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Erosion and use of the coast in the northern Sardinia (Italy)

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Abstract

The study provides an overview of coastal erosion of northern Sardinia, indicating the causes and the effects of the most relevant and identifies critical areas to the possible scenarios of extreme events. The knowledge of the state of natural balance of the coasts is essential for planning and protection in the medium-long term and requires careful evaluation of the risks and potential dangers, obtainable through geomorphological, sedimentological and meteomarine data interpretation, and degree and the human settlement type. Many of sardinians waterways are torrential and have poor solids discharges due to existence of the dams, was 393 (56 large reservoirs and 336 small reservoirs) that remove sediment to natural beach nourishment. It is enough to calculate the volume of sediment trapped from the reservoir to have a phenomenon dimension, total 4,372,933.5 m^3 for Cedrino in use from 1989 to 1,085,700.0 m^3 for Cixerri in activity since 1992 and 2498.226,2 m^3 for Bidighinzu in use since 1959. An interference with such significant contributions to the sea involves a sedimentary deficit in the system which leads to an inevitable retreat of shorelines. For the evaluation of the areas with greater sensitivity and vulnerability, it is over considered the human load resulting from the infrastructure presence and activities along the coast and next to the river banks. It has also been decided through a questionnaire meant to assess the value of an environmental asset (in this case a stretch of coastline) which is understood as a "sense of well received" by the people, because it has become clear that the remediation or enhancement cannot be delegated to a mere technical-scientific approach but there has to be shared with the community. The integrated analysis of these factors helped to identify critical situations and vulnerabilities along the coasts of Northern Sardinia that led to the mapping of areas at risk.

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Keywords: coastal erosion; coastal use; coastal planning; tourism management; Sardinia; Italy.

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1. Introduction

Coastal erosion is a natural phenomenon, which has always existed and has contributed throughout history to shape European coastal landscapes. Coastal erosion, as well as soil erosion in water catchments, is the main process which provides terrestrial sediment to the coastal systems including beaches, dunes, reefs, mud flats, and marshes. In turn, coastal systems provide a wide range of functions including absorption of wave energies, nesting and hatching of fauna, protection of fresh water, or places for recreational activities. However, migration of human population towards the coast, together with its ever growing interference in the coastal zone has also turned coastal erosion into a problem of growing intensity. Coastal erosion is usually the result of a combination of factors – both natural and human induced – that operate on different scales [1, 2].

The increase in value of coastal areas for the leisure and recreation of millions of tourists worldwide is ever more relevant, this being the most expanding sector in the global economy, Tourism demand is increasing worldwide. The challenge for Europe's coastal and maritime resorts is to exploit this potential sustainably in order to offer attractive jobs to its people. Coastal and maritime tourism can be a major source of growth and jobs, especially for the young. Tourism is a growing business: in 2013, the number of nights spent in hotels or similar establishments in the EU28 reached a peak of 2.6 billion. Almost half of these nights being spent by the sea, the coastal tourism industry is faced with huge challenges. A healthy natural environment is a huge asset but tourism generates lots of pressures on local environment and ecosystems, such as higher water use, increased waste generation and accumulated emissions from air, road and sea transport in peak seasons [3].

Sardinia (Italy) has a highly active coastline, with 2/3 of its whole length (more than 1900 km). In particular, the coast of the island has been facing a severe beach erosion problem over the past 35/40 years, especially along the northern part. This has meant an enormous loss of coastal land, coastal resources, coastal economy, in addition to societal impacts. The main causes of coastal zone loss include both natural and anthropogenic activities. In Sardinia these problems are increasingly a matter of concern because tourism, most notably beach tourism, is a key sector in the economy.

These pressures can turn into a range of problems in different fields such as:

• Coastal Planning and Management – allowing undue chaotic and casuistic construction, at times in hazard areas, with all the problems inherent therein, leading to a landscape degradation and all problems associated;

• Erosion – a result of using hazard prone areas, interference with the line of the coast and reduction of the principal (main) rivers' sediment supply [4, 5].

Research operated mainly on the morphodynamic processes analysis taking place in the coastline physiographic unit and in the morphologic basin of each beach tract. The work considered all the littorals of Sardinia's north profile from the beach in Bosa, west, up to the Siniscola beach in the promontory of Capo Comino (Fig. 1). Many details of the phenomena of coastal and river dynamics that characterize these beaches and their watersheds have been obtained in order to obtain an overview of the equilibrium state of the major coastal strips, especially those which are the subject to higher human pressure.

For the evaluation of the areas with greater sensitivity and vulnerability, the human intervention resulting from the presence of infrastructure and activities along the coast and near the river terraces is over considered. It was also decided, through a questionnaire, to assess the value of an environmental asset (in this case a stretch of coastline) understood as a "sense of well received" by the people, because it is obvious that the remediation or enhancement cannot be delegated to a mere technical-scientific approach but to the sharing community.

The integrated analysis of these factors helped to identify critical situations and vulnerabilities along the coasts of Northern Sardinia that led to the mapping of risk areas.

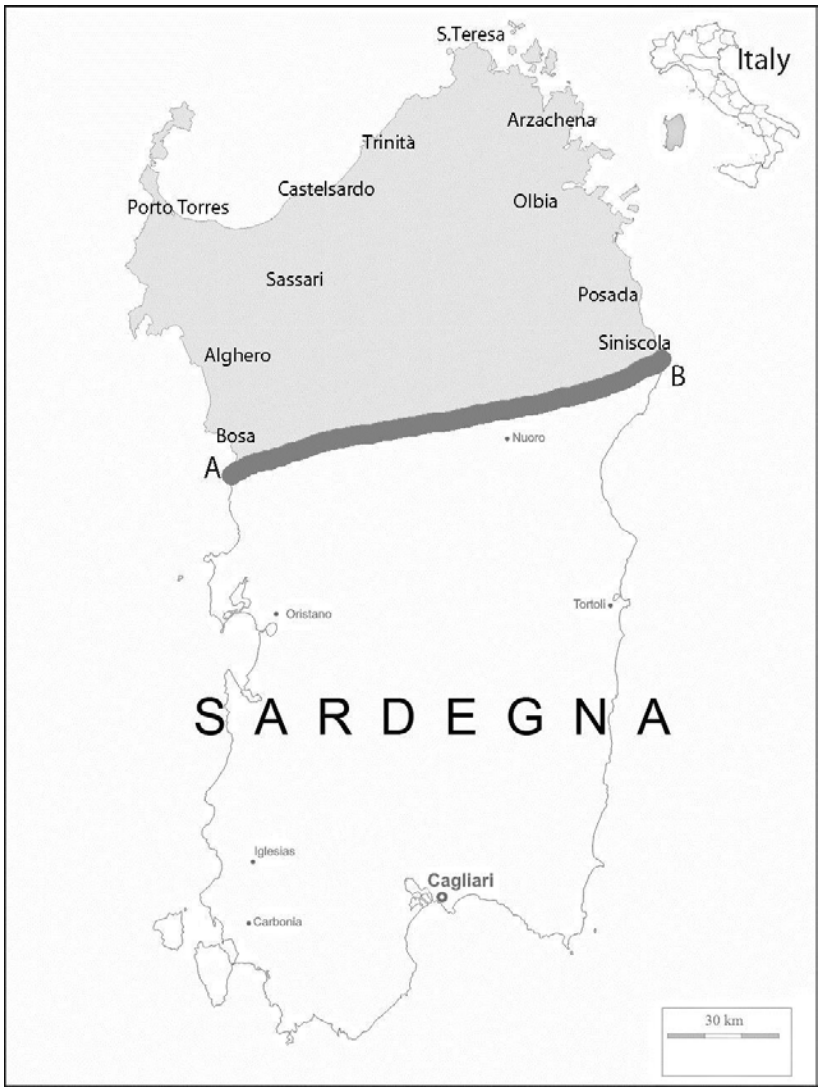

Fig. 1. Localization of the studied area

2. Methodology

2.1. Study area

The study area is approximately 1/3 of the coast line in Sardinia for a development of about 600 kilometers of coastline, including archipelagos and small islands; the beaches are numerous and were considered especially the longer littoral, more than 200 m. The considered territory is geologically very different formed by rocks of different ages; formations from the Lower Paleozoic until the Late Pleistocene are present and the coastal landscape is constantly different for both geological composition, type of beach and processes of physical evolution. The role of the river system is important since the age of each basin is different and the behavior of each river depends mostly on bedrock that dominates in every inner territory [6]. The speed of water flow from the mountainous area to the

beach has an important role in hydro-geologic risk and often times of concentration are very different in each river basin that feeds the beach or portions of it (Fig. 1) [7].

2.2. Methodology

There was also a lack of a correct approach to problems with data integration and a lack of information for a clear overview of the status of the issue based on updated information.

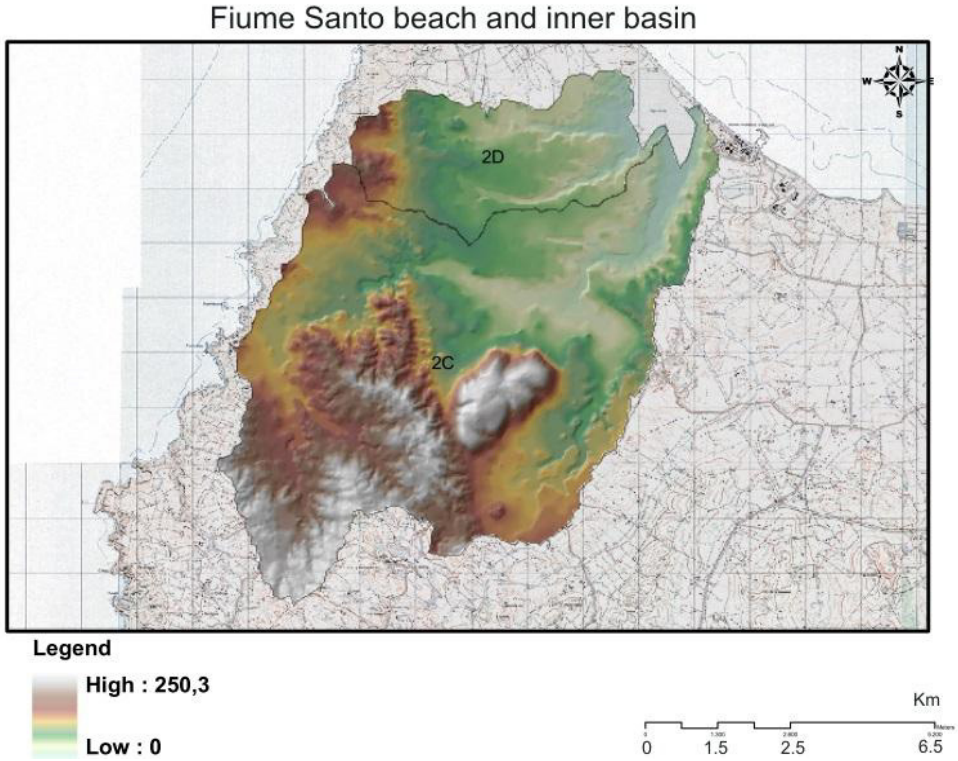

Fig. 2. Hypsometry map of the whole basin in Fiume Santo beach (NW coast).

The aims of this study are as follows: to investigate and monitor the coastal erosion situation along the coast of Sardinia. Integrating these different parts will be extremely useful in effectively determining policies, regional action plans, and solutions to the problems of coastal erosion in Sardinia. The final result will be the development of sustainable coastal erosion management in Sardinia the lack of an approach to problems with data integration and the lack of information for a clear overview of the status of the issue based on updated information.

Morphogenetic processes in the coast and within river basins, their geomorphological evolution and dynamics in some man-made beaches with a high impact on tourism were identified, with the aim to underline the critical erosion and environmental sensitivity (Fig. 2) [8].

1. Acquisition and analysis aerial surveys, topographic and bathymetric;
2. Analysis of bathymetric and meteomarine data;
3. Acquisition of morpho-sedimentary and composition data of the beaches;
4. Morphological evolution of the coastline study;
5. Identification of the critical issues and the environmental sensitivity;
6. Identification of the physiographic units affected by erosion risk;
7. An investigation concerning the human effects in some most representative beaches was carried meant both for tourist use (such as the beach at Capriccioli, NE coast) and for the particular situation of degradation (such as

coast of Marritza, North). This research, carried out on a large scale, has provided points for reflection and discussion (Fig. 3). The "perceived value" parameter of the environmental heritage has also been considered in the analysis of environmental vulnerability.

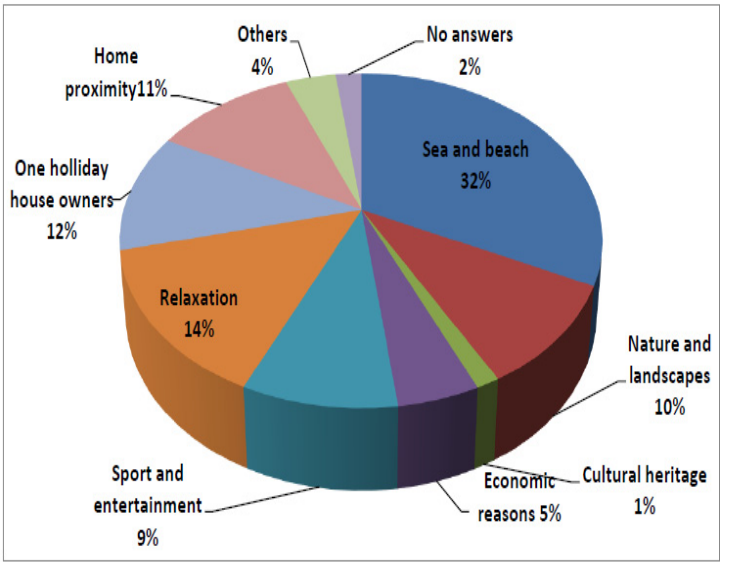

Fig. 3. Total respondents: repartition based on the chosen settlement reasons. Values %.
(Source: Data analyzed from "Beach carrying capacity study, 2014").

3. Results

Research operated mainly on the morphodynamic processes analysis taking place in the coastline physiographic unit and in the morphologic basin of each beach tract.

On the different territories (coastal and inner) 17 main areas to identify have been mapped and signed by a code W1/N1/E1, respectively assigned to the western seaboard (W), in the northern (N) and eastern (E), followed by the sequential number of reference on the homogeneity basis of the territory and independently from the beaches [6].

The areas mentioned are the following:

1. W1. Bosano physiographic unit (Temo river basin);
2. W2. Planargia physiographic unit (north Planargia minor basins);
3. W3. Alghero physiographic unit (Rio Barcariver and smaller basin);
4. W4. Argentiera physiographic unit (Argentiera smaller basins);
5. N1. Nurra Stintino-Fiume Santo physiographicunit (Rio Astemini-Fiume Santo rivers);
6. N2. Porto Torres physiographic unit (Rio Mannu of Porto Torres river Basin);
7. N3. Romangia physiographic unit (Platamona– Marritza area);
8. N4. Anglona physiographic unit (Frigiano creek basin - Anglona);
9. N5. Coghinas physiographic unit (Coghinas river basin);
10. N6. Northern Gallura physiographic unit;
11. E1. Liscia physiographic unit (Liscia river basin);
12. E2. San Giovanni physiographic unit (S.Giovanni creek and smaller ones)
13. E3. Olbia physiographic unit (Padrongiano river);
14. E4. San Teodoro physiographic unit (Eastern Gallura);
15. E5. Posada Siniscola physiographic unit;
16. E6. Capo Comino physiographic unit.

The study considered the index of landslide risk and the probability of flooding based on the general conditions of the basin, its hydrological response and time of concentration of the water system (Fig. 4) [7].

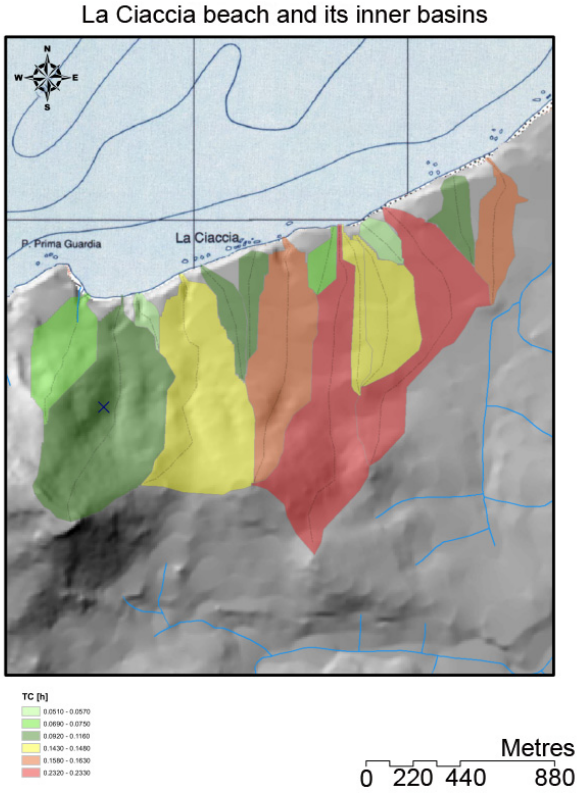

Fig. 4. The speed of water flow from the mountainous area to the beach of La Ciaccia shows a very different time in each basin that nourish the strips of the beach.

The frequency of extreme events occurs, once they were considered "exceptional" and relegated to long turnaround times, and they led to reconsider the carrying capacity of rivers and the downsizing of the banks sufficient to contain the floods no longer. We must, therefore, consider these events as usual and increasingly incisive rapid evolution of the coastal landscape, thanks to the amount of water and to narrow the time of its duration of precipitation (“water bomb” in Italian journalistic expression; flash flood in English) [9].

For the rating of the yearly sediment transport, reference was made to the data obtained by the Gavrilovic S.4 method (1972) [10], which provides an annual average value of erosional material not directly correlated to the mobilized volume during a flood event. It should be noted that the volume calculated by the Gavrilovic method evaluates the quantity of eroded material; only a part of it, however, undergoes a transport to the mouth. The critical erosion is classified into high, medium and low.

Environmental sensitivity is defined in terms of various indicators that represent the physical situation of the coastline (including the state property and its territorial context), in relation to the protection rules system that emphasizes its value. It is classified into high, medium and low.

In the characterization of individual physiographic units many cartographic sources were consulted (marine charts, aerial photos from 1954 to 2008), Atlas of the Italian Beaches, coastal geological maps. The evolution of the seabed morphology, highlighting the steepness and depth than the average level of the sea. The data identified the limit unit physiographic close 10 m depth. The acquisition of morpho-sedimentary availed by literature sources and surveys conducted in 2012, in 2013 and in 2014 partially.

The available data are abundant only in some parts of the coast, as in the industrial coastal zone of Porto Torres and River Santo thermo-power plant. The sedimentological analyzes were performed on sands samples taken from the emerged beach, from the shoreline and from the seabed to 5, 10 and 15 m depth. The more frequented beaches were performed by explorations of the seabed by diving to a maximum depth of -15 meters that allowed the

understanding of the active dynamics in some parts of the coast.

This is made in order to highlight the morphologies in a submerged and emerged area as a function of their frequency or consistency over time: the barrier islands, spits, cuspidate beaches, etc. A particular attention was paid to the pocket beaches (mainly in the north-eastern riass of Gallura district) for the specific richness of Sardinia in this kind of beach. Another type of beach where a dune system is present required a greater attention, in many cases they have an important extension. In some places, Sardinia has the most important dune fields in the Western Mediterranean Sea.

These systems are defined by a morpho-evolutionary profile of sequential type, where it recognizes a backshore and a foreshore, the presence of incipient dunes, and backshore bounded by fixed dunes (primary and secondary). Those dunes are composed by sand from the surf zone (active), while the secondary dunes are developed as a result of subsequent modification of the primary dunes. It proceeded to the identification of areas with periodic instability or continuous losses in the beach material volume in consideration to the wind contribution or destruction of coastal dunes.

The study has provided for the processing, the bathymetric data obtained by existing and acquisitions in situ, in order to be able to apply a model of the energy flows directed toward the coast. The buoy systems of the coasts of Sardinia (National Network RON) were used to measure the waves. Starting by the sea bed a georeferenced xyz point cloud was extrapolated, necessary to rebuild the database morphological system of the emerged and submerged beaches. For the present study, the software SMS (Surface-water Modeling System - STWAVE model) has been used, that generated the wave states due to the action of winds and waves in the main directions. This database has been processed to define a qualitative mesh which derive from the mathematical matrix in order to obtain the projection of wave trend and the information on perturbative wind and morphology character (Fig. 5 and 6) [6].

The data collection and processing had resulted in a new vision and updated to the actual situation in the northern coast of Sardinia; although many places were already known, this research has allowed us to confirm or fully assess the risks and the possible evolution of the whole region referable to the considered beach. The diachronic analysis of shorelines shows the growth trend of the past 50 years and quantified the change of individual tract of beach by GIS Digital Shoreline Analysis System (DSAS). This analysis, on the beach of Alghero, confirmed a decline of -13 m of the beach since 1977 with an average annual shift of the shoreline 0.23 meters/year. The system has also been applied in the presence of works anthropogenic that affect the evolution of the shoreline (Fig. 7).

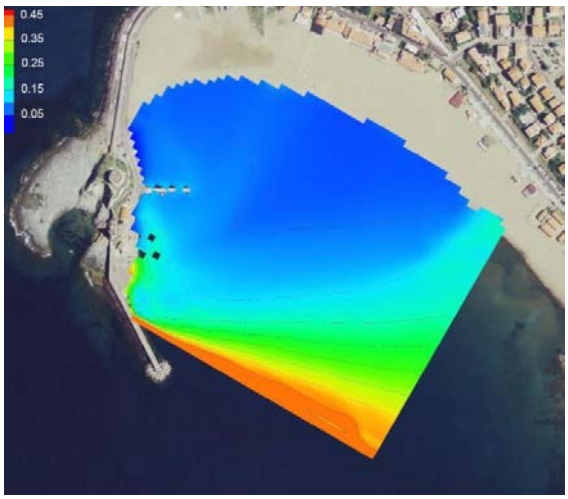

Fig. 5. Processing dynamic energy map expressed by wave motion on the beach in accretion of Bosa (W coast). The scale of the energy increases toward the red colors.

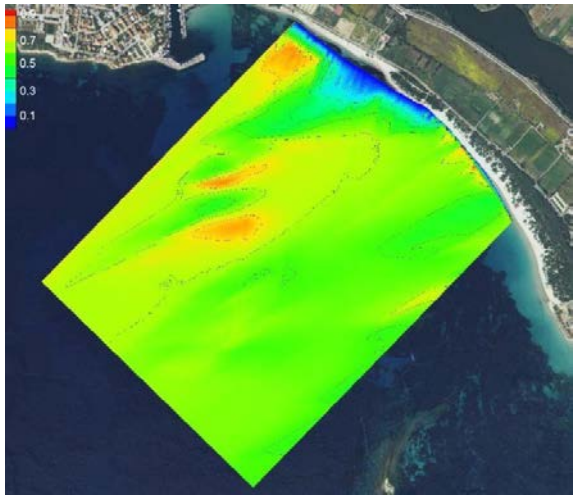

Fig. 6. The waves energy in the beach of Alghero (W coast), a particular littoral affected by an intense erosive process. The high energy hits the beach during the southwestern storms.

However, the final results come from the administration of the questionnaire in four selected localities for their particularly aspects of beaches present on the island. It is specific from each location by location, history, socio-economic level of tourist attractiveness and environmental issues presented. The questionnaire entitled "Study of the carrying capacity of the beaches", aimed at both tourists and residents, was developed by the University of Sassari and University of Ferrara; it is mixed, with open and closed answers, given anonymously and in four different parts. The objective was to build an identity kit of the tourist, the quantification of the number of tourists, and to know the characteristics and habits, their perception of the area chosen as a holiday destination, and the quality attributed to the services. Moreover, we tried to bring out the critical issues perceived by the tourist, unmet needs (Fig. 8). The services deemed deficient, so that we can learn valuable tips for planning and growth of tourism [6].

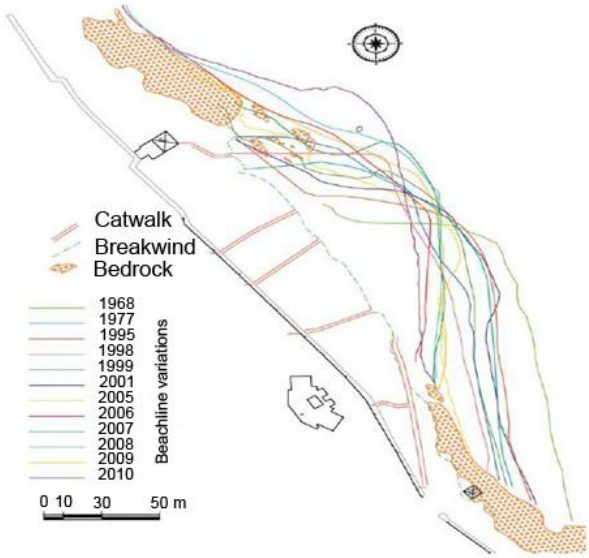

Fig.7. The map of shoreline variation from 1988 to 2010 years in the cuspidate beach of La Pelosa, near the village of Stintino in the most western part of the northern coast.

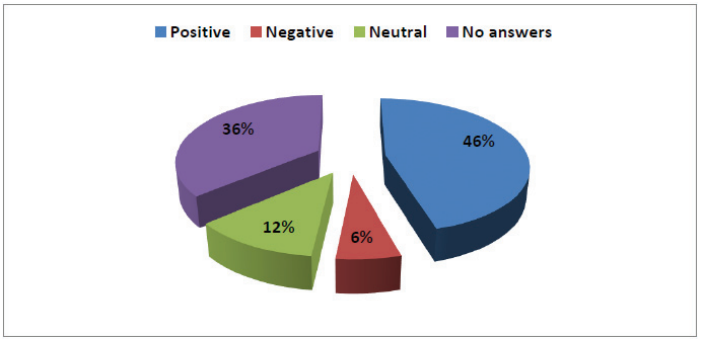

Fig. 8. Resident tourist respondents regarding the global touristic impact on settlement development. Values% . (Source: Data analyzed from "Beach carrying capacity study, 2014").

4. Discussion and Conclusion

The data collection and processing have resulted into a new vision and updated to the actual situation in the northern coast of Sardinia; although many places have already been known, this research has allowed us to confirm or fully assess the risks and the possible evolution of the whole region referable to the considered beach.

The analysis of morphological features in the physiographic units made possible to evaluate many aspects of dynamic character of the inner area and the coast, in order to take considerations on the erosional processes in the medium and long term [11]. Knowledge of climate that generates the wave's movement, and the inclination of the sea bottom have allowed us to evaluate the dynamics of the waves and their energy. The wave energy is high (type surging) where you have elevated coasts, and this is discharged directly on the rocky shores or on the cliffs with special risks where these are formed by Tertiary volcanic rocks.

The erosion at the foot of the slopes tends to retain for the long term, a straight line to the shoreline. A high wave energy is also on beaches and consists of loose materials such as gravel and pebbles where they form an area of wave breakers in plunging. In these areas, the energy determines the sedimentation of fine fractions, which are removed by the drift currents. This condition is particularly prevalent in much of the north coast of Sardinia. Areas with minor wave energy (wave breakers of spilling type) will have on the seabed at low inclination, mainly along all the coasts where the contributions of sediments (river mouths) are more abundant and deposits along the coast are made by sandy-grained course. Generally, these beaches remain stable until external causes that lead to changes in their balance intervene (poor river inputs, anthropogenic activity).

The morphology of the sea beds has defined some physiographic units (17) on a consistent depth and slope, especially for those rugged coastline tracts, with few meters wide inlets. In some cases, the limits of the unit coincide with capes, heads prominent towards the sea, even in waters less than 10 m. The division of the physiographic units, and their characterization provide a useful basis for remedial measures planning by an artificial beach nourishment coast with sandy and highlight the danger in the cliffs often naively considered stable areas [2].

The data sedimentology showed that the different dynamics, related to the transport, erosion and sediment deposit, are to be related to the weather and sea and morphological characteristics of the sites. For the considerable areal extent of the study and the many elements both natural and human (harbors and coastal defense) the size range of sediments is extremely large: the average grain size range from 1.5φ to 2.2φ (gravels very fine to fine sands) (Fig. 9).

In general, sedimentology showed a homogeneous particle size typical of the dune in the most part of beaches. In the submerged sites, the sands sampled along the coast shows a medium-fine and moderately well unsorted character from the shoreline to -10 m depth. Only in some special cases medium and poorly sands are detected, sorting for the presence of a bioclastic component with a low degree of organogenic shattering, which reveals a decreased energy and a low transport capacity.

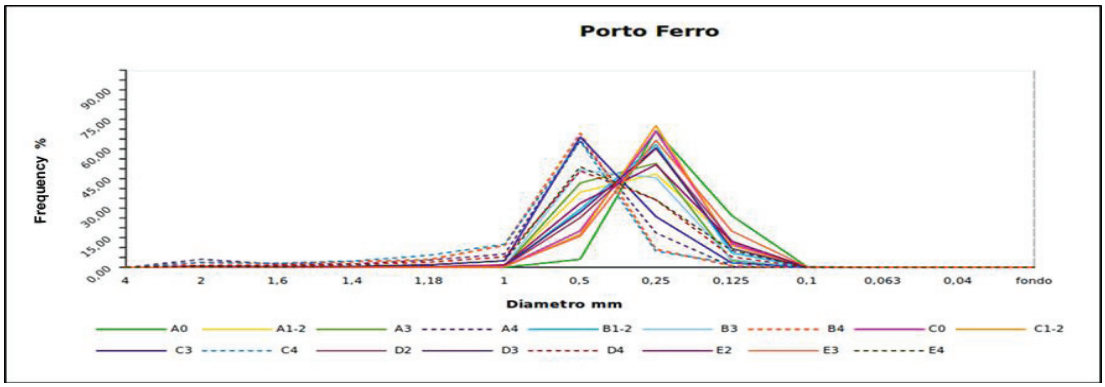

Fig. 9. Frequency histogram of the sands on the Porto Ferro Beach (W coast) where an extensive dune field is present.

The collection of all data on the sedimentological characteristics of the emerged and submerged beaches, the geomorphological coastlines and marine weather characteristics have identified the main individualities of the physiographic units and to expose their morphological and sedimentological processes in place. It was possible to assess the vulnerability of the coast to erosion through diachronic analysis of the coast area and the application of specific indices of erosion in particular for some coasts (Alghero, Siniscola, Marritza, Stintino and other minor). Analysing marine climate, based on data collected from the RON buoy in Alghero and Siniscola, to the west and east coasts, has highlighted the areas affect by coastal dynamics mainly. The maximum level is between 285 N and 315 N in the western quadrant, so the ruling and dominant winds are those from the fourth sector: Mistral and Occidental (Fig. 10).

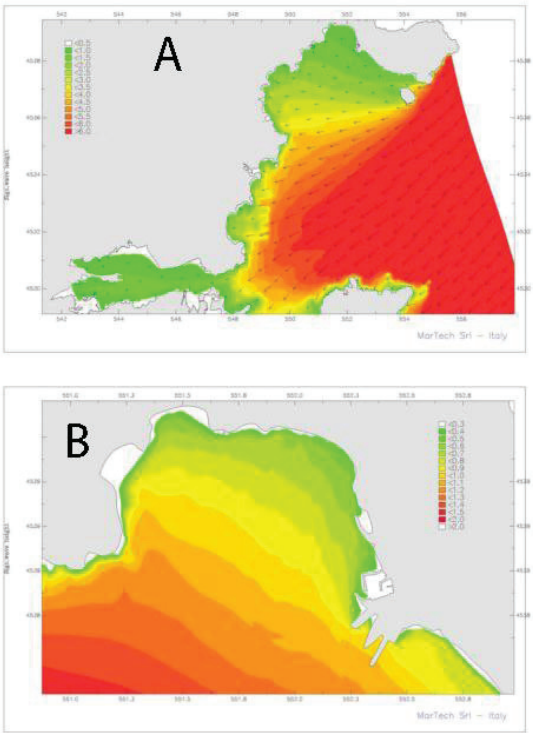

Fig. 10. Storm events on the east coast of Olbia ria with the northeast winds (A) and with the winds from the southwest on the beaches of Golfo Aranci, in the same ria (B). The return periods of extreme events were calculated.

Therefore, the more significant storms are in the IV Sector, while those in the III Sector are limited. To the eastern coast, the dominant winds come from the II Sector with a maximum between 120 N and 165 N, mainly Sirocco, while most relevant storms are the first quadrant (Grecale).

The "perceived value" parameter of the coast has been considered in the analysis of environmental vulnerability The structured questionnaire and administered as part of this work is divided into 4 sections, for a total of 26 questions, most closed questions, which correspond to specific areas of investigation (four seaside resorts in Northern Sardinia: Marritza in the town of Sorso, La Marina in the town of Castelsardo, Bosa and the twin beaches of Capriccioli in Arzachena).

In particular, the beaches of Bosa and Castelsardo are inserted in the urban context, unlike Marritza and Capriccioli are within a few kilometers the Sorso and Arzachena towns respectively. Moreover, the latter differs from the others as much for the environment as for the tourist vocation: Capriccioli is set in a prestigious area, the Costa Smeralda, characterized by a high tourist development; Marritza, on the contrary, falls in a socio-economic lifeless, slightly attractive for the tourism industry, and marked by environmental problems such as coastal erosion, which in thirty years has radically changed its landscape.

The primary objective was not to quantify the number of tourists who visit the beach but the analysis of the question, because it aimed to analyze the services offered by the region and their enjoyment according to the needs and expectations, all this with a view to planning the use of cultural and environmental resources. One part of the questionnaire, finally, was given to the sociological understanding of the impact of tourism, through the evaluation of contact of foreigners with the residents and inversely. In particular, residents were asked to take stock, not only the attitude of the tourists, but also the fallout of the global phenomenon for the settlement.

The questionnaire covered a random 821 between tourists and residents in order to be representative of the composition tourist; the foreign component represents approximately 30% of the sample (Fig. 11).

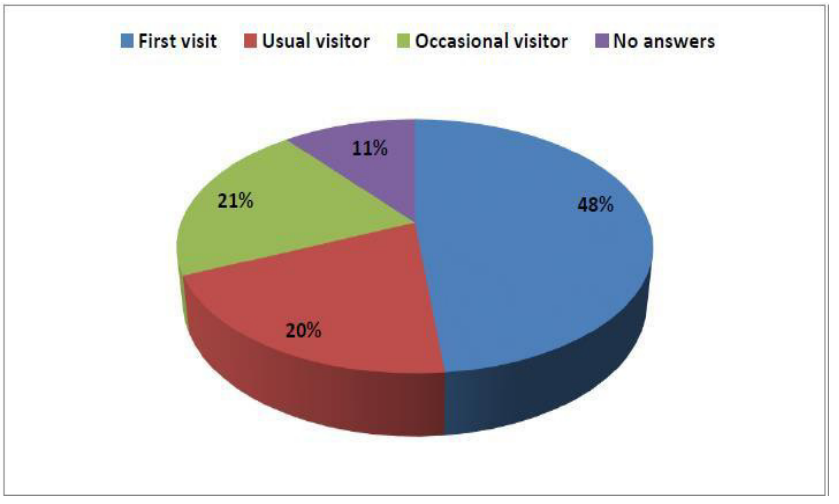

Fig. 11. Total respondents: frequency based distribution. Values%. (Source: Data analyzed from "Beach carrying capacity study, 2014")

This has allowed to rebuild, for the first time in these areas, a first identity kit of a frequent type. The questionnaire shows that the opinion about the landscape, and the landscape is decidedly positive. In fact, more than 67% of the sample knows the phenomenon of coastal erosion and is aware that it is a very significant problem, although it has some difficulties to define it precisely.

They have difficulty understanding what is meant by Integrated Coastal Zone Management (ICZM) considering a majority an important issue to be dealt with (53%). However, the Italians (43%) less than foreigners (46%), showed a greater knowledge about the beach nourishment, the nature of the intervention, but the doubts emerge on the need for interventions to the beach. Many respondents show apprehension that an intervention may be necessary for the beach, and whether any continued over the years may have contraindications for the beach, including the fact that it is not decisive, combined with the high cost involved.

The visitor, during his stay, had contacts with the residents (71%), but especially with the tourism industry and

operators in general, which has judged the attitude definitely friendly (64%), in keeping with the arguments tourists interviewed residents, believing the positive performance of non-residents against them (45%). The majority of users who have agreed to undergo the interview have a good level of education: 34% (high school graduate) and 30% (degree) (Fig. 12). The majority of interviewed, 48%, declare to visit the resort for the first time, 21% of being an occasional visitor, and 20% regularly attend. However, the majority of them, 85%, declare themselves fully satisfied with the holiday and the overall enjoyment. The interview is very aware of the environment and believes that the beaches are a public good.

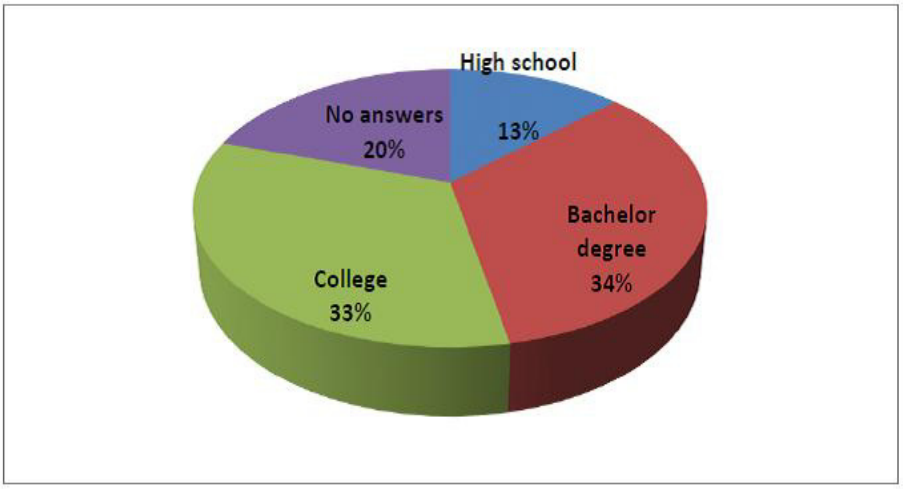

Fig. 12. Respondents: Distribution based on study level. Values %. (Source: Data analyzed from “Beach carrying capacity study, 2014”)

However, it would not be willing to pay an amount to conservation or reconstruction of the landscape, as widely believed to give its contribution to the payment of taxes already. Another very important result is the perception of crowding on the beach: the majority of interviewed (78%). A group of 4 images, propose anthropogenic different scenarios, has chosen one of the scenarios on average busy finding them more reassuring than the desert landscape (20%). For the characteristics of the beach, they estimate the proper amplitude, the recreational activities that you can practice, and they are not satisfied with the equipment and services available.

In conclusion, a mapping is constructed, where the following have been identified: the equilibrium state of physiographic unity (danger for erosion or flooding) and the pressure of use (environmental vulnerability and “well perceived”). The data have allowed the creation of a general mapping for the northern coast where sector, and all the situations studied are summarily represented along the analyzed coast (Fig. 13).

The map allows you to dynamically recognize all areas subject to higher or lower risk of beach erosion and the risk that affects some areas of dunes nourishing directly the beaches. The human impact has been assessed in the set of physical processes and thus it is not represented but its evaluation has allowed to obtain a "model" of the costs user that will be beneficial for the overall planning of the coastal area in northern Sardinia.

The work has the merit of providing further new knowledge for the protection and enhancement of the northern coast of Sardinia focusing the physical processes affecting especially the recent geomorphological evolution of the Sardinian territory. The limitations of this work are contained in the complex events that plague everywhere the coastal areas where the beach has value only if it is used. This aspect has been only marginally content only for a very small number of beaches but Sardinia is very poor for the physical and socio-economic data. Therefore, this piece of work/ study, linked to a broad study has lasted for about three years, and it is intended as a further contribution to Sardinia island which sees a possible future based almost exclusively on the economy of tourism, especially in coastal zone.

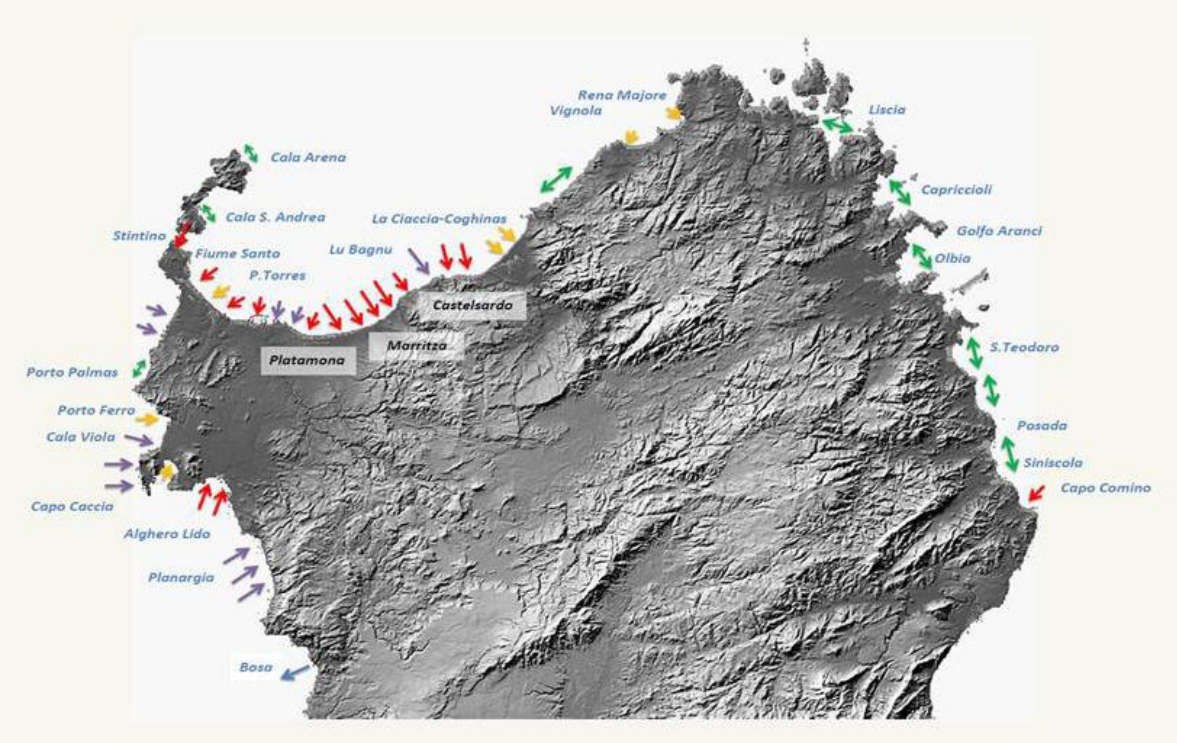

Fig.13. General map of the northern coast highlighting the type of processes. The areas subject to erosion are represented with colored arrows of variable size depending on the intensity of the process (vectorial). The red arrows indicate erosion, blue arrows indicate the progradation of the beaches while the yellow arrows show the erosion of the dunes. The purple color indicates the erosion of the cliffs. The double-headed arrow indicates stability.

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