050	0.406	0.055	1.114
T6_BS	1.800	1.674	1.710	1.310	0.085	0.610	-0.190	1.109
T6_MSL	2.288	2.069	2.130	1.383	0.078	0.696	-0.206	1.020
T6_BO	1.907	1.927	1.910	1.219	0.053	0.389	-0.025	0.924
T6 SB	1.965	1.966	1.968	1.221	0.052	0.387	-0.059	0.901
T6_DF	2.077	2.013	2.040	1.215	0.049	0.357	-0.052	0.798
T7_BS	1.965	1.708	1.774	1.357	0.093	0.712	-0.267	1.198
T7_MSL	1.708	1.567	1.602	1.326	0.097	0.636	-0.178	1.120
T7_BO	1.804	1.847	1.802	1.199	0.051	0.388	0.072	1.042
T7_SB	1.942	1.963	1.958	1.221	0.052	0.389	-0.021	0.907
T7_DF	1.849	1.918	1.880	1.208	0.051	0.373	0.079	0.912
T8_DF	1.833	1.897	1.854	1.199	0.049	0.372	0.083	0.975

IV) Samples 2011

Sample	Mode (Phi)	Mean - MZ (Phi)	Median (Phi)	Sorting Index (mm)	Deviation (mm)	Inclus. Graphic St. Deviation	Inclus. Graphic Skewness	Graphic Kurtosis
TR1BIS BS	1.160	1.021	1.067	1.322	0.141	0.611	-0.082	1.027
TR1BIS MSL	1.316	1.405	1.342	1.237	0.082	0.471	0.152	1.121
TR1BIS BO	1.815	1.772	1.779	1.229	0.059	0.461	-0.046	0.997
TR1BIS DF	1.928	1.940	1.930	1.223	0.053	0.394	-0.048	0.921
TR2BIS BS	1.573	1.268	1.362	1.433	0.150	0.780	-0.209	1.022
TR2BIS MSL	1.719	1.627	1.645	1.296	0.086	0.550	-0.099	1.002
TR2BIS BO	1.846	1.826	1.817	1.222	0.056	0.432	-0.040	1.005
TR2BIS DF	2.093	2.029	2.058	1.205	0.046	0.343	-0.075	0.792
TR3BIS BS	1.643	1.449	1.519	1.337	0.106	0.658	-0.183	1.064
TR3BIS MSL	1.761	1.679	1.702	1.253	0.071	0.524	-0.123	1.102
TR3BIS BO	1.870	1.888	1.860	1.221	0.054	0.403	-0.002	0.970
TR3 BIS DF	1.720	1.682	1.691	1.214	0.061	0.439	0.003	1.018
TR4BIS BS	1.209	1.002	1.056	1.465	0.196	0.846	-0.140	1.075
TR4BIS MSL	1.799	1.731	1.749	1.257	0.068	0.522	-0.108	1.062
TR4BIS BO	1.752	1.685	1.705	1.216	0.061	0.492	-0.110	1.205
TR4 BIS DF	2.093	2.029	2.058	1.205	0.046	0.343	-0.075	0.792
TR5BIS BS	1.378	1.298	1.318	1.378	0.131	0.672	-0.053	0.971
TR5BIS MSL	1.750	1.707	1.717	1.187	0.052	0.438	-0.023	1.160
TR5BIS BO	1.625	1.518	1.546	1.280	0.088	0.507	-0.089	0.998
TR5BIS DF	2.149	2.042	2.085	1.230	0.051	0.433	-0.129	1.018
TR6BIS BS	2.079	1.512	1.601	1.472	0.135	0.750	-0.202	0.851
TR6BIS MSL	2.160	1.937	2.035	1.267	0.062	0.520	-0.320	1.073
TR6BIS BO	1.613	1.572	1.585	1.253	0.077	0.466	-0.033	0.989
TR6BIS DF	2.162	2.077	2.116	1.194	0.042	0.362	-0.078	0.937
TR7BIS BS	1.713	1.437	1.572	1.341	0.106	0.801	-0.356	1.410
TR7BIS MSL	1.220	1.144	1.175	1.201	0.082	0.424	-0.045	1.079
TR7BIS BO	1.777	1.790	1.763	1.178	0.048	0.397	0.037	1.179
TR7BIS DF	1.805	1.821	1.801	1.223	0.057	0.434	0.018	0.989
TR8BIS BS	1.610	1.280	1.451	1.486	0.157	1.122	-0.383	1.508
TR8BIS MSL	1.893	1.938	1.914	1.243	0.058	0.451	0.039	1.021
TR8BIS BO	2.042	1.884	1.923	1.270	0.064	0.507	-0.111	0.989
TR8BIS DF	2.005	2.010	2.020	1.227	0.052	0.396	0.022	0.895

V) Samples - bathymetric survey 2009

Sample	Mode (Phi)	Mean - MZ (Phi)	Median (Phi)	Sorting Index (mm)	Deviation (mm)	Inclus. Graphic St. Deviation	Inclus. Graphic Skewness	Graphic Kurtosis
1	2.28	2.267	2.255	1.17	0.033	0.425	-0.025	1.341
2	2.34	2.378	2.332	1.219	0.039	0.425	0.034	1.069
3	2.68	2.594	2.635	1.218	0.033	0.439	-0.043	1.102
4	2.7	2.648	2.675	1.197	0.029	0.437	0.006	1.179
5	2.57	2.513	2.536	1.226	0.036	0.418	-0.053	0.997
6	2.33	2.292	2.293	1.214	0.039	0.496	-0.124	1.286
7	2.32	2.302	2.289	1.205	0.038	0.444	-0.04	1.143
8	2.25	2.182	2.205	1.19	0.038	0.462	-0.096	1.271
9	2.66	2.548	2.594	1.205	0.032	0.376	-0.128	0.93
10	2.61	2.591	2.553	1.232	0.037	0.453	-0.117	1.103
11	2.54	2.4	2.44	1.27	0.045	0.561	-0.122	1.191
12	2.49	2.481	2.483	1.239	0.039	0.473	-0.037	1.148
13	2.74	2.696	2.711	1.152	0.021	0.393	-0.019	1.39
14	2.27	2.218	2.23	1.176	0.034	0.0447	-0.067	1.311
15	2.31	2.287	2.281	1.202	0.037	0.432	-0.041	1.099
16	2.24	2.151	2.193	1.171	0.035	0.456	-0.165	1.462
17	2.18	2.062	2.106	1.264	0.057	0.509	-0.151	1.08
18	2.74	2.696	2.709	1.172	0.024	0.441	-0.015	1.313
19	2.38	2.404	2.367	1.233	0.04	0.5	-0.033	1.309
20	2.61	2.494	2.533	1.242	0.039	0.491	-0.194	1.203
21	2.67	2.559	2.605	1.239	0.037	0.496	-0.165	1.216
22	2.52	2.457	2.467	1.231	0.038	0.429	-0.144	1.022
23	2.27	2.223	2.232	1.187	0.035	0.433	-0.035	1.187
24	2.13	2.006	2.043	1.279	0.062	0.511	-0.123	1.029
25	2.43	2.435	2.418	1.231	0.039	0.438	-0.04	1.054
26	2.69	2.588	2.634	1.237	0.036	0.502	-0.156	1.229
27	2.53	2.472	2.487	1.236	0.039	0.491	-0.162	1.252
28	2.28	2.329	2.276	1.158	0.03	0.391	0.092	1.417
29	2.72	2.625	2.669	1.211	0.031	0.5	-0.174	1.357
30	2.41	2.301	2.334	1.248	0.044	0.543	-0.194	1.19
31	2.28	2.205	2.228	1.209	0.04	0.49	-0.12	1.222
32	2.06	2.034	2.053	1.218	0.049	0.378	0.014	0.869
33	2.32	2.104	2.102	1.054	0.012	0.166	-0.289	2.01
34	2.64	2.55	2.587	1.217	0.034	0.399	-0.062	0.957
35	2.68	2.585	2.627	1.214	0.032	0.415	-0.076	1.031
36	2.3	2.339	2.289	1.182	0.034	0.389	0.081	1.178
37	2.3	2.3	2.278	1.193	0.036	0.425	0.004	1.158
38	2.26	2.189	2.209	1.223	0.044	0.491	-0.093	1.147
39	2.08	1.977	2.011	1.292	0.066	0.536	-0.09	1.004
40	2.38	2.414	2.381	1.231	0.039	0.44	0.039	1.063
41	2.23	2.139	2.186	1.146	0.03	0.39	-0.13	1.424
42	2.22	2.145	2.183	1.142	0.029	0.364	-0.096	1.358
43	2.64	2.568	2.603	1.208	0.032	0.385	-0.03	0.949
44	2.59	2.509	2.537	1.246	0.039	0.472	-0.101	1.092
45	2.3	2.345	2.294	1.186	0.034	0.388	0.094	1.141
46	2.24	2.218	2.219	1.242	0.047	0.488	0.01	1.006
47	2.36	2.398	2.359	1.217	0.038	0.407	0.029	1.006
48	2.303	2.307	2.281	1.190	0.035	0.404	0.013	1.127

VI) Coordinates – transects

	T1	T2	T3	T4
MSL	9 47 54 40 32 95	9 47 57 40 32 90	9 47 66 40 32 76	9 47 78 40 32 65
SP	9 47 52 40 32 88	9 47 55 40 32 90	9 47 66 40 32 72	9 47 58 40 32 58
	T5	**T6**	**T7**	**T8**
MSL	9 47 89 40 32 57	9 48 00 40 32 50	9 48 21 40 32 42	9 48 72 40 32 20
SP	9 47 93 40 32 50	9 48 04 40 32 43	9 48 31 40 32 31	9 48 73 40 32 18

	T1BIS	T2BIS	T3BIS	T4BIS
MSL	9 47 57 40 32 89	9 47 60 40 32 85	9 47 68 40 32 73	9 47 84 40 32 60
SP	9 47 52 40 32 88	9 47 54 40 32 83	9 47 65 40 32 71	9 47 78 40 32 56
	T5BIS	**T6BIS**	**T7BIS**	**T8BIS**
MSL	9 47 96 40 32 52	9 48 06 40 32 47	9 48 31 40 32 39	9 48 73 40 32 20
SP	9 47 93 40 32 50	9 48 04 40 32 43	9 48 30 40 32 35	9 48 73 40 32 18

VII) Accidental species

Table 3.7: rel. 1 *Tamarix gallica* L. +; rel. 15 *Juncus maritimus* Lam. +.2, *Euphorbia peplis* L. +.2, *Plantago coronopus* L. +.2; rel. 18 *Nerium oleander* L. +; rel. 45 *Cistus monspeliensis* L. +; rel. 34 *Inula viscosa* (L.) Aiton +, *Daucus carota* L. subsp. *maximus* (Desf.) Ball +; rel. 73 *Pistacia lentiscus* L. +; rel. 77 *Cakile maritima* Scop. +; rel. 90 *Cutandia maritima* (L.) Richter +; rel. 93 *Ononis variegata* L. +, rel. 96 *Convolvulus althaeoides* L. +, *Lonicera implexa* Aiton +.2.

Table 3.10: rel. 39 *Chondrilla juncea* L. +, *Carlina corymbosa* L. +, *Cistus salvifolius* L. +; rel. 23 *Vitex agnus-castus* L. 1.2; rel. 36 *Lagurus ovatus* L. +, *Daucus carota* L. subsp. *maximus* (Desf.) Ball +, *Holoschoenus romanus* (L.) Fritsch +, *Medicago marina* L. +, *Dactylis glomerata* L. +.2; rel. 3 *Osyris alba* L. 1.1; rel. 29 *Cistus monspeliensis* L. 2.2, *Inula viscosa* (L.) Aiton 1.2, *Sporobolus pungens* (Schreber) Kunth +, *Euphorbia paralias* L. +.2, *Briza minor* L. +; rel. 86 *Crucianella maritima* L. +.2, *Ononis reclinata* L. +.2.

Table 3.11: rel. 4 *Ruscus aculeatus* L. 1.2, *Oryzopsis miliacea* (L.) Asch. et Sch. +; rel. 100 *Smilax aspera* L. 1.1; rel. 85 *Ononis reclinata* L. 1.2; rel. 87 *Asphodelus microcarpus* Salzm. et Viv. 1.1, *Urospermum dalechampii* (L.) Schmidt +; rel. 41 *Medicago marina* L. +; rel. 6 *Rhamnus alaternus* L.; rel. 101 *Phillyrea angustifolia* L. 1.1, *Chamaerops humilis* L. +.2; rel. 17 *Holoschoenus romanus* (L.) Fritsch +.2, *Imperata cylindrica* (L.) Beauv. +.2.

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