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Volumetric Change of the Coastal Dunes of the Isla De Buda (Ebro Delta) Between 2005 and 2017 Using LIDAR Data

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Abstract: The latest storms have highlighted the vulnerability of the Ebro delta coast, especially in the Buda Island area. There, the dune field is being significantly reduced due to erosion caused by large waves. This paper shows the volumetric variation of the dune field of the Buda Island using LiDAR data in the period 2005-2017. By 2017, almost half of the area and volume of the dunes that were present in 2005 had been lost. Changes in this coastal stretch as a result of storms Gloria (2020) and Filomena (2021) have also been analysed using Sentinel-2 images. The results show that the Buda Island suffers a strong erosion that involves the loss of a large part of the dune sediments and the retreat of the coastline.

Keywords: coastal dunes; LiDAR data; Buda Island

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1. Introduction

Dunes are accumulations of sediment caused by wind dynamics [1]. The main function of coastal dune systems is to prevent coastal erosion. According to Rodríguez-Santalla et. al. (2009) [2], in winter the dunes are eroded by local storms, carrying sand offshore where it is temporarily stored in submerged sand bars forming the winter profile, thus diminishing the energy of the surge; while in summer, the swell transports sand bars onto the shoreline building up the beach and the dunes are reconstituted again. In addition, the dunes have a high ecological value due to the high diversity of flora and fauna kept at it. Therefore, it is important to conserve the dunes and prevent their degradation, for which requires to monitor them using LiDAR data, satellite images or aerial photographs, among others.

This study was carried out on the Buda Island, in Ebro delta (Tarragona, Spain) (Figure 1), which began to form some 18,000 years ago due to the sea level rise, and has changed its morphology up to the present day. These changes were accelerated in the 20th century by the reservoirs construction in the Ebro basin, which meant that only 1% of the sediments that previously reached the delta reached it [2]. As a result, the delta is no longer controlled by river dynamics, but by currents and waves [8]. This, together with the subsidence of the delta plain and the increase in storminess (frequency and/or intensity), are leading to a general shoreline retreat; which also affects the dune development by decreasing their space and the quantity of sediment available. A detailed description of the processes that affect the Ebro delta, as well as its evolution, can be seen in Jiménez et al. (1997) [8]; Rodríguez-Santalla and Somoza (2019) [7], among many others.

The area most affected by these phenomena is the Buda Island, which is home to an important field of barjanoid dunes, which are faced with the Eastern waves, the most energetic (Figure 1). The Buda Island can be described as a shallow closed lagoon separated from the sea by a strip of land increasing in width towards the south [18]. Due to the exposure of Buda Island to waves, the dunes are in continuous degradation and the coastline is receding. According to Rodríguez-Santalla and Somoza (2019) [7], the coastline in this area has receded almost 3000 m from 1927 to the present. A description of the dune field of Buda Island can be found in Sánchez-García et al. (2019) [9].

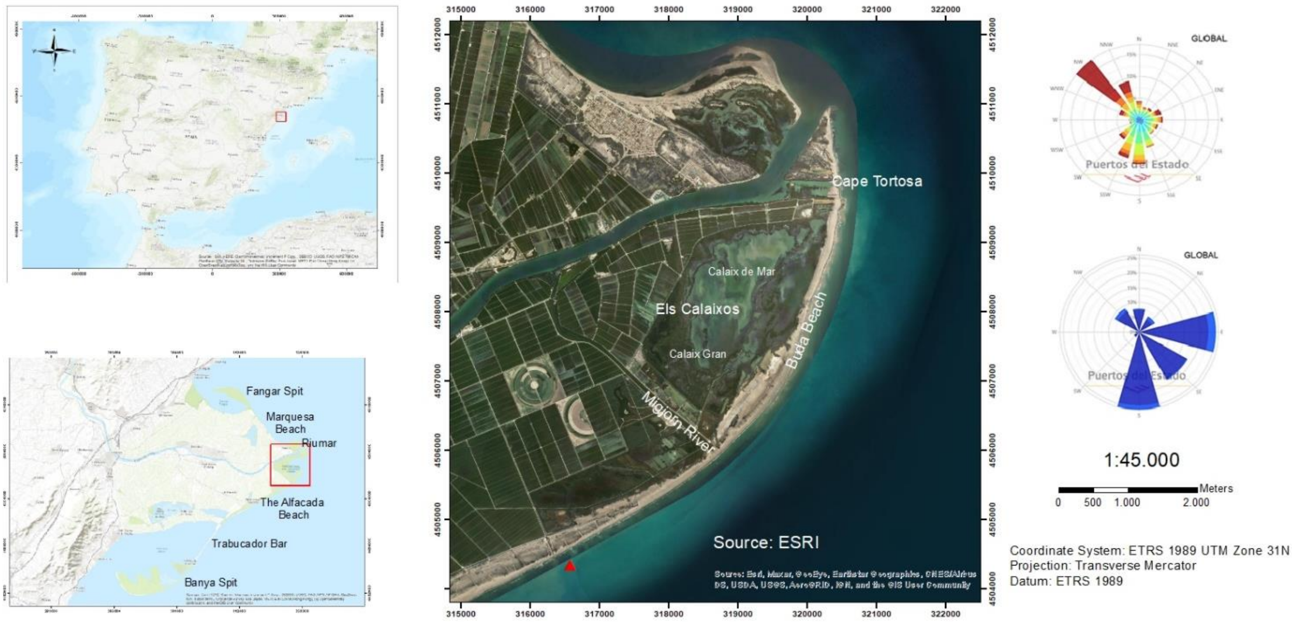

Figure 1. Location of Buda Island, the wind rose (average wind speed (m/s)) and the Wave rose (significant wave height (m)). Source: Puertos del Estado (www.puertos.es/es-es (accessed on 5 October 2021)).

Between 20 and 23 January 2020, the storm Gloria occurred, during which there were strong gusts of wind, rainfall of up to 120 mm in one day and high waves penetrating 3 km inland [10,11]. One year later, on 9 and 10 January 2021, the Filomena storm caused damage due to heavy rainfall [12].

The objective of this work is to analyze the volumetric changes of the Buda Island dune field, associated with the dynamics of its coastline, and to show the impacts caused by two stormy events: The Gloria storm (January 2020) and the Filomena storm (January 2021).

2. Materials and Methods

To carry out this study, LiDAR data from 2005, 2011, 2013 and 2017 from the Cartographic and Geological Institute of Catalonia were used, as well as Sentinel-2 images showing the study area before the storm Gloria (27/12/2019), after it (05/02/2020) and following the storm Filomena (17/01/2021). The ArcGIS 10.6 Geographic Information System was used to process these data.

The sediment balance between 2005 and 2017 has been carried out thanks to the Digital Terrain Models (DTM), created from LiDAR data. These data in *laz* format are decompressed to *las* format and a LAS-Dataset is created, which is converted into a raster, thus obtaining the DTM. The base-height of the dunes was established at 40 cm above sea level [14]. In this way, after reclassifying the rasters, they are multiplied by the original raster and the area corresponding to the study is extracted by means of a mask. These DTMs obtained are finally compared thanks to the Cut&Fill option of ArcGIS, and the Surface Volume tool allows the area and volume of the area to be calculated for each year [14].

On the other hand, to analyse the evolution of the coastline during storms Gloria and Filomena, the coastlines before and after the two storms are digitalized from Sentinel-2 images. These shorelines are grouped into a dataset and a baseline is created that will be used to calculate the rates of shoreline change, Net Shoreline Movement (NSM), using the ArcGIS extension Digital Shoreline Analysis System (DSAS 4.3) [17]. NSM is the distance (m) between the oldest and most recent line; and EPR is the value of NSM divided by the time interval in years between those lines, expressed as the change in m/year [17].

3. Results

3.1. Evolution of the Dunes on Buda Island Between 2005–2017

Figure 2 shows the areas that have eroded and those that have increased in volume in each time period from Cut&Fill analysis. In addition, Table 1 shows the rates of change of area and volume in the area in each period.

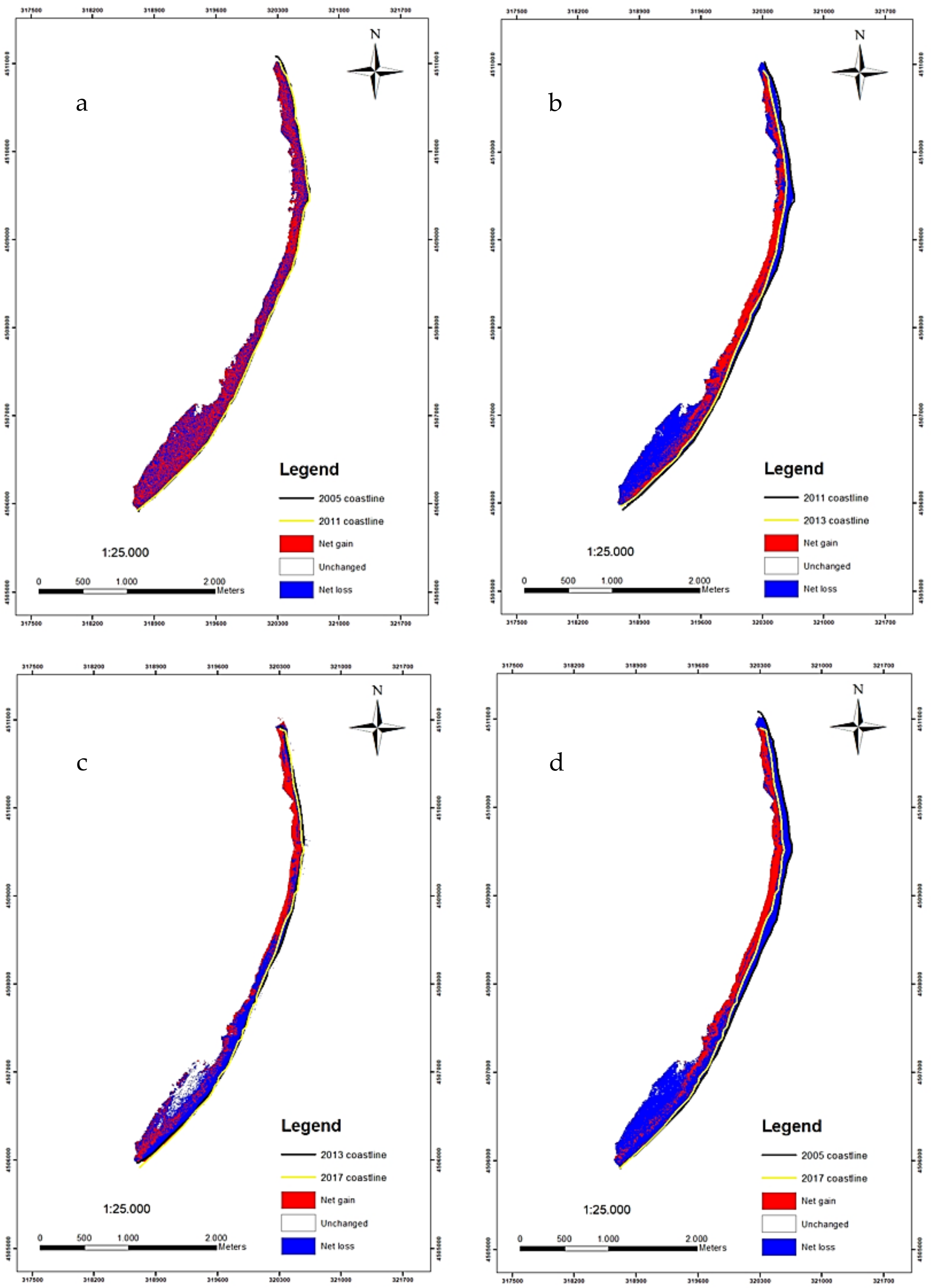

Figure 2. Sediment gain and loss in the dunes of Buda Island in periods 2005–2011 (**a**), 2011–2013 (**b**), 2013–2017 (**c**), 2005–2017 (**d**).

Table 1. Rates of change of area and volume in the area in the different periods.

Period	Rate of change of area (%)	Rate of change of volume (%)
2005–2011	−2,38	−0,31
2011–2013	−33,68	−32,43
2013–2017	−4,50	−16,43
2005–2017	−38,16	−43,71

Between 2005 and 2011 (Figure 2a) the Cut&Fill analysis does not show clear areas of erosion or deposition, but the balance of area and volume is negative. In the period 2011–2013 (Figure 2b), the retreat of the coast is evident, as is the deposition of sediment in the central part and north of Buda Beach, while erosion predominates in the south. In this case, up to a third of the area and volume that was present in 2011 is lost. In relation to the years 2013–2017 (Figure 2c), the erosive trend continues in the south and some accretion can be seen in the north, although the total balance of the area and volume is again negative.

With reference to the overall balance 2005–2017 (Figure 2d), the map shows a clear erosion on the coast, much more intense in the south than in the north of Buda Island. The mean erosion of the coast between 2005 and 2017 has been 8 m, resulting a retreat of 0,6 m/year. While in the south the dunes existing in 2005 have almost disappeared, in the rest of the study area the dune systems have been eroded and have retreated inland. Quantitatively, the variation in area and volume is negative and very significant in both cases, as 38% of the area occupied by the study area in 2005 and 43% of the volume of sediments have disappeared. In short, the coast of Buda Island has lost almost half of the volume that formed the dune bodies twelve years ago. This erosive trend in area and volume is causing the dune systems to weaken and Buda Island to become more vulnerable to storms.

3.2. Variation of the Coastline of Buda Island After Recent Storms

Figure 3 shows the positions of the coastline before the storm Gloria (2019), after it (2020), and just after the storm Philomena (2021). As we can see from Figure 3, the Gloria and Filomena storms have caused the coastline retreat of the Buda and San Antonio islands, reaching 100 linear meters of retreat in some sections (profile 8).

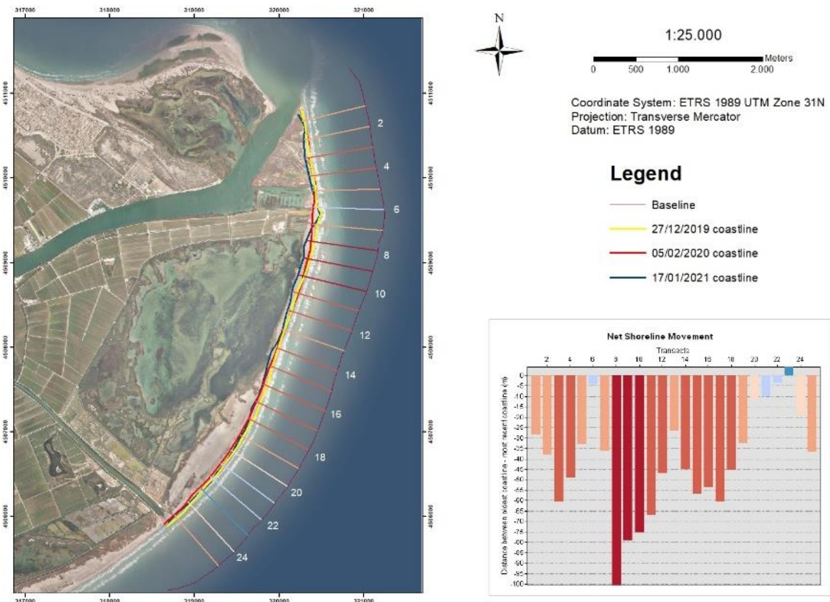

Figure 3. Evolution of the coastline of Buda Island and Net Shoreline Movement for each transect after storms Gloria (2020) and Filomena (2021). Orthofoto source: ESRI Co.

4. Discussion

The coast of the Buda Island shows a continued erosion ever since the impact of the dams was clearly reflected on the coast [7], alternating periods of greater or lesser erosive intensity [18]. While in the period 2005-2011 the erosion was not too intense, between 2011 and 2013 the erosion rate was very significant, so much so that almost one third of the area and volume was lost This coincides with the big storms, which occurred in of April 2012 and January 2013 [15].

In addition, the dune field developed along the coast is negatively affected by erosive processes. According to Jimenez et al., 2011, during major storms, the barrier is massively overwashed, especially at the northern part, leading to the full submerge of the beach and, eventually the breaching of the barrier in its northernmost part, as happened during the during the storms of Gloria and Filomena.

In short, the sedimentary balance is always negative, although the rate of erosion varies according to certain factors related mainly to the intensity of storm surges. This erosion and non-recovery of the sediment is making the delta system more vulnerable to changing conditions. On the other hand, it appears that there is an increase in the frequency and/or intensity of storm events as well as a potential sea-level rise which will affect to the present morphology of the delta [19]. The erosion of the Tortosa Cape (Buda and San Antonio islands) can endanger the stability of other areas of high ecological value such as El Garxal wetland, which is protected from the strongest waves by the Buda Island, in addition to accelerating the erosive processes of the entire deltaic system. For these reasons, the Spanish Administration is looking for different alternatives that minimize erosive processes and allow the conservation of the entire delta. A review of the different proposals can be seen in Rodríguez-Santalla and Navarro (2021). The one certainty is that until the problems of imbalance caused by of loss of vertical accretion of the delta plain due to sediment retention in the dams and the subsidence, are finally resolved, the Ebro delta, as well as the majority of the Mediterranean deltas, will increase their vulnerability accentuated by global change.

5. Conclusion

At present, the influence of waves dominates over that of fluvial processes in the Ebro delta, together with the subsidence and the erosion during storm events, means that in the most vulnerable areas such as Buda Island, the loss of sediment from the dune bodies does not cease.

Since the river Ebro stopped transporting sediment to its mouth, the coastline has continued to recede, leading to a loss of surface area and volume of the dune fields. But this erosion is increased by storms such as Gloria and Filomena, which are very intense, and after them, the resilience of the area is not being very high.

The erosion of Buda Island could accelerate the erosive processes of the entire deltaic system and lose one of the main Mediterranean formations of enormous geological and environmental value.

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