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COASTAL CHANGES BETWEEN THE HARBOURS OF CASTELLÓN AND SAGUNTO (SPAIN) FROM THE MID-TWENTIETH CENTURY TO PRESENT

--Manuscript Draft--

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Abstract:	This paper analyses the coastal changes between the harbours of Castellón and Sagunto from 1956 until the present day. Images of the coastlines in different years have been obtained from various sources (aerial photographs, satellite images, orthophotos) in order to estimate and compare the rates of shoreline advance and retreat. The results indicate a widespread tendency toward erosion due to human activity, which has limited the supply of sediments from source areas to the beaches. High rates of accretion are only recorded at places where maritime infrastructures especially upstream of the harbour: an advance of 230 m was recorded in Burriana harbour, and one of up to 180 m to the north of Sagunto harbour. In contrast, retreats of more than 175 m were estimated in some sites in the study area. Hard engineering structures (groin field, breakwater) and artificial nourishment of beaches had a strong influence on the coastline's behaviour from 1998 to 2018. Short-term coastal trend is erosive which is associated with storm events from January 2015 to December 2018.
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Response to Reviewers:	

Cover Letter

Regional studies in Marine Science
Editor-in-Chief

Dear Sir:

Here enclose the paper " COASTAL CHANGES BETWEEN THE HARBOURS OF CASTELLÓN AND SAGUNTO (SPAIN) FROM THE MID-TWENTIETH CENTURY TO PRESENT", written by Inmaculada Rodríguez-Santalla, Borja Martínez-Clavel, Mar Roca, Miriam Pablo , Luis Moreno-Blasco and Ana María Blázquez.

This research is carried out in one of the most erosive coastal areas of the Spanish Mediterranean. The mapping of coastlines using ArcGis tool since 1956 has allowed recording an evolution of the coastline whose accretion and erosion are due to the construction of maritime infrastructure, the action of storms and the alteration of the amount of sediments they contribute the rivers. The study at several time scales allows us to observe the importance of each factor in each moment. In addition, this zone has suffered since the middle of the last century, an aggressive anthropic action that has severely modified land uses due to an increase in urbanization.

We have made most of the changes suggested by the referees. We would like to publish it in your journal, if you consider it convenient. Thank you very much for this much appreciated opportunity.

Sincerely

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Regional studies in Marine Science
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Dear Editor-in-Chief,

Enclosed please find the revised manuscript COASTAL CHANGES BETWEEN THE HARBOURS OF CASTELLÓN AND SAGUNTO (SPAIN) FROM THE MID-TWENTIETH CENTURY TO PRESENT containing corrections made in response to your comments and those of the referees. We are grateful for your helpful observations. Below is a point-by-point response to the remarks.

Referee 1:

- All the specific comments have been addressed. A new figure (figure 4) includes the sketch to clarify the methodology, as requested in regard to line 162. The request regarding line 129 has been answered in new lines 127-131. However, we do not have information onthe sand volume used for the beach nourishments (line 99); we are happy to remove the sentence if the referee deems it necessary.
- Regarding the other corrections:
    - All numerical scales have been removed
    - The entire bibliography has been reviewed and new and updated citations have been added.
    - Table 1 has been checked
    - Table 4 has been completed and erosion and accretion data from the subunits have been included. We do not have data on sand nourishments.
    - Table 5 has been checked and completed and the surface areas have been included. A new figure (figure 9c) completes this information.

Referee 2:

- Specific comments:

1. *The authors identified coastal changes in the research area using temporal lens for long(1956-2018), medium(1998-2018) and short term(2015-2018). However, it*

is difficult for the reader to follow the authors' interpretation of the results because they did not clearly provide the basis for the setting of these time-scales. For example, there was a large artificial nourishments in the study area (line 99, line 283), and it is not clear which of the time-scales is associated with it.

The text has now been restructured and the information on the time scales is now brought together in point 4.3. This reorganization has improved the reading and comprehension of the information. The processes are defined according to the time scales in this section.

2. *By interpreting the coastline evolution in the study area, the authors found that the dominant tendency to erode only at short-term time-scale was due to storms and potential sea level rise. However, as the authors suggested in Chapter 5, if the several artificial nourishment projects directly advanced coastline and disturbance sediment fluxes so that affected long-term and medium-term time-scale coastal changes, it needs to be discussed more widely in Chapter 4 in relation to the factors that caused erosion trend.*

We now provide further support for our results and discussion with some additional data and new references. Section 4.3 brings together the information on the time scales and the dominant processes. We would have liked to be able to quantify the sand replenishment, but unfortunately we do not have this information.

3. *In chapter 4.2, The authors calculated the sedimentary transport in 5 zones with quantitative manner. However, since the zones have different lengths as shown in Table 3, it would be helpful for better understanding to readers that standardization (such as the amount of change per unit length of shoreline) along with suggesting changes in the total amount of sediment by zone. Furthermore, I believe a richer discussion could take place if authors could present the internal dynamics of each zone which has been distributed in chapter*

We have standardized table 3 with the information the reviewer suggests. Elements of the present internal dynamics of each zone have been included in chapter 4.2 (lines 246-248, 250, 253, 254, 257, 266-268, 290, 298, 305-306, 311-313), thus broadening the range of the discussion. In chapter 3 have been included lines 176-177.

4. *The content of chapter 4.3 is somewhat generalistic and insufficient to support the link between land use transformation and shoreline changes in the study areas. Specific analyses should be made, such as contrasting land use changes in areas where coastal changes are prominent and not, or vice versa.*

Specific analyses of coastal areas have been carried out comparing 1990 and 2018. Changes in land use have been contrasted in areas with significant coastal changes. Section 4.4 (previously 4.3) has been completed, as requested by the referee. The results indicate an intense anthropization of the study area, both the coastal zone and inland: this is the focus of the expansion of this section. In chapter 3, lines 179-189 have been included.

- Minor corrections have been made

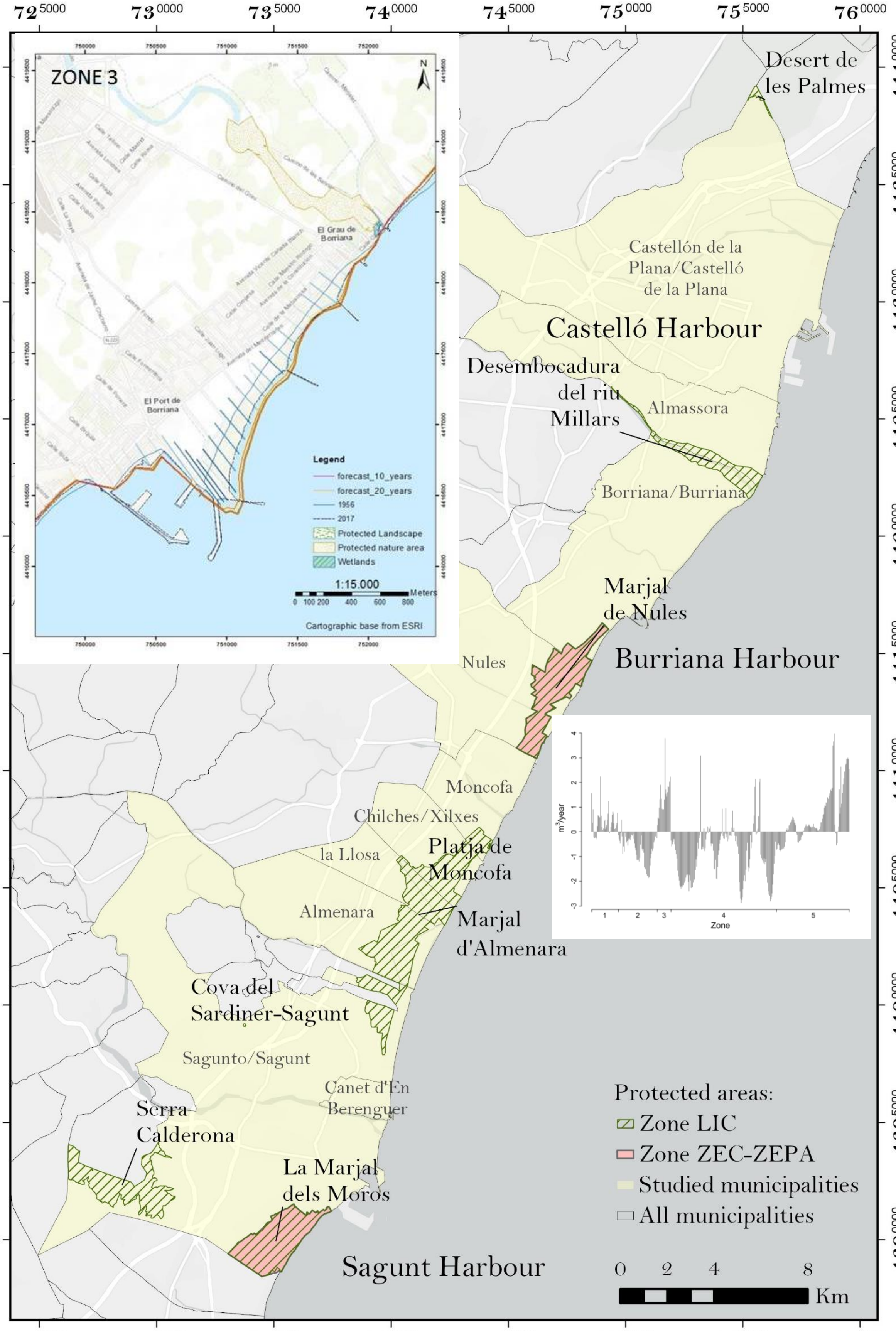
Referee 3:

- The English has been revised throughout the manuscript by a native English-language scientific editor.
- The material and methods section has been completed. Lines 128-132, Lines 135-139 and Lines 179-189.
- The results and discussion have been restructured and improved. A discussion on time scales has been added in section 4.3.
- The conclusions have been rewritten.

Highlight

- Coastal migrations have been determined between the Castellón and Sagunto Harbours from 1956 to present
- Anthropic action is the main cause of coastal evolution in the study area.
- There are advances and coastal retreats of more than 200 m since 1956
- The impact of human activity is confirmed by the analysis of coastal land uses between 1990 and 2018

Graphical Abstract



COASTAL CHANGES BETWEEN THE HARBOURS OF CASTELLÓN AND SAGUNTO (SPAIN) FROM THE MID-TWENTIETH CENTURY TO PRESENT

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Abstract

This paper analyses the coastal changes between the harbours of Castellón and Sagunto from 1956 until the present day. Images of the coastline in different years have been obtained from various sources (aerial photographs, satellite images, orthophotos) in order to estimate and compare the rates of shoreline advance and retreat. The results indicate a widespread tendency towards erosion due to human activity, which has limited the supply of sediments from source areas to the beaches. High rates of accretion are only recorded at places located upstream of the harbour: an advance of 230 m was recorded north of Burriana harbour, and one of up to 180 m to the north of Sagunto harbour. In contrast, retreats of more than 175 m were estimated in some sites along the study area. Hard engineering structures (groin fields, breakwaters) and artificial nourishment of beaches had a strong influence on the coastline's behaviour from 1998 to 2018. Short-term coastal trend is erosive which is associated with storm events from January 2015 to December 2018.

Key words: Coastal migration, shoreline evolution, human impact, Western Mediterranean Sea, Spain, Geographic Information System.

1. INTRODUCTION

Since the middle of the last century, the coastline has become a magnet for the development of recreational activities and urban expansion. Many of these urban planning processes have intervened in and modified the sedimentary dynamics that characterise these ecosystems (Bird, 2008). Today, around one quarter of all European coasts suffer from erosion, despite the efforts of the authorities to alleviate the problem through sand nourishment programmes and the building of groin fields and breakwaters (EUROSION, 2005, Pilkey and Cooper, 2014; Anfuso et al., 2015). Factors such as the construction of reservoirs in the river basins, the deterioration of seagrass meadows, the destruction of the dune systems and even the poorly defined prominence of climate change, all play a fundamental role in the coastline evolution (Pardo-Pascual y Sanjaume, 2001; Pardo-Pascual et al., 2019). The speed of these changes has alarmed both, the scientific community and the citizens, since problems of erosion are causing the disappearance of beaches, threatening infrastructure and placing a considerable strain on economic resources (Viciana, 2001). Monitoring shoreline evolution is essential to understand and anticipate coastal risks under global change (climate and human-induced stresses) (Ariza et. al., 2010, Nicholls et al., 2016).

Some studies of the Mediterranean littoral have shown intense erosion rates in certain areas of the coast, associated with activities such as the extraction of sand deposits and gravel from rivers and beaches, which have had a negative impact over the littoral dunes (Pardo-Pascual and Sanjaume, 2001; Pardo-Pascual et al., 2012a). Also, the construction of dams in the Mediterranean basin has reduced fluvial sedimentary inputs causing the retention of sediments, which have been systematically extracted from the coastal transport system over the last century. At the same time, the intense urbanisation of the coastline in response to the “sun and beach” tourism model in the southern European countries has led to the destruction of dune fields, which are the main suppliers of sediments for beaches. Hard engineering works involving the construction of groins and breakwaters have contributed to halting the erosion at the site of intervention and have protected the coast from marine invasion in periods when storms overwhelm coastal beach ridges, which are still preserved (Pranzini et al., 2018). However, they have also changed the coastal morphology and caused exposure to waves with a different angle of incidence, increasing the probability of erosion. Harbours and groins cause notable changes in coastal sedimentation patterns because they constitute an absolute barrier to longshore drift; and consequently, they produce a massive accumulation updrift of the barrier, and a loss of materials downdrift of the groin (EUROSION, 2005; Bernatchez and Fraser, 2012). Therefore, the decrease in sand supply and the changes in the coastal orientation increase erosion in the medium- and long-term in this coastal stretch. In contrast, an additional input of sediments is produced by human action through beach nourishment, a very common practice along the Castellón coast since the 1980s in line with the expansion of the tourism industry (Obiol, 2003; Obiol and Pitarch, 2011).

The aim of this paper is to analyse the evolution of the coastline over the past sixty years between the harbours of Castellón and Sagunto (around 40 km) (Fig. 1), in order to identify the coastal sections which have suffered the most from erosion and the possible causes. It also aims to determine the influence of human activity, that is, the numerous interventions that have disrupted the coastal dynamics and have changed the use of the shoreline in recent decades.

2. STUDY AREA

The study area is located on the Spanish Mediterranean coast, in Valencian Community region (Fig. 1). It is limited at the West by sandstone reliefs of the Espadán Mountain belonging to the Iberian Range (IGME, 1974; Sos-Baynat, 1981), where it sits in a depression caused during the Upper Miocene to Oligocene by the intersection of faults of Iberian orientation NW- SE (Iberian Fault) and others transverse to these with NE-SW direction, which led to a tectonic subsidence (Pérez-Cueva, 1979). This depression is bounded by faults parallel to the coast which were filled during the Pliocene and Quaternary with alluvial fans that are now linked to the coast with sandbar-lagoon systems (Mediato, 2016; Blázquez et al., 2018; Rodríguez-Pérez et al., 2018).

The dominant storms are from ENE with a significant wave height close to 4 m and a period of 11.5 s while the most frequent swell in the area are from E (Fig. 2), being current directions generally from N to S (Fig. 1). Astronomical tide ranges from 20 to 30 cm (CEDEX, 1996) and an Atmospheric pressure variations produce a change in the mean sea level which can reach up to 75 cm (López et al., 2016).

The study area covers around 40 km and is made up of urban or semi-urban beaches belonging to eight municipalities on the Valencian coast (Table 1). Two main rivers, Mijares in the north and Palancia in the south, along with Belcaire and Salvador rivers (Fig. 1) are the sources of the fluvial deposits that reach the coast (Segura et al., 1995). The beach sediment is mainly sand and, in the northern areas, mostly pebbles and gravel, with a low content of sediment of biological origin. However, some sections have been artificially nourished with sand to promote tourism (Obiol, 2003). The major maritime infrastructures are commercial and fishing harbours (Sagunto, built in 1902; Castellón, built in 1915; and Burriana, built in 1932) and a yacht harbour (Siles in Canet de Berenguer, built in 1983), which have altered the coastal dynamics because of interrupting the longshore transport of sand, being the sediment deposited updrift of the obstacle and causing erosion downdrift.

According to CEDEX (2015), the study coast consists in two main physiographic units or littoral systems which are limited by the three harbours. Each of the above units includes sub-units that have a similar littoral dynamic (Fig. 3):

1. Physiographic Unit North, between Castellón and Burriana harbours
    a. Sub-unit Castellón harbour to Mijares river mouth (Zone 1)
    b. Mijares river mouth to Burriana harbour (Zone 2)
2. Physiographic Unit South, between Burriana and Sagunto harbours
    a. Burriana harbour to Almenara beach (Zone 3)
    b. Almenara beach to Siles Yacht Harbour (Zone 4)
    c. Siles Yacht Harbour to Sagunto Harbour (Zone 5)

To relieve the erosive problem caused by the presence of the harbours, even worse because of the low sedimentary contribution from the rivers due to regulation of its basins, different hard engineering structures have been constructed (some examples of hard engineering structures can be seen in Fig. 3). The study area presents a high level of tourist activity, which began to develop widely in 1970s and early 1980s, directly co-related by the detriment of the industrial and agricultural sectors. By the increase in tourism, the construction sector responded quickly to the demand for holiday homes in the coastal area. Despite all the construction, the study area still presents a high ecological value (Fullana, 2001), with six Sites of Community Importance (SCI) and five Special Bird Protection Area (SBPA) (Fig. 1). Nules, Almenara and Moros coastal lagoons, and the river mouth of the Mijares are examples of high environmental value habitats (Gascó et al., 2005).

3. MATERIALS AND METHODS

Defining the evolution of coastlines requires accurate positional information from different time periods (De la Peña, 2007; Rodríguez-Santalla et al., 2009), therefore sometimes different information sources (satellite images, maps, orthophotos, topographic surveys, and so on) are needed in order to cover the lead time of the analysis. In this study orthophotos were used (Table 2). The aerial photograph was georeferenced and transformed to the ETRS89 reference system. The coastlines were digitized manually following the wet/dry boundary, since this is a micro-tidal coast (Boak and Turner, 2005). The software used was ArcGIS 10.x© and the error obtained was below the pixel size (Dehouck, 2004).

The temporal length has allowed considering three different time scales: long-term (1956-2018), medium-term (1998-2018) and short-term (2015-2018), in order to assess the dominant processes in each section depending on the time scale. Jiménez et al. (1995) indicate that, on the short-term time scale, storms and wave energy are the most influential factors in coastal dynamics. In contrast, on the long-term time scale, the effects of water-level oscillations (meteorological tides and long-term, relative mean sea-level variations) play an important role and may blur the wave signal.

To calculate the variations of the coastline position at different times, DSAS tools for ArcGIS© have been used (Himmelstoss et al., 2018). Although there are other procedures based on digital satellite image processing (El-Asmar, 2002; Pardo-Pascual et al., 2012b); or in LiDAR data processing (Hardin et al., 2014; Mahabot et al., 2018), DSAS seems the more common and more appropriate tool to be used in large areas, and also when different information sources are considered (Oyedotum, 2014; Kannan et al., 2019, Rodríguez-Santalla, et al., 2021). For this, transects of 100 meters each were plotted to define the coastline positions in each available year. DSAS computed different statistical parameters from each transect, providing insights into the rates of accretion or erosion of the points where transects intersects the coastline. The parameters used have been (Crous and Pintó, 2006; Ahmad and Lakhan, 2012; Maio et al., 2012; Moussaid, et al., 2015):

- Net Shoreline Movement (NSM) is the distance (m) between the oldest and most recent line.
- End Point Rate (EPR): is the value of NSM divided by the time interval in years between those lines, expressed as the change in m/year (Thieler et al., 2009).
- Linear Regression (LRR): This parameter is used to analyse trends of changes in the coastline over long periods of time. LRR is equivalent to EPR but includes the uncertainty associated with the calculation of the regression line by adapting to the lines where the associated error is low (Gómez-Pazo et al., 2019).

The negative value of NSM, EPR and LRR indicates recession of the shoreline, while a positive value denotes accretion. According to the obtained erosion/accretion rates, the study area has been divided into five zones (Fig. 3) which coincide with the physiographic units mentioned above. For each zone a shoreline evolution pattern has been provided. Table 3 shows the number of transects and length of each zone.

Additionally, to complete this study, the sedimentary balance rates were estimated (ΔV). To this end, a hypothesis is needed about how the changes in beach profile occur. The assumption followed in this study is the Hallermeier (1981) profile, modified by Birkemeier (1985), according to which the beach profile advances or retreats with no change in profile shape: $\mathbf{\Delta V = \Delta Y (B + dc)}$; where: ΔY = rate of change (m^2/year), B = berm height (meters), dc = depth of closure or active depth (meters), according Figure 4. In the study area, the maximum berm height was 1.9 m (CEDEX, 1996). To facilitate the calculations, this is not included in the computations and the error is assumed, given that it is not highly significant and affects all sections alike. The depth of closure, or active depth, is the distance measured from the still water level, where the bottom surface is no longer stirred by the wave action and beyond which there are no significant changes in the profile (De la Peña, 2007). In the study area, the depth of closure varies between 3.9 and 4.2 m (CEDEX, 1996). This procedure obtains an estimation of the volume of sediments transported between different coastlines, as well as the advance or retreat in the yearly rate (Table 4).

In order to study the anthropic pressure in the coast over the course of the land use changes, Corine Land Cover (CLC) data for 1990 and 2018 were used. Using ArcGIS Pro, areas were calculated grouping land use into six categories: agriculture, forest, harbours, industrial areas, urban and wetland. First, statistics were computed for the map extent of the study area, obtaining area values for each land use category (in hectares). Second, for the purpose of analysing land use changes in the coastal area, geographical area statistics were calculated for CLC 1990 and 2018 as well, using a buffer of 2000 meters from the coastline (IGN) and splitting land use areas into the five zones used in the DSAS analysis, in order to discern any relationship between areas of accretion or erosion and changes in land use. Since each zone has a different length, and therefore a different land extension, two graphs were created in order to obtain land use types in % for each zone, and to be able to compare absolute ratios between zones regardless of the land extension.

4. RESULTS AND DISCUSSION

4.1 Coastline changes

As indicated above, the study area was divided into five zones according to the LRR parameter obtained from the DSAS software for long-term changes (Fig. 3).

Figure 5(a) shows the evolution rates of LRR and NSM for long-term (1956-2018). Regarding the LRR parameter, it shows an alternation of accretionary and erosive sections, but the NMS parameter (Min NSM) shows an erosive trend in all sections except for Zone 3, located just north of the Burriana harbour. The mean values of the EPR parameter for medium-term evolution (1998-2018) present an accretionary trend for each zone (Fig. 5b), although the mean values of the NSM follow a similar pattern to long-term. The short-term (2015-2018) results show an erosive trend in all areas (Fig. 5c).

The coastal dynamics of the study area is strongly conditioned by the presence of coastal defence works. In 1957, the only barriers to longshore transport were represented by the three major harbours. This explains the long-term trend, which shows the alternation between erosive and accretionary areas associated with those infrastructures (Fig. 6).

Zone 1 starts from the groin protecting the refinery located south of the harbour of Castellón, and it ends at northern limit of the mouth of the Mijares River, just where the coast changes its orientation. It presents advances, with an LRR value of 0.6 m/year, being the maximum distance close to 140 m (max NMS). For the medium-term time scale, the EPR value increased considerably in relation to the long-term, but in the short-term this is the zone with the highest erosion values, due to a major erosive process in Benafeli beach (profiles 373 and 374). Figure 7 shows this coastal stretch in 1957, 1998 and 2018.

Zone 2 extends between the delta of the Mijares River and El Grao of Burriana beach (N). The North of this coastal stretch presents small advance rates, and then decreases until reaching rates with negative values, with a maximum retreat of -113 m for long-term trend. In the medium-term, Zone 2 always shows positive values, but in the short-term, it goes through cycles of positive and negative values, being the mean EPR -1.20 m/year.

Zone 3, located upstream of the harbour of Burriana (Fig 7), has a high rate of accretion, due to the harbour of Burriana interrupts the longshore drift and retains the sediment updrift of this infrastructure. Advance rates in this area are very high, reaching 1.5 m/year and 2.3 m/year in the long- and medium-term respectively. The maximum accretion reaches 230 m between 1956 and 2018, and over 100 m between 1998 and 2018. Despite the position it occupies in relation with the harbour, Zone 3 presents erosion in the short-term, especially in the northern vertex of the triangle formed by the deposits, which is supported by three groins (Fig. 6f).

Zone 4 is situated between the harbour of Burriana and El Canal de la Gola in Almenara beach. This zone presents a constant trend towards erosion in the long-term time scale, although it shows occasional stretches with a sedimentation trend, caused by hard engineering works carried out to recover the coastline (Fig. 8); it presents the more important recession in large scale (-175 m). Between 1998 and 2018 the trend reverses and a clear advance is observed related to the nourishment and improvement of all beaches of Zone 4 carried out in 2014 (Ministry for the Ecological Transition and the Demographic challenge, 2021a), which has continued until the present day. Also, in the short-term, Zone 4 shows the profiles with the greatest recession (profile 238).

Finally, Zone 5 is located between Almenara beach and Sagunto Harbour. This section also includes Siles Yacht Harbour 2 km northwards from the Sagunto Harbour. Zone 5 is the only one which presents accretion in the three time scales analysed. The advance is very pronounced in the northern dock from Sagunto Harbour and in its area of influence between 1998 and 2018.

4.2 Sedimentary transport rates

The variation in the volume of sediments from the coastlines was obtained following Hallermeier (1981) (Table 4). The results are consistent with the earlier coastal migration analysis. Zone 1 presents a positive global balance of sediment variation, with a total of nearly 4,500 m3/year and a yearly coastal advance of 0.13 m. Almost the whole Zone 2 presents a negative sediment balance and a progressive increase in the loss of volume along transects in this area, resulting a net loss higher than 14,600 m^3/year of sedimentary material representing an erosion of 0.41 m/year. In Zone 3 a positive balance is recorded in all transects, with a total 8,500 m^3/year. Due to the direction of currents, (NE-SW), much of the sediment transported from Zone 2 is eventually deposited in Zone 3 because of the barrier effect of Burriana harbour. The mean yearly coastal advance is 0.69 m. Zone 4 generally shows a negative balance, reaching nearly -24,500 m^3/year, with a mean retreat rate of 0.25 m/y. Finally, Zone 5 presents a positive sedimentary balance slightly higher than 20,000 m^3/year. As in Zone 3, in this section much of the sediment of the previous area builds up, due to the direction of the longshore currents and its impoundment in Sagunto Harbour, causing a shoreline accretion of 0.35 m/year.

Sediment transport rates are consistent with changes in the coastline position in the different sections, being values showed in Table 4 also consistent according to CEDEX (1996). Considering the results of the sedimentary balance and exchange rates, Zone 1 (south of Castellón Harbour), presents a predominance of the accretion process and its sedimentary balance is positive, though small. The beaches in this area have numerous protection structures, breakwaters and groins, with the consequent effects on erosion and sedimentation patterns elsewhere in the coastal zone due to the diffraction of waves (Rodríguez-Santalla, 2003; Crous and Pintó, 2006; Espinosa and Rodríguez-Santalla, 2009). Moreover, hard engineering coastal works are reported, four of them perpendicular and two parallel to the coast. These structures were built in the second half of the last century, like the others observed in most of the study area (Pardo-Pascual, 1991). According to the technical study by CEDEX (1996), the beaches in this area have suffered continuous erosion since the creation of the Castellón Harbour (1915), due to the sediment barrier that this infrastructure represents. Later engineering works were built to protect this coastal stretch from erosion, resulting in a mitigation of the negative trend. Similar processes after the construction of infrastructures of this type, causing changes in the littoral dynamics (Crous and Pintó, 2006), have been reported in studies on the Mediterranean coast. In some studies (EUROSION, 2005; Bernatchez and Fraser, 2012; Anfuso et al., 2015), it has been shown that infrastructures of this type will only act on a limited stretch, increasing erosion downstream and requiring the extension of the groin field. However, the results of the present study indicate a slight growth of the beaches, which may be due to the nourishment with more than 400,000 m^3 of terrestrial material carried out by the National Coastal Authority in 1994 (CEDEX, 1996).

The contribution of sediments of the Mijares River is negligible (Zone 2), due to the presence of intense human activity in this river bed (Viciana 2001; Crous and Pintó, 2006). The significant reduction of its delta and the retreat of the coastline by almost 100 m between 1956 and 1990 provide evidence of this phenomenon (Pardo-Pascual, 1991). Therefore, the area has a high rate of retreat, with an annual loss of almost 15,000 m^3 of sediment. According to a study conducted by Greenpeace (2006), the Almassora beach in this area has lost more than one million cubic meters of sand since the construction of Castellón Harbour, and a project for its artificial nourishment is now necessary (CEDEX, 2015). As a result of the losses and the progressive increase in erosion rates, protection barriers were built in almost the entire section to prevent the loss of infrastructure and farmland as early as 1957. However, no hard engineering coastal works are observed in this zone.

Located updrift of Burriana Harbour, Zone 3 presents high accretion rates with a sediment increase of 8,500 m^3/year. This infrastructure has had the same effect on the evolution of the coast as Castellón Harbour (Rodríguez-Santalla, 2003). The construction of the harbour interrupted the longshore transport, generating an accumulation updrift of the infrastructure (EUROSION, 2005; Bernatchez and Fraser, 2012; Anfuso et al., 2015). Accretion rates in this area are very high, with advances of 150 m between 1956 and 2012 and of 200 m until 2018. In this zone, five hard engineering coastal works are recorded.

Zone 4 covers the area from Burriana Harbour to The Gola Channel. Its location with regards to the harbour means that contribution of sediments is very low. Moreover, the sediment contribution from the agriculture channels is also very low because of the presence of gates that prevent connections with the sea. Consequently, Zone 4 is the area with the highest rate of retreat, with a loss of sediments of 24,500 m^3/year, resulting in a coastline erosion of 175 m during the study period. In this zone, some hard engineering coastal works are observed at the end of the stretch.

The last area, Zone 5, is located between The Gola Channel and Sagunto Harbour. Due to the construction of two harbour infrastructures and the discharge of supplementary material on the northern beaches of Burriana Harbour, this is the section of the whole study area with the largest accretion rates, with a sedimentary balance of 20,000 m^3/year (HIDTMA, 2005). Moreover, no coastal defences are observed, and the maximum accretion is registered in the southern section, near Sagunto Harbour. Nevertheless, data shown in Table 4 indicates that the total volume changes considering the five zones is -6,034 m^3/year, which along the study period represents 368,000 m^3 of eroded material. The numerous infrastructures associated with human activity have caused serious distortions of the coastal dynamics. However, river dams and variations in the hydrological regime have had a major influence on the volume of sediment reaching the coastal system. Definitely, severe imbalances have been caused in the dynamic processes of coastal winds and the rivers (Pardo-Pascual et al., 2012a). The barrier effect of the harbour has generated processes of erosion which have eroded the beaches located downdrift of the breakwaters. In addition, the presence of several harbours in the study area generates serious alterations in the coastal dynamics by dividing the physiographic units and interrupting the distribution of sediments along them (Crous and Pintó, 2006). On the other hand, seafront promenades limit wind processes which used to transfer large amounts of sediment for the formation of dunes and sandy coastal areas (Hernández et al., 2005). These sandy formations have direct implications for the coastal dynamics, and reserves of aggregates are essential to maintain the stability of the maritime system (Viciana, 2001).

Another key factor is the possible sea level rise associated with the climate change due to human activity envisaged for the twenty-first century. The analysis of sea level data provided by observatories in the Western Mediterranean basin bears witness to the presence of a slight upward trend, varying between 0.9 and 1.5 mm/year. This has had an erosive impact on the coast with annual retreat rates between 0.05 and 0.18 m/year (Pardo-Pascual and Sanjaume, 2001). This means that the erosive effects associated with the foreseeable rise in the sea level due to climate change will be strongly reinforced by the widespread deficit. Another relevant factor to the process of erosion and accretion on the coast is the remains and possible clumps of seagrass (*Posidonia oceanica* Delile), which act to trap sediment in the supralittoral zone of the beaches (Cantasano, 2011). In storm episodes, *Posidonia oceanica* leaves emerge from rhizomes being transported by ocean dynamics to the coast, where they are retained favouring sediment accumulation.

Therefore, human action has had a decisive influence on the coastal area development during the past centuries (Obiol and Pitarch, 2011), which scale action is likely to increase in the near future. Consequently, it is essential to be aware of how and where human actions impact will take place on the coastal areas, and specially in this study area. The future dynamics will be a result of past actions, but also decision-making and spatial planning taken today (Hadley, 2009).

4.3. Dominant processes and time scales

The results obtained in the study area suggest that dominant processes can change significantly depending on the time scale used to analyse the coast. At long- and medium-term scales, dominant processes are related to the interruption of the coastal longshore current, which is manifested in the alternation of erosive and accretive coastal stretches. However, this trend may be reversed due to beach nourishment works carried out to promote tourism, which are observed especially in the mid-term time scale. In contrast, at the short-term time scale, storms and wave energy are the most influential factors in coastal dynamics.

According to Jiménez et al. (1997), the results over the medium- and long-term are co-related to the presence of hard engineering defence coastal works. These constructions resolve specific problems of erosion nearby, but have a negative impact on the surrounding areas. The dominant processes related to the alteration of the coastal longshore current are shown in Zone 1; Figure 7 depicts this coastal stretch in 1957, 1998 and 2018. The 1957 image shows the first coastal defences in Zone 1 (Fig. 7a), built to stop erosion due to the interruption of the sediment transport that Castellón harbour entails. Currently, due to the expansion of the harbour in the early 2000s, those coastal defence works are included within the port. Downstream, protecting the refinery, there is a sea wall, followed by several coastal defences (Fig. 7b). Figures 6c and 6d show as these hard-engineering solutions have been modified adjusting them to new situations. This is why Zone 1 shows positive values in medium- and long-term, in spite of being just downdrift of the harbour.

As can be seen, the accumulative trend is only registered in certain sectors, due primarily to alterations in the marine dynamic produced by the construction of groins, breakwaters, jetties and harbour docks. These accumulations occur northwards of these structures due to the longshore drift in the NE-SW direction. There are two sectors that retain most of the sediments, located north of the harbours of Burriana (Zone 3) and Sagunto (Zone 5). A coastline advance of nearly 230 m has been estimated for the first case and one of up to 183 m for the second.

Recession trends are observed in Zones 2 and 4, reaching 113 and 175 m respectively. The main causes of this erosion are the low contribution of the rivers in the area; the destruction of the dune morphology on the coast; the degradation of the *Posidonia oceanica* Delile meadows, which reflect an increase in the hydrodynamics; and, probably, the progressive rise in the sea level due to climate change. In addition, the barrier effect of the harbour of Castellón after its successive extension works, joint with the lack of sediment caused by the regulation of the Mijares river, have produced large-scale erosion in Zone 2 that have obliged the construction of maritime structures in order to mitigate the erosive effects of the waves. The trend is completely reversed in the mid-term time scale (1998-2018) because of the beach nourishment works for tourism carried out, being the last done in 2015 (CEDEX, 2015).

This sedimentary model on the long scale is repeated in nearby areas (Pardo Pascual et al., 2019), whose origin is attributed to the same causes. An analysis of the isobaths (1 m) confirms this model, since it identifies a shallow and more developed shoreface in Zones 1, 3 and 5 and, in contrast, a shallow shoreface in Zones 2 and 4 (Ministry for the Ecological Transition and the Demographic challenge, 2021b).

In the last decade (1998-2018) the contribution of sand through beach replenishment has increased the sedimentary load. This has helped to counteract the loss of sedimentary material through storm episodes, the decrease in the contribution of the source areas, and the erosion located in the southern area caused by the obstacles perpendicular to the longshore current. The beach nourishment and the hard engineering works have allowed the maintenance of a positive trend in the medium-term. According to Luo et al. (2015), a combination of hard and soft engineering measures often produces positive results in terms of reducing coastal beach erosion and maintaining a minimum beach width.

The analysis of short-term behaviour shows the dominant trend is coastal erosion in all zones, except in Zone 5. According to Jiménez et al. (1997), the erosion process in the short-term time scale can be related to storms. Figure 2 shows the storm events between from January 2015 to December 2018, being the more severe storms recorded in winter period. According to the data provided by the SIMAR point 2084118 (Puertos del Estado, 2021), 70% of the storms come from the E and SE direction. Since 2015, the number of storms with wave heights exceeding 2 m has risen; similarly, in some cases wave heights in excess of 4 m have been recorded (as high as 6 m in a storm in 2020), indicating the increasing energy of storms over this time scale. The dominant trend may indicate the effects of climate change and, therefore, increases in the energy of the events and in meteorological tides, which undoubtedly contribute to the erosion of most of the study area. There, between 2015 and 2018, up to

14 measures have been carried out on the coast, many of them to repair storm damage (Ministry for the Ecological Transition and the Demographic challenge, 2021c). Every year the Spanish Administration must spend part of the budget on emergency works to mitigate the effects of winter storms (Olcina, 2009; López-Dóriga et al., 2020). Nevertheless, as it can be verified, these techniques do not guarantee total population protection against erosion and flooding risks insevere storms (Nelson et al., 2017).

The advance of erosion in the study area, which manifests itself especially in the short-term time scale (except Zone 5), may be an effect of climate change: that is, the presence of more energetic episodes and a rise in sea level. The harbours of Siles and Sagunto account for the sedimentary accumulation on the short-time scale in this part of the study area.

4.4. Land use changes and their relation to the physiographic units

Figure 9 shows the outcomes of land use change analyse from 1990 to 2018, using Corine Land Cover data. According to the general extension of the study area (Fig 9a and 9b), the results show the increase of the land allocated to urban and industrial use (7 % in 1990 to 18%) to the detriment of agricultural zones from around 82% in 1990 to around 67% in 2018 (Table 5), entailing an increase in land suitable for development.

Thereby, coastal anthropization is clearly the main factor in relation to the pressure exerted on coastal areas. The increase of urban and industrial areas was especially notable between 2000 and 2006, when the construction sector was booming throughout Spain in response to the expansion of the holiday home tourism model (Obiol, 2003; López et al., 2007; Obiol and Pitarch, 2011). Moreover, due to harbour development, the land occupied by this activity suffered an increase from 0.42% to 1.05%. Regarding wetlands, between 1990 and 2018, a 1.3% increase of the area were occupied by coastal lagoons and salt marsh has been recorded, due to the recovery at the beginning of 2000s of some areas as wetlands, among them the Almenara marsh. Zooming into the coastal area identifies several clear patterns. Figure 9c displays the percentage of area for the same six land types shown in Figure 9a and 9b, applied, in this case, in the coastal area of influence (referred to in this study as the 2 km inland buffer from the coastline) by the five zones used throughout the study. Generally, as shown in Table 5 for the coastal area land uses, agricultural coastal land has decreased from 87% to 69%, while forest areas have fallen from almost 5% to 2%. However, coastal wetland areas have appeared from scratch, rising to 6.9%, and urban and industrial areas rose from 6.4% in 1990 to 20.5% in 2018. The increase in urban areas is associated with the rise of population in all coastal municipalities; Canet d'En Berenguer is a clear example, with a population increase of 421% from 1991 to 2017 (from 1539 to 6473 inhabitants). In addition, the downward trend in the harbour areas is explained by the methodology used in CLC cartography, since some of these areas were classified as industrial areas in 2018.

Looking at Figure 9c, Zone 1 shows how urban and industrial areas increased from zero up to 31% of the coastal area, to the detriment of agriculture and forest land (which fell from 100% to 69%). However, Zone 2 is to the least disturbed area, with an urban coverage of less than 1%. Zone 3 developed along the same lines as Zone 1 from 1990 to 2018, suffering from the highest increase in urban areas (29%). In Zones 4 and 5, the recovery of the wetlands is notable (5.44% and 15.61% respectively) in order to protect the coastal area; in contrast, the urban areas have more than doubled (8% to 13% and 13% to 32% respectively).

Analysing trends grouping zones according to their sedimentary behaviour, Zones 1, 3 and 5, that is, the sections where coastal sedimentary accumulation is recorded, have a higher rate of land use change in 2018 than in 1990, with a very significant increase in urban and industrial use. In contrast, Zones 2 and 4, where erosive trends along the coast were identified over the course of the study, are the ones in which land use had changed least since 1990; Zone 4 shows an increase in the urban area compared with the last century, although it remains smaller than the accretion zones. This indicates that coastal urbanization and the greater development of harbour activity are the main drivers of anthropization in the study area, showing associations between highly urbanized areas and accretional zones (1, 3 and 5) and between highly agricultural areas and eroded zones (2 and 4).

5. CONCLUSIONS

This research analyses the different positions of the coastline from 1956 to 2018, using orthophotos and ArcGIS tools. The results indicate an alternation of coastal sections that suffer erosion and others that show accretion. The processes responsible for these changes depend on the time-scale observed.

The coastal changes on the long-term scale (1956 - 2018) are determined in particular by the interruption of the coastal longshore current due to anthropic obstacles (namely, hard engineering structures) built in the second half of the last century. To the north of these obstacles there is coastal accretion (Zones 1, 3 and 5) while to the south there is intense coastal erosion (Zones 2 and 4). To compensate for erosion and for the purposes of tourism promotion, numerous coastal regenerations have been carried out, which confuse the analysis of the erosive signal in the medium time scale (1998 - 2018).

An advance of 230 m was recorded to the north of Burriana harbour, and one of up to 180 m to the north of Sagunto harbour. These contrast with retreats of more than 175 m estimated in certain sites in the study area. These changes in the coastline vary over time as a result of the movement of sediments, due both to natural dynamics and to the interference of human activity.

The dominant processes on the short-term scale (2015-2018) are storms, which cause coastal regressions in all areas except Zone 5. These episodes are increasingly energetic, which explains, to some extent, why their effects are visible at this time scale. Other indirect and recent human actions that might have contributed to coastal erosion in the study area are the sea level rise associated with climate change, and local factors such as regression of seagrass.

The analysis of land use changes between 1990 and 2018 shows that coastal anthropization is the main source of pressure on coastal systems. Urban and industrial uses have risen to the detriment of agricultural land and forest areas; coastal urbanization is even more accentuated in Zones 4 and 5, and new developments have appeared very quickly from scratch in Zones 1 and 3, from 0% to 31% and 34% respectively. Moreover, the recovery of coastal lagoons and salt marshes is notable, with an increase in wetland surface in Zones 4 and 5. The analysis shows that there may be a direct relationship between land use changes grouped by zones and erosive and accretional areas. First, zones with rapidly growing urbanization areas (1, 3 and 5) coincide with accretion zones. In contrast, Zones 2 and 4, which have had a much lower urban growth, are directly related with areas with erosive trends.

However, in the face of the pressure exerted by human settlements and the existence of hard engineering infrastructures for the artificial maintenance of beaches, continuous coastal monitoring is essential in order to provide data able to guide decision-making in operational management, and also to help to plan for future scenarios in orders to mitigate the negative impact of climate change.

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FIGURES AND TABLES

Figure 1. Location of the study area (the position of Fig. 2 is marked) and Protected Coastal Zones (Natura 2000). Source: a) ESRI ©; b) López et al., 2016

Figure 2. Significant wave height data from SIMAR point 2084118 (location is indicated in Figure 1). Source: Puertos del Estado (www.puertos.es/es-es)

Figure 3. Zoning of the study area based on the LRR parameter, following the results obtained in the long-term analysis. Also, some photographs illustrating each zone are shown.

Figure 4. Sketch of the variables used to calculate the sedimentary balance (ΔV).

Figure 5. Results of LRR (meters/year), EPR (meters/year) and NSM (meters) parameters: 5a. long-term (1956-2018); 5b medium-term (1998-2018); 5c short-term (2015-2018).

Figure 6. Orthophotos from the years 1957, 1998 and 2018 of Castellón Harbour (Figures 6a, 6b and 6c); Burriana Harbour (Figures 6d, 6e, 6f); Siles Yacht Harbour (Figures 6g, 6h, 6i,) and Sagunto Harbour (Figures 6j, 6k, 6l,). Source: www.ign.es.

Figure 7. Orthoimages of Zone 1: 7a and c show orthoimages from 2018 and the same area in 1957; and 7d in 1998. Source: IGN (www.ign.es). 6b shows oblique aerial photographs. Source: Guide to Beach (miteco.gob.es)

Figure 8. Some examples of hard engineering structures in Zone 4: L'Estany in L'Alcudia Beach; El Grao Beach and Les Cases Beach), Photographs source: Guide to Beach (miteco.gob.es).

Figure 9. Corine Land Cover maps of 1990 (9a) and 2018 (9b) reclassified in 6 land use types. 9c shows graphs of land use mean in percentages according to the coastal area (2000 m buffer from coastline) splitted by study zones (1 to 5). Source: IGN http://centrodedescargas.cnig.es/CentroDescargas/catalogo.do?Serie=SIOSE

Table 1. Main characteristics of the beaches in the study area (miteco.gob.es)

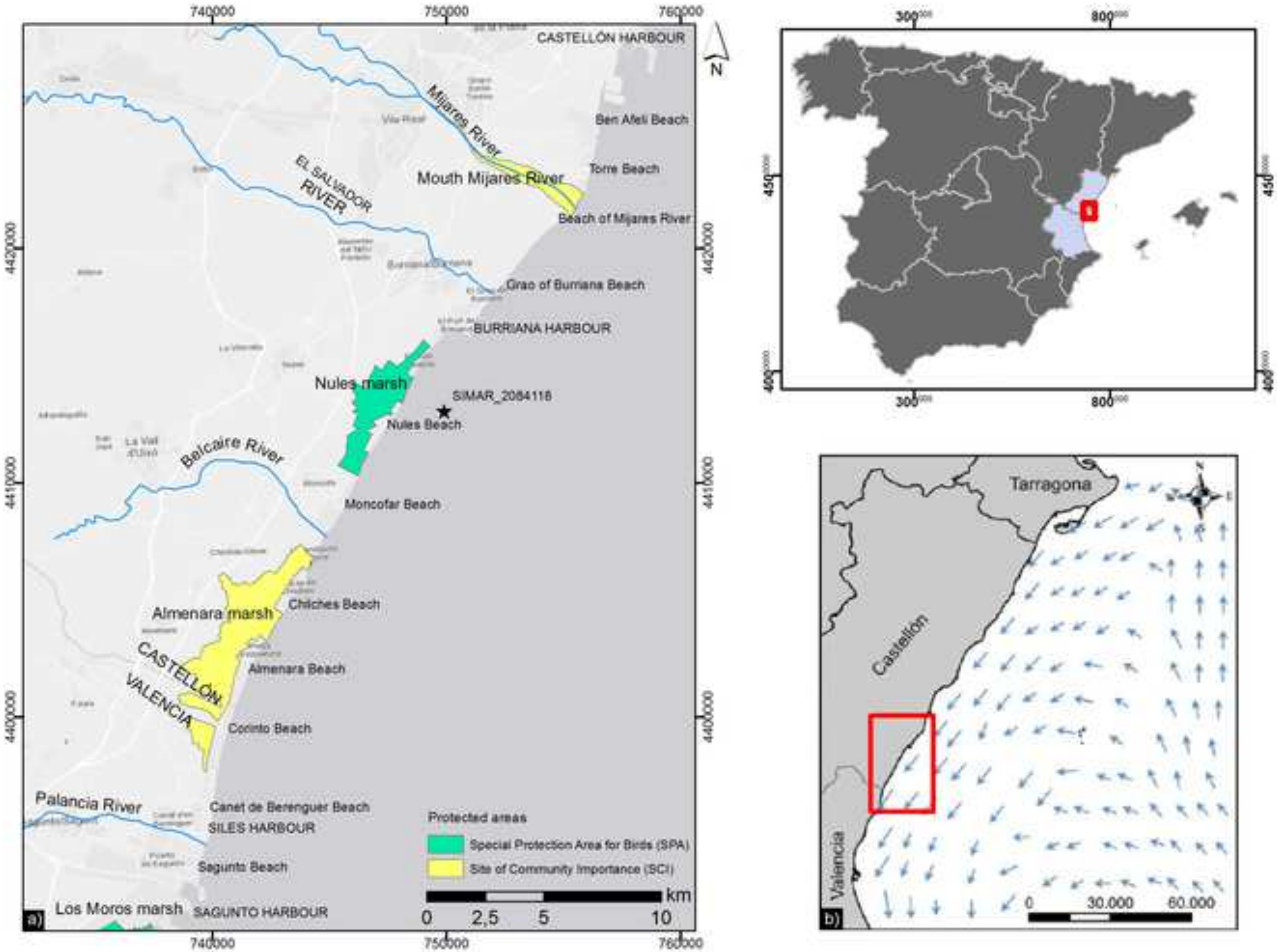
Table 2. General characteristics of the images. (IGN = Geographic Institute of Spain; ICV = Cartographic Institute of Valencia)

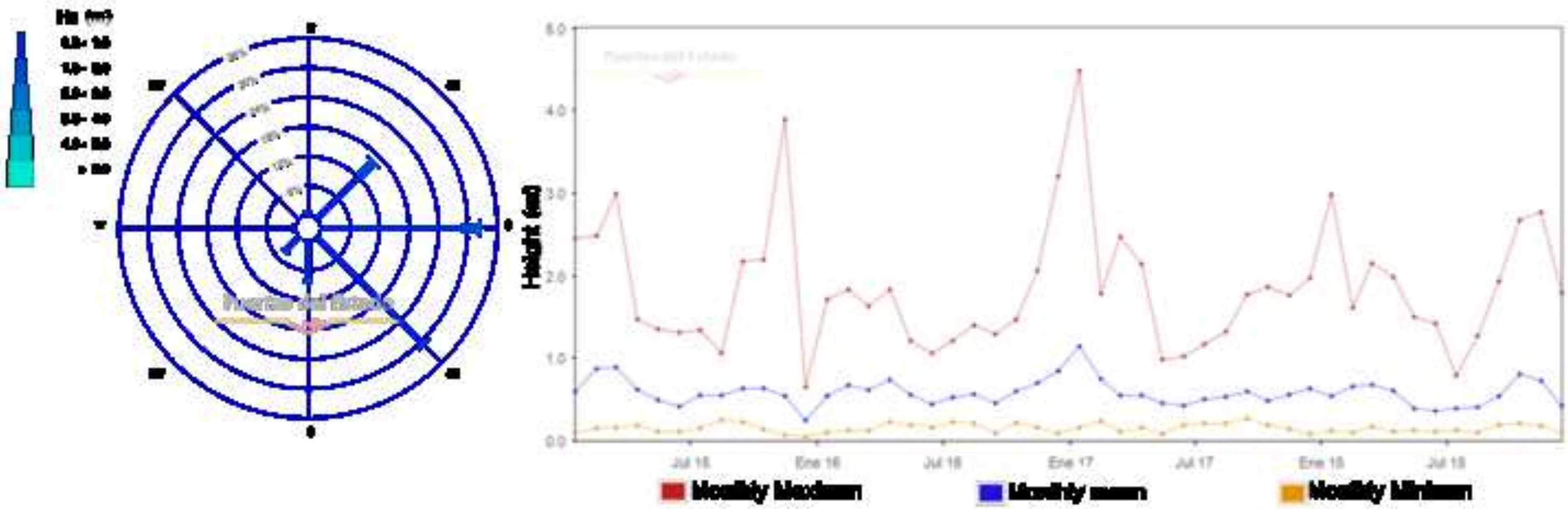
Table 3. Number of transects and length of each area defined in Figure 3.

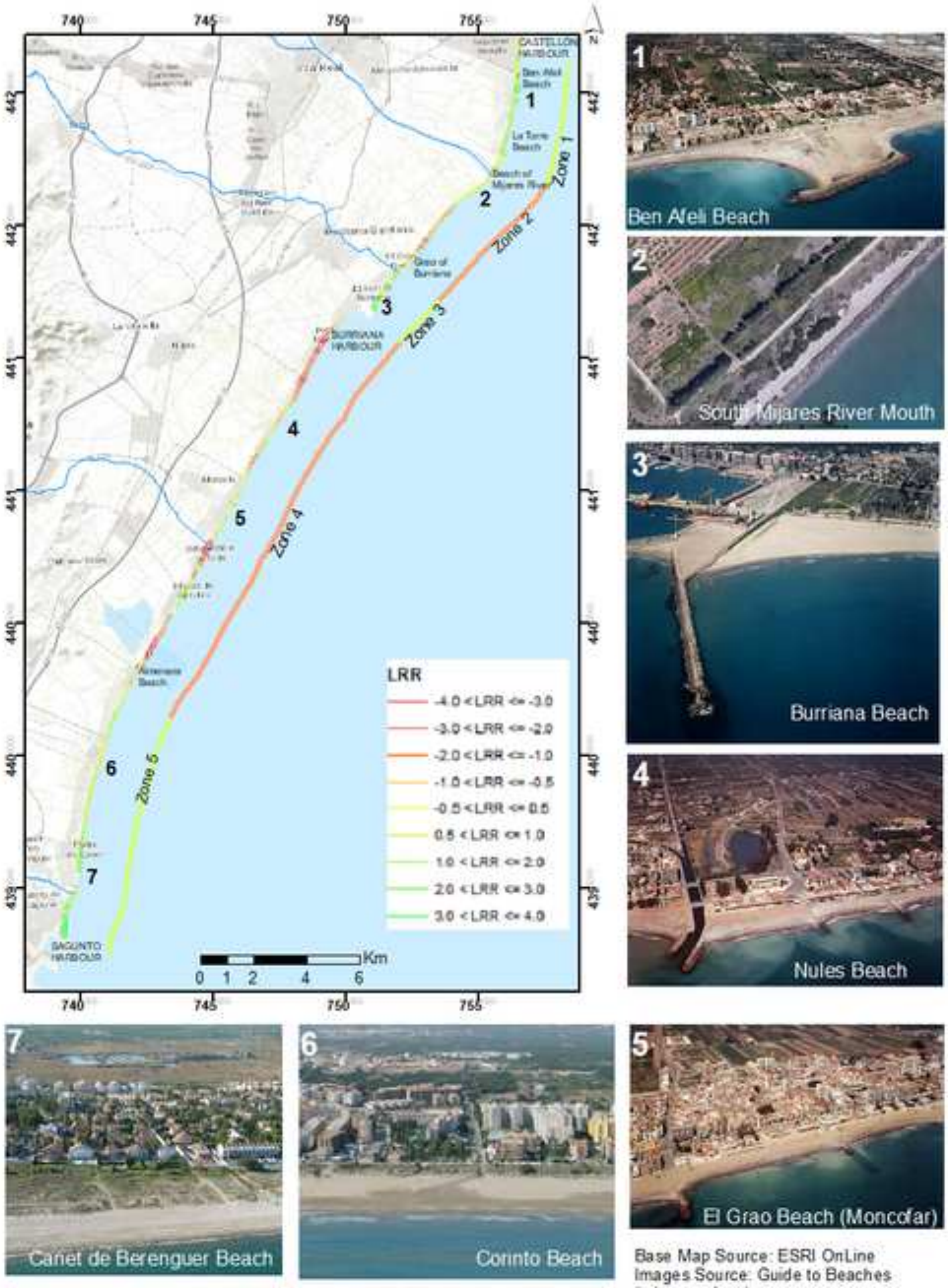
Table 4. Yearly rates of volume change and advances or retreats by zones.

Table 5. Land use changes for each of the classes considered in the map extent (uses 1990 and 2018) and in the 2000 m coastal area (uses coast 1990 and 2018). Estimation of the surface of each of the classes considered.

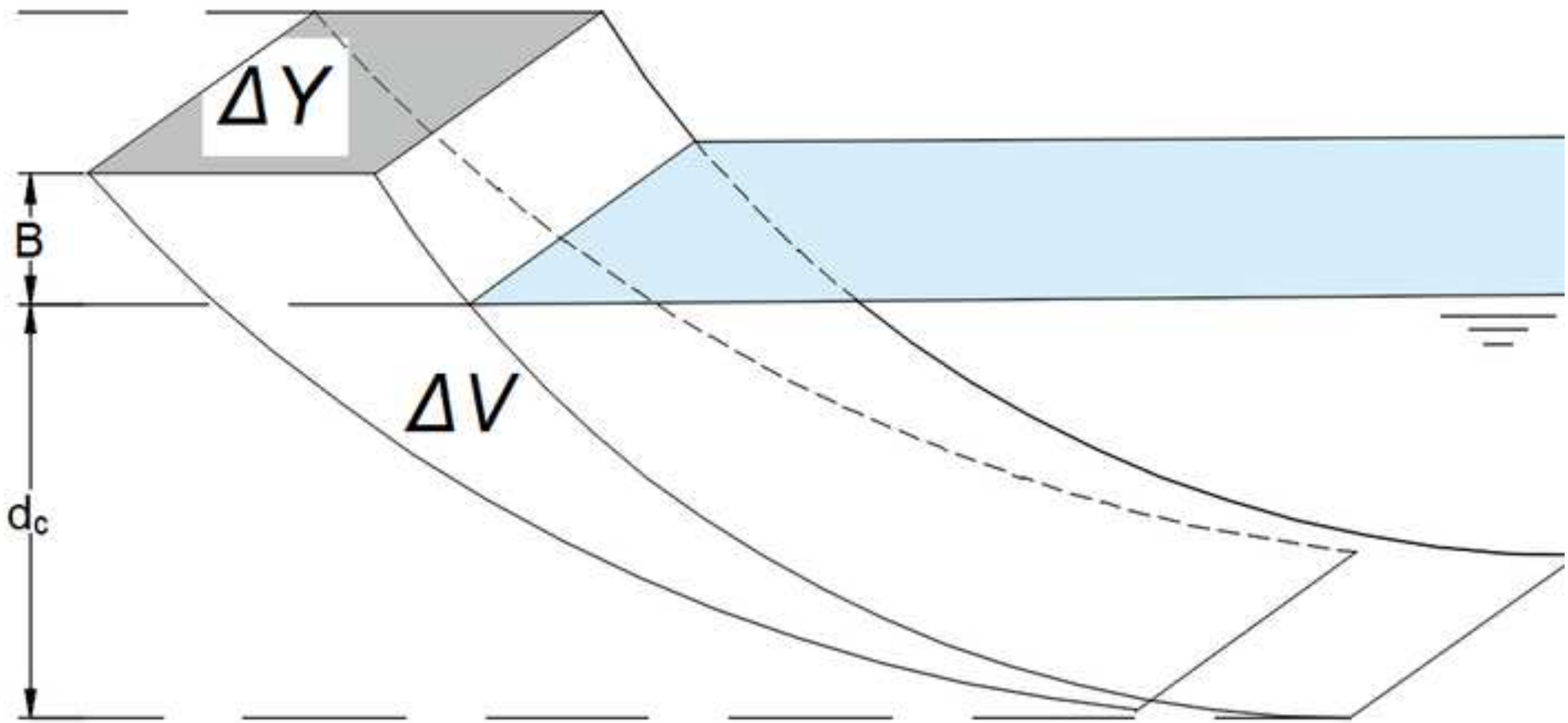
Figure 1


CASTELLÓN HARBOUR
N
Mijares River
Ben Afeli Beach
Torre Beach
Mouth Mijares River
EL SALVADOR RIVER
Beach of Mijares River
Grao of Burriana Beach
BURRIANA HARBOUR
Nules marsh
SIMAR_2084118
Nules Beach
Belcaire River
Moncofar Beach
Chilches Beach
Almenara marsh
Almenara Beach
CASTELLÓN
VALENCIA
Corinto Beach
Palancia River
Canet de Berenguer Beach
SILES HARBOUR
Sagunto Beach
Los Moros marsh
SAGUNTO HARBOUR
Protected areas
Special Protection Area for Birds (SPA)
Site of Community Importance (SCI)
km
0 2,5 5 10
740000
750000
760000
4420000
4410000
4400000
a)
Tarragona
Castellón
Valencia
0 30.000 60.000
b)


Height (m)
5.0
4.0
3.0
2.0
1.0
0.0
Jul 15
Ene 16
Jul 16
Ene 17
Jul 17
Ene 18
Jul 18
Monthly Maximum
Monthly mean
Monthly Minimum



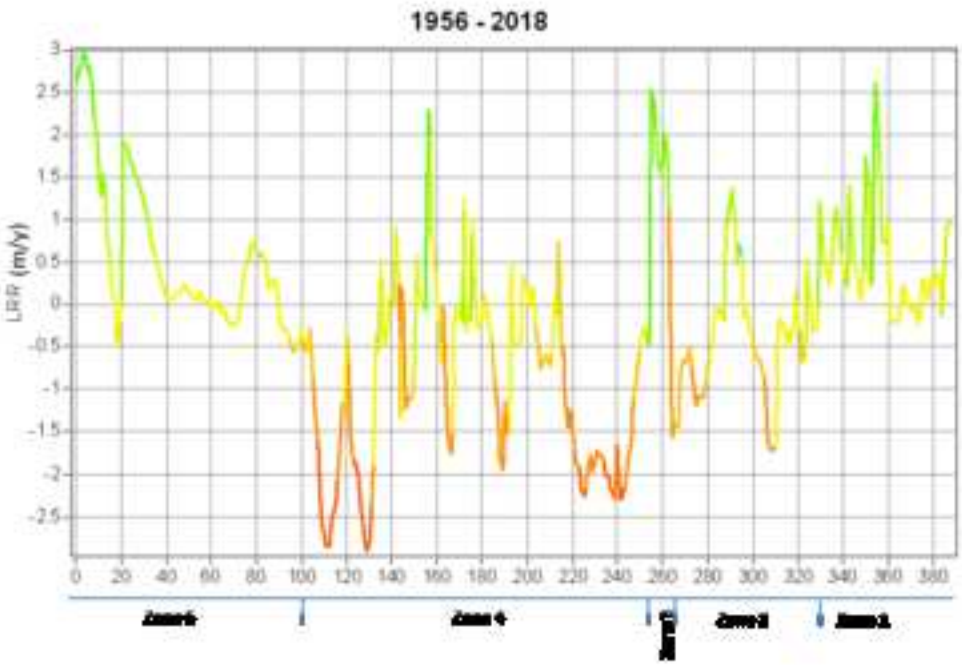
Base Map Source: ESRI OnLine
Images Source: Guide to Beaches (miteco.gob.es)



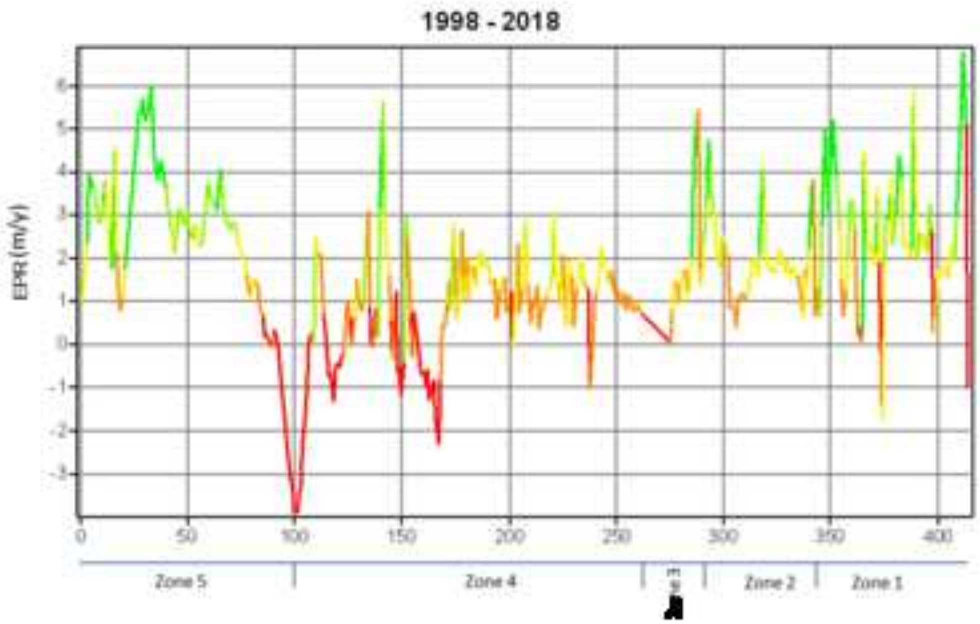
$$\Delta V = \Delta Y \cdot (B + d_c)$$

Figure 5a

Click here to access/download;Figure;Fig5a_rate1956-2018.png



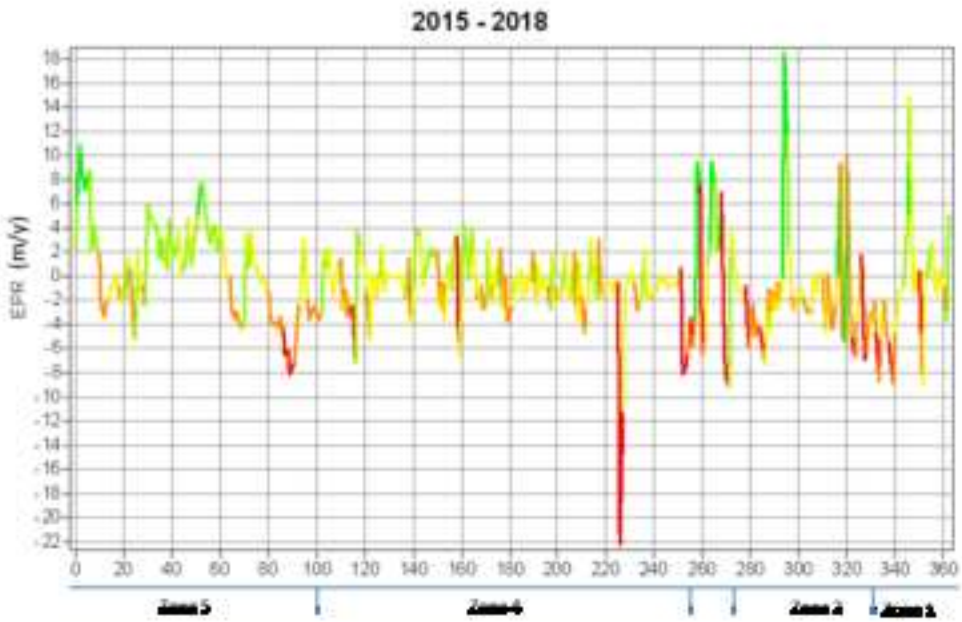
1956-2018	Mean LRR	MAX LRR	MIN LRR	Mean NSM	MAX NSM	MIN NSM
Zone 1	0,60	2,37	-0,21	23,52	136,36	-17,91
Zone 2	-0,61	0,52	-1,72	-40,96	29,09	-113,31
Zone 3	1,57	4,2	0,46	88,23	230,96	16,30
Zone 4	-0,86	2,41	-2,9	-55,28	130,64	-175,03
Zone 5	0,73	2,93	-0,50	41,05	183,05	-32,36



1998-2018	Mean EPR	MAX EPR	MIN EPR	Mean NSM	MAX NSM	MIN NSM
Zone 1	2,44	6,79	-1,72	41,70	111,99	-32,74
Zone 2	2,08	5,20	0,41	39,47	98,80	7,77
Zone 3	2,31	5,45	0,06	43,90	103,62	1,14
Zone 4	0,68	5,63	-3,88	13,09	106.93	-73,80
Zone 5	2,66	5,98	-0,83	50,44	113,61	-15,86

Figure 5c

Click here to access/download;Figure;Fig5c_rate2015-2018.png



2015-2018	Mean EPR	MAX EPR	MIN EPR	Mean NSM	MAX NSM	MIN NSM
Zone 1	-1,57	15,03	-9,05	-3,14	30,07	-18,11
Zone 2	-1,20	18,58	-7,35	-2,41	37,16	-14,69
Zone 3	-1,02	9,54	-9,19	-2,05	19,08	-18,39
Zone 4	-0,90	4,36	-22,26	-1,80	8,71	-44,52
Zone 5	1,26	10,8	-5,24	2,53	21,6	-10,48

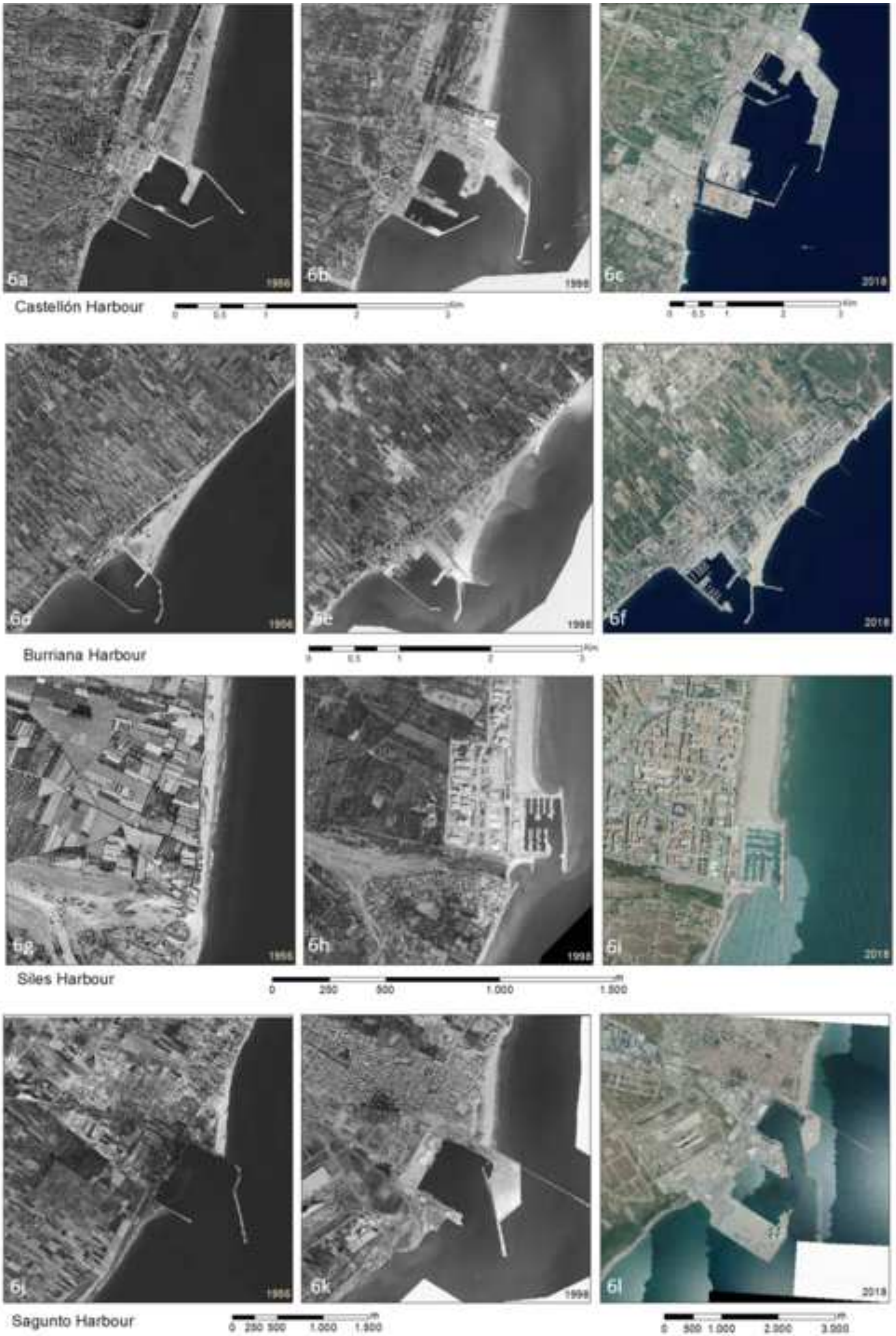

6a
1956
6b
1998
6c
2018
Castellón Harbour
6d
1956
6e
1998
6f
2018
Burriana Harbour
6g
1956
6h
1998
6i
2018
Siles Harbour
0 250 500 1.000 1.500
6j
1956
6k
1998
6l
2018
Sagunto Harbour
0 250 500 1.000 1.500
0 500 1.000 2.000 3.000

Figure 7a

Click here to access/download;Figure;Fig7a.jpg

Figure 7b Click here to access/download;Figure;Fig7b.png

Figure 7c

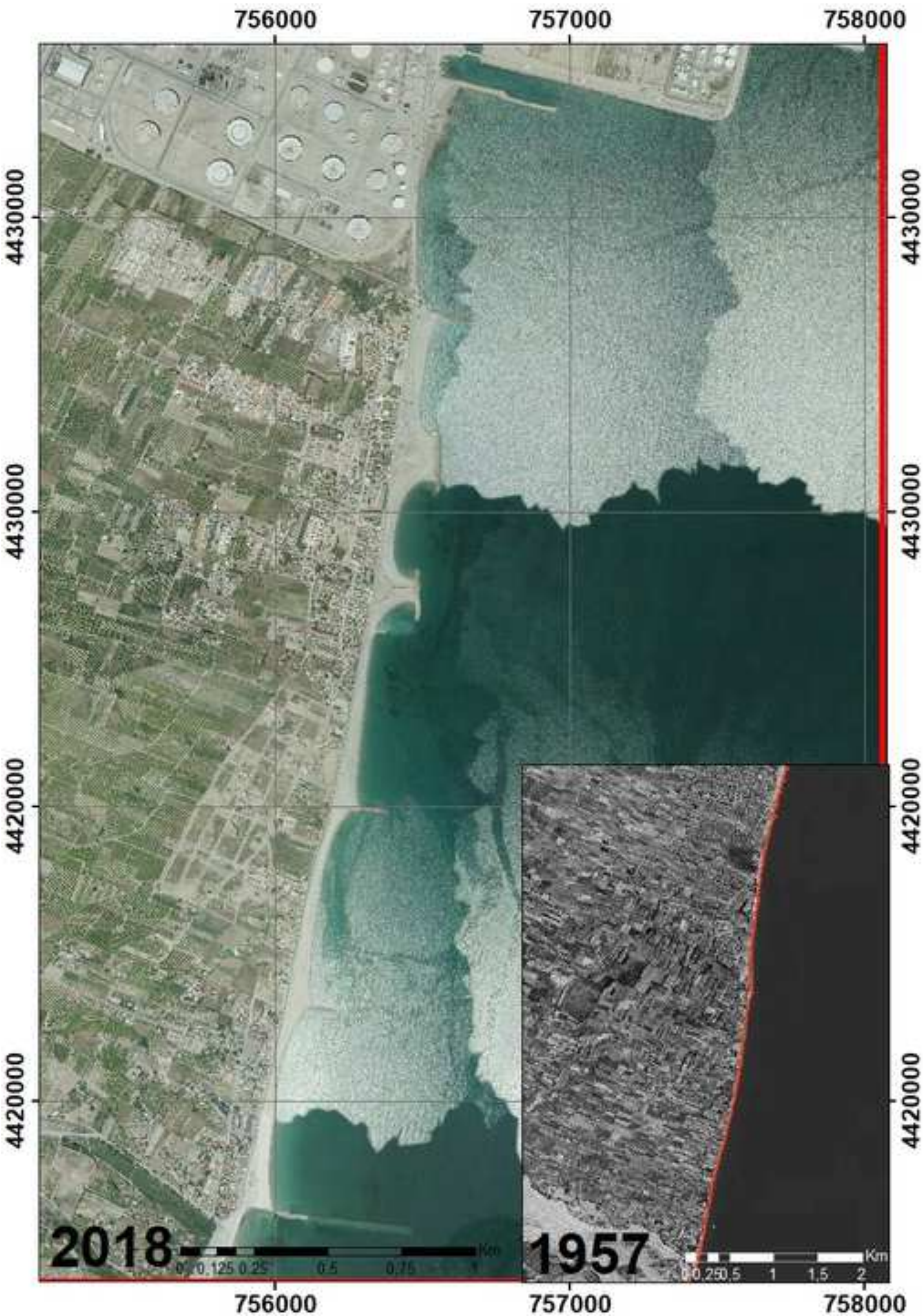

756000
757000
758000
4430000
4430000
4420000
4420000
2018
1957
Km
0 0.25 0.5 1 1.5 2

Figure 7d

Click here to access/download;Figure;Fig7d.jpg

Figure 8

Click here to access/download;Figure;Fig8.png

Figure 9a

Click here to access/download;Figure;Fig9a_Uses1990.jpg

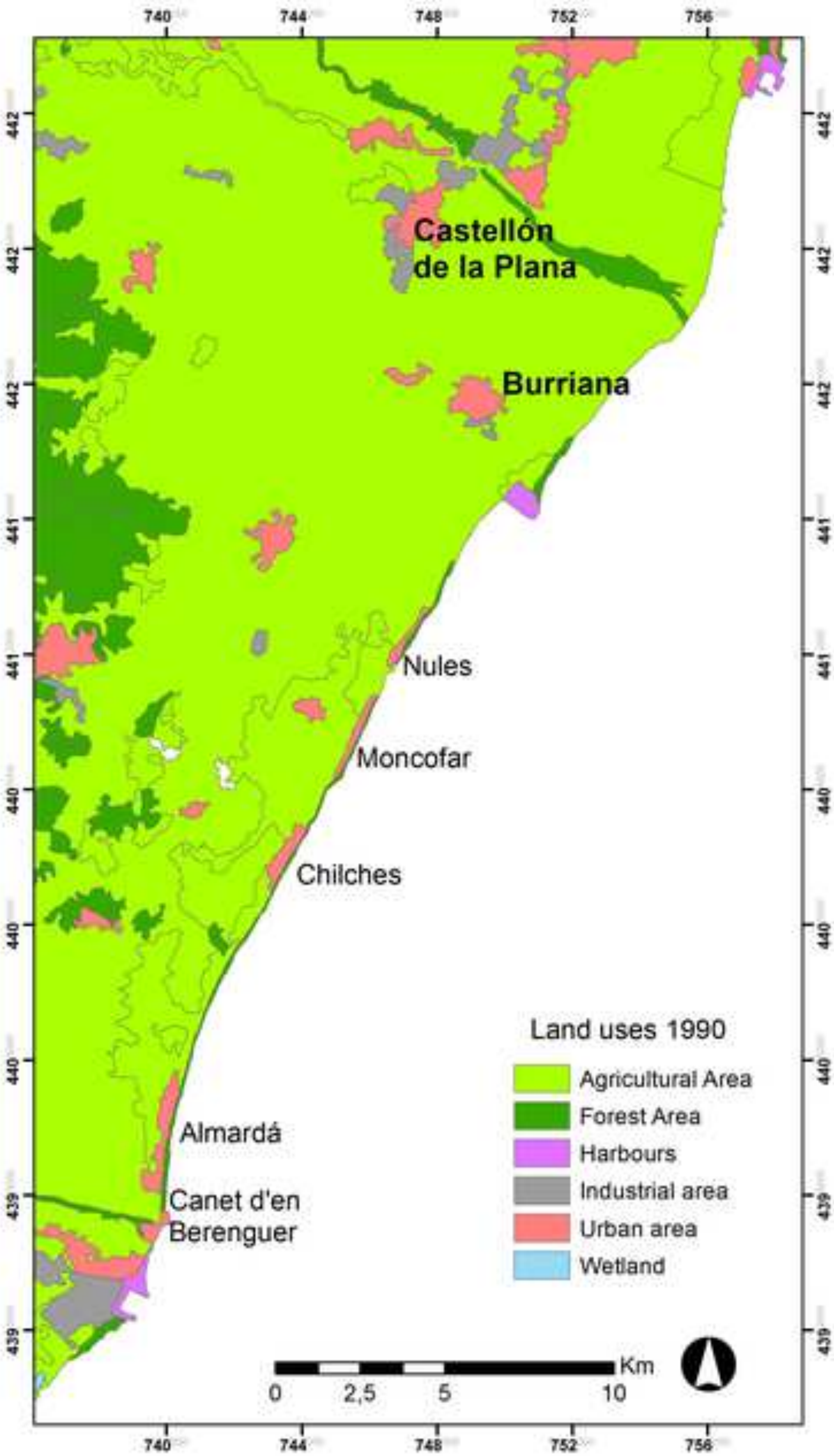


Figure 9b

Click here to access/download;Figure;Fig9b_Uses2018.jpg

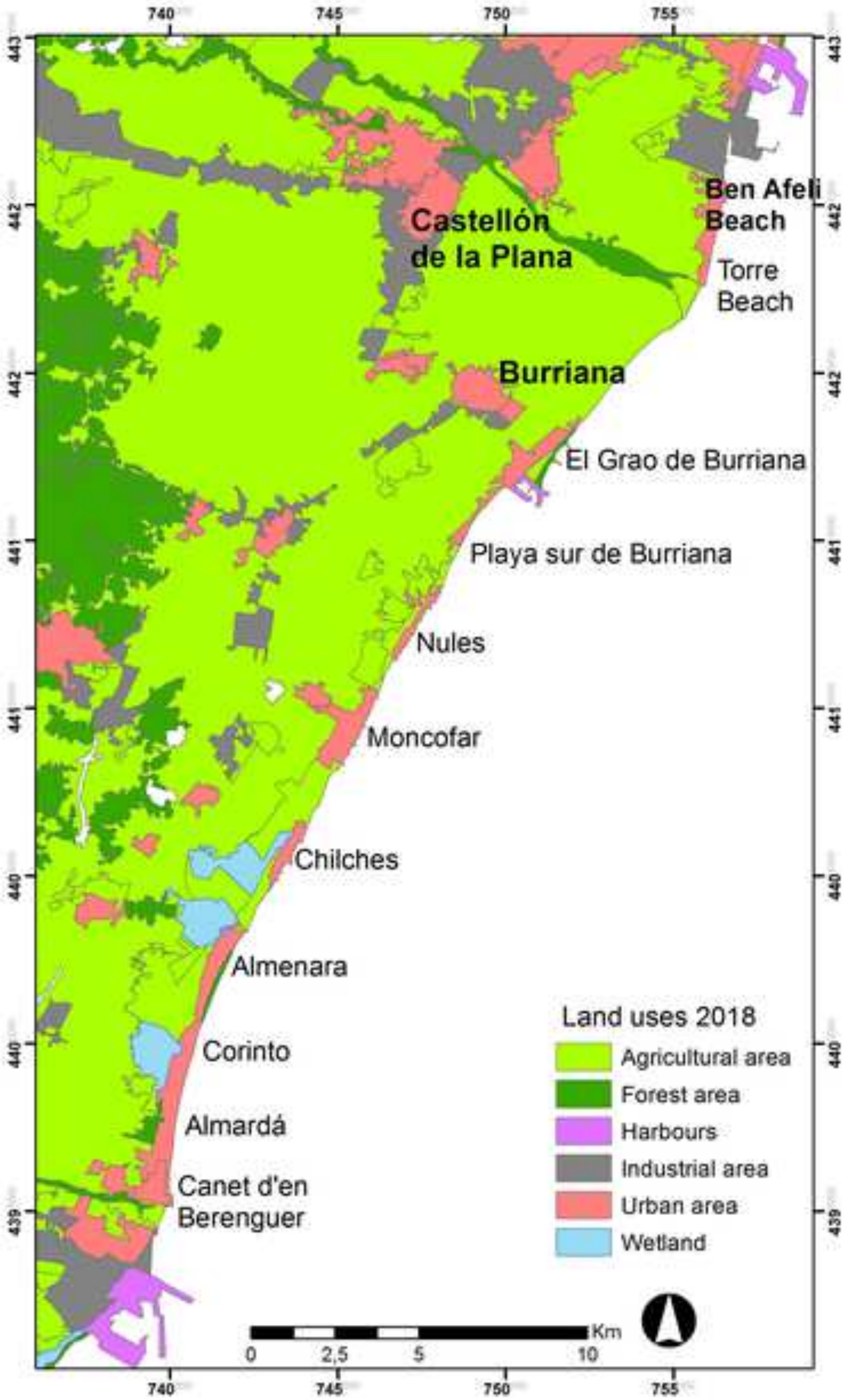
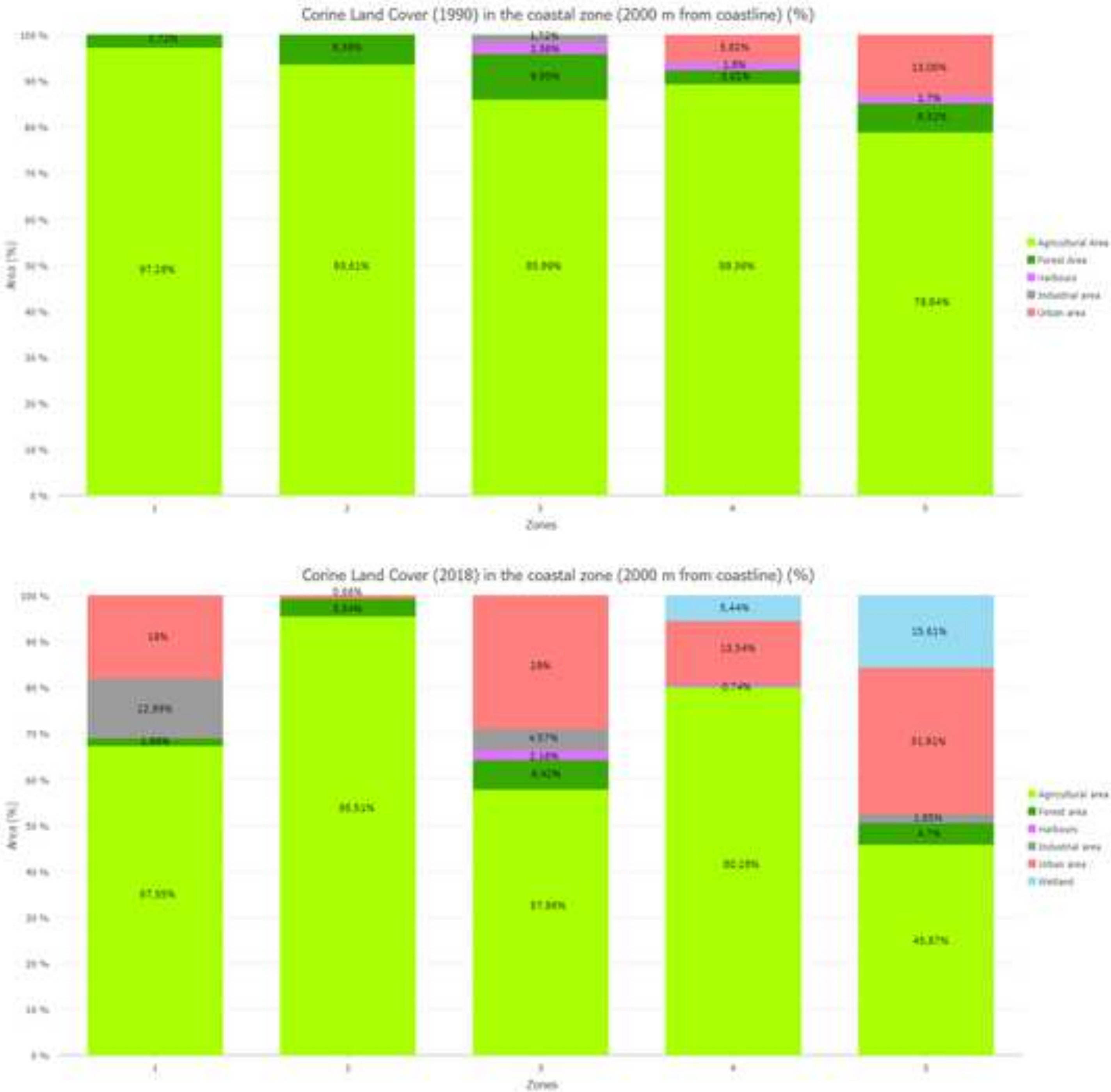


Figure 9c

Click here to access/download;Figure;Fig9c Uses changes.tif



MUNICIPALITY	NAME	LENGTH (m)	WIDTH (m)	SEDIMENT	BEACH TYPE
Almasora	Ben Afeli	450	20	Sand and pebble	Urban
	La Torre	2,200	15	Sand and pebble	Urban
Burriana	Grao/ El Grao	1,050	70	Sand and pebble	Urban
	L'Arenal	1,000	120	Sand	Urban
Nules	L'Alcudia	1,355	15	Pebbles	Semiurban
	Bovalar	1,188	20	Pebbles	Urban
	Les Marines	680	15	Pebbles	Urban
	Rajadell	1,035	10	Pebbles	No urban
Moncofa	Pedraroja	500	15	Pebbles	Urban
	El Grau	1,200	15	Pebbles	Urban
	Masbo	800	20	Pebbles	Urban
	Belcaire	500	10	Pebbles and rock	No urban
	Beniesma	1,300	10	Pebbles and rock	No urban
	L'Estanyol	560	30	Sand and pebble	Semiurban
Xilxes/Chilches	Les Cases	400	50	Sand and pebble	Urban
	El Cerezo	2,000	30	Sand and pebble	Semiurban
La Llosa	Llosa beach	1,000	30	Sand and pebble	No urban
Almenara	Casablanca beach	2,610	23	Sand and pebble	Urban
Sagunto	Malvarrosa	1,200	65	Pebbles	Semiurban
	Corint	1,300	28	Sand and pebble	Semiurban
	L'Alamardá	2,030	50	Sand and pebble	Semiurban
	Sagunt beach	1,200	100	Sand	Urban

Table 1. Main characteristics of the beaches in the study area (miteco.gob.es)

Date	Type	Scale	Source
1956	Aerial photo	1:32.000	IGN
1998	Orthophoto	1:5.000	ICV
2000	Orthophoto	1:5.000	ICV
2007	Orthophoto	1:5.000	ICV
2012	Orthophoto	1:5.000	IGN
2015	Orthophoto	1:5.000	IGN
2018	Orthophoto	1:5.000	IGN

Table 2. General characteristics of the images. (IGN = Geographic Institute of Spain; ICV = Cartographic Institute of Valencia)

Zone	Transects	Length (m)
1	325-390	5,919
2	295-324	5,898
3	266-294	2,044
4	95-265	16,629
5	1-94	9,657
TOTAL		40,147

Table 3. Number of transects and length of each zone as defined in Figure 3.

Zone	ΣΔV (m^3/year)	Advance/Retreat yearly rate (m/year)
1	4,443	0.13
2	-14,649	-0.41
3	8,489	0.69
4	-24,474	-0.25
5	20,157	0.35

Table 4. Yearly rates of volume change and advances or retreats by zones.

	USES 1990		USES 2018		USES COAST (1990)		USES COAST (2018)	
Class	Ha	%	Ha	%	Ha	%	Ha	%
Agricultural	39146.09	82.36	32316.63	67.58	6721.75	87.43	5453.28	69.74
Forest	4881.41	10.27	5677.40	11.87	368.74	4.80	189.33	2.42
Harbours	199.70	0.42	502.90	1.05	106.34	1.38	34.47	0.44
Industrial	1159.76	2.44	4257.93	8.90	8.78	0.11	161.96	2.07
Urban	2097.62	4.41	4391.76	9.18	482.80	6.28	1443.22	18.46
Wetland	44.03	0.09	670.26	1.40	0.00	0.00	536.65	6.86

Table 5. Land use changes for each of the classes considered in the map extent (uses 1990 and 2018) and in the 2000 m coastal area (uses coast 1990 and 2018). Estimation of the surface of each of the classes considered.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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