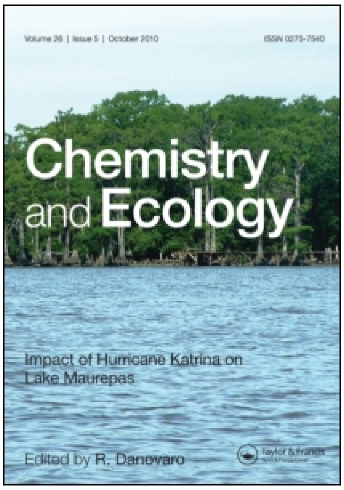

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Evaluation of the effectiveness of a seasonal nourishment programme of the pocket beaches of the city of Genoa

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The aim of the study was to monitor several beaches of the city of Genoa following artificial nourishment programmes carried out in 2003. The programmes, which involved depositing fluvial material from the Bisagno Torrent in the swash zone, were carried out as part of the seasonal nourishment of the beaches of Boccadasse, Bagnara and Caprafico to the east of Genoa, which are subject to intense erosion. The study provided for a preliminary survey in April 2003, before the nourishment, and three other surveys were subsequently carried out to evaluate the effectiveness of the intervention through the evolution of the beach. The morphological and sedimentological surveys were carried out in July and November 2003 and April 2004 to evaluate the development of the beach in both high and low energy situations. The suitability of the material was evaluated using the method proposed by Hobson. From the data obtained from the field studies it was possible to demonstrate that the interventions had only partially counteracted the annual sedimentary losses of the beaches. The quantities of material deposited were inadequate to enable the beaches to re-equilibrate their compromised morphodynamic profiles and adapt to the wind-wave conditions. Therefore, we consider it essential to undertake the reconstruction of the beaches and not simply try to maintain them in this way. The use of greater quantities of material would permit not only the widening of the backshore but also the creation of more stable morphodynamic profiles that would last longer.

Keywords: pocket beach; nourishment; monitoring; cross-shore profile variation; Liguria

1. Introduction

The so-called soft beach-protection option, based on artificial nourishment, is now established and practiced worldwide. This technique makes it possible to recover those littoral tracts compromised by erosive phenomena by reducing the undesired effects of rigid structures such as groynes and breakwaters.

This technique has been used in Italy since the 1960s when it was first introduced on the beaches of Liguria [1].

The main feature of these early interventions was the limited quantity of material used, defining them as ‘small nourishments’ [2,3]. The nourishment programmes carried out on the beaches of

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Borgo Prino, Pietra Ligure and Lavagna, employed 83 m^3/m, 90 m^3/m and 160 m^3/m of material respectively [4], and obtained average advances of about 30 metres. These results were basically due to the generally coarse granulometry of the Ligurian littoral, which consequently required less material than interventions with finer sediments [5]. Furthermore, the morphology of the coast, characterised by beaches of reduced size, laterally limited by rocky promontories, and often lying on a gently sloping abrasion shelf [6,7] limited the cross- and long-shore dispersion of the sediments apart from reducing the sedimentary prism of the foreshore [8].

On the basis of the presumed success of these early interventions, the Ligurian administration, in setting forth regulations for beach nourishment [9], opted for a particular type of small nourishment programme, defined as seasonal nourishment, with the aim of replacing the annual deficit in the sedimentary budget with quantitatively modest sedimentary top-ups. It was intended that these top-ups would involve depositing less than 10 m^3 per linear metre with a maximum of 1000 m^3 of material for each intervention. The main advantage of this type of intervention is the reduced impact of the nourishment programme on the marine environment [3,10].

These beaches, of limited size, are 'pure gravel beaches' [11], that is the backshore, as far as the surf zone, consists mainly of gravel and pebbles, but with Iribarren values referable to a plunging type [12], that is to say an intermediate type, while the foreshore consists mainly of sandy sediments.

These beaches are more or less intensely influenced by erosive phenomena that impoverish the littoral.

Anthropic pressure is the principal cause of this problem [13]; in fact, the heavy anthropic pressure on the Ligurian coast and adjacent catchment areas has practically annulled the sedimentary transport of the local watercourses.

To supplement the scarce natural supply, the public authorities have been forced to intervene periodically with limited nourishment programmes of the type described above, also bearing in mind the existence of partially compromised Posidonia Oceanica beds in the area [14], which could be further damaged in the case of intervention with massive quantities of material.

This study specifically examined the effectiveness of the interventions in terms of morphosedimentary variations to the littoral in relation to its erosive state.

The aim of the present study was to evaluate the effectiveness of this type of nourishment in the seriously compromised pocket beaches lying along the eastern coast of the city of Genoa.

2. Material and methods

2.1. *Study area*

The tract of coast analysed, which contains the main eastern beaches of the city of Genoa, lies at a pivotal point of the Alp-Apennine system [15]; it is characterised by structures with predominantly N-S and E-W orientations that influence not only the hydrographic network but also the morphology of the littoral. In fact, the coast is predominantly rocky with prominent capes that protect small, mainly pebbly, beaches lying in small inlets and hinder littoral drift, which is almost non-existent.

The morphology of the area, with mountains very close to the sea, influences not only catchment areas, which are consequently of limited dimensions with short, fast-flowing watercourses, but also limits the expansion of the city, which has consequently stretched along the coast and developed inland only where there are major valleys.

Human activity has practically obliterated the natural morphology just as it has reduced or completely annulled the solid supply of the local watercourses. Consequently the beaches of the area are deprived of natural transport.

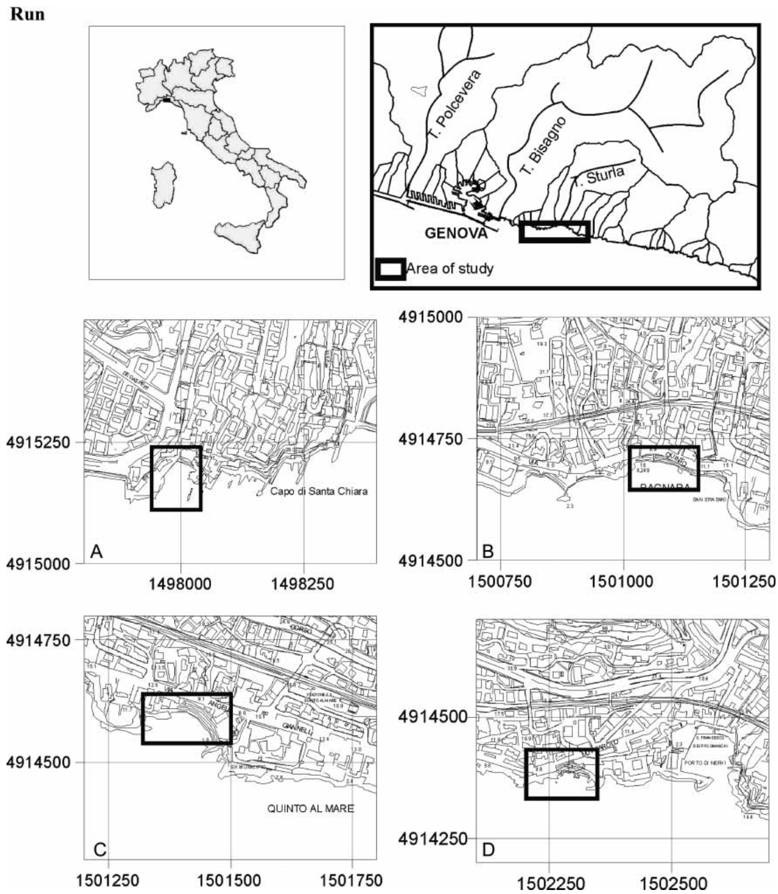

Figure 1. Study area: (A) Sector 1 (Boccadasse), (B) Sector 2 (Bagnara), (C) Sector 3 (Bagnara), (D) Sector 4 (Caprafico).

Four littoral tracts have been considered in the present work (Figure 1), all definable as coarse-grained pocket beaches of small dimensions (maximum length 90 m and width 30 m). They are distinguished from each other by the different natural or man-made barriers protecting them from wave action. In particular, Sector 1 (Boccadasse) lies in a deep natural inlet and is only exposed to wave action from the SW. Sectors 2 and 3 (Bagnara) lie along a stretch of rocky coast and are separated by a cape to which a number of protective groynes are attached. The other extremes of the two beaches are protected by similar structures. Sector 4 (Caprafico) lies at the foot of a high rocky cliff where the very irregular cliff-face protects the actual beach. However, the last three sectors are exposed to all wave action from the southerly directions.

2.2. *Wind-wave climate*

The area is mainly exposed to winds from the second and third quadrants: that is the Libeccio, which is the dominant sea (15% of frequency), with a fetch greater than 800 km and an off-shore wave height of more than 3 m; the Sirocco with a fetch of 200 km and waves of about 2 m; and the southerly wind, weaker than the others, with a fetch of 180 km and smaller waves [16].

The characteristics of the waves induced by the two prevailing winds are reported in Table 1 [17].

Table 1. Wave characteristics (T_R = return time; H_S = significant height of off-shore wave; T_0 = wave period).

	SW (Libeccio)		SE (Sirocco)	
T_R (years)	H_S (m)	T_0 (sec)	H_S (m)	T_0 (sec)
1	2.50	7.0	1.50	5.00
10	3.60	9.36	3.00	8.53
20	3.98	9.83	3.30	8.95
30	4.38	10.32	3.60	9.35
50	4.71	10.70	4.00	9.86
100	5.10	11.13	4.50	10.45

The sedimentary dynamics of the area are thus principally determined by S-W waves that generate detrital flow towards the east but are also strongly influenced by the coastline as stated above.

2.3. *Nourishment*

The four nourishment programmes were carried out in spring 2003 with coarse-grained alluvional material from the Bisagno Torrent (gravel 85.9%, sand 13%, pelite 1.1%) but with a pelite fraction well below the requirement of the regional regulations [9]. The suitability of the material was evaluated with the graphic method proposed by James [18] and Hobson [19]. The nourishment was carried out by depositing 10 m^3 of material per linear metre of beach.

The study was made by selecting and sampling sediments from four morphological reliefs of the backshore (April, July and November 2003, April 2004) and two bathymetric campaigns (July and November 2003) conducted with a single-beam echo-scanner with a single frequency and differential GPS and sediment sampling with a Van Veen bucket with a maximum depth of about 12 m.

The granulometric analyses of the sediments was performed by dry sifting, using the Wentworth Scale at 1/2ϕ [20], to determine the dimensions and sedimentological parameters (mean, median grain size, sorting, kurtosis and skewness) according to the method proposed by Folk [21].

3. Results

3.1. *Material used*

The textural characteristics of the beach and the borrowed sediment are reported in Table 2 with the quantities of material deposited at each site and the theoretical trend based on the analytical procedures applied.

Table 2. Textural characteristics and quantities of the sediments deposited and their predicted theoretical trends.

Sector	Gravel (%)	Sand (%)	Pelite (%)	Median (Φ)	Sorting σ	Quantity deposited (m^3)	Theoretical trend (m^3)
Borrowed	85.9	13.0	1.1	−3.167	1.651		
Sector 1	84.6	15.3	0.1	−3.273	1.683	400	380
Sector 2	86.7	13.3	0	−3.002	1.627	900	880
Sector 3	54.4	45.4	0.2	−2.292	2.104	900	860
Sector 4	86.3	13.6	0.1	−3.641	1.54	600	480

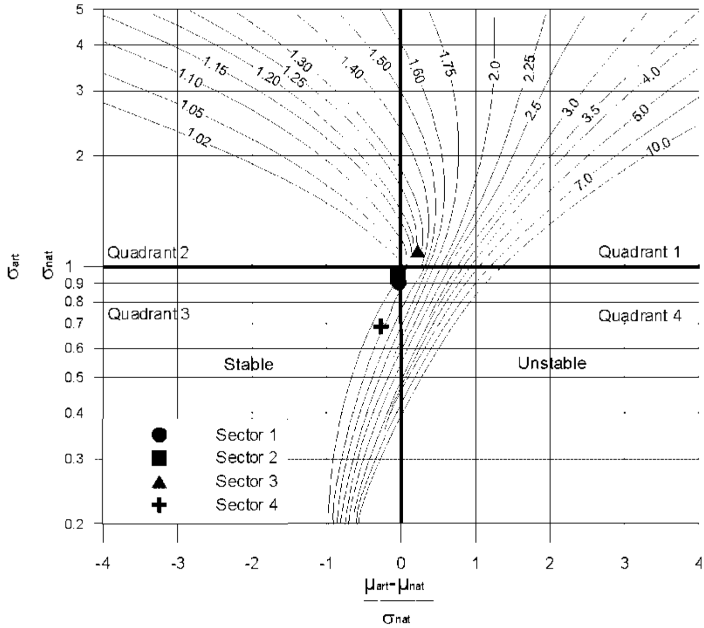

Figure 2. Filling factor (Hobson, 1977 [18]).

The borrowed sediment was compatible with the actual material on the beaches; the filling factor, which permitted us to estimate the quantity of sediment necessary to create a stable situation on the beach, had values between 1.02 and 1.25 (Figure 2) with a theoretical pattern between 77 and 98%. The nourishment material proved to be coarser and less sorted than the native material in Sector 3, practically the same in Sectors 1 and 2 and slightly less coarse and sorted in Sector 4.

3.2. *Monitoring*

Monitoring demonstrated that after one year the benefits of the nourishment had been annulled and that the beaches had returned to their original state or had experienced a further retreat. The seasonal evolution of the intervention, reconstructed from the morphological studies, demonstrated an initial advance in all sectors after the nourishment (July 2003), followed by some success (November 2003) with a new morphodynamic situation and the redistribution of the nourishment material and the transfer of sediment from the backshore to the foreshore with the seasonal change from low-energy (summer profile) to higher-energy (winter profile) hydrodynamic conditions [22]. The final relief, however, did not demonstrate the restoration of the initial conditions and, in fact, all sectors showed a substantial retreat except Sector 2. Table 3 shows the variations in the coastline during the study period. It is possible to detect a notable retreat in

Table 3. Variations in the coastline: + advance, − retreat.

	Initial width (meters)	Apr.03–Jul.03 (meters)	Jul.03–Nov.03 (meters)	Nov.03–Apr.04 (meters)	Apr.03–Apr.04 (meters)
Sector 1	40	+3	−14	−2	−13
Sector 2	16	+4	−3	0	+1
Sector 3	26	+4	−4	−2	−2
Sector 4	18	+6	−12	+4	−2

Table 4. Volumetric variations: + increment, − loss.

	Apr. 03–Jul. 03 Emerged (m^3)	Jul. 03–Nov.03 Emerged (m^3)	Nov.03–Apr.04 Emerged (m^3)	Apr.03–Apr.04 Emerged (m^3)	Jul. 03 – Nov. 03 Submerged (m^3)
Sector 1	+12	−45	−19	−52	+43
Sector 2	+10.5	−4.3	−6.5	−0.3	+4.1
Sector 3	+9.9	−13	−6.8	−10.1	+13.2
Sector 4	+9.4	−7.8	+2.6	+4.2	+7.5

Sector 1 and less obvious retreats in Sectors 3 and 4; only Sector 2 retained its pre-intervention profile.

Table 4 provides further information on the evolution of the intervention in terms of volumetric variations. It demonstrates that the major part of the material deposited passed to the foreshore. In two cases the loss was greater than the quantity of material deposited and, in fact, in Sector 1 the loss was five times. Only the backshore of Sector 4 showed a net gain.

The morphological cross-section characteristics of each beach were determined using a single profile. These demonstrated the mode of distribution and the new characteristics assumed by the different beaches. In Sector 1 (Figure 3a) it was possible to observe a redistribution of material on the foreshore to a depth of 6 m, the formation of a more dissipative profile and the formation of a berm on the backshore during winter: a structure missing from the successive relief, but which contributed to the advance registered. In Sector 2 (Figure 3b) it was also possible to observe a transfer of sediment to the foreshore with a preferential accumulation at a depth of about 3.5 m, interpretable as the beginning of a bar. The advance of the beach reported above was not caused by an increase in the sediments but the migration of material from the backshore/foreshore to the surf zone. Sector 3 (Figure 3c) registered the least morphological variations; there was a general impoverishment of the backshore in favour of the foreshore and it was also possible to observe a preferential accumulation similar to that of Sector 2 but of decidedly smaller dimensions. The foreshore of Sector 4 (Figure 3d), which had the steepest initial slope, demonstrated an evolution

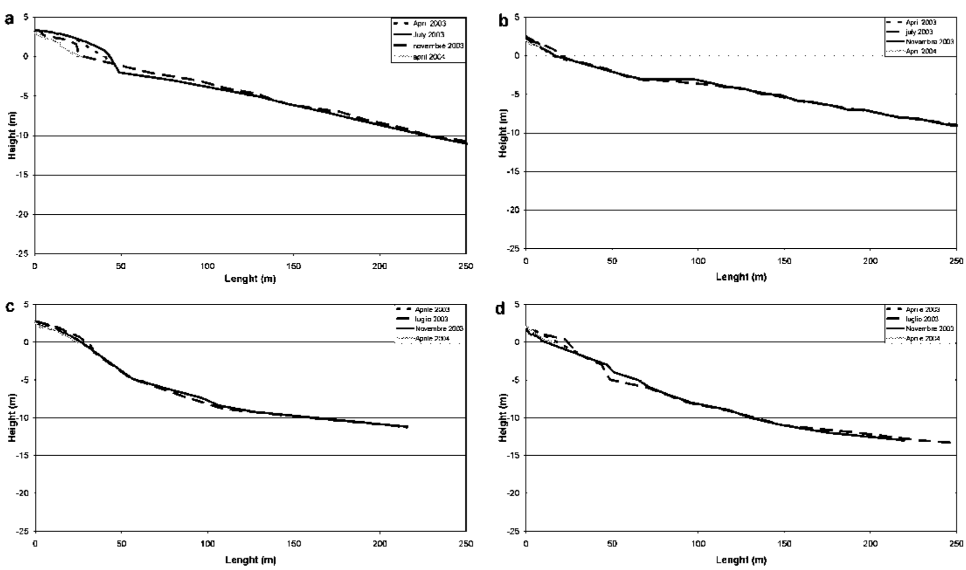

Figure 3. Morphological cross-shore profiles: (a) Sector 1 (Boccadasse); (b) Sector 2 (Bagnara); (c) Sector 3 (Bagnara); (d) Sector 4 (Caprafico).

Table 5. Sedimentological indexes.

Period	Median	Incl. Graphics St. Dev.	Skewness
Sector 1			
April 2003	−3.273	1.683	0.61
November 2003	−2.613	1.531	0.203
April 2004	−2.113	2.219	−0.217
Sector 2			
Period	Median	Incl. Graphics St. Dev.	Skewness
April 2003	−3.002	1.627	0.263
November 2003	−2.028	1.633	0.07
April 2004	−3.883	2.226	−0.025
Sector 3			
Period	Median	Incl. Graphics St. Dev.	Skewness
April 2003	−2.292	2.104	0.042
November 2003	−1.992	1.172	0.238
April 2004	−3.308	1.137	−0.074
Sector 4			
Period	Median	Incl. Graphics St. Dev.	Skewness
April 2003	−3.641	1.54	0.712
November 2003	−2.94	1.017	−0.034
April 2004	−3.225	1.383	−0.081

towards a more dissipative state and an accumulation of sediments along the shore line. The new situation demonstrated a net gain on the backshore despite the retreat of the surf zone.

The sedimentological studies substantially confirmed the findings of the morphological studies, showing the textural variations that the deposited material underwent during the evolution of the littoral (Table 5).

It was possible to observe a diminution in the grain size in the period immediately following the nourishment, followed by an increase in the median grain size during the erosive period highlighted above. The regressive phase is also well demonstrated by the sedimentological skewness index which evolved towards negative values. The sediments were poorly or very poorly sorted, a common feature of pebbly-gravely littoral sediments [23]. Only Sector 1 showed a different trend with a progressive diminution of the median dimension in line with the other indexes, which were extremely variable. This anomaly can be explained by the intense erosion in this area that carried away a notable quantity of material, exposing material with different textural characteristics. The negative values of the asymmetry parameter of the final relief confirm the erosive trend of the sector.

4. Discussion

The results reveal that the material deposited did not always balance the natural sedimentary deficit in the study area. In particular, Sector 1 was the worst affected, Sector 3 suffered a more contained loss, Sectors 2 and 4 enjoyed substantial stability even if this was demonstrated in different ways. The different trends of the four sectors can be explained by the principal morphodynamic parameters that characterise each littoral tract and are reported in Table 6. The Iribarren number ξ_0 [12], which makes it possible to link the morphology of the beach to the characteristics of the off-shore wave action, demonstrated that all the sectors initially had intermediate profiles, that is a reflective situation near the shoreline, with the exception of Sector 2, which had a dissipative profile. Using Yang's parameter [24] to describe the profiles, it was possible to identify the tracts undergoing erosion and to establish that only Sector 3 was not undergoing erosion. An analogous

Table 6. Hydrodynamic parameters of the four sectors studied (potential erosion values in bold).

	Iribarren (ξ_0)		Yang Index (erosion >0.5)		Run $up_{sign.}$ ($R_{1/3}$)		Maximum level of the beach	
	Lug.	Nov.	Lug.	Nov.	Lug.	Nov.	Lug.	Nov.
Sector 1	1.68	0.26	**1.7**	0.2	4.9	1.4	**3.3**	3.3
Sector 2	0.36	0.33	0.4	0.3	1.7	1.6	2.2	2.5
Sector 3	1.0	0.9	**1.1**	**0.9**	3.5	3.2	**2.7**	**2.8**
Sector 4	1.1	0.5	**1.1**	0.5	3.7	2.2	**1.9**	**1.8**

situation was observable on the backshore when comparing the run $up_{sign.}$ [25] (the value of the maximum wave height along the beach) with the beach dimensions; again only Sector 2 was able to contain the wave action and the other tracts were potentially subject to the reflective effects of the rigid structures lying at the ends of the beaches. Sector 3 was in a particularly critical state because of the reduced width of the beach.

The winter situation was different and could only be partly explained by the seasonal evolution of the beach, more likely being due to the new situation. The parameter ξ_0 indicated that all the profiles had assumed a more dissipative morphodynamic profile. Due to this new situation the only beach subject to erosive phenomena, according to Yang's index, was Sector 3.

As a result of this even the backshore enjoyed more favourable conditions even if there was a notable retreat of the coastline as in the case of Sector 1. Only Sectors 3 and 4 were undersized in relation to the run up_{sign}.

A comparison of these last observations and the results of a field survey revealed that the borrowed material was distributed proportionally, in line with the hydrodynamic profiles of the beaches, to assume a more stable configuration. Therefore, in relation to the morphodynamic situation of the beach, the deposited material had nourished the entire littoral of Sectors 2 and 4, only the submerged beach of Sector 3, and had been entirely lost by the backshore of Sector 1.

5. Conclusions

The study highlighted the different morphodynamic evolutions of each sector following the nourishment. It was possible to observe how the quantity of material deposited did not always balance the seasonal sedimentary deficit. In particular, the foreshore areas subject to impoverishment the nourishment was practically nullified as the material used to nourish these zones only served to preserve the existing critical condition. Only in one of the four areas was the quantity of material adequate to maintain the original situation. We must therefore conclude that this type of intervention is inadequate for preserving the littoral in areas subject to serious erosive phenomena and it would be better to first determine the real nourishment needs of the beaches and undertake their reconstruction before undertaking top-up programmes to balance the seasonal deficit.

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