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EVALUATING THE EFFECTIVENESS OF A SUBMERGED GROIN AS SOFT SHORE PROTECTION

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Abstract

The Marina di Carrara harbour (Tuscany, Italy), was built in the early 1920s and since then has been trapping longshore moving sediments coming from the north, the main cause of beach erosion along downdrift beaches. Since the 1930s, seawalls, groins and detached breakwaters have been built along 6.7 km of the coast south of the harbour, so that now each kilometre of beach is protected by 1.4 km of hard structures (protection ratio). Since these types of defence have induced some degree of shoreline progradation, the local tourist operators have asked that shore protection be extended southward, where the increasing erosion rates are due to the more northern structures.

In 1998, the administrative body of the region of Tuscany financed a project to test soft shore protection in the area. If the results are positive, these soft shore protection measures could be applied to the southern beaches, and eventually gradually replace the hard northern structures. In spring 1999, an experimental underwater groin was built approximately 1 km downdrift from the southern hard structure, along a stretch of beach where erosion rate over the last 20 years has been approximately 4 m/yr. The groin was built with 2.5 x 1.8 x 0.7 m polypropylene bags filled with sand. The groin is 180 m long; it is rooted inside the backshore and reaches the –3 m isobath with a mean depth of approximately 1 m.

Morphological and sedimentological beach evolution was monitored and four surveys performed during which cross- and long-shore bathymetric profiles were acquired as well as sediment samples. Preliminary results from this monitoring show that the submerged groin effectively interacts with nearshore dynamics, boosting natural processes and increasing seasonal bar cross-shore shifting. Due to the limited length of the structure, during severe storms, the bar system moves offshore of the groin head, and rip currents are stabilised by the structure itself. Under these conditions, beach erosion near the groin increases, but the end of the storm, enhances the efficiency of the structure to draw in sediments. Under fair weather, the protected beach is wider on the backshore and less steep on the foreshore. The erosion rate fell to 1 m/yr, and although a longer period is required to draw definite conclusions, the tourist operators are satisfied. In contrast to events resulting from emerged rock rubble/boulder groins, beach evolution is symmetrical on both sides, and no significant changes have been observed along downdrift beaches. Grain-size variations proved to be limited, but for a small increment in coarse material at the groin root.

C. L. Goudas et al. (eds.), Soft Shore Protection, 199-210.

Results of the first year of monitoring suggest that this type of soft defence should be longer and fully cross the bar system in order to prevent scouring at the groin head, where strong currents occur during storms. These currents are responsible for sediment loss in the protected area.

1. Introduction

Marina dei Ronchi is located in northern Tuscany (Figure 1). In this area, potential net longshore sediment transport has been estimated to be moving southwards at approximately 150000 m^3/yr (Aminti et al., 1999). The sediment source for the Marina dei Ronchi beach is the Magra River, outflowing at the northern margin of the physiographic unit and feeding the beaches to the south as far as Forte dei Marmi, as demonstrated by beach sediment petrography (Gandolfi & Paganelli, 1975).

The construction of the industrial harbour at Marina di Carrara in the early 1920s caused interception of the southward longshore drift, inducing rapid progradation in the updrift beach and erosion downdrift. The Marina di Carrara beach experienced shoreline progradation of approximately 300 m following construction of the harbour, although in recent years (1985–1998) the trend has reversed (Cipriani & Pranzini, 1999) and the shoreline has retreated as a consequence of a strong fall in the Magra River sediment load (Pranzini, 1995). Marina di Massa, which is located downdrift, has experienced severe erosion since the early 1930s (Albani, 1940), even though the harbour updrift jetty was then only 400 metres long, in contrast to its present length of 900 metres. In 1930, the first seawall was constructed in order to protect the coastal highway and in 1957 a series of breakwaters were added, even though a 2 kilometre stretch of the beach south of the harbour had already vanished (Berriolo & Sirito, 1977).

In the meantime, shoreline retreat was gradually shifting southward, and a series of hard structures such as seawalls, breakwaters, groins and submerged breakwaters were built along the coast (Figure 1). Today, a 6.7 kilometre-long stretch of coast south of the harbour is protected by 9.3 kilometres of hard structures (1.4 km of hard structures per km of coastline).

In 1970, a bypass system was projected in order to transfer approximately 200 000 m^3/yr sand from the northern side of the harbour to the south. After several interruptions, the experiment was finally abandoned in 1974 on account of the expensive maintenance costs and the structural instability of the harbour's northern jetty due to sand dredging at its foot.

During the late 1980s and early 1990s, artificial beach nourishment projects using sand dredged from inside and outside the Marina di Carrara harbour were performed along the Marina di Massa beaches, but the results were limited due to the small volume and fine texture of the sediments (Iannotta, 1997). This led to the local tourist operators requesting further hard structures in order to stabilise the shoreline. Indeed, between the Lavello and Frigido rivers (Figure 1), groins and submerged breakwaters were effective in stabilising the beach that was retreating at a rate of approximately 1 m/yr. during the period 1938–1978 (Cipriani & Pranzini, 1999).

However, beach erosion continued to increase southward. Figure 2 shows the evolution of the shoreline between 1938 and 1998 in the study area. Sectors 9 – 13 show an expansion of the dry beach after the construction of coastal defences, while sectors 14 – 17 show an increase in beach erosion as a consequence of the construction of the same structures.

2. The project

The study beach is located at Marina dei Ronchi, some 7 km south of Marina di Carrara harbour, and extends for less than 2 km between Magliano and Poveromo Creeks (Figure 1). In order to stabilise the shoreline retreat without increasing sediment starvation to downdrift beaches, the administrative body of the region of Tuscany financed a research project on coastal morphodynamics for the entire physiographic unit. Research included studies of the wave climate and sediment transport models, morphological and sedimentological studies, investigation of offshore sand reservoirs, testing experimental defence and evaluation of the environmental impact of the project. To test the experimental defence, it was decided to build a submerged groin along a stretch of coastline experiencing erosion and free of hard structures. The object was evaluation of the effectiveness of a submerged groin as soft shore protection downdrift to a highly protected coast (Figure 1). An accurate monitoring program was developed in order to gain information on coastal morphodynamics in the vicinity of the submerged groin and its effects on adjacent beaches.

Prior to the execution of the submerged groin, a study using a numerical model was undertaken, using the morphological and sedimentological data and wave climate gained from studies on the physiographic unit. The model tested several angles of wave approach, as well as groin length and angle to the shoreline, in order to measure the interaction of the groin with longshore currents and sediment transport (Aminti & Cappietti, 2000). After several options, it was decided to test a submerged groin 180 m long, perpendicular to the shoreline with a berm elevation ranging from 0 at the shoreline to 1.5 m at the groin offshore tip along the –3 m isobath. Numerical model simulations forecast aggradation in the foreshore and only limited areas of erosion. In particular, the model detected no beach erosion along downdrift beaches (Aminti, 1998).

The submerged groin was built between February and May 1999, approximately 1 km south of the last rock rubble/boulder construction, the jetties at the Magliano Creek mouth. The stretch of coastline where the submerged groin was built is characterised by a shoreline retreat of approximately 4 m/yr. over the last 20 years. The position of the groin on the beach offers a good opportunity to test its effectiveness as a soft shore protection.

The groin is 180 m long, running from the body of the backshore to the –3 m isobath, and thus it is completely covered by sand and water. Its environmental impact is therefore not relevant either as far as the view is concerned, or in relation to the circulation of the seawater. The project forecast an angle of 90 degrees to the shoreline, although the construction was oriented slightly to the south. The groin is made of 3 x 1.8 m polypropylene bags containing a volume of approximately 1.5 m^3 of sand for a mean weight of 3.7 tons. The weight of the sand bags should guarantee its stability under extreme storm conditions.

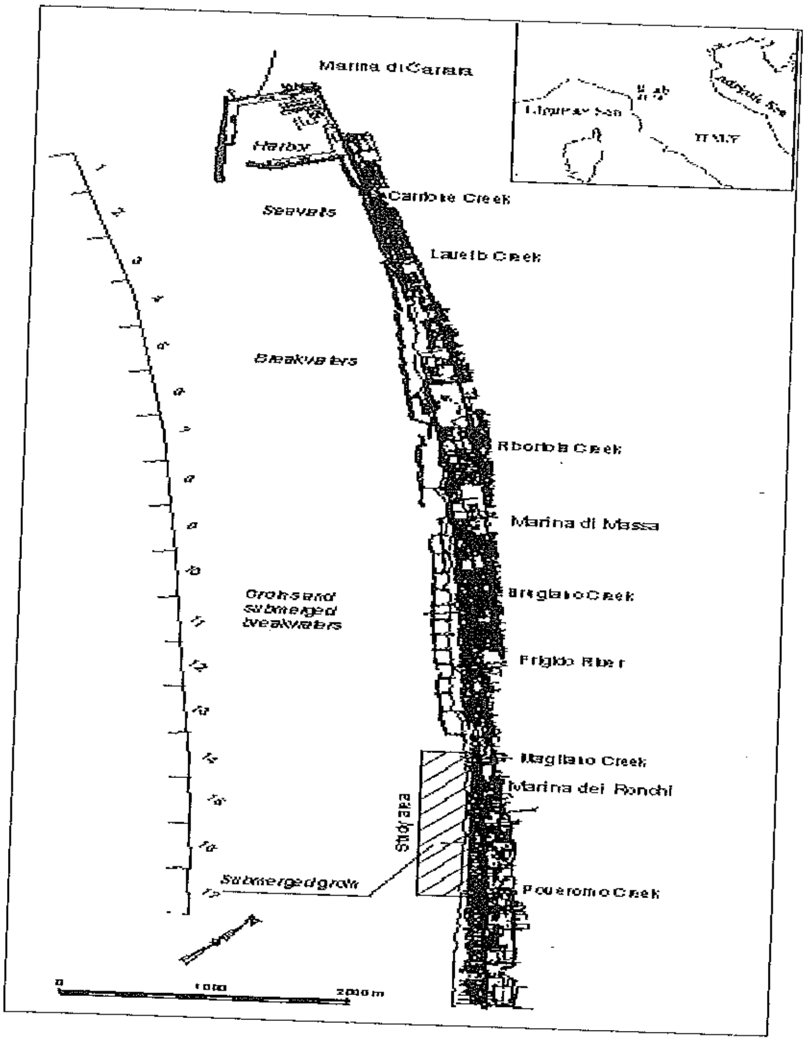

Fig. 1. Location of the study area and identification of the sectors in which the coast has been divided to analyse shoreline evolution

Land machinery was employed throughout the construction of the groin (Figure 3). The sand bags were deposited following the plan in Figure 4, so forming a 2, 3 or 4 layer structure, depending on the water depth. The help of divers assured the correct positioning of the sand bags in the foreshore. On the backshore, the sand bags were set inside a trench and covered with sand. Work ended in May 1999 and by the beginning of the summer season, the groin was already covered with sand even in the foreshore, so there was no visible trace of the works.

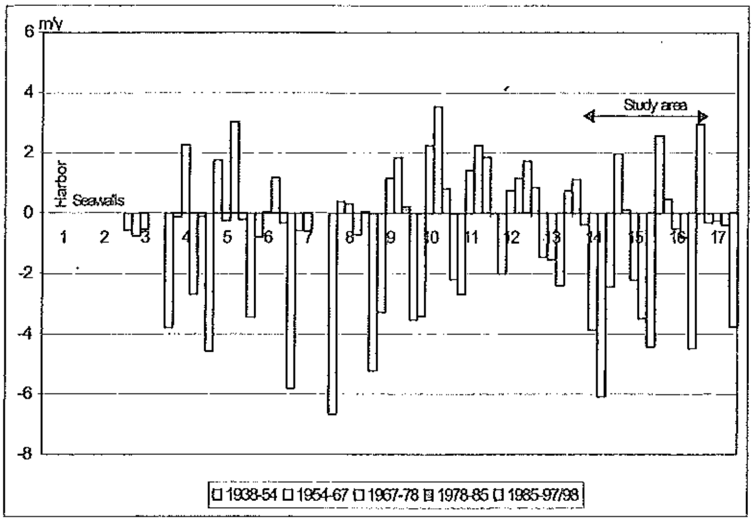

Fig. 2. Mean shoreline evolution in the different sectors (see Fig. 1) over the last 60 years

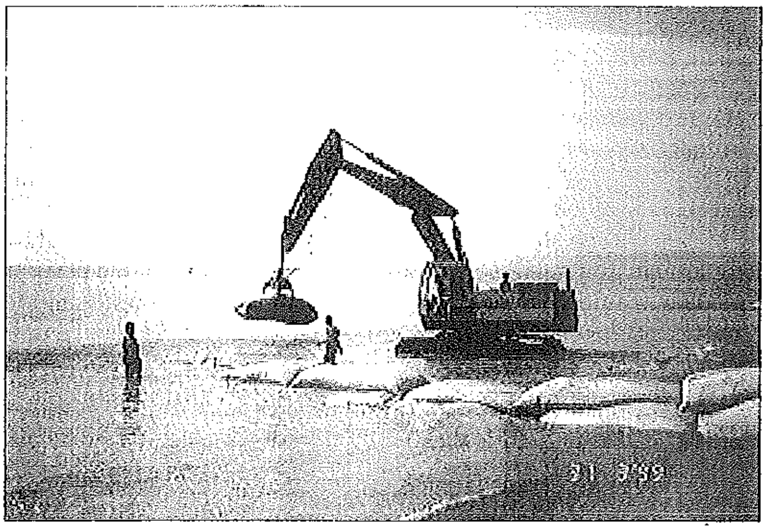

Fig. 3. Submerged groin construction

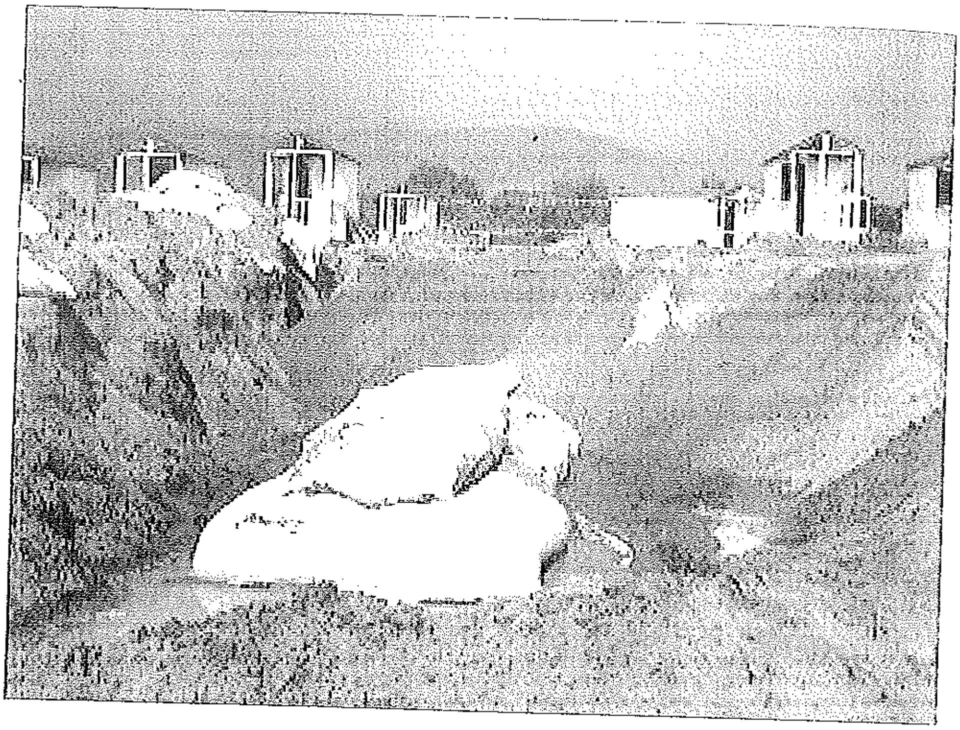

Fig. 4. Groin root on the backshore

3. Materials and methods

To gather information on beach response after the construction of the submerged groin, a monitoring program was carried out between February 1999 and April 2000. It consisted of four bathymetric surveys (Feb. 1999, Oct. 1999, Feb. 2000 and Apr. 2000) and two sedimentological surveys, taken during the bathymetric surveys in October 1999 and February 2000. Pre-work sedimentology was known from a survey performed in 1997. The shoreline position was also surveyed. The study area was investigated through 20 transverse sections from the backshore to the nearshore at the –8 m isobath and additional parallel sections in order to acquire further information on the nearshore morphology in the vicinity of the groin (Figure 5).

Using the SURFER software package, it was then possible to calculate changes in beach elevation by comparing beach profiles. Backshore surface variations were computed from comparisons of the shoreline positions.

During the October 1999 and February 2000 surveys, approximately 6 sediment samples were collected along 12 transverse sections, for a total of 159 samples. Each sample was dry-sieved at 1/2 phi intervals and Folk & Ward (1957) textural parameters were obtained. Grain size parameters were then mapped for each survey and the correlation between beach morphology and sediment texture was analysed.

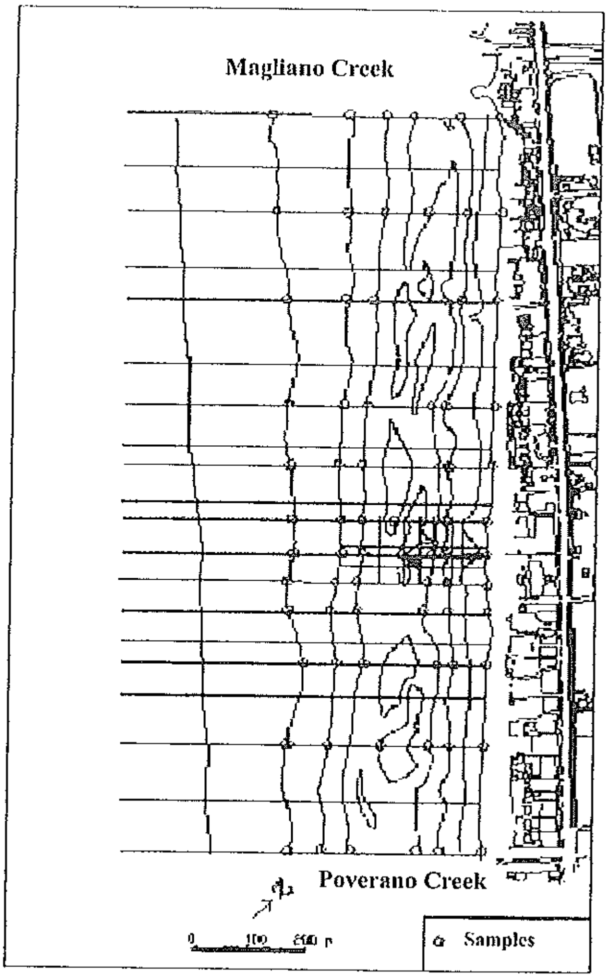

Fig. 5. Surveyed sections location and beach sediment samples position

4. Beach morphology evolution

Analysis of beach morphology evolution consisted of comparison of different bathymetric surveys in order to evaluate beach response following groin construction. The study revealed that the nearshore was characterised by a bar-trough system that moved within the –5 m isobath, which itself remains fairly stable (Figure 6).

Nearshore morphology after construction of the submerged groin (Oct. 1999) showed aggradation (sediment deposition inducing vertical elevation of the sea bottom) in the foreshore. In particular, the –2 m and –3 m isobaths shifted offshore and tended to form a cusp around the submerged groin (Figure 6b). On the other hand, nearshore morphology, surveyed in February 2000, was similar to the first survey (Feb. 1999), as a result of the similar seasonal wave climate (Figures 6a and 6c). In February 2000, the nearshore morphology survey was characterised by rhythmic features probably due to rip currents (Figure 6c). On the other hand, the October 1999 survey showed a crescentic nearshore as defined by Greenwood and Davidson-Arnott (1979) (Figure 6b).

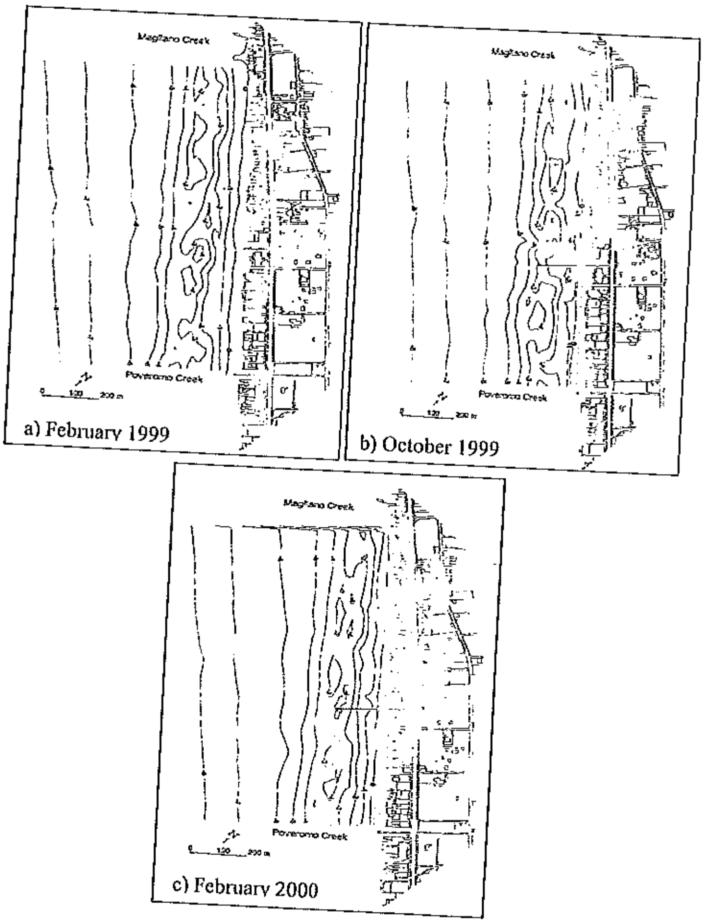

Fig. 6. Contours maps acquired from the different surveys carried out during the monitoring period

The bathymetric data for each Digital Elevation Model (DEM) was subtracted from the DEM of a different survey. This revealed areas of accretion and erosion. As expected from the profile analysis, this resulted in the volume of sediment being redistributed inshore of the –5 m isobath and in particular between the –2 m and –3 m isobaths. This was probably due to the adjustment of a typical storm profile (dissipative) to a fair weather profile (reflective) between February and October 1999, rather than a systematic effect induced by the submerged groin (Figure 7A). On the contrary, as shown in Figure 7, maximum changes in nearshore morphology appeared near the groin. Comparisons of bathymetric surveys in February 1999 and October 1999 revealed maximum accretion values on both sides of the structure (Figure 7A). This indicates the effectiveness of the submerged groin to trap material without inducing sediment starvation to down-drift beaches. In addition, comparison of October 1999 and February 2000 surveys showed erosion in the nearshore along the –2 m and –3 m isobaths, with a localised erosion area around the submerged groin (Figure 7B).

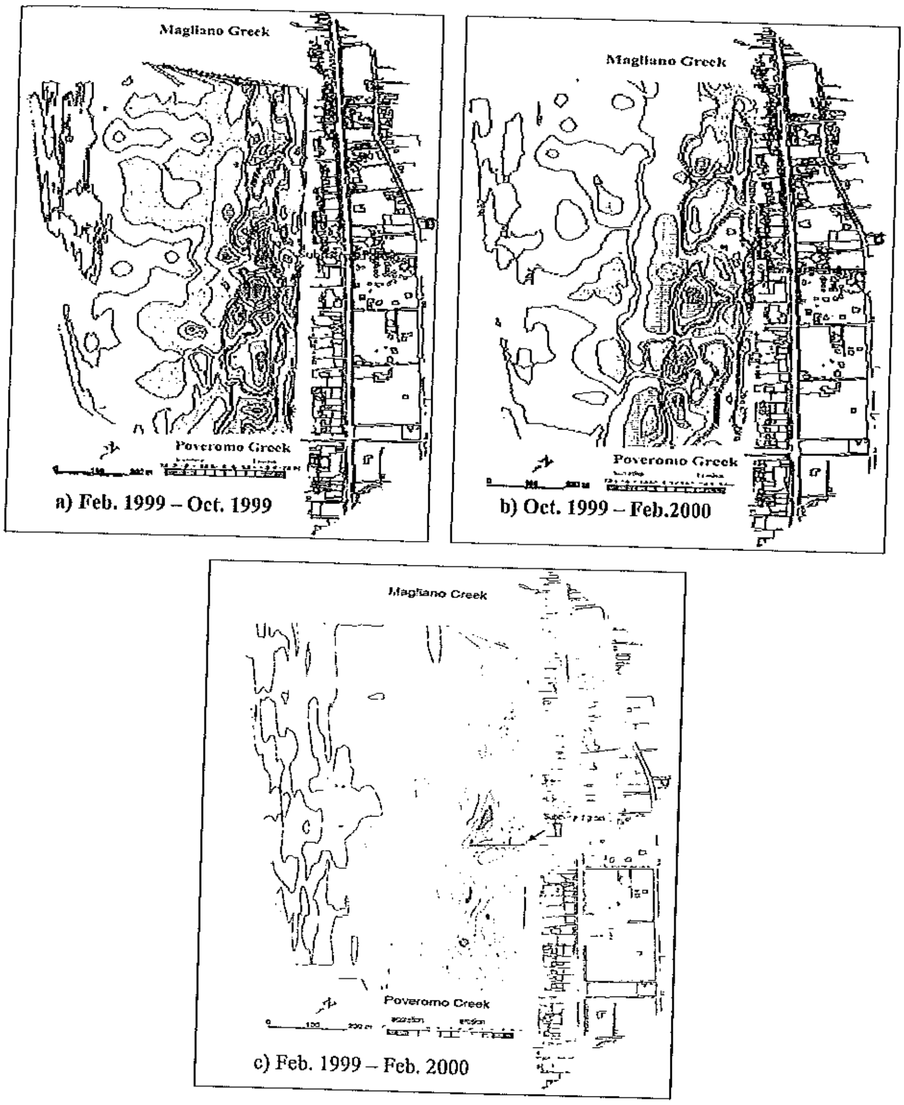

Fig. 7. Depth variations in the study area in the year following construction of the submerged groin

Results from the monitoring period (Feb. 1999 / Feb. 2000) indicate limited changes in beach morphology, diluted along the nearshore (Figure 7C). In the vicinity of the submerged groin, erosion reached values of approximately 2 m (vertical scouring of the sea bottom) especially at the submerged groin offshore tip (Figure 7C). On the other hand, deposition occurred downdrift of the submerged groin between the –2 m isobath and the shoreline (Figure 7C).

Figure 8 shows the shoreline evolution provided by the most representative bathymetric surveys. It shows three shoreline positions: the first (Feb. 1999) before the groin was constructed, the second (Oct. 1999) after the summer period and the third (Feb. 2000), one year after the first survey.

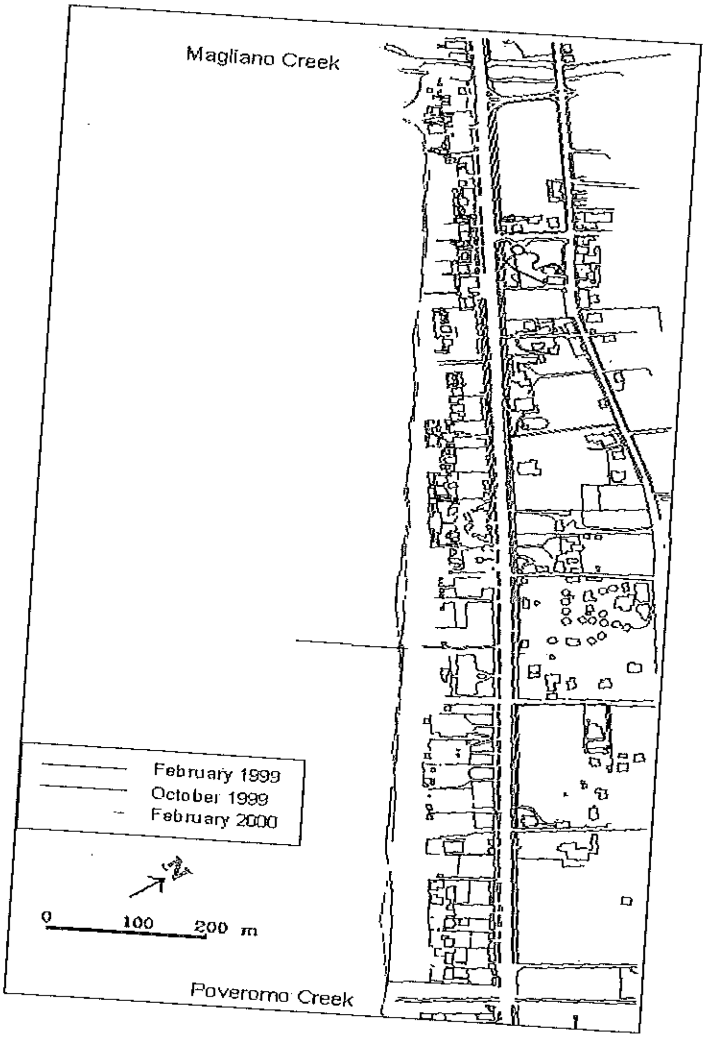

Fig. 8. Shoreline position in the study area during the monitoring period

5. Conclusions

Although the study area was monitored for only one year, useful information emerged which adds to our understanding of the behaviour of submerged groins. We have proved that submerged groins interact with nearshore dynamics accelerating natural processes, namely the seasonal cross-shore displacement of the bar-trough system. Submerged groin performance is closely related to actual length. In fact, in our case, since the submerged groin did not fully cross the bar system, strong currents concentrated at its head and created deep scouring, which could lead to the collapse of the structure. During low energy conditions, the submerged groin efficiently traps sediments inducing significant sediment deposition along its entire profile. The sedimentological impact of the submerged groin on the beach is negligible, although a slight increase in grain size was detected along the swash zone. The environmental impact is positive due to the fact that the groin is completely covered by sand both on the backshore and on the foreshore and near-shore region.

Acknowledgements

This study was supported by the MURST, Project "Analisi delle variazioni sedimentologiche e morfologiche delle piagge indotte da interventi di difesa e ricostruzione della fascia costiera" (Resp. G. Fierro) and by the GNDCI, Linea 2, U.O. 51 (Resp. G. B. La Monica).

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