land

MDPI

Article

Evolution of Sediment Parameters after a Beach Nourishment

Juan J. Santos-Vendoiro [1], Juan J. Muñoz-Perez [1,*], Patricia Lopez-García [1], Jose Manuel Jodar [1], Javier Mera [1], Antonio Contreras [2], Francisco Contreras [2] and Bismarck Jigena [1]

[1] Facultad de Ciencias del Mar y Ambientales, Universidad de Cadiz, 11510 Puerto Real, Cadiz, Spain; juanjo.santosvendoiro@alum.uca.es (J.J.S.-V.); patricia.lopezgarcia@uca.es (P.L.-G.); josemanuel.jodar@uca.es (J.M.J.); javier.merabaston@alum.uca.es (J.M.); bismarck.jigena@gm.uca.es (B.J.)
[2] Escuela Politecnica, Universidad de Cadiz, 11202 Algeciras, Spain; antonio.contreras@uca.es (A.C.); francisco.contreras@uca.es (F.C.)
* Correspondence: juanjose.munoz@uca.es

Abstract: A methodology for monitoring the behaviour and size of sand after a beach nourishment process is presented herein. Four sampling campaigns (before and just after the nourishment, after six months and one year later) were performed on four beaches of the Gulf of Cadiz (Spain). D_{50} and sorting size parameters were analysed. Among the results, it should be noted that differences of up to 20% between native and nourished sand values disappear only one year after the nourishment.

Keywords: beach nourishment; coastal zone management; beach erosion

Citation: Santos-Vendoiro, J.J.; Muñoz-Perez, J.J.; Lopez-García, P.; Jodar, J.M.; Mera, J.; Contreras, A.; Contreras, F.; Jigena, B. Evolution of Sediment Parameters after a Beach Nourishment. *Land* **2021**, *10*, 914. https://doi.org/10.3390/land10090914

Academic Editors: Pietro Aucelli, Angela Rizzo, Rodolfo Silva Casarín and Giorgio Anfuso

Received: 8 July 2021
Accepted: 25 August 2021
Published: 29 August 2021

1. Introduction

Beach nourishment is a common process conducted when the coastline is being subjected to erosion because of natural or anthropogenic causes, as it replaces sediments within a littoral system and allows natural forces to continue their operation [1,2]. This process involves the placement of large volumes of sand along the beach profile [3]. Nourishments are also often associated with exposed coasts with intensive levels of development or great recreational value [4]. Due to their response to different forms of energy, such as wind, storms, waves, or modifications of the sea level, beaches are undergo a flux of erosion-accretion [5]. This is not different in the Gulf of Cadiz zone, where this study was centred. For example, during the 2000s, more than 47 restoration operations were carried out on several beaches in the area [6,7]. The importance of the nourishments is rising, mostly because of the growth of the population living in coastal areas, which is increasing the budget destined to these proceedings [8]. For example, in the U.S., 53% of the population live in coastal states (having increased by 33 million between 1980–2003). In fact, houses built in non-nourishing zones tend to be significantly smaller than those located in nourishing zones [9]. In areas where there is potential for tourist or urban development and erosion problems are detected, scientifically based engineering solutions are expected to control or mitigate these phenomena [10]. Additionally, a great number of residents of coastal areas are aware of coastal erosion/beach loss, which is important to raise a better understanding of coastal risks and hazards [11]. On the contrary, some studies have even suggested that beach nourishment and other hazard mitigation measures could encourage coastal development, thus increasing risk [12].

Although the effects of erosion in populated areas present a major problem, it is worth noting that these nourishments are not only performed on urban beaches, but also in places where there is a lower economic impact but a significant ecological value (for more information about these processes, see nourishments of that kind in [13]). Additionally, there have been reports suggesting that not every nourishment has a positive environmental effect if performed incorrectly, or in the wrong place. For instance, the formation of rip currents attributable to sandbars caused by the modification of the original state of the beach have been described [14]. The addition of new sediment to beaches requires a sound understanding of form–process continuums in order to achieve the desired response of morphodynamic systems [15]. Moreover, as nourished sand does not last forever, the periodicity of maintenance work must be established or at least foreseen. That is why the Shore Protection Manual [16] featured in 1984 the James' renourishment factor (R_J) [17] is trying to answer the basic question of how often renourishment is required when the borrow source is different from the native beach sand. Unfortunately, due to the lack of accuracy in the prediction, this abacus was removed from the new version, the Coastal Engineering Manual [18]. Thus, afterwards, new attempts to address the problem have been presented by other researchers, e.g., [19,20]. Moreover, some statistical studies have been performed where renourishment rates for U.S. projects are typically in the range of 5% per year (or less) of the initial nourishment volume [21].

Due to these maintenance cost and safety problems, it is important to investigate the evolution over time of the borrow sand dumped on the beach. A crucial question appears: is it possible that the granulometric characteristics of the borrow sand evolve towards the original ones of the native sand and, if so, when?

Thus, the objective of this study was to analyse the behaviour of the sand after beach nourishment. A methodology to study the evolution of the two most representative values, D_{50} (mean diameter of the grain) and sorting (standard deviation with respect to the mean grain), generalisable to any other site, was applied.

2. Study Area

Samples were taken from four beaches located in the Gulf of Cadiz: Santa María del Mar (SMM), Victoria (VB), Camposoto (CB), and La Barrosa (BB) (Figure 1). SMM has the particularity that it is embedded between two lateral groynes that confine it.

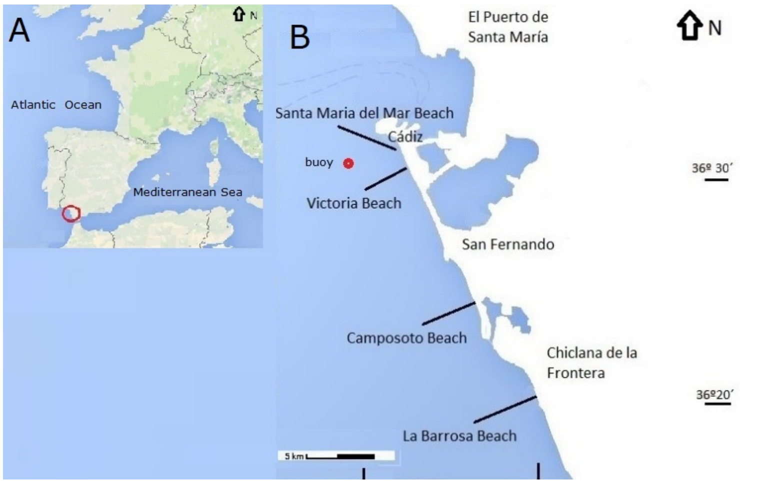

Figure 1. Location of the study area (**A**), the four beaches analysed in the Gulf of Cadiz and the wave buoy (**B**).

An aerial view of these four beaches and their monitored profiles, as well as an indicative wave rose diagram, is shown in Figure 2.

SMM (Figure 2A) is a pocket beach enclosed between two groynes [22]: the northern one has dimensions of about 240 linear metres, while the southern is about 212 linear metres long. The length of the beach measured between the starting points of the two groynes is 600 m and about 400 m between the heads. It is influenced by rip currents and undertows, corresponding to the characteristic outflow pulses of the incoming water mass. This phenomenon causes a loss of sand that is impossible to recover, due to the bathymetric conditions consisting of the existence of a small rocky step [23].

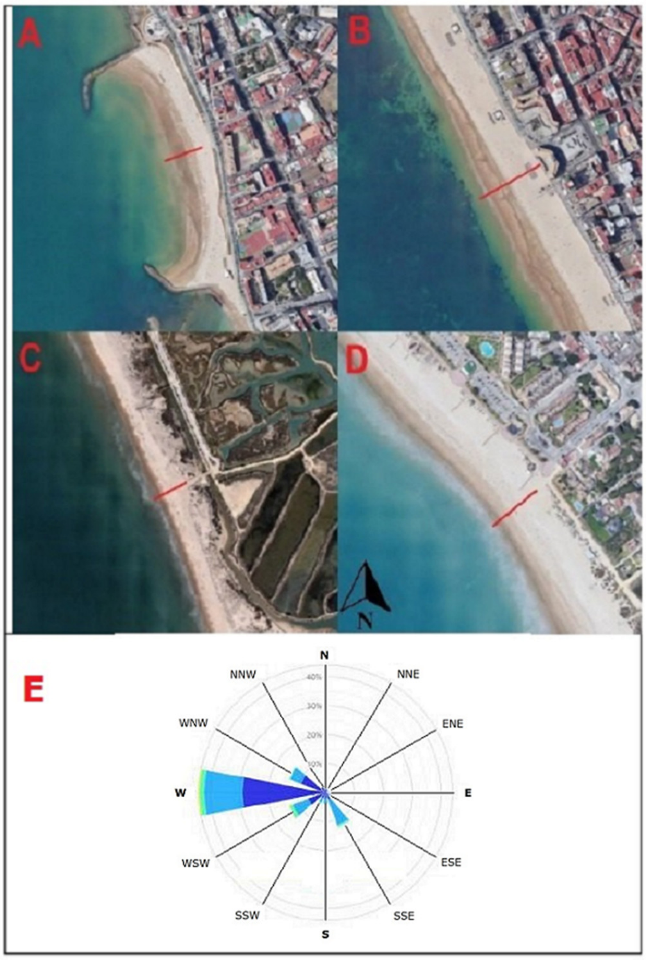

Figure 2. Location of the profiles monitored in the four different beaches: SMM (**A**), Victoria (**B**), Camposoto (**C**), and Barrosa (**D**). A wind rose diagram (**E**) is also presented. The orientation of the beaches is approximately NNW in all of them.

Victoria Beach (Figure 2B) is a three-km-long beach located, like SMM, in the city of Cadiz. Some submerged rocky shoals in front of its shoreline furnish it with a certain amount of heterogeneity [24].

Camposoto Beach (Figure 2C) is located in the south, also facing the Atlantic Ocean, in a littoral spit which consists of quartz-rich sand beaches, dune ridges (locally showing washover fans), and salt marshes [25].

Barrosa Beach (Figure 2D) is the southernmost beach in this study, with a general northwest/southeast orientation. Its total length is 3 km and it has both a promenade with a high urban development (northward) and a dune ridge with lower human occupation (southward) [26]. Nourishment was performed in the urbanised northern sector.

Victoria and Camposoto are part of the same physiographic unit. They are also large beaches that naturally recover most of the sediment. Therefore, annual nourishments for tourist purposes are not necessary.

On the other hand, Santa María and Barrosa are urban beaches with larger sand grain sizes and, subsequently, a shorter intertidal zone. Anthropic actions like scrapping accelerate the natural process of recovery in those beaches.

Climate and Morphologic Characteristics

The climate in the study area is Mediterranean, with a regime of sea surface temperatures of a semi-warm subtropical type (mean value of 16.6 °C) [27]. Rains are within a

Humid Mediterranean regime, with October/November and March/April being the most intense months, but not surpassing 600 mm of water annually [28].

Wave regimes in the area are highly seasonally dependent, with a mean significant height (Hs) of 0.84 m and a mean period (Tz) of 7 s [29]. Sea waves are responsible for 28.5% of the wave energy while swell waves comprise remaining 71.5% [30,31]. For a more detailed description of the wave data, www.puertos.es (15 August 2021) can be consulted. The position of the local buoy (6.33° W, 36.50° N) is located in Figure 1.

Wave runup is important to coastal managers, nearshore oceanographers, and coastal engineers because it delivers much of the energy responsible for beach erosion [32,33].

The tidal range has a mean amplitude of 2.2 m (meso-tidal) [30,31], with the highest amplitude being of about 4 m. The effect of wind and atmospheric pressure on sea level variations is not negligible on this stretch of coast [34]. The sand from the four beaches studied here consists of fine-medium sediment. The average D_{50} is about 0.25 mm, consisting of 90–95% quartz and 5–10% bioclasts [35].

For a proper comprehension, visual data of Hs, peak period (Tp), and wave direction are shown in Figure 3.

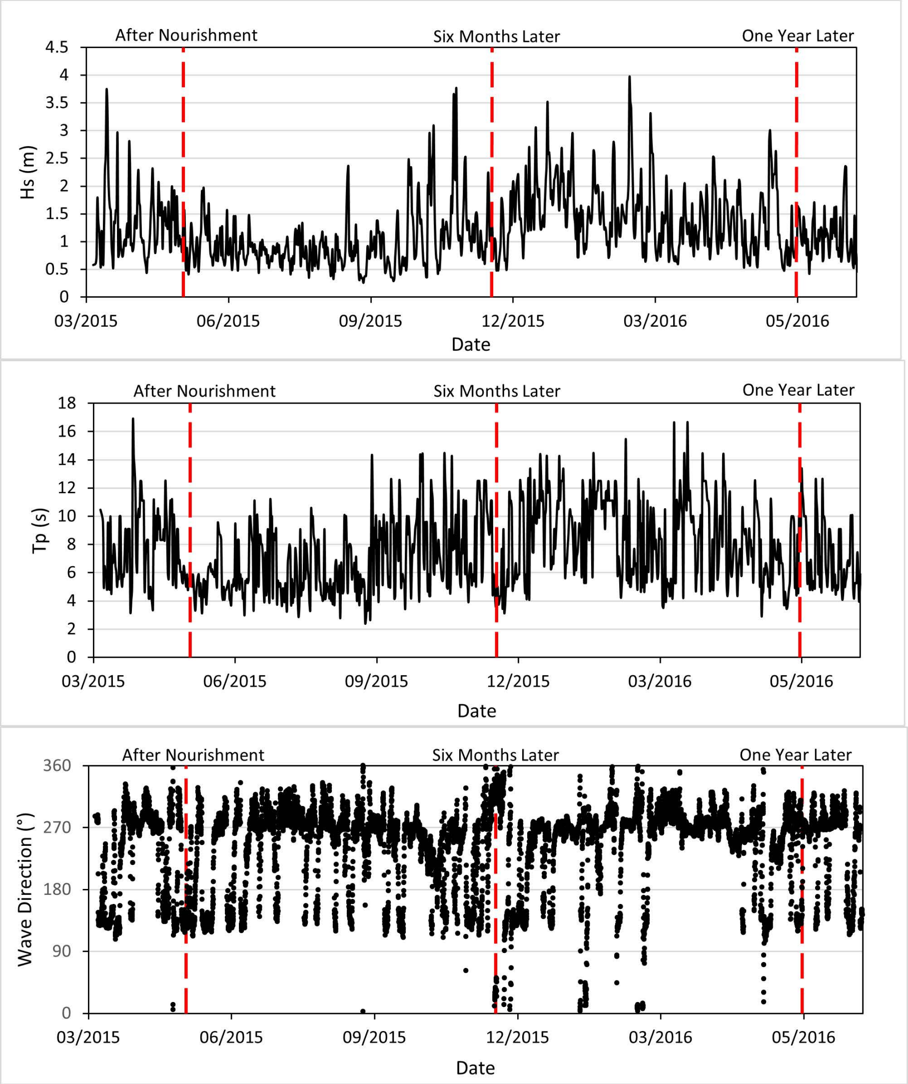

Figure 3. Wave data during the monitoring time between March 2015 and June 2016: Hs (in meters, (**top**)), Tp (in seconds, (**centre**)), and wave direction (being 0° and 360° in the north, 90° in the east, 180° in the south, and 270° in the west, (**bottom**)). The survey dates used in the analysis are marked vertically. Source: own elaboration with data from the Spanish port administration www.puertos.es (15 August 2021).

3. Materials and Methods

This analysis was carried out with samples taken from the SMM, Victoria, Camposoto, and Barrosa beaches during the 2015–2016 period. Dredging and beach nourishment works began and were finished in May–June 2015. A sampling of sand before nourishment, at the end of April, was performed to determine the natural configuration of every beach and, therefore, its native sand parameters. Afterward, three additional samplings of sand were performed semi-annually after the nourishment to monitor their evolution. D_{50} was measured in mm, while sorting was calculated in phi units, a logarithmic scale, following the research of Damveld et al. [36]. The dates of these four campaigns are shown in Table 1.

Table 1. Dates of the monitoring campaigns when samples were taken.

State	Date
Native	April 2015
Just after nourishment	May–June 2015
six months later	November–December 2015
one year later	May–June 2016

This section is separated in two parts: first, a description of how these samples were taken from the beaches, and after that the procedure followed at the laboratory.

3.1. Beach Sand Sampling

Samples were taken from a profile located at the centre of each beach. These profiles, as shown in Figure 2, are perpendicular to the coastline.

Sampling was carried out for four different levels in each transverse profile (Figure 4). The elevations of these levels were: −1 m (submerged), 0 m (the Lowest Low Water Level, LLWL or datum), 2 m (intertidal zone), and 4 m (over Highest High Water Level, HHWL or dry beach).

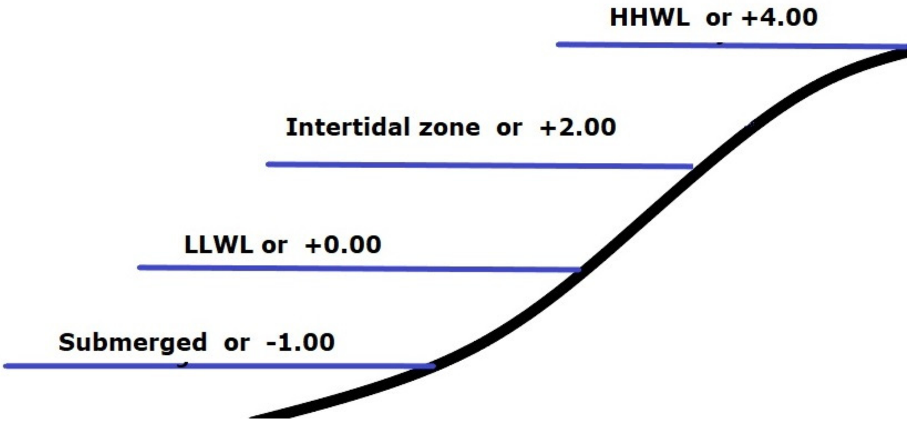

Figure 4. Different levels surveyed in each beach profile.

Once these profiles were defined, the next step involved taking the samples following the procedure of [37], established according to the recommendations proposed in [38].

Subsequently, the process of extracting the sand from the different points (carried out manually) began. This whole procedure is shown in Figure 5, offering a visual description of the different steps of the sampling at the different levels (Figure 5A).

The first step involved the elimination of a first layer, the most superficial one where bioclasts (pieces of shells) were found (Figure 5B). Then, a 20 × 20-centimetre square was made (Figure 5C). Excavation began with a small shovel to a depth of 20 centimetres to collect the sand taken in a small mound (Figure 5D). Next, one part of that (about 300 g) collected sand was deposited in small plastic bags (Figure 5E). Finally, the identifying data (place and date) of each of the points sampled was labelled on each of the plastic bags using a permanent ink marker (Figure 5F)

A Van Veen grab can typically be used to collect submerged samples by throwing it into the sea at a depth of −1 m. Sand accumulates inside it, and the rope is later hoisted to lift the bucket. This procedure can also be done by hand if the conditions are favourable, i.e., at a shallow depth (~1 m) and under slow-current conditions. In our case, samples were collected directly by hand, because fines tend to escape from the Van Veen grab.

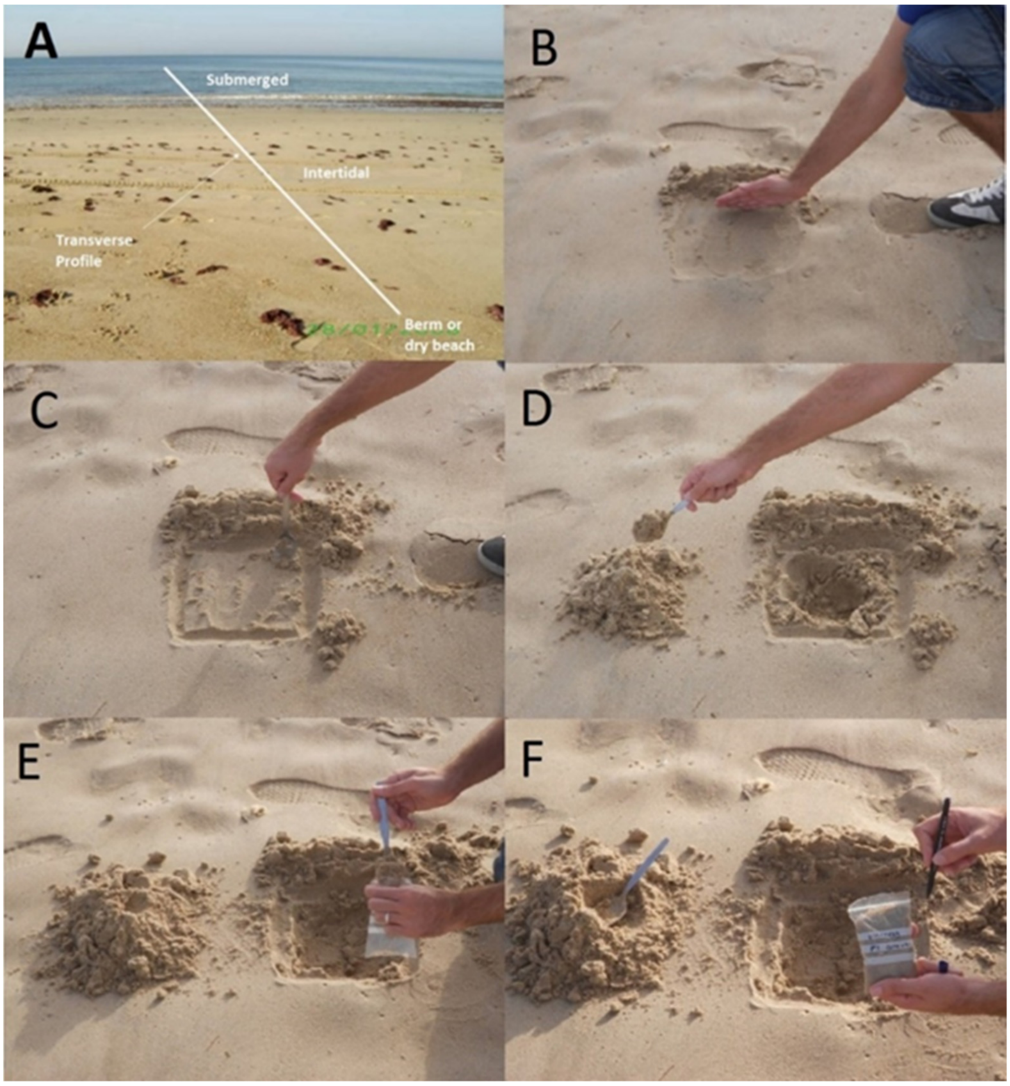

Figure 5. Methodology proposed by [37] for beach sand sampling. (**A**): profile with different levels; (**B**): elimination of the first layer because of bioclasts; (**C**): drawing of the 20 cm square for extraction; (**D**): excavation and production of a pile adjacent to the sampling pit; (**E**): mixing and sampling; (**F**): labelling.

3.2. *Laboratory Analysis*

Grain size is one of the most important sediment particle properties. Sieve analysis is known to be an essential technique for classifying materials and sedimentary environments. It is, therefore, a widely used method in fields such as marine geology or coastal engineering [39].

Grain size is related to the tendency of the sediments to remain in suspension [40]. That is, the greater the D_{50}, the more difficult its removal is. In this case, the laboratory procedures for the granulometry and statistical studies followed the methodologies of [37,39].

According to the usual requirements of the Spanish Coastal Department, the sieves used in the laboratory had the following mesh openings:

- 2 mm
- 1 mm
- 500 µm
- 355 µm
- 250 µm
- 125 µm
- 75 µm

The process was the identical for every sample:

The sample (about 100 gr) was placed on top of the sieve column (i.e., the 2 mm mesh) and, for the filtration process, we placed the sieves into a machine which shook them for 10 min. The fractions for each mash were determined by weighting with a digital scale which was accurate to within 0.1 gr. Two different 100 g samples from each bag were tested and the rest reserved. The differences found were never greater than 0.1 gr (0.1%).

Subsequently, the results were analysed with specific software (Gradistat, a Microsoft Excel add-on [41], was used here).

4. Results and Discussion

4.1. D_{50}

The D_{50} data results were compiled for each of the beaches (see Table 2). To facilitate the observation of temporal patterns, these data are also plotted in Figure 6. Moreover, total variations in D_{50} (between the sand one year later and the native sand) were also compiled and a percentage difference (Dif $_{\%}$) was calculated according to Equation (1) and shown in Table 3 to facilitate the understanding of the sediment's size evolution.

$$Dif\ \% = \frac{D_{50Native} - D_{50Final}}{D_{50Native}} * 100 \tag{1}$$

Table 2. Values of D_{50} at SMM, VB, CB, and BB for each monitoring campaign.

		D_{50} (mm) in Each Zone			
Beach	**Time**	**Submerged**	**LLWL**	**Intertidal**	**HHWL**
Santa Maria (SMM)	Native (N)	0.2	0.18	0.18	0.23
	After nourishment (AN)	0.21	0.21	0.25	0.27
	six months later (6M)	0.27	0.28	0.29	0.23
	one year later	0.2	0.2	0.2	0.23
Victoria (VB)	Native	0.16	0.18	0.28	0.26
	After nourishment	0.25	0.22	0.24	0.24
	six months later	0.3	0.28	0.29	0.21
	one year later	0.21	0.2	0.28	0.26
Camposoto (CB)	Native	0.18	0.22	0.24	0.23
	After nourishment	0.33	0.28	0.28	0.24
	six months later	0.34	0.32	0.33	0.22
	one year later	0.21	0.22	0.24	0.23
Barrosa (BB)	Native	0.23	0.26	0.38	0.21
	After nourishment	0.27	0.25	0.33	0.24
	six months later	0.32	0.31	0.33	0.21
	one year later	0.22	0.26	0.34	0.21

Evolution of D_{50} values during the different stages of the study:

In general, sands of medium-fine size with a characteristic golden colour and with little variability along the entire beach were observed [42]. However, Figure 6 shows D_{50} values equal to or greater than native sand after the nourishment of the beach. Values between 0.25 and 0.30 mm were maintained in all the analysis, with this being of vital importance for the stability of the beach. This larger size resulted from the larger grain size of the sand used for nourishment relative to the native sand (see the D_{50} values reached just after nourishment in Table 2). For instance, we can see how the grain size of the native sand was less than that of the borrowed sand at SMM. The largest D_{50} values within the nourished sand were found in the upper area of the beach, given that sand was dumped almost entirely in the upper area of the beach due to the pumping system, to reach a settling of the sand [43] as shown in Figure 7.

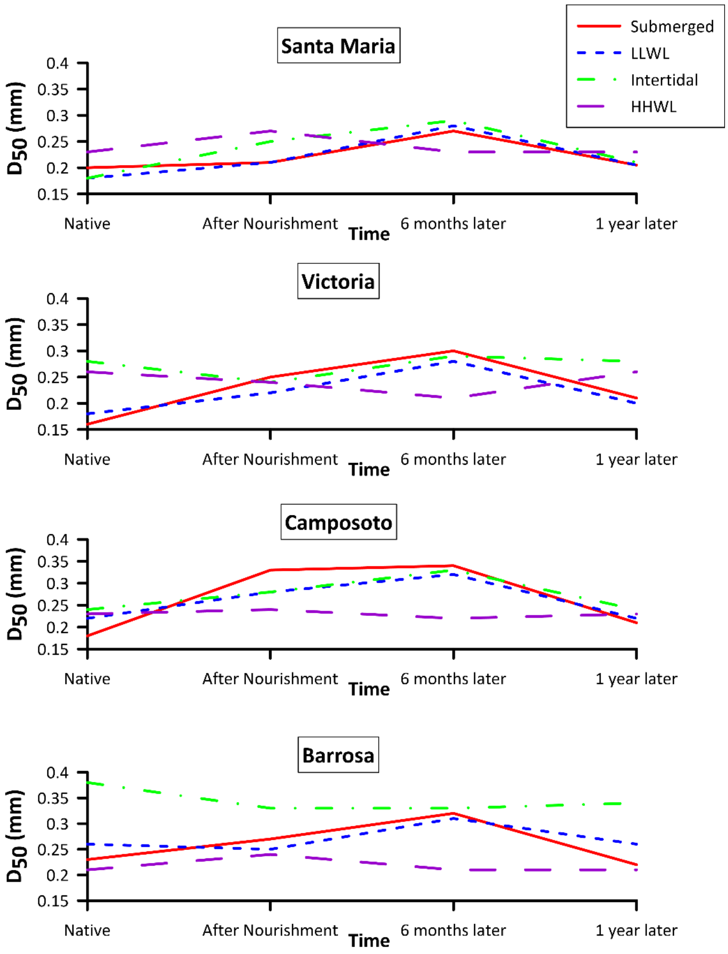

Figure 6. Results of D_{50} (in mm) obtained at the four beaches (Santa Maria del Mar, Victoria, Camposoto, and Barrosa) during one year of monitoring.

Table 3. Total variation of D_{50} (between native sand and nourished sand after one year) at SMM, VB, CB, and BB at the different levels of the profile (Submerged, LLWL, Intertidal, and HHWL).

		Total Variation in mm and Dif% of D_{50} in Each Zone			
	Beach	**Submerged**	**LLWL**	**Intertidal**	**HHWL**
Variation (in mm and in %)	Santa María	0.00 mm 0.00%	−0.02 mm −10.10%	−0.02 mm −10.10%	0.00 mm 0.00%
	Victoria	−0.05 mm −31.30%	−0.02 mm −10.10%	0.00 mm 0.00%	0.00 mm 0.00%
	Camposoto	−0.03 mm −16.70%	0.00 mm 0.00%)	0.00 mm 0.00%	0.00 mm 0.00%
	Barrosa	0.01 mm 4.30%	0.00 mm 0.00%	0.04 mm 10.50%	0.00 mm 0.00%

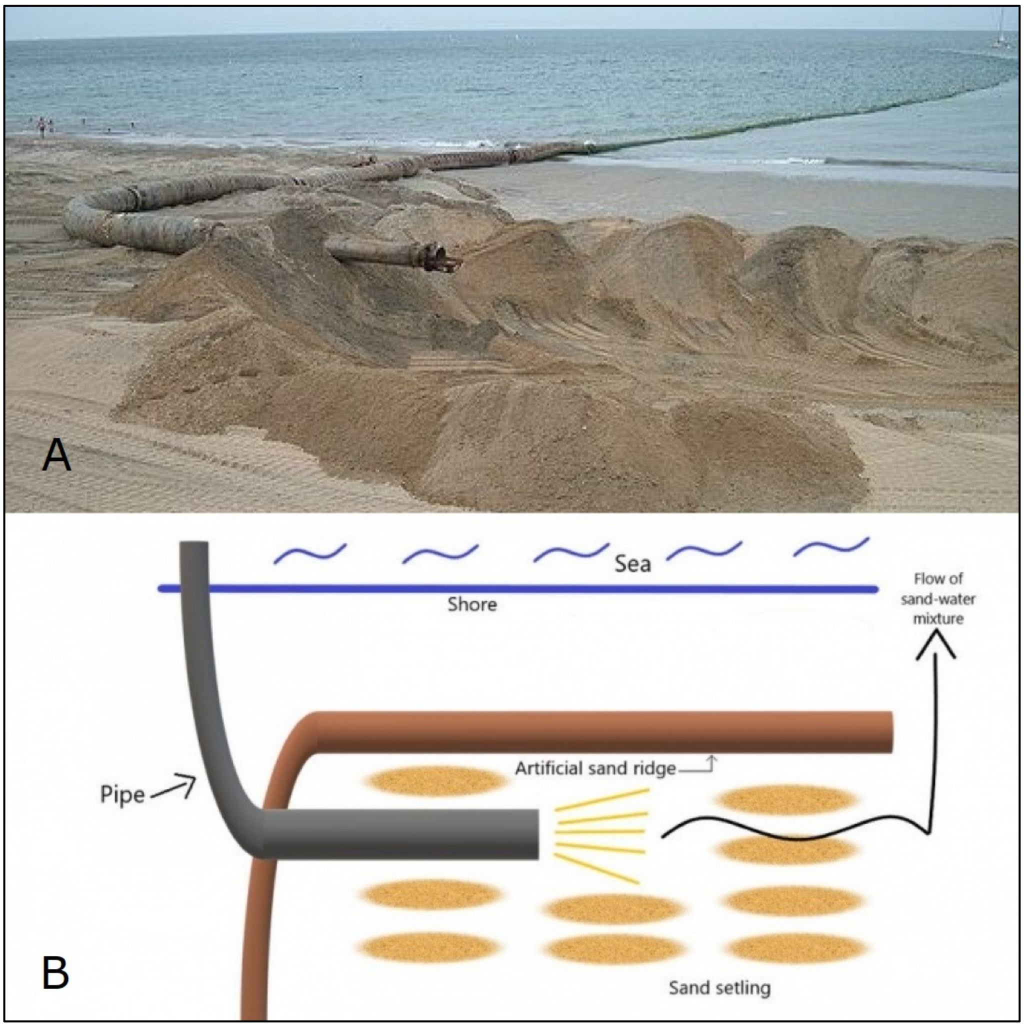

Figure 7. Sand pumping system in a photo (**A**) and schematised diagram (**B**). The pipe is brought to the beach and placed within an artificial ridge. This pipe releases a mixture of sand and water (approximately in a 1/5 proportion) that, thanks to the ridge, settles most of the sediment before reaching the shore.

To understand the behaviour over time of the data shown in Figure 6, it is worth noting that the erosion season (sea waves) ends by May while the sand accretion season (swell waves) lasts until October (see Hs in Figure 3). Summer conditions or a warm climatic season started just after nourishment helping to maintain this structure of the profile. Thus, the migration of fines from the submerged to the emerged zone explains why the D_{50} values decreased slightly during the months immediately after nourishment on the emerged beach but increased on the submerged beach (Figure 6). This is consistent with the variable morphological impacts (depending on the forcing factors, such as storm surge intensity, magnitude, and duration) observed by other authors such as Monteruil et al. [44]. Reeve and Spevack [45] also stated that storm events can lead to large but often transient deformations of the beach, with the effects being smoothed over a period of months.

In the transit between both moments, i.e., six months after the nourishment, great differences (up to 0.07 mm) could be observed between the different points (levels) of the profile: the D_{50} decreased in HHWL (e.g., from 0.27 to 0.23 in SMM) while D_{50} increased in the rest of the profile (e.g., D_{50} increased by 20% in the submerged zone in VB, Table 3). This change is produced by the summer waves (swell) that the beach receives during this period, transporting fine material from the submerged area and low tide to the upper part of the beach [22]. Obviously, the process is reversed during the stormy season [46].

In summary, nourishment (anthropic process) ended in May, at the moment when swell waves (a natural process) started transporting fines from submerged zones to the dry beach, as shown in Figure 8.

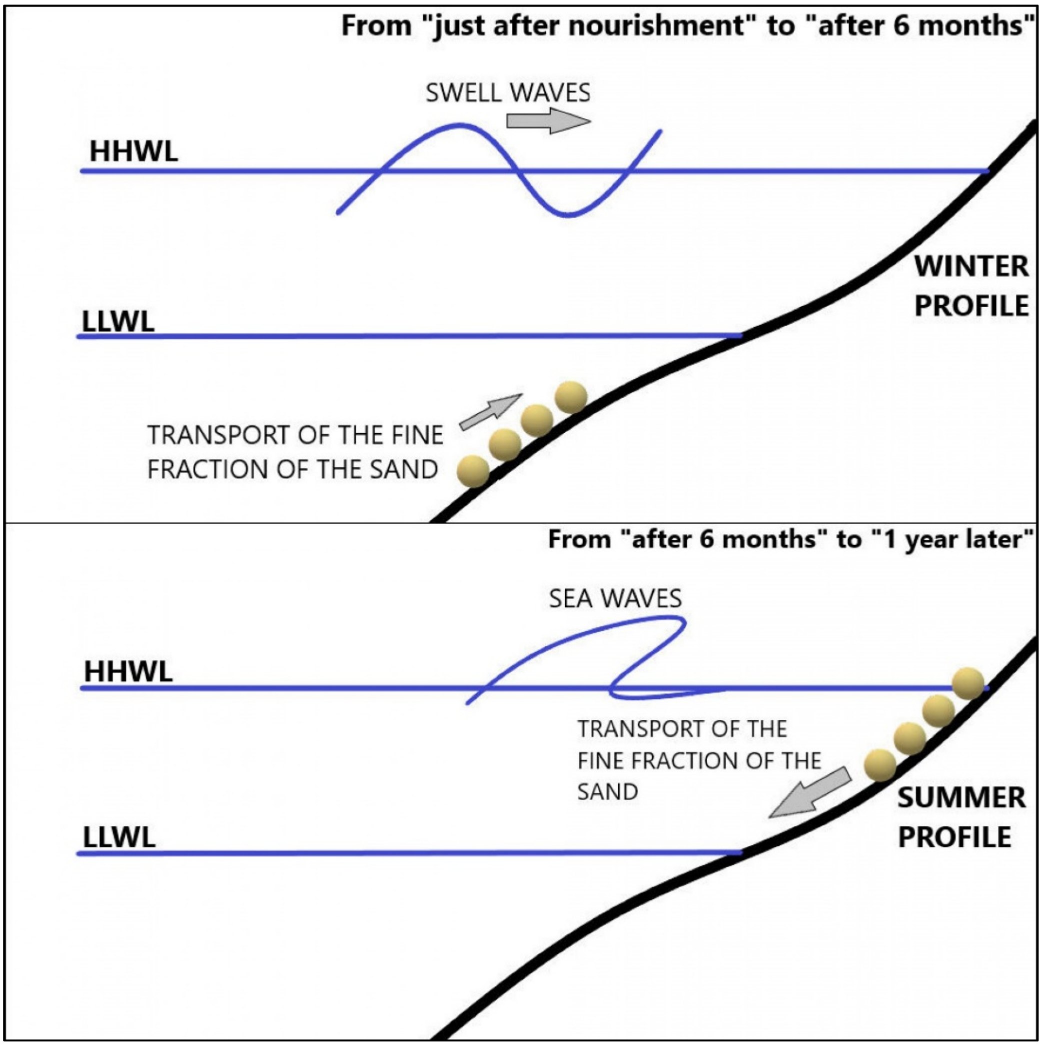

Figure 8. Sketch showing the upwards movement of the fine fraction of the sand by swell waves during the summer season (**top**) and downwards due to sea waves during the winter season (**bottom**).

After one year, the new D_{50} values matched those of the native sand D_{50} in HWWL on all the beaches (Table 3); variations in D_{50} (between native and nourished sand) ranged from 0% to 10% at most in the rest of the points on the profile. Thus, sand size distribution was practically the same as before the nourishment except for the case of the submerged zones of VB and CB where D_{50} was still larger than before (0.05 and 0.03 mm, respectively). These beaches only differ in that their slope is milder than that of SMM and BB. Thus, a clear explanation for this anomaly has not been found and, therefore, further investigations are needed. However, a worthy conclusion is that the old fashioned renourishment factor R_J becomes 1 just one year after the nourishment work and, thus, the erosion rate becomes the same that previously.

The success of the beach nourishment has been verified through the homogeneity of D_{50} values, which were very similar to the native values, achieved just one year after the nourishment works. However, the irreversible loss of sand is also still the same because the hydrodynamics have not changed, with estimates of erosion in some areas of the Gulf of Cadiz of more than 1 m/year [47].

4.2. Sorting

In the same way as was carried out for the D_{50} values, the sorting results were compiled for each of the beaches (see Table 4). To facilitate the observation of temporal patterns, the evolution over time of sorting values is shown in Figure 9. Moreover, since the sorting values are expressed in phi units (not as easy to interpret as mm), the sorting values were interpreted by using the indications given in Table 5 adapted from Roman-Sierra et al. [37]. We must remember that the mathematical expression of the phi scale (φ) is given in Equation (2) by:

$$D\,(\varphi) = -\log 2\ D(\mathrm{mm}) \tag{2}$$

where D is the grain diameter in phi units and d is the grain diameter in millimetres.

Table 4. Sorting values for every beach and surveying campaign.

		Sorting (φ Units) in Each Zone			
Beach	**Time**	**Submerged**	**LLWL**	**Intertidal**	**HHWL**
Santa María	Native	0.68	0.6	0.73	0.57
	After nourishment	0.47	0.46	0.98	1.2
	six months later	1.62	1.15	1	0.64
	one year later	0.72	1.09	0.63	0.7
Victoria	Native	0.61	0.5	0.63	0.58
	After nourishment	0.66	0.51	0.58	0.52
	six months later	1.26	1.06	0.62	0.47
	one year later	0.61	0.59	0.74	0.55
Camposoto	Native	0.66	0.82	1.03	0.57
	After nourishment	0.81	0.45	0.58	0.61
	six months later	1.31	0.98	0.64	0.56
	one year later	0.72	0.93	0.84	0.67
Barrosa	Native	0.88	0.55	0.62	0.59
	After nourishment	1.08	0.46	0.61	0.55
	six months later	1.17	1.01	0.65	0.5
	one year later	0.73	0.64	0.67	0.57

Table 5. Classification of sorting values, adapted from Roman-Sierra et al. [37].

Phi Range	Standard Deviation (Sorting)
<0.35	Very well-sorted
0.35–0.50	Well-sorted
0.50–0.71	Moderately well-sorted
0.71–1.00	Moderately sorted
1.00–2.00	Poorly sorted
2.00–4.00	Very poorly sorted
>4.00	Extremely poorly sorted

Native sorting values ranged from 0.50 to 1.03 for the four beaches, therefore classifying these as having moderately well-sorted sands with some scarce locations of moderately sorted material (Table 5). Some of the beaches, such as SMM and VB, seemed to have almost negligible variations in their grain sizes of less than 0.2 ø.

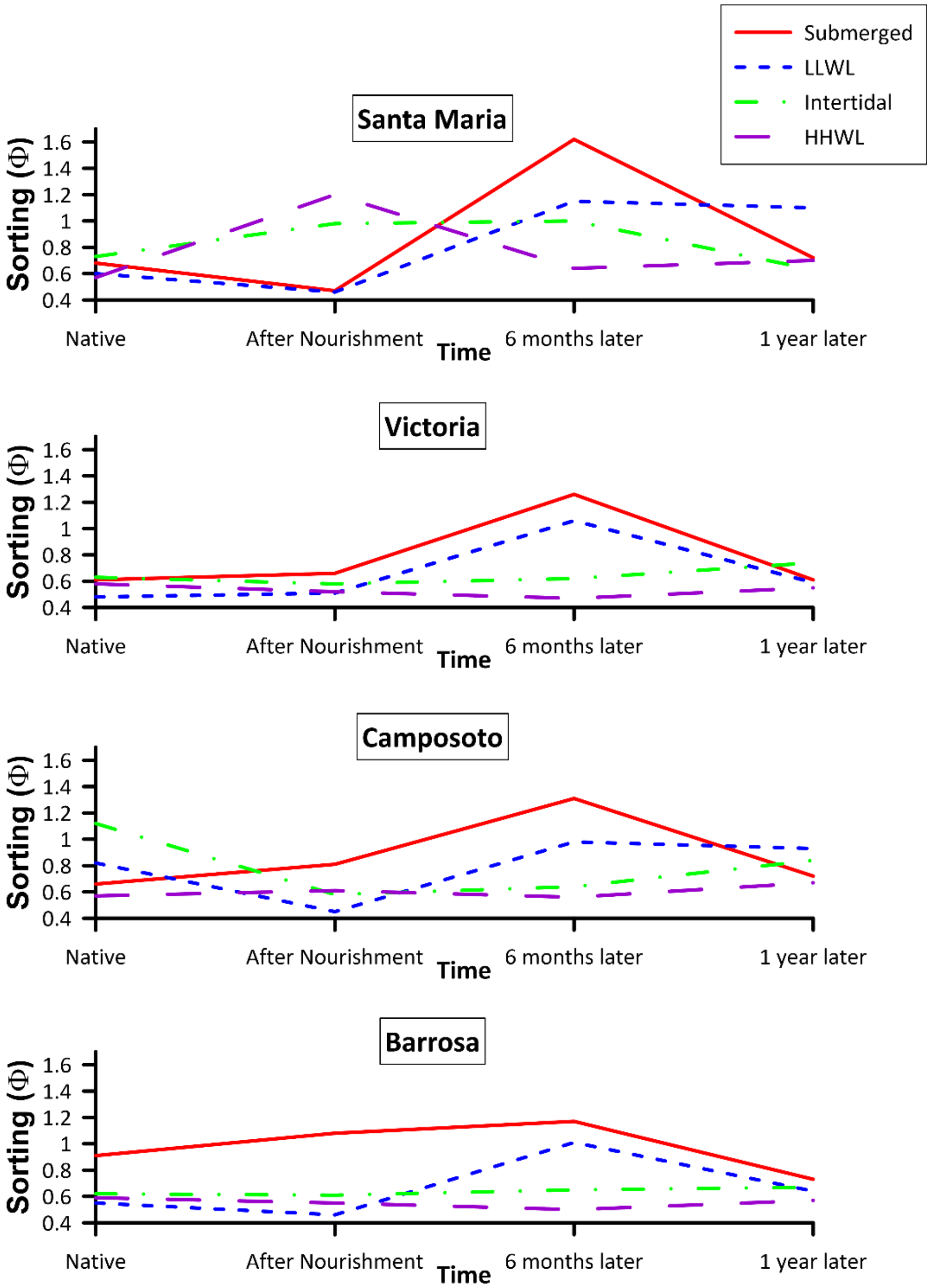

Figure 9. Results of sorting (φ units) obtained for the established elevations (submerged, LLWL, intertidal and HHWL) in the four monitored beaches.

Because nourishment was carried out with sand whose sorting is similar to the native sand's values and because of the sand being poured on the upper beach (Figure 7), there was not a big difference in the sorting at any level except for the intertidal and HHWL at SMM (Figure 9) just after the nourishment. Some changes were observed six months later in the lower (LLWL) and submerged parts of the beach profile, probably due to the movement of the finer sand grains. After one year, the sorting values decreased, becoming very close to the previous native values, being less than 0.75 ø (moderately well sorted) at all levels except at the LLWL at SMM and CB, where slightly higher values were observed (1.09 and 0.93 ø, respectively). Thus, we can state that there was not a significant difference between the sorting of native and nourished sand after one year.

5. Conclusions

The study aimed to identify and explain the behaviour of sand size after a beach nourishment. A generalisable methodology to study the evolution of the D_{50} and the sorting was presented. For this purpose, samples were taken from four different beaches, at different levels (submerged, LLWL, intertidal zone, and HHWL) over time. These campaigns were carried out before and just after the nourishment (in May at the end of the eroding season), six months later (after the swell or accretion season), and finally, one year after the nourishment.

Thus, a decrease of D_{50} (up to 20%) was observed in HHWL six months after the nourishment, whereas D_{50} increased in the rest of the profile. This phenomenon coincided with the summer season during which swell waves moved upwards the fine fraction of the sand from the submerged area. The process was reversed during the winter or stormy season and, eventually, D_{50} became almost identical to the native values one year after the nourishment.

Regarding sorting, the four beaches had native sorting values ranging between 0.50 to 1.03 and, therefore, were classified as having moderately well-sorted sands with some scarce locations of moderately sorted sands. No sorting differences were detected just after the nourishment except in the upper part of the beach where the sand was poured. Six months later, some changes were observed in the LLWL and the submerged zone, probably due to the upward movement of the finer fraction of the sand. Nevertheless, one year after the nourishment and similarly to the D_{50}, sorting values became very close to the original native sand's ones.

Author Contributions: Conceptualization, J.M.J., J.M. and J.J.M.-P.; methodology, J.J.S.-V., P.L.-G., J.M.J., J.M., B.J., A.C., F.C. and J.J.M.-P.; software, J.J.S.-V., P.L.-G., J.M.J., J.M.; validation, J.M.J., B.J., A.C., F.C. and J.J.M.-P.; formal analysis, J.M.J., B.J., A.C., F.C. and J.J.M.-P.; investigation, J.J.S.-V., P.L.-G., J.M.J., J.M., B.J., A.C., F.C. and J.J.M.-P.; original draft preparation, J.J.S.-V., P.L.-G., J.M.J., J.M.; review and editing, J.M.J., B.J., A.C., F.C. and J.J.M.-P. All authors have read and agreed to the published version of the manuscript.

Funding: Funds for APC payment were provided by Coastal Engineering Research Group from University of Cadiz.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Silva, R.; Martínez, M.L.; Hesp, P.A.; Catalan, P.; Osorio, A.F.; Martell, R.; Fossati, M.; Miot da Silva, G.; Mariño-Tapia, I.; Pereira, P.; et al. Present and Future Challenges of Coastal Erosion in Latin America. *J. Coast. Res.* **2014**, *71*, 1–16. [CrossRef]
2. Elko, N.; Briggs, T.R.; Benedet, L.; Robertson, Q.; Thomson, G.; Webb, B.M.; Garvey, K. A century of U.S. beach nourishment. *Ocean Coast. Manag.* **2021**, *199*, 105406. [CrossRef]
3. Liu, G.; Qi, H.; Cai, F.; Zhu, J.; Lei, G.; Liu, J.; Zhao, S.; Cao, C. Morphodynamic Evolution of Post-Nourishment Beach Scarps in Low-Energy and Micro-Tidal Environment. *J. Mar. Sci. Eng.* **2021**, *9*, 303. [CrossRef]
4. Asensio-Montesinos, F.; Pranzini, E.; Martínez-Martínez, J.; Cinelli, I.; Anfuso, G.; Corbí, H. The Origin of Sand and Its Colour on the South-Eastern Coast of Spain: Implications for Erosion Management. *Water* **2020**, *12*, 377. [CrossRef]
5. Jóia Santos, C.; Andriolo, U.; Ferreira, J.C. Shoreline Response to a Sandy Nourishment in a Wave-Dominated Coast Using Video Monitoring. *Water* **2020**, *12*, 1632. [CrossRef]
6. Muñoz-Perez, J.J.; Roman-Sierra, J.; Navarro-Pons, M.; da Graça Neves, M.; del Campo, J.M. Comments on "Confirmation of beach accretion by grain-size trend analysis: Camposoto beach, Cádiz, SW Spain" by E. Poizot et al. (2013) Geo-Marine Letters 33(4). *Geo-Mar. Lett.* **2014**, *34*, 75–78. [CrossRef]
7. Poizot, E.; Anfuso, G.; Méar, Y.; Bellido, C. Confirmation of beach accretion by grain-size trend analysis: Camposoto beach, Cádiz, SW Spain. *Geo-Mar. Lett.* **2014**, *33*, 263–272. [CrossRef]
8. Gopalakrishnan, S.; Smith, M.D.; Slott, J.M.; Murray, A.B. The value of disappearing beaches: A hedonic pricing model with endogenous beach width. *J. Environ. Econ. Manag.* **2011**, *61*, 297–310. [CrossRef]

9. Armstrong, S.B.; Lazarus, E.D.; Limber, P.W.; Goldstein, E.B.; Thorpe, C.; Ballinger, R.C. Indications of a positive feedback between coastal development and beach nourishment. *Earth's Future* **2016**, *4*, 626–635. [CrossRef]
10. Martell, R.; Mendoza, E.; Mariño-Tapia, I.; Odériz, I.; Silva, R. How Effective Were the Beach Nourishments at Cancun? *J. Mar. Sci. Eng.* **2020**, *8*, 388. [CrossRef]
11. Alves, B.; Rigall-I-Torrent, R.; Ballester, R.; Benavente, J.; Ferreira, Ó. Coastal erosion perception and willingness to pay for beach management (Cadiz, Spain). *J. Coast. Conserv.* **2015**, *19*, 269–280. [CrossRef]
12. Cutler, E.M.; Albert, M.R.; White, K.D. Tradeoffs between beach nourishment and managed retreat: Insights from dynamic programming for climate adaptation decisions. *Environ. Model. Softw.* **2020**, *125*, 104603. [CrossRef]
13. Herrera, A.; Gomez-Pina, G.; Fages, L.; de la Casa, A.; Munoz-Perez, J.J. Environmental Impact of Beach Nourishment: A Case Study of the Rio San Pedro Beach (SW Spain). *Open Oceanogr. J.* **2010**, *4*, 32–41. [CrossRef]
14. Fletemeyer, J.; Hearin, J.; Haus, B.; Sullivan, A. The impact of sand nourishment on beach safety. *J. Coast. Res.* **2018**, *34*, 1–5. [CrossRef]
15. Benedet, L.; Finkl, C.W.; Campbell, T.; Klein, A. Predicting the effect of beach nourishment and cross-shore sediment variation on beach morphodynamic assessment. *Coast. Eng.* **2004**, *51*, 839–861. [CrossRef]
16. USACE, US Army Corps of Engineers. *Shore Protection Manual*; USACE: Washington, DC, USA, 1984.
17. James, W.R. *Techniques in Evaluating Suitability of Borrow Material for Beach Nourishment (No. 60)*; US Coastal Engineering Research Center, 1975; Available online: https://erdc-library.erdc.dren.mil/jspui/bitstream/11681/2871/1/TM-CERC-No-60.pd (accessed on 15 August 2021).
18. USACE, US Army Corps of Engineers. Coastal Engineering Manual. 2002. Available online: https://www.publications.usace.army.mil/USACE-Publications/Engi (accessed on 15 August 2021).
19. Chu, M.L.; Guzman, J.A.; Muñoz-Carpena, R.; Kiker, G.A.; Linkov, I. A simplified approach for simulating changes in beach habitat due to the combined effects of long-term sea level rise, storm erosion, and nourishment. *Environ. Model. Softw.* **2014**, *52*, 111–120. [CrossRef]
20. Anthony, E.J.; Cohen, O.; Sabatier, F. Chronic offshore loss of nourishment on Nice beach, French Reviera: A case of over-nourishment of a steep beach. *Coast. Eng.* **2011**, *58*, 374–383. [CrossRef]
21. Campbell, T.; Benedet, L. Beach nourishment magnitudes and trends in the US. *J. Coast. Res.* **2006**, *39*, 57–64.
22. Bernabeu Tello, A.M.; Muñoz Pérez, J.J.; Medina Santamaría, R. Influence of a rocky platform in the profile morphology: Victoria Beach, Cádiz (Spain). *Ciencias Mar.* **2002**, *28*, 181–192. [CrossRef]
23. Muñoz-Perez, J.J.; Gutierrez-Mas, J.M.; Parrado, J.M.; Moreno, L. Sediment Transport Velocity by Tracer Experiment at Regla Beach (Spain). *J. Waterw. Port Coast. Ocean Eng.* **1999**, *125*, 332–335. [CrossRef]
24. Muñoz-Pérez, J.J.; Medina, R.; Tejedor, B. Evolution of longshore beach contour lines determined by the E.O.F. method. *Sci. Mar.* **2001**, *65*, 393–402. [CrossRef]
25. Bellido, C.; Anfuso, G.; Plomaritis, T.A.; Rangel-Buitrago, N. Morphodynamic behaviour, disturbance depth and longshore transport at Camposoto Beach (Cadiz, SW Spain). *J. Coast. Res.* **2011**, 35–39.
26. Benavente, J.; Reyes, J.L. The application of morphodynamic indices to exposed beaches of Cadiz Bay. *Bol. Inst. Esp. Ocean.* **1999**, *15*, 213–220.
27. Vargas, J.M.; García-Lafuente, J.; Delgado, J.; Criado, F. Seasonal and wind-induced variability of Sea Surface Temperature patterns in the Gulf of Cádiz. *J. Mar. Syst.* **2003**, *38*, 205–219. [CrossRef]
28. Montero de Burgos, J.L.; González Rebollar, J.L. *Diagramas Bioclimaticos*; Ministerio de Agricultura, Pesca y Alimentación: Madrid, Spain, 1974; ISBN 9788474792058.
29. Reyes, J.L.; Martins, J.T.; Benavente, J.; Ferreira, Ó.; Gracia, F.J.; Alveirinho-Dias, J.M.; López-Aguayo, F. Gulf of Cadiz beaches: A comparative response to storm events. *Bol. Inst. Esp. Ocean.* **1999**, *15*, 221–228.
30. Ministry of Public Works. *Maritime Works Recommendations. Anex I: Wave Climate on the Spanish Coast*; Ministerio Obras Publicas: Madrid, Spain, 1992; p. 76.
31. Jódar Tenor, J.M. *Estudio de la Evolución de los Sedimentos tras la Regeneración de la Playa de Santa María del Mar (Cádiz)*; University of Cadiz: Cadiz, Spain, 2001.
32. Stockdon, H.F.; Holman, R.A.; Howd, P.A.; Sallenger, A.H. Empirical parameterization of setup, swash, and runup. *Coast. Eng.* **2006**, *53*, 573–588. [CrossRef]
33. Davis, R.A. Beach and Nearshore Zone. In *Coastal Sedimentary Environments*; Davis, R.A., Ed.; Springer: New York, NY, USA, 1985; pp. 379–444. ISBN 978-1-4612-5078-4.
34. Aboitiz, A.; Tejedor Álvarez, M.B.; Muñoz Pérez, J.J.; Abarca, J.M. Relation between daily variations in sea level and meteorological forcing in Sancti Petri Channel (SW Spain). *Ciencias Mar.* **2008**, *34*, 491–501. [CrossRef]
35. Poullet, P.; Muñoz-Perez, J.J.; Poortvliet, G.; Mera, J.; Contreras, A.; Lopez, P. Influence of different sieving methods on estimation of sand size parameters. *Water* **2019**, *11*, 879. [CrossRef]
36. Damveld, J.H.; Borsje, B.W.; Roos, P.C.; Hulscher, S.J.M.H. Horizontal and Vertical Sediment Sorting in Tidal Sand Waves: Modeling the Finite-Amplitude Stage. *J. Geophys. Res. Earth Surf.* **2020**, *125*, e2019JF005430. [CrossRef]
37. Román-Sierra, J.; Muñoz-perez, J.J.; Navarro-Pons, M. Influence of sieving time on the efficiency and accuracy of grain-size analysis of beach and dune sands. *Sedimentology* **2013**, *60*, 1484–1497. [CrossRef]

38. Syvitski, J.P.M. *Principles, Methods and Application of Particle Size Analysis*; Syvitski, J.P.M., Ed.; Cambridge University Press: Cambridge, UK, 1991; ISBN 9780521364720.
39. Roman-Sierra, J.; Navarro, M.; Muñoz-Perez, J.J.; Gomez-Pina, G. Turbidity and Other Effects Resulting from Trafalgar Sandbank Dredging and Palmar Beach Nourishment. *J. Waterw. Port Coast. Ocean Eng.* **2011**, *137*, 332–343. [CrossRef]
40. Black, K.P.; Parry, G.D. Entrainment, dispersal, and settlement of scallop dredge sediment plumes: Field measurements and numerical modelling. *Can. J. Fish. Aquat. Sci.* **1999**, *56*, 2271–2281. [CrossRef]
41. Muzambiq, S. Sedimentation Model Area of Lau Kawar Lake from Volkanic Eruption of Sinabung Mountain in Karo District, North Sumatra Province. *Int. J. Adv. Eng. Manag. Sci.* **2019**, *5*, 269–274. [CrossRef]
42. Edwards, A.C. Grain size and sorting in modern beach sands. *J. Coast. Res.* **2001**, *17*, 38–52.
43. Muñoz-Perez, J.J.; Gutiérrez-Mas, J.M.; Moreno, J.; Español, L.; Moreno, L.; Bernabeu, A. Portable Meter System for Dry Weight Control in Dredging Hoppers. *J. Waterw. Port Coast. Ocean Eng.* **2003**, *129*, 79–85. [CrossRef]
44. Montreuil, A.L.; Chen, M.; Brand, E.; Verwaest, T.; Houthuys, R. Post-storm recovery assessment of urbanized versus natural sandy macro-tidal beaches and their geomorphic variability. *Geomorphology* **2020**, *356*, 107096. [CrossRef]
45. Reeve, D.E.; Spivack, M. Evolution of shoreline position moments. *Coast. Eng.* **2004**, *51*, 661–673. [CrossRef]
46. Payo, A.; Kobayashi, N.; Muñoz-Pérez, J.; Yamada, F. Scarping predictability of sandy beaches in a multidirectional wave basin. *Cienc. Mar.* **2008**, *34*, 45–54. [CrossRef]
47. Anfuso, G.; Benavente, J.; Gracia, F.J. Morphodynamic responses of nourished beaches in SW Spain. *J. Coast. Conserv.* **2001**, *7*, 71–80. [CrossRef]