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The effects of sediment used in beach nourishment:

Study case El Portet de Moraira beach

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The effects of sediment used in beach nourishments: Study case of El Portet de Moraira beach

ABSTRACT

Actions taken to prevent or reduce coastal erosion often do not have the desired effect, leading to major problems instead of solving the original one. This research focuses on why a nourished beach— with borrowed sand and 0.05% of particles less than 0.063mm— causes the presence of suspended particles that are observed by beach users as turbidity. This means that the colour of the water was not its characteristic blue, even with calm wave conditions. This research involved a shoreline evolution analysis and a sedimentological study of the sand from 1977 to 2017. The results show that the turbidity episodes that occurred after the beach fill of May 2017 do not coincide with major storms that affected the beach. Furthermore, prior to this beach nourishment, even after the most important storms turbidity was not so pronounced. However, when the pre-nourishment and post-nourishment sediment are compared and analysed in detail, by studying the microstructure and morphology of the sand particles, their composition and morphology were observed to be completely different. These differences are also reflected in the accelerated particle weathering test, with the post-nourishment particles showing greater dissolution of carbonates. From its mineralogy, the post-nourishment material presents a smaller proportion of quartz in its composition and a significant amount of particles (9.6%) formed by clusters of Calcium and Silicon. The separation of this mineralogical composition produced by waves explains the formation of particles measuring less than 0.063 mm, a fact that has also been confirmed by the accelerated particle weathering test. This is, therefore, the cause of turbidity in the swash zone of the beach.

Keywords: *shoreline evolution; sand beach; sand mineralogy; sand morphology; beach nourishment; water turbidity*

1. INTRODUCTION

Coastal erosion is a natural phenomenon that is becoming a growing problem. This issue is the result of multiple factors (rising sea levels, the frequency of major storms, lack of sand input from rivers and ravines etc.), many of them a result of global climate change (Mee, 2012). Furthermore, given the importance of coastal regions for humans, anthropogenic activities increase and, as a result, coastal erosion rises (Steffen et al., 2007). Some of these actions have even led to the disappearance of important coastal habitats such as seagrass meadows (Aragonés et al., 2015; Orth et al., 2006; Pagán et al., 2016; Waycott et al., 2009).

Over the last few decades, there has been a gradual shift in coastal defence techniques, tending in recent years to soft actions such as the nourishment of sandy beaches as an erosion mitigation mechanism (Dean, 2003; Trembanis and Pilkey, 1999). The placement of sand on the beach is considered by many authors to be the most acceptable form of coastal stabilization (Aragonés et al., 2016; Hobbs, 1988; Leonard et al., 1990; Magoon et al., 2001; Walker and Brodeur, 1993). Therefore, periodic artificial beach filling is widely regarded as an acceptable method of beach protection and dune restoration (Hanson et al., 2002). Additionally, increasing pressure from tourists has involved, for example, requests from coastal residents to protect their properties from coastal hazards, such as flooding, sea level rise, etc. (Obiol Menero, 2003). Therefore, governments should provide solutions, such as beach nourishment for protection against erosion (Kriebel, 1988).

Some researchers have found that taking the shoreline location as a reference point indicates a regression from the initial position and therefore, significant volumes of sediment have been lost (Aragonés et al., 2015; Roeland and Piet, 1995; van Koningsveld and Mulder, 2004). Different procedures of beach nourishment have been tested on a world-wide basis. Thus, van Duin et al. (2004) observed how the studied beaches had disappeared in just two years after their nourishment, a fact that can also be analysed in the study carried out by van Koningsveld et al. (2009). However, the conclusions of both studies do not specify where the exact destination of the nourished sand on the coast. Grunnet and Ruessink (2005) demonstrated that after the nourishment the autonomous migration of sandbars was halted during the period of 6 to 7 years. Therefore, an important issue related to assessing the success of this type of beach action is that there is no regular protocol to monitor the changes that occur after the sand placement (Leonard et al., 1990; Stauble, 1988).

To contain coastal erosion, it is necessary to understand the factors that generate it, such as wave energy or the properties and origin of sediment. Waves and ocean currents mobilize the sediment. The thickness of the activation layer depends on the slope of the beach, as well as the significant breaking wave height(Anfuso et al., 2000; Jackson and Malvarez, 2002; King, 1951. Others authors include sediment porosity and period {Ciavola, 1997 #122) and others add the incidence angle of swell (Bertin et al., 2008).

The erosive process begins with the movement of the particle. This happens when the instantaneous force of the fluid is greater than the grain's resistance force, which is a function of particle weight, particle angle at rest, lifting force and drag force (Allen, 1970; Komar, 1987; van Rijn, 2007). Once the sediment is set in motion, its mineralogical composition is another aspect that can influence the erosive process (Roberts et al., 1998). For example, the high proportion of carbonates in the sediment composition influences its dissolution (Milliman, 1993; Milliman and Syvitski, 1992; Syvitski and Kettner, 2008 by the action of CO2 which causes acidification of seawater {Harrould-Kolieb, 2012 #114). Another element that influences the sediment erosion process is the breakage and separation of the particles that form the sample (López et al., 2016a).

In addition, it is essential to assess the influence of changes in sand fill (from quarries, marine dredges, rivers, etc.) on water quality and therefore, the integrity of coastal ecosystem {Pagán, 2016 #76}. In this sense, the *Posidonia oceanica* meadows, which are found in the Mediterranean Sea, are an indicator of water quality and can be affected by turbidity, reduction of light and/or silting (Medina et al., 2001).

Therefore, it is clear that many factors may influence coastal erosion, but their exact influence is not well known. For this reason, this article aims to analyse the reasons why El Portet de Moraira beach (Teulada, Spain), suffered a major change after its nourishment. This beach had turquoise blue waters (Figure 1a and c) prior to the beach fill in March 2017 with 8,000 t of borrowed sand. With 0.05% of grain size finer than 0.063 mm, a suspended plume of sediments was formed after being in contact with the incoming waves (Figure 1b and d). For this purpose, the historical evolution of the beaches will be studied, and the evolution of particle wear, its mineralogy and morphology will be analysed in detail to identify the differences between the material existing on the beach and the material contributed during a beach nourishment.

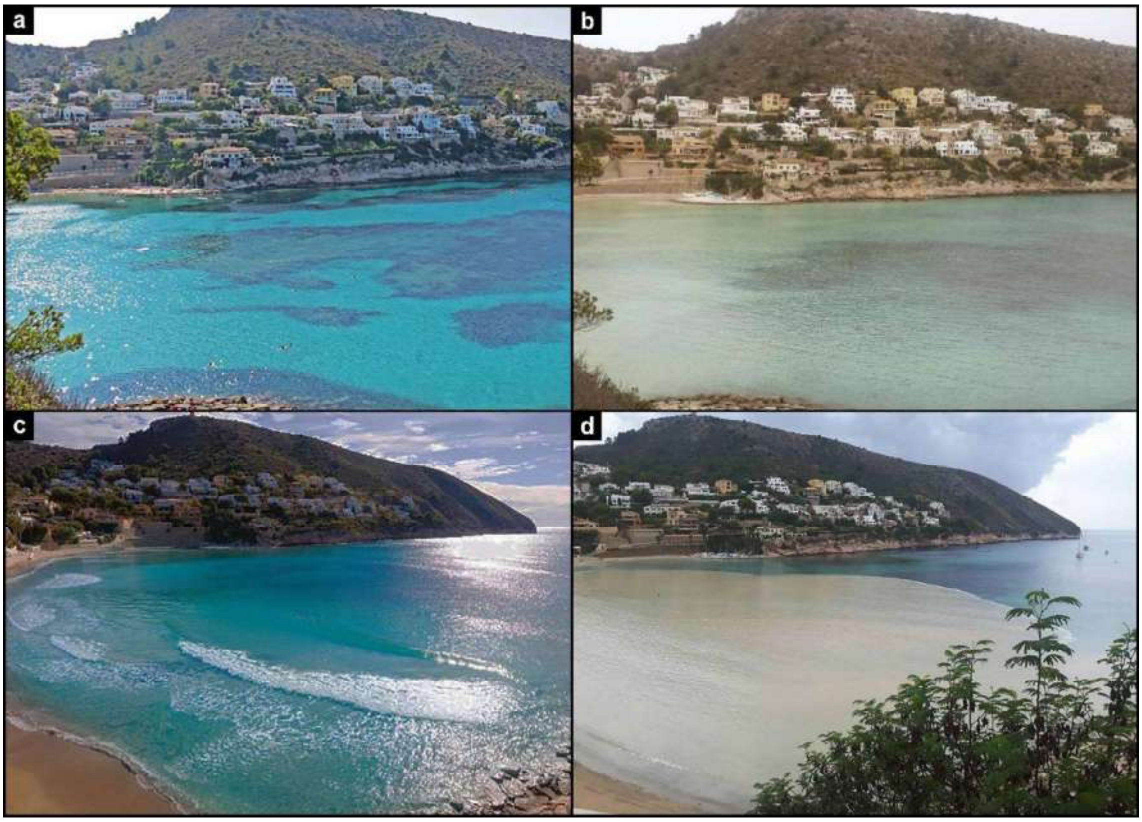

Figure 1. a) Photograph prior to nourishment (Spring 2016)**. b**) Photograph after nourishment (03/24/2017). **c)** Photograph prior to nourishment with light swell (06/18/2015). **d)** Photograph after rainfall post-nourishment (08/29/2017).

2. STUDY AREA

The province of Alicante is located in the southeast of the Iberian Peninsula and it has 244 km of shoreline (Figure 2a). Two different morphological zones can be delimited in Alicante province: i) the northern part (in which the beach under study is located) comprises two thirds of Alicante province. It is a mountainous land with river valleys and gravel beaches are the most common found. ii) The southern third of Alicante consists of a large alluvial plain and it is entirely comprised of sandy beaches.

The study focuses on El Portet de Moraira beach (Figure 2c), which is located in the municipality of Teulada (38º41'14.43''N and 0º8 '46.66''E). The beach is placed between Cape d'Or on the east and, on the west, by a low-rise cliff that reaches the Moraira Port. Its total length is about 330 m (Figure 2d).

The basin of the studied area is composed of hillside and limestone debris, with some traces of loams, sandy limestones and clays. This basin flows mainly into the Moraira ravine, with some contributions to the coastal area (Figure 2). However, as can be seen, more than 90% of the basin's surface area is urbanized (Figure 2e and f). According to the National Soil Erosion Inventory (INES) 2002-2012 in Alicante, the soil erosion on slopes where it has not yet been eroded ranges between 10 and 50 t/(ha-years). However, given the high degree of urbanization, roads are virtually non-existent today, which means that the basin no longer contributes material to the coastal zone, as shown in later sections by the historical evolution of the coastline.

As far as climatology is concerned (Figure 2e), the maximum precipitations take place between September and December with average precipitations of 78 mm/month. The summer period is the hottest and with less precipitation, which indicates that these precipitations are not the main cause of turbidity observed in the area during the period studied.

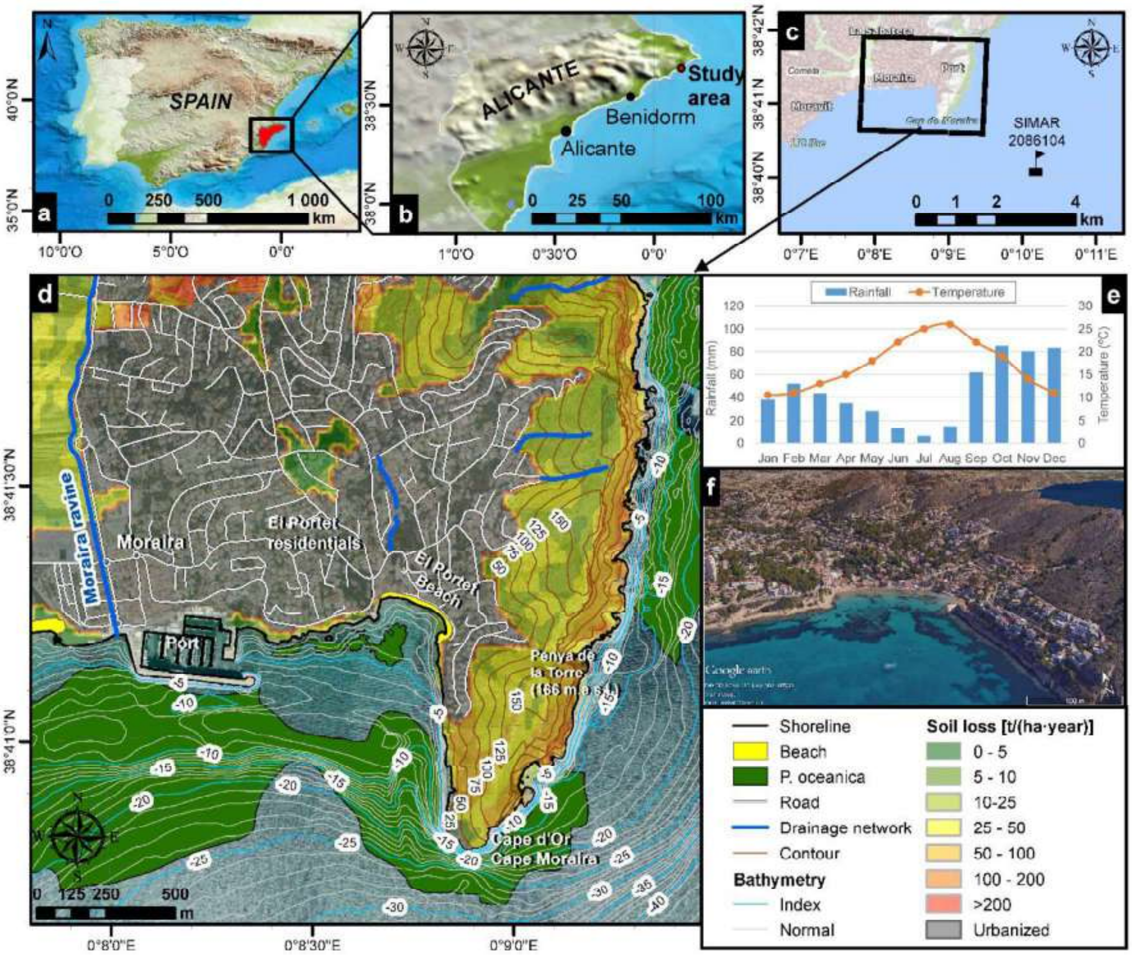

Figure 2. a) Location of the study area in the Iberian Peninsula; **b)** location of El Portet de Moraira beach in the province of Alicante; **c)** detail of the studied area, with the location of the SIMAR node used for wave data; **d)** Location of the ravines of the urbanized land and soil loss; **e)** Study area climogram; **f)** aerial image of El Portet de Moraira beach.

Because of the lack of contributions due to the urbanization of the basin, the beach has suffered a continuous process of erosion over the time. The beach has been nourished twice with sand to control the problems due to the erosion of the shoreline in two different periods. The first one, in 1985, with 40,000 t of sand from dredging. The second, in March of 2017, with 8,000 t of sand from the screening of natural aggregates were used to nourish the beach. After the last nourishment, a great turbidity is observed. The water colour of the beach, before turquoise and crystalline (Figure 1a), has changed to brown and turbid (Figure 1b).

3. METHODOLOGY

For determining the causes of the water turbidity caused by the last beach nourishment, the procedure was as follows (Figure 3): i) analysis of the shoreline historical evolution and the equilibrium profile; ii) maritime climate and iii) sediment analysis.

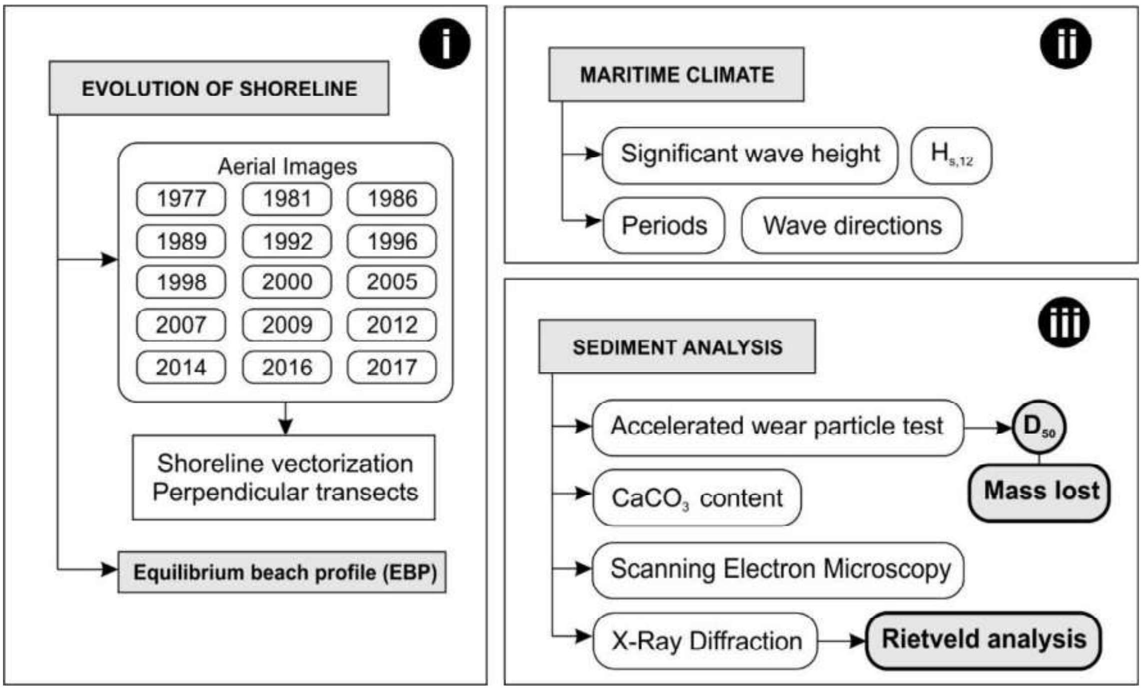

Figure 3. Process followed in the study.

3.1. Study of the evolution of the coast

To study the evolution of the shoreline, several aerial images, indicated in Table 1, were used. Since not all the images used to study the shoreline evolution were georeferenced, the first step was the photogrammetric restitution of all those non-georeferenced images (Table 1) applying the method described by Pagán et al. (2017).

Table 1. Summary of the available aerial images information.

Date	Source	Image	Format	Spatial reference
1977, 1989	Cartoteca IGN	Aerial	ECW	None
1981, 1986, 1992, 1996, 1998	DGC – SPC Alicante	Aerial	ECW	None
2000, 2005, 2007, 2009, 2012, 2014	PNOA	Orthophoto	ECW	UTM ETRS89 H30N
2016, 2017	Digital Globe	Orthophoto	TIFF	WGS84

The georeferencing process of the aerial images was carried out using ArcGIS 10.1®. The orthophoto used as a base for georeferencig the aerial images was the most recent (2014). The errors obtained was less than 0.5 m RMS (root mean square). Since all the aerial images were collected in summer and the state of the sea was relatively calm, the methodology provides optimal results for the manual vectorization of the shoreline at a scale of 1: 1000.

Once the aerial images have been obtained, the evolution of the shoreline has been analysed. A series of perpendicular transects to the shoreline were created. Transects separation was established in 40 m stretches and its length was from the wall or limit of the beach stretching 120 m out to sea. The methodology allows measurement of the width of the dry beach each year in each transect (Supplementary data 1 and 2). Subsequently, the beach surface has been obtained and the areas were compared for each period so as to analyse the evolution (accretion or regression shoreline).

Four periods have been chosen (between 1977 and 2017) to study the evolution of the shoreline. The first period was from 1977 to 1981, from the first available aerial image to the last one before the first beach nourishment in 1985. The second period was 1981-1986 and it includes the beach nourishment carried out in 1985. The next period studied was 1986-2016 and enables analysis of the evolution of the beach nourishment from 1985 to 2016. The last period analysed was 2016-2017, which includes the most recent beach nourishment.

3.2. Equilibrium beach profiles (EBP)

The transversal profile after the nourishment was estimated, and this was based on the 2006 known-profile, the beach width after the beach was nourished and the volume of material discharged.

Subsequently, in the future equilibrium beach profile (EBP) is determined by assuming that the sand is distributed over the profile with no particle loss due to the sediment transport. For determining the EBP morphology, the model proposed by Aragonés et al. (2016) was used. It takes into account the *Posidonia oceanica* in the energy and morphology of the final profile.

3.3. Maritime climate

Concerning the marine dynamics in the study area, it hardly experiences tidal intensity, like the rest of the Mediterranean, where the oscillations due to the atmospheric pressure are even more influential than the tide itself. In this sense, the importance of the astronomical tides is very insignificant, with values that oscillate around 0.3 m, while the meteorological tides can reach values of up to 0.45 m (http://www.puertos.es , and Ecolevante (2006)).

The waves in the area are conditioned by Cape d'Or to the east and the Peñón de Ifach to the southwest (Figure 2c), so the range of incidental waves is between N171°E and N151°W. To determine the characteristics of the swell, the data of the SIMAR Node 2086104 (0.17°E, 38.67°N), located about 3 km from the study area (Figure 2c), were used. The SIMAR Node data were treated using the software AMEVA v1.4.3 (IHCantabria, 2013), obtaining for each period studied the significant wave height, the wave height $H_{s,12}$ (exceeded 12 hours a year), and their corresponding periods, directions and probabilities of occurrence.

The SIMAR data series provided by Puertos del Estado, have been collected over 61 years, during the period between 1958-2017, making it the most complete database for the Mediterranean Sea (Infantes et al., 2009).

3.4. Analysis of El Portet de Moraira beach sediments

To characterize the sediment of El Portet de Moraira beach, samples were collected in 2004 before the beach nourishment and after the beach nourishment in 2017 (April 6, 2017). In both periods, the four samples were collected as follows: i) three from the surf zone (centre and ends of the shoreline) and one from the centre of the backshore. Before testing, all samples were reduced using a splitter to ensure the homogeneity and representativeness.

To simulate the erosion the sand particles suffer in the surf zone of the beach the accelerated wear particle test proposed by López et al. (2016a) was used. The test allows analysing the decrease of the D_{50} of the sample. In this test, 75 g of beach sand sample and 500 ml of seawater from the beach studied were poured on a magnetic stirrer at 1600 rpm in 24-hour cycles. The number of cycles applied to each sediment sample to reduce the size of the particles below 0.063 mm was used as a reference for the analysis of the wear resistance of each sediment. The size distribution of the sand sample was carried out according to UNE 103101 (1995), UNE 7050-2 and UNE 103 100 after each cycle. In addition, after each cycle, the measurement of $CaCO_3$ content in the water was carried out using Bernard calcimeter method according to UNE 103200-93.

The Scanning Electron Microscopy (SEM) allows images of the sample to be obtained, as well as the elemental composition and its possible changes (Melgarejo et al., 2010), and was used to evaluate elemental and morphological analysis of the sediments. SEM has allowed observation of the microstructure and the morphology of the sand grains and identification of broken particles, fractures and heterogeneities in the sediments. The mineralogical phases in the sediments were determined by X-ray diffraction (XRD).

A Hitachi S3000N SEM, with an X-ray detector for microanalysis (EDS) and variable pressure mapping, was used to examine the morphology. The dry and clean sand samples were placed in a SEM sample holder using carbo tape to adhere them. It has not been necessary to cover them with a metal film (usually gold sputtering), since the equipment has a variable pressure working mode for observing non-conductive samples. This technique was carried out before the samples were subjected to the accelerated wear particle test.

To identify the mineral phases of the sediments, each sample was reduced in size (<0.063 mm) using a laboratory ball mill. The mineralogical phases were determined by X-ray diffraction (XRD) using a Bruker D8-Advance diffractometer for powder analysis. An acceleration voltage of 40 Kv, 40 mA of current and an angular sweep (2-Theta) of 4 to 60º were used. The mineral phases of the samples were quantified by means of a Rietveld analysis using PANalytical Highscore Plus 4.6 software.

4. RESULTS

The evolution of the shoreline in the study area (Figure 4) shows a generalized loss of width over the entire length in the period 1977-1981, with an average value of -0.79 m/year. After the 1985 nourishment (40,000 t), an average increase of 2 m is observed with respect to the 1977 shoreline. However, this width is lost in the next period analysed, with 9.5 m of beach width lost. The nourishment of 2017 (8,000 t) increased the average width 6 m compared to 1977, achieving a beach width of about 20 m.

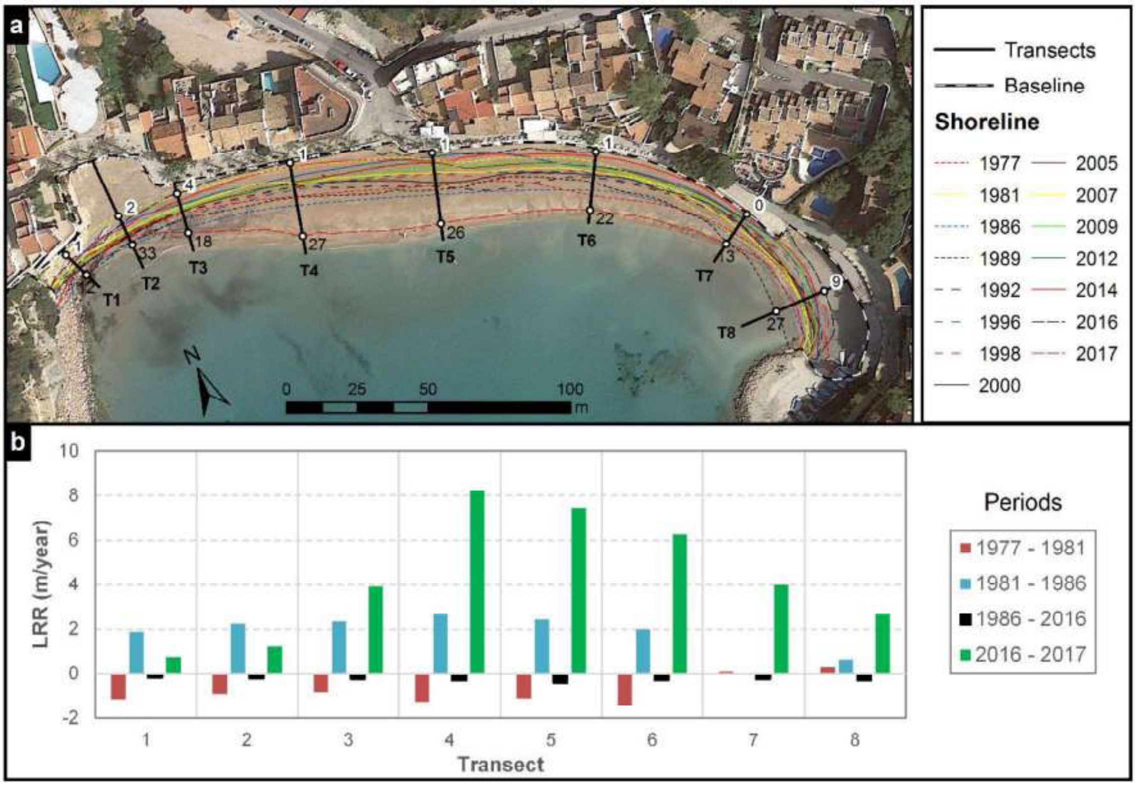

Figure 4. Evolution rates by transect and periods.

Given the difference in the volume of sand used in the two beach nourishment and that the final beach width is approximately the same, it was decided to study the cross-shore profile.

Thus, Figure 5 shows that the profile obtained after nourishment in 2017 is excessively vertical (m = 0.084), which indicates that as the material is distributed for the formation of the equilibrium profile, and 10 m of beach width will be lost.

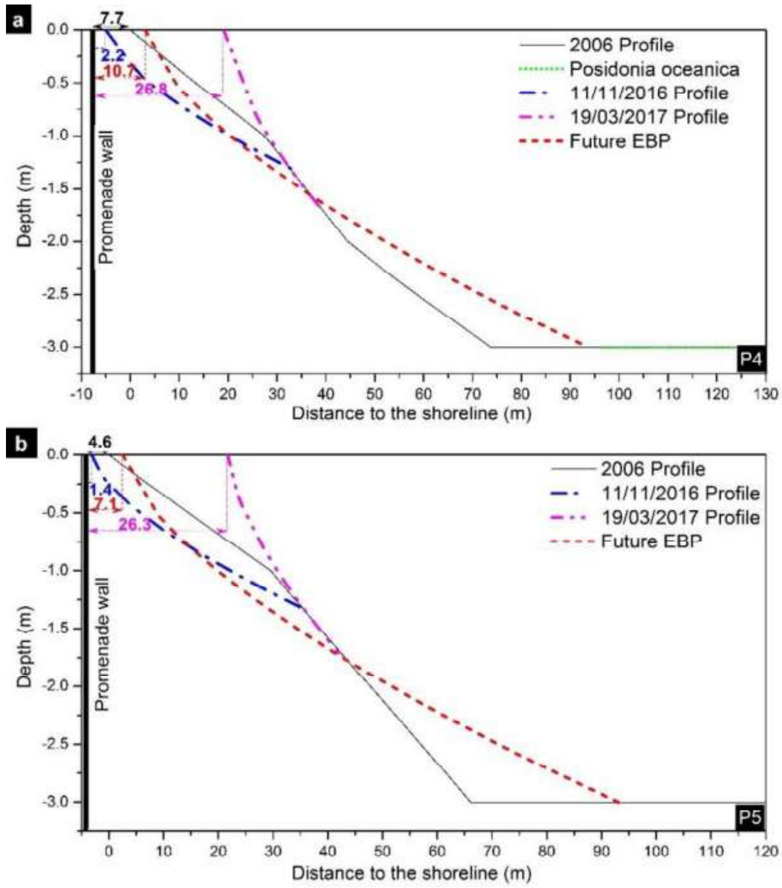

Figure 5. Cross-shore profile after 2017 nourishment and future profile.

However, this does not explain why water turbidity occurs. Therefore, the incident waves on the beach were studied to check if this turbidity was due to the action of the storms on the coast. As Table 2 shows, the waves are very similar in the different studied periods. However, it was observed that even with small wave heights, or periods of relative calm (See supplementary data 3), turbidity remains in the near-shore area (Figure 1 b,d). This led to an analysis of the type of sediment.

Table 2. Table 2. Incident waves in the area by periods of study.

Period	Incident waves	Frequency	$H_{s,12}$ (m)	T_p (s)
1977 -1981	S (171-191.25)	0.1325	2.50	10.0
	SSW (191.25-209)	0.1292	2.50	10.3

1981-1986	S (171-191.25)	0.1203	2.50	9.5
	SSW (191.25-209)	0.1192	2.30	10.1
1986-2016	S (171-191.25)	0.1089	2.30	10.8
	SSW (191.25-209)	0.1297	2.90	12.3
2016-2017	S (171-191.25)	0.1164	2.00	9.9
	SSW (191.25-209)	0.1180	2.30	10.9

Firstly, the initial granulometry of the material collected directly from the beach was carried out to determine the D_{50} and the content in fines (< 0.063 mm). D_{50} of the material prior to the last nourishment (pre-nourishment) was 0.313 mm and after the nourishment (post-nourishment) was 0.378 mm, while the fine content in both samples was practically zero (Figure 6a), less than 0.03% and 0.05%, respectively. Subsequently, the behaviour against the accelerated wear test was analysed and completely different results were observed (Figure 6b). The pre-nourishment material showed progressive wear, while the post-nourishment material suffered a loss of 14% in the first cycle, disappearing almost completely in the third cycle, with more than 50% of the material measuring less than 0.063 mm. The mineralogical composition of the samples was analysed to try to determine the reason for this very different behaviour between both sands. The diffractograms of Figure 6 show that the greatest difference between the two samples was the higher calcite content of the post-nourishment sand, which implies the possibility of greater dissolution of $CaCO_3$, a result that can be observed in Figure 6c.

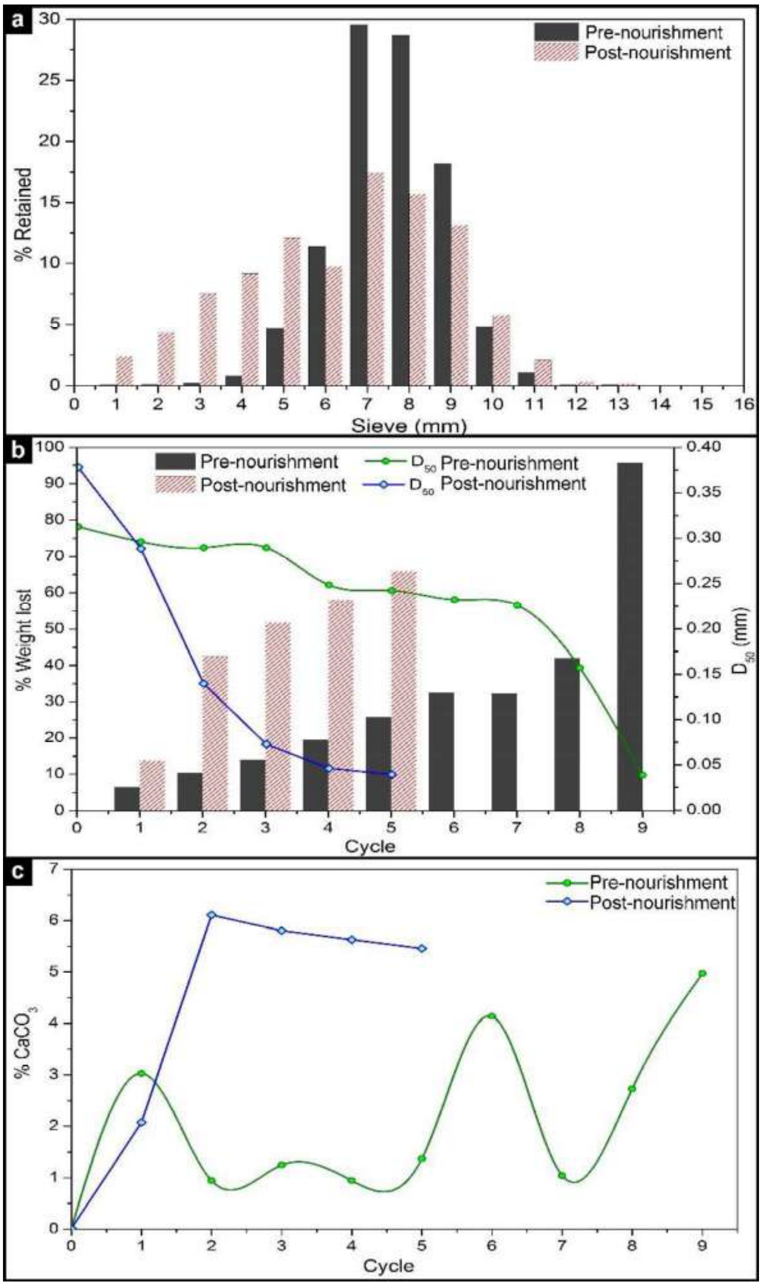

Figure 6. a) Granulometric fractions present in the initial samples. **b)** D_{50} and simple weight evolution during the accelerated wear test. **c)** Dissolved $CaCO_3$ evolution during the accelerated wear test.

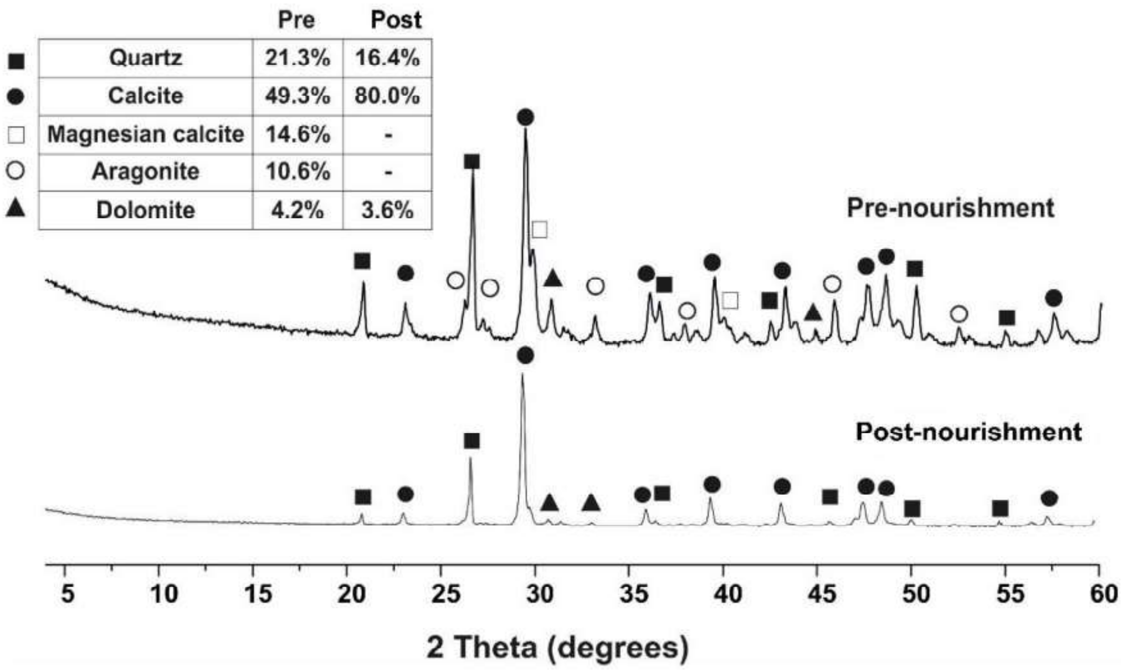

Figure 7. Sand diffractograms pre and post-nourishment. The table shows the quantitative analysis of the mineralogical phases obtained by Rietveld.

Although the dissolution of $CaCO_3$ could explain the greater wear and tear suffered by the post-nourishment sand compared to that previously existing on the beach, it does not explain the reason for the turbidity of the water. For this reason, the morphology of the particles was studied (Figure 8). Some particles were found to have a more rounded edge morphology, almost no angularity at the edges. However, some quartz particles with fracture faces, conchoidal fractures and even initial cracks of grain breakage appeared in the minority (Figure 8a). While in the post-nourishment sediment (Figure 8b) more angular particles are observed, where erosion has not had sufficient time to round off the particles. The majority of the grains show fractured faces. Also noteworthy are the Ca-Si clusters (Figure 8b and Figure 8), which influences the erosion of the particle, so a representative percentage of conglomerate particles of Ca-Si in the post-nourishment sediment were determined. SEM photographs were taken of the totality of the sample holder at 50x magnification and all the particles and conglomerate particles of Ca-Si were counted manually. The findings indicate that 9.6% of the sample were Ca-Si particles.

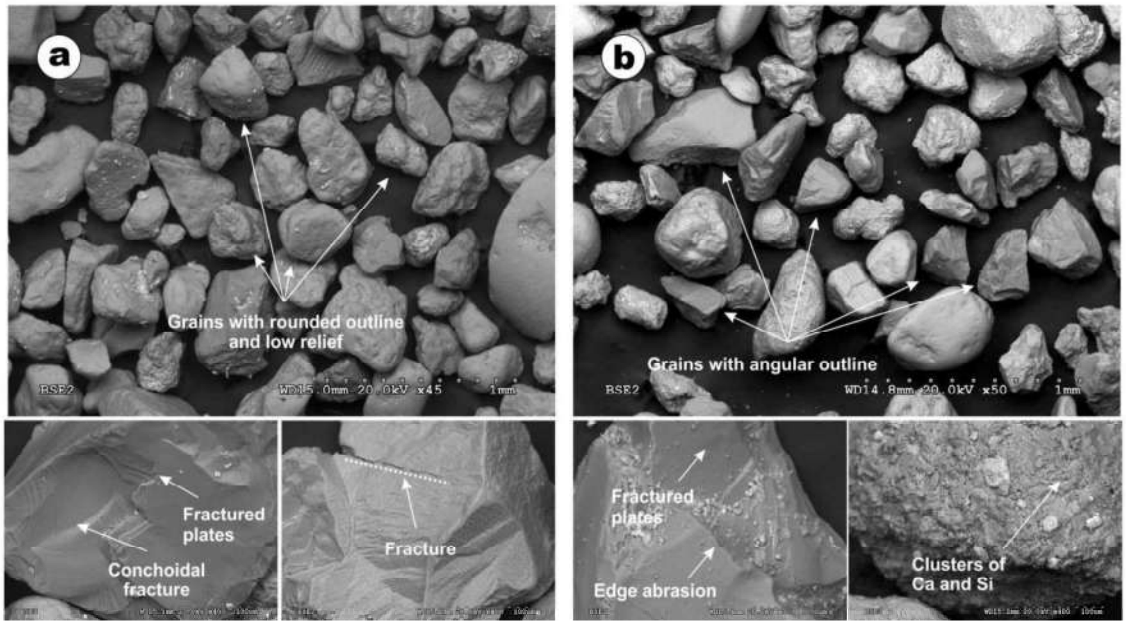

Figure 8. a) Pre-nourishment sediment where the morphology of round grains and minor fractures predominate. **b)** Post-nourishment sediment where grains with angular edges predominate and Ca-Si clusters also stand out.

Figure 9. Ca-Si clusters in post-nourishment sediment samples.

5. DISCUSSION

Traditional measurements of the shoreline, such as retaining walls, breakwater and docks are useless because they are responsible for the erosion, degradation and destruction of the shoreline. Beach nourishment is, on the other hand, a protection alternative that directly addresses the problem of receding shorelines, since the sand comes from external sources (Seymour et al., 1996). The experiments done in this work set out to prove that the adequacy of the routine sequence performed by a coastal engineer before a beach nourishment ensures the stability of the nourishment over time. The routine sequence is: i) finding sand with average size D_{50}, which must be bigger than the existing sand on the beach, and with no grains below size 0.063 mm, ii) studying the perpendicular equilibrium profile, in order to check its possible influence on the ecosystem of the area. These studies will affect the wideness and volume of the poured sand for the beach nourishment.

Since 1977 the beach has suffered a continuous erosive process that has lead in some zones to the complete vanishing of the berm, as seen in Figure 3. However, the erosive process has been different in the analysed periods. Between 1977 and 1981, the erosion rate was of -1.6 m/year. After the beach nourishment in year 1985 this rate decreased to -0.3 m/year. The swell has also been studied, and no meaningful change can be found (see Table 2); therefore, reason would indicate that a change in swell has not varied the erosion rate. There are no sand samples available from those years (before 1985), and consequently the mineralogical composition cannot be studied. The mineralogical composition of the sand has an important influence on the evolution of the shoreline, as shown by López et al. (2016a); López et al. (2016b). These works proved that the mineral forming the sand could erode.

The analysis of the pre-nourishment material (1985-2016) shows on the one hand a 20.77% of bigger D_{50}, a result that would justify a more vertical profile (Figure 5). Using the models developed by Aragonés et al. (2017) for the area of study, the equilibrium profiles have been obtained for the sediment post-nourishment. The comparison shows how the profile cuts the pre-existing one just before the *Posidonia oceanica* meadows, so the beach nourishment should not affect this marine phanerogama (Figure 5a). In addition, analysing Figure 6 and 6 indicates that the pre-nourishment sand is composed of: 7.5% more quartz (this mineral is the one with the highest hardness of the components found in the studied sands); 11.4 % aragonite; and the remainder is calcite. The Aragonite is the most soluble mineral so the variations in percentage that exist among the other minerals forming each sand type (quartz, aragonite, and calcite) would not be enough to justify differences in their behaviour with swell.

Beaches, as coastal ecosystems, are also areas of great environmental risk, due to the human activities both on the sea and on land. The human activities could affect directly or indirectly the species and communities in the ecosystem (Halpern et al., 2009). That is the reason why a nourishment might cause alarm, among other things, because of the initial width loss in the first years, or the possible environmental damage that the turbidity of the water might cause due to the new material used for the beach nourishment. In the case of the study presented in this paper, there has been an observable lack of tranquillity among beach users due to the large amount of material in suspension that has been generated under the influence of wave energy (Figure 1). The alarm has mainly been caused by the high ecologic and environmental value of the beach, due to the presence of *Posidonia oceanica* at 3 m depth (Figure 5). The formation of the profile after beach nourishment would make the beach width decrease by up to 10 m (average), which means a loss of 50% of the initial dry beach (Figure 5). This width variation is due to the formation of the new profile, because the ortophoto was taken only 3 days after the sand deposition. Given the wide ranging potential impact on the coastal marine environments, the beach managers should prioritize human activities and take action to minimize the impact of these human actions. Examples such as the flooding of the *Posidonia oceanica* during the beach nourishment must be avoided (Aragonés et al., 2015; Pagán et al., 2016). At this point, the questions that should be asked are two-fold: is it possible that the regression of the beach would be more important once the transversal profile has been stabilized? And, would the colloidal material disappear at that point?

Many works can be found where the essential aspects for the design of beach nourishment are described (Bruun, 1986; Bruun, 1988; Dean, 1988; Dean, 1996; Dean, 1998; Houston, 1991; Houston, 1995; Kana, 1989; Kana, 1993; Kana, 1996). However, a very important factor, such as the used sediment in beach nourishment has been less studied, although there are studies on regenerations indicating that, for example, the density of sediment influences the longevity of a beach nourishment more than the size of the sediment (Eitner, 1996; Roberts et al., 1998). The precedent through which, a priori, these beach nourishments were studied, does not refer to any doubt about the material to be used. The accelerated waste test (López et al., 2016a) makes us think about two different materials in the sand of the present-day beach. The result of the material post-nourishment shows that there are particles formed by a mineral cluster (Figure 8), and after only 2 cycles of the accelerated waste test 42.52% of the particles have a diameter less than 0.063 mm, and what is worse, the D_{50} has decreased by 62.96% with only a 6.11% loss of $CaCO_3$. If we compare these results with the material used in 1985, 10.4% of the particles had a diameter less than 0.063 mm, D_{50} decreased by 7.34%, and the dissolved $CaCO_3$ was 0.95% (Figure 6c,d). This result indicates that the behaviour of each sand type against swell will be different. If the swell is similar, and the value of D_{50} is bigger the mineralogy will not be the determinant factor for the behaviour of the sand.

The SEM analysis is also necessary to understand the different behaviour of the two types of sand (nourishments of 1985 and 2017). In fact, the SEM reveals that the pre-nourishment sand is quite homogeneous, with homogenous calcite, and a strong chemical bond within the whole particle, which makes these particles difficult to break with a blow (Figure 8 b). In addition to that, fractured plates can be found only in certain grains, but they are not common. This may mean that sand was sieved and crushed before use. However, in Figure 8b, corresponding to the sand used for the nourishment done in 2017, a conglomerate of silicon dioxide and other minerals, quartz and calcite, in a complex formation is visible. The chemical and crystallographic differences justify the existence of brittle union among different small particles forming the conglomerate. Under the energy of a swell, these types of particles are broken into small particles that form a colloid, and they become suspended in the water. These types of particles are also observed to be the main component of the sediment used for the most recent beach nourishment (9.6% of the sample). This difference in the morphology of the sand justifies the different behaviour against swell, and gives a satisfactory explanation of the laboratory accelerated tests (Figure 8) and the field data (Figure 1).

With the obtained and analysed results, it is possible to state that the durability of the sand formed by conglomerates (2017) will be smaller than that formed by homogeneous particles (1985), which is consistent with what was observed by other authors who have analysed the sediment particles (Fonseca et al. 2012; Pagán et al. 2018). The regression of the shoreline will be bigger with the sand used in 2017. On the other hand, it can be expected that the suspended material will disappear when the conglomerate disappears, and it will remain as long as calcite and silicate conglomerates are present in the sand. The amount of matter suspended forming a colloid will be bigger when the energy of the swell is bigger.

The results of this work highlight the importance for coastal engineers to have studied mineralogy and morphology of the sediment before taking any decision related to beach nourishment. More detailed studies are needed on the evolution of sediment particle wear that is related to the size, mineralogy and morphology of the particles. This is key for ensuring the selection of the most suitable material for the beach being nourished.

6. CONCLUSION

This work analyses the different behaviour of two sands used in the nourishment of the same beach. This different behaviour is mainly based on a great turbidity generated by the second sand (post-nourishment). From the analyses carried out it can be concluded that:

- Both the first nourishment sand (1985; pre-nourishment) and the second sand (2017; post-nourishment) do not have particles less that 0.063 mm in their granulometry, with values lower than 0.03% and 0.05%, respectively.
- During storms, the pre-nourishment sand did not produce turbidity episodes such as those generated by the post-nourishment sand even on calm days.
- The behaviour of both sands against the accelerated sediment wear test is completely different, the pre-nourishment material lasts twice as long as the post-nourishment material, which could explain the turbidity generated since the post-nourishment material loses 40% of its mass after 2 test cycles.
- The mineralogical composition and morphology of the sediment particles can explain the observed phenomena, since the post-nourishment sample has a lower proportion of quartz in its composition, as well as a very important proportion of calcium and silica conglomerated particles (9.6%), with a very weak chemical bond between these components that facilitates their fast disintegration, creating particles in suspension and, therefore, explains the great turbidity caused by this sample.

Thus, this study not only examines the causes of great turbidity in a recently nourished beach, but the study also provides an analysis method that the coastal engineer should apply before selecting the sandy material in any beach nourishment.

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