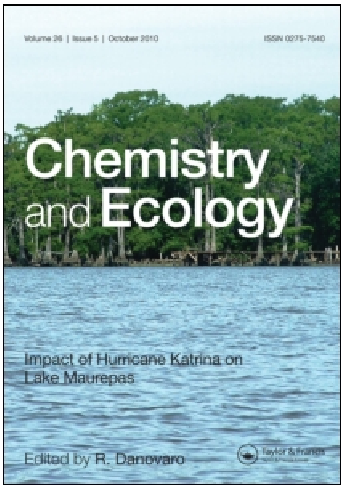

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The port of Genoa-Voltri (Liguria, Italy): A case of updrift erosion

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The effects of port structures on 'downdrift' shoreline areas have been extensively studied and are widely known today. Their effects on 'updrift' areas are less well known. However, these morphosedimentological variations, although not comparable in intensity to the previous variations, can produce relatively important phenomena on the shoreline, especially in the case of a significant drift. In fact, they can modify the coastal exposure to the wave–wind climate and produce a variation in the drift and sedimentary budget in different areas; consequently, they can produce erosive and accumulation phenomena. This paper presents a study of the shoreline to the west of the port structures of Genoa-Voltri that have altered the local sedimentary dynamics, causing disequilibrium to the nearby beach with an evident progradation in the eastern area of the shoreline and a significant regression in the central area.

Keywords: Port; Coastal dynamics; Coastal erosion; Long-shore transport; Sedimentary balance

1. Introduction

The purpose of the present investigation is to study the effects of port structures on the updrift zone of the port structures of Genoa-Voltri and estimate the modifications and the possible consequences of the phenomenon on littoral stability. Such morphosedimentary variations can have relatively important effects on the littoral, especially in the presence of a significant secondary drift. In fact, secondary drifts can modify the exposure of coastal waters to wave action and produce a variation in the intensity of the littoral drift and the sedimentary budget of different sectors of the coast [1]. Consequently, these variations can initiate erosive phenomena and significant accumulations of sediments.

The port of Genoa-Voltri, which was completed in the early 1990s, is situated at the western extremity of the urban area of the city of Genoa. The coastal tract to the east is almost completely urbanized, while the area to the west still preserves some natural characteristics,

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including a relatively wide beach between the port structures to the east and a stretch of cliffs to the west [2, 3]. The port consists of an imposing breakwater situated about 1 km offshore at a depth of between 25 and 30 m.

The coastline is exposed to all waves coming from the second and third quadrant, but with the construction of the breakwater, it is has been partially protected from the waves induced by the Scirocco (south-easterly wind) and Mezzogiorno (southerly wind), which now only affect the central and western areas. However, the port structures have not significantly modified the main wave action produced by the Libeccio (south-westerly wind). Although the new scenario does not produce variations in the littoral drift, it modifies its intensity in some parts. The littoral budget in this zone is guaranteed not only by the littoral drift, from west to east, but also by the presence of two relatively modest watercourses, the Cerusa (basin of 23 km^2) and Leira (basin of 29 km^2). The mouth of the latter has jutting structures that also complicate the sedimentary dynamics of the area.

This study was carried out along two parallel lines: in the first, the wind-wave conditions of the area were studied; the results were then used to construct refraction diagrams of the main wave action (Libeccio, Mezzogiorno, and Scirocco) before and after the construction of the port. In the second a study was undertaken to determine the sedimentological and morphological dynamic before and after the construction of the port.

2. Materials and methods

The studies were conducted on two distinct lines:

- Modifications to the development of wave action caused by the port structures: with reference to the case under examination and the situation related to the Scirocco with 1 yr periods of return. Wave heights were studied in relationship to the local wave direction using a model REF/DIF 1 v. 2.5 [4] in the grid points adopted for the investigation, highlighting the presence of a shadow zone produced by the breakwater. It should be noted that this model, which considers the processes of refraction and diffraction, has been developed in a suitable parabolic form for interpreting inconstant depth situations as foreseen by the mild-slope equation.

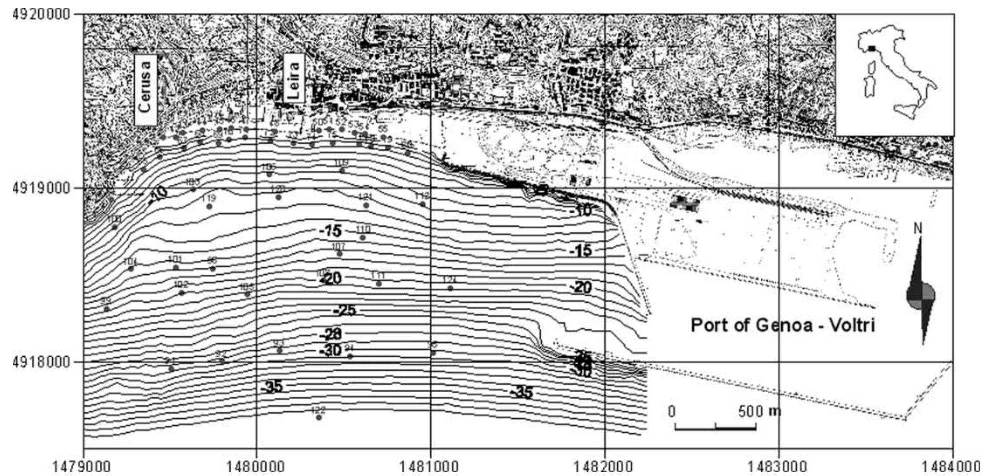

Figure 1. Bathymetric chart of the study area and sampling sites.

- Morphosedimentary variations to the littoral following the construction of the port: the variations to the coastline were established from aerial surveys of Liguria taken between 1944 and 2000 [5] and, subsequently, a field study of the backshore and nearshore zones. In particular, two campaigns were undertaken to obtain morphological profiles of the backshore zone and a bathymetric study of the nearshore zone (figure 1). Sedimentary samples were collected from the beach face and at depths of 5, 10, 20, and 30 m. Subsequently, a textural analysis was performed on these in the laboratory, using a granulometric scale of $(1/2)\phi$, and the principal sedimentological indices were determined [6, 7].

3. Results and discussion

3.1 *Wind-wave climate and modifications to wave action*

The area presented wind-wave characteristics typical of the central area of Liguria, which is predominantly exposed to waves coming from the second and third quadrants. In particular, the Libeccio sector, which is the source of the most intense and most frequent annual sea, is characterized by a fetch greater than 800 km and an annual maximum offshore wave height of more than 3 m. The Scirocco sector, with a fetch greater than 200 km, is characterized by annual wave heights of about 2 m. Finally, the Mezzogiorno, weaker than the preceding, with a fetch of 180 km and a smaller maximum wave height and a more or less frontal incidence, has hardly any influence on the drift.

The sedimentary dynamics of the area are essentially conditioned by the SW wave action that determines the main sedimentary drift towards the east, while the secondary sedimentary drift in the opposite direction can be attributed to the strong SE side wind.

The determination of the refraction diagrams of the main action (Libeccio and Scirocco) before and after the construction of the port has revealed that the wave action due to the Libeccio has not undergone any notable modifications, while there has been a notable change in the action of the Scirocco. In fact, the port structures have created a wide shadow zone that protects the entire tract to the east of the Leira Torrent from this action (figure 2). The sedimentary dynamics of this sector are, consequently, governed by the Libeccio alone.

3.2 *Morphosedimentary characterization*

The sedimentological study indicated that the condition of the entire littoral is governed by Libeccio agitation. In fact, it is possible to observe that the beach tends to curve towards the east, and its slope tends to decrease at the same time, passing from values decisively superior to 10% in the extreme western sector to values around 8% near the Leira Torrent. In agreement with this morphological situation, the texture of the sediments undergoes a gradual diminution in the same direction, passing from ϕ values between 2 and 3 (2–4 mm), associated with gravel, to a sandy granulometry with ϕ values between 0 and 1 (0.5–1 mm). The presence of jutting structures at the mouth of the Leira Torrent causes a variation in the disposition of the littoral with a decisive retreat in the sector on its left bank, also confirmed by the granulometric trend and the slope.

The morphology of the nearshore zone shows a uniform trend with a mean slope of 5%, with the exception of the tract of cliffs to the west. In the central zone, there is also a wide tract with a lesser slope between the 10 and 15 m bathymetries. The coarse-grained texture of the beachfront is substituted by sandy sediments with a general tendency of the size to diminish in an offshore direction. The mean grain-size distribution clearly supports this description

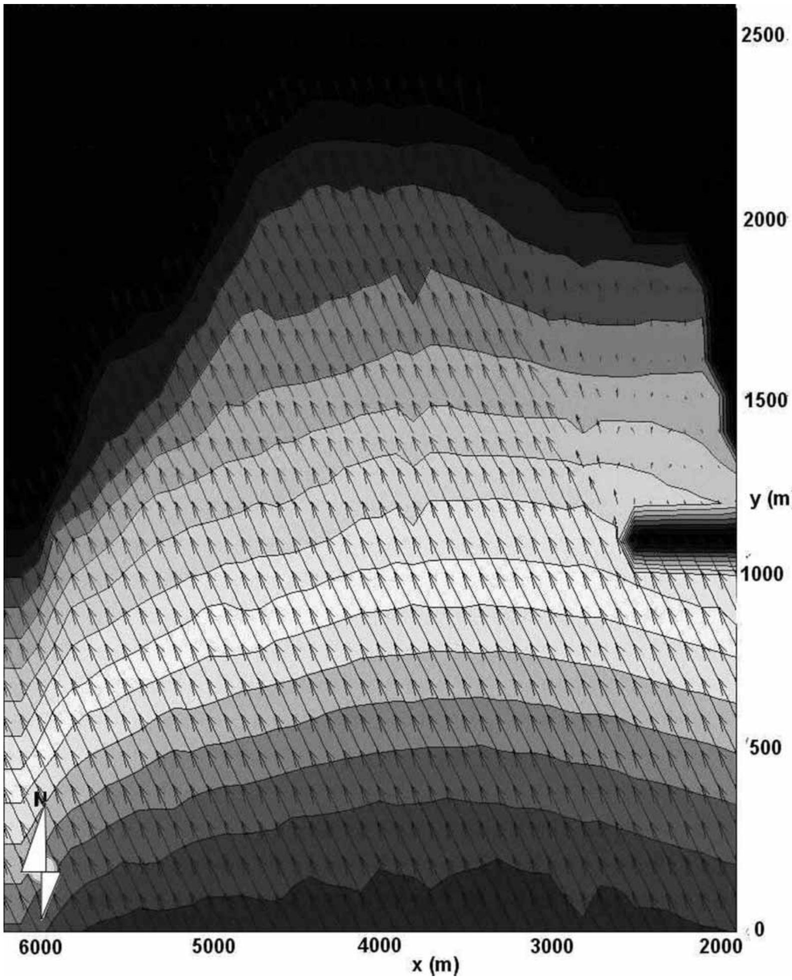

Figure 2. Values of wave heights given in form of vectors with the local wave direction, Scirocco storm.

(figure 3). Furthermore, it is possible to observe a rapid diminution of the dimensions with depth in the extreme eastern sector, indicating an accumulation of sediments.

The study of the distribution of modal class 2ϕ (0.25 mm) highlights the littoral drift acting on the westernmost sector and pushing the sediments eastwards. This indicates an accumulation zone in the protected sector in the extreme east (figure 4).

The distribution of modal class 3ϕ (0.125 mm) enabled us to determine a sector on the left bank of the Leira Torrent that is subject to a notable impoverishment; this fraction is initially pushed offshore and then eastwards (figure 5).

3.3 *Medium-term evolution of the littoral*

The evolution of the coastline was determined from aerial surveys taken in 1944, 1973, 1983, 1993, and 2000 (figure 6). These showed a substantially uniform littoral evolution until the 1980s. After 1983, it is possible to note the first modifications due to the beginning of the filling in of the port area. The reliefs of 1993 and 2000 highlight the beginning of a modest but continuous retreat in the area to the east of the mouth of the Leira Torrent and the advance of

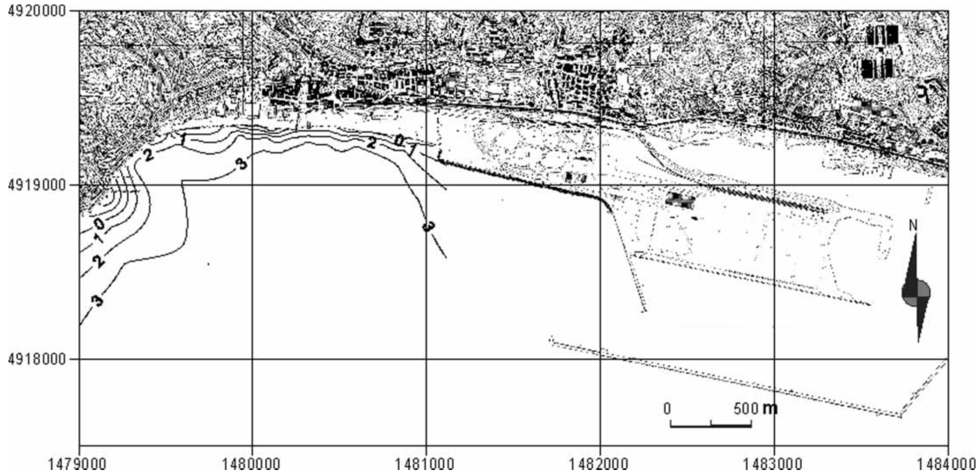

Figure 3. Distribution of the mean grain size (ϕ).

the extreme eastern sector. An analogous situation is noticeable in the western sector with a modest retreat in the west and a significant expansion near the jutting structures at the mouth of the Leira.

A comparison of the bathymetric reliefs taken in 1970 by the 'Istituto Idrografico della Marina' [8] and those taken in 2000 by the University of Genoa (figure 7) show a wide prograding sector in the updrift zone of the port structures and erosion of the westernmost tract and near the cliffs. In the central area, near the mouth of the Leira, it is possible to distinguish an accumulation of modest dimensions in the shadow cone generated by the offshore breakwater (distribution 3ϕ).

This accumulation seems to be referable to a dispersion of sediments as the result of transversal transport accentuated by the increasing arching of the coast, and therefore interpretable as an erosive beachfront phenomenon rather than accretion. Minor erosive phenomena are also observable to the east of this.

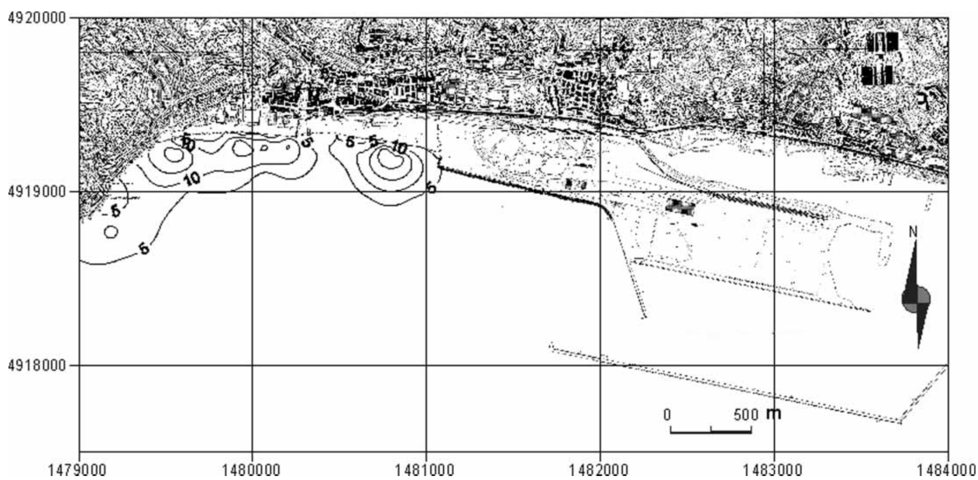

Figure 4. Distribution of modal class 2ϕ (0.25 mm).

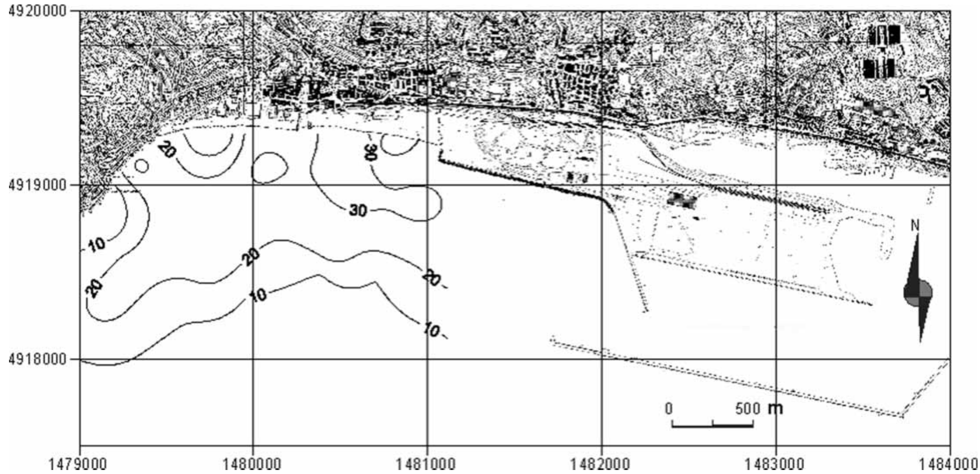

Figure 5. Distribution of modal class 3ϕ (0.125 mm).

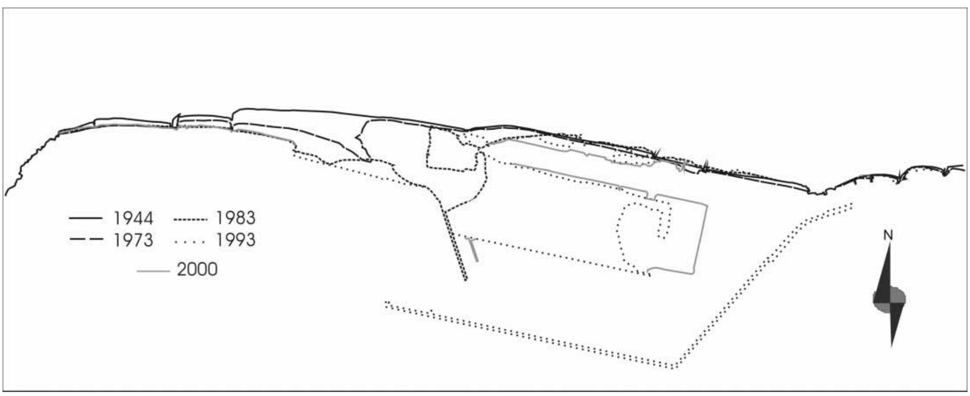

Figure 6. Variations in the coastline between 1944 and 2000.

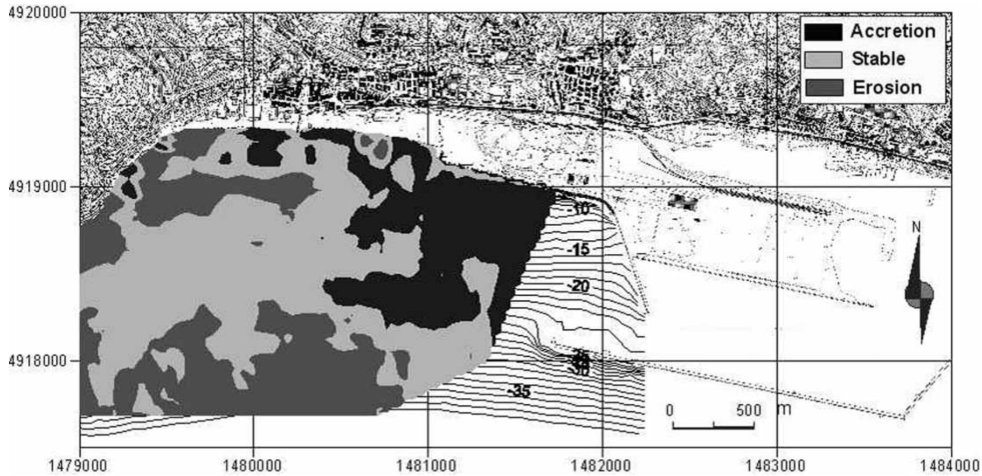

Figure 7. Comparison of bathymetric reliefs taken before and after the construction of the port structures.

3.4 *Short-term evolution of the littoral*

The comparison of the morphosedimentary findings for the backshore obtained in 2002 and the preceding findings, obtained in 2000, confirm what has been said above. The beachfront textural variations indicate an increase in the average dimensions (figure 8) in the central

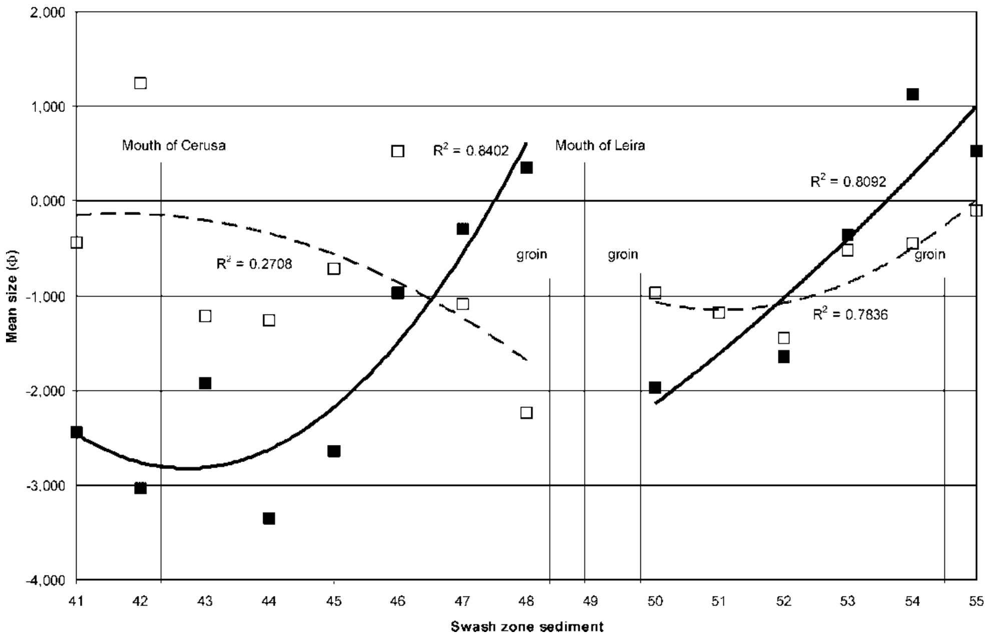

Figure 8. Variation in the median parameter (ϕ) of the swash zone.

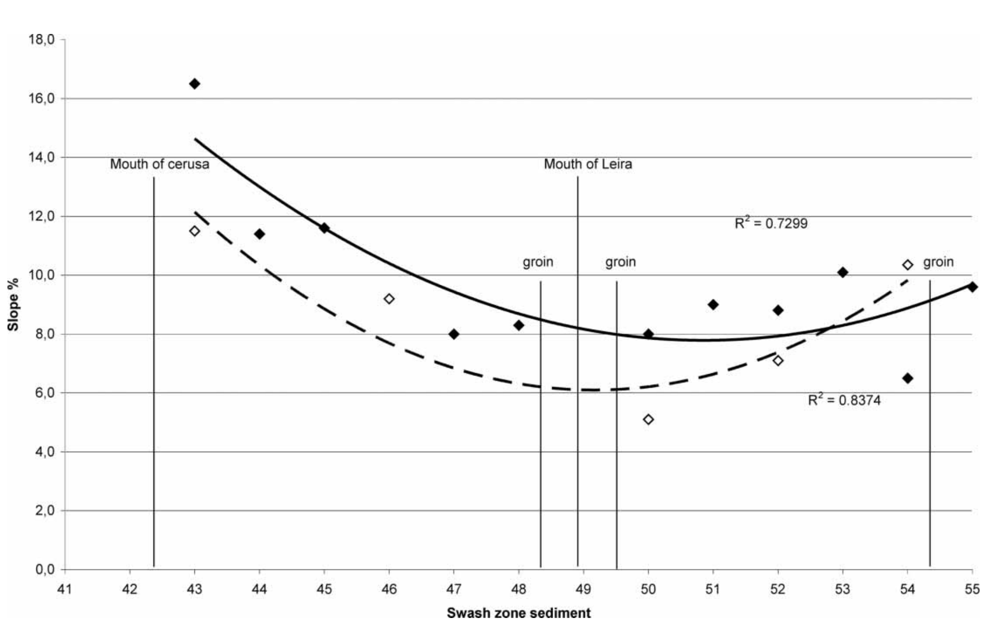

Figure 9. Variation in the slope of the beach at the swash zone.

area to the right of the Leira Torrent and an opposite trend in the more westerly sections. An analogous trend is observable on the other side of the Leira, also at the expense of more westerly sectors. This situation confirms a decisive progradation of the port updrift sector at the expense of the sector on the left bank.

Analogous indications are observable when comparing the average slope of the backshore (figure 9). In fact, in agreement with the textural information, there is a substantial uniformity in the behaviour of the sector to the west of the Leira and a notable variation to the east, with a decisive increase in the slope near the mouth of the torrent and a net diminution at the opposite end.

4. Conclusions

This study has made it possible to demonstrate that the construction of the port structures has caused a notable and ongoing transformation in the sedimentary dynamics of the area and the morphosedimentary equilibrium. In fact, while the littoral to the west of the mouth of the Leira has not undergone a significant change, the sector to the east has undergone considerable progradation at the expense of the areas adjacent to the watercourse. This section has been decisively penalized by the decline of the Scirocco-induced secondary drift that can no longer combat the primary sedimentary drift towards the east. The situation is further complicated by the presence of jutting structures at the mouth of the Leira that partially interrupt the sedimentary transport. To further confirm the situation, the longshore potential transport was determined according to the method proposed by Bijker [9, 10] (figure 10).

Figure 10 shows how littoral transport decreases rapidly from the west towards the mouth of the Leira and undergoes a brusque increase to the east of it. That increase could be attributed to the port structures and evaluated at 25% of the total transport.

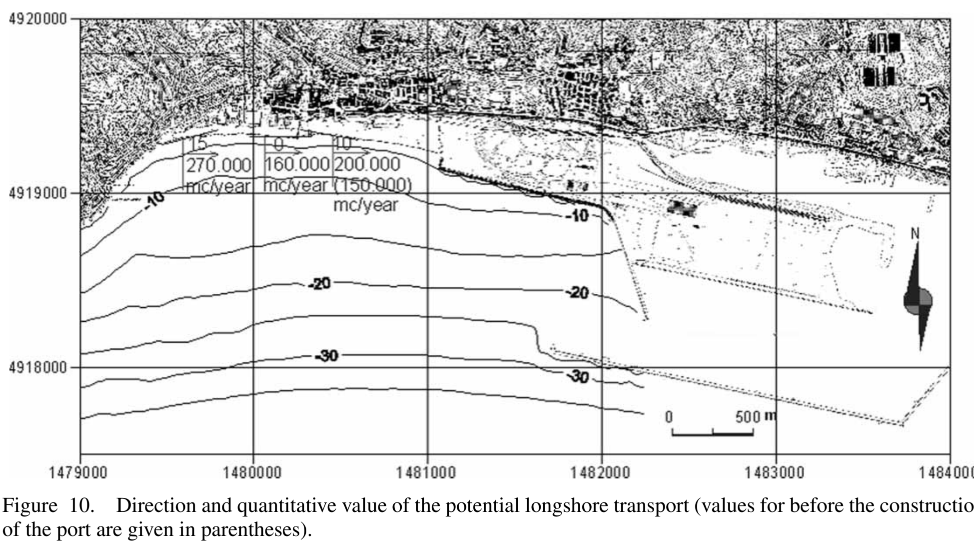

Figure 10. Direction and quantitative value of the potential longshore transport (values for before the construction of the port are given in parentheses).

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