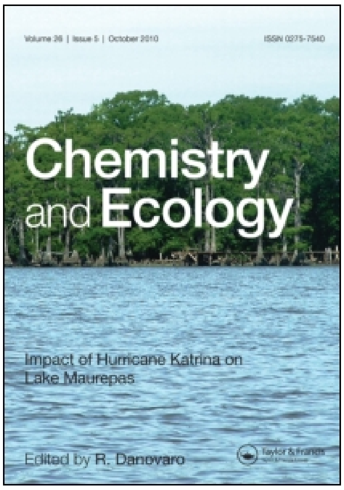

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EVALUATION OF THE EFFICACY OF COASTAL DEFENCE STRUCTURES IN RELATION TO COASTLINE VARIATIONS

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A process of evaluating the efficacy or inadequacy of coastal defence structures has been proposed through a study of littoral evolution inferred by analysis of coastline variations.

This study was undertaken in two parallel phases which have set the incorporation of cartographical and field measurement data in a geographical information system (GIS) package.

The GIS package provided for the establishment of the distinct layers based on the chronological order of events (layer of coastal relief and layer of the construction of the defence structure). This GIS application has made it possible to construct a dynamic archive of morphological–sedimentological information useful for determining the evolution of the littoral in the period following any defensive intervention and to evaluate its efficiency.

In addition, other than the usual query, it is possible to automatically calculate the areal variations of the littoral inferred from the coastlines and to consequently make a semiquantitative estimate of the sediment moved.

Keywords: Coastline; Coastal defence structure; GIS; Coastal evolution

1 INTRODUCTION

This article presents a pilot study aiming to create a methodology suitable for taking a census of coastal defence structures and evaluating their efficacy and is a part of the project 'Il Mediterraneo, Difesa del mare e delle Coste – Progetto 5.1' of the Ministry of Environment, Dipartimento per lo Studio del Territorio e delle Sue Risorse of the Università di Genova in collaboration with ENEA-CRAM of S. Teresa. A sample area along the eastern Ligurian coast, between Punta Portofino and Punta Mesco, was selected for the development and successive testing of the methodology.

The evolution of a littoral depends on a multitude of morphological and sedimentary parameters whose results, in the medium term, are essentially revealed in coastline variations. On the other hand, any intervention for the defence of the coastline has the expansion of the littoral as its primary objective and its success is evaluated as a function of this increase.

This study proposes a procedure for evaluating the efficacy or inadequacy of the intervention inferred from the study of the variations in the littoral through the analysis of the coastline variations using a geographic information system (GIS) for the implementation

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of the data (AA.VV., 2000). The information system developed, despite the limitations imposed by the adoption of a single indicator for the evolutive trend of the littoral, could provide a useful tool for agencies involved in the management and protection of the coastal area.

2 MATERIALS AND METHODS

The study was undertaken in two parallel phases that provided for the incorporation of the data from the census and that from the classification of the coastal defence structures, and the study of the coastline in a GIS.

2.1 Census of Defence Structures

A census of the defence structures was taken using the following parameters:

- Type of coastal defence structure: Five types of construction were taken into consideration; emerged breakwaters, groynes, sea walls, non-conventional work and beach nourishment (Cortemiglia *et al.*, 1982).
- Structural characteristics: Works were distinguished according to the material used; concrete, natural blocks or mixed. This parameter is of particular importance as it furnishes information on the degree of permeability of the work to the finest sedimentary fractions.
- Dimensions: The main axis of the structure that predominantly influences the sedimentary dynamic was taken into consideration.
- Year of construction: When possible, otherwise a reference period was inserted to give an approximate dating to the structure.

The data were successively inserted in a database.

2.2 Determination of the Coastline

The determination of the coastline was carried out using topographic maps (Regione Liguria, 1978), aerial surveys (Regione Liguria, 1944; 1973; 1983; 1993) undertaken at different altitudes and field measurements using differential positioning systems (Global Position System).

A database, containing information on the textural characteristics of the littoral, based on the relief data, or the lithological characteristics in the case of rocky coast, was also created in this case.

The data were processed using Autocad® software and were exported in .dxf format to be inserted in the GIS package Arc View® (AA.VV., 1998). The structure of the project (Fig. 1) provided for the establishment of distinct layers on the basis of the chronology of events (layer of coastal relief and layer of construction of the defence structure). The .dxf files were loaded on Arc View® as themes (Add theme) and each of these was converted to the shapefile format. The final result was the creation of numerous files in shapefile format and some of these containing different layers. In Fig. 2 the legend taken from the project realised in Arc View® is shown.

The upper part of Fig. 3 shows the database about an area of movement sediment during the period between 1983 and 2002, with mq of sediment and the trend of the beach. The lower part shows the database with type, structural characteristics, dimensions and year of construction of a coastal structure.

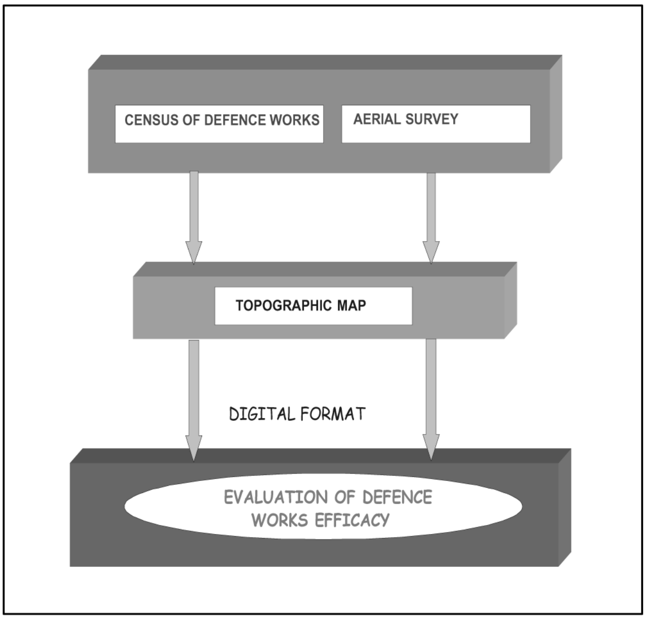

FIGURE 1 Structure of the project.

3 RESULTS AND DISCUSSION

The methodology described above was applied to a stretch of the eastern Ligurian coast extending for about 66 km between Punta Portofino and Punta Mesco (Fig. 4).

FIGURE 2 Legend of the project.

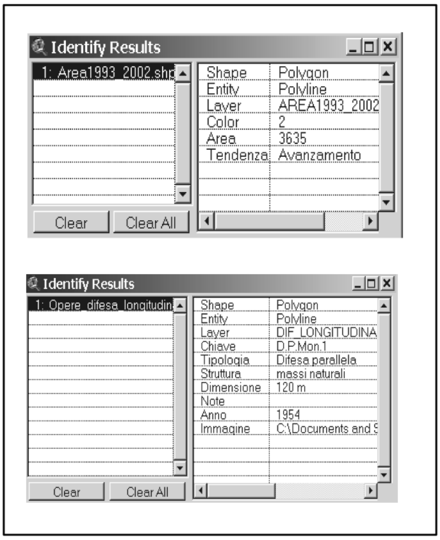

FIGURE 3 Databases of the movement sediment and the coastal structure.

This coast is characterized by a succession of rocky cliffs (Cevasco *et al.*, 2000), coastal plains and pocket beaches (Rollando and Terranova, 1992), also of discrete dimensions. The sedimentary supply is guaranteed by the presence of numerous watercourses of which the principal is the Entella, with a drainage surface of about 380 km^2, which nourishes the littoral of Chiavari–Lavagna and Sestri Levante. In the extreme eastern tract, characterized by rocky cliffs, there are alluvial plains of limited importance, bordered by small beaches (Bonassola,

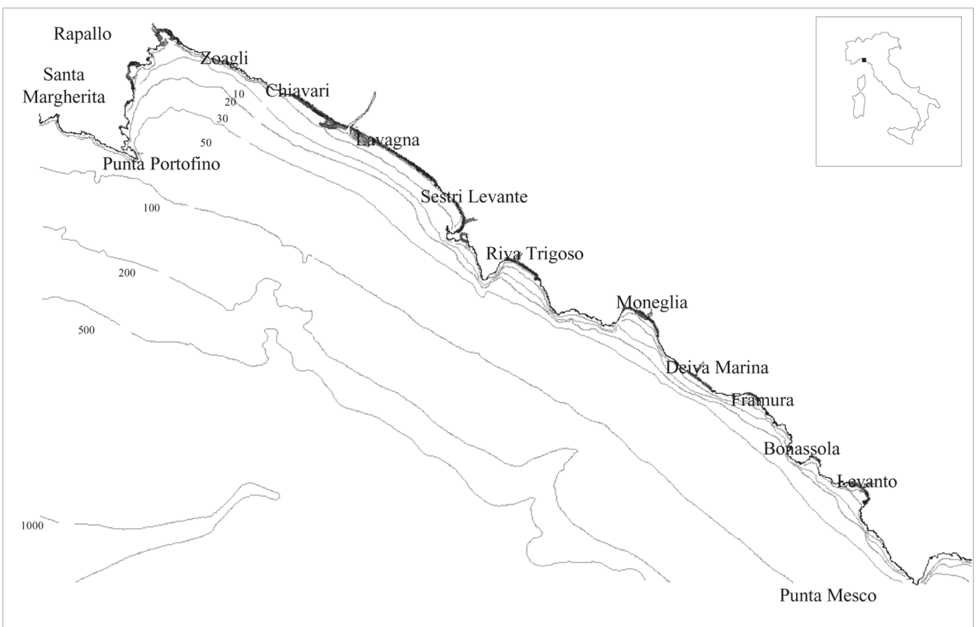

FIGURE 4 Survey area: the eastern Ligurian coast between Punta Portofino and Punta Mesco.

Moneglia, Levanto) fed by torrents of reduced dimensions (Brandolini, 1995; Terranova, 1987).

The choice of study area was dictated by the diverse morphological and urban characteristics of the two areas described above (Terranova, 1993).

The first analysis of this area was carried out through the study of two maps of the Atlas of the Italian beaches (AA. VV., 1985; 1988; 1990), as it is the first step to understand the natural dynamics of the littoral and it also shows the trend of this coast.

The western sector has been subject to heavy anthropic activity, since the beginning of the 20th century. In fact, this coastal strip has been strongly influenced by the construction of the main arteries of communication, notable urban development and marinas of remarkable size (Chiavari, Lavagna, Santa Margherita, Rapallo and Sestri Levante), which have triggered serious erosive phenomena. Subsequently, numerous coastal defence structures have necessarily been set up in the sector of Chiavari and Lavagna to counteract this evolutive trend.

The extreme eastern sector has been less affected by anthropic development, with the exception of the railway line along the coast, but has also been the subject of erosive phenomena, essentially imputable to natural causes.

The analysis of the sample area revealed that port areas occupy all the sedimentary coastal tracts: a total of 6 km, about 20% of the beaches in the area. This situation, apart from reducing space, is also the cause of serious modifications to the littoral dynamic with negative consequences for the adjacent areas (Berriolo and Sirito, 1972).

The defence works are essentially of four types: emerged breakwaters (no. 12;1755 m), sea walls (no. 38; 6175 m), groynes (no. 60; 1892 m) (Fig. 5), and beach nourishment (no. 18; 5,000,000 m^3). Other types of construction common to other tracts of the littoral, including other tracts of the Ligurian littoral, such as barrier islands and submerged barriers, were not identified. The areal distribution of the defence structures covers almost the entire area studied, with the exception of some pocket beaches usually of limited dimensions (Paraggi, a pocket beach close to Portofino, Bonassola, Deiva Marina, S. Michele di Pagana, a pocket

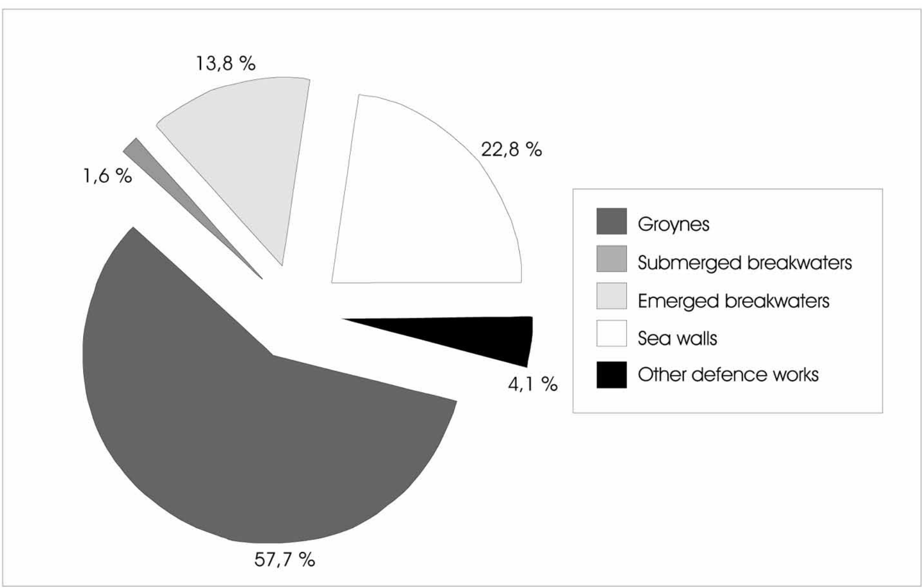

FIGURE 5 Pie chart of defence works distribution.

beach close to Santa Margherita). Their greatest frequency is obviously in the more economically important coastal tracts that are also subject to the greatest erosive phenomena. In fact, it is possible to observe massive works along the littoral of Chiavari (Cortemiglia, 1971) and Lavagna–Cavi (Cortemiglia and Terranova, 1978; Terranova, 1979) and, to a lesser extent, that of Moneglia and Levanto. The efficacy of these works does not always seem to have been verified, especially in those cases where the works were undertaken without effective planning and as isolated initiatives, as at Riva Trigoso where, after the construction of a groyne, a loss of the littoral equivalent to 268 m^2/year has been recorded, notwithstanding beach nourishment. In other cases (the littoral of Chiavari) the extent of the erosive phenomena was such that the only artificial construction proved to be ideal for the protection of the civil infrastructure but unable to recreate the beach.

In assessing the efficacy of the different types of defence structures in relation to variations in the coastline, the study revealed that transversal defences seem to achieve good results in the Lavagna–Cavi tract when associated with nourishment. In fact, while a loss of the littoral equal to 2069 m^2/year was recorded before the reorganization of the defence works and a nourishment of 5,000,000 m^3 in 1955–1970; the years following that period have witnessed substantial stability. However, the undesirable side effects of this type of defence, such as erosion in the downdrift areas, should not be ignored. An example of this is the eastern littoral of Moneglia where the downdrift beach has registered a deficit of 317 m^2/year.

Emerged breakwaters show a certain efficacy in protecting the tracts of the littoral but often cause accentuated erosion along the adjacent and submerged beaches due to the phenomena associated with the reflection of wave motion, as in the case of Moneglia and Framura.

Sea walls demonstrate negative effects in all cases, due to the reflection of wave motion; these problems can also involve tracts of the adjacent littoral (Deiva Marina, Framura, Moneglia). These structures are generally used in cases in which wave motion threatens the infrastructure or along tracts of rocky coast, which are subject to instability phenomena (Regione Liguria, 1999). Only at Bonassola has there been a case of nourishment without structural work. The study of the evolution of the littoral seems to suggest that this is the type of intervention providing the best result. In fact, after the depositing of sediments, the littoral still displays substantial stability.

4 CONCLUSIONS

The GIS application, realized through temporal succession of events, has made it possible to construct a dynamic archive of the morphological–sedimentological information useful for determining the evolution of the littoral in the period following any defensive intervention and to evaluate its efficacy (Fig. 6). Its application to the pilot area demonstrated its functionality, making it possible to simplify the presentation of the available data.

A final analysis of the area shows that structural intervention alone is often inadequate. The best results are achieved when the construction of coastal defence structures is undertaken in conjunction with nourishment programmes. However, it should be noted that although the defence structures have slowed down the erosive phenomena, to a greater or lesser degree, they have never resolved the problem definitively. The exception is Santa Margherita, where the massive structural works and the particular form of the littoral have practically annulled the sedimentary dynamic, creating an evolutive stasis.

Groynes seem to have been more successful along wide littoral (Lavagna) than on pocket beaches (Moneglia, Levanto). This phenomenon is presumably due to the morphology of the

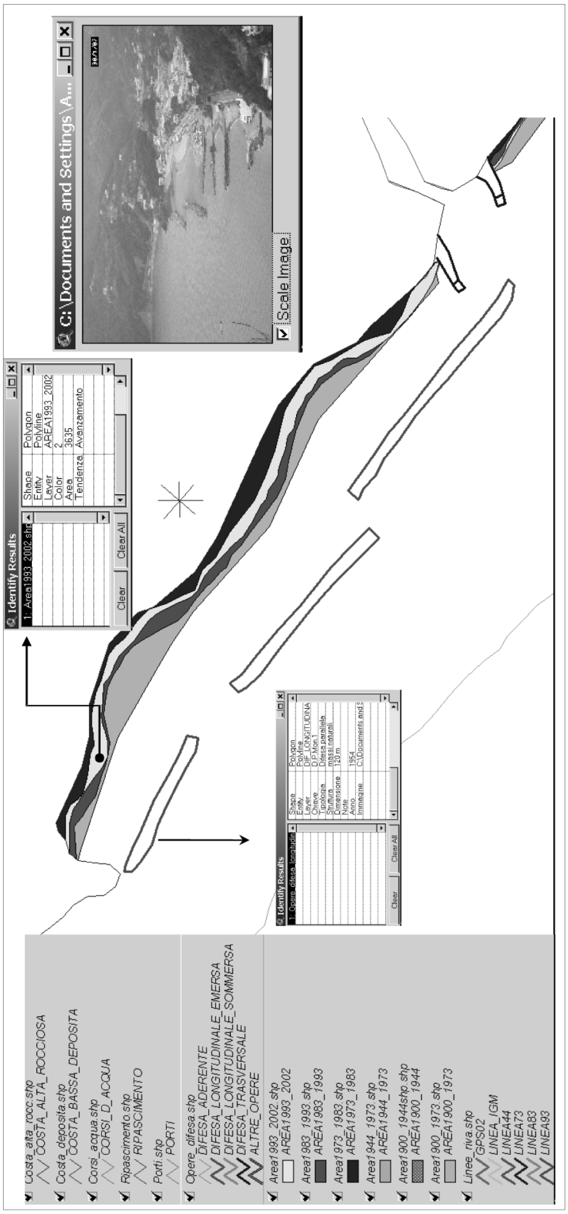

FIGURE 6 An example of GIS application.

latter (between two rocky capes) that creates wave motion practically parallel to the coastline, limiting the lateral transport of sediment in favour of the transversal. On the contrary, emerged breakwaters have been used with relative success on the pocket beaches, where such causes of erosive phenomena as the wearing away of sediments and their off-shore transport, beyond the coastal sedimentary dynamic, predominate.

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