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Shoreline Evolution And Protection Strategies Along The Tuscany Coastline, Italy.

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ABSTRACT

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The Tuscany coastline in Italy has experienced severe beach erosion since the latter part of the 19th century. The littoral sediment budget has been dramatically and negatively affected by changes in land use in the river basins and construction of shoreline defence structures and coastal amenities such as harbours. This paper synthesises the findings of coastal studies implementing cross shore profiles from the backshore to the 8m isobath, dry beach and nearshore sediment analyses, and photo-restitution of maps for the years 1938, 1954, 1967, 1978, 1985 and 1997/98. Elucidation of the littoral cell dynamics obtained from these data analyses highlights the morphological and sedimentological processes acting on the coast and recognition of both the natural and human influences working on local and regional scales. The results also illustrate the potential ineffectiveness of relying on traditional 'hard' engineering protection methods for ongoing mitigation strategies. It is hypothesized that in many cases, coarse clastic nourishment projects (under the framework of "Back-To-The-Beach" protection strategies) may offer a more viable and feasible option to all concerned parties. The modification of current protection structure configurations to more 'softer' options such as submergence is also currently being tested as a viable coastal zone management strategy deemed more appropriate to meet the criteria of recent policy changes for managing Italian coastlines.

ADDITIONAL INDEX WORDS: *Coastal defence,Harbours, Sedimentology, Littoral cells*

INTRODUCTION

Natural and human-induced influences on short term shoreline change and long term coastal evolution can be variable over a wide range of different temporal and spatial scales. The importance of assessing, either quantitatively or qualitatively, these causes or factors in coastal processes is paramount to the design and implementation of integrated coastal zone management strategies. This is especially true as contemporary erosion threatens to become a major environmental hazard in the absence of unified coastal defence strategies for protecting long stretches of coast as a whole (EL-ASMAR and WHITE, 2002). In many cases defence designs have been implemented without any *a priori* knowledge of the 'local' or 'regional' processes operating in the area.

The identification of time-averaged littoral processes can greatly impact management decisions. Identifying the major points of sediment input into the coastal unit and related littoral cell dynamics is vital to understanding the potential impact and performance of any defence strategies. Each littoral cell contains a coherent trend of littoral transportation and sedimentation, including sources and sinks and transport paths (FRIHY et al., 2002). In many cases it is predicted that existing knowledge of these coastal units would greatly affect management and planning decisions.

This paper details the results of recent coastal process studies along the Tuscany coastline in Italy, and elucidates the influence of human interventions along the coast on littoral dynamics and subsequent shoreline evolution. These areas have experienced severe contemporary beach erosion since the latter part of the last century. The longshore component of the littoral sediment budget has been dramatically affected by building of coastal infrastructure such as harbours, and changes in land use in the river basins. Mitigation techniques have traditionally relied on engineered coastal defences such as groins, breakwaters and seawalls. In many cases these structures exacerbate the problem both locally (increase in energy from reflected waves expedite the removal of sediment) and regionally (the removal of nearshore alongshore sediment from the sediment budget). Further, these structures usually result in the loss of dry beach area in the immediate vicinity. The shoreline configuration of these areas has been altered to a state where the length of engineering structures equals (or, in many cases, exceeds) the length of protected shoreline. The incremental costs of construction of new structures in downdrift areas and the annual maintenance costs to ensure structure stability and integrity retract from the cost-benefits of implementing these schemes. More so, although these constructions support short term objectives of protection, they fail to rectify the initial problem of shoreline erosion *vis a vis* the imbalance between the supply of sediment input and the volume of sediment being removed.

PHYSIOGRAPHIC SETTING

The littoral system which extends from Livorno Harbour to River Magra (Figure 1) constitutes a physiographic unit approximately 63 km long and divided between the administrative regions of Regione Toscana (60 km) and Regione Liguria (3km of most northerly section).

The northern coastline of this study, extending from the River Magra to Viareggio harbour is characterised with a high density of anthropisation, first from the harbour activity at Carrara and Viareggio, and more recently from increasing tourist activity at Marina di Massa, Forte dei Marmi and the town of Viareggio. The northern section is significant by the number of coastal defences in operation, which were constructed to meet the demands of increased tourism by stabilising the shoreline.

The features of the coastline extending from Viareggio to the mouth of the River Arno represent naturally operating systems due to limited tourist visits, and limited defence structures. Large tracts of the coastline are inside the boundaries of Park Regionale Migliarino San Rossore Massaciuccoli. Five breakwaters constructed to protect the presidential Villa di San Rossore located in Gombo and groins located at the mouths of the Rivers Morto Nuovo and Arno are the only structures present.

ENZO:

FIGURE OF PHYSIOGRAPHIC UNIT

INCLUDING......
CITIES
RIVERS
HARD STRUCTURES
SECTION PROFILE NUMBERS

Figure 1. Location map of study unit including shorelines that have been stabilised by a high density of hard structures.

The southern section of this physiographic unit, extending from the mouth of the River Arno to Livorno Harbour, is characterised by moderate anthropisation with a coastal settlement at Marina di Pisa which is defended by a series of breakwaters to protect the coastal highway and tourist amenities. The port facility at Livorno has recently been expanded northwards and transformed former beach areas into "hard" coastlines using a series of connecting breakwaters and seawalls.

The principal rivers feeding the coastline are the River Magra, River Serchio and River Arno. The River Arno is 241 km in length, has a basin 8228km^2 in area and is the primary river in this region. The river sediment load has been reduced from 5,615,0000 m^3/yr during the 16th and 19th centuries to 1,910,000 m^3/yr in the last fifty years (AMINTI et al., 1999). The River Magra, located at the extreme northern boundary of this physiographic unit, is the third largest river in this area, 62 km long, and extending across a hydrographic basin 1693 km^2 in area. The river supplies the coast with a substantial sediment load (632 x 10^3 t/yr) and is the primary source feeding the northern beaches. The River Serchio is 89 km long, has a catchment basin 1408 km^2 in area and carries approximately 23 x 10^3 t/yr of sediment to the coast (CAVAZZA, 1984). The sediment contribution these rivers has been dramatically reduced during the past centuries in response to demographic and landuse changes within the basin areas. Accurate estimatation of the reduction in sediment loads are not available.

METHODS

The 63 km of coastline between the River Magra and Livorno was surveyed using 393 topographic surveys of the dry beach and nearshore to a depth of 10 m. The profiles were spaced every 250m, with lesser distances (50 m) in the vicinity of maritime operations. Completion of these surveys occurred (total 630 km cumulative length) during four field seasons: January 1997 (Cinquale to Marina di Carrara Harbour), May 1997 (Livorno Harbour to Viareggio Harbour), January 1998 (Viareggio Harbour to Cinquale), and October 1998 (Marina di Carrara Harbour to mouth of the River Magra).

Each survey involved sediment sampling and subsequent dry sieve analyses at 10 minute periods with 1/2 phi sieve intervals. The remaining material in the tray of the sieve sections was considered the fine material (< 4 phi). The standard sediment statistics were calculated from cumulative frequency distribution curves to obtain grain parameters such as mean size and sorting. The 1st percentile and percentage of fines were also calculated. Maps of these parameters were used to visually represent and interpret the results.

To examine the shoreline evolution digital layers were created from photo-restitution from aerial photographs dated 1938, 1954, 1967, 1978, 1985 which were represented in an atlas (Coste Toscane) at a 1:5000 scale. These were supplemented with shoreline data from 1997 and 1998. The variation in shoreline position was calculated for chronological time intervals: 1938-1954, 1954-1967, 1967-1978, 1978-1985, 1985-1997/1998. The littoral system was divided into 127 sections, each spaced 500 m apart, or in some cases defined by either morphological or coastal structures boundaries, in order to analyse the shoreline trends. The variation in coastal area (m^2) and beach widths (m) were calculated for each profile and averaged for each coastal section to obtain rates of shoreline change (m/yr). Aerial photographs taken on November 1999 and March 2000 at a scale of 1:2500 were used as reference maps.

RESULTS

Coastal Structures

The littoral environment immediately south of the River Arno is dominated by the presence of connected parallel breakwaters and a continuous seawall at Marina di Pisa. In addition many smaller sized structures of variable design have been built by local property owners with little planning, and without the proper permits to protect the coastal infrastructure and highway. This has resulted in more than 5km of hard structures built along 2.5km of coastline.

The shoreline at Marina di Pisa (sections 20 - 25) shows little deviation in shoreline displacement from 1938-1998 and it is assumed that the coastline is stable due to the presence of the connected parallel breakwaters built at the beginning of the last century. These results suggest that the defences have been efficient in protecting the coastal properties located on the back beach areas, but at a huge cost associated with initial construction and subsequent maintenance of structure integrity after large winter storms. The water depth seaward of the structures has increased to 7m depth which implies a large loss of sediment from the beach profile. The increased delta erosion and associated lateral beaches suggests that the material entering the littoral system is being taken offshore by wave reflection processes on the structures – which may be perceived as an argument for removal or modification of the structures. The beaches in the southern section continued to erode but at different rates. The lack of constant erosion rates is probably a reflection of the numerous defence structures subsequently built as well as the time periods for which the surveys were done e.g. extreme storminess (Recurrance Interval = 100 years) recorded in the autumn of 1966 preceding the surveys in 1967. For the two study sections south of Marina di Pisa (numbers 18 and 19) the measured erosion of the last years is similar in magnitude to the amount of deposition recorded in downdrift sections. These beaches retreated 59.5 and 11.5 m respectively, between 1938 and 1997 (figure 2), compared to, during the same time periods, a progradation of similar magnitude (62.6 m) of beaches in Tirrenia (location 14).

The beaches at Marina di Ronchi (locations 99 through to 104), accreted from 1938 to 1954 on the scale of tens of meters (approximately 31.7m at location 103; 47.3m at location 101), are progressively eroding in recent times especially with the introduction of coastal defence projects that have recently been established e.g. beach restoration at Marina di Massa (AMINTI et al., 1998). Beach erosion has become the dominant pattern in this area especially since the construction of the port at Marina di Carrara served to block the littoral drift and cause a marked reduction in sediment moving alongshore. A sediment bypass system was abandoned in 1970 due to high operational costs and instability at the harbour jetties. The zone of retreat gradually shifted southward leading to the construction on a series of hard structures. Currently 9.7km of hard defences protect 6.7km of coastline at Marina di Massa (figure 3). Local requests from stakeholders further south for similar type protection strategies were deemed imprudent, primarily, as it was expected that these structure would impact the famous seaside resort of Forte dei Marmi in the south.

Between 1954 and 1998 beaches at Ronchi retreated approximately 120 meters (121m in location 104, in figure 2) which has detrimental affects on local tourism. In order to address this Regione Toscana financed a project in 1998 to construct and

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HIGHLIGHT.........
STRUCTURES;
HARBOUR;
DRIFT DIRECTION

Figure 2 Results from photo-restitution of shoreline displacement for the time intervals between 1938 and 1997/98.

monitor the performance of a submerged structures comprising of geotextile bags filled with sand. The preliminary results (AMINTI et al., 2001) indicate that the beach areas at Marina di Massa would be stabilised in the presence of such structures. Further, this choice of shoreline defence is aesthetically more appealing rather than hard emergent structures.

PHOTO OF STABLE COAST

Figure 3

The shoreline at Marinella di Sarzana, located in the northern region, suffered intense erosion between 1978 and 1985. Shoreline analyses indicated the beach retreated approximately 30.1m (4.29 m/yr). Construction of further coastal defence structures such as groins, breakwaters (oblique) has resulted in a significant reduction in beaches in the north. Erosion in the beaches immediately south of the constructions (locations 121 and 123) ranged between 0.54 and 0.74 m/yr. In 1999 four groins were constructed, in addition to small beach nourishments of coarse materials. Preliminary results suggest that beach stabilisation has not been realised even in the presence of such structures.

Harbours

The expansion of the beach areas south of the port at Viareggio for all the analysed time periods results from the blocking of the littoral drift moving alongshore from erosion of the River Arno delta (Figure 4). This has an updrift feeder effect on beaches located north of the harbour as would be expected. These beaches north of the harbour are famous tourist destinations and comprise some of the most renowned beaches in Italy for recreation. They form an integral natural resource for tourist exploitation. Analyses of the shoreline evolution shows that this area has experienced erosion but not to the same scale that the south beaches have accreted. Successively for this area, the shoreline prograded, so that the 1998 shoreline was 70m further seaward for the first two sections, and approximately 60m seaward for the next two sections compared with the 1938 survey. This is explained by a couple of findings. Firstly the original harbour construction did not interrupt the northward sediment flow. The structure border was angled and sediment which was deposited south of the harbour was regularly dredged until a bypass system was put in place in 1970's. This system was designed to move the sediment from the south to north beaches. More recently the beaches south of the structure have expanded to a point where natural bypassing occurs.

The most recent time period of analyses (1985 - 1997) for location 92 and those further north show patterns of shoreline recession, which are a response to operations and processes occurring further northward. These are assumed to be affects of construction at Marina di Carrara port facilities which interrupted the southward littoral drift processes – effects which are also compounded by the reduction in river discharge of sediments from the river Magra.

The port at Marina di Carrara was built at a critical time for the northern beaches of the study area. Between 1881 and 1928 the beaches of Fiumaretta, immediately south of the River Magra, retreated 500m due to the reduction in sediment input from the river. Before the harbour construction the eroded material from these beaches moved southward and caused beaches near Marina di Carrera to accrete – which were a signal of updrift erosion. A loss of 634,759 m^2 of dry beach along 2.8km of coastline occurred in beaches north of the river mouth of the Parmignola. South of this area the beaches expanded in area approximately 20,226 m^2 along 1.5 km of coast which ceased after harbour construction. Construction of the harbour, begun in 1920, resulted in trapping of the littoral drift moving southward, and associated expansion of the beaches at Marina di Carrara. A rapid shoreline advance occurred in the period 1954 - 1967, with beach progradation in the order of 21.1m (1.62m/yr). However when the beach evolved to a parallel orientation with the dominant waves
these rates were reduced. A related influence to this was the reduction in beach erosion further north due to implementation of coastal defences which, subsequently, reduced the littoral sediment budget.

PHOTO OF HARBOUR

Figure 4 Aerial Photo of Viareggio harbour.

In the south, at the mouth of the River Calambrone the coastline is defended be a series of connecting breakwaters to protect areas zoned for industrial and harbour use. These defence structures terminate at the northern boundary of the port facility. The harbour of Livorno, built in the 16th century without any external structures, was protected by a circular dyke in 1852 and then progressively expanded to the north, occupying the coastal plain and adding long breakwaters. In 2000 a new harbour expansion was carried out, with the construction of a breakwater enclosing an area to be filled with sediment dredged inside the harbour which was determined to be too polluted to be dumped offshore.

The construction of the seawalls to expand the yards resulted in an artificial shoreline expansion. In the period 1938-1997, from Sector 3 to the northern extremity of this area (Sector 11) the coast accreted with the sole exception of Sector 4, where very limited erosion occurred (-0,07 m/yr). Mean shoreline advancement ranged from 0,21 m/yr, in Sector 3, to 0,51 m/yr, in Sector 6. These conditions dramatically changed after the construction of the new breakwater in 2000: Sectors 2 (in its unprotected part), Sectors 3 and 4 experienced severe erosion. Shoreline retreat of

4,24 m/yr occurred in Sector 3, in the southern part of Calambrone beach, where several bathing facilities were damaged. Conversely, the beach between Calambrone and Tirrenia is strongly accreting, with values of 3,85 and 3,72 m/yr in sectors 6 and 7. It is assumed that the eroded material from sectors 2-4, adjacent to the harbour, are responsible for this shoreline progradation. The simulated currents field in both the present and past harbour designs were examined using a numerical model (Mike21). Following harbour extension these distinct current patterns were shifted northward and appear more concentrated near the shoreline. Numerical simulations suggest that waves approaching the coast from the SW, W and NW are highly refracted and dissipated due to the presence of shoals. For all simulated wave directions, the wave rays converge in the nearshore behind the shoal leading to a favorable conditions for accretion. In addition, the northward expansion of the harbour has also instigated futher movement of sediment away from Calambrone by modifying the wave generated current patterns.

DISCUSSION

Nearshore Profiles

The variation is nearshore slopes is seen as a varying response of the nearshore system to wave climates, the difference in sediment characteristics, and the varying degrees of anthropogenic influences along the coast. The influence of these factors is greatest for the first section of the profiles but is less prevalent in the distal regions. Examples from Marina di Pisa and Marina di Ronchi illustrate these patterns. Mean water depths between the sea wall and detached breakwaters approximates 2m, while immediately seaward of the structures the water depths reach 7m (figure 5). Moving offshore the nearshore profile is almost horizontal with mean slopes <0.5% down to the 15m isobath. Analysis of the nearshore morphology shows the loss or reduction of the bar system in areas where coastal defences have been constructed. Wave energy dissipation is very limited at these depths and waves break directly over the structure. This has resulted in continual scouring and a need for constant structure maintenance. Further, wave reflection processes result in offshore movement of sediment rather than alongshore thus resulting in sediment budget deficits in downdrift beaches. Conversely, where an abundant sediment supply exists linear bar systems and dissipative type profiles are evident e.g. convergence area between Marina di Pietrasenta and Cinquale. An average slope of ***1.16%*** occurs from the shoreline to 5m isobath and ***0.71%*** between the 5m and 10m isobath.

NEARSHORE PROFILES

Figure 5

Sedimentology

The varying influences of anthropogenic and natural factors, river processes and coastal defence and coastal structures are all evident in the sediment analyses. Beach sediment parameters allow the identification of cross- and long -shore fluxes and a better identification of the cell system previously described by other authors. The mean grain size ranges from –3.09 to 3.60phi, which represents gravel to fine sands according to the classification of KRUMBEIN (1934). In general, there is an inverse relationship between grain size and depth, with coarsest material on the beach with fining offshore to deeper water depths. The reduction in grain size at 10m depth is characteristic of the morphological and energy environments of this zone. The sediments eroding from the Arno delta and lateral beaches move southward as far as Livorno and, northward to the zone of convergences, exhibit a trend of *downdrift fining*. Other areas that show fining patterns are beaches downdrift of the harbours e.g. at Viareggio. In this case the presence of both structural breakwaters and the harbour impede the movement of the coarsest material. From figure 6 it is evident that a jump in grain size of approximately 1 phi exists between sediments located on the beaches updrift of the harbour and those located immediately downdrift. Analysis of sorting in the sediments show that the study area comprises of very well sorted to very poorly sorted material (0.20 phi $< \rho <$ 2.99 phi) according to the categories proposed by Folk and Ward (1957). Shoreline areas and harbour areas protected by high density of structures results in much lower energy conditions and poorer sorting of beach material.

ENZO: SAME FIGURE SHOWN IN BOOK!

Figure 6 Mean grain size distributions for study area. Littoral cell boundaries defined by varying longshore directions are also shown.

Future ICZM Strategies

The wish to protect future economical, social and cultural values of coastal zones in Europe continually conflicts with the need to face almost irreversible trends from the sea (climate change, sea level rise, erosion) and from land (urbanization, tourism, industrialization, fisheries). In recent years coastal zone management in the Tuscany region has undergone a restructuring due to new general state legislation but also to the effort of small research groups affiliated with local administrations and University Institutes (CIPRIANI et al., 2003). Historically, beaches in Italy were state owned which meant initial management costs were generally attributed to the state, while regional governments were held responsible for maintenance and associated costs, at least formally (HANSEN et al., 2002). The substantial revenues from tourism exploitation go to the local municipalities. In the past there were no cost-benefit analyses of projects and huge discrepancies existed between who is paying and who is receiving the benefits. This fundamental flaw in management policies was addressed in recent legislation that have resulted in a comprehensive re-structuring of responsibilities from central to regional areas. It has resulted in more comprehensive and coherent objectives in coastal zone management. These decisions are in line with ICZM principles adopted by the European Council and European Parliament under the form of a Recommendation (COM/00/547) of 17 Sept. 2000, advocating knowledge based decision making and knowledge benchmarking. The new strategy for coastal management proposes the cessation of hard structures construction in order to defend coastal settlements and infrastructures from shoreline retreat, and to encourage the following: beach erosion prevention, use of soft engineering (beach renourishments), and the abandonment of the existing hard structures. Evidence from these studies shows the long term dertimental effects to both the littoral dynamics and aesthetic value of the coast by continuing to rely on hard defences for shoreline protection.

Back-To-The-Beach

Currently two test sites are being monitored along the Tuscany coast that follow the design approaches described in the new coastal protection policies. These include a gravel beach nourishment at Marina di Pisa and submerged groins at Marina di Ronchi. The working title for this research group, based in the University of Florence, Tuscany is "Back-To-The-Beach". In 2001 the local municipality at Marina di Pisa endorsed the construction of a 30m wide gravel beach in front of a section of seawall as an optional 'softer' shoreline defence strategy. It is proposed to lower the existing breakwaters below MSL after the gravel beach is completed. Physical model simulations performed at the University of Florance and the Coastal Engineering Laboratory at Polytechnic Bari suggest that gravel beaches can offer equivalent protection than the seawalls and breakwaters. This experiment is described in detail in Cammelli et al., (in press) in this proceedings. Regione Toscana financed a project in 1998 to construct and monitor the performance of a submerged structures comprising of geotextile bags filled with sand at Marina di Ronchi. The preliminary results are described in detail in AMINTI et al., (2001) and AMINTI et al., (in press). The results, thusfar, are encouraging and indicate that the beach areas at Marina di Ronchi would be stabilised in the presence of such structures with limited impact on downdrift shorelines.

CONCLUSIONS

A moderate sedimentary deficit is presently affecting the northern Tuscany coast and is responsible for a mean annual shoreline retreat of 0.23m (data for 1985-1998), with strong local variations. The severe erosion on the northern side of the Arno River mouth (20m/yr from 1994-1997) shows the importance of regional factors, both human and natural, present inside the catchments of rivers feeding the coast, whereas the accretion of beach updrift of the Marina di Carrara harbor (44.6m from 1938-1998) and the erosion of the downdrift beach (106m in the same period) is a measure of the importance of local factors. The nearshore slope and the presence and shape of longshore bars are strictly related to the shoreline evolution and to the presence of coastal structures. Beach sediment properties allow the identification of cross- and long-shore fluxes and a better identification of the cell system previously described by other authors. The results of this study give new insight of the processes reshaping this coastline and provide important findings to design and implement an updated integrated coastal zone management strategy.

Preliminary findings suggest that recent policy changes in ICZM for the Region can be satisfied using gravel nourishments and submerged structures.

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