Beach nourishment impact on Posidonia oceanica: Case study of Poniente Beach (Benidorm, Spain)

Article *in* Ocean Engineering · October 2015

DOI: 10.1016/j.oceaneng.2015.07.005

Aragonés Luis
University of Alicante

Javier García
University of Alicante

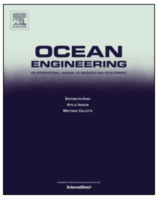
Isabel López
University of Alicante

Ocean Engineering 107 (2015) 1–12

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng



Beach nourishment impact on *Posidonia oceanica*: Case study of Poniente Beach (Benidorm, Spain)

L. Aragonés [a],*, J. García-Barba [a], E. García-Bleda [a], I. López [a], J.C. Serra [b]

[a] Department of Civil Engineering, University of Alicante, Carretera San Vicent del Raspeig s/n, 03690 Alicante, Spain
[b] Department of Transportation, ETSI Caminos, Polytechnic University of Valencia, Camino de Vera s/n, 46022 Valencia, Spain

ARTICLE INFO

Article history:
Received 16 September 2014
Accepted 6 July 2015

Keywords:
Posidonia oceanica
Beach nourishment
Burial
Cross-shore profile

ABSTRACT

The importance of nourishment processes on the beaches of Mediterranean Sea has been increasing since the end of the 20th century due to its socio-economical awareness (tourismboost) and environmental implications (possible impact on *Posidonia oceanica* meadows and important processes of dredging and earth movements). However, in many cases, and especially in eastern Spain, relevant actions have been made which had caused that, after 20 years, the beaches in which these works were carried out will be in a similar situation with the original one.

The present study analyzed the Poniente Beach (Benidorm, Spain), a beach where the nourishment works of 1991 have caused the disappearance of the *Posidonia oceanica* meadows and a regression process that will lead to the disappearance of the beach in a few years.

To this end, data from bathymetry, georeferenced orthophotos, grain size analysis and swell study have been obtained and analyzed, understanding the importance of the works done to be consistent with the environment in which they were developed, and providing a work process which can ensure the existence of the nourished beach starting from the maintenance of *Posidonia oceanica* meadows.

1. Introduction

Artificial nourishment of beaches consisting of sand dumping on the dry beach is more common in recent years than the construction of rigid structures, becoming the main alternative in fighting erosion processes (Hamm et al., 2002; Medina et al., 2001). In much of the Comunidad Valenciana's coast, located in eastern Spain, this type of actions have been concentrated on, within a short period of time, in such a way that only considering those interventions which include twenty-nine artificial nourishment of dredging sand were carried out between 1985 and 1999 (Beachmed, 2003).

These types of "soft" actions, so called because they do not introduce rigid elements on the beach, are often considered the most environment-friendly option. Nevertheless, it is well known that some nourishments can cause damage to the adjacent *Posidonia oceanica* meadows (Fernández Torquemada and Sánchez Lizaso, 2005; González-Correa et al., 2008) as they may significantly increase the turbidity of the water and thus reduce the incidental light on the meadow, leading to drastic changes in its growth and its subsequent disappearance (Medina et al., 2001). On the other hand, beach replenishment can also lead to the burial of the plant in extreme cases. If the deposition of sand is moderate, not involving a prolonged burial, the plant will be able to resist since the average vertical growth rate has been evaluated at 1 cm/year in the Mediterranean Sea (Marbá and Duarte, 1998). However, if sediment deposition is very strong and persistent, the plant may have difficulties to grow fast enough, dying as a result of the burial. In this regard, Manzanera et al. (1998) carried out an experiment in which several plants of *Posidonia oceanica* were completely buried, causing that after 200–300 days a hundred per cent of rhizomes were dead.

In some other cases, it has been observed that the contribution of sand has led to a considerable decrease in the health of the nearby *Posidonia oceanica* meadows. This is the case of the nourishment of Lisa Beach, in Santa Pola (Spain) in 1985 (González-Correa et al., 2008), or the expansion and construction of the Port of Altea (Spain), which produced a negative impact in the distribution and structure of the *Posidonia oceanica* meadow due to the turbidity increase and epiphytes load, which caused the reduction of the light in the area (Fernández Torquemada and Sánchez Lizaso, 2005).

This conflict in line with the key environmental elements of the coast has caused an environmental concern that explains the decrease of this type of actions in the Mediterranean coast since the 1990s (Medina et al., 2001). The impact of Posidonia oceanic

---

* Corresponding author. Tel.: +34 690716678.
E-mail addresses: laragones@ua.es (L. Aragonés), javier.garciabarba@ua.es (J. García-Barba), e.garcia.bleda@gmail.com (E. García-Bleda), isalopu.il@gmail.com (I. López), jserra@tra.upv.es (J.C. Serra).

http://dx.doi.org/10.1016/j.oceaneng.2015.07.005
0029-8018/

could be highlighted from both the negative (dumping area of material) and the area of extraction (Landaeta, 2001).

However, there are some nourishments out from Comunidad Valenciana, carried out from the criterion of sustainability, which shows the need to take the biocenosis of the area into account, such as the replenishment that was conducted in the Saint George Bay in Malta in 2004 (Borg et al., 2006). It shows that *Posidonia oceanica* was chosen as a biomarker for the biological component of the EMP (Environmental Monitoring Programme), due to its wide distribution and sensitivity to anthropogenic perturbations (Pergent-Martini et al., 2005). In this case, the monitoring showed that an important offshore transport of sediments had occurred and that beach replenishment work did not produce negative effects in the marine environment (Borg et al., 2006).

On the other hand, *Posidonia oceanica* provides other advantages that could be lost if they disappear. The three-dimensional structure of rhizomes form a certain reinforcement for the sandy sediment of the submerged beach which, along with the roots and leaves, hinder the sedimentary movements of the seabed, consolidating the sandy substratum and making the submerged beach profile changes much slower than what they would be in the absence of the meadow (Medina et al., 2001). In addition to the reinforcement of the sandy soil, the foliage of the meadow increases the roughness of the seabed, facilitating the wave energy dissipation (Gacia et al., 1999). The absorption of wave energy might be in some cases between 30% and 40% of the total energy (Bouderesque and Meinesz, 1982).

There are references that support the profile change observed after the death of part of the meadow, for instance, the case of the beach erosion on the Gulf of Giens (France), where the partial disappearance of the *Posidonia oceanica* meadow, caused the disappearance of sandy substrate and the erosion of the seabed, due to the spill in two points of a wastewater treatment plant, which tended to reach a new equilibrium profile (Maggi, 1973).

Maggi (1973) also noted that there was an increase in the average size of the beach particles, which attributed to the dragging of the thickest grains that had been trapped by the roots of the plants and was released after their death.

This paper will discuss a particular case which will provide important information that can be extrapolated worldwide, especially to the Mediterranean Sea, since *Posidonia oceanica* is an endemic seagrass from this zone (Medina et al., 2001). The nourishment carried out on Poniente Beach (Benidorm) in 1991 is an exemplary project to study beach nourishment's effects on *Posidonia oceanica*, since part of the meadow was buried during its execution. In order to evaluate the possible consequences of that artificial replenishment in subsequent beach erosion processes, the historical evolution of different beach descriptors has been studied up to the present. From the results obtained, how the nourishment process should be carried out was analyzed, suggesting a more sustainable practice that meets both the physical demands of a beach nourishment project as well as the marine environmental protection requirements including the criteria of marine environment maintenance and beach functionality (Borg et al., 2006).

2. Study area

The area under study corresponds to Poniente Beach (Benidorm, Spain) (Fig. 1), located in the Spanish Mediterranean, and it represents a very important point for the tourism of Comunidad Valenciana (Mazón, 2010). Part of this success is due to its two beaches of fine sand (0.300 mm), Poniente Beach and Levante Beach, with lengths of 3008 m and 2261 m respectively (Ecolevante, 2006). Both beaches are included in a closed littoral system, forming a headland embayment. This is important, since its study could be compared to other authors' investigations related to similar coastal systems (Grunnet et al., 2004). Their location in the western Mediterranean makes them to be afflicted with some frequency by sea storms that cause economic damages to the activities implemented in the littoral (Olcina and Torres, 1997). However, since these beaches are south-facing and they are protected by the massif of Sierra Helada, only E–SE swells really reach the beaches, remaining the excluded E directions (most frequent sea storms), E–NE and NE. Therefore, the storms impact is lower than the one in other parts of Eastern Spain.

High frequencies of the swells from the E–SE direction were, indeed, what prompted the research on, ultimately, the nourishment of the East side of Poniente Beach in 1991 (MOPT, 1991). The beach replenishment was developed over 1350 m of coastline, corresponding to the section between the Benidorm port and the mid-point of the beach, where the regressive trend disappears.

These actions were conducted as an emergency measure to the E–SE sea storms that took place in those years, with waves impacting on the maritime promenade wall causing structural damage on it and even mismatch problems in its base (MOPT, 1991).

The adopted solution was the artificial contribution of sand in the eastern half of the beach (Poniente Beach, Fig. 1) of 710,847 m^3 coming from the dredging of the seabed next to Sierra Helada mountain (MOPT, 1991). The nourished beach length was 1350 m, so, the unit volume of sand dumped was higher than 500 m^3 per linear meters of beach, this increase the initial beach width from 20 m to 100 m after the process (Fig. 2). This width increase required the creation of a breakwater to contain the sand and prevent the port from silting up (Fig. 3).

3. Methodology

This section describes the methodology used studying the behavior of Poniente Beach over time.

3.1. Historical coastline evolution

The analysis of the historical evolution of the coastline was realized by the superposition of series of georeferenced orthophotos (Ojeda et al., 2013) from 1956 until 2012 (Fig. 4). Specifically, the studied orthophotos correspond to years 1956, 1981, 1986, 1990, 1992, 1994, 1996, 1998, 2005, 2007, 2009 and 2012, and their analysis has allowed to observe the coastline trend before and after nourishment. To this end, the surfaces won and lost between each pair of compared orthophotos have been calculated, distinguishing between the eastern half of the beach, the western half and the beach as a whole.

In order to define in greater depth the evolutionary trend of the beach in plant the net longshore solid transport was calculated. As first approximation, the theoretical transport was calculated using the CERC formulation, considering default values for its two calibration coefficients (SPM, 1973). Since this formulation assumes the condition of unlimited availability of material, it can provide quantitative results far removed from reality, although it is qualitatively valid to define the direction of net transport. Therefore, the real annual transport between 1991 and 2006 has also been calculated and analyzed the sedimentary balance on the beach, through the volume variations observed by comparing cross-shore beach profiles. Thus, not only the real transport is quantified, but also the validity of the CERC formulation can as well evaluated in the study area.

Also, based on wave data from Alicante Coastal Buoy 1616 (38.25°N; 0.41°W), provided by the public institution Ports of the

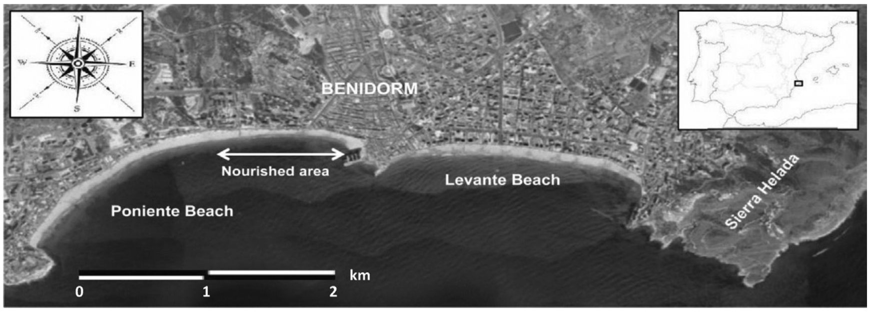


Fig. 1. Study area (source of the orthophoto: Valencian Cartographic Institute, taken in 2012).

Fig. 2. Aerial image of Poniente Beach location before nourishment (left) and during nourishment (right) .
Source: MOPT, 1991.

State, the analytical calculation of the average swell flow direction has been carried out. This buoy belongs to the REDCOS network.

3.2. *Regressive rates and swell distribution*

Another calculated variable has been the annual average width loss on the beach (m/year), studying shoreline displacement for each considered period over 12 profiles perpendicular to the coast. By this, it can be analyzed if the regression has been constant over time or by contrast, there have been stable periods or critical moments of strong regression.

In parallel with this study of regressive rates, an analysis of the historical evolution of the swell distribution was done, in order to assess whether higher or lower regressive events are caused by extraordinary wave conditions or, on the contrary, there are different causes.

Thereby, using data from the SIMAR-44 buoy network (38.5°N, 0.17°W) from 1958 to 2001, as well as data from the WANA buoy network (38.5°N; 0.08°W) from 2002 to 2012, both provided by the public institution Ports of the State, make the historical evolution of swell in the area to be studied. In order to do this, the swell distribution has been sectorized in the same intervals of time between each orthophoto and the next, obtaining for each period direction frequencies, as well as the medium regime of wave height and peak periods. Apart from frequencies, the significant wave height in deepwater exceeded 12 h per year (H_s, o_{12}) (Hallermeier, 1978, 1981) was calculated for each direction and chosen as a comparison parameter between different periods.

3.3. *Cross-shore profiles*

In addition to the plant study, the beach cross-shore behavior has been analyzed, based on the bathymetric data provided by the

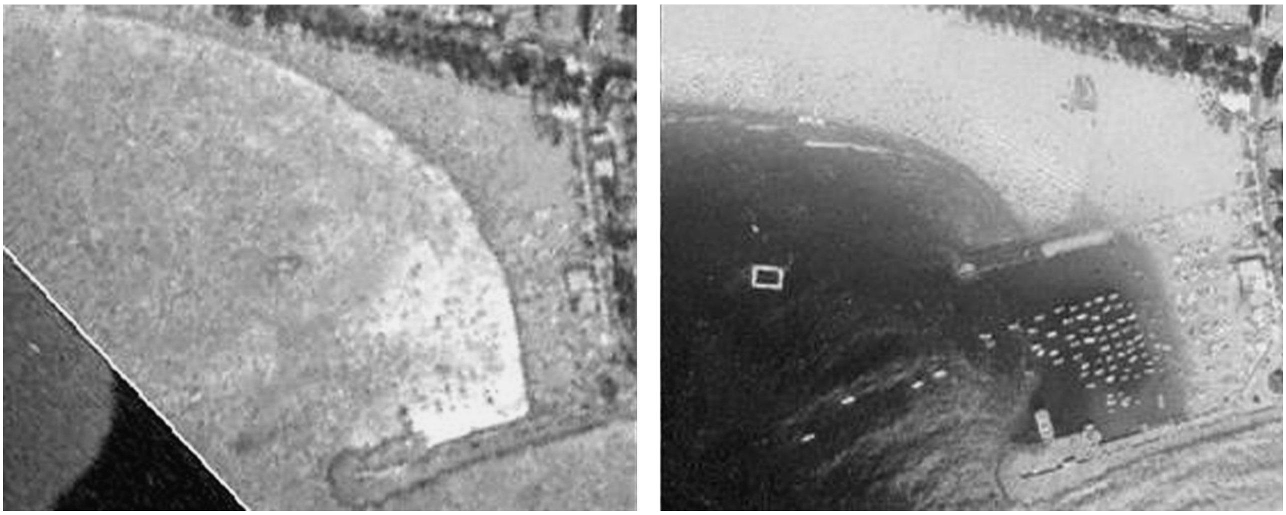


Fig. 3. Previous state without outer seawall (left) and state after nourishment with the presence of the breakwater (right).
Source: MOPT, 1991.

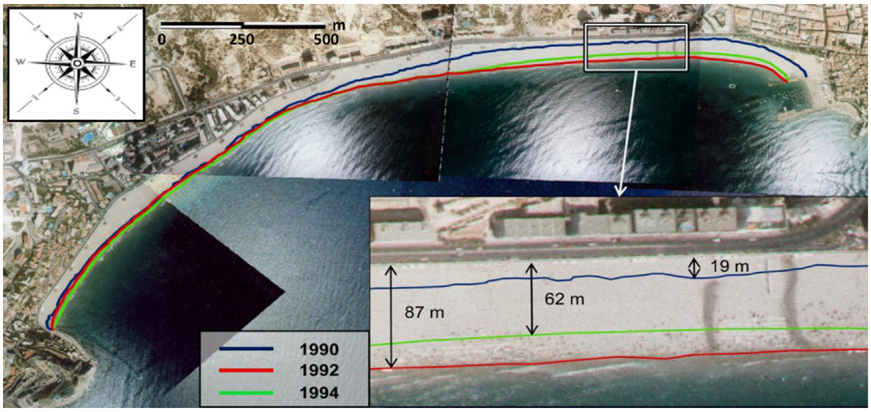


Fig. 4. Sequence of superimposed orthophotos between 1990 (before nourishment), 1992, and 1994 (after nourishment).

Provincial Service of Coasts of Alicante. The bathymetric equipments were formed in November 1989, March 1991 (before regeneration) and May 1991 (after the regeneration) by a radio positioning Maxiran system, with frequency band from 420 to 450 Mhz and in 2006, by a system of multibeam wave compensator probe, speed meter vessel, differential GPS corrected by satellite and other auxiliary elements. With the bathymetry obtained in each period, a study on the evolution of twelve cross-shore profiles (distributed along Poniente Beach shoreline) was carried out for the four different dates, obtaining a total of forty-eight profiles. Those corresponding to 1989 begin in bathymetric—10 m and continue to the depth −32 m referred to the MWL (Ecolevante, 2006). Profiles of 1991 before and after nourishment cover of the promenade wall to the depth – 11 m. Finally, 2006 profiles are initiated on the promenade and continue until bathymetric – 32 m.

3.4. *Posidonia oceanica*

An analysis of the *Posidonia oceanica* meadow position in front of the nourished area has been done. Field data relative to the beginning of the *Posidonia oceanica* meadow (distance to the coast and depth) gathered in the eastern zone of Poniente Beach several months after the nourishment (Sánchez Lizaso, 1991) have been compared with those corresponding to the landward edge of the meadow in 2006, extracted from ecomapping study ECOLEVANTE, developed by the State General Coast Service (Ecolevante, 2006). In addition, data from leaf density and length have also been obtained, parameters that may have changed as well, affecting the *Posidonia oceanica*–beach relationship.

3.5. Sedimentology

Another studied variable was the historical evolution of Poniente beach granulometry in order to analyze its influence on the variations suffered by the beach. Thus, the values of the average sediment size of dry beach (D_{50}) have been collected and compared to the years 1987, 2006, 2012 and 2014. Moreover, data from the granulometric distribution (separated by grain size fractions) have been studied at different depths for the years 1987 to 2006, with the aim of analyzing it, if the proportions of clay, silt, and sand have varied from one year to another and if these changes could have affected *Posidonia oceanica*.

All dry beach granulometric data, including those of 1985 (Chapapría, 1987), 2006 (Ecolevante, 2006) and the extraction from tests at the University of Alicante corresponding to 2012 and 2014, are referred to samples taken in the intertidal zone of the beach. These samples were dried after its extraction during 24 h in oven to proceed subsequently to its granulometric test. The following parameters were obtained from these trials: Quantile, Ø16, Ø84, Ø50, media (Folk and Ward, 1957), the first, second and third quartile (*Q*1, *Q*2 and *Q*3), typical deviation, percentiles 90 and

10 (P_{90} and P_{10}), Sorting (S_o), Skewness (S_k), Kurtosis (K), uniformity coefficient (C_u) and concavity coefficient (C_c). However, among all, it has been the second quartile value - equivalent to the parameter D_{50}- the one chosen as the main variable to make the comparison and study of sedimentological evolution.

It must be indicated that the data gathering corresponding to 1987 was held in December, just a month after the high-density rainfall occurred on November 3, 1987, with precipitations up to 377 mm in some municipalities from northern Alicante (Olcina and Rico, 2000).

4. Results

The results obtained from the analysis of all the studied variables are given below.

4.1. Historical coastline evolution

Fig. 5 shows the variation of the beach surface over time extracted from the studied georeferenced orthophotos. In the historical evolution of the surface it has been considered a distinction between the eastern half of the beach (regenerated zone), western half and the beach as a whole. This distinction allows to identify in a better way the different beach behaviors along itself, as well as the different transports (alongshore or transversal) taking place.

The theoretical net longshore transport calculated from the CERC formulation has turned out to be 94,593.48 m^3/year towards west direction. Meanwhile, the real transport, calculated from the volume of sand accreted on the western side between 1991 after nourishment and 2006 by the comparison of cross-shore profiles, adopts a value of 13,222.59 m^3/year in the same direction. In terms of the analytical calculation of the average swell flow direction, this has yielded a result of N149. 5°E represented in Fig. 6.

4.2. Regressive rates and swell distribution

Variations of the beach width, calculated along the profiles represented in Fig. 7, were obtained from the comparison of orthophotos, validating them with beach cross-shore profiles obtained from the bathymetries of other years. These data have enabled to calculate the annual average regression rates, resulting that the higher regressive rate values were found in profile 3 (Fig. 7), with losses exceeding the 10 m/year over the years immediately following the nourishment [1992–1994], as shown in Fig. 8. This figure represents the relationship between the dominating swell distribution and regression on the eastern side of the beach for each studied interval of time, using the regression values corresponding to Profile 3 (Fig. 8). The waves rose from Poniente Beach, also shown in Fig. 8, presents two clearly dominant directions, E–SE and S–SW, the second one in a smaller proportion. The swell distribution for each studied period has been

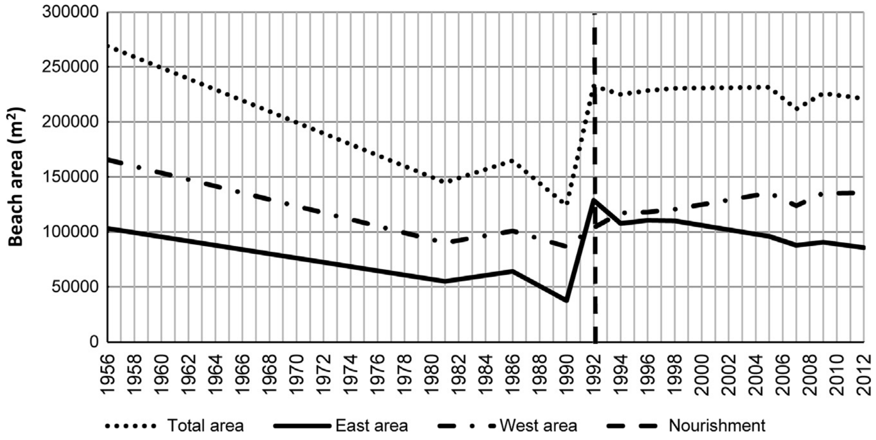


Fig. 5. Historical evolution of the Poniente Beach area.

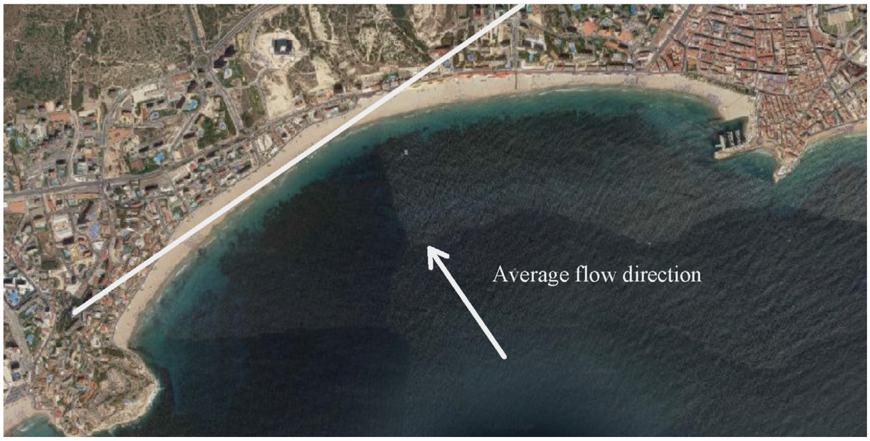


Fig. 6. Average flow direction and perpendicular line to it.

Fig. 7. Cross-shore profiles distribution along the beach.

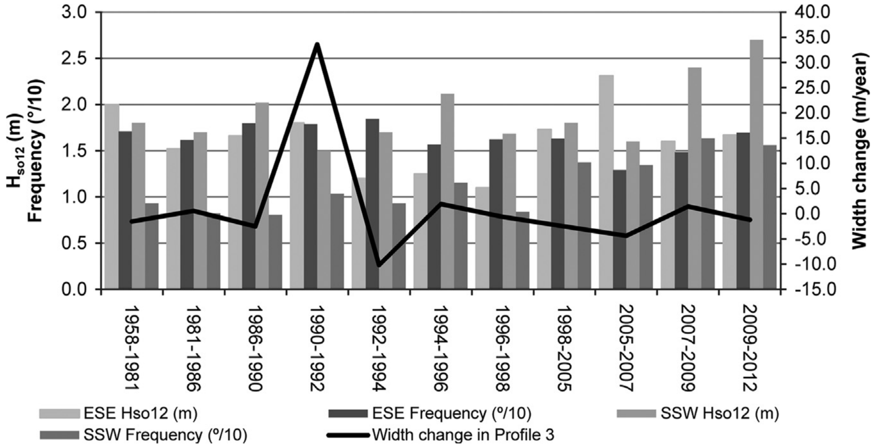


Fig. 8. Relationship between dominating swell distribution and beach width change (m/year).

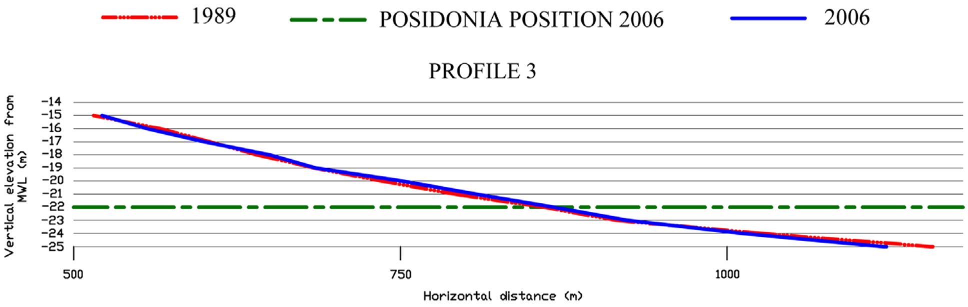


Fig. 9. Concurrence between 1989 and 2006 profiles from depth − 15 m.

defined by the wave height Hs,o$_{12}$ and frequency for each of these two directions during the period considered.

4.3. *Cross-shore profiles and Posidonia oceanica*

With regards to the beach cross-shore study, Fig. 10 represents three of the profiles taken for 1989, 1991 before and after nourishment, and 2006 (Fig. 7). The first corresponds to the nourished area closest to the port, the second represents the central part of the nourished zone, where there has been greater regression, and finally, the third one is representative of the western side of the beach, out of the artificially fed zone. These profiles were shown until the depth − 15 m, since beyond this point, 1989 and 2006 profiles coincide almost perfectly in all cases, as shown in Fig. 9. *Posidonia oceanica* position in 1991 after nourishment and in 2006 is also represented, as well as the slopes and width variations between these two years. It must be said that the position of *Posidonia oceanica* shown in Fig. 9 represents the lower limit (offshore edge) of the meadow, while Fig. 10 shows its upper limit. On the other hand, the reason why no *Posidonia oceanica* position is given for 1991 in Profile 7 is that, there are no available *Posidonia oceanica* data along the western zone of the beach for that year.

4.4. *Sedimentology*

Below are presented the results obtained from the study of the beach sediment evolution. Firstly, Fig. 11 shows the variation

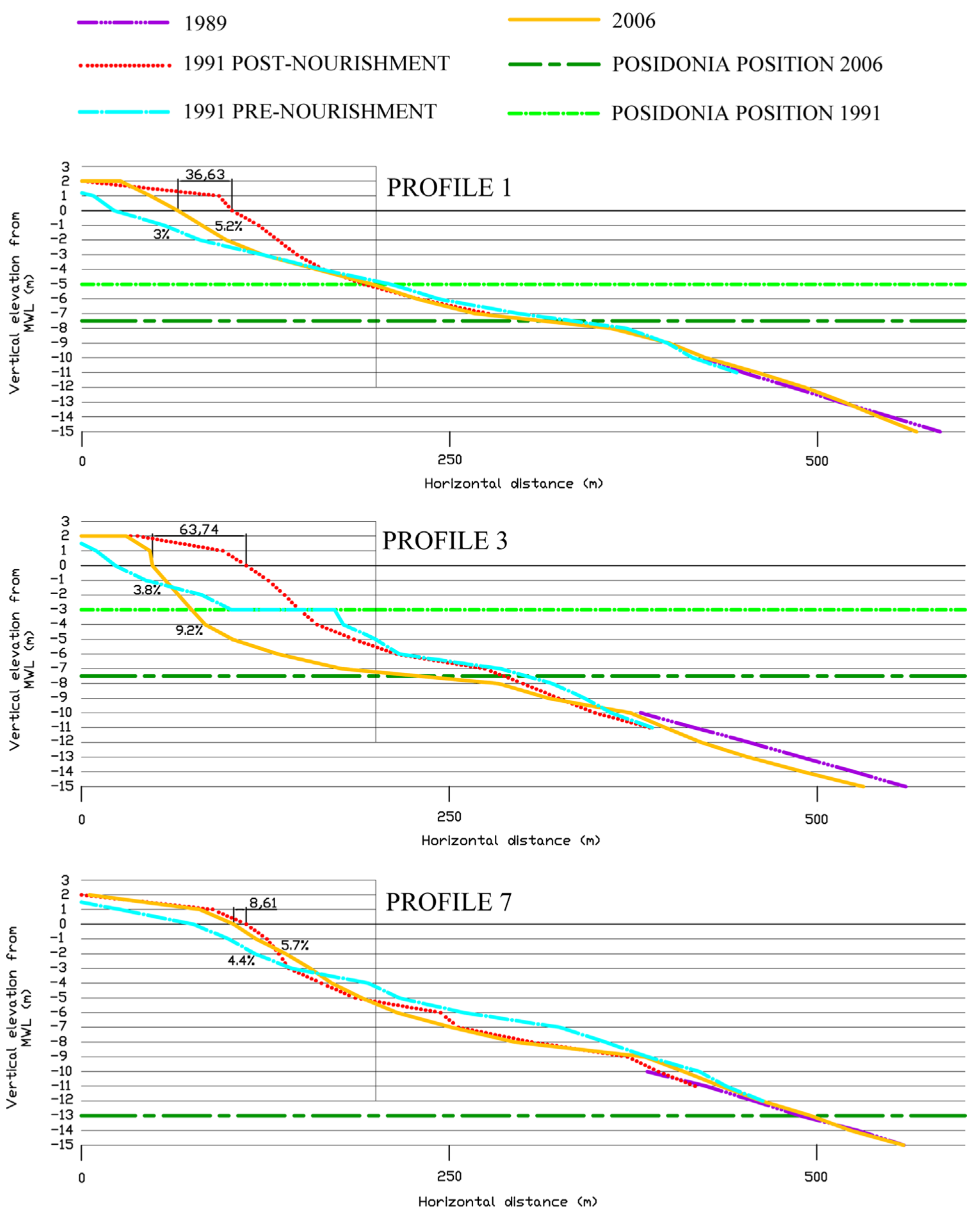


Fig. 10. Comparison of the most representative cross-shore profiles until depth – 45 m before and after nourishment.

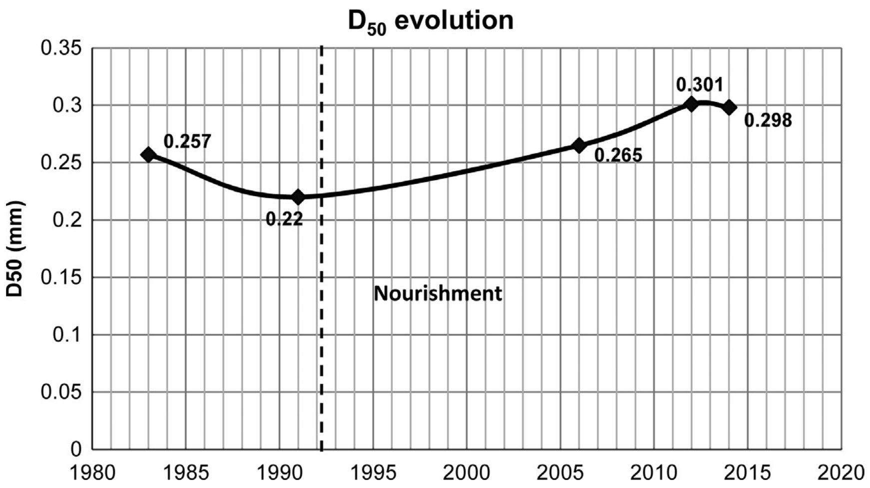


Fig. 11. Historical evolution of the average grain size on dry beach (D_{50}).

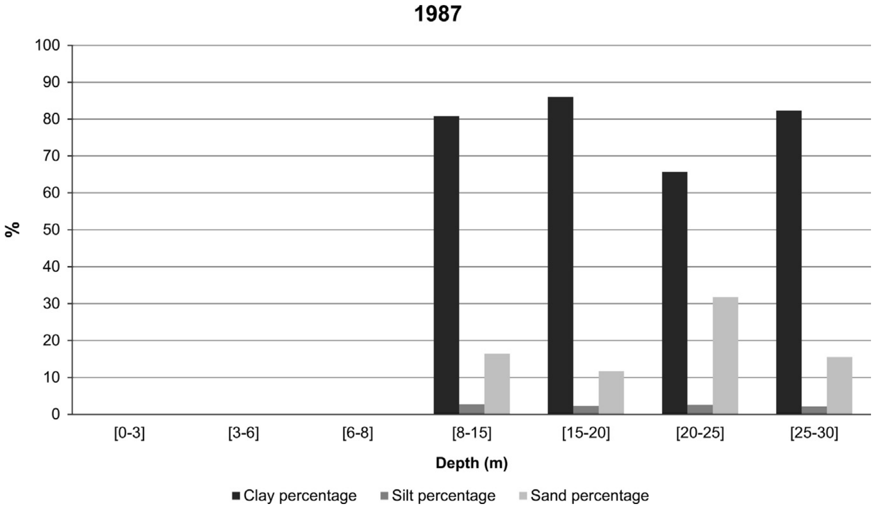


Fig. 12. Granulometric proportions by fractions at different depths in 1987.

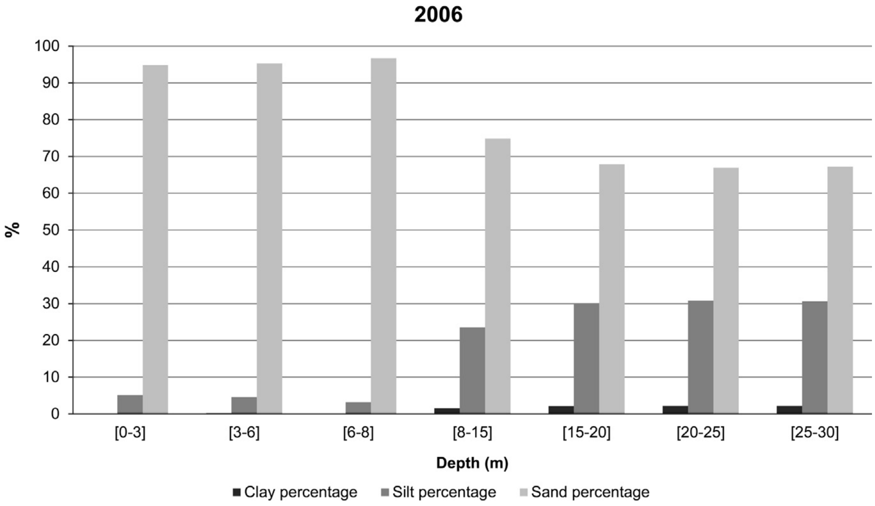


Fig. 13. Granulometric proportions by fractions at different depths in 2006.

experienced by the average grain size on dry beach (D_{50}). On the other hand, the data from sedimentological distribution of the samples taken in 1987 and 2006 according to the official test (UNE, 2012) was compared. The obtained results are shown in Figs. 12 and 13.The samples used to define the sedimentology of the beach do not belong to a unique profile, but they were taken at different sections and depths along the coastline.

5. Discussion

Cross-shore loss of material can be seen in Fig. 5, adopting a value of 3802 m^2/year during the period [1992–1994], immediately subsequent to nourishment. The reason why they correspond to cross losses is the fact that the material lost along the eastern zone is not fully compensated by the sediment won in the western zone. After the nourishment, the intersection between the two curves (East area and West area) must be pointed out, this is as a result of the regression of the eastern side and accretion in the west, indicating a clear movement of the coastline in an anti-clockwise direction (1992–2012: 5°). On the other hand, the higher slope of the curve from the eastern zone with respect to the western zone justifies that cross loss of material commented before. Therefore, it is concluded that the beach is suffering not only a plant disequilibrium, but also transversal.

In the nourished section of the beach, the biggest annual area loss was found between 1992 and 1994, when values of 10,405 m^2/year were reached. It can be observed how the negative slope of the curve in this period is the most vertical one among all those considered.

With respect to width loss rates, Fig. 8 shows regression events in Profile 3 of eastern zone in most of the period, both before and after nourishment, the highest one occurs during the interval of time [1992–1994] with 10.21 m/year losses, which is rated 134% higher than the second highest value, which was only 4.36 m/year in the period [2005–2007]. However, there are also periods of stability or even some accretion, such as the one occurred during the period [1994–1996], with a beach width increase of 1.95 m/year. In recent years, the regressive trend continues, although it has never come to adopt similar values to those presented in the period [1992–1994], being during [2009–2012] slightly higher than 1 m/year.

The swell distribution study, which has been carried out to check if it could justify different rates of regression obtained for each of the studied time intervals, showed that there is a clear balance between the S–SW and E–SE directions in the periods in which the regression on the eastern zone of the beach is low or even accretion happens, what would justify that behavior, since the net longshore transport is near zero. These periods of relative stability of the beach are presented, on one hand, when the S–SW frequencies surpass E–SE frequencies, like in the period [2007–2009], where with frequency values of 0.148 and 0.163 for E–SE and S–SW respectively, an accretion of 1.45 m is produced. On the other hand, this stability also appears during moments in which despite of being the E–SE frequencies higher, S–SW wave heights are clearly superior. This case is corresponding to the period [1994–1996], which presents E–SE and S–SW frequencies of 0.1566 and 0.1153 respectively, but where Hs,o_{12} wave heights from S–SW direction are 69.2% higher, it produces an accretion of 1.95 m.

Therefore, it is observed that the higher or lower regression along the eastern side of the beach can be justified by the swell distribution that took place for each period. However, the great regressive rate in the years immediately following nourishment [1992–1994] is a real exception to this last statement. It is true that the domain of the E–SE direction during those years was very clear (Fig. 8), with frequencies of 0.1789 against a value of 0.1035 for the other direction, however this domain was not higher than the one which took place in other periods, as in [1986–1990], where the difference of frequencies was even more important. Nevertheless, with similar distributions of waves, the regression rate during the period [1992–1994] was 10.21 m/year, compared to a value of 2.53 m/year for the interval [1986–1990]. Therefore, there must be an additional cause to justify that behavior, a cause which can be found in the cross-shore-profile study of the beach.

Among the three profiles shown in Fig. 10, it is worth noting the evolution of Profile 3, located in the central and most impacted part of the zone under regression. In this case, unlike what one could expect, the sediment has not been lost gradually after the nourishment, returning the profile to its previous position before nourishment, but instead, in 2006 the cross profile on these points is very different from March 1991. It has developed a much higher slope, rising from 3.8% in 1991 before the beach replenishment to 9.2% in 2006, almost the profile of a gravel beach (Longuet-Higgins and Parkin, 1962), having lost over the years a total of 63.74 m beach width. To better understand the strong profile change produced, the volume of sand lost in Profile 3 after nourishment if it had returned to the situation prior to these actions would have been about 184.3 m^3/m, however, after the profile change, between the profile of 1991 before nourishment and 2006, additional 417 m^3/m have been lost. This means that the loss of material after the nourishment has been more than three times of what is expected if it had returned to the original profile.

Meanwhile, western zone profiles, represented by Profile 7, do not present this pronounced change in slope, but instead it has remained relatively stable. Indeed, the accretion occurred in the western zone of the beach, caused by the gradual contribution of sand coming from the East, has allowed to increase the beach width over the years without causing the commented destabilization of the initial profile. This fact is remarkable, since it can indicate that nourishments carried out in stages, with small and gradual sand contributions, may be more beneficial to the beach, not damaging the *Posidonia oceanica* meadow.

Finally, Profile 1 does not present the same evolution as Profile 3, despite of being in the same regressive zone, what can be explained by its proximity to the port, whose outer seawall offers important protection.

Profile 3 also shows that the point from which the profile of 2006 begins to match the profiles, previous to nourishment, is located around the level – 8 m, depth where the *Posidonia oceanica* meadow approximately starts in that year (Ecolevante, 2006). At lower depths, where *Posidonia oceanica* does not exist (it has gone from placing the height – 3 m in 1991 to – 7.5 m in 2006), is where the profile change happens.

All this shows that the excessive material dumped during nourishment was the cause of the regression of the meadow since it buried the plant causing its death (Manzanera et al., 1998). With the disappearance of part of the meadow, its profile stabilizer effect disappeared, as it stopped consolidating the sandy stratum where it was located. Besides, its wave energy reduction effect disappeared as well. *Posidonia oceanica* regression forced that beach section to evolve in a short period of time towards a new equilibrium profile, with a slope 142% higher than the one present in 1991 before nourishment. This resulted in fast and strong longitudinal and cross sediment losses.

This behavior would be the one that, along with the E–SE sea storms, would give an explanation to what happened in the interval [1992–1994]. Since 1994, when the new cross-shore profile was already formed, regression rates returned to levels much lower than in those two years. Indeed, in the period [1992–1994] regressive rate was 10.21 m/year, while the next highest value of regression corresponds to the period [2005–2007] with only 4.36 m/year.

Regarding the sedimentological evolution, Fig. 11 shows a gradual increase in the average grain size (D_{50}) on the dry beach, rising from 0.220 mm after nourishment to 0.301 mm in 2012. In 2014 the value is 0.298 mm so it seems that the increasing trend has stabilized around 0.3 mm. This gradual increase in the average grain size can be explained by the bedload transport of coarser sediments that were fixed by the roots of *Posidonia oceanica* and were released after its death (Maggi, 1973).

With regards to the distribution by fractions in 1987 and 2006, it can be observed how 1987 data present very high proportions of clay (< 0.0039 mm) (Fig. 12) produced by the torrential rains and floods that were led to the beach along the ravines (Xixo ravine and Folletes ravine), which are very common in the study zone (Olcina and Rico, 2000). Indeed, data from that year presents clay proportions above 80%. However, in 2006 this clay has almost disappeared. This shows precisely that temporary changes which clearly affect the quality and transparency of the waters,—indispensable factors for the permanence of the marine seagrass in the zone (Medina et al., 2001)—are not involved in the recoil of *Posidonia oceanica* in the study zone (Aragonés et al., 2014), although this does not mean that they have not diminished any of its properties (González-Correa et al., 2008). So the temporality is a determining factor for the survival of this seagrass. However, the persistent flood of *Posidonia oceanica* with sand does make the plant disappear (Medina et al., 2001) and that is the reason why the meadow regression takes place after nourishment, along with a change in the particle size distribution of the seabed. Indeed, Fig. 13 shows that in 2006 the fraction of sand predominates, especially within the Cornaglia point, with values higher than 90%, and also beyond the bathymetric – 8 m, with values higher than 60%. Therefore, the sludge corresponding to 1987 has disappeared mostly and now is the sand fraction that prevails. During flood periods such as November 1987, the sludge has covered the meadow, but its persistence in the zone has not been long enough to cause the death of the plant.

In 2012, the eastern side of Poniente Beach suffered regression rates around 1 m/year and presented width values below 30 m in some points. Taking this into account, a trend has been observed (Fig. 14) and it sets that in about 10 years the beach will face the same problems of 1991. This fact indicates that the nourishment actions carried out would have been useful for 1991–2024 period (33 years), while damaging such an important element as *Posidonia oceanica*, needs thousands of years to be formed (Mateo et al., 1997).

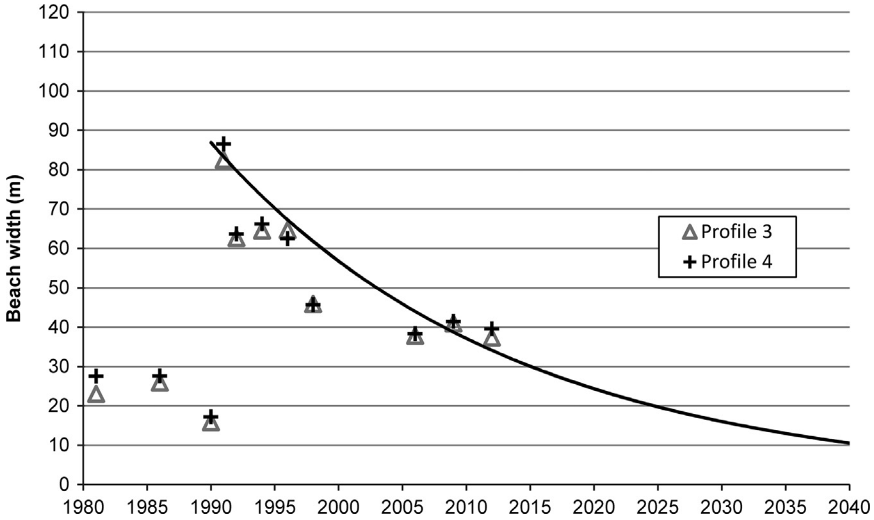


Fig. 14. Trend and evolution of the beach width in profiles 3 and 4.

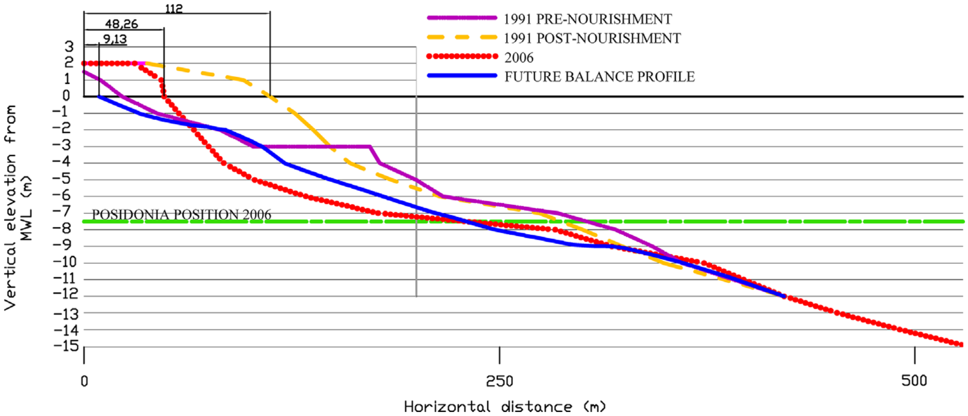


Fig. 15. Possible situation of Profile 3 in 10 years.

This future situation is confirmed by comparing these results with the profiles of other beaches with similar wave characteristics, *Posidonia oceanica* meadow position and grain size (Ampolla Beach, Moraira Beach), which allows to make an estimation about the shape of beach profile once the balance was reached (Fig. 15). As it can be observed, the estimated profile resembles the profile previous to nourishment, thus confirming the observed trend of how in 10 years, if current regression rates continue, this beach zone will almost disappear. Thus, the prediction is based on the fact that this beach will get an equilibrium situation when its cross-shore profile is equal to the balance profile of other stable beaches with similar conditions.

For new nourishments, more sustainable alternatives should be taken into account. One possibility would be its execution by dumping stages every several years, thus avoiding the impact on *Posidonia oceanica* and reducing the high initial losses of material offshore. At the same time, this would mean lower costs and environmental impacts as a result of the dredging. The following section suggests an alternative nourishment methodology to the one that was carried out.

It is considered that the volume of material dumped on Poniente Beach in 1991 was excessive, and consequently other methodologies such as staged nourishment would reduce the sand volume, which is a scarce resource, and not least, it would decrease environmental impacts, highlighting among all, the *Posidonia oceanica* disappearance.

It is worth noting the conclusions drawn in paragraph 5 about the behavior of the western zone of Poniente Beach, which has increased its beach width up to 15 m without variations neither in the cross-shore profile nor *Posidonia oceanica* conditions, due to a gradual natural nourishment of the zone. This fact supports the realization of this type of nourishment by stages since the development and durability of the meadow is not affected as long as the sand contributions into its surface are proportional to their ability to consolidate.

6. Alternative nourishment suggestion

6.1. Methodology

Whereas, the economic and environmental impacts that Poniente Beach nourishment involved, an alternative nourishment system has been developed. Using data related to the longshore transport present in the study zone, cross-shore profile of 1991 before nourishment, as well as the type of sand used, a virtual situation has been suggested considering what would have happened if they had utilized a different volume of material and beach width.

6.2. Results

Indeed, since Profile 3 represented in Fig. 10 shows how the nourishment buried part of the *Posidonia oceanica* meadow, Fig. 16 introduces an alternative nourishment system in which the

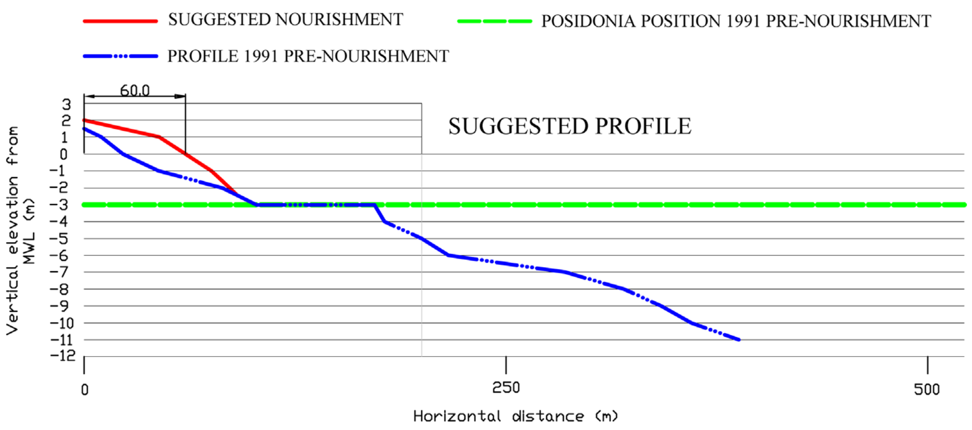


Fig. 16. Representation of the suggested nourishment in the eastern zone of Poniente Beach (cross-shore profile 3).

marine seagrass would have not been buried. In this way, the beach functionality would remain, following “Guidelines about actions in beaches” of the General Service of Coasts (Public Body), which sets out a range of values between 30 and 60 m of beach width for its functionality as an area of recreation and public use (MAGRAMA, 2008). Therefore, it would have been enough to nourish the beach until a width of 60 m as shown in Fig. 16. Last and not least, it has been tried to keep a minimum width of the beach as well as a satisfactory beach height in order to maintain its protective character when facing sea storms (Larson and Kraus, 1989). According to these authors, for width values higher than 25 m, beach protection is guaranteed, provided the ordinate of the landward edge of the beach is high enough (1.5–2.0 m). In this case, the beach height at the landward boundary is appropriate (about 2 m) to provide the required shore safety; therefore, the beach width will be the parameter to consider.

The fact that the contribution value required for the suggested nourishment would have been 183,564 m^3 is noteworthy, representing a decrease of 74% compared with the 710,847 m^3 dumped in 1991. Since the meadow would not be buried, neither the death of *Posidonia oceanica* nor the destabilization of the profile (Fig. 16) may occur, it could then be assumed that regression rates would have been similar to those before and after nourishment (once the profile stabilized), little higher than 1 m/year, and therefore, much lower than those 10 m/year which took place in the period [1992–1994].

This implies that after approximately 20 years, the beach would be approaching its functional minimum width of 30 m, which would force a new nourishment in order to reach the initial 60 m again. The volume needed for this second stage of nourishment has been calculated at 158,066 m^3, so in total, 341,630 m^3 would have been enough to get approximately the same functional period and the same protection which was obtained in the beach in 1991.

6.3. Discussion

Fig. 16 highlights the advantages if a nourishment with a lower width increase had been executed. A width of 60 m in a first stage would have provided a suitable functional width, so *Posidonia oceanica* meadow would not have been buried and its death would be avoided.

If the plant had not died, the beach profile would have kept its stability and it would have reduced the initial great losses after nourishment and the consequent regression, maintaining at the same time a more dissipative profile. It is estimated that a second nourishment stage, giving a 60 m width to the beach again, would not have been needed until 20 years later approximately.

It has been calculated that the total volume for both nourishment stages would be 341,630 m^3, so with a 52% of material saving, the beach functional period obtained with the nourishment of 1991 would have been equaled, and all this without damaging the *Posidonia oceanica* meadow.

7. Conclusions

The nourishment of the eastern zone of Poniente Beach in 1991 involved the dumping of a big amount of sand in a short period of time, what produced the burial of part of the nearby *Posidonia oceanica* meadow and its subsequent death. The well-known capabilities of this plant in terms of beach stabilization and wave energy reduction disappeared with it, therefore, the beach cross-section was forced to evolve towards a profile with a higher slope. This profile quickly evolved resulting in greater longshore and cross-shore material losses. As a result of this, during the two years following nourishment, the beach lost more than 20 m wide. Once the new profile was reached, regression levels continued, but in lower proportions.

The volume of dumped material was excessive and well above the necessary to obtain a sufficient beach width. As a result of this excess of material, part of the *Posidonia oceanica* meadow was buried, which led to its death and a high sand loss in the short term. So, it can be concluded that nourishment was not managed from the criterion of sustainability. The loss of these scarce resources creates a significant management challenge because the dredging actions necessary for sediment extraction are associated with many negative environmental and economic effects that affect both where the material is extracted and where it is placed. That is the reason why for future actions, alternative nourishment systems should be taking into account, managing them in a sustainable way, with appropriate dumping volumes to minimize the impacts on environmental conditions, while maintaining the beach functionality and its use as a protective element of the coast.

Finally, the aim of this paper has been, on one hand, to investigate the processes that have taken place at Benidorm's Poniente Beach after its nourishment as an informative element for future actions. With the information obtained, some conclusions have been extracted which could be useful for future beach nourishments around the world and especially in the Mediterranean area. Since this article has been able to demonstrate that temporary processes with durations lower than 1 year, do not generate the disappearance of *Posidonia oceanica*. However, longer burying periods cause the death of the plant and the disequilibrium of the beach cross profile, causing a greater recoil of the shoreline. On the other hand, it has been proposed that a sustainable nourishment criterion, significant volumes of sand (a scarce resource in the world) would have been saved, while maintaining the functionality and protection of the coastline without modifying the environment.

Acknowledgments

We are grateful to Alicante General Service of Coasts for the useful information provided and to the Primary Sources and Secondary Sources.

References

Aragonés, L., Pagán, J.I., López, P., Serra Peris, J.C., 2014. 17 years of changes (1989–2006) in bathymetry and sediments texture in Segura River mouth. In: Lollino, G., Manconi, A., Locat, J., Huang, Y., Canals Artigas, M. (Eds.), Engineering Geology for Society and Territory—Volume 4. Springer International Publishing, pp. 137–142.
Beachmed, 2003. Evaluación de recursos sedimentarios en los fondos antelitorales de la Comunidad Valenciana. Generalitat Valenciana.
Borg, J., Micallef, A., Schembri, P.J., 2006. Spatio-temporal variation in the structure of a deep water Posidonia oceanica meadow assessed using non-destructive techniques. Mar. Ecol. 27, 320–327.
Bouderesque, C., Meinesz, A., 1982. Découverte de l'herbier de posidonia. Cahier 4 Parc National de Port-Cros, Parc Naturel Regional de la Corse i GIS. Posidonia, Marseille. 77 pp.
Chapapría, 1987. Procesos litorales en las costas valencianas al sur del cabo de San Antonio, Memoria. Vol. 1. Polytechnic University of Valencia.
Ecolevante, 2006. Estudio ecocartográfico del litoral de las provincias de Alicante y Valencia. General Service of Coasts of the State, Madrid.
Fernández Torquemada, Y., Sánchez Lizaso, J.L., 2005. Effects of salinity on leaf growth and survival of the Mediterranean seagrass *Posidonia oceanica*. J. Exp. Mar. Biol. Ecol. 320, 57–63.
Folk, R.L., Ward, W.C., 1957. Brazos River bar: a study in the significance of grain size parameters. J. Sediment. Petrol. 27, 3–26.
Gacia, E., Granata, T.C., Duarte, C.M., 1999. An approach to the measurement of particle flux and sediment retention within seagrass (*Posidonia oceanica*) meadows. Aquat. Bot. 65, 255–268.
González-Correa, J.M., Fernández Torquemada, Y., Sánchez Lizaso, J.L., 2008. Long-term effect of beach replenishment on natural recovery of shallow *Posidonia oceanica* meadows. Estuar. Coast. Shelf Sci. 76, 834–844.
Grunnet, N.M., Walstra, D.J.R., Ruessink, B.G., 2004. Process-based modelling of a shoreface nourishment. Coast. Eng. 51 (7), 581–607.
Hallermeier, R.J., 1978. Uses for a calculated limit depth to beach erosion. In: Proceedings of the 16th Coastal Engineering Conference, ASCE. pp. 1493– 1512.
Hallermeier, R.J., 1981. A profile zonation for seasonal sand beaches from wave climate. Coast. Eng. 4, 253–277.
Hamm, L., Capobianco, M., Dette, H.H., Lechuga, A., Spanhoff, R., Stive, M.J.F., 2002. A summary of European experience with shore nourishment. Coast. Eng. 47, 237–264.
Landaeta, J., 2001. Potenciales impactos ambientales generados por el dragado y la descarga del material de dragado. (Venezuela), Instituto Nacional de Canalizaciones. Dirección de Proyectos e Investigación (Ed.).
Larson, M., Kraus, N.C., 1989. SBEACH: Numerical model for simulating storm-induced beach change. Report 1: empirical foundation and model development. Technical Report CERC.
Longuet-Higgins, M.S., Parkin, D.W., 1962. Sea waves and beach cusps. Geogr. J. 128, 194–201.
Maggi, P., 1973. Le problème de la disparition des herbies à Posidonies dans le golfe de Giens, Science et Pêche. 221, 7–20.
MAGRAMA, 2008. Guidelines About Actions in Beaches. General Service of Coasts of the State, Madrid.
Manzanera, M., Pérez, M., Romero, J., 1998. Seagrass mortality due to oversedimentation: an experimental approach. J. Coast. Conserv. 4, 67–70.
Marbá, N., Duarte, C.M., 1998. Rhizome elongation and seagrass clonal growth. Mar. Ecol. Prog. Ser. 174, 269–280.
Mateo, M.A., Romero, J., Pérez, M., Littler, M.M., Littler, D.S., 1997. Dynamics of millenary organic deposits resulting from the growth of the Mediterranean seagrass *Posidonia oceanica*. Estuar. Coast. Shelf Sci. 44, 103–112.
Mazón, T., 2010. Benidorm. Un destino turístico de altura. Rev. Investig. Tur. 2, 8–22.
Medina, J.R., Tintoré, J., Duarte, C.M., 2001. Las praderas de Posidonia oceánica y la regeneración de playas. Rev. Obras Públicas 3 (409), 31–43.
MOPT, 1991. Proyecto de liquidación de obras de emergencia de la playa de Poniente de Benidorm (Alicante). General Service of Coasts of the State, Madrid.
Ojeda, J., Díaz, M.P., Prieto, A., Álvarez, J., 2013. Línea de costa y sistemas de información geográfica: modelo de datos para la caracterización y cálculo de indicadores en la costa andaluza. Geogr. Investig. (Univ. Alicante) 60, 37–52.
Olcina, J., Rico, A.M., 2000. Estudios sobre lluvias torrenciales e inundaciones en la provincia de Alicante (1982–1999). Ser. Geogr. 9, 71–92.
Olcina, J., Torres, F.J., 1997. Incidencia de los temporales de levante en la ordenación del litoral alicantino. 26. Papeles de Geografía de la Universidad de Murcia, Murcia, pp. 109–136.
Pergent-Martini, C., Leoni, V., Pasqualini, V., Ardizzone, G.D., Balestri, E., Bedini, R., Belluscio, A., Belsher, T., Borg, J.A., Boudouresque, C.F., Boumaza, S., Bouquegneau, J.M., Buia, M.C., Calvo, S., Cebrian, J., Charbonnel, E., Cinelli, F.C.A.G.D.M., Dural, B., Francour, P., Gobert, S., Lepoint, G., Meinesz, A., Molenaar, H., Mansour, H.M., Panayotidis, P., Peirano, A., Pergent, G., Piazzi, L., Pirrotta, M., Relini, G., Romero, J., Sanchez Lizaso, J.L., Semroud, R., Schembri, P.J., Shili, A., Tomasello, A., Velimirov, B., 2005. Descriptors of *Posidonia oceanica* meadows: use and application. Ecol. Indic. 5, 213–230.
Sánchez Lizaso, J.L., 1991. Provided data related to *Posidonia oceanica* position in 1991, Unpublished results.
SPM, 1973. U.S. Army Corps of Engineers, CERC. Shore Protection Manual, 1st ed.
UNE, 2012. Tests for geometrical properties of aggregates. Asociación Española de Normalización y Certificación (AENOR). UNE-EN 933-1.