Geomorphological Environment: Dunes in Agrigento Coast

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GEOMORPHOLOGICAL ENVIRONMENT: DUNES IN AGRIGENTO COAST

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RIASSUNTO: La fascia costiera di San Leone (Agrigento-Siclia), è costituita da una spiaggia sabbiosa delimitata verso terra da un complesso dunale di particolare pregio. L'assetto geomorfologico di questo litorale è stato influenzato dal forte grado di antropizzazione del luogo. La fascia costiera nel tempo ha subito degli avanzamenti e arretramenti. Sono stati quindi analizzati e proposti alcuni rimedi, mirati alla ricostruzione, al mantenimento e alla difesa della duna.

ABSTRACT: The coastline of San Leone (Agrigento) is characterised by sandy beaches delimited on the interior by a particular dunal complex. The geomorphological aspects of this coast have been influenced by a high degree of site anthropization and undergone advances and regressions over time. Several recommendations for reconstructing, maintaining and defending the dunes are proposed and analysed.
KEY WORDS: Coastal environment, dunes, coastal geomorphology.

1. Physical environment

San Leone (Agrigento) coastline is included between the mouth of the Akragas river (also known as San Leone river) and the mouth of the Naro river. San Leone coastline belongs to the physiographic unit 10. This area has a hilly morphology and it is localized in south-west Sicily, confining with the Mediterranean Sea. The coastline is long approximately 5.6 Km and its geographic disposition is in the direction NW/SE.

Behind the coastline, from west to east, we find the seaside resort of San Leone, which extends from the mouth of the Akragas River until the so-called zone «Ragno d'oro», where the «Viale delle dune» originates, path that skirts almost the whole shoreline taken into consideration and that ends, in its turn, in the called area «Le Dune». This zone is adjacent to the Lido Cannatello (bathing place), near to the mouth of the Naro river.

San Leone coastline is well linked up with the chief town Agrigento. The roads

that link up Agrigento with San Leone are: Francesco Crispi street, provincial road N°4 and Emporium avenue. In this treatment, the coastal physiographic unit has been chosen as territorial level of analysis, or rather that littoral strip in which the movements of sediments are delimited and where there are no exchanges with other adjacent physiographic units. Thanks to this scale, it is possible to analyse in detail the development effects of the dynamics coastal.

In the figure 1 there are shown the 21 physiographic units into which the Sicilian shorelines has been divided, figure 2 describes the studied area.

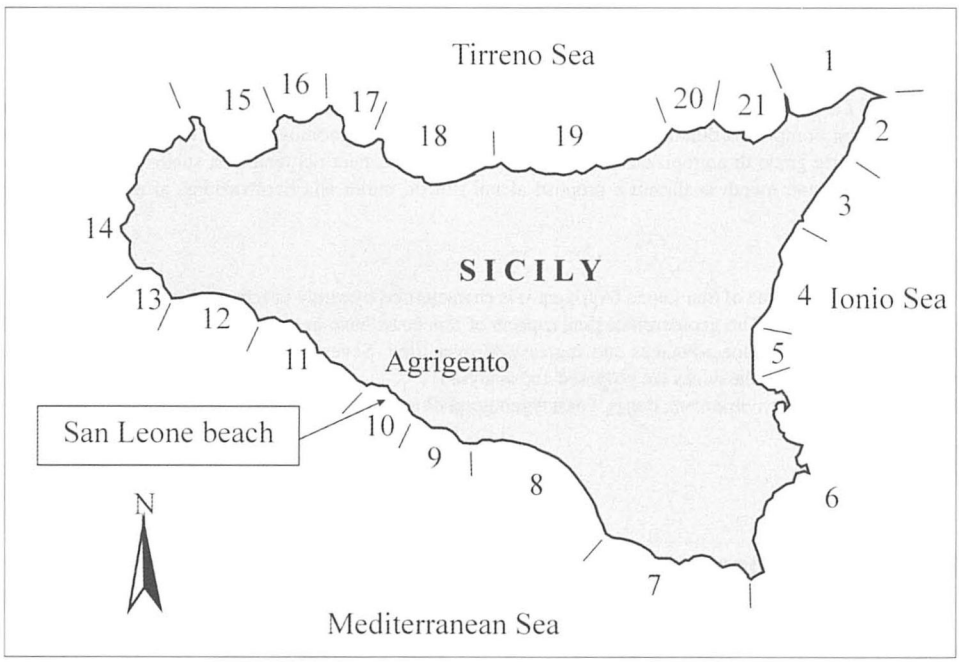

Figura 1: The 21 physiographic units: 1) Milazzo - Capo Peloro; 2) Capo Peloro - Scaletta Zanglea; 3) Scaletta Zanglea - Giardini; 4) Giardini - Porto di Catania; 5) Porto di Catania - Punta Castelluzzo; 6) Punta Castelluzzo - I. delle Correnti; 7) I. delle Correnti - Punta Braccetto; 8) Punta Braccetto - Licata; 9) Licata -Punta Bianca; 10) Punta Bianca - Capo Rossello; 11) Capo Rossello - Capo San Marco; 12) Capo San Marco -Punta Granitola; 13) Punta Granitola - Capo Feto; 14) Capo Feto - Capo San Vito; 15) Capo San Vito - Capo Rama; 16) Capo Rama - Capo Gallo; 17) Capo Gallo - Capo Mongerbino; 18) Capo Mongerbino - Cefalù; 19) Cefalù - Capo D'Orlando; 20) Capo D'Orlando - Capo Calavà; 21) Capo Calavà - Milazzo.

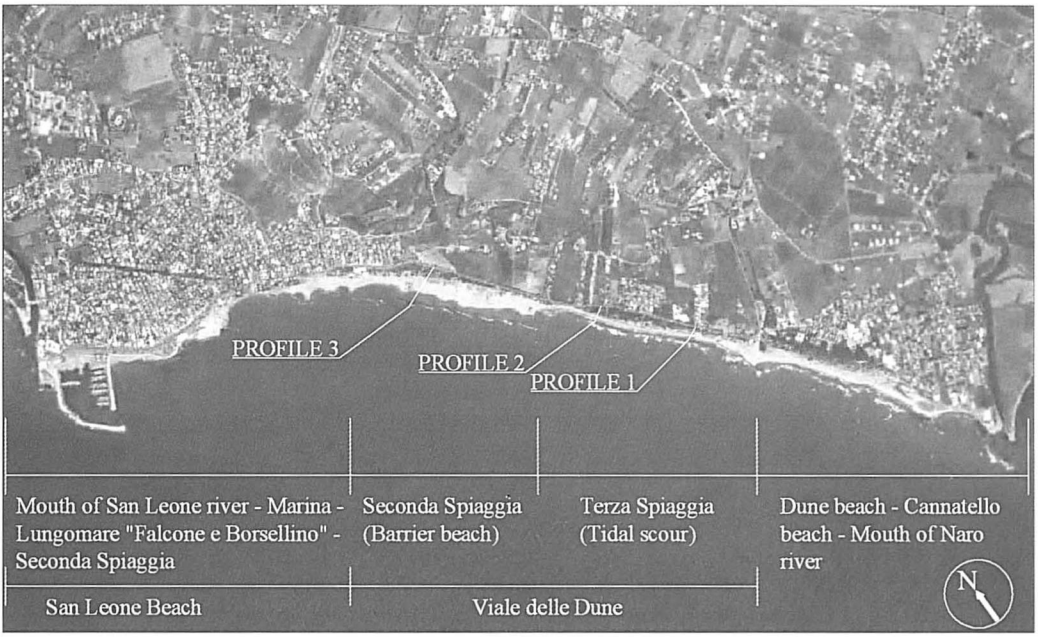

Figura 2. The San Leone coastline (Agrigento)

2. San Leone (Agrigento) geology

The area is characterized by Plio-Pleistocene lands with different features (incoherent, pseudo-coherent and lithoid). Among the genetic mechanisms that have determined their formation, a very important role has been played by the processes of sea advance and regression that has produced the sedimentation of sand stone and sand in heteropy with marly clays (Fm of Agrigento).

These genetic mechanisms have brought to the formation of lands clayey, slimy and of conglomerates pertaining at the marine terrace. This terrace is wide inside in outcrop in the coastal area of Agrigento. In particular, the coast that precedes the inhabits place of San Leone and Cannatello is characterized geologically by incoherent lands pertaining to «marine terrace» and dune shorelines. The geologic context is invariable also towards east, in C.da Cannatello, where the area occupied from the dunal sandy sediments becomes really denser. These sediments are overlapped to the alluvium typical of the Naro River's mouth. The nature of the sediments, after flowing into the sea, is strictly linked up with the petrography characteristics of the rocks outcropping, inside the river basins. The superficial waters transport sediments into the sea, allowing their distribution along the coast. It can be affirmed that the lithological successions typical of the basins of Agrakas river and Naro river, are constituted of clayey formation (Tertiary). These sediments are covered in some parts from lands of the evaporitic series («Gypseous Sulphurous

Serie» –middle– upper Messinian). We have executed drawing of samples of sediments both from the emerged shore (to 5 meters from the shoreline and 30 cm deep) and the submerged shore (through 5 m deep submersion).

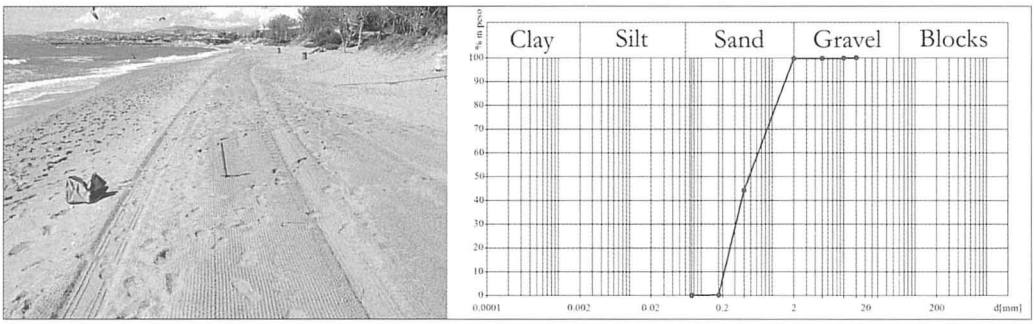

Figura 3. a) sampling along Terza beach; b) granulometric curve

The depth value has been chosen equal to 5 m because that value is equal to the «depth of closing». Beyond this value the samplings, repeated year after year, do not show variations in the bathymetric.

Figure 3b and 4b illustrate the granulometric curves of the samples drawn near the «Third beach» (fig. 3a) and offshore (fig. 4a) being considered as representative of the average shoreline conditions.

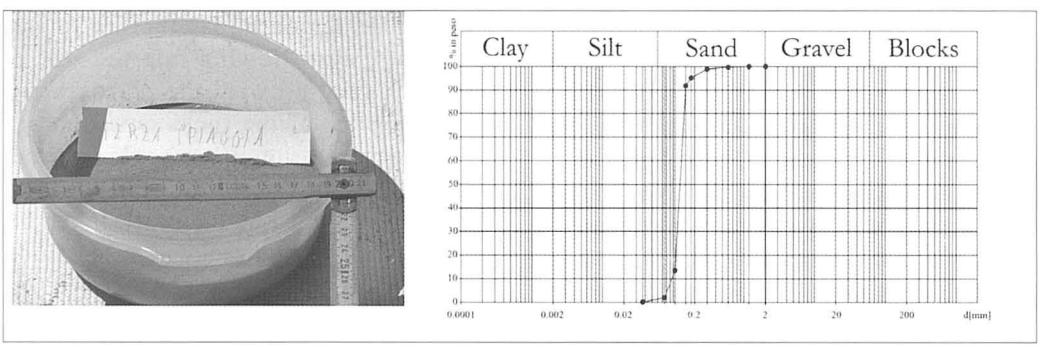

Figura 4: a) sample drawn offshore Terza beach at a distance of about 500m from the shoreline and at a depht of 5 m; b) granulometric curve.

From the granulometric curves that have been made, it has emerged that the D_{50} of the samples drawn on land is on average of 0,4mm, while which one of the samples drawn on the submerged shore is of 0,13mm. In both cases the curves indicate that drawn samples are sand.

Images of the samples previously mentioned have been acquired (besides fig. 5a and 5b) through electronic microscope and acquired through digital telecamera, allowing to analyze the geometric aspects of the shape of clastic elements.

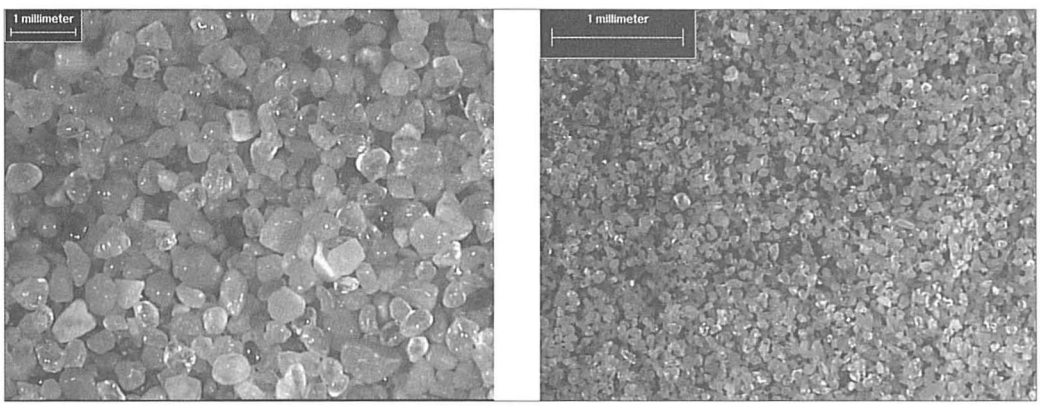

Figura 5: a left) samples drawn in the emerged beach; b right) samples drawn in the flooded beach.

From the analysis of these images, it has emerged that the clastic elements which form the samples have mostly spherical shape and they show an elevated degree of rounding. The superficial weaving of grains is glittery, opaque and carved. Yellow ochre, white and the grey are the principal colours. The granular components are calcite and quartz (in traces). Fossiliferous microfauna is absent both in the samples drawn on the emerged shore and on the sunken one. This study shows how the fundamental difference between the samples drawn on the emerged beach and on the submerged one is almost exclusively a dimensional difference.

3. Geomorphological environment

The coast consists of sandy beaches limited in the inner side by rock slopes or alluvial plains. Morphologically, the territory along the coast area is characterized by a landscape with very soft and bland shapes, imposed by the presence of Plio-Pleistocene outcropping sedimentary lands with clayey-arenaceous matrix. It is possible to find the presence of remarkable sub-level surfaces produced by the erosive-sedimentary processes dues to the sea transgressions in the hinterland, which have strongly moulded the country plain. The

coastal dunes that we meet along this shore are formed by the sand transported by the wind from the surface of the beach. They constitute an element of transition between the beach and the hinterland. In the backing shores the eolic deposits can miss or if not, they show signs of erosion at the basis and the vegetation on the external side results often with the roots exposed, as it happened along the coastline subject of the study, precisely along «Terza Spiaggia» (fig. 6a), and the «Spiaggia delle dune».

Well defined geometric elements as enclosures or buildings along St. Leone coastline, provoke often an accumulation of sand on the windward side. The vegetation represents a less rigid obstacle and it reduces gradually the wind speed.

Where vegetation is present the dune is softly joined with the beach (fig. 6b) as it occurs along the shore area sheltered from the emerged breakwater barriers in proximity of the Second Beach.

The first psammophilous plants occurring on the very inner part of the Second Beach, represent such an obstacle to form a first embryonic dune. This dune, if not damaged by the seasonal oscillations of the shoreline, can grow up to constitute a real dune (foredune). In this process, the vegetation, which keeps on growing above, has a decisive role as it always remains a semi-permeable barrier.

As it is shown in figure 6b, the beach vegetation has a parallel course with the shore. It is possible to observe an area without vegetation and an area of plants (which survive in an environment rich in sodium chloride) that progressively covers with shrubby and arboreal dune vegetation.

In this coast, the dune disposition is always parallel to the shore, independently from the direction from which the wind blows, so that the geometry of the dunes system cannot be used as palaeoclimatic indicative to recognise those anemologic conditions of the age of their formation.

The reason for that has to be found in the fact that vegetation can grow at a much defined distance from the sea. At that distance vegetation can contribute to the formation of a sandbar, which results to be always parallel to the shore. Along the analysed coastal area, it is possible to find the urban agglomerations of San Leone and Cannatello (Agrigento). Urbanizations

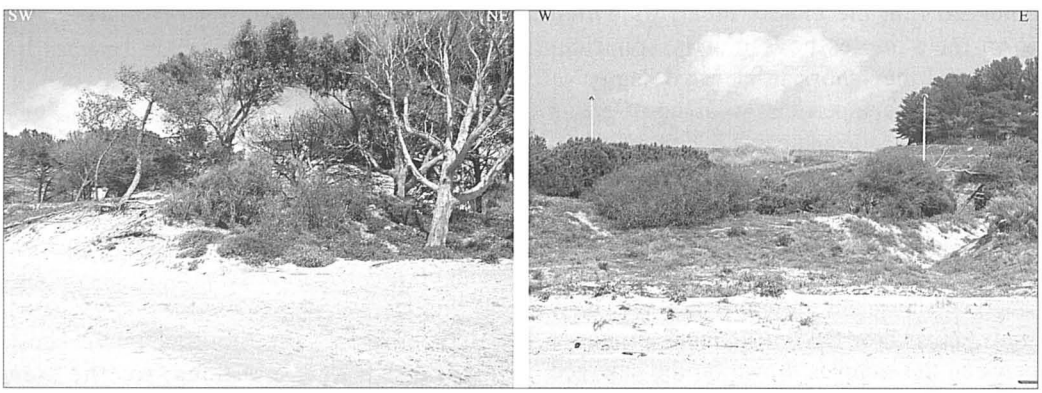

Fig. 6: a left) phenomenon of erosion to the foot of the dune; b right) foredune of the Second beach.

(roads, piping systems, sewer systems, and so on) which serve these settlements, have caused the urgency to create along the coastal area a greater number of services (marina, heliport, walk along the promenade, and so on) which, time after time, have modified the dynamics of the natural processes, provoking in some strips of the shore, the moving back process of the coastline.

All of it has, as a consequence, the necessity of carrying out works of protection, in order to secure the constructions a sure safety. It provoked a progressive deterioration of the coast, which has in the loss of many dune systems one of the most alarming signals. These systems, already threatened by the general moving back process of the coastline, have been partly destroyed to build lines of communication, urban settlements and more recently, even local settlements on the beaches for the carrying out of plays (fig. 7).

In the evaluation of the development trend of the shore (fig. 8) under consideration, three spatial intervals have been defined, for each of which a specific deepening is proposed:

1) Interval Mouth River Akragas - seafront «Falcone-Borsellino».

It deals with the coastal area completely anthropic where the dock of San Leone and the seafront terrace stand, sheltered from an almost uninterrupted system of emerged breakwater barriers - Length approximately 1.150m.

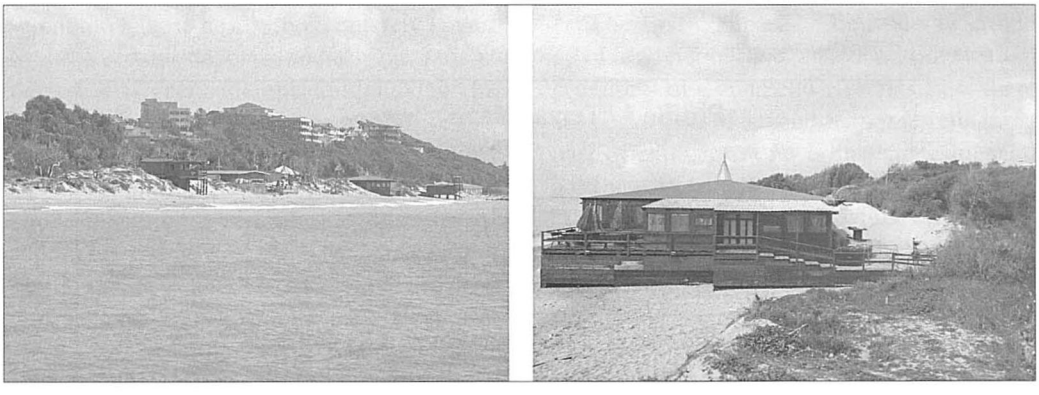

Figura 7. Sight of the coastal dune attacked by the anthropic settlements.

This first interval of coast is absolutely urbanised, subject to a sequence of interventions that have completely modified the nature of the landscape.

During the first half of the 70's a front of land protected to sea by a wall of bank in reinforced concrete, so that the line of shore advancing about 20-25m. As a protection of the work a sequence of 6 barriers breakwater has been therefore erected, with limestone blocks, able to create some inner sea-inlets of deposition, with the formation of small beaches.

Contextually, the construction of the tourist dock of San Leone was carried out, which at the beginning, was constituted only

by the west dock with a length of around 200m, then widened to the actual dimensions of approximately 560m, overhanging the sea of around 350m. At the moment, there is also the eastern dock, around 240m of length.

As regards past years to such a period, there have been no important phenomena of advancement or moving back such as to give prominence to, except some peaks in proximity of the mouth of the San Leone River, probably consequent to variations of the solid transport in the years.

2) Interval of beach protected from the breakwater barriers.

It deals with the sector of sandy shore protected from a sequence of emerged breakwater barriers involving the First and the Second Beach - Length around 1.500m.

The cartographic comparison between the datum of 1885 and that one of 1913 underlines during this interval a clear advancement of the beach with maximum superior to 80m. In the following time segment which starts from 1913 until 1931, there are considerable withdrawals of almost 130m. Between 1931 and 1960 there were other phenomena of withdrawal, however elevated with values around 70m.

This phenomenon has been attributed to the realization of interventions between the end of the 50s and the first 60s consisted in the realisation of rocky blocks to protect the ancient village of San Leone from the direct action of the wavy motion that, in the winter months, was a threaten for the existing constructions; actually, barriers have been carried out in rocks skimming to the coast so that to attenuate the waves action.

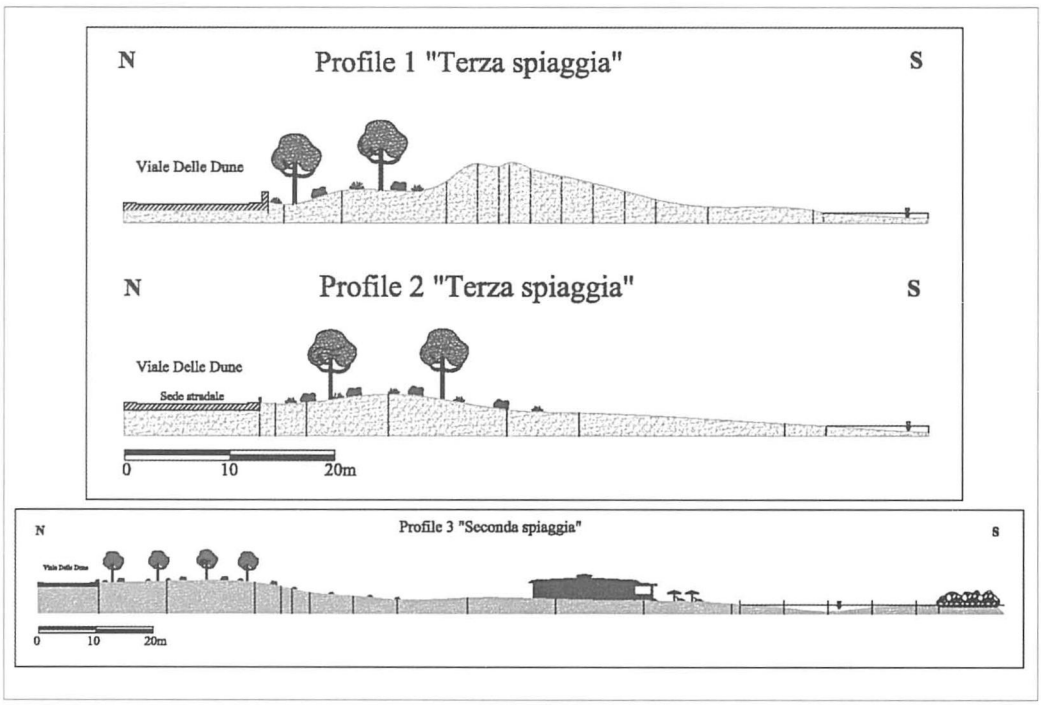

Figura 8. The Second «beach» and the Third «beach» profiles

However, this intervention has caused an imbalance of the coastline dynamics preventing the taking in load of the sandy material to transport towards East and so the increase of the erosive potential of the sea, which gathered in the adjacent coastal waters.

The following interventions through the construction of the dock and the seafront prevented the dispersion towards East of the solid deposits deriving from the San Leone River and have even more accented the erosive power of the sea; to these effects it must be added those deriving by the interventions of reclamation inside the basin of the San Leone river, actually extended to the first 90s, consistent in the realization of harnessing and cementing of many streams tributaries in the principal water course, able to limit the natural capacity of the river solid transport. In the following years, part of the «tombolo» shore has been completely covert by new coastal deposits and during the last period it is recorded the tendency to the formation of new small dunes fronts.

The actual trend is therefore that of prevalent stationariness, with a portion of shore in which a remarkable quantity of sediments trapped by the barriers results to be subtracted to the dynamics of the sea. The comparison among the data of 1931 and 1998 shows, as a matter of fact, a prevailing advancement of the coast line, artificially imposed by the breakwaters.

3) Intervallo di spiaggia libera «Viale delle Dune» - Cannatello.

It deals with the segment of shore without protection, extending from the orthogonal groin, which delimits the protected shore close to the third traverse of the Viale delle Dune, up to the mouth of the River Naro - Length approximately 2.650m.

The phenomenon of urbanisation of the western coastal part has caused, naturally, the increase of erosive processes on the East coastal waters, exposing the part of beach free from the breakwater barriers to the erosive action of the wavy motion, so evident during the last years.

The strip under examination is included among the end of the protected shore (in proximity of the third crossroad) and the mouth of the Naro River (in proximity of Cannatello Beach) for a length of around 2.650 meters.

Also for this sector of shore, feed mainly derives from solid deposits from the Akragas river and from the small intermediate deep valleys that flow along this line of coast, with the sediments' displacement, garanteed by the drift coastal current facing East.

Obviously, for the reasons above listed, the evolution of this coastline is exclusively linked up to the modifications occurred in the western shore.

The first comparison between 1885 and 1913 underlines a marked withdrawal in proximity of Cannatello Beach, where there are peaks also of around 80m, the remaining part of this shoreline is instead subject to advancements not over 20m in proximity of the third beach and withdrawals of around 10m in proximity of the beach of Dunes. In the period among 1913 and 1931 further significant variations of the shoreline have been recorded. Shoreline keeps on going backwards in proximity of the zone among Cannatello Beach and the mouth of the Naro river, with peaks just a little over 90m, while the advancements are around 50m in proximity of the third beach. Eventually, no meaningful variations have been found in the shoreline related to the beach of Dune.

In the comparison among 1931 and 1966 a positive trend of the beach can be underlined, with a average advancement of around 10 meters associated with the withdrawal of the western sector, with the displacement of the coastal deposits towards East. The negative datum is recorded

however one more time, in the zone included among Cannatello Beach and the mouth of the Naro River, most probably caused by the interventions of reclamation that at that time were started inside the basin.

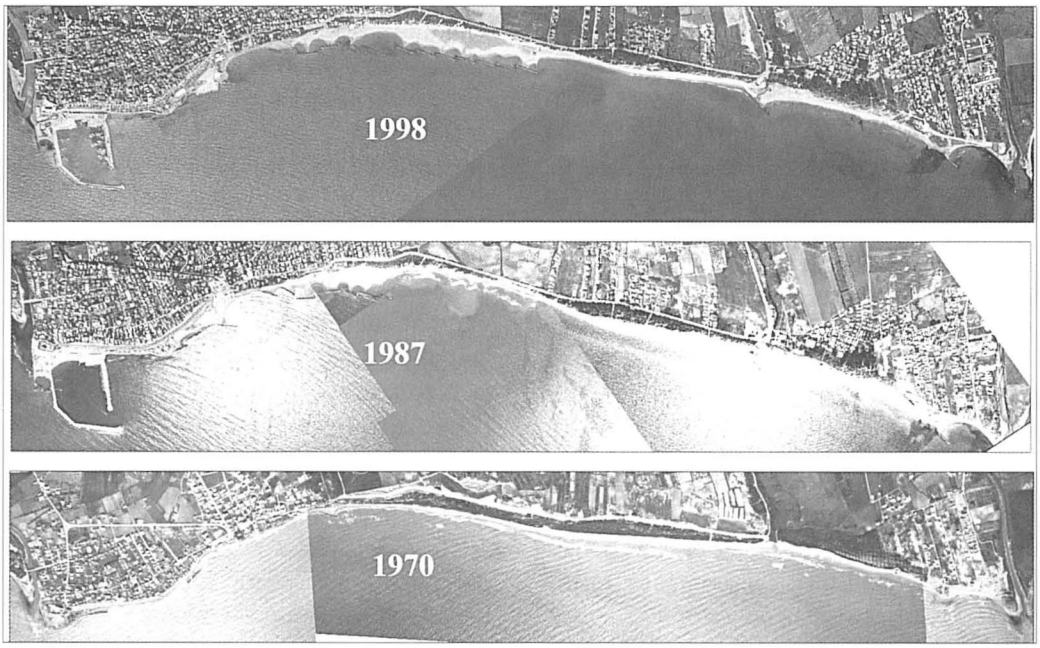

Figura 9. Variation of the coastline.

In the following interval among 1966 and 1970, a negative trend is recorded, once again, with withdrawals that, on average, are around 20m. Conditions of greater erosion are found also in this case in the strip adjacent to the mouth of the Naro River (eastern sector).

From 1970 to 1987 there were no significant fluctuations of the shoreline's trend, the only important variations are those due to the advancements artificially produced through an oblique groin by the shoreline related to the Dune beach. Another oblique groin, put by Cannatello Beach, in order to protect of the road and the beach in front of the agglomeration risen in the West side of of River Naro's mouth.

Among 1987 and 1992 after the construction of the breakwater barriers, situated in the western side, there is the presence of erosive processes, mainly gathered along the West coastline. The cartographic comparison with the year 1992 allows to record so a withdrawal with peaks of around 30 meters that involves the western zone of the line under examination and an irregular advancement in the oriental segment, in the strip that goes from of le Dune beach towards Cannatello Beach.

In time this permanent situation keeps on worsening and the comparison with the 1998 cartography puts in evidence a further withdrawal situated in the most western part, with a reduction of the beach of around 30m, a further peak is also recorded in proximity of the Dune beach with a withdrawal of around 40m.

During the last years, the zone of free beach has been subject to heavy flood that have subsequently provoked the withdrawal of the shore in particular in the western area. The erosion is manifested both against the natural structure of the beach, seriously attacking and damaging in more strips the dune, both against the anthropic structures carried out in the immediate vicinity of the back beach, with serious damages, even if they are yet located, on the road for «Viale delle Dune».

In conclusion, the under waves zone next to the anthropic interventions, which consist in the breakwater barriers parallel to the coastline, nowadays is subject to intense erosive phenomena. Along this strip of shore, there was a dune and retro-dune structure in equilibrium, characterized by typical vegetation of the Mediterranean bush, consolidating the same dune. The increase of the erosive process has provoked the tapering of this portion of coast area which separated Viale delle Dune from the shoreline. In particular, from the budget of the sediments along this shore is absent the bringing due to the beaches protected by the emerged breakwater barriers, with consequent intensification of the erosion near the areas not protected. Moreover, it must be added the fact that in the two basins related to the courses of water flowing along the shore, interventions of reclamation have been carried out until the first 90's, such as harnessing many affluent streams to the principal watercourses and even artificial obstructions that have definitely limited the natural capacity of solid transport of the rivers, with further negative consequences on the budget of the sediments. All of this has caused not only the withdrawal of the coastline, but also the consequent erosion of the dune at the back, which has the function of «natural reserve of sand» for the before beach, and which has been more and more tapering until to fade away.

4. Considerations on the defence of the Dune System

The erosive phenomenon along this shore has aroused in the years particular attention and interest the community, as it has provoked the partial destruction of the coastal dune, that represents over that a natural structure of particular interest and merit under the environmental profile, geomorphologic, landscape profile, also an essential barrier to protect what is situated in proximity of it (roads, inhabited places, agricultural grounds, etc.). The restoration or the reconstruction of a tombolo and of the relative ecosystem can certainly have no other purpose if not the restoration of the naturalness. A project of reconstruction can involve both the reinforcement of an existing natural dune or in height or in depth and the reconstruction of a dune whereas it does not exist anymore. The best work of redevelopment is always achieved through the reconstruction of beaches and dunes similar as much as possible to those original. The dune bars face the great tides of storm, prevent the approaching of the big waves and they prevent directly the damage of the works situated along the coast and the flood of the inner zones.

The growth of the dune can be promoted and its structure can be strengthened against the erosion if it succeeds in making grow appropriate vegetation on it, during an adequate period with the purpose to have a well developed radical apparatus. For the

phytostabilisation it is possible to use local and shrubby herbage. However, the reforestation of the dunes is not a simple operation, as the substratum is in continuous evolution and the roots of the new little plants are continually exposed by the wind. It is then necessary to make them stable with dead hedges or with nets and panels before proceeding to their planting. Examples of this type of interventions can be observed both in Italy and in the rest of the world and they show a great variety of typologies, which converge generally in bedding *Ammophila*.

The species more used are *Ammophila littoralis* (*A. breviligulata* in America) or, along the Atlantic coasts, *Uniola paniculata, Panicum amarum, Panicum amarulum*. The plants must to be bed with great care, covering them almost entirely with sand, so that the plant can have an easier access to the damp and it can be protected from the baring of the wind and from the stamping; separately or in groups at a distance of around 50cm.

It is better to resort to the transplantation, instead of the seeding: besides the difficulty to find the seeds, in fact, it would be necessary an excessive irrigation. When the sand is trapped by plants collocated too close, a dune with narrow base grows; on the other hand, if the same number of plants is set with small density, the base of the dune will result wider. When the *Ammophila* are planted too close it is very difficult the reclamation of other dune species.

It is important to specify that this system does not work anywhere, but only where there is enough dynamics to build, that is in other words where there is a good bringing of sand, otherwise the dune can form and the plants of *Ammophila* decay. Another problem is that *Ammophila* vegetates with difficulty unless it is at least 2 m above sea level.

It must be expect from 2 to 5 years so that the *Ammophila* creates a strong roots apparatus, and up to 10 years before getting the maximum resistance against the erosion. An active program of enrichment and maintenance of the vegetation can considerably improve the survival and the efficacy of the *Ammophila*. More recent experiences use also other species: particularly it results useful the *Otanthus maritimus*, that bears the aerosol and the sprays very well and it has a good edifying capability. It is evident that these interventions need the preclusion to the access, at least up to the moment in which the vegetation has not completely covered the dune; preclusion that is achieved by means of the construction of enclosures or in alternative superelevate paths or wood platforms (fig. 10) so that the passage of people do not produce a furrow which the wind could then deepen and widen.

Another methodology that can be used is the «construction of the dunes through enclosures». These enclosures are constituted by wood sticks or brushwood, or from plastic structures or mesh of juta or coconut fibre. We can proceed by installing a single fence, with following raisings of a single row, after the first one has been filled; or with a double row of fences, spaced out of four times the height, followed by raisings also constituted by a double line. The enclosures' porosity has to be of 50% with empty and full spaces of 5 cm: they can be submerged even in one year.

However, sand's accumulation varies according to the season, the year and the location: under favourable conditions sand rises of 1-2 m generally in one year. The enclosures have the vantage that they can be set in any season of the year ant they start immediately to hold the sand, while it is necessary to wait that vegetation takes root and grows sufficiently. the wideness of the beach has the great influence on the speed of accumulation: it is evident that the wider is the surface before the barrier, the greater is

Figura 10. Platform on the dune that allows the access to the Second Beach from the viale delle Dune

the quantity of sand the wind can rise. It must be said nevertheless that the favourable conditions before mentioned are by now enough rare: very often the bringing of sand from the sea and therefore from the wind results very scarce. Also the beach can be no so large. This does not mean that the enclosures must no to be used, as there is always a bringing of sand. Considering how much sand is important and precious, it is opportune in these situations, to do the possible to harness it, rescuing from the dynamics of the beach and the dune. *The Oficina Tecnica Devesa-Albufera* uses branches of *Spartina versicolor* 50-80 cm tall to delimit square of 4x3 m. After many years of experiments, this structure with a permeability to the wind of 40-50% is resulted the most successful and cheap to fix the sand, to facilitate its accumulation, for its least impact on the environment. In time the palings are cover by sand (2^{nd} -3^{rd} year), they decay (4^{th} -5^{th} year) and they disappear, leaving the dune with a totally natural aspect since the 6^{th} -7^{th} year. In effect it deals with a structure that effectively simulates the *Ammophila* peopling.

In some strips of this shore the dune bar results corroded to the foot directly from the waves. In this case it is possible to create a basal barrier in wicker: keeping in mind that it has to be necessarily a very resistant work being on direct contact with the strength of the waves. Finally, it is necessary not to forget that the safeguard of the dunes and their reconstitution find obstacles in a part of the resident population and the summer frequenters, which see a limitation to the exploitation of the coastal area. The protection of the dunes, after they have been formed and got stable, even during the same intervention, is a key factor in the efforts to mitigate the impacts in the different components.

The following typologies of action must be expected:

1) physical protection, that involves the reparation of the fences and the maintenance of the vegetation. Interruptions of the enclosure increase the probability that the dune is damaged by the erosion of the wind and by the passage of the people;

2) legal protection, that includes the possibility to adopt some ordinances that give to the corporate bodies in charge of the arrangement of the dunes the authority to regulate the allowed and forbidden activities in the area of the dunes and to clearly define the areas of dune and beach. The municipal police, the coastguard, the beach-attendants will provide to make ordinances respected. The violations will be settled with administrative sanctions;

3) programs of education and sensitization to increase the awareness about the importance of the dunes as natural protection. It is fundamental the construction of superelevate gangways in wood or of pedestrian paths pleasantly practicable to cross the dune and to reach the beach, to avoid the stamping of the dunes areas so intensely frequented: in fact, people use them with pleasure because walking on the sand is very tiring. In this way the environmental problem is restricted in limited areas where the damage of the vegetation and the erosion of the dune are prevented by technical devices.

5. Conclusion

The study has paid particular evidence to the problems linked up to the erosive phenomenon (withdrawal of the shoreline with consequent destruction of the dune) with the purpose not only to find its causes but also of get durable and effective solutions. The causes result very complex and articulated, but, among these, there are certainly the uncontrolled urbanisation and the negative budget of the sediments brought by the two rivers (Akragas and Naro) that flow on the shoreline. The trend of the coastal evolution has been established taking into consideration the most important modifications of anthropic origin imposed to the coastline and its important variations in the long term and in the short period.

We have studied also the esteemed ecosystems in site which, according to what has been previously said, are these days threatened by the erosion and by the wrong human behaviours, that with excessive carelessness has ignored them up to now, without taking into account how many advantages derive from the «good health» of such natural structures. Finally we have also analyzed possible remedies, aimed to the reconstruction, the maintenance and the defence of the dune, proposing a sustainable use of the dunes ecosystem.

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