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The effect of coastal defense structures (mounds) on southeast coast of Buenos Aires province, Argentine

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ABSTRACT

The rapid increase of tourism and urbanization in the coastline of Buenos Aires province resulted in the need of infrastructure and services development along the entire coast. However, the lack of environmental criteria of human activities altered the aero and hydrodynamic conditions and is causing important cliffs regression and beach erosion.

In this scenario and to minimize such problems, since 1980's, installing coastal defense structures became a very used method. The main types used in the study area are mounds built with blocks of quartzite and set up as longitudinal defenses on the cliff base. It was seen that these structures reduced coastline retreat but caused several environmental alterations changing natural dynamic conditions. These alterations caused serious consequences in coastal configuration, local and regional hydrodynamic, morphometry of beaches, environment and ecology of the coast and obviously, in the human activities and recreation areas.

This paper analyses the coastal system evolution after mounds settlement, their functions and consequences to nature (comparing altered environments with those which still preserves natural conditions) and discuses its advantages and disadvantages with the objective of establish precedent for future integrated and conscious coastal management projects.

1. Introduction

During the last decades, the increase of urbanization and tourism activities have brought serious changes in the natural environments of this area, affecting direct and indirectly, the input rates of sediment supply to the coast (López and Marcomini, 2011). The lack of sustainability between human activities and the geomorphological setting of the coastal system has increased the erosion on those well-developed urban centers (Marcomini and López, 2008). The main effects are cliffs regression and beach erosion. According to Bértola (2006), the anthropogenic processes of beach alteration (with direct or indirect effects) exceed the morphodynamics variations originated by natural process.

The main causes of disturbance in the natural balance of coasts and its environmental conditions are originally related to the building and management of Mar del Plata harbor and other coastal protection structures. The construction of Mar del Plata breakwaters in 1920 induced an important longshore drift undersaturation downdrift. By 1970, the shoreline had been compartmentalized by adding a large number of different groins (Marcomini and López, 2006). Despite of they increase the accumulation rate of sand in beaches, they didn't solved the problem and the erosion extended northward affecting the most important beaches of the resort (Isla, 2006). According to Bruun (1990), man's intervention in coastal processes began with the installation of breakwaters to protect ports against waves and sets of groins in the seafront for coastal protection and beach rebuilt. This type of construction began in the 19th century in the Mediterranean and on the British Isles shores (Bruun, 1990). The effects of this type of human intervention are described later by Bruun (1995). He shows the long and short term disturbances effects during the 20th century in different coasts of the world, from Florida, France and Egypt to Japan.

The rapid erosion along Buenos Aires coast is caused by several processes that act in concert; these are natural processes that occur frequently (storm surges and waves) and anthropogenic activities such as human settlement and harbor and coastal defenses.

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Consequently, between 1920 and 1970, more than 60 groins were built to mitigate the continuous displacement of the erosive wave to Mar de Cobo and Mar Chiquita (30 km northwards). The coastline retreat rates obtained were about 5 and 6 m/year (Schnack et al., 1983; Merlotto and Bértola, 2009; San Martín, 2012), being a regional erosion process (López and Marcomini, 2011). In Santa Clara del Mar, Schnack et al. (1983) registered regression rates slightly higher to 1 m/year. In 2001, a report of the State Print Direction and Official Newsletter of Argentina (DIEBO, 2001) mentions a territory loss of about 9470 m^2 along 2260 m of coast (including the locations of Playa Dorada, Santa Helena, Frente Mar and part of Atlántida) between 1982 and 2001. It also reveals a coastline retreat of about 4.19 m and an erosive rate of 0.21 m/year during that period. A similar coastline retreat rate was calculated by Bunicontro (2012), getting values among 0.49 and 0.20 m/year, between 1975 and 2009.

Numerous protection techniques have been applied to prevent coastline retreat in General Pueyrredón and Mar Chiquita resorts. One of the most frequent has been the setting up of rocky mounds. These structures, built with blocks of quartzite, are set up on the cliff foot over rocky wave cut platform. These types of structures began to be built in 1980's decade to reduce cliff retreat and protect the Nº 11 road. The main use of mounds is to protect cliffs from wave attack. The dissipation of wave energy through absorption rather than reflection distinguishes rubble mound breakwaters from other types of fixed breakwaters (Palmer and Christian, 1998). However, the excessive sea cliffs armoring can be an erosive practice in those places were the source of sand to the beaches and to the littoral drift depends exclusively on the cliff erosion (Runyan and Griggs, 2003).

The present study aims to analyze the general characteristics of mounds as coastal protection structures in this area and its evolution during the last years. This will allow us to determine its effectiveness and to identify the main changes on some natural environment aspects, as the coastal hydrodynamics, coastal ecology, beaches morphodynamics and the recreational use of this tourist resource.

1.1. *Study area*

The studied area extends southeast of Buenos Aires province, Argentine (Fig. 1), from Mar del Plata toward Mar de Cobo, with a length of about 4 km along Buenos Aires coast. It includes Playa Dorada, Santa Helena, Frente Mar and Atlántida localities, southern Santa Clara del Mar resort.

1.2. *Background*

Types and designs of coastal defense structures, as rubble mounds, were described by the Coastal Engineering Research Center of United States (1984). An overall review of physical processes involved with rubble mound structures (hydraulic and structural parameters) and its classification was done by Van der Meer (1995). Other techniques use compact armor units interlocked each other but despite more than six decades of applied research, design continues to be based largely on experience and physical modeling of the proposed structure (Palmer and Christian, 1998). Later, Sigurdarson et al. (2001) describes the Icelandic type berm breakwater used since 1980 as a successful solution for navigational safety in harbor entrances with heavy breaking waves. For these authors, the goal of the design of a berm breakwater is to achieve the highest wave energy absorption to minimize wave reflection and overtopping. Other contributions about designs and general set up of these structures were done by Losada (2005) followed by Sigurdarson and Viggosson (2005). Also, Mani (2007) discusses the construction of an S-type rubble mound sea wall and its effectiveness as an alternative method to protect the beach in the east coast of India.

Locally, Tassara and García (2005) analyzed the positive and negative effects of setting up these mounds on the studied area, focusing on the integrated management to diminish vulnerability. On the other hand, as the amount of sediment delivered to the Argentine continental shelf by cliff erosion is higher than the fluvial transport, it should be also considered in the balance of beaches fed by longshore transport (Isla and Cortizo, 2014). According to these authors, Buenos Aires is a populated province where cliff erosion is a critical problem at tourist areas and the north cost of Mar del Plata is the most affected by man-made constructions, blocking beach drift. Considering this, riprap walls and revetments are assumed to be the most economic solution to maintain the stability of these cliffs.

2. Material and methods

The construction and characteristics of the coastal defense structures currently located in Playa Dorada, Santa Helena and Frente Mar were studied through a historical survey and the analysis of aerial photographs of 1975 and 1985 (scale 1:20.000, Geodesy Department of Buenos Aires) and satellite images Google Earth 2003, 2009 and 2011. Structures descriptions were supported by field observations and technical specifications of the work “Defense of N°11 Road by cliff protection” (DIEBO, 2001). A morphometric analysis of the beach was done by performing topographic profiles transverse to the coastline, using a Total Station. The profile, named “Type Profile” (37° 52′ 56.1″ S–57° 31′ 4.3″ W), was referenced to a setpoint in the urban area with Global Positioning System (GPS) in case of future monitoring.

The annual volume of sediment eroded from cliffs was calculated first in m^3/m/year and then considering the entire coast (4 km) in m^3/year. Annual erosion rates (m/year) were multiplied by the height of the cliffs in order to obtain the volume eroded per meter of coastline. The rate were estimated considering a mean coastal retreat for the studied area (0.47 m/year) proposed by Isla and Cortizo (2014) and by Bunicontro (2012); and the average height of the cliffs was estimated in 7 m.

Sediment samples were collected at the foreshore (low tide, mid tide and high tide) and backshore (stormline), and on the ancient beach at the continental side of the mound. Grain size analysis was conducted to determine the beach hydrodynamics. Sediments were dried divided up to obtain a weight between 80 and 100 g. They were sieved using a Ro-Tap during 15 min with sieves between −2 and 4 phi (from coarse to fine sand). Statistical parameters as mean, median, mode, sorting, skewness and kurtosis were estimated.

Mineralogical composition of sediments were determined using petrographic microscope and were compared with the sediments of the same environments of another profile (Beach Profile A) near Santa Clara del Mar Beach (37° 50′ 16.4″ S–57° 29′ 52″ W). It is important to notice that the main mode of the sample between the mound and the cliff was very fine sand almost silt, so the secondary mode (medium sand) was analyzed. The classification of the sediments was determined using the ternary diagram proposed by Folk et al. (1970).

3. Geological settings

3.1. *Geology*

The studied coastal zone is represented by cohesive cliffs carved on Santa Clara Formation (middle to late Pleistocene, Schnack et al., 1982). It is composed by yellowish to dark brown clayey silt to

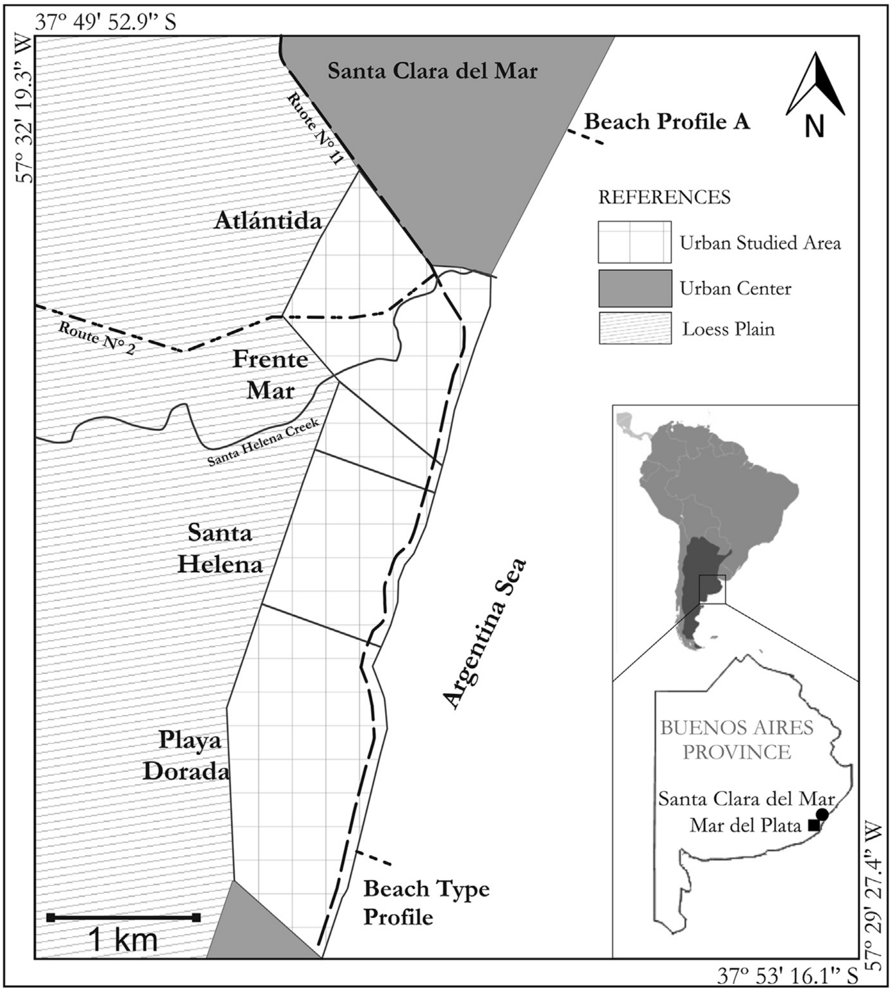


Fig. 1. Location map of the studied area.

sandy silt. This sequence is well represented in the cliff's profiles of Santa Clara del Mar, nearby Santa Helena stream, with a maximum thickness of 2 m. According to Bunicontro (2012), the sedimentary rocks in this area are feldespathic and lithic sandstones with a significant amount of feldspar (between 35% and 55%), quartz (30%) and lithic fragments (between 11% and 34%). Feldspar fraction is mainly potassic, the quartz is monocrystalline and lithic fraction is composed by volcanic and sedimentary rock fragments, pumice fragments and volcanic glass. Mafic and opaque minerals are minority (10%) and its binding material is a micrite matrix constituting almost the 60% of the samples (Bunicontro, 2012). About 38% of the total samples are sand (clastic fraction).

Santa Clara Formation is overlyed by paleosoils and continental deposits (limestones and sandstones) of Pleistocene–Holocene. This sequence ends with the marine transgressive deposit sequence Mar Chiquita Formation (late Holocene), defined by Schnack et al. (1982), which is not present in Santa Clara del Mar but northward in Mar Chiquita town.

3.2. *Geomorphology*

The geomorphology is represented by marine erosion features such as active cliffs, pillars, arches, caves and abrasion platforms. According to Bunicontro (2012), the active cliffs are 4–10 m high and are carved on Santa Clara Formation sedimentary rocks. They present irregular profiles due to the presence of resistant carbonate levels and friable loess levels. Thus, the formation of caves at the bottom of the cliffs is frequent due to wave erosion. Also there are numerous headlands and bays along the coast which increase the coastline sinuosity. The mass movement processes are active on the cliffs and is frequent the presence of blocks slides scattered on the beach. In several sites of the coast is usual to find an abrasion platform at the active cliff front. Wave cut platform are formed by loessic sediments (Pampeano Formation) and appear discontinuously along the coast between Playa Dorada and Atlántida locations. They reach a width of about 20 or 30 m during low tide and their surfaces are irregular with holes and gutters transverse to the coastline. The platform is frequently covered by the mussel *Brachidontes rodriguesi* and green algae (Bunicontro, 2012).

The aeolian landforms are scarce and are dominated by thin sand sheets on the active cliffs and relics of hanging stabilized dunes.

In this region there are several permanents fluvial creeks like Santa Helena winding stream that leads southern Santa Clara del Mar location. In front of the active cliff there are some gullies of variable development. They have several meters long (4–5 m), 0.15–0.2 m depth and 0.3 m wide. Sometimes pedestrian paths to the beach are associated with creeks by increasing the surface runoff velocity and the scoring.

3.3. *Coastal hydrodynamic*

The area has a micro-tidal regime with average amplitude of 0.82 m and a maximum of 1.70 m (Naval Hydrography Service, 2013). The mean wave height is about 0.91 m with a period of 9.5 s while the maximum height reached was 2.3 m (Lanfredi et al., 1992). The largest wave heights are registered during the *sudestadas* (storm surges that affect Buenos Aires coast). According to Bértola et al. (2013) during normal climate onshore transport is produced, while during storms the waves produce an offshore transport of sediments. Generally, winter and spring have been the most erosive periods and during summer and autumn there wasn't a dominant net trend. It was observed that the influence of seasonal cycles in sedimentary balances is not as important in partial balances as the storms effects, due to the large amount of sediments transported during these sporadic periods (Bértola et al., 2013). These drastic changes of sediment volumes increase when storms overlap themselves.

Some researches indicate that the sand transported by wave action presents a net motion toward the north and northeast along the south coast of Buenos Aires province (Isla, 2006; Bértola, 2006).

The rate of longshore currents through the coastline between Mar del Plata and Mar Chiquita (from SO to NE) is 0.26 m/s to 0.3–0.5 m/s (Naval Hydrography Service, 2000). Caviglia et al. (1991) estimated a volume of longshore drift sediments between 300,000 and 1,000,000 m^3/year, from Mar del Plata northward. Later the estimated rates of littoral transport between the coasts of Miramar and Mar del Plata varied between 400,000 and 700,000 m^3/year. Then, according to the Ministry of Transport, Public Works and Water Works of the Government of the Netherlands (1997), the littoral transport values between Santa Clara del Mar and Mar del Plata were about 150,000 and 200,000 m^3/year while between Santa Clara del Mar and Mar Chiquita did not exceed 25,000 m^3/year.

4. Results

4.1. *Coastal defense structures*

4.1.1. *General features*

Currently, the rocky mounds are located near the cliff base along the south coast of Santa Clara del Mar, between Playa Dorada, Santa Helena and Frente Mar locations. They are composed of quartzite blocks from Mar del Plata quarries selected according to their size and those without large cracks or high weathering (DIEBO, 2001). According to this report, they were built with a crowning width of 5.60 m, at an altitude of +3.0 m and have two parts: core and coating. The core is the internal part and it is built with rocks of about 30 and 300 kg, with a crowning width of 1 m at an altitude of +2.0 m. The coating overlies the core and involves rocks over 3 ton. At the slope side, the coating (of about 2 m) consists of two layers of rocks which are placed one by one to increase the interlocking leaving no free spaces. On the top of the coating there is a single layer of rock up to 1 m of thickness, with carefully selected fragments in order to leave parallel faces to obtain an upper flat and horizontal surface (DIEBO, 2001) (Fig. 2).

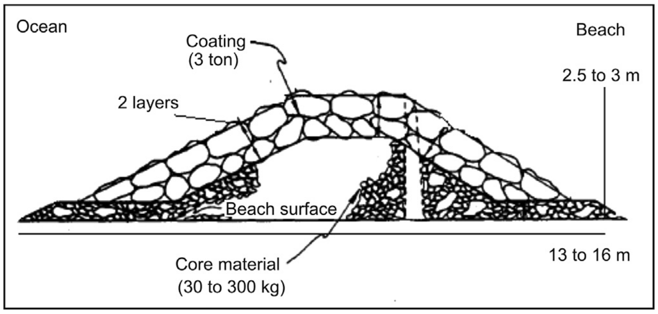


Fig. 2. Mound's structure scheme. Taken and modified from Shore Protection Manual of Department of Army, USA (1984).

According to Bunicontro (2012), the mounds have about 1.5–2.5 m height and 13–16 m average wide. They present a visible variable length, between 135 and 760 m, according to their construction stage. They are located in cliff base or at a maximum distance of about 25 m away.

The aerial photographs show that in 1975 this type of coastal protection structure did not exist in the study area. Between 1975 and 1985 the construction of the first mound is recognized ("Structure A"), located in the coast of Santa Helena location. It is currently placed between Sebastián Gaboto and Aviso Sobral roads, with 255 m length and 13 m wide (Fig. 3).

As stated by Tassara and García (2005), this first mound was built in 1984 and it was made of quartzite blocks of about 0.5 and 1 ton with a cross section of 27.75 m^2 (Lagrange, 1993). Currently, this structure presents a little offshore extension at its southern end. So, it is consider as a combined structure (mound-breakwater). The remaining structures were built between 1985 and 2003. Later and until 2011, have been expanded and extended along the coast to acquire the design they show today. During the last years, the mean changes were made in the "Structure C and D". In the first case, the mound was extended from 185 m in 2003 to 658 m in 2011. On the other hand, the mound "D", which now has about 760 m length, was divided in two sections of 95 m and 345 m in 2003. The "Structure B" corresponds to the least extensive mound. It is located 200 m southeast Playa Dorada location and is 135 m long and 15 m wide (Fig. 4).

4.2. *Structure and environment evolution*

The installation of this type of structure caused significant alterations in the coastal system that have to be considered in the future coastal management projects. These modifications include ecological disturbances, changes in the hydrodynamics of the beach profile and changes in the coastal morphological configuration.

4.2.1. *Changes in the coastal configuration*

Originally, along Santa Helena and Playa Dorada coasts and even in those places without mounds, the coastal configuration consisted on active cliffs and sand beaches (mainly represented by a foreshore of low slope and eventually by a narrow backshore). In this area the cliff was about 5 m high and, after the coastal defenses, its base was covered with a mixed ramp generated mainly by mass movements. Between the mound and the cliff, the restricted backshore develops an almost horizontal deposit consisting of cliff falling material. The cliff is no longer active and began to develop inactive features with many fluvial gullies and mixed ramps at the base (Fig. 5).

Also, during the construction stage, new access roads were built to transport quartzite rocks to the beach generating cuts on the cliffs and the destruction of the sand sheets that were lying on the cliffs due to the movement of heavy machinery. During this same stage, several fluvial gullies were formed increasing the fluvial erosion along the cliff.

4.2.2. *Changes in beach profile morphology*

The natural sand beach profile has suffered important modifications after the mounds installation. The main morphological changes are shown in Fig. 6, which illustrates a comparison

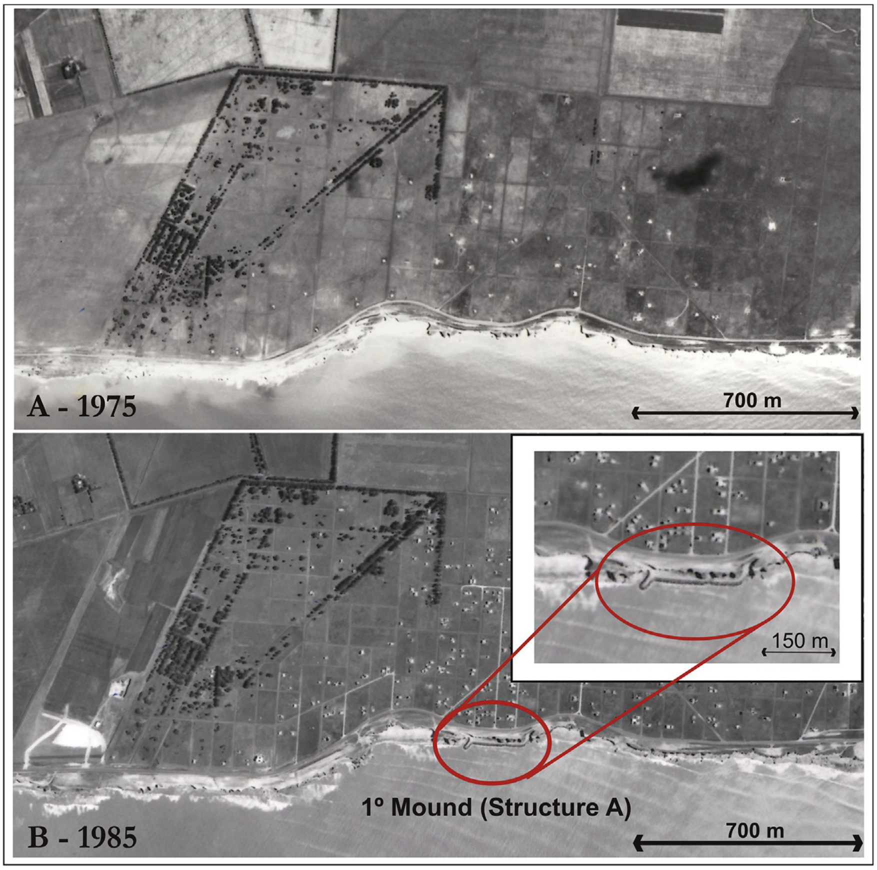


Fig. 3. Mounds evolution in the studied coast between 1975 and 1985. Notice the first mound in Santa Helena coast back in 1985.

between the original beach profile and the modified beach profile after more than 25 years since the mound construction. The original sand beach was short in extension (10–30 m) resting on the abrasion platform. The beach was not well developed. The backshore was usually absent. As the wave level reaches the cliff base during high tides frequently, the foreshore dominated the beach environment.

The mound installation can be done in two ways: close to the cliff base through the entire beach or placed some meters seaward from the cliff. As a consequence some morphometric parameters changed. In both cases, beach width was reduced due to the presence of the mound. In those places where the mound didn't occupy all the beach extension, the foreshore was divided in two environments: a restricted backshore between the cliff and the mound, isolated from the direct wave action, and the new foreshore (Fig. 7).

On one hand, the restricted backshore began to be affected by some continental processes such as mass movements, blocks slides, debris and mud flows and aeolian ramp generation, which had an important impact on the sediment supply and dynamics. This new environment is up to 10 m wide and its slope was reduced from 3° to almost horizontal. This is a result of the sediments incorporation that increases the restricted backshore aggradation by flooding during storm surges and the continental input by mass removal process on the cliffs, runoff sediments and wind contribution. On the other hand, the foreshore reduced its width but increased strongly its slope from of 2.7° average (Bunicontro, 2012) to almost 7°. This is due to the wave reflection over the mounds structure. In places where there is no mound the foreshore slope keeps between 2° and 5° with an irregular presence of an abrasion platform almost horizontal.

4.2.3. *Changes in coastal dynamics*

During its operation, the mounds prevent the shoreline retreat by absorbing the wave energy and isolating the cliff base from the sea. The beach zone between the mound and the cliff is no longer affected by the wave attack but is partially flooded during storm surges (Fig. 7). The absence of wave along this beach fringe changes the environment conditions and the sediment transport from the wave dominated environment to a continental environment modified by wind, mass wasting and temporary lakes. Also, since the waves do not reach the cliff bases, there are variations on the sedimentary balance of the coastal area. This occurs because the sandy sediments input from cliffs erosion to the drift current decreases. According to Isla and Cortizo (2014) as the amount of sediment delivered to the Argentine continental shelf by cliff erosion is higher than the fluvial transport, it should be also considered in the balance of beaches fed by longshore transport. To quantify this, we have calculated the total volume of material eroded from cliffs, obtaining a result of 3.3 m^3/m/year; similar to the result obtained by Isla and Cortizo (2014) for this zone (between 3 and 5 m^3/m/year). However, it is important to consider that only sandy sediments are incorporated to the longshore transport because the finer ones are lost offshore. Therefore, considering that cliffs have about 38% of sand (Bunicontro, 2012), the input is about 1.25 m^3/m/year. If we consider that mounds occupy 46% of the coastline (1.83 km of 4 km) the amount of sand supplied from the entire studied coast to the littoral drift reduces from 5000 m^3/year to 2712 m^3/year. This undoubtedly contributes to the undersaturation of the flow and promotes the erosive effect northward in those sites without defense structures.

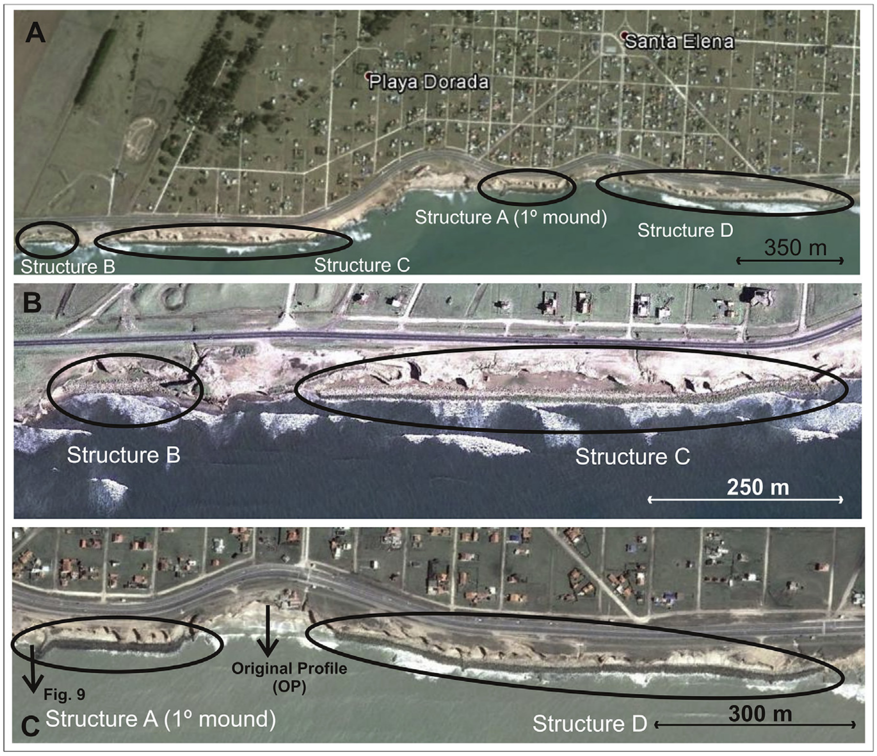


Fig. 4. A: Location map of the different mounds along the entire studied coast in 2014. The first one is named as "Structure A" while the others are named in order from south to north. B: Mound detail of Structure B and C. C: Mound detail of Structure A and D. Notice the location of the Original Profile (OP) analyzed in Fig. 6 and the location of the photograph of Fig. 9, in "C".

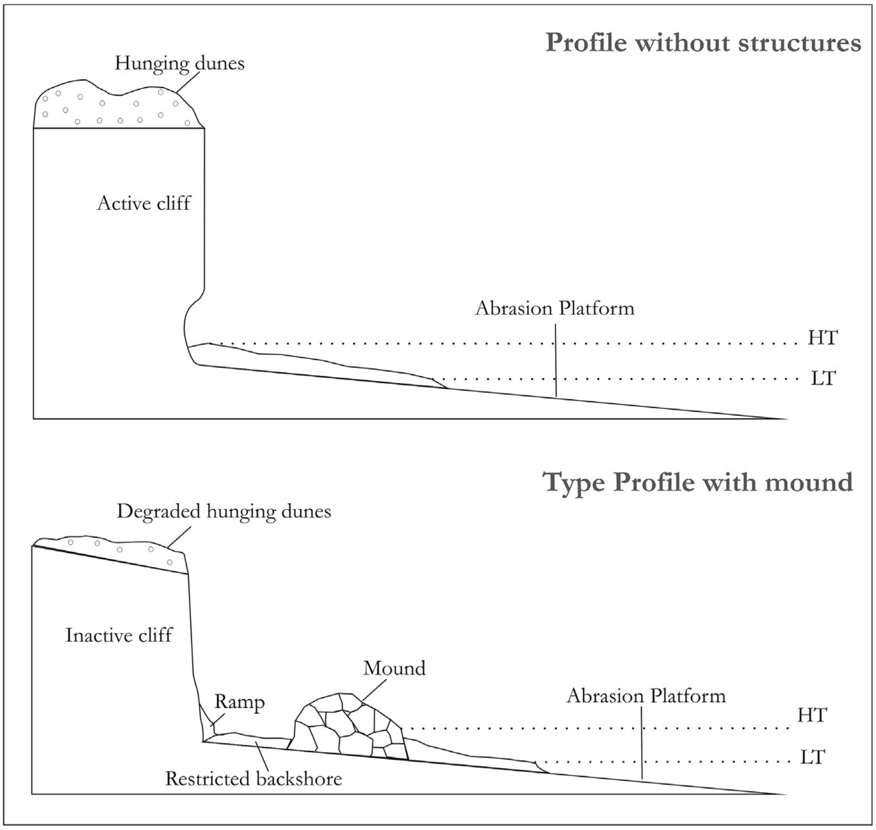


Fig. 5. Comparative scheme of a beach profile without (above) and with (down) defense structures; HT: high tide, LT: low tide.

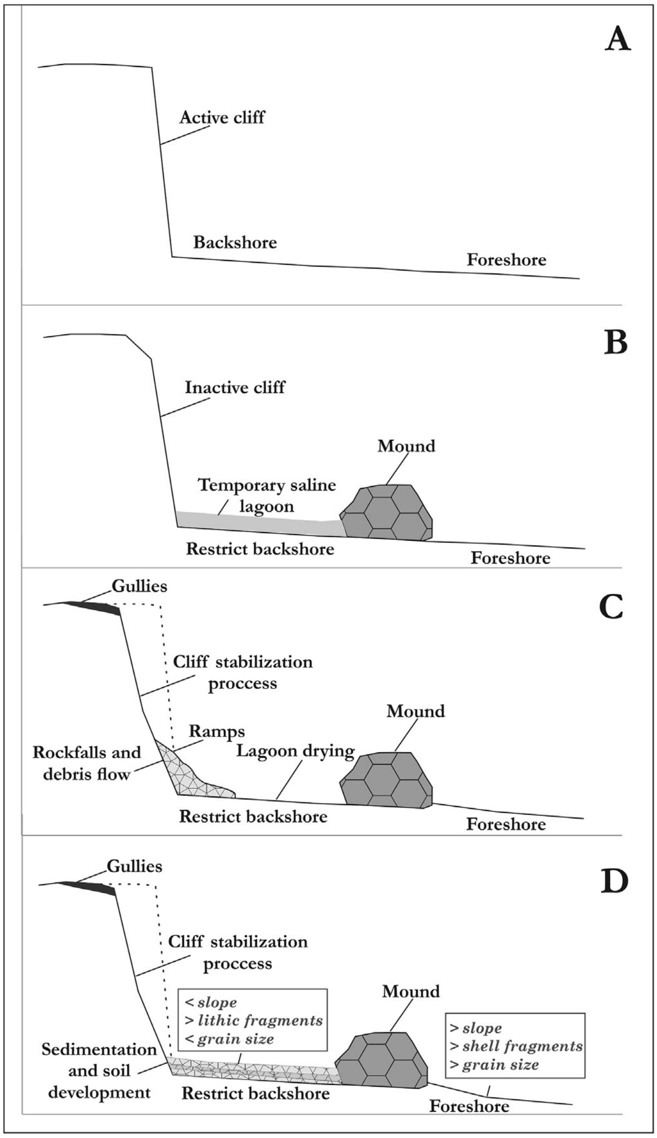


Fig. 6. Comparative scheme of a beach profile altered by the presence of a mound over time. A. Original beach profile with protection structures. See Fig. 4 to see its location. B. After mound installation, cliff became inactive and the restricted backshore could be temporarily flooded. C. The lagoon dries, mixed ramps are visible and cliffs began its stabilization process. D. It shows the main textural, compositional and morphological changes both in the foreshore and the restricted backshore, as it occurs nowadays.

4.2.4. Changes in sediments composition and texture in beach environments

Originally in coasts without defenses, the beach profile showed environments (like foreshore and backshore) composed mainly by medium sand sediments (2 Φ), moderately sorted (0.80–0.90), symmetric to negative skewness (−0.3 to 0.01) and leptokurtic to very leptokurtic distributions (1.1–1.6).

After mounds installation, some of these parameters changed. Mainly the mode and sorting were affected, and also the transport and composition.

The most important textural change is located at the restricted backshore while the rest of the sediments samples analyzed along the transverse beach profile are constituted by medium sand with a mode of 1.5 and 2 Φ (Fig. 8). Only beach sediments inland the mound (restricted backshore) are characterized by very fine sand with a clear mode of 4 Φ, moderately sorted (0.76), with negative skewness (−0.38) and very leptokurtic distribution (1.89).

Then, the main changes are in the swash zone, which has a bimodal distribution (with main mode of 1.5 Φ and a second one of 2.5 Φ) and is poorly sorted. The rest of the samples present a unimodal distribution with moderate sorted to well sorted sediments. In turn, most samples present mesokurtic distributions and negative skewness.

Although all the samples have three types of transport (traction, saltation and suspension) only in the restricted backshore suspension dominates with more than 74% of the sample over 3.5 Φ. In the rest of the environments the saltation dominates with more than 87% of the total and an inner truncation of the population situated in 2 Φ. In the storm area and the high and mid tide environments, the saltation section extends from 0.5 to 3 Φ, being wider in the swash zone (from −1 to 3.5 Φ). Except in this last environment, in the rest of them the traction–saltation truncation is in 0.5 Φ while the saltation–suspension truncation varies between 3 and 3.5 Φ. Only storm area shows that the percentage of sediment transported by traction is over 12%, being less than 6.5% in the rest on the samples.

The petrographic analysis allowed us to recognized lithic fragments, mainly volcanic, shells, quartz and potassic feldspar as the predominant components of the current sediments. There is a small amount of heavy minerals in all the analyzed samples. Table 1 shows a comparison between the altered beach profile and a natural beach. There, it can be observed the main compositional changes in the most important environments.

The distinctive changes arise in the restricted backshore samples compared with the foreshore ones. Although the amount of quartz and feldspar are similar on both environments and profiles, the most altered values are lithic and shells fragments, and heavy minerals (Fig. 8). It is important the abundance of lithic fragments

Fig. 7. Comparative photographs in Santa Helena coast during (2011, on the left) and after the mound construction (2013, on the right). It can be seen the temporary ponds in the restricted backshore during high tides or surge storms, and the ramps with vegetation during low tides.

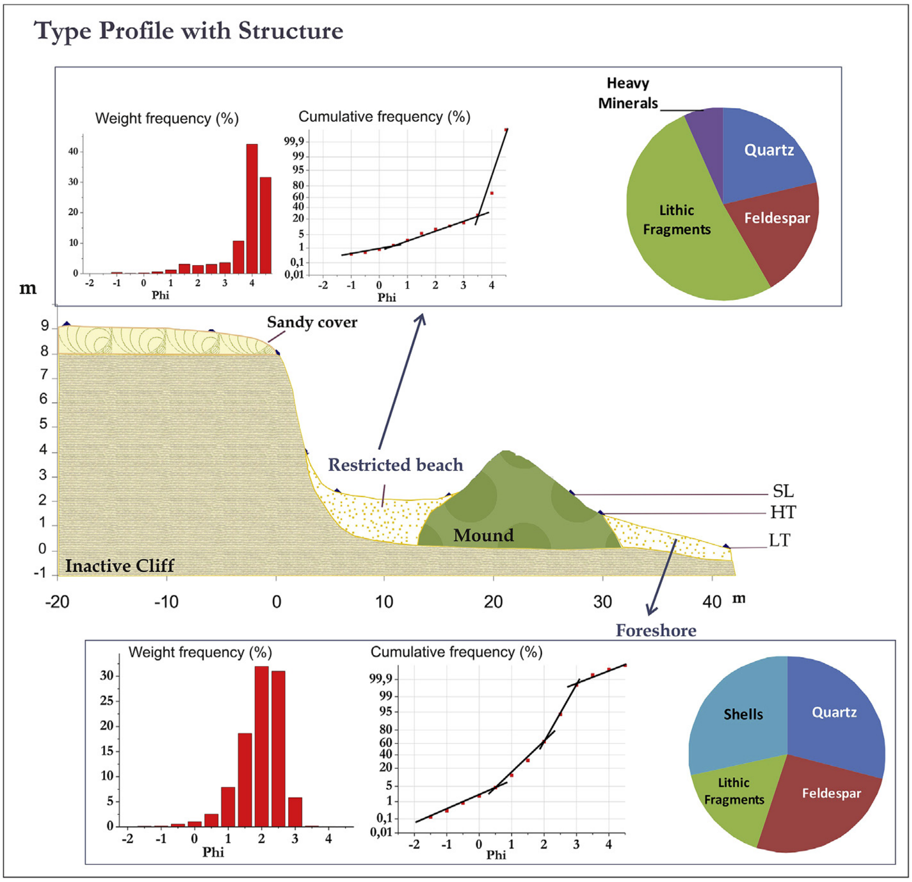


Fig. 8. Scheme of a beach profile affected by a mound. Note the textural, compositional and transport differences between the restricted backshore and the foreshore. SL: storm level; HT: high tide; LT: low tide.

over those of quartz and feldspar. In turn, those values (51.7%) are quite above the average of lithic fragments in the rest of the samples (16%). The same occurs with heavy minerals percentage (6.6% versus 1.4%). On the other hand, the restricted backshore samples do not present shells fragments as it is frequent in the other environments (almost 30%) (Table 1).

These new characteristics on sediments are irreversible and permanent while mounds remain in the coasts. The changes in grain size have a direct impact on ecology features of the beach. Those places where sediments became finer are likely to develop soils and consequently vegetation. This is obviously related to the alteration of the organisms and benthic communities that live in these beaches, not only in backshore where the sediments are finer but also in the foreshore where sediments are coarser.

Also, the composition and grain size conditioned the type of transport in each environment altering all the natural hydrodynamics.

Mostly in all samples, the light clastic fraction is formed by lithic fragments, intraformational fragments, quartz, potassic feldspar and plagioclase. The main lithic fragments are volcanic with equant and rounded grains. They present porphyritic texture composed of plagioclase microlites, quartz and glassy matrix. The sedimentary lithic fragments are less abundant and belong to altered sandstones with iron oxides and clayey material. The volcanic glass is specially concentrated in the restricted backshore sample (Table 1) and is composed by glass shards and pumice fragments. The intraformational fragments are carbonate and correspond to remains of shells mainly concentrated in the intertidal zones and the backshore of the beach profile "A" (Table 1). The quartz is mostly monocrystalline with fresh, equant and rounded grains. Some of them show sharp, partially dissolved or corroded edges. The polycrystalline quartz is chert type presented as fine to very fine homogeneous aggregates. The potassic feldspar is abundant and is represented mainly by orthoclase with moderate to intense clay alteration. The microcline (less extended) has equant and rounded grains. The amount of plagioclase is lower, with tabular individuals and polysynthetic twins, being from well preserved to deeply altered to sericite and clays.

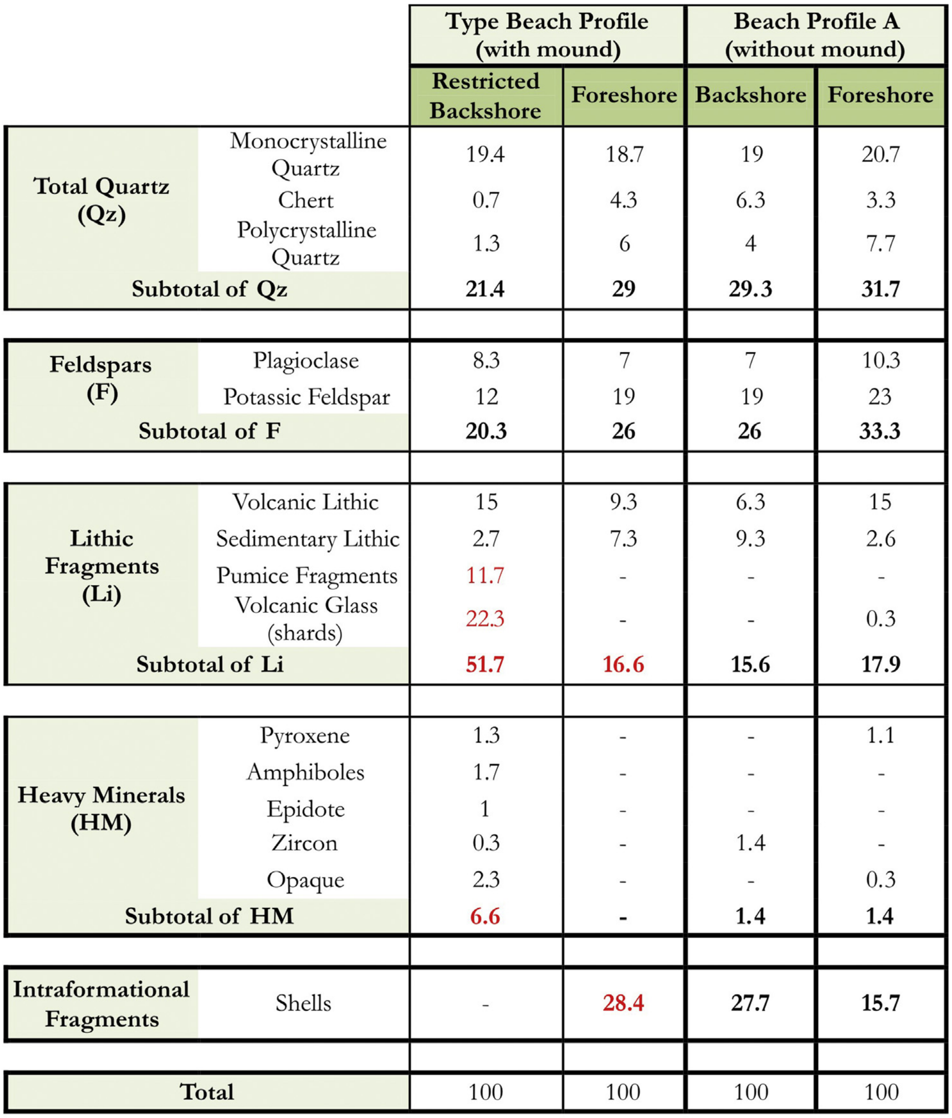
The heavy fraction is a minority and it is represented mainly by amphiboles, pyroxene and opaque minerals.

According to Folk et al. (1970) ternary diagram, both samples of the Type Profile are classified as lithic to feldspathic sand, while the samples taken in Santa Clara del Mar (beach profile "A") classifies as feldspathic to lithic sand. In addition while in all the samples the monocrystalline quartz–feldspars–lithics proportion is similar, the sample behind the mound shows a remarkable predominance of lithics.

4.2.5. Changes in the recreational use of the beach

Another important modification as a result of the installation of this type of defense structures is related to the beach use as a recreational environment. In this case, it is not possible the construction of resorts or spas since it doesn't exist a backshore development or is restricted to a few meters during low tides. On the other hand, the foreshore or "wet beach" is very narrow and the waves reach the mounds base quickly, minimizing its extension during high tide and preventing its use during most of the day. Also, as the slope increases the beach becomes more reflective. As a

Table 1
Comparative table between the Type Beach Profile (affected by mound) and a Beach Profile without structure's influence. Both backshore and foreshore are analyzed to show the main differences (values in red) between the two profiles and each environment.



		Type Beach Profile (with mound)		Beach Profile A (without mound)	
		Restricted Backshore	**Foreshore**	**Backshore**	**Foreshore**
Total Quartz (Qz)	Monocrystalline Quartz	19.4	18.7	19	20.7
	Chert	0.7	4.3	6.3	3.3
	Polycrystalline Quartz	1.3	6	4	7.7
Subtotal of Qz		**21.4**	**29**	**29.3**	**31.7**
Feldspars (F)	Plagioclase	8.3	7	7	10.3
	Potassic Feldspar	12	19	19	23
Subtotal of F		**20.3**	**26**	**26**	**33.3**
Lithic Fragments (Li)	Volcanic Lithic	15	9.3	6.3	15
	Sedimentary Lithic	2.7	7.3	9.3	2.6
	Pumice Fragments	11.7	-	-	-
	Volcanic Glass (shards)	22.3	-	-	0.3
Subtotal of Li		**51.7**	**16.6**	**15.6**	**17.9**
Heavy Minerals (HM)	Pyroxene	1.3	-	-	1.1
	Amphiboles	1.7	-	-	-
	Epidote	1	-	-	-
	Zircon	0.3	-	1.4	-
	Opaque	2.3	-	-	0.3
Subtotal of HM		**6.6**	**-**	**1.4**	**1.4**
Intraformational Fragments	Shells	-	**28.4**	**27.7**	**15.7**
Total		100	100	100	100

result, this affects largely the habitants of the nearby locations. The restricted zone between the mound and the cliff constitutes an area that can hardly be recreational due to the soils and vegetation development and the predominance of very fine sediments. As a result of these characteristics, during strong rainfalls periods or extraordinary tides, this environment becomes slippery, muddy and impassable during several days. This makes it difficult beach access due to the presence of temporary ponds.

4.2.6. Ecological changes

The main ecological changes are seen in the restricted backshore. As a result of the temporary floods and the fine sediments decantation it is common the development of soils and the presence of vegetation (Fig. 9). This zone can be flooded or dried but always as a saline environment similar to a marsh. Also, and as a consequence of mound installation, the substrate changes from sandy to rocky where the mound is, and from sandy to silty, in the restricted backshore. This undoubtedly affects the development of

Fig. 9. Santa Helena's coast in 2011. The restricted backshore is dominated by vegetation and partially covered by mixed ramps. Notice the mound's dimensions in comparison with the man below, how close is the road from the cliff and see how the heavy machineries are working on mounds at the background. See the location of this photograph in Fig. 4 ("C").

benthic communities of the beach and thus the entire food chain.

The relation between the changes in texture sediments and its ecological impact hasn't been reported before. This shows that beyond geological and geomorphologic changes there is a biological alteration that should be taken into consideration as one of the mound's effects.

5. Conclusions and recommendations

Installing mounds as coastal defenses has generated direct impacts such as creeks generation along the cliffs, changes in coastline configuration, openings of new access to the beach, ecological alterations on backshore, hanging dunes excavation, changes on the beach profile morphology and a negative visual impact. As well as indirect impacts: the decrease of sediment supply from cliffs to littoral drifts and morphological, textural and mineralogical changes along the transverse beach sub-environments. Also, recreational use of beaches for tourism was altered.

Morphological changes have been demonstrated both in backshore and foreshore. The backshore reduced its width from 30 m to almost 10 m and its slope from 3° to almost horizontal while the foreshore reduced from 20 m to 10 m but increased considerably its slope up to almost 7°.

The backshore environment turned into a restricted beach totally isolated from the direct wave action. The amount of lithic fragments, volcanic glass and heavy minerals increased while bioclastic material (carbonate) decreased. The sediments texture shows a trend to diminish the grain size and sorting in this environment. The grain size is very fine with a composition dominated from cliff sediments without any marine reworking and, on the other hand, foreshore concentrates larger percentages of bioclastic material with a minor amount of lithic fragments and a medium grain size.

It was estimated that a 46% of the studied coast is protected by mounds. This introduces a loss of sediments input by cliff erosion to the littoral system of about 1.52 m^3/m/year. Currently, the input of sand from cliffs has been reduced from 5000 m^3/year to 2712 m^3/year due to the mounds installation.

Although mounds reduce cliff retreat by wave attack, the fluvial action (gullies) is another erosive factor to take into consideration in the future coastal management projects for this area. It is recommended to study the coastal dynamics before using any type of defense structure and to perform a serious evaluation of its effects and benefits.

Even though it is demonstrated that the use of these structures diminishes the cliff retreat rates, it's also important to consider in the management of coastal zones that these defenses induce other alterations in the coastal environments that have to be taken seriously by the planning authorities. The affected communities should know the impacts that the structures will produce and use them as evaluation criteria in order to choose the best type of work. Also, if defenses continue to extend along coastline it could produce a severe undersaturation of the littoral drift and consequently an increase on beach erosion rates.

In places where the erosion problems are very intense and mounds became self-defeating it should be consider the relocation of the properties in risk as an appropriate option.

It is extremely important to offer information to the population about the coastal problems and solutions to achieve an integrated and regional coastal management.

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