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Sediment Budget Implications from *Posidonia oceanica* Banquette Removal in a Starved Beach System

Simone Simeone *, Antonio Gian Luca Palombo, Fabio Antognarelli, Walter Brambilla, Alessandro Conforti and Giovanni De Falco

National Council of Research—Institute for the Study of Anthropic Impact and Sustainability in Marine Environment, 09170 Oristano, Italy; lucombo@gmail.com (A.G.L.P.); fabio.antognarelli@cnr.it (F.A.); walterbrambi@gmail.com (W.B.); alessandro.conforti@cnr.it (A.C.); giovanni.defalco@cnr.it (G.D.F.)

* Correspondence: simone.simeone@cnr.it

Abstract: This study discusses the potential impact of removing Posidonia banquette on the sediment budget of a siliciclastic-sediment-starved beach-barrier system. The morphology as well as the sediment volumes of this system were estimated. The banquette's composition and sediment content were determined with samples collected during five sampling campaigns conducted in one year. The carbonate content of the system was estimated by analyzing three 1 m long cores collected along the barrier. Five digital terrain models from DGPS surveys were used to compute the beach's average morphology to estimate the sediment volumes. The carbonate and siliciclastic sediment content from the cores were used to calculate the overall beach's sediment mass. Total sediment mass accounted for 126,000 m^3, of which ca. 86% was siliciclastic quartz sand and approximately 14% was carbonate sediment. Total banquette deposition during the year accounted for 2300 m^3, with a maximum and averaged sediment content of 339 kg m^3 and 78 kg m^{-3}. A permanent loss of ca. 1.31% of total mass will occur if 5000 m^3 of banquette were to be removed. In such beach settings, banquette removal may limit sediment availability, reducing the overall sediment mass and decreasing beach resilience against climate change effects such as sea level rise.

Keywords: Mediterranean beaches; banquette; *Posidonia oceanica*; sediment budget

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1. Introduction

The relevance of the natural environment to human activities, both economical and recreational, has become of greater importance in the last decades. Coastal environments and beaches in particular are examples where nature's conservation is highly beneficial for the community and tourist industry as a whole [1]. For this reason, coastal populations and tourists, as well as policy makers, are changing their perception on how economic development is strictly dependent on nature's conservation [1]. To increase tourist attraction, removing seagrass litter deposits is a common practice on sandy coastal shores. Along the Mediterranean coast, this activity is usually carried out by either beach managers or municipalities [2–6].

Posidonia oceanica is the most representative endemic seagrass species in the Mediterranean Basin, covering approximately 1.5% of the sea surface [7,8]. It develops extended meadows at water depths ranging from the surface down to 40–50 m [9,10]. However, its lower limit is commonly considered as being dictated by water transparency [11,12].

Furthermore, marine ecosystems such as *P. oceanica* are natural suppliers of biogenic carbonates which sometimes become the main sediment source for the beach, which increasingly turns more calcareous [13–16]. This has been observed in a western Sardinian beach (western Mediterranean), where these carbonate factories are responsible for providing approximately 46,000 × 10^3 kg per century of the present-day biogenic sediment to the coastal system [14].

Posidonia oceanica sheds leaves during the autumn and the resulted cast litter is deposited ashore by the concurrent action of wind waves and of wave-induced littoral currents [9,17]. These deposits, referred to as "banquette" [18], are commonly observed in the beach faces of the Mediterranean's sandy shores [3,19] and are not only made up of organic material, such as leaves and rhizomes, but also sediments [20].

Several studies have focused on the implications of seagrass litter removal on sandy shores around the world. The authors of [21] found that on exposed Mediterranean beaches, seagrass litter removal (when carried out using heavy machines) may compromise sediment exchange between the bar and berm, altering beach face morphology. Heavy machine operations on the beach face and backshore flatten the beach profile, increasing beach vulnerability to wave run-up and modifying the beach sediment budget [3,5,16,22,23]. Sediment content of as much as 100 Kg m^{-3} can be found interlayered within the Posidonia banquette structure [5,19,24]. Hence, when Posidonia litter is removed, a permanent loss of sediment coupled with less nutrient and biomass availability for the coastal ecosystem occurs [20,25].

Sediment-budget-wise, the practice of removing banquette may have a stronger impact on starved beach systems. These are systems where, in their present state, the sediment composition is made up in part or entirely of reworked grains, not newly supplied from their original geological sources [26]. For this reason, sediment loss due to removal operations may negatively affect the whole sediment budget, posing significant risks to shoreline retreat, as well as beach resilience to storm events and sea level rise.

The aim of our study is to estimate the impact of *Posidonia oceanica* banquette removal in the overall sediment budget of a beach, where no present-day supply from geological source rock is occurring and new sediment supply is only provided by biogenic carbonates generated in nearby marine ecosystems, such as *Posidonia oceanica* meadows.

2. Materials and Methods

2.1. Study Area

The study area is located in the Sinis Peninsula, on the western coast of Sardinia Island (western Mediterranean) (Figure 1). The alternation of cliffs and siliciclastic beaches characterize the Sinis coastline, where no significant rivers shed terrigenous sediment from the inland. The beaches are primarily composed of coarse and very coarse siliciclastic grains and fine biogenic carbonate [3], the former being likely derived from the erosion of the granite outcrops at Mal di Ventre Island and referred to as relict [3,13]. The term "relict" sediment was used by different authors [13,27] to highlight that the sediments of these beaches have no present-day sediment sources providing them with siliciclastic coarse grains (mainly quartz).

Previous studies [14,27,28] have highlighted that the carbonate sediment composing the Sins beaches are mainly of biogenic origin provided by coastal ecosystems, such as *Posidonia oceanica* meadows colonizing the rocky sea bottom in the shallow waters off the coast of the Sinis Peninsula. Along the coast of the Sinis Peninsula, the most important beaches, from north to south, are Mari Ermi, Is Arutas, Maimoi and San Giovanni (Figure 1).

In this area, the main geological outcrops are characterized by aeolian and marine sandstone that, at present, are not relevant as sediment sources for the beaches of the Sinis Peninsula [21,27].

This study is focused on the beach of Mari Ermi, classified by [29] as a beach ridge system (or barrier system) ca. 1 Km in length and ca. 60 m wide. The beach sediment characterization carried out by [27,29] highlighted that the composition is primarily of coarse siliciclastic sand and gravel with a carbonated content of approximately 20%. To the north, the beach is bounded by a rocky cape, which also influences its orientation, whereas in its submerged part, it shows a large rocky outcrop also extended to the central beach. To the south, the presence of a limited submerged beach does not show morphological feature development such as bars and along the back of the ridge, several ephemeral ponds are present from north to south [29].

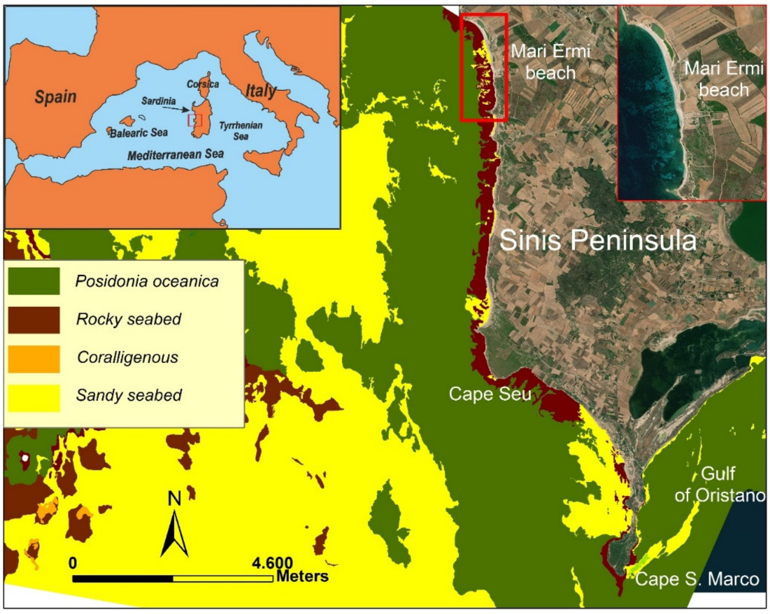

Figure 1. Study area. Inset map showing Mari Ermi Beach.

On this beach, banquette is usually deposited by waves and storms and the Marine Protected Area's management body has never performed any removal or beach cleaning operations.

2.2. Beach and Banquette Surveys

Ground surface elevation data of the beach, as well as areas occupied by banquette deposits, were acquired using a real-time kinematic (RTK) differential global positioning system (DGPS) [19,30–32]. Following the methodology in [19], positioning data (X, Y and Z) were sampled in RTK mode along a series of cross-shore transects, spaced ca. 45 m apart (Figure 2), during 5 survey campaigns from September 2020 to June 2021.

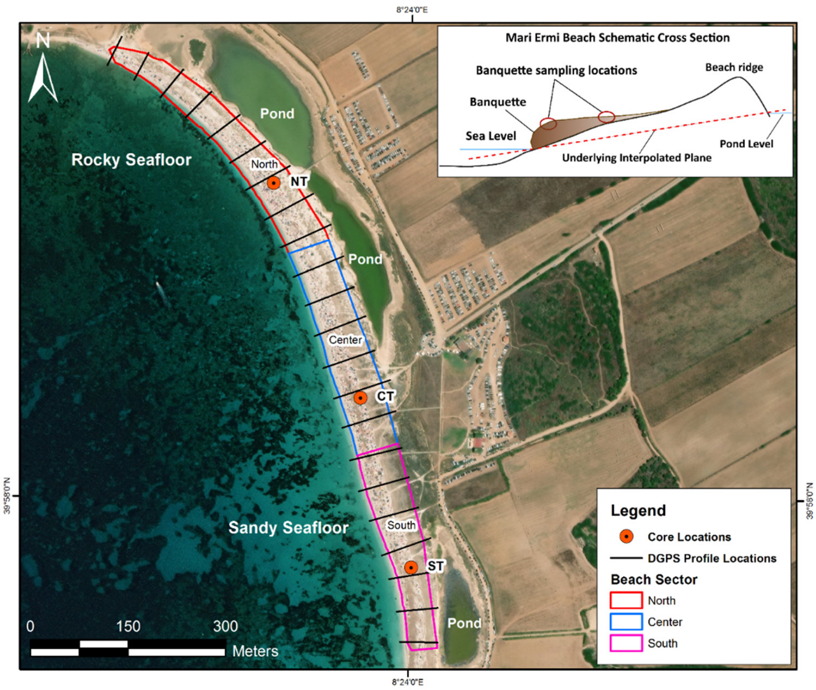

Figure 2. Aerial photograph of Mari Ermi showing beach sectors and beach profile locations. Inset figure shows schematic beach sections with banquette sampling locations and the underlying interpolated beach surface.

For each survey, a digital elevation model (DEM) for both the beach's ground surface (including banquettes) and the banquette–sediment interface were created. Following the methodology explained in [19], the thickness of banquette structures was determined using a graduated pole inserted in the banquette body down to the beach sediment underneath. This procedure allowed us to compute the banquette–sediment interface used to calculate the banquette volumes. Volumes of banquette during each survey were estimated by subtracting the banquette–sediment interface DEM from beach's ground surface DEM. This allowed us to obtain volumes of banquette for each survey. Using SURFER package 10.0 (Golden Software®, Golden, CO, USA), the acquired DGPS elevations were interpolated following the "natural neighbour interpolation" methodology [19].

2.3. Banquette Composition Characterisation

A total of 62 banquette samples was collected during four sampling campaigns, conducted in July 2020 (10 samples), October 2020 (16 samples), February 2021 (20 samples) and April 2021 (16 samples). Samples were preferably collected on the banquette berm crest and between the former and the landward limit of the accumulation (Figure 2), using a box corer of 0.008 m^3.

Following the methodology applied by [19], the dry weight percentage of sediments, leaves and rhizomes for each banquette sample was determined. The samples were initially wet-sieved using a 2.5 mm mesh to separate leaves and rhizomes from the sediments. The rhizomes were then manually separated from the leaves and the sediments were further separated from the remaining fibers using a saline solution (160 mg l^{-1}). Rhizomes, leaves and fibers were oven-dried at 50 °C and weighed in order to measure the dry biomass of rhizomes and leaves. Sediments were washed thoroughly with distilled water, dried (80 °C for 48 h) and weighed [19]. The banquette's compositional percentages of sediments, leaves and rhizomes were then plotted on a ternary diagram. For each survey, the total sediment mass within the banquette was calculated in relation to the computed deposited volume.

2.4. Carbonate Content on Core Sediments

To estimate the percentage of carbonate content within the Mari Ermi beach ridge, a total of 3 manually hammered cores was collected on the top of the structure, in the northern, center and southern sectors, named NT, CT and ST, respectively (Figure 2). Coring was carried out using 5 cm-diameter, 1 m-long PVC corers. At the lab, each core was longitudinally cut in half and sediment sampled at each facies/lithological change, for the ST core only (south). A total of 18 samples was collected and was quartered down to a weight of ca. 1 gr, in order to determine carbonate content (% of carbonate) using a Dietrich–Frühling calcimeter.

The carbonate content in each core has been also estimated using strontium (Sr) element concentration, detected along one half of each core using a portable Olympus® Vanta Family X-Ray Fluorescence analyzer (hereafter pXRF). This is because strontium, among other metals, is incorporated into the biogenic and non-biogenic calcite crystal lattice [33–38] and, consequently, can be used as a proxy for an estimation of carbonate content. XRF acquisition was carried out every 2 cm along the exposed core section, with sensor at a constant distance of 0.5 cm from the sediment. To use the pXRF's strontium concentration as a proxy for direct carbonate identification, a calibration curve was used to plot the data (both pXRF %Sr and % $CaCo_3$ from the 18 core samples) recorded for the ST core. The values of two pXRF Sr measurements sampled every 2 cm were averaged in order to perform the calibration with the $CaCo_3$ content in sediment samples. The calibration equation allowed us to generate a computed carbonate content log curve for each of the available cores. To calculate the $CaCO_3$ content for the NT and CT cores, and to obtain a more uniform result, the values of %Sr from the pXRF where averaged every 4 cm. Both log curves (% Sr XRF and computed $\%CaCo_3$) for each core were then plotted against depth below the ground surface. Both the measured and the computed carbonate percentages were used for the estimation of total mass of biogenic carbonate within the Mari Ermi beach ridge structure and sediment budget calculation.

3. Sediment Budget Calculation

To estimate the volume of the Mari Ermi beach ridge, a digital elevation model (DEM) was created for each survey. DEMs were obtained from the DGPS data collected during each survey campaign by using SURFER package (Golden Software®, Natural Neighbor grid method). Finally, an averaged DEM was obtained averaging the DEMs from each survey. The averaged DEM was divided into three main sectors, north, center and south, to characterize each one's carbonate and siliciclastic relict sediment content. DEM boundaries are shown in Figure 2 and color-coded to represent each of the beach sector (north, center and south) where the sediment budget was calculated. The seaward limits range from 0.4 to 0.6 m a.s.l., whereas the landward limits are close to the ponds' shoreline and range from 1.4 to 1.6 m a.s.l. (Figure 2).

The overall sediment volume along each sector of the Mari Ermi beach ridge was computed by subtracting the gridded underlying substrate surface from the averaged DEM [14]. We obtained the underlying beach surface by interpolating the elevation data along the shoreline, ranging between 0.4 m and 0.6 m a.s.l., with elevation data along the ponds' shoreline in the back barrier, ranging between 1.4 m and 1.6 m a.s.l.

The sediment volume was converted into sediment mass by applying a porosity value of 0.3 [39], a calcite density of 2.71 Kg m^{-3} and a quartz density of 2.62 kg m^{-3}, as explained in [14]. For each beach sector (north, center and south), the average carbonate content was estimated based on each core data (NT, CT and ST). The obtained values, coupled with the dry density of sediment, allowed us to estimate the mass of both siliciclastic quartz and biogenic carbonate sediments.

To determine the potential sediment loss due to banquette removal on the whole beach, the averaged and maximum sediment content was calculated for the entire sample dataset (n = 62). The total loss of sediment mass caused by banquette removal was calculated considering 100 m^3, 2000 m^3 and 5000 m^3 of banquette.

4. Results

Figure 3 shows the area occupied by banquette deposits during the surveyed months, from July 2020 to June 2021. A total of 2321 m^3 of banquette was deposited on Mari Ermi beach during the whole study period. The total maximum mass of sediment recorded within banquette structures is 497 $\times$ 10^3 Kg (Table 1). This value does not account for the survey of June because no banquette samples were collected during that survey. Based on our surveys, the autumn and winter seasons (October 2020 and February 2021) are characterized by the largest areas and volumes occupied by *Posidonia oceanica* banquettes.

The calculated volumes for October and February are 694 m^3 and 990 m^3, respectively (Table 1). On the other hand, the spring and summer seasons show a sensible decrease in banquette deposition accounting for 250 m^3 in July 2020, 273 m^3 in April 2021 and 114 m^3 in June 2021 (Table 1).

For each survey, we determined the maximum sediment content, which ranges from 137 kg m^{-3} up to 339 kg m^{-3} recorded in July 2020 and October 2020, respectively. The resulted sediment mass within banquette structure is presented in Table 1. As shown in the table, maximum sediment mass was recorded in October 20 (236 $\times$ 10^3 Kg). Additionally, no samples for these data were collected during the June 2021 survey.

The ternary diagram in Figure 4 highlights that banquette samples collected at Mari Ermi beach are characterized by a very low number of rhizomes (ranging from 0%–13%), whereas sediment and leaves can be in excess of 90% of the total weight. From our data, sediment content in banquette ranges from 0% to 92% and 31 out of 62 samples show sediments account for more than half of banquette's total weight. (Figure 4, Table S1).

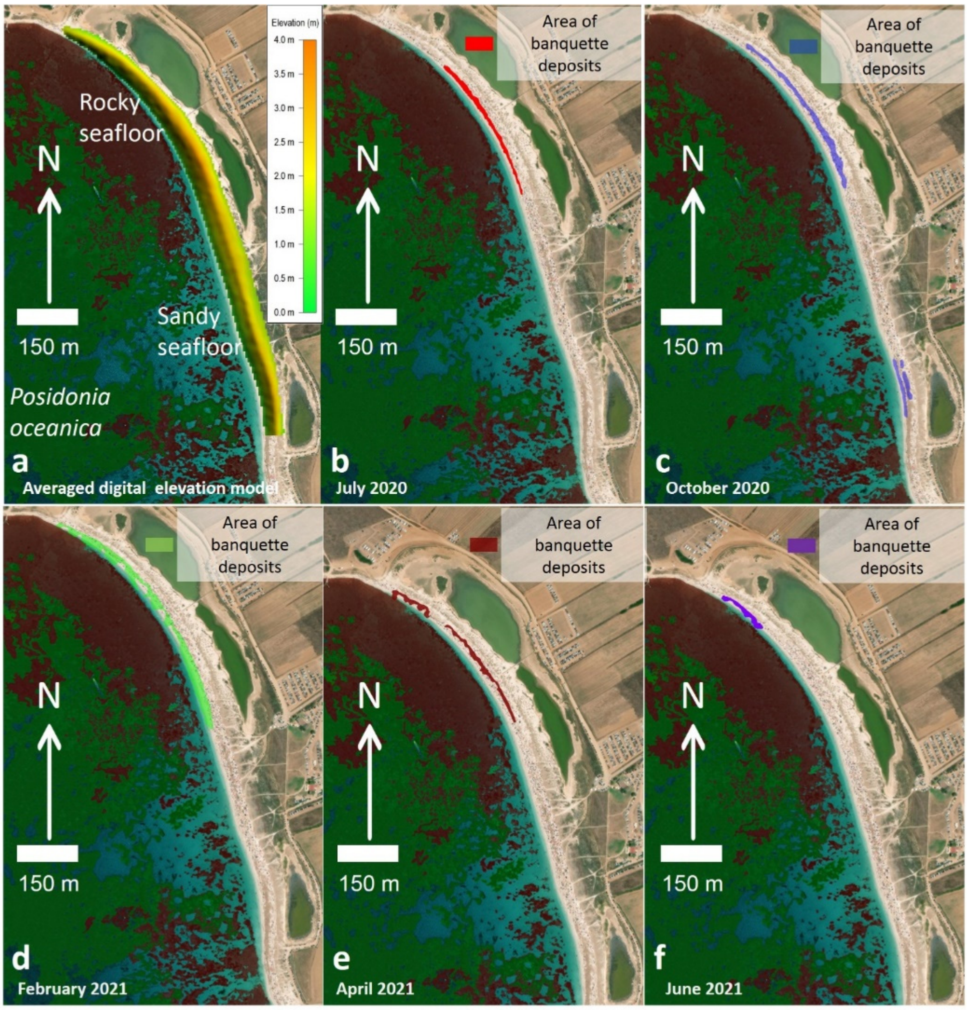

Figure 3. (**a**) Average digital elevation model of Mari Ermi beach barrier; (**b**–**f**) areas occupied by banquette deposits from July 2020 to June 2021 (from DGPS survey).

Table 1. Volume of banquette deposited (m^3) and maximum sediment content (10^3 Kg) on Mari Ermi beach, from July 2020 to June 2021.

Survey Period (Number of Samples)	Max ÷ Avg. Sedim. Content (Kg M^{-3})	Volume of Banquette (M^3)	Max Sedim. Mass (10^3 Kg)
July ′20 (n = 10)	137 ÷ 105	250	34
October ′20 (n = 16)	339 ÷ 126	694	236
February ′21 (n = 20)	184 ÷ 35	990	182
April ′21 (n = 16)	163 ÷ 62	273	45
June ′21	No samples	114	No samples
Total (n = 62)		2321	497

4.1. Carbonate Content on Cores

The calibration curve in Figure 5 shows strong positive correlation (R2 = 0.87) between core ST’s strontium data, recorded from pXRF analysis and calcium carbonate content from the 18 core sediment samples. By applying the equation in Figure 5 (y = 11.023×–0.0799), we computed the percentage of carbonate for cores NT and CT, where no sediment samples were collected. The chart shows that for Sr values below 0.01%, carbonate content result was very low. This is due to the resolution limitation of the pXRF instrument. For this reason, for Sr values below 0.01%, carbonate content was considered as 0%.

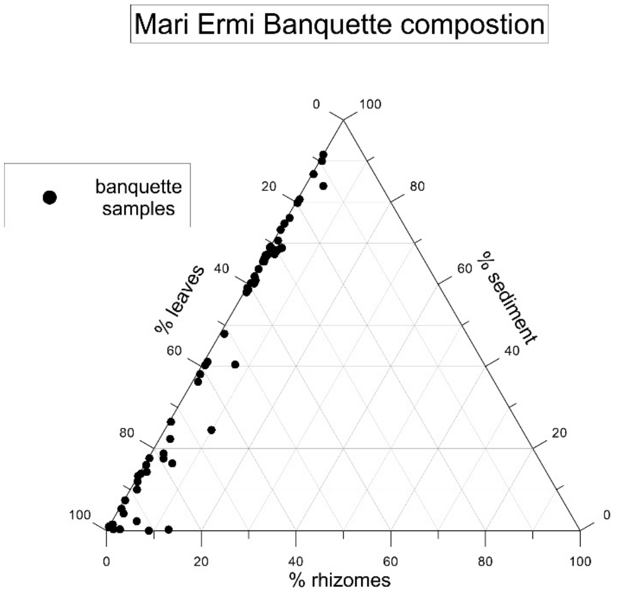

Figure 4. Ternary plot representing Posidonia banquette composition in % of leaves, rhizomes and sediment.

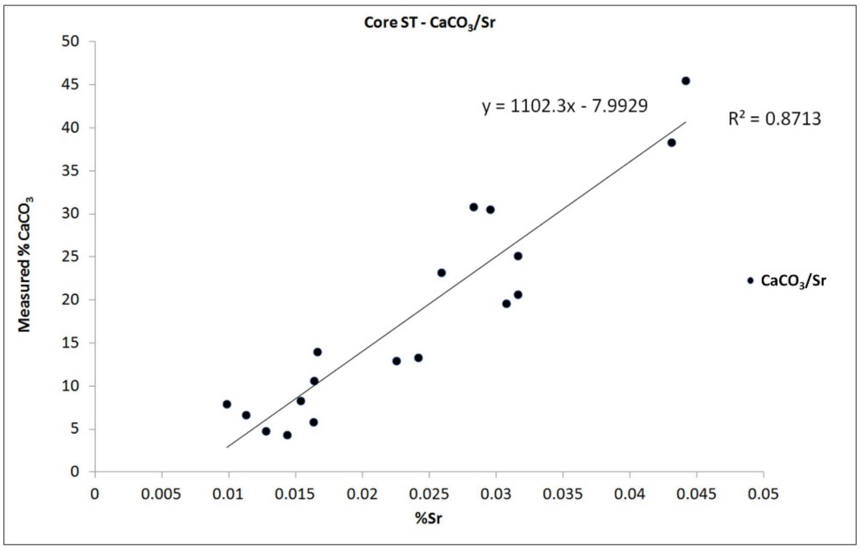

Figure 5. Calibration chart for measured carbonate content and strontium values from XRF analysis for core ST.

The computed carbonate content logs and XRF logs are plotted against depth below ground surface in cm, as seen in Figure 6, where a photo of each log is also plotted at scale against the log curves. The core photos show the carbonate sediments are associated to the yellowish to brownish horizons, clearly visible along each section, and to peaks in both log curves. These carbonate layers are likely representative of changes in weather condition and/or short-term depositional events. It is noticeable that for all the cores, the computed %$CaCO_3$ curve appears to be smoothed compared to the %SrXRF one. This smoothing effect is because the strontium data recorded from pXRF was averaged every 4 cm, while sampling with pXRF was conducted every 2 cm. The NT core in Figure 6a shows significantly less carbonate content in comparison to the CT and ST ones (Figure 6b,c). The percentage of CaCo3 readings for NT core ranges from ca. 25% (ca.17 cm depth) to 0%. A large portion of the core from approximately 28 cm to 77 cm depth (Figure 6a) shows no carbonate readings, which is related to values of pXRF Sr content <0.01%.

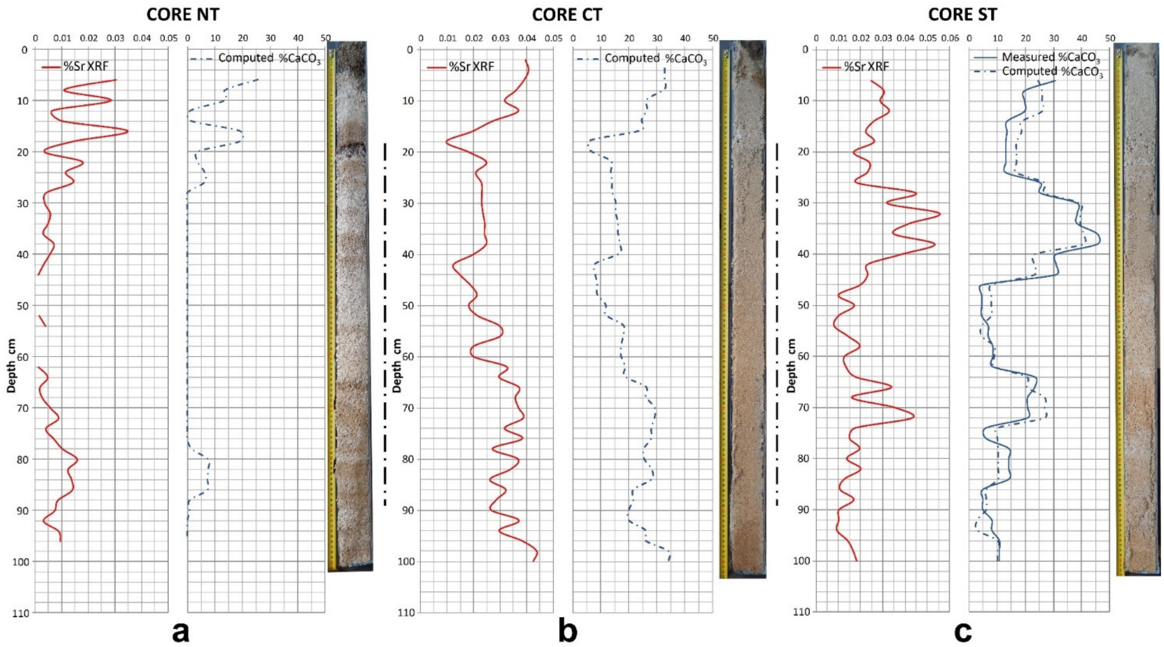

Figure 6. Core logs and core photos for the three wells representing %XRF from pXRF tool, computed carbonated content and for core ST, also measured carbonate content from sediment; (**a**) %XRF from pXRF tool and computed carbonated content along NT; (**b**) %XRF from pXRF tool and computed carbonated content along CT; (**c**) %XRF from pXRF tool, measured carbonate content and computed carbonated content along ST.

The core CT from the central sector of Mari Ermi beach (Figure 6b) shows carbonate content ranging from 5% (at ca. 21 cm and 45 cm depth) to 39% (at ca. 100 cm depth). Figure 6c shows both computed and measured calcium carbonate logs in core ST, from the southern sector of the beach ridge structure. Highest readings for both lab-measured and computed %$CaCo_3$ are recorded at the depth of 38 cm, accounting for approximately 45.5% and 41%, respectively.

The lab-measured average carbonate content for the whole CT core was 17%, whereas in wells NT and CT, it accounted for 3% and 23%, respectively. These values were used to compute the sediment mass for the three sectors of the beach.

4.2. Sediment Budget

The sediment volume for the three sectors of Mari Ermi beach was computed and presented in Table 2. The volume of the whole beach ridge system accounts for 68,055 m^3, of which 27,448 m^3 (40.33%) are estimated in the northern sector, 27,304 m^3 (40.12%) in the central sector and 13,303 m^3 (19.54%) in the southern sector (Table 2).

Table 2. Mari Ermi beach sediment budget calculated for each sector and for the whole system and parameters used for the calculation.

Parameters for Sediment Mass Calculation	Unit	North	Center	South	Total
Volume of beach ridge system	m^3	27,448	27,304	13,303	68,055
Porosity of sands	adim	0.3	0.3	0.3	
Calcite density	10^3 Kg m00AF^3	2.71	2.71	2.71	
Quartz density	10^3 Kg m^{-3}	2.65	2.65	2.65	
Carbonate content of beach ridge sediments	%	3	23	17	
Dry density of beach sediments	10^3 Kg m^{-3}	1.86	1.86	1.86	
Mass of carbonate (biogenic sediments)	10^3 Kg	**1533**	**11,689**	**4209**	**17,431**
Mass of siliciclastic relict sediments	10^3 Kg	**49,556**	**39,132**	**20,552**	**109,240**
Total mass of sediments	10^3 Kg				**126,671**

The total mass of sediment in the Mari Ermi beach ridge system accounts for 126.67 × 10^3 Kg, of which 109.24067 × 10^3 Kg (86%) represent siliciclastic quartz sediment, whereas biogenic carbonate accounts for 17.43167 × 10^3 Kg (14%).

From the whole dataset, the average and maximum sediment content within the banquette samples was 78 Kg m^{-3} (average sediment weight in samples of 0.6 Kg) and 339 Kg m^{-3} (maximum sediment weight in samples of 2.7 Kg), respectively.

Using these values, we performed a sensitive analysis (Table 3) simulating the potential impact of sediment loss considering removing 100 m^3, 2000 m^3 and 5000 m^3 of banquette. We considered these three volumes following data published in [3], where for several Sardinian beaches, a deposition in excess of 5000 m^3 of banquette was recorded.

Table 3. Different scenarios on the sediment budget caused by removing banquette on Mari Ermi beach system.

Posidonia oceanica **Banquette Removal and Impact on Sediment Budget**				
Average sediment content	**78 kg m^{-3}**	100 m^3 of banquette removed	2000 m^3 of banquette removed	5000 m^3 of banquette removed
Impact on sediment budget (10^3 Kg)		**7.8**	**156**	**390**
Impact on sediment budget (%)		**<0.1%**	**0.12%**	**0.31%**
Maximum sediment content	**339 kg m^{-3}**			
Impact on sediment budget (10^3 Kg)		**33.9**	**678**	**1695**
Impact on sediment budget (%)		**<0.1%**	**0.54%**	**1.34%**

Taking into account a sediment content of 78 Kg m^{-3} (Table 3), the impact of removing 100 m^3 of banquette would cause a sediment loss of 7.867 × 10^3 Kg (<0.1%). Removing 2000 m^3 of banquette would cause a sediment loss of 15,667 × 10^3 Kg (0.12%), whereas the removal of 5000 m^3 would cause a sediment loss of 39,067 × 10^3 Kg (0.31%).

By using a sediment content of 339 Kg m^{-3} (Table 3), the impact of removing 100 m^3 of banquette would cause a sediment loss of 33,967 × 10^3 Kg (<0.1%), removing 2000 m^3 of banquette would cause a sediment loss of 67,867 × 10^3 Kg (0.54%), whereas the removal of 5000 m^3 would cause a sediment loss of 169,567 × 10^3 Kg (1.34%).

5. Discussion

We estimated the total mass of a beach barrier system mainly composed of siliciclastic quartz sand by analyzing sediment samples and processing multi-temporal data from DGPS surveys. The estimation of annual volume of banquette deposition was carried out, allowing us to calculate the potential sediment loss from the system if the banquette were to be removed.

In starved beach systems, new sediment supply is limited or null, as observed in several locations along the Mediterranean coastline [20,40]. Removing banquette structures from these systems may cause a permanent loss of sediment and potentially induce beach erosion and morphological modifications, as well as reducing beach resilience to storm events [5,21,23,41].

Banquette removal operations are a common management practice in the Mediterranean region [6]. However, very few studies have been carried out assessing the sediment budget implications due to banquette removal on starved beach systems such as our study site [5].

Several studies have quantified large volumetric accumulations of banquette along the Mediterranean coastline [5,20,42]. The authors of [12] reported an accumulation greater than 2000 m^3 in the Sinis Peninsula, which may rest on the beach face up until the next season, as observed by [19].

At Mari Ermi beach, we recorded a cumulative volumetric banquette deposition of 2321 m^3 during our study period. A single depositional event in excess of 900 m^3 was recorded in February 2021.

Our study highlights that the beach of Mari Ermi is composed of ca. 126.67067 × 10^3 Kg of sediment, of which ca. 86% is represented by a siliciclastic relict composition [13,27]. A calculated 14% of the total sediment composition is represented by present-day biogenic carbonates likely provided by the marine ecosystems colonizing the waters near Mari Ermi beach. The contribution of carbonate sediment by marine ecosystems has also been observed by several authors in different Mediterranean and Australian coastal settings [14,15,40,43,44]. Both siliciclastic relict and biogenic carbonate sediment may be trapped within the banquette structures during their building processes.

We estimated the sediment content within the Mari Ermi banquette structures range from 0 to 339 Kg m^{-3}. *Posidonia oceanica* beach wracks are often removed from the beach face by means of different methods. When these accumulations are of important volumes, heavy machines are widely used, causing significant sediment loss due to non-selective removal [6].

We quantified the potential impact of banquette removal operations on the sediment budget of a starved beach system, considering 78 Kg m^{-3} and 339 Kg m^{-3} as average and maximum values of sediment content, calculated from the whole sample dataset. Our sensitive analysis takes into account three different volumetric scenarios: 100 m^3, 2000 m^3 and 5000 m^3 (Table 3). These values are based on data published by [3] that explore the amount of the removed banquette from Sardinian beaches. In particular, the authors reported that on several beaches of the Sardinian Island, the volumes of banquette removed accounted for more than 2500 m^3, with maximum values of more than 5000 m^3.

Table 3 shows that removing 100 m^3 of banquette would have a limited impact on the beach's sedimentary budget. On the other hand, removing larger volumes of Posidonia leaf litter (2000 m^3 and 5000 m^3), would expose the beach to a significant sediment loss and a depletion of total sediment budget. Indeed, taking into consideration the 5000 m^3 removal scenario, our sensitive analysis shows a sediment loss ranging from 0.31% to 1.34% of the available budget (Table 3). On sediment-starved beaches, such as Mari Ermi, the present-day sediment supply may not be able to balance the sediment depletion due to the removal operation. In fact, more than 80% of the sediment composing this beach is coarse and very coarse siliciclastic quartz sand that [27] assumed was derived from the reworking and re-distribution of the material eroded from the granitic outcrops of Mal di Ventre Island off the coast of the Sinis Peninsula. At present, no source of this sediment is found along the area and the headlands limiting the beach to the north and to the south are sandstone [27] with no presence of siliciclastic quartz sand. For this reason, the erosion of these headlands and outcrops cannot provide new siliciclastic quartz sediment to the beach.

Furthermore, our volume estimation on Mari Ermi beach highlighted that the total carbonate biogenic sediment accounted for no more than 17% of the total sediment volume composing the barrier. This value is very low when compared with other mixed carbonate–siliciclastic sediment beaches where biogenic carbonate sediment is produced by marine ecosystems and can be relevant in sediment budget maintenance [14]. Following these considerations, the natural supply of carbonate from marine ecosystems cannot be able to balance very large sediment loss likely caused by banquette removal, in particular when heavy machinery is used.

Removal operations may also affect the beach response to storms because this practice could directly influence the beach morphology by destroying berms as well as other morphological features. Recent studies conducted on Mediterranean beaches highlighted that the banquette deposits located along the beach face can limit the run-up and can mitigate the overwash and flooding [23,41]. On Mari Ermi beach, the banquette can be very important on the berm edification (Figure 3); in fact, a previous study highlighted that the beach berm is built up by alternating layers of *P. oceanica* banquettes and sediment [27]. Our data confirm the importance of the banquette on the morphology of this beach, and as shown in Figure 3, the swash zone can be widely occupied by banquette mainly during the autumn and winter seasons (Table 1). These deposits characterize the beach face of Mari Ermi and may directly interact with the waves in case of storm occurrence.

Furthermore, the water infiltration along the beach surface may also be influenced by deposition of banquette. The authors of [41] found that the water infiltration increases in the presence of intertwined reeds and seagrasses within the beach berm, and this setting seems to increase its flexibility and preserve it against destructive wave action [41].

Reducing sediment availability in a beach and barrier system may also affect the beach's adaptation to climate change and sea level rise (SLR). The large volumes of sediment loss due to banquette removal may affect the sediment availability with the consequence of reducing both the barrier's thickness and the beach's resilience in response to storm events and increasing the overwash. This is also considering that in our study area, recent studies forecasted that the SLR for the year 2100 will vary from 0.54 m to 1.34 m [29,45].

Our study confirms that large volumes of *Posidonia oceanica* banquette may trap a large amount of beach sediment within their structures. The common practice of removing banquette from the beach, often using heavy machines, may lead to a permanent sediment loss. This practice may negatively affect the beach's resilience and the adaptation to the forecasted SLR in those systems where sediment supply is limited or null.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14152411/s1, Table S1: Banquette samples composition expressed both in weight and in percentage.

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