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Detecting problematic beach widths for the recreational function along the Gulf of Valencia (Spain) from Landsat 8 subpixel shorelines

This work shows a continuous and regional monitoring of the beach width and how to link it with the recreational function of these spaces. Shorelines automatically derived from Landsat 8 satellite were employed for this purpose, covering up to 83 dates (2013 – 2016) and 150 km of beaches. The study included the microtidal beaches of the Gulf of Valencia, a strongly developed coast with intensive use in the Western Mediterranean. Beach widths were defined in alongshore coastal segments of 80-meter length. Annual mean width and annual percentiles appeared as representative statistics of the beach state and the most unfavorable widths occurred throughout the year. Considering these statistical descriptors, beach segments were classified according to their adequacy to sustain a recreational function. The integration of descriptors of the beach width and use of the beach data on a regional scale offers a holistic approach to identify potentially problematic segments, crucial information for coastal managers.

Keywords: Coastal dynamics; Automatic shoreline extraction; Intra-annual beach variability; Remote sensing; Coastal management; Western Mediterranean

Introduction

Beaches are natural environments able to provide protective, habitat and recreational function (Prodger, Russell, Davidson, Miles, & Scott, 2016). The latter one constitutes an important socioeconomic resource (Alexandrakis, Manasakis, & Kampanis, 2015; Gopalakrishnan, Smith, Slott, & Murray, 2011; Gormsen, 1997) in areas as the Mediterranean, where 500 million tourists per year are forecasted for 2030 (UNWTO, 2013). Beaches are worldwide threatened by erosive processes (Bird, 2013; Cooper & McKenna, 2008). At the regional level, they are motivated by disturbances in sediment transport and its entry into the coastal system. Worldwide, higher global temperatures will alter hydrodynamics and rise sea level (Nicholls & Cazenave, 2010; Slott et al., 2006) with forecasts ranging from 0.45 to 0.82 m by 2081–2100 according to the IPCC Fifth Assessment Report (IPCC, 2014) under the worst-case scenario of 2.6–4.8 °C global warming. Alterations of the shoreline position and reductions of the beach surface jeopardize the maintenance of the beach functions. This may result in loss of habitats (Feagin, Sherman, & Grant, 2005; Fish et al., 2005), increased coastal flooding (Hinkel et al., 2013), and a threat to the tourism industry and the economy associated with the recreational function (Gopalakrishnan et al., 2011; Phillips & Jones, 2006).

The management of the beaches considering their recreational function has become a great concern of Integrated Coastal Zone Management (Micallef & Williams, 2002). The need for certain physical characteristics in order to maintain the beach functions makes it necessary to pay special attention to their morphology (Ballesteros et al., 2018; Jiménez et al., 2011). Focusing on the characteristics of the beach from the recreational point of view, different authors have emphasized the necessity of a favorable sediment status and have even defined a minimum beach width. Although the criteria are heterogeneous, most authors have pointed out that a width below 30-35 m would be detrimental to the development of recreational beach functions (Alemany, 1984; Houston, 1996; Jiménez et al., 2011; Sardá et al., 2009; Yepes, 2002). Likewise, Valdemoro and Jiménez (2006) pointed out that previous surveys (CEDEX, 2000; Jiménez & Sánchez-Arcilla, 2001; Villares, 1999) identified the excessive beach width as a problematic issue for recreational purposes, as users may perceive it as uncomfortable (Cabezas-Rabadán et al., 2019). Recently, the width of the beach has begun to be used by administrations to regulate the use of the beaches and the development of activities, as in the Territorial Action Plan for Green Coastal Infrastructure (PATIVEL) for the Valencian region in Spain (GVA, 2018).

Considering the management associated to the beach morphology, it is essential to identify processes and to quantify the dynamics of key parameters through the implementation of long-term monitoring (Defeo et al., 2009; Micallef & Williams, 2002) that supply up-to-date and objective information.

Therefore, it is necessary to define parameters or indicators for describing the coastal state (Giardino, Santinelli, & Vuik, 2014; Van Koningsveld, Davidson, & Huntley, 2005). Shoreline position and beach width seem useful for that purpose. In order to define them, traditional methods as photointerpretation (Ford, 2013; Jones et al., 2009; Morton et al., 2004) only provide measurements at specific moments. Among the most recent techniques, DGPS allows surveying large areas (Pardo-Pascual et al., 2005; Psuty & Silveira, 2011) although they require in-situ data acquisition while video-based techniques (Aarninkhof et al., 2003; Davidson et al., 2007; Sánchez-García, Balaguer-Beser, & Pardo-Pascual, 2017) are limited to a local scale. By contrast, remote sensing is a potential source of useful data for coastal planning as it offers a continuous record of data of the whole terrestrial surface, even in remote areas (Cenci et al., 2017; Guariglia et al., 2006). Since 2008, Landsat mission has offered free available satellite medium-resolution imagery of the last three decades with worldwide coverage. Different algorithms have been developed in order to overcome the restriction of an excessively coarse spatial resolution (30 m) and to allow defining Satellite-Derived Shorelines (SDS) with sub-pixel precision (Almonacid-Caballer, 2014; Foody, Muslim, & Atkinson, 2005; Hagenaars et al., 2018; Li & Gong, 2016; Liu et al., 2016; Liu et al., 2017; Pardo-Pascual et al., 2018; Pardo-Pascual et al., 2012). Recently, SHOREX has appeared as a system that offers an automated definition of the shoreline position at major spatial and temporal scales (Palomar-Vázquez et al., 2018). Although the accuracy of this methodology is lower than that of traditional sources, it opens a new scenario with many available measurements throughout the year. The intra-annual changes can reflect the beach response to storms and other events (Cabezas-Rabadán et al., 2018; Pardo-Pascual et al., 2014) allowing an approach to the most unfavorable situations for the maintenance of beach functions throughout the year (Cabezas-Rabadán & Pardo-Pascual, 2017), unknown with traditional techniques.

Continuous monitoring of shoreline data has great potential to characterize beach morphology as well as to quantify key parameters of the beach state and its dynamism. These data would be especially interesting for management if it was possible to integrate them with information on the recreational function of beaches. It would allow the identification of beach segments in which their physical characteristics (such as emerged width) conflicts with their use. The integration of data related to the human use of the beaches as well as their morphology can be achieved by applying GIS tools to coastal areas (Anfuso & Martínez, 2009; Cenci et al., 2017).

Based on tens of Landsat 8 subpixel shorelines per year, the main goals of this work are (i) quantifying statistical descriptors of the beach width after monitoring its intra-annual variability, and (ii) integrating width descriptors and recreational use data to identify segments with negative influence on the recreational function.

The work is carried out on the microtidal beaches of the Gulf of València (Spanish Mediterranean). This coast faces high anthropogenic pressure and recreational use as well as erosive problems, constituting a representative example of the coastal areas in which this application of the shoreline data would be useful for coastal management.

Study area

The analysis was developed on the beaches of the Gulf of Valencia, on the east coast of the Iberian Peninsula, between the Ebro Delta and the Sant Antoni Cape (Fig. 1). This coast constituted a sedimentary cell nowadays fragmented by different artificial sediment traps (Pardo-Pascual & Sanjaume, 2019). It has an average astronomical tidal range below 20 cm and small waves (H_s = 0.7 m; T_p = 4.2 s). Nevertheless, during storms the water level position can raise up 1.32 m, and the significant height of the waves can reach 6.55 m, and 15 s of peak period (Pardo-Pascual et al., 2014; Pardo-Pascual & Sanjaume, 2019), causing important losses of sediment on the beach.

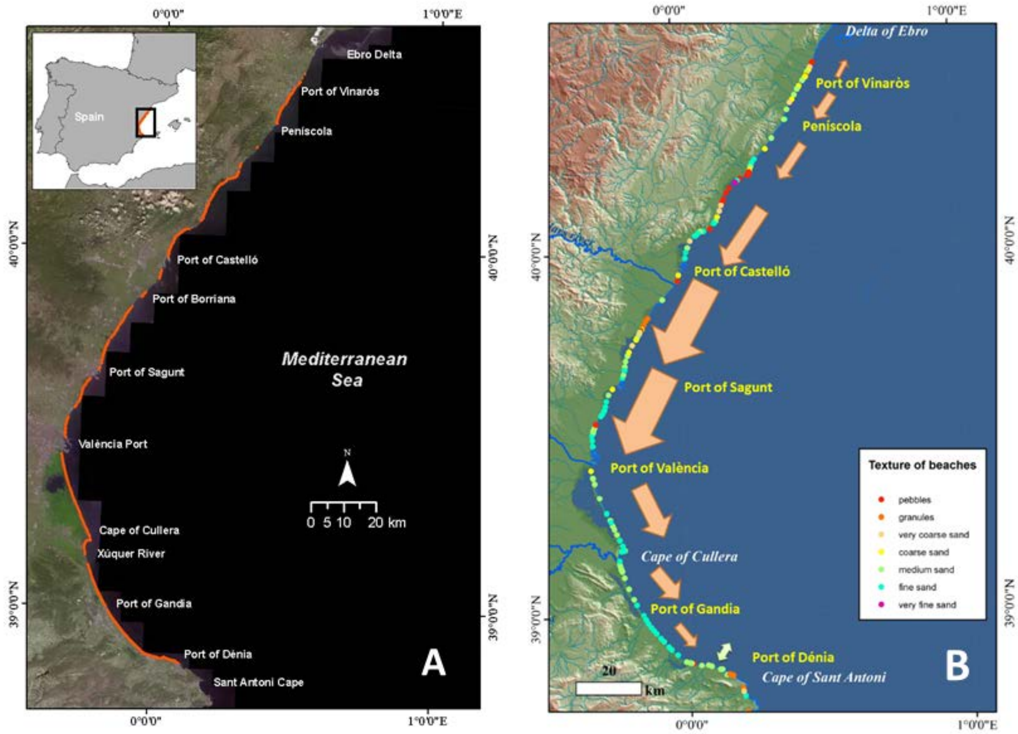

Fig. 1. A) Study area along the Gulf of Valencia and the main ports and alongshore obstacles. B) Transport pattern (arrows) along the study area and Sediment texture distribution (MAGRAMA, 2007).

This area has a strong littoral drift that provokes southerly sand transport and contributes to the distribution of the sediment alongshore (Fig. 1B) sometimes interrupted by the presence of civil engineering structures (Sanjaume & Pardo-Pascual, 2005). It is a sedimentary coast composed mainly of medium and fine sandy beaches, all of which also include some stretches of granules and gravel (MAGRAMA, 2007; Pardo-Pascual & Sanjaume, 2019; Sanjaume, 1985). In the Valencian region, practically all the beaches are equipped for a leisure purpose (Obiol-Menero, 2003). They are intensively used and constitute the basic resource of the tourist industry. The recreational value of these spaces provides important benefits to the society, and this sector contributes to the economy of the Valencian region with more than 14 % of the regional GNP (Rico-Amorós, Olcina-Cantos, & Sauri, 2009).

A process of tourist-residential urbanization has been developed linked to the recreational use of the beaches. Buildings and constructions have been located very close to the coastline, and a large number of groins (141) and marinas (16) have been built (Pardo-Pascual & Sanjaume, 2019). This high anthropogenic pressure has greatly degraded the littoral and contributed to a significant coastal regression (Obiol-Menero, & Pitarch-Garrido, 2011; Yepes & Medina, 2005) that affects over 26% of the region (European Comission, 2009). This phenomenon has led to numerous anthropogenic actions and nourishment projects in order to maintain the beach size (Hanson et al., 2002). During the period 1983-2002, 287 actions were carried out and budgeted at €170 million, with an average of 15 actions/year and €0.6 million/action (Obiol-Menero, 2003). The maintenance of the beaches is a responsibility of the Directorate General of Coast (DGC) part of the Ministry of Environment, although it is managed by different units such as the Valencian Demarcation, responsible for developing regional policies (Barragán-Muñoz, 2010).

Data

Two are the main inputs for the present paper:

On the one hand, a set of Satellite-Derived Shorelines (SDS) from Landsat 8/OLI (Operational Land Imager) between May 23rd, 2013 and December 27th, 2016. Shoreline positions were defined from the short-wave infrared band (SWIR-1, 1566-1651 nm, 30m/pixel) using the SHOREX system following a well-established methodology (Palomar-Vázquez et al., 2018) reaching a subpixel accuracy of 6.6 m RMSE (Pardo-Pascual et al., 2018).

The study area (Gulf of Valencia, eastern Spain) is covered by Landsat paths 198 and 199, rows 32 and 33 (Fig. 2). The available number of images was not homogeneous along the study area: Sectors B and C, that covered most of the coast, had an overlap of scenes and up to 77 and 83 shorelines respectively (Fig. 3) while, at the northern and southern extremes, sectors A and D only had 32 and 36 shorelines.

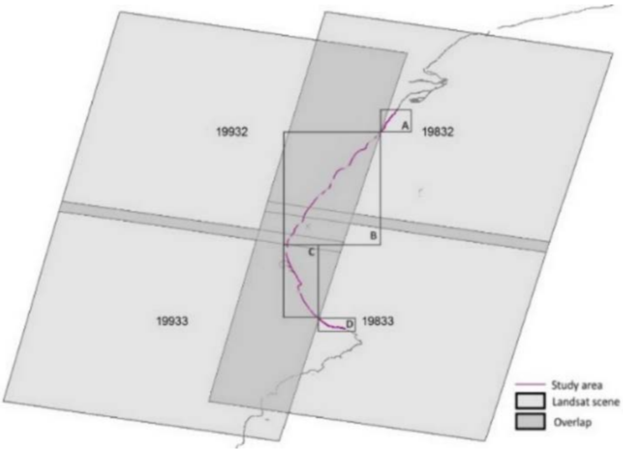

Fig. 2. Considering the number of available images (and therefore potential shorelines to be defined) there are four different sectors. B and C comprise the overlap of Landsat paths 198 and 199 (highlighted). Images available free of charge from USGS archive (http://glovis.usgs.gov/).

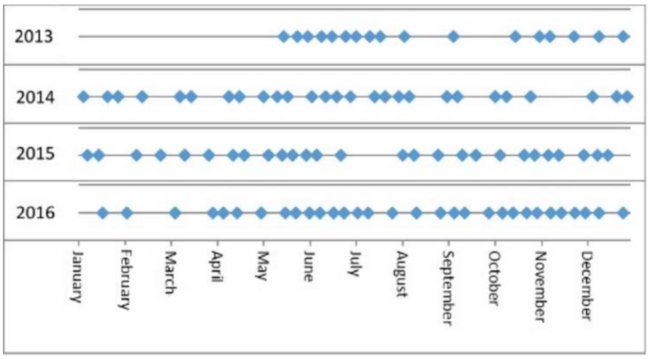

Fig. 3. Example of Landsat 8 imagery used in sector C, the one with more available images.Gaps in shoreline data availability appeared due to the cloudy days. Furthermore, there were no images available for the first months of 2013 as the satellite had just been launched

On the other hand, for defining the recreational use of each beach segment the information of two public and open databases were analyzed: the Spanish Catalogue of Beaches (MAPAMA, 2017) and the Land Cover and Use Information System of Spain SIOSE (IGN, 2011). The Catalogue of Beaches provided descriptive information about the state, characteristics, and management of the beaches. It was used to define the level of facilities' supply and the occupancy rate. The SIOSE 2011 database was used as land use input: for each 80-meter analysis segment, the existence of coverage associated with the recreational use of the beach and the tourism sector (residential, hotel, commercial or camping use) was determined. In those cases, the distance from each beach segment to those coverages was identified. The data about beach width and beach usage were combined using GIS tools in order to obtain a beach recreational usage indicator for each segment.

Methodology

The methodology here described creates a bridge between SDS and recreational use of the beach data. Firstly, the beach width is defined and classified in terms of adequacy for sustaining the recreational function. Secondly, the recreational function of the beaches is parameterized. Finally, both sources are linked in order to define the influence of the widths on the recreational function.

Definition of the beach width

In order to determine the width, the inland boundaries of the beaches were defined as the inner limit with the promenade or the closest buildings, vegetation or dunes. This line was digitalized in GIS software using PNOA orthophotographies of the study area with 0.25 m spatial resolution (IGN, 2015). The inner line was fixed or almost stable along the study period, and the error associated with the photointerpretation clearly presented a lower magnitude than the definition of the shoreline position. The length of the segment of 80 m was chosen for the analysis as it was considered adequate to detect problematic segments while avoiding occasional width changes related to regressions at the inner edge of the beach, or due to small-scale formations on the coastline such as beach cusps. Therefore, the inner line was divided alongshore into 80 m segments, and the shoreline points of each date were associated with the closest segment. For each segment, the distance from each satellite shoreline to the inner line gives the average subaerial beach width on every available date. (Fig. 4).

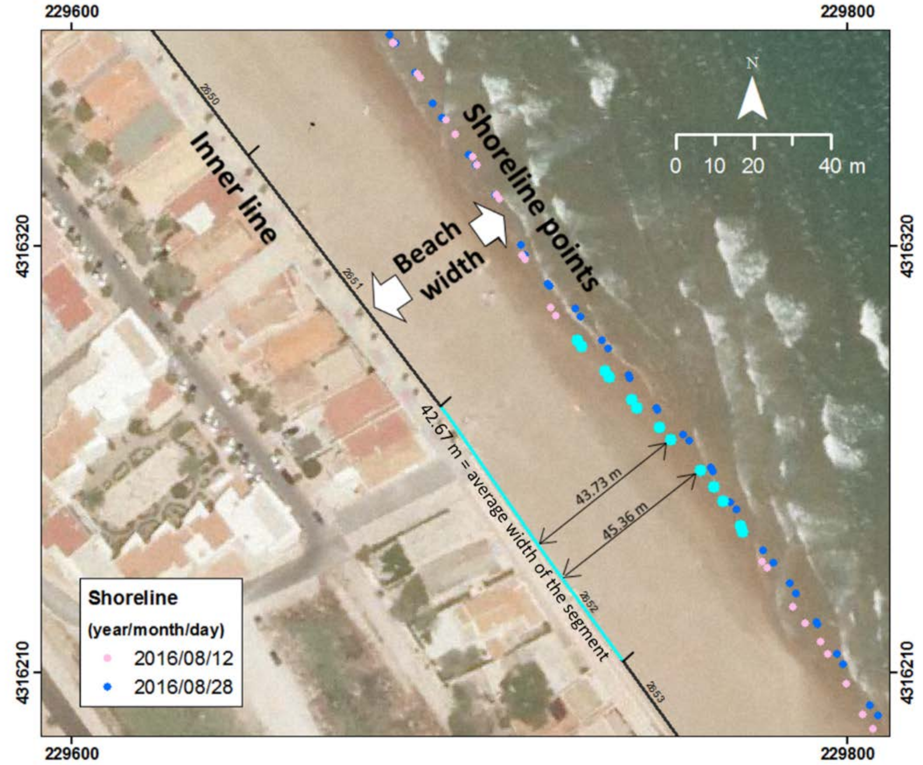

Fig. 4. Detail of the shoreline points of 12th and 28th of August, 2016 and the inner line segments of 80 m length used as a reference. Beach width on the highlighted 80 m segment was calculated as the average distance to the associated shoreline points on the date 2016/08/28 (42.67 m). The distances of two shoreline points are shown as an example (45.73 and 45.36 m). ETRS89 UTM31N.

Different statistics were defined as potential descriptors of the beach width:

-Annual mean width (AMW), as the average of all the widths recorded over each year.

-Annual percentiles P_{10}, P_{15}, P_{20}, P_{30}, and P_{50}, being percentile P_n the distance at which n % of the points are located more inland.

Definition of criteria for detecting segments with inadequate width for the recreational function

Widths below (or above) certain thresholds may be perceived as negative by beachgoers. Different works have defined 30-35 m as the minimum beach width (Alemany, 1984; Lozoya, Sardá, & Jiménez, 2011; Sardá et al., 2009; Yepes, 2002), while other works support the existences of a negative perception of excessive widths (Cabezas-Rabadán et al., 2019; Valdemoro & Jiménez, 2006).

Following the previous criteria and according to the width data, beach segments were classified reflecting their inadequacy for sustaining the recreational function (Tab. 1). Segments narrower than 30 m were considered to have an insufficient width and therefore problematic for the recreational function, and they were given a problematic value of 2. Similarly, those under 15 m, half of the problematic threshold, were defined as very narrow and received an associated value of 3. Otherwise, segments wider than 120 m, four times the problematic threshold had their width defined as very wide and received a value of 1, considering the disturbance of having to walk to reach the areas close to the shore. Finally, segments between 30 and 120 m wide were considered adequate for the recreational use and therefore their inadequacy value was 0. Following these criteria, an analysis of the width situation on the beaches of the Gulf of Valencia was carried out.

Table 1. Classification of beach segments according to their width and their inadequacy for maintaining the recreational function.

Beach width (m)	<15	15-30	30-120	> 120
Classification	Very narrow	Narrow	Adequate	Very wide
Inadequacy value	3	2	0	1

The next step is to define how to use the beach width descriptors previously described (AMW or percentiles) to decide whether a segment is adequate or not for recreational use. In order to analyze the strictness of the descriptors when detecting inadequate widths, we compared the number of detected segments employing each parameter as well as considering the width data of the different years. A comparison of the use of the width parameters P_{10} and the annual mean width (AMW) was carried out on beach segments experiencing problems associated with insufficient widths. Those segments were selected as in that area the General Directorate of Sustainability of the Coast and the Sea (DGCS) repeatedly carried out nourishments considered as necessary for recovering the beach after storm episodes.

Width influence on the recreational function of the beach

The existence of excessive or insufficient beach widths presents an inconvenience on the recreational function of the beaches. However, it finally depends not only on the width but also on the recreational use of the beach. Therefore, for each analysis segment, the recreational use of the beach was defined considering the occupancy rate, the facilities supply, and the development as a recreational space and tourist resort of the beach itself and the surrounding land (Fig. 5). From the Spanish Catalogue of Beaches (MAPAMA, 2017) we defined indicators rating the beach occupancy (low use “1”; medium use, “2”; high use “3”) and the facilities supply (low-equipped “1”; semi-equipped “2”; full-equipped “3”). The recreational and tourist development of the beach was defined according to SIOSE 2011 (IGN, 2011) rating the presence of land cover associated with recreational use in the vicinity of the beach (Non-existent, “1”; existent located less than 500 m away, “2”; located less than 150 m away, “3”). These values were averaged for each segment in order to define the “recreational use” of the beach, with values ranging from 1 to 3.

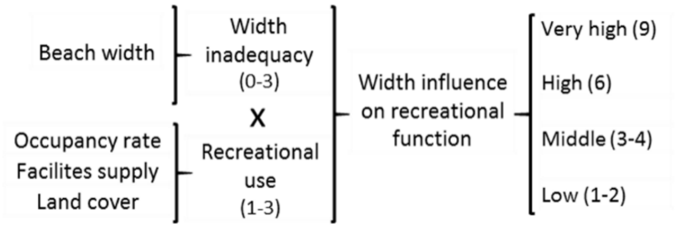

Fig. 5. Methodology for obtaining indicators of (i) the width inadequacy for sustaining the recreational use and (ii) the recreational use. They are combined in order to define the width influence on the recreational function.

This parameter was combined in a matrix (Tab. 2) with the width inadequacy (very narrow “3”, narrow “2”, very narrow “1” or adequate “0”) defined according to, on the one hand, the percentiles 10 and 90 and, on the other hand, the annual mean width.

Table 2. Width influence on the recreational function of the beach

Beach width (m) and inadequacy value	Recreational use		
	Low (1)	Intermediate (2)	High (3)
30-120 m, adequate (0)	0	0	0
> 120 m, very wide (1)	1	2	3
15-30 m, narrow (2)	2	4	6
< 15 m, very narrow (3)	3	6	9

The width influence on the recreational function of the beach was defined according to the different values of the matrix as non-existent “0”, low “1-2”, middle “3-4”, high “6” or very high “9”. This analysis was implemented in GIS in order to obtain the values along the whole study area.

Results

Characterization of the beach width

Shoreline positions were defined by points along 154 km of the coast for the period 2013 – 2016. Figure 6 shows, for three 80-meter analysis segments (A, B and C) the distances to the coastline points recorded on the different dates of 2016. These distances define the beach width following the methodology shown in Fig. 4. Several points can be seen vertically aligned for each date given that not every point in an 80 m segment has the same distance to the inner line. This variability is caused by high alongshore fluctuations (as shown in Fig. 4). At the same time, significant changes appeared throughout the year, apparently following an annual oscillation.

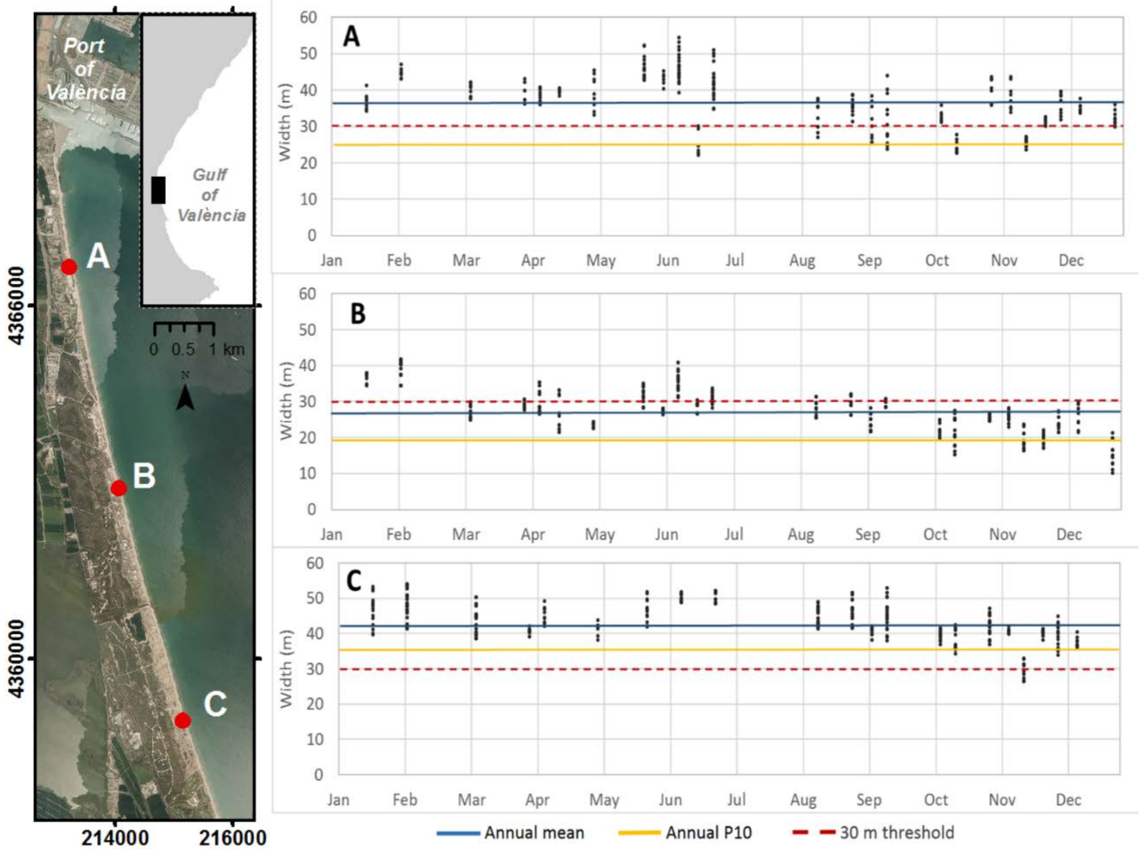

Fig. 6. On three analysis segments of the same coastal sector: shoreline points along 25 dates from 2016 employed for defining the annual mean width (AMW) and the annual 10th percentile (m), and the problematic threshold of 30 m.

Following this example, the annual mean width (AMW) was defined for all the beach segments of the Gulf of Valencia from the width values registered during 2016 (Fig. 7, 8). There was a great diversity of widths, ranging from 3.5 up to 195 m. The mean width during the year 2016 was 51.90 m and the median was 44.91 m. Nevertheless, the vast majority of beaches had an AMW between 30 and 45 m (37.6 %) and between 45 and 60 m (25.1 %). Beaches wider or narrower were progressively less common. This is of interest considering the potentially insufficient or excessive widths for recreational use. An important percentage appeared below the 30 m threshold (12.8 %), while very few beaches were narrower than the critical 15 m (1.3 %). About wide beaches, a significant amount presented between 60 and 120 m (20.7 %), but the percentage of those wider than the 120 m threshold was very small (3.8 %).

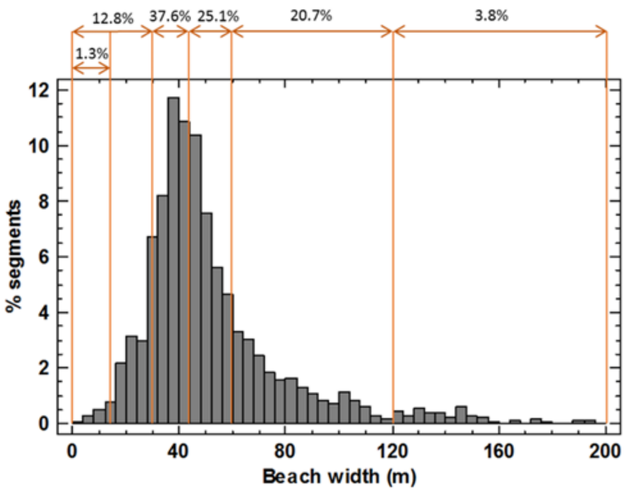

Fig. 7. Annual mean width of the beach segments (m) considering the shoreline positions along 2016.

Fig. 6 also shows that several punctual measurements were very distant from their respective AMW. As an example, for the segments A, B, and C the minimum widths registered (22.20, 10.10 and 26.39 m respectively) were well below the annual mean widths (37.27, 27.94 and 43.20 m). Considering this, P_{10} was calculated as a parameter to express the width on the basis of all the data but giving more weight to the most unfavorable cases. The values of P_{10} (26.45, 19.91 and 36.67 m) appeared remarkably below the AMW. As a result, comparing both statistical descriptors with the problematic threshold (defined as 30 m), the width on the segment C is adequate, while the segment B registers an insufficient width. Nevertheless, segment A becomes the most interesting: while the AMW (37.55 m) stayed over the problematic threshold, P_{10} (26.86 m) appeared below it.

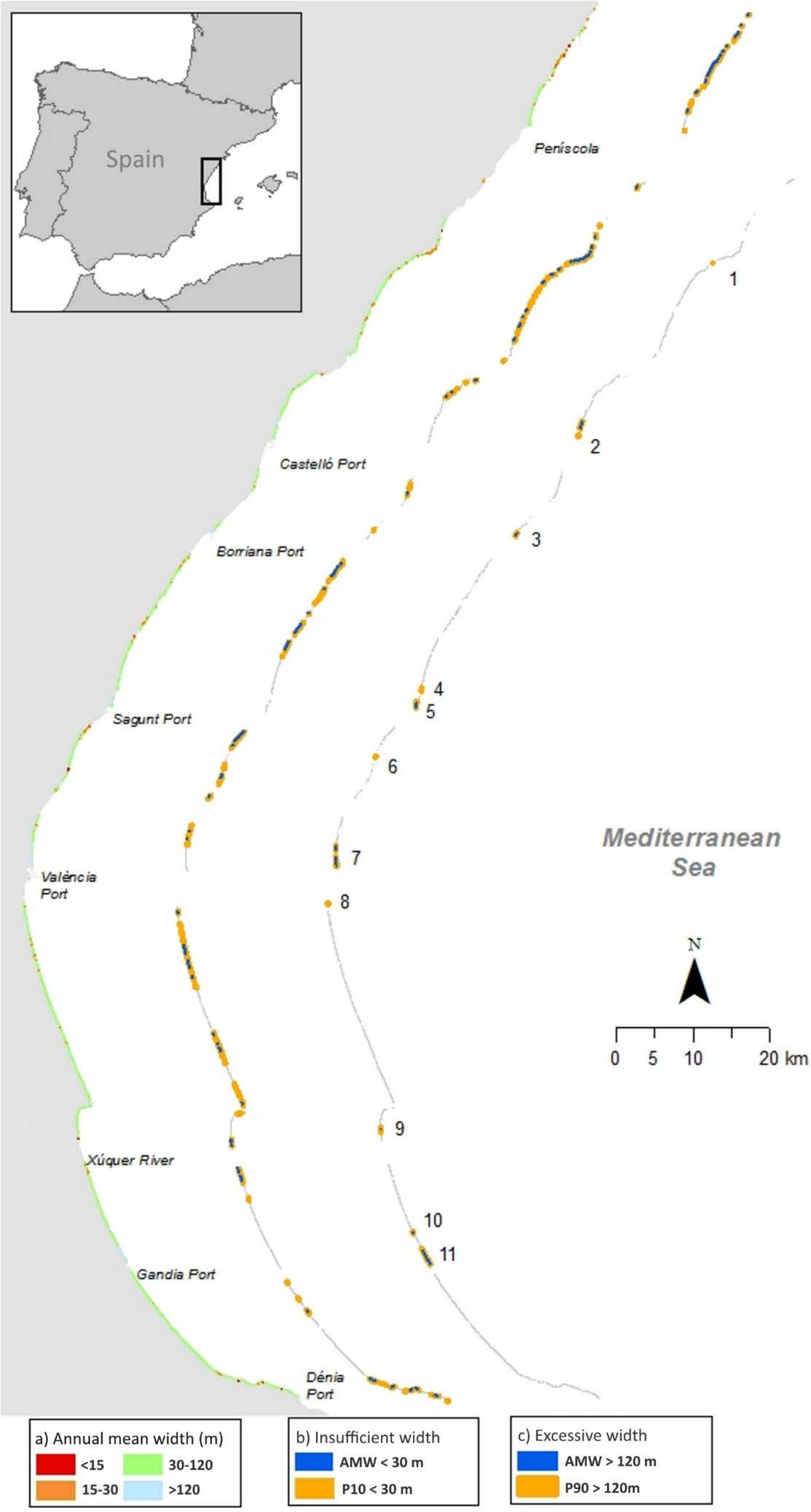

Fig. 8. a) Annual mean width (AMW) (m), b) Segments narrower than 30 m, c) segments wider than 120 m.

The differences between the AMW and the percentiles varied a lot among analysis segments. The average difference between AMW and $P_{10}$of the beach widths was 7.9 m. Nevertheless, in some cases, the difference was very small, close to two meters, while in other segments it was greater than 20 m (Fig. 9).

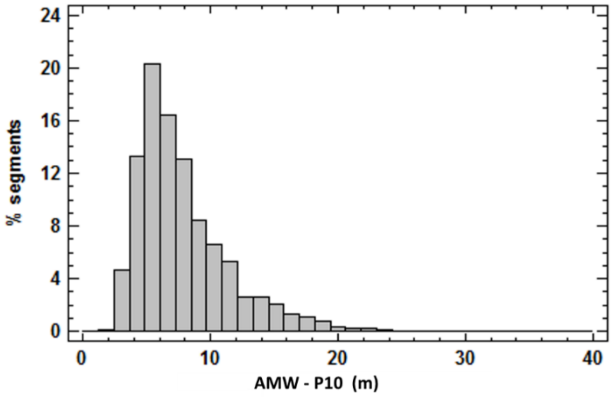

Fig. 9. Difference between AMW and P_{10} considering 2016 data and all the segments of the Gulf of Valencia.

Therefore, in several cases, the width characterization varied a lot when using as reference the AMW or annual percentiles. In order to compare the results, the annual percentiles and the AMW were defined for the Gulf of Valencia. Results showed how the use of lower percentiles increased the characterization of segments with lower widths, and vice versa (Fig. 10).

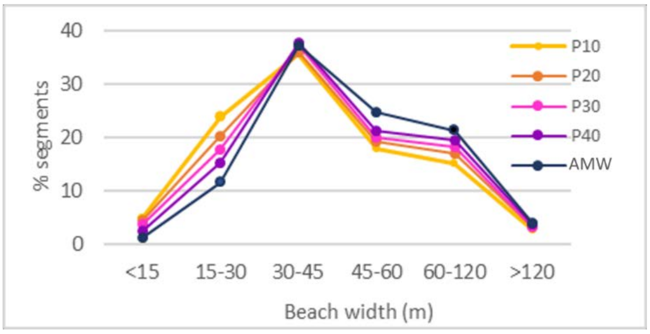

Fig 10. Classification of beach segments employing different percentiles and the AMW from 2016 shoreline data.

While in the case of segments between 30 and 45 m the differences were small, there were major differences in those segments narrower than 30 m. This is important, as those were the segments that could experience functional problems. Therefore, the identification of the insufficient width situations may be crucial in them. In particular, the AMW was the parameter that identified the fewest number of segments as narrower than 30 m (and therefore under the problematic width threshold).

The objective was to detect the problematic segments, either too narrow or too wide. While AMW identified few problematic cases, P_{10} and P_{90} were able to detect segments with inadequate widths even when the problematic situation was not constant along the time. The different strictness in the detection occurred similarly the four years analyzed (Fig. 11). At the same time, it seemed that the mean position was more stable between the different years than small percentiles that probably were more affected by extreme positions of the shoreline.

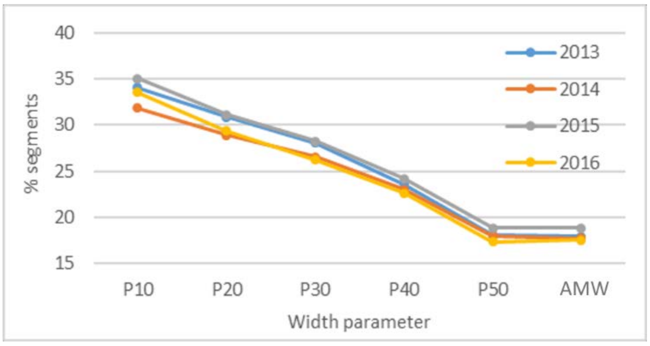

Fig. 11. Detection of segments narrower than 30 m with different width parameters.

Potentially problematic segments (narrower than 30 m) were detected along the Gulf of Valencia using both P_{10} and annual mean width during 2016. The P_{10} considered as problematic more segments (29% of the segments) than the annual mean width (13%) (Fig. 12). The most remarkable effect is that the P_{10} identified problematic areas rather than isolated segments giving geographical robustness to the analysis (Fig. 8).

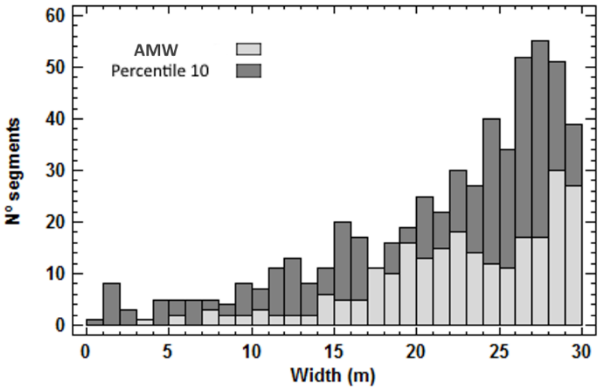

Fig. 12. Detection of problematic segments (narrower than 30 m) by the parameters annual mean width (AMW) and the P_{10}. The latter one allowed to detect more segments than the AMW.

A comparison between P_{10} and AMW was made on the erosive beach of Piles, where the width is a problematic issue for the maintenance of beach functions. There, beach nourishments have been repeatedly carried out by the Valencian Demarcation of the Directorate General of Coast (DGC): 6500 m^3 of sand were supplied between December 2016 and March 2017 trying to compensate the damage caused by the storm events of November and December 2016. Previously, 2530 m^3 were dumped between October and November 2015, and more recently 2960 m^3 in November 2017. Despite the evident erosive problems, the AMW of 2016 was over the problematic threshold of 30 m. On the contrary, $P_{10}$was sufficiently restrictive and considered the most adverse positions registered throughout the year. This allowed the identification of all the beach segments that experienced functional problems (Fig. 13).

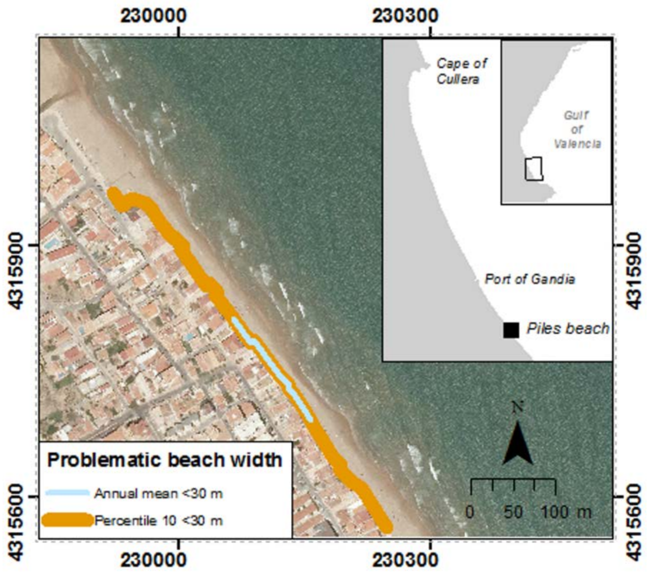

Fig. 13. Identification of beach segments narrower than 30 m according to their AMW (thin line) and the P_{10} (thick line) of 2016 on the erosive beach of Piles, south of Gandia Port. P_{10} allows better identification of the problematic segments. PNOA orthophoto, ETRS89 UTM 31N.

Too wide beaches can also be problematic for recreational functions. Therefore, segments wider than the 120 m threshold were identified according to both the AMW and the P_{90}. In several cases, the AMW was below the threshold although the P_{90} exceeded it. According to the P_{90}, the stricter parameter, 7.68 km of beaches were identified as wider than 120 m (almost 5 % of the studied area). Eleven different sectors along the Gulf of Valencia could be identified considering consecutive segments with very wide width (Tab. 3, Fig. 8). These sectors were sediment accumulations located mainly north of obstacles to the longshore sediment transport (Fig. 1). Some of them were jetties which aim is to support and to maintain a wide beach (sectors 1 and 6), while jetties associated to sectors 8 and 9 attempts to protect the accumulation in the mouth of Xúquer and Túria rivers. Nevertheless, the majority of very wide sectors were associated with ports (2, 3, 4, 5, 7, and 11). Especially remarkable due to their length were the sectors 2 (1.1 km), 7 (1.7 km) and 11 (2.2 km), associated to Castelló, Valencia, and Gandia ports, all of them leaning on their northern jetties.

Table 3: Segments wider than 120 m according to the P_{90} and 2016 shoreline data, as well as their AMW and the associated disturbance elements.

Sector	Beach	Length (m)	Annual mean width (m)	Associated disturbance element
1	Torreblanca	80	100.2	Groins for sand accumulation
2	Castelló	1120	126.3	Castelló Port
3	Borriana	400	139.9	Borriana Port
4	Canet	320	108.8	Canet Port
5	Sagunt	880	136.5	Sagunt Port
6	El Puig	240	109.7	Jetties for sand accumulation
7	Malvarrosa	1760	147.8	Valencia Port
8	Pinedo	160	146.9	Jetties at Túria river mouth, Valencia Port
9	Sant Antoni	320	113.5	Jetties at Xúquer river mouth

10	Ahuir	160	116.8	Vaca River mouth
11	Gandia Nord	2240	137.6	Gandia Port

Width influence on the recreational function

The negative influence on the recreational function was defined considering both the recreational use of the beach and the width inadequacy (Tab. 4).

The Gulf of Valencia showed high recreational use of the beaches: only 14.28 % of the segments had a low recreational use, while 42.16 % and 43.56 % had intermediate and high use respectively. The recreational function of the beach was mostly developed on beaches with an adequate width (30-120 m). According to the AMW, 35.75 % of these segments had an intermediate use, and 37.10 % had high use. Nevertheless, it is important to notice that several times segments with inadequate width also fostered recreational functions. Although it was very rare on segments narrower than 15 m (1.30%), it was quite common on segments between 15 and 30 m, that plenty of times fostered intermediate (5.47 %) and high recreational use (2.50 %). The opposite situation appeared on very wide beaches (more than 120 m), the majority of which had a high use (3.65%).

When considering the classification of segments according to the widths defined by $P_{10}$and P_{90} percentiles it appeared a similar pattern. Nevertheless, a higher percentage of segments appeared associated with inadequate widths. Thereby, high recreational use was identified in a higher percentage of segments narrower than 15 m (1.15%) and between 15 and 30 m (7.5%) than with the AMW. Similarly, intermediate recreational use was experienced by segments between 15 and 30 m (10.42), and below 15 m (2.50%).

Tab. 4. Distribution of segments (%) according to their recreational use and beach width, defined both by the annual mean width (AMW) and P_{10} and P_{90}.

% of segments	Width defined by AMW (m)				Width defined by P_{10} and P_{90} (m)			
Recreational use	<15	15-30	30-120	> 120	<15	15-30	30-120	> 120
Low	0.16	3.54	10.58	0.00	1.30	5.84	7.09	0.05
Intermediate	0.83	5.47	35.75	0.10	2.50	10.42	28.82	0.42
High	0.31	2.50	37.10	3.65	1.15	7.50	30.38	4.53

The negative influence of width on the recreational function was considerably smaller when considering the AMW instead of the percentiles 10 and 90 (Fig. 14). Thereby, according to the mean, in 16.6 % of the segments the width negatively affected the recreational function of the beach. On the contrary, when using percentiles the influence appeared in 33.7 % of the cases. This occurred similarly in all the levels of influence.

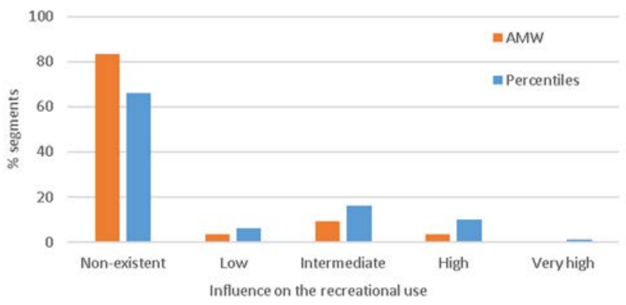

Fig. 14. Segments affected by an inadequate width on the recreational use. Width inadequacy has been defined according to the percentiles 10 and 90 (blue) and the annual mean width (AMW).

Percentiles proved to be more restrictive parameters for defining the width inadequacy. Therefore, the inadequacy defined from them was finally combined in GIS software with the recreational use data in order to elaborate cartography about the influence on the recreational function along the whole study area. The cartography shows the influence with a high level of detail, and it allows its visualization in GIS software in combination with other layers of information.

Fig. 15 shows the negative influence on the recreational use on the 35 km of coastline located at the southern end of the study area, between the municipalities of Gandia and Dénia. This section is of great interest since it presented important contrasts in beach width and use. Although most segments had high anthropic pressure and recreational use, the north of Gandia showed an important stretch of beach with low recreational use, which contrasted with the high use of most of the beaches in the same municipality. In terms of beach widths, the vast majority of the segments were between 30 and 120 m wide. However, to the north of the port of Gandia, some stretches exceeded 120 m, resulting in a low and medium influence on the recreational function of the beaches. On the other hand, south of this port (between the municipalities of Daimús and Oliva) there were several narrow segments with high influence. Finally, in the most southern stretch of coast (municipality of Dénia) numerous segments were narrow (15-30 m) or very narrow (below 15 m). This, in turn, resulted in very high influence on those segments with high recreational use. While some municipalities (as Oliva, Dénia or Gandia) have coastal fronts of several km, others only cover a few hundred meters. An extreme case of this irregularity is Dénia, which presents a municipal surface fragmented. Likewise, the municipalities that cover a greater stretch of coast presented greater differences inside the municipality. In this case, the municipality of Gandia stands out: while some segments were wider than 120 m and had a high recreational use, others were narrower than 15 m and showed low use.

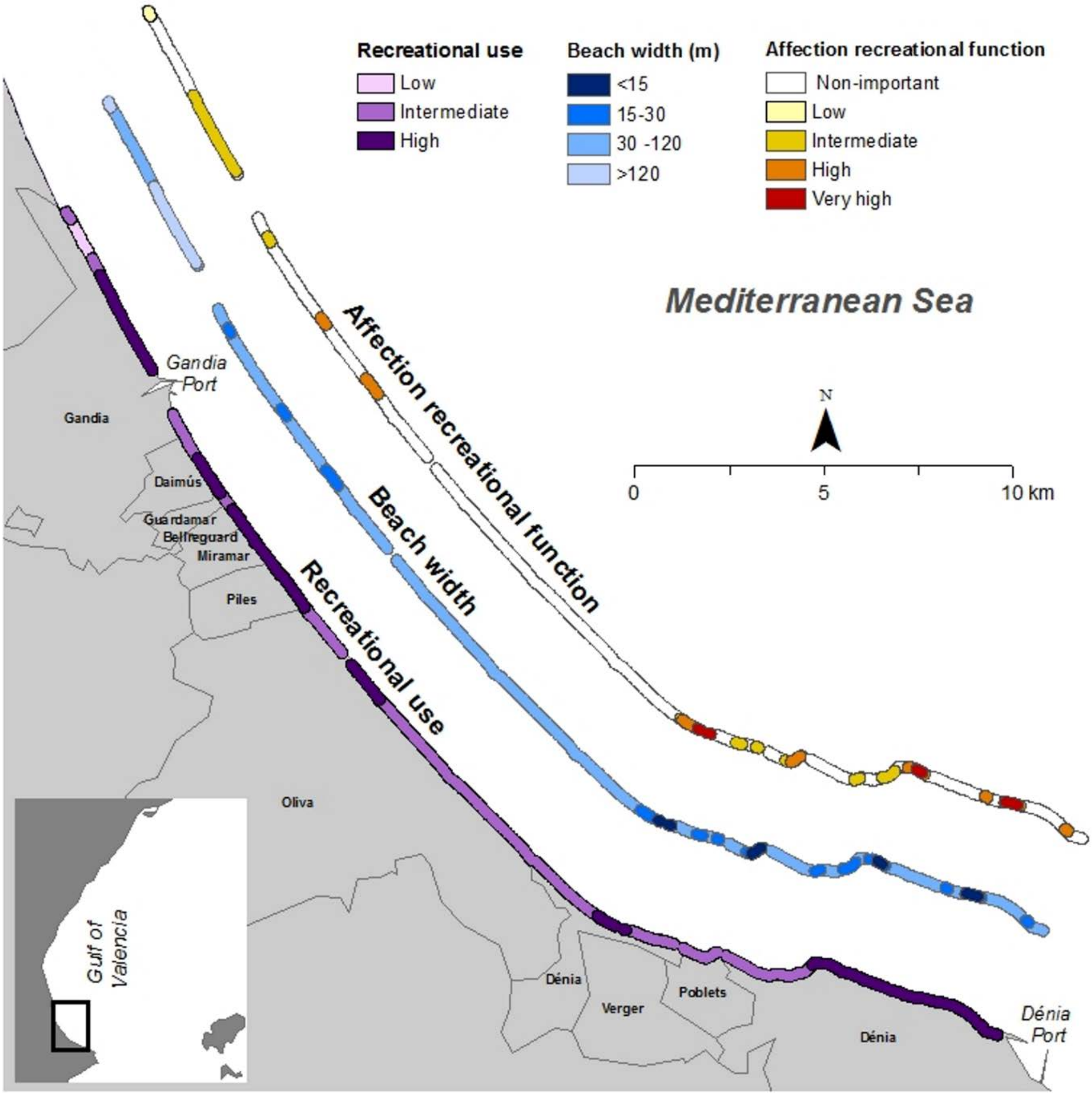

Fig. 15. Detail of the recreational use, beach width (m), and influence on the recreational function defined along 36 km sector of the studied coast.

Discussion

A proper management and planning of the coast requires updated, continuous, homogeneous and organized data. Simple and objective methodologies are necessary for describing the state and changes of the coast through indicators (Giardino et al., 2014; Van Koningsveld et al., 2005). Although different techniques could have been used for defining the shoreline position, this work employs as input data Satellite-Derived Shorelines (SDS) with subpixel accuracy automatically defined from satellite imagery by the SHOREX system (Palomar-Vázquez et al., 2018). Shoreline positions were defined up to 83 dates on the beaches throughout the Gulf of Valencia along the period 2013 – 2016. The availability of shoreline positions data on a large number of dates provides information about the intra-annual variability (Cabezas-Rabadán et al., 2018) and the most unfavorable state of the beaches throughout the year (Cabezas-Rabadán & Pardo-Pascual, 2017). These data make it possible to robustly define the mean width, an indicator of the beach state useful in evolutionary studies (Almonacid-Caballer et al., 2016). However, the annual mean width (AMW) can differ greatly from the widths recorded at the most unfavorable times along the year, in which the beach is too narrow and it cannot fulfill its functions. The annual percentiles represent an approximation to those situations. They are defined from a large volume of data accomplishing the needs of a robust approach (Cenci et al., 2017). When trying to detect segments with either very wide or insufficient width for the recreational function of the beach, P_{10}appears as a more restrictive parameter than the annual mean. While the latter one may hide a significant number of dates in which recreational function is negatively affected by insufficient width, P10 detects as problematic between two and 2.5 times more segments. This pattern occurred similarly considering the shoreline data of the different studied years. The values of both width parameters were compared on a beach with proven situations of insufficient width and, while the AMW was inefficient in the definition of problematic segments, P10 gave more weight to the most unfavorable positions and identified the problematic segments properly. It would confirm that the P10 is a more sensitive parameter to the extreme events registered differently each year, also supported by the fact that P10 varied more between the different years.

After characterizing the beach widths throughout the Gulf of Valencia, the identification of problematic width segments was carried out. Contiguous segments along large coastal sectors were identified due to their insufficient width using P_{10}, as opposed to the AMW, giving geographical robustness to the analysis. Widths under 30 m appeared at the northern end of the Gulf of Valencia associated with enclosed and pebble beaches (Fig. 1B). However, the central and southern half of the Gulf also showed segments with insufficient widths, confirming a change in the cumulative trend of these sandy beaches associated with the structural scarcity of sediments suggested by other works (Pardo-Pascual & Sanjaume, 2019). Likewise, very wide were also identified and, although the proportion of affected segments was relatively small, they had remarkable widths. Beaches too narrow or too wide demonstrates the existence of large imbalances in the distribution of the sediment. It is mainly a consequence of anthropogenic actions modifying the morphology of this coast (Obiol-Menero, 2003; Pardo-Pascual & Sanjaume, 2019). In most of the cases, it is partially caused by the presence of obstacles to longitudinal transport as ports and groins (Fig. 1.B) on a coast with important alongshore transport (Fig 1.A). Up to 13.5 million m3 of sand were dumped along 100 km of the Valencian coast between 1982 and 2002 (Obiol-Menero, 2003), mainly as a local response to the erosive retreatments of touristic beaches. In parallel, punctual hard solutions have been constructed due to the same reasons. Nevertheless, the large imbalances of sediment along the Gulf of Valencia show the inefficiency of the local solutions in solving a regional problem, as they do not show benefits in the middle and long term. In fact, hard solutions displace the erosive problems or even increase their magnitude affecting larger areas.

As a result, several conflictive sectors were detected due to either insufficient or excessive width: in 10% of the segments (15.3 km) the influence on recreational function was high, and in 1% of them (1.8 km) it was very high. The results also show how beach width, recreational use and, therefore, the influence on the recreational function had a high variability along the coast, even inside a municipality. It appeared a discrepancy between these parameters and the municipal boundaries. This discrepancy was accentuated by the heterogeneity in size and shape of the municipalities as the length of the stretch of coastline corresponding to each of them is very variable. The width thresholds in which the beach starts to be perceived as too narrow or too wide are not precisely defined yet, and they could be different on each beach. Nevertheless, it seems clear that beachgoers may perceive inadequate widths as a negative aspect of the beach, conditioning the type of user by increasing the density, reducing the number of visitors or even impeding the use the beach (Cabezas-Rabadán et al., 2019; Valdemoro & Jiménez, 2006). Furthermore, the value of properties on the seafront, as well as hotel prices, appear linked to the beach width (Gopalakrishnan et al., 2011; Pompe & Rinehart, 1994; Rigall-I-Torrent et al., 2011). In the Gulf of Valencia, the exploitation of the beaches and the littoral through sun and beach tourism has an extreme socio-economic value (Obiol et al., 2011). Therefore, the maintenance of beach widths able to sustain the recreational function must draw the attention of coastal managers. The subaerial surface is a dynamic aspect that should condition beach exploitation (Valdemoro & Jiménez, 2006). In fact, the Valencian region has begun to regulate the use and activities on the beaches based on, among other criteria, the width of the beach (GVA, 2018). Thus, shoreline position and width data integration in GIS result of great interest for coastal managers as they allow the detection of conflict zones and prioritize actions.

Shoreline position and beach width data, as well as the statistical descriptors of their annual variability, may help to fill the shortage and fragmentation of long-term data able to describe coastal dynamics or the human impacts on the system (Defeo et al., 2009). The data provided can be of great interest as an input of the beach integrated assessment tools, which aim is monitoring, detecting conflicts and acting as a management framework for beaches from a holistic approach (Lucrezi, Saayman, & Van Der Merwe, 2016). Shoreline positions, as well as the width of the beach, could be used as valuable descriptors of the state of the beaches, to quantify their changes and their erosive potential.

This study has defined the width and the uses of the beach for alongshore segments of 80 m long. Studies with a similar purpose have worked on larger coastal sections such as at the municipal level (Ballesteros et al., 2018). However, that scale makes it impossible to distinguish the status of different beaches within the same municipality or even parts of the same beach, and it blurs the reality because municipalities have very different surfaces. While allowing a detailed view of the problematic segments, the analysis carried out offers a large-scale vision extending beyond administrative boundaries and covering the entire region and the sediment cell, probably the most reasonable scale for defining the state of the sediment (Marchand et al., 2011). It allows the analysis of the causes and solutions to these problems from a broader perspective. Most of the erosive problems in the studied beaches affect the whole Gulf of Valencia, as they are strongly related to a regional sediment depletion (Pardo-Pascual & Sanjaume, 2019; Sanjaume & Pardo-Pascual, 2005). Thus, the study of the phenomenon and its possible solutions should be based on a large-scale approach, in line with managers' preference for a holistic view of the entire system (Giardino et al., 2014).

Employing this large-scale vision, several very wide sectors were identified. Given the artificial origin of these accumulations and their conflict with the recreational function, they could be cataloged as sources of sand. Identifying sediment reservoirs with appropriate features becomes essential for the management (Marchand et al., 2011) of a coast as the Valencian one, that has a strong recreational use as well as experiences erosive processes (Cabezas-Rabadán et al., 2019). This is in line with the “Strategic sediment reservoirs”, a key concept for erosion management according to the Eurosion project. These reservoirs could be a significant source of sediment with proper characteristics for nourishments and therefore a partial solution to the sand scarcity of environmental and economic impact lower than seabed extraction or hard measures (Gault et al., 2011). This would constitute an attempt to re-establish the balance of the system, and it matches the sand bypass already proposed for local specific erosion problems in the Valencian Region (Yepes & Medina, 2005).

Apart from supplying updated data, the shoreline can be defined by historical images allowing retrospective analyses. Thus, it is possible to quantify the current state, but also to analyze its evolutionary and cyclical patterns, or to predict the state in the near future. This is especially remarkable in Mediterranean coasts, where management shows a lack of anticipation to the problems (Valdemoro & Jiménez, 2006) with measures usually taken in a reactive way from a local perspective are commonly taken (European Comission, 2004). Sea level rise will require estimates of the changes, different in each region, in order to assess the impacts and the adaptation alternatives (Nicholls & Cazenave, 2010). The availability of coastal morphological data in large temporal and spatial scales integrated with data of the human use of the coast can be a great help in planning responses to these future scenarios.

Nevertheless, it is important to notice that the analysis has been limited by certain elements. First, there is limited availability and distribution of images throughout the year, which is not homogeneous. Likewise, during storms satellite images are not available due to the presence of cloud masses (Pardo-Pascual et al., 2014), which means that the smallest widths recorded annually are always greater than those that actually occur. Therefore, the measured widths and the identification of problematic segments are more conservative. The results are also affected by the precision of the algorithm employed when defining the shoreline position.

Previous works defined an RMSE of 6.6 m for Landsat 8 shorelines on sandy beaches and microtidal coasts (Pardo-Pascual et al., 2018). In order to evaluate to which extent the uncertainty in the shoreline definition conditions the results of the study, it is necessary to analyze the variability of the lines analyzed over the studied years. Analyzing all the segments throughout 2016 it is observed that only 0.8% of them present variability in a range smaller than the 6.6 m of the uncertainty of the method. Therefore, even assuming that the level of precision in the determination of each of the lines can be improved, it is evident that the results are robust. There are important differences in the width defined for each segment within each date. This is due to the fact that the shoreline and the inner line of the beach are not completely parallel and do not have rectilinear morphologies. About the shoreline, it experiences oscillations associated with high-detailed morphological formations (as beach cusps) as well as the wave's swash. About the inner line of the beach, considered constant along the studied period, it has curvatures due to the location of the buildings, promenades, and dunes. The studied coast is very artificialized and micro-tidal, with a very stable inner line, and therefore it can be considered constant. Nevertheless, it is possible that other coasts registered marked changes in the morphology over time. The appropriateness of the length of the analysis segments (80 m) and the possibility of using a shorter length to homogenize the width in each of them can, therefore, be discussed. Finally, it is necessary to point out that, although beach width is a very useful parameter for characterizing the state of Mediterranean and microtidal beaches, it may be useful in other environments with a higher tidal range.

Considering SDS as input, the results of the analysis carried out can be improved in the future as long as this data source improves its precision. The availability of new data sources, as satellite Sentinel-2 images, will allow achieving higher levels of accuracy, as well as an increase in the frequency of data capture. Sentinel-2A and Sentinel-2B in combination with Landsat-8 will provide a global median average revisit interval of 2.9 days (Li & Roy, 2017). This opens up new possibilities in the use of SHOREX for the analysis and monitoring of changes caused by storms and human actions.

Conclusions

This paper offers a new perspective for using SDS in the management of microtidal environments, especially on beaches with a high tourist use as happens in most of the Mediterranean. The supply of key data for studying the beach state and their impact on the human exploitation of these spaces may help managers in prioritizing actions, as well as in planning strategies against sea level rise and erosive patterns from large spatial and temporal scales.

The systematic recording of beach widths throughout the year on 80-meter segments allows obtaining and analyzing representative statistics of the morphology of the beaches in a simple way. Beach width and its annual variability appear as useful descriptors of the beach state. They may help in understanding the impact of beach morphology in the human exploitation of these spaces. Annual percentiles are intuitive and objective descriptors for characterizing the intra-annual variability. P_{10} offers an approach to the most unfavorable situations registered throughout the year. It has greater sensitivity to detect unfavorable widths than the annual mean width. P_{10} allows identifying as problematic coherent geographic zones instead of small disconnected segments. It proves its consistency and robustness for mapping beaches with problems in maintaining their key functions.

Too narrow and wide beach segments have been detected along the Gulf of València. The results are consistent with previous works and show the existence of sediment imbalances consequence of the anthropogenic interventions that have modified the coastal morphology. The detection of these segments allows studying the morphological state of beaches on their use and recreational function. The combination of width data with information about the recreational use allowed identifying segments in which the width is inadequate and negatively affects the recreational function. The integration in GIS software offers a regional view of the entire sedimentary cell and, simultaneously, a detailed view of the most conflictive segments within each municipality. It can be appreciated that these problems are not associated with municipal boundaries and that, therefore, neither should managers' responses be.

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