

Article



Coastal Modification in Relation to Sea Storm Effects: Application of 3D Remote Sensing Survey in Sanremo Marina (Liguria, NW Italy)

Ilaria Ferrando ¹^(b), Pierluigi Brandolini ²,*^(b), Bianca Federici ¹^(b), Antonio Lucarelli ³, Domenico Sguerso ¹^(b), Danilo Morelli ²^(b) and Nicola Corradi ^{2,4}^(b)

- Geomatics Laboratory, Department of Civil, Chemical and Environmental Engineering (DICCA), University of Genoa, 16145 Genoa, Italy; ilaria.ferrando@edu.unige.it (I.F.); bianca.federici@unige.it (B.F.); domenico.sguerso@unige.it (D.S.)
- ² Department of Earth, Environment and Life Sciences (DiSTAV), University of Genoa, 16132 Genoa, Italy; danilo.morelli@unige.it (D.M.); nicola.corradi@unige.it (N.C.)
- ³ Drafinsub Survey, 16126 Genoa, Italy; alucarelli@dssurvey.com
- ⁴ National Research Group for Coastal Environment (GNRAC), 16132 Genoa, Italy
- Correspondence: brando@unige.it



Citation: Ferrando, I.; Brandolini, P.; Federici, B.; Lucarelli, A.; Sguerso, D.; Morelli, D.; Corradi, N. Coastal Modification in Relation to Sea Storm Effects: Application of 3D Remote Sensing Survey in Sanremo Marina (Liguria, NW Italy). *Water* **2021**, *13*, 1040. https://doi.org/10.3390/ w13081040

Academic Editors: Giorgio Anfuso and Elias Dimitriou

Received: 1 March 2021 Accepted: 6 April 2021 Published: 9 April 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). Abstract: Integrated remote sensing techniques, such as photogrammetry from unmanned aerial vehicles (UAV), mobile laser scanners (MLS) and multibeam echosounders (MBES), are particularly effective in detecting and measuring coastal and seabed features and their modifications over time (4D analysis) induced by sea storms. In fact, these techniques allow the production of very high-resolution 3D models, with a continuum between above and below sea level. The present research is focused on the area of Portosole Marina (Sanremo, Western Liguria), affected by a severe sea storm in October 2018 and the following restoration. Two integrated 3D surveys were performed in February 2019 and in November 2019, obtaining accurate and reliable high-definition digital surface models (DSMs) in both emerged and submerged areas. The comparison between the two surveys highlighted volumetric changes in the seabed induced by the sea storm and the effects of a temporary worksite on the emerged and submerged breakwater. In particular, a total deficit of sediments of about 5000 m³ caused an average lowering of about 4 cm over the entire area, concurring with the breakwater instability. This study aims to contribute to the understanding of coastal system resilience within ongoing global climate changes, that is, increasing the intensity of extreme events in the Mediterranean area.

Keywords: geomorphological coastal changes; sea storm effects; integrated 3D remote sensing surveys; sedimentary dynamics; western Ligurian sea

1. Introduction

The most advanced integrated remote sensing techniques, such as photogrammetry from unmanned aerial vehicle (UAV), mobile laser scanner (MLS) and multibeam echosounder (MBES), applied to a geomorphological survey of coastal areas and to topographic measurements of coastal infrastructures, allow creating very high-resolution 3D models [1–13]. These methods are particularly effective in detecting and measure seabed features and their modifications induced by extreme events, such as severe storm surges and short-term local variations in sea level [14–16]. Detailed reconstructions of sea storms effects, such as seabed and beach instability other than damage to port infrastructure, provide coastal scenarios assessment of the impact of extreme marine events, such as the 2018 Vaia Storm [17], which are intensifying in the context of ongoing global warming/climate changes [18–20]. The application of remote sensing integrated systems also represents support in assessing resilience and vulnerability, in the monitoring of geo-risk and in the evaluation of proper mitigation measures within land management in coastal/fluvial areas [21–31].

The present research is focused on Portosole Marina (Sanremo, Western Liguria), affected by a severe storm in October 2018 [32–34]. After this event, the breakwater of Portosole Marina was restored. Two integrated 3D surveys were performed: the first one (survey 1) carried out in February 2019 [35] and the second one (survey 2) in November 2019, before and after the restoration, respectively. A system integrating laser scanner in mobile mode (MLS) and multibeam echosounder (MBES) mounted on a survey boat was employed to get a continuous metrically reliable 3D model. The good quality of data coming from such integrated survey has already been verified, both in terms of continuity and coherence of the MLS and MBES point clouds on the overlapping area and of metrical accuracy, which was centimetric for both emerged and submerged areas referred to the 0 mean-sea levels (MSL) [35].

The aim of the present research is the 4D very high-resolution morpho-dynamic analysis through the comparison of the two surveys of the study area to highlight the seabed changes both from metric and geomorphological points of view.

The comparison between the two surveys was performed employing multiple procedures. First, a simple difference in elevation between the two entire DSMs was performed. Then, the test area was divided into three regions, characterized by homogeneous morphology, applying such difference in elevation to each region. Hence, the total deposited and removed volumes were computed for each homogeneous region. Finally, a comparison was performed along vertical sections.

Then, the high-resolution bathymetric data were analyzed both for verifying the state of conservation of the maritime structures from a structural point of view and for highlighting erosion and accumulation of sediments. The detailed and quantitative analysis of these elements represents a useful tool for assessing the coastal area's vulnerability to intense storm surge.

The paper follows with a brief description of the study area and the employed survey techniques (Section 2). Subsequently, details on the storm that affected Sanremo in October 2018 are reported (Section 3). A description of the analysis procedure and a discussion on the obtained results are outlined in Sections 4 and 5, respectively.

2. Study Area

The study area is located in the central sector of the Sanremo coastline (Liguria, northwest of Italy). It is included in a wide bay of about 8 km extent, located between the Cape Nero promontory to the west and the Cape Verde promontory to the east (Figure 1), respectively featured by outcrops of marly arenaceous flysch (Campanian–Eocene) and polygenic conglomerates (Pliocene) [36].

The area is characterized by a narrow fluvial-coastal plain formed by the alluvial deposits of the Foce, Mafalda, San Romolo, San Francesco, San Lazzaro, San Martino and Val D'olivi streams and by the sediments deriving from sea cliff erosion and landslide phenomena affecting the nearby rocky coast [37–44]. The coast is mainly exposed to storms of Libeccio (225°) and Scirocco (135°).

The former coastal morphology has been almost totally modified by the expansion of urban settlements and by the construction of port infrastructures. Consequently, today this coastal zone appears as a "techno-coast", as occurs in many other Ligurian and Italian areas [45–51].

The natural geomorphological dynamics, together with the anthropic transformations that have occurred over time, have marked different conditions of the coastline and its beaches here summarized:



Figure 1. Location of Sanremo: Portosole study area. (**A**) The orthophoto of the Liguria Region (2016) shows how the narrow coastal plain of Sanremo and the course of the main streams crossing it (light blue dotted and continuous lines) are totally occupied by urban settlements. The zoom (**B**) shows the area of the Porto Antico and its ancient piers (dotted yellow line) and the Portosole area, where the morpho-bathymetric surveys were realized (**C**).

- Up to the middle of the 19th century, the coast was affected by a progradation of the beaches, thanks to the sedimentary input by the different watercourses and the erosional retreat of the sea cliffs. It is demonstrated by the historical map of Matteo Vinzoni [52], showing the former conditions of the coast in 1753 (Figure 2);
- After the second half of the 19th century, the beaches were generally affected by erosion, albeit with alternating phases of advancement and retreat. Since the beginning of the 20th century, to counteract the effects of sediments deficit connected to the port works on sediment transport, the construction of numerous defense works was necessary;
- Since 1965 up to the mid-seventies, several works of sea-embankments (reclamation area) and beach nourishment have been carried out;
- Between 1975 and 1980, the Portosole Marina was built between the Porto Vecchio (west) and the mouth of the San Martino stream (east). This has determined the current coastal layout, together with recent and further expansion and reinforcement work. The construction of Portosole caused the disappearance of pre-existing beaches, in erosion (about 13 m in the period 1944–1973) and protected by six groins. The artificial advancement of the coastline due to the construction of the infrastructures (techno-coast) was more than 350 m;
- The small beach about 90 m in extent, located between the mouth of the San Martino Stream and the root of the breakwater, assumed the characteristics of an anthropic pocket-beach [53–55]. In fact, it is between the maritime works and the jettied mouth of the stream, which reached its current layout between 2013 and 2016. Figure 3 shows the variations of the shoreline position over the years. Overall, the multi-temporal coastal line comparison shows a fairly stable equilibrium of the shoreline, with advancement of about 3 m (1983–2016). The alternating stages of advancement and retreat were presumably due to the restoration works at the river mouth and to small maintenance interventions of beach nourishment [56–58]. Since 1983 (Figure 3), the eastern side of the jetted mouth is constituted by the seawall.

The study here presented concerns the breakwater of the Portosole Marina and the facing seabed (Figure 1, box C), with a total extent of about 850 m, together with the small artificial pocket beach immediately to the east.



Figure 2. Historical map of Sanremo coast (1753): (1) Mafalda, (2) San Romolo, (3) San Francesco, (4) San Lazzaro streams; (A) and (B) represent the current locations of Porto Vecchio and Portosole, respectively (modified after [52]).



Figure 3. Variations of the position of the shoreline over the years 1944–2016 [58], Liguria Region orthophoto of 2016 used as background. (A) Photo taken from the west (the point of view is indicated in white on the main map) shows the features of the shoreline deposits. The coordinates are expressed in the ETRF2000–2008.0 reference system with UTM 32 projection.

3. The Event of 29 October 2018

On 29 October 2018, the Portosole Marina and the entire coastline were affected by an intense storm that caused severe damage to the breakwater and surrounding areas.

This event was part of a wider meteorological event, known as the Vaia storm, which affected the entire Mediterranean basin with particular intensity on the Ligurian and North Adriatic Sea. The storm developed from 27 to 29 October 2018, generating a cyclonic circulation centered on the west of Corsica, with a drop in pressure up to 17 hPa in 18 h. This depression, moving towards Italy's northeast, caused extreme southerly winds with gusts up to 119 km/h at Genoa airport and 171 km/h at La Spezia weather stations [17]. This cyclogenesis, together with the collision of warm air masses from the south and the cold front over the Alps from the north, led to developing heavy rainfall, winds and storms (Figure 4).



Figure 4. Wind at 10 m (m/s) and mean sea-level pressure (hPa) during Vaia Storm on 29 October 2018, 00 UTC (modified after ARPAL (Regional Agency for Ligurian Environment Protection) [34]).

Referring to the study area, at the Marina of Loano weather station, located about 52 km northeast of Sanremo, southerly winds from 230°, with gusts of 180 km/h and average velocity of 82 km/h, were recorded on 29 October 2018 [33,34]. It resulted from a baric minimum of 976 hPa and a gradient of 8 hPa between Provence and Corsica (Figure 4).

The wave buoy at Capo Mele, located about 35 km northeast of Sanremo, recorded a significant wave height (Hs) of 6.5 m with a period of 11–12 s and a maximum wave peak of 10.3 m, with the sea initially coming from the southeast and then in rotation from the southwest. A sea-level rise of about 50–60 cm was recorded [34], ascribed to a storm surge due to a depression minimum, with a wave tide of about +/-15-20 cm.

4. Materials and Methods

4.1. Portosole

The site was surveyed in February 2019 (survey 1) using a survey boat equipped with a multibeam echosounder (MBES) and a mobile laser scanner (MLS). On that occasion, the emerged part of the breakwater was surveyed also using a camera mounted on an unmanned aerial vehicle (UAV) and the 3D model was derived by Agisoft Metashape© [59] Structure for Motion processing. To correctly set the parameters of such elaborations, refer

to [60] while adopting the tool coming from [61] to plan the UAV photogrammetric survey in a realistic way, obtaining a rigorous evaluation of the precision. The UAV 3D model resolution and accuracy are comparable with MLS ones [35]. Note that the Laser Scanner accuracy could be higher, on the order of a few millimeters in static conditions [62], but the results of an MLS on a boat, hence supported by IMU measurements, could be on the order of a few centimeters.

A second survey was performed in November 2019 (survey 2) with the same survey boat and the same survey criteria.

The survey boat was equipped with the Teledyne Reson PDS2000 platform (Teledyne RESON B.V., Rotterdam, Netherlands [63]) for the simultaneous acquisition of an MBES R2Sonic 2024 (R2Sonic, Austin, TX, USA), a sound velocity profiler (SVP) RESON mod. SVP-15 (RESON B.V., Rotterdam, The Netherlands), an inertial measurement unit (IMU) IXBLUE mod. HYDRINS III (IXBLUE, Paris, France), a MLS RIEGL mod. LMS-Z420i (RIEGL, Horn, Austria) used in profiler mode and a GPS 5700 TRIMBLE (Trimble Navigation Limited, Dayton, OH, USA) receiver in "rover" real-time kinematic configuration (GPS-RTK).

The MBES R2Sonic 2024 is characterized by 256 beams of $0.5^{\circ} \times 1.0^{\circ}$, along and across track beamwidth, at 400 kHz.

To investigate the portions of the sea bottom close to the free surface, the transducer was mounted on a joint angled at 25°, thus physically tilting the transducer to exploit the entire swath of the MBES.

The MLS RIEGL mod. LMS-Z420i is a time of flight (TOF) instrument, characterized by a 1 km maximum range and a repeatability of 8 mm on a single measurement and 4 mm on average in static 3D configuration. In mobile profiler mode, accuracy varies between 2 and 5 cm, depending on the distance of targets and objects measurement and on the quality of IMU (angular precisions). In the present case, precisions in the order of 2–3 cm were obtained, measured and compared both with Total Station and GPS-RTK data.

The MBES/MLS systems required a preventive calibration phase both to synchronize the time scale of each instrument (including IMU) and to compensate the roll, pitch and yaw angles of the system concerning the theoretical (0,0,0) point, called common reference point (CRP). Data of both instruments were processed by the software platform Teledyne Reson PDS2000.

The two performed surveys are framed in the same reference system and cartographic projection, i.e., ETRF2000–2008.0 projected in UTM 32. Three ground control points (GCPs) located along the breakwater structure permit to to register the two point clouds so that they are in the same reference frame.

For survey 1, a (10 \times 10) cm digital surface model (DSM) was produced for the forthcoming elaborations. The DSM reproduces both the emerged and submerged parts of the study area; the first one was obtained from the MBES survey, while the latter was obtained from the MLS survey.

On the contrary, for survey 2, the single point clouds deriving from the MBES and MLS surveys were made available. A (10×10) cm DSM of the entire study area, including both MBES and MLS, surveyed areas, was realized using the Rasterize tool of the free and open-source CloudCompare ver. 2.10 [64].

4.2. Resulting Products

As a preliminary step, particular attention was paid to the removal of the background noise (despiking) and to data filtering. This is essential for automatic/semi-automatic noise removal in the water column, typically caused by navigation motion and reflections of some types of structures geometries.

The quality of the original point clouds related to survey 1 was assessed as follows: First, the MBES, MLS and UAV point clouds have been compared at the head of the Portosole breakwater through the free and open-source software CloudCompare ver. 2.10, to estimate their overlapping area. From these point clouds, three DSMs with (10×10) cm cell resolution were computed using the CloudCompare Rasterize tool. Besides the DSM cell height, the Rasterize tool allows computing the per-cell population (i.e., the number of points falling in a cell) and the heights standard deviation (i.e., the dispersion of height values inside a cell) for each cell of the DSM. Thus, these two parameters can give a rough indication of the point cloud density and of the distribution of height values, respectively. It resulted that the UAV DSM had a higher average value of per-cell population (48), whereas the MBES and MLS DSMs have lower and comparable values; moreover, the MBES and MLS DSMs have similar values of average standard deviation (0.074 m and 0.067 m), showing a substantial comparable distribution of heights in the point clouds, while the UAV DSM has a lower value (0.036 m), probably due to the flatter surveyed area (the breakwater emerged part, mainly constituted by a flat service area, other than the rocky blocks forming the breakwater). These results confirmed the good quality and the reliability of the point clouds derived by the integration of the employed survey techniques. Further details on point clouds quality assessment are available in [35].

The DSMs, derived by MBES and MLS integrated surveys, describes both the breakwater and the sea bottom facing it. The difference in time between the two surveys was enhanced employing different procedures here described, thought to be applied as much automatically as possible and to different case studies.

A simple difference in elevation between the DSMs was performed using the Cloud-Compare M3C2 plugin [2], which computes the signed distances between input point clouds, i.e., the obtained distances have positive or negative signs. The M3C2 output is a new point cloud where each point represents the distance along a defined direction (the vertical direction in the present case, i.e., along the z-axis of a conventional right-handed orthogonal Cartesian triplet) between the reference and the compared point clouds. The M3C2 output cloud follows this convention: positive sign if the compared DSM has a higher height concerning the reference DSM, negative sign vice versa.

To better quantify the metrical difference, a histogram was created, dividing the distance values into 256 classes of 0.05 m of amplitude and computing the number of occurrences for each class. Therefore, the histogram displays the number of occurrences of each class along the y-axis and the central value (v_c) of the 256 classes along the x-axis, obtained as

$$v_c = \frac{v_f - v_i}{2} \tag{1}$$

where v_f and v_i are the final and the initial value of each class.

The average value μ and standard deviation σ of this distribution were computed as follows:

$$\mu = \frac{\sum v_c \times n}{\sum n}$$
(2)

$$\sigma = \sqrt{\frac{\sum((v_c - \mu) \cdot n)^2/n}{\sum n}}$$
(3)

where v_c and n are the central value and the number of occurrences of each class, respectively.

This procedure was first applied to compare the entire surveyed area, then on smaller areas, characterized by homogeneous morphology. To divide the entire surveyed area into regions characterized by homogeneous morphology, a manual re-allocation was necessary using the Segment tool of CloudCompare. It allows the assignment of the boundary between areas with near-zero slopes (the sea bottom) and areas characterized by slopes different from zero (the rocky blocks constituting the breakwater). Moreover, the breakwater was divided into two regions, the submerged and emerged areas, respectively.

A comparison was also performed along vertical sections oriented orthogonally to the pier. The sections were extracted starting from a directrix polyline following the pier development using the CloudCompare Extract sections along polylines tool, with a 10 m step between two consecutive sections, for a total of 75 sections. Each section trace is 250 m long orthogonally to the directrix, and it has a thickness of 0.2 m in the xy plane. The section thickness is a required parameter for the Extract sections along polylines tool in case, besides the linear sections (profiles), the corresponding point cloud portions (section clouds) are needed, as in the present case. For this purpose, a thickness of 0.2 m guarantees that the section includes at least one point of the DSM, as its spacing is 0.1 m. Thus, following the tool terminology, the section cloud is a set of points falling inside a parallelepiped of undefined height and base given by the section trace length and its thickness, whereas the profile is a line that approximates the points joining them. Since the profile, for its definition and construction, describes the points configuration using approximation, the section clouds were analyzed. Figure 5 graphically represents the difference between the profile (depicted as a black line) and the section cloud (depicted as red points), referring to a portion of a representative section on the head of the breakwater of Portosole.



Figure 5. Profile (**black line**) and section cloud (**red points**) of a portion of a representative section on the head of the breakwater of Portosole.

Finally, the total deposited and removed volumes were computed for each homogeneous region using the CloudCompare Compute 2.5D volume tool. It requires a reference point cloud (DSM 1) as input, which is referred to as the initial epoch of study, and a second surface (DSM 2), referred to as the final epoch. The computed volumes and the ratio q between deposited and eroded volumes (in absolute value) were computed for the three portions.

Then, to give an overall idea of the average height variation (Δ h), the ratio between the volume variation Δ V and the total extent S was computed for the sea bottom, the submerged and the emerged breakwater portions, using the relation in Equation (4), where V_d and V_e are the deposited and the eroded volumes, respectively.

$$\Delta h = \frac{\Delta V}{S} = \frac{|V_d| - |V_e|}{S}$$
(4)

5. Results

A comparison between the DSMs derived by MBES and MLS integrated surveys, performed on February 2019 and November 2019, was carried out for the entire Portosole breakwater extent, revealing breakwater modifications (Section 3). Moreover, the analysis revealed some peculiar aspects of the morphological features and sedimentary dynamics of the seabed facing the breakwater and of the beach located between the root of the breakwater and the mouth of the Rio San Martino.

5.1. Results on DSMs Comparison

The difference in time between the DSMs relative to surveys 1 and 2, hereafter DSM 1 and DSM 2, were enhanced employing different procedures, whose results are presented here.

First, a simple difference in elevation between the two entire DSMs was performed. The DSM 1 was taken as a reference, whereas the DSM 2 was assumed than the surface. The result is depicted in Figure 6. The distances between DSM 1 and DSM 2 range between -7.5 and 5 m, but most of the values are centered around 0 m, as shown in the histogram in the top left part of Figure 6. The resulting average value and standard deviations of different values are 0.06 m and 0.43 m, respectively.



Figure 6. Comparison between digital surface model (DSM) 1 (reference surface) and DSM 2 (compared surface). The histogram shows the distribution of distance values.

Assuming a tolerance interval of $\pm 3\sigma$ in amplitude, the difference values must range between ± 1.3 m, centered on the average value (μ), and, at least theoretically, the distance values outside the tolerance interval should be considered as outliers. It is evident that this criterion is not applicable to the area surveyed as a whole because height differences due to changes over time, both in the sea bottom and in the breakwater, can be higher than 1.3 m, not being outliers.

For this reason, three homogeneous regions were identified and analyzed separately: sea bottom, submerged breakwater and emerged breakwater. The obtained homogeneous regions of DSM 1 and DSM 2 are shown in Figure 7a,b, respectively.



Figure 7. Sea bottom (blue), submerged breakwater (green) and emerged breakwater (red) for DSM 1 (a) and DSM 2 (b).

The differences in elevation between DSM1 and DSM2 relative to the three homogeneous areas (Figures 8–10), together with their average values (μ) and standard deviations (σ), were computed.

The Gaussian functions $N(\mu, \sigma^2)$ fitting the distribution of DSMs differences of the three homogeneous portions are represented in Figure 11. The differences between DSMs and Gaussian functions are represented by blue histograms and red lines, respectively, with their values, reported on the left and right y-axes, respectively. For all the three cases, the class values are limited within their confidence intervals (amplitude of 3 σ) to improve the readability of the graphs. The average values (μ) and standard deviations (σ) of DSMs distances in the three homogeneous portions are also reported in the table inside Figure 11.



Figure 8. Comparison between DSM 1 (reference) and DSM 2 (compared) on the sea bottom, with distance values limited within the interval (-0.25; 0.25) m.



Figure 9. Comparison between DSM 1 (reference) and DSM 2 (compared) on the submerged breakwater, with distance values limited within the interval (-0.25; 0.25) m.



Figure 10. Comparison between DSM 1 (reference) and DSM 2 (compared) on the emerged breakwater, with distance values limited within the interval (-1; 3) m.



Figure 11. Fitting between a Gaussian function (red line) and the distribution of DSMs differences of sea bottom (**a**), submerged breakwater (**b**), and emerged breakwater (**c**). The distance values are limited within the interval (-1; 3) m, corresponding to the $\mu \pm 3\sigma$ confidence interval.

For a more accurate comparison between the DSMs, 250 m long vertical sections and with a 10 m, for a total of 75 sections, were extracted. These section traces, represented in pink in Figure 12, are oriented orthogonally to the breakwater, whose directrix is represented as a black line in Figure 12.



Figure 12. Sections traces (**pink**) and directrix (**black**) along the pier. Section trace number 12 is highlighted in red for considerations in the text.

Figure 13 represents a view of the section clouds (from the head of the breakwater, thus almost from southwest to northeast). The red-magenta and blue-cyan section clouds depict the submerged and emerged breakwater points for DSM 1 and DSM 2, respectively. To perform this, the CloudCompare Filter points by values tool was used to distinguish the points below 0 m from the points above it. Figure 14 represents a zoom of the extracted section clouds along the section trace number 12, highlighted in red in Figure 12, to better underline and quantify the distances between DSM 1 and 2.



Figure 13. View of the section clouds of DSM 1 and DSM 2. The red and blue sections refer to the submerged portion of DSM 1 and 2, respectively, whereas the magenta and cyan sections are relative to the emerged portion.



Figure 14. Zoom of the section cloud relative to section trace number 12.

As highlighted in the overall view of the section clouds (Figure 13) and in the zoom reported in Figure 14, and as expected from the previous analysis, the section clouds relative to DSMs 1 and 2 are almost undistinguishable over sea bottom and submerged breakwater areas, whereas a distance between them is noticeable concerning the emerged part of the breakwater.

In conclusion, the DSM 2 is globally slightly lower than the DSM 1 over the sea bottom and the submerged breakwater areas, due to the erosive phenomena that took place; on the contrary, its average height is higher for the emerged breakwater area due to the construction of a temporary service track, which was built to allow the transit of the vehicles transporting rocky blocks and other materials for the restoration of the breakwater.

Moreover, it is noteworthy to underline how the values of average values μ and standard deviations σ reported in the table inside Figure 11 are compatible with the ones computed using an independent method and contained in the following Table 1. Furthermore, in this case, the most pronounced variation is found in the emerged breakwater portion.

Table 1. Deposited and removed volumes between DSMs 1 and 2, surface extensions, ratios (q) between deposited and removed volumes, and average height variations (Δ h) for the three homogeneous portions.

| Homogeneous Portion | Deposited Volume (m ³) | Eroded Volume (m ³) | Surface (m ²) | q (-) | Δh (m) |
|----------------------|---------------------------------------|------------------------------------|------------------------------|----------|-----------|
| Sea bottom | 950 | -5964 | 113,500 | 0.16 | -0.04 |
| Submerged breakwater | 1094 | -1483 | 18,068 | 0.74 | -0.02 |
| Emerged breakwater | 15,022 | -221 | 13,688 | 67.9 | 1.08 |

The total deposited and eroded volumes, the ratio q between them and the ratio Δh between the volume variation ΔV and the total extent S were computed for each homogeneous portion (Table 1).

5.2. Results on Morphological and Sedimentary Dynamics of the Seabed

The survey conducted in February 2019 (Figure 15A), before the restoration of the breakwater, and the one in November 2019 (Figure 15B), when the restoration was completed, have allowed highlighting variations both in the emerged structure of the breakwater and in the morpho-sedimentary features of the seabed (Figure 15C).

The seabed morphology facing the breakwater shows a regular deepening (about 4%) of the bathymetry, between 10 m up to 14 m (section A–A' in Figure 15C).

Section A–A' in Figure 15C shows the erosion operated at the base of the breakwater by the reflection of the waves, highlighted by a depression between 0.5 and 0.8 m in-depth. The section B–B' in Figure 15C shows the presence of *Posidonia oceanica* matte partially affected by erosion [65–68]. The *Posidonia oceanica* upper limit, reported after [58,69], is mapped in the zoom of Figure 15.

Between the root of the breakwater and the mouth of the Rio San Martino, there is a small anthropic pocket beach, confined between the maritime infrastructure and the jetted river mouth with quays and embankments, whose foot extends into the submerged beach.

As shown in the sections C–C' in Figure 15C, D–D' and F–F' in Figure 16, ripple marks of different sizes can be recognized, whose wavelengths range between 0.4 and 1 m, according to the hydraulic regime. Their structures indicate a vergence towards the coast.

The section E-E' in Figure 16 indicates two erosive channels due to the backflow currents following the sea wave runup on the beach [51].

As shown in Table 1, the ratio between deposited and eroded volumes highlights that the sea bottom was affected by a total deficit of about 5000 m³ of sediment, with an average lowering of about 4 cm over the entire area. In particular, as shown in Figure 15C, erosional features were found close to the base of the submerged breakwater (section A–A') and along the sea bottom (e.g., section C–C'); no significant change was detected in the matte areas (section B–B').



Figure 15. Morpho-bathymetry of the study area related to the two surveys: (**A**) February 2019; (**B**) November 2019. The zooms in (**A**) and (**B**) show the high detail of the acquisition; the white dotted line indicates the upper limit of the *Posidonia oceanica* seagrass after [58]. The red lines indicate the sections reported in (**C**), where the black and red lines refer to February and November 2019, respectively. The red box in (**A**) indicates the location of the zoom reported in Figure 16.



Figure 16. Zoom of the eastern sector of the study area (for location, see Figure 15): the red lines indicate the location of sections shown in the left box.

Analyzing the height variations along the entire breakwater, an average lowering of 2 cm was found in the submerged breakwater due to the adjustment of stone and concrete blocks, while the emerged breakwater shows an average increase of 1 m due to the restoration works.

6. Discussion

The comparison between the DSMs obtained from the survey immediately after the storm (survey 1) that affected Sanremo in October 2018 and the second one (survey 2) after the restoration of the breakwater allowed the detection of 3D variations of the study area over time (4D analysis) with centimetric accuracy. In particular, significant breakwater modifications due to the temporary worksite, the block adjustment of the submerged breakwater and a globally slight erosive phenomena along the sea bottom were revealed.

Concerning the comparison on the sea bottom, the average value of the difference between the surve1 and survey 2 was very close to zero, and the standard deviation was very low, as expected, due to the almost 2D structure, with limited variation along the z-axis. The observed differences, highlighted in blue in Figure 8, could be due to different meteorological and marine conditions encountered during the two surveys. In fact, the blue "stripes" highlight the roll artifacts of the MBES, so they are not effective differences concerning the previous survey, i.e., accumulation/erosion of sediments. In the area where such blue "stripes" are not present, the comparison between the two surveys provided quantitative data of the effects of the October 2018 storm on the geomorphological-sedimentary processes on the sea bottom in front of the breakwater, confirming the reliability of highresolution survey data within coastal hazard evaluation [70–72]. The comparison on the submerged breakwater area shows an average value of differences close to zero but a higher standard deviation concerning the value of sea bottom, probably due to the 3D structure of the blocks forming it. In fact, even in the case of small movements/rotations of the blocks forming the breakwater, the standard deviation of the differences can vary significantly. The comparison in the emerged breakwater area presents the highest average value and standard deviation. In particular, the height difference of approximately 1 m is due to the temporary service track built over the breakwater between the two surveys to allow the transition of material-handling vehicles to transport rocky blocks. The new road construction also affects the standard deviation value, which is higher than the ones of the sea bottom and submerged breakwater.

The employed survey methods and the resulting products allowed to detect and measure bottom forms related to sedimentary structures and subcritical/supercritical hydraulic flows, such as ripple marks and erosion channels. This highlights their usefulness in recognizing the direction of sedimentary transport and the intensity of the hydraulic flow [73–75]. In fact, in both the surveys, the orientation of the ridges of the asymmetrical ripple marks allowed to identify the directions of the provenance of the waves and the refraction waves due to the interaction with the breakwater and the seabed [76,77]. DMS 1 showed the erosive effects produced by the storm, while DMS 2, confirming the persistence of these erosive processes, provided detailed quantitative data on the variation of the seabed that occurred during the 9 months between the two surveys. In fact, a noteworthy result of the comparison between the two surveys was the measurement of volumetric changes in the seabed and the submerged and emerged breakwater. The surveys showed that the erosion produced by the October 2018 storm, especially at the base of the breakwater, was not compensated by sufficient sedimentary contributions after 9 months. This is evidence of an ongoing sedimentation deficit, resulting in the instability of the rock and concrete blocks at the base of the breakwater. As found in other coastal sectors with high anthropogenic pressure, insufficient sediment supply is attributable to changes in the river network, the obstacle of port infrastructure on the littoral drift and the capture of the sediment by canyon heads [28,42,78-81].

7. Conclusions

Integrated remote sensing techniques have been successfully applied to survey both the breakwater and the neighboring beach of Portosole Marina. Mobile laser scanner (MLS) and multibeam echosounder (MBES), eventually integrated with photogrammetry from (unmanned aerial vehicle) UAV, result to be very effective and reliable to obtain high-definition digital surface models (DSMs) both of the emerged and submerged areas.

The surveys presented in this study were carried out in a coastal stretch totally modified by human intervention consisting of a port infrastructure, an artificial pocket beach and a jetted stream mouth, defined as "techno-coast".

The marine event of 29 October 2018 that affected the area of Portosole Marina represented an outstanding storm associated with the transition of deep low-pressure (976 hPa) over the Ligurian Gulf. This caused a significant sea-level change with a local increase of about 50–60 cm. The phenomenon provoked a great wave penetration on the coasts, as observed in other sectors of Eastern Liguria, with catastrophic effects on port infrastructures and urban facilities.

To verify the coastal impact of the storm, two integrated 3D surveys were performed in February 2019 and in November 2019. The collected data allowed to obtain accurate and reliable high-definition DSMs, both of the emerged and the submerged areas. The comparison between the two surveys highlighted volumetric changes in the seabed and the effects on the emerged and submerged breakwater induced by storm. The estimated deficit of sediment is about 5000 m³, with a lowering of about 4 cm over the entire submerged area, which contributed to the instability of the breakwater base. The second survey confirmed the sea bottom's erosional state, which is not compensated by the coastal sediment supply. This shows that the storm's effects superimposed ongoing erosional phenomena along the coastal stretch strongly affected by anthropogenic impact.

The recurrence of high-intensity sea storms, as also evidenced by the event that affected Eastern Liguria in November 2000 with similar characteristics (Hs 5.8, period 9–11 s), shows the current increase of storm surges hazard and coastal risk in the Mediterranean area. This highlights the importance of providing adequate coastal zone management measures for risk mitigation through the definition of proper marine flooding hazard scenarios), considering the ongoing climate change and related sea-level rise.

Author Contributions: Remote sensing and field survey, A.L.; Geomatics and numerical elaboration, I.F., B.F. and D.S.; Geomorphology and Sedimentology, P.B., D.M. and N.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Research financed with University of Genoa funds (FRA).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data presented is available under request from the corresponding author.

Acknowledgments: The authors thank Portosole Marina of Sanremo for the support and availability of the data.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Mills, J.P.; Buckley, S.J.; Mitchell, H.L.; Clarke, P.J.; Edwards, S.J. A geomatics data integration technique for coastal change monitoring. *Earth Surf. Process. Landf. J. Br. Geomorphol. Res. Group* 2005, 30, 651–664. [CrossRef]
- Lague, D.; Brodu, N.; Leroux, J. Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (N-Z). *ISPRS J. Photogramm. Remote Sens.* 2013, 82, 10–26. [CrossRef]
- Mancini, F.; Dubbini, M.; Gattelli, M.; Stecchi, F.; Fabbri, S.; Gabbianelli, G. Using unmanned aerial vehicles (UAV) for highresolution reconstruction of topography: The structure from motion approach on coastal environments. *Remote Sens.* 2013, 5, 6880–6898. [CrossRef]
- Monteys, X.; Harris, P.; Caloca, S.; Cahalane, C. Spatial prediction of coastal bathymetry based on multispectral satellite imagery and multibeam data. *Remote Sens.* 2015, 7, 13782–13806. [CrossRef]

- 5. Troisi, S.; Del Pizzo, S.; Gaglione, S.; Miccio, S.; Testa, R.L. 3D models comparison of complex shell in underwater and dry environments. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* 2015, 40, 215–222. [CrossRef]
- 6. Turner, I.L.; Harley, M.D.; Drummond, C.D. UAVs for coastal surveying. Coast. Eng. 2016, 114, 19–24. [CrossRef]
- Aguilar, F.J.; Fernandez, I.; Casanova, J.A.; Ramos, F.J.; Aguilar, M.A.; Blanco, J.L.; Moreno, J.C. 3D Coastal Monitoring from Very Sense UAV-Based Photogrammetric Point Clouds. In *Advances on Mechanics, Design Engineering and Manufacturing*; Springer: Cham, Switzerland, 2017; pp. 879–887.
- Capra, A.; Castagnetti, C.; Dubbini, M.; Gruen, A.; Guo, T.; Mancini, F.T.; Troyer, M. High Accuracy Underwater Photogrammetric Surveying. In Proceedings of the 3rd IMEKO International Conference on Metrology for Archeology and Cultural Heritage, Lecce, Italy, 23–25 October 2017; pp. 696–701.
- 9. Chen, B.; Yang, Y.; Wen, H.; Ruan, H.; Zhou, Z.; Luo, K.; Zhong, F. High-resolution monitoring of beach topography and its change using unmanned aerial vehicle imagery. *Ocean Coast. Manag.* **2018**, *160*, 103–116. [CrossRef]
- Mattei, G.; Troisi, S.; Aucelli, P.P.C.; Pappone, G.; Peluso, F.; Stefanile, M. Multiscale Reconstruction of Natural and Archaeological Underwater Landscape by Optical and Acoustic Sensors. In Proceedings of the 2018 IEEE International Workshop on Metrology for the Sea, Learning to Measure Sea Health Parameters (MetroSea), Bari, Italy, 8–10 October 2018; pp. 46–49.
- 11. Aucelli, P.P.C.; Cinque, A.; Mattei, G.; Pappone, G.; Rizzo, A. Studying relative sea level change and correlative adaptation of coastal structures on submerged Roman time ruins nearby Naples (southern Italy). *Quat. Int.* **2019**, *501*, 328–348. [CrossRef]
- Federici, B.; Corradi, N.; Ferrando, I.; Sguerso, D.; Lucarelli, A.; Guida, S.; Brandolini, P. Remote sensing techniques applied to geomorphological mapping of rocky coast: The case study of Gallinara Island (Western Liguria, Italy). *Eur. J. Remote Sens.* 2019, 52, 123–136. [CrossRef]
- Guida, S.; Corradi, N.; Federici, B.; Lucarelli, A.; Brandolini, P. Laser Scanner and Multibeam Integrated Survey for The Assessment of Rocky Sea Cliff Geomorphological Hazard. In *Earth Observation Advancements in A Changing World*; Chirici, G., Gianinetto, M., Eds.; AIT: Firenze, Italy, 2019; Volume 1, pp. 162–165.
- 14. Scicchitano, G.; Pignatelli, C.; Spampinato, C.R.; Piscitelli, A.; Milella, M.; Monaco, C.; Mastronuzzi, G. Terrestrial Laser Scanner techniques in the assessment of tsunami impact on the Maddalena peninsula (south-eastern Sicily, Italy). *Earth Planets Space* **2012**, *64*, 889–903. [CrossRef]
- 15. Piscitelli, A.; Milella, M.; Hippolyte, J.-C.; Shah-hosseini, M.; Morhange, C.; Mastronuzzi, G. Numerical approach to the study of coastal boulders: The case of Martigues, Marseille, France. *Quat. Int.* **2017**, *439*, 52–64. [CrossRef]
- 16. Oprandi, A.; Mucerino, L.; De Leo, F.; Bianchi, C.N.; Morri, C.; Azzola, A.; Benelli, F.; Besio, G.; Ferrari, M.; Montefalcone, M. Effects of a severe storm on seagrass meadows. *Sci. Total Environ.* **2020**, *748*, 141373. [CrossRef]
- 17. Biolchi, S.; Denamiel, C.; Devoto, S.; Korbar, T.; Macovaz, V.; Scicchitano, G.; Vilibic, I.; Furlani, S. Impact of the October 2018 storm Vaia on coastal boulders in the northern Adriatic Sea. *Water* **2019**, *11*, 2229. [CrossRef]
- 18. Gaertner, M.A.; Jacob, D.; Gil, V.; Domínguez, M.; Padorno, E.; Sánchez, E.; Castro, M. Tropical cyclones over the Mediterranean Sea in climate change simulations. *Geophys. Res. Lett.* **2007**, *34*, 1–5. [CrossRef]
- 19. Lionello, P.; Galati, M.B.; Elvini, E. Extreme storm surge and wind wave climate scenario simulations at the Venetian littoral. *Phys. Chem. Earth* **2012**, *40*, 86–92. [CrossRef]
- 20. Gonzáles-Alemán, J.J.; Pascale, S.; Gutierrez-Fernandez, J.; Murakami, H.; Gaertner, M.A.; Vecchi, G.A. Potential Increase in Hazard from Mediterranean Hurricane Activity with Global Warming. *Geophys. Res. Lett.* **2019**, *46*, 1754–1764. [CrossRef]
- Faccini, F.; Brandolini, P.; Robbiano, A.; Perasso, L.; Sola, A. Instability, precipitation phenomena and land planning: The flood of 2002 in lower Lavagna valley (Eastern Liguria, Italy). *Geogr. Fis. Din. Quat.* 2005, 7, 145–153.
- 22. Brandolini, P.; Faccini, F.; Robbiano, A.; Terranova, R. Geomorphological hazards and monitoring activity along the western rocky coast of the Portofino Promontory (Italy). *Quat. Int.* **2007**, 171, 131–142. [CrossRef]
- 23. Brandolini, P.; Canepa, G.; Faccini, F.; Robbiano, A.; Terranova, R. Geomorphological and geo-environmental features of the Graveglia Valley (Ligurian Apennines, Italy). *Geogr. Fis. Din. Quat.* **2007**, *30*, 99–116.
- Casella, E.; Rovere, A.; Pedroncini, A.; Mucerino, L.; Casella, M.; Cusati, L.A.; Vacchi, M.; Ferrari, M.; Firpo, M. Study of wave runup using numerical models and low-altitude aerial photogrammetry: A tool for coastal management. *Estuar. Coast. Shelf Sci.* 2014, 149, 160–167. [CrossRef]
- 25. Brandolini, P.; Cevasco, A. Geo-Hydrological Risk Mitigation Measures and Land-Management in A Highly Vulnerable Small Coastal Catchment. In *Engineering Geology for Society and Territory*; Springer: Cham, Switzerland, 2015; Volume 5, pp. 759–762.
- 26. Galve, J.; Cevasco, A.; Brandolini, P.; Piacentini, D.; Azañón, J.M.; Notti, D.; Soldati, M. Cost-based analysis of mitigation measures for shallow-landslide risk reduction strategies. *Eng. Geol.* **2016**, *213*, 142–157. [CrossRef]
- Carpi, L.; Mucerino, L.; Besio, G.; Corradi, N.; Ferrari, M. MAREGOT Project Experience: Integrated Approach to Understanding Coastal Dynamics Behaviour. In Proceedings of the 2019 IMEKO TC19 International Workshop on Metrology for the Sea: Learning to Measure Sea Health Parameters, MetroSea, Genoa, Italy, 3–5 October 2019; pp. 167–171.
- 28. Ferrari, M.; Carpi, L.; Pepe, G.; Mucerino, L.; Schiaffino, C.F.; Brignone, M.; Cevasco, A. A geomorphological and hydrodynamic approach for beach safety and sea bathing risk estimation. *Sci. Total Environ.* **2019**, *671*, 1214–1226. [CrossRef]
- 29. Mucerino, L.; Albarella, M.; Carpi, L.; Besio, G.; Benedetti, A.; Corradi, N.; Firpo, M.; Ferrari, M. Coastal exposure assessment on Bonassola bay. *Ocean Coast. Manag.* 2019, *167*, 20–31. [CrossRef]
- Ascari, M.; Baccino, L.; Sanguineti, G. Ricerche Sulle Variazioni Delle Spiagge Italiane. Le Spiagge Della Riviera Ligure; C.N.R.: Roma, Italy, 1937; p. 328.

- 31. Porta, M.; Buosi, C.; Trogu, D.; Ibba, A.; De Muro, S. An integrated sea-land approach for analyzing forms, processes, deposits and the evolution of the urban coastal belt of Cagliari. *J. Maps* **2020**. [CrossRef]
- 32. Mentaschi, L.; Besio, G.; Cassola, F.; Mazzino, A. Developing and validating a forecast/hindcast system for the Mediterranean Sea. *J. Coast. Res.* 2013, *65*, 1551–1556. [CrossRef]
- Iengo, A.; del Giudice, T. Analysis of the 29 October 2018 Sea-Storm in The Ligurian Sea. In Proceedings of the 2019 IMEKO TC 19 International Workshop on Metrology for the Sea, Genoa, Italy, 3–5 October 2019; pp. 145–150.
- Pedemonte, L.; Corazza, M.; Forestieri, A. Internal Technical Event Report from CMI—ARPAL. Available online: https:// www.arpal.gov.it/contenuti_statici//pubblicazioni/rapporti_eventi/2018/Report_speditivo_20181027-30_vers20181122.pdf (accessed on 6 November 2020).
- 35. Lucarelli, A.; Brandolini, P.; Corradi, N.; De Laurentiis, L.; Federici, B.; Ferrando, I.; Lanzone, A.; Sguerso, D. Potentialities of Integrated 3D Surveys Applied to Maritime Infrastructures and to The Study of Morphological/Sedimentary Dynamics of The Seabed. In Proceedings of the IMEKO TC-19 International Workshop on Metrology for the Sea, Genoa, Italy, 3–5 October 2019; pp. 161–166.
- 36. Giammarino, S.; Fanucci, F.; Orezzi, S.; Rosti, D.; Morelli, D.; Colbianchi, M.; Di Stefano, A.; Fravega, P.; Vannucci, G.; Piazza, M.; et al. Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000. In *Foglio 258–271 San Remo*; ISPRA Servizio Geologico d'Italia, Regione Liguria: Genova, Italy, 2010; p. 134. Available online: https://www.isprambiente.gov.it/Media/carg/note_ illustrative/258_SanRemo.pdf (accessed on 6 November 2020).
- Zingaro, M.; Refice, A.; Giachetta, E.; D'Addabbo, A.; Lovergine, F.; De Pasquale, V.; Pepe, G.; Brandolini, P.; Cevasco, A.; Capolongo, D. Sediment mobility and connectivity in a catchment: A new mapping approach. *Sci. Total Environ.* 2019, 672, 763–775. [CrossRef]
- 38. Fierro, G.; Berriolo, G.; Ferrari, M. Le Spiagge Della Liguria Occidentale; Regione Liguria: Genova, Italy, 2010; p. 174.
- 39. Corradi, N. La costa della Liguria. In *La Costa d'Italia*; Ginesu, S., Ed.; Carlo Delfino: Sassari, Italy, 2011; pp. 185–200. ISBN 978-88-7138-581-5.
- 40. Brandolini, P.; Faccini, F.; Robbiano, A.; Terranova, R. Slope instability on rocky coast: A case study of Le Grazie landslides (eastern Liguria, northern Italy). *Geol. Soc. Lond. Spec. Publ.* **2009**, *322*, 143–154. [CrossRef]
- 41. Scarpati, A.; Pepe, G.; Mucerino, L.; Brandolini, P.; Firpo, M. Rocky cliff landslide hazard: The capo Noli promontory case study (western Liguria, NW Mediterranean Sea). *Rend. Online Soc. Geol. Ital.* **2013**, *28*, 137–141.
- 42. Fierro, G.; Berriolo, G.; Ferrari, M. Le Spiagge Della Liguria Centro-Orientale; Regione Liguria: Genova, Italy, 2015; p. 96.
- 43. Brandolini, P. The Outstanding Terraced Landscape of The Cinque Terre Coastal Slopes (Eastern Liguria). In *Landscapes and Landforms of Italy*; Springer: Cham, Switzerland, 2017; pp. 235–244.
- 44. Pepe, G.; Mandarino, A.; Raso, E.; Scarpellini, P.; Brandolini, P.; Cevasco, A. Investigation on farmland abandonment of terraced slopes using multitemporal data sources comparison and its implication on hydro-geomorphological processes. *Water* **2019**, *11*, 1552. [CrossRef]
- 45. Brandolini, P.; Faccini, F.; Paliaga, G.; Piana, P. Man-made landforms survey and mapping of an urban historical center in a coastal Mediterranean environment. *Geogr. Fis. Din. Quat.* **2018**, *41*, 23–34.
- 46. Ascione, A.; Aucelli, P.P.; Cinque, A.; Di Paola, G.; Mattei, G.; Ruello, M.; Russo Ermolli, E.; Santangelo, N.; Valente, E. Geomorphology of Naples and the Campi Flegrei: Human and natural landscapes in a restless land. *J. Maps* **2020**. [CrossRef]
- 47. Brandolini, P.; Mandarino, A.; Paliaga, G.; Faccini, F. Anthropogenic landforms in an urbanized alluvial-coastal plain (Rapallo city, Italy). *J. Maps* **2020**. [CrossRef]
- 48. Cappadonia, C.; Di Maggio, C.; Agate, M.; Agnesi, V. Geomorphology of the urban area of Palermo (Italy). *J. Maps* **2020**, *16*, 1739154. [CrossRef]
- 49. Faccini, F.; Giardino, M.; Paliaga, G.; Perotti, L.; Brandolini, P.; Giardino, M.; Paliaga, G.; Perotti, L.; Brandolini, P. Urban geomorphology of Genoa old city (Italy). *J. Maps* **2020**. [CrossRef]
- 50. Roccati, A.; Mandarino, A.; Perasso, L.; Robbiano, A.; Luino, F.; Faccini, F. Large-scale geomorphology of the Entella River floodplain (Italy) for coastal urban areas management. *J. Maps* **2020**. [CrossRef]
- 51. Mucerino, L.; Carpi, L.; Schiaffino, C.F.; Pranzini, E.; Sessa, E.; Ferrari, M. Rip current hazard assessment on a sandy beach in Liguria, NW Mediterranean. *Nat. Hazards* **2021**, *105*, 137–156. [CrossRef]
- 52. Vinzoni, A. Pianta della città di Sanremo (1753). In *Raccolta dei Tipi, disegni e mappe, Mappe e tipi della Repubblica di Genova, involto RR, n. 2.;* Archivio di Stato: Genova, Italy, 1753.
- Short, A.D.; Masselink, G. Embayed and Structurally Controlled Beaches. In Handbook of Beach and Shoreface Morphodynamics; John Wiley & Son: Chichester, UK, 1999; pp. 230–249.
- 54. Simeoni, U.; Corbau, C.; Pranzini, E.; Ginesu, S. *Le Pocket Beach. Dinamica E Gestione Delle Piccole Spiagge*; FrancoAngeli: Milano, Italy, 2012; p. 177.
- Mastronuzzi, G.; Aringoli, D.; Aucelli, P.P.; Baldassarre, M.A.; Bellotti, P.; Bini, M.; Biolchi, S.; Bontempi, S.; Brandolini, P.; Chelli, A.; et al. The geomorphological map of the Italian coast: From a descriptive to a morphodynamic approach. *Geogr. Fis. Din. Quat.* 2017, 40, 1–36.
- 56. Berriolo, G.; Sirito, G. Spiagge e Porti Turistici; Ulrico Hoepli: Milano, Italy, 1972; p. 430.

- 57. Lamanna, S. Il Sistema Informativo Geografico Della Costa e Il Censimento Delle Opere Costiere Della Regione Liguria. In *Lo Studio e la Rappresentazione Della Costa Ligure nel Progetto Europeo BEACHMED-E., A Cura Di Corinna Artom;* Regione Liguria: Genova, Italy, 2008; pp. 113–119.
- SICoast-Regione Liguria. Available online: https://geoportal.regione.liguria.it/catalogo/mappe.html (accessed on 31 August 2020).
- 59. Agisoft Metashape[®]. Available online: https://www.agisoft.com/ (accessed on 25 March 2020).
- 60. Gagliolo, S.; Fagandini, R.; Passoni, D.; Federici, B.; Ferrando, I.; Pagliari, D.; Pinto, L.; Sguerso, D. Parameter optimization for creating reliable photogrammetric models in emergency scenarios. *Appl. Geomat.* **2018**, *10*, 501–514. [CrossRef]
- 61. Passoni, D.; Federici, B.; Ferrando, I.; Gagliolo, S.; Sguerso, D. The estimation of precision in the planning of UAS photogrammetric surveys. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2018**, *42*, 837–843. [CrossRef]
- Fagandini, R.; Federici, B.; Ferrando, I.; Gagliolo, S.; Pagliari, D.; Passoni, D.; Pinto, L.; Rossi, L.; Sguerso, D. Evaluation Of The Laser Response Of Leica Nova Multistation MS60 For 3D Modelling And Structural Monitoring, Computational Science and Its Applications—ICCSA 2017. In *Lecture Notes in Computer Science*; Gervasi, O., Ed.; Springer: Cham, Switzerland, 2017; pp. 93–104.
- 63. Teledyne Reson PDS2000. Available online: https://www.teledyne-pds.com (accessed on 25 March 2020).
- 64. CloudCompare (version 2.10) [GPL Software]. Available online: http://www.cloudcompare.org/ (accessed on 25 March 2020).
- 65. Vacchi, M.; Montefalcone, M.; Bianchi, C.N.; Morri, C.; Ferrari, M. The influence of coastal dynamics on the upper limit of the Posidonia oceanica meadow. *Mar. Ecol.* **2010**, *31*, 546–554. [CrossRef]
- Ferrari, M.; Montefalcone, M.; Schiaffino, C.F.; Bianchi, C.; Corradi, N.; Morri, C. Geomorphological Constraint and Boundary Effect on Posidonia Oceanica Meadows. In *Rendiconti on Line Della Società Geologica Italiana*; Società Geologica Italiana: Roma, Italy, 2013; Volume 28, pp. 62–65.
- 67. Montefalcone, M.; Albertelli, G.; Nike Bianchi, C.; Mariani, M.; Morri, C. A new synthetic index and a protocol for monitoring the status of Posidonia oceanica meadows: A case study at Sanremo (Ligurian Sea, NW Mediterranean). *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2006**, *16*, 29–42. [CrossRef]
- 68. Montefalcone, M. Ecosystem health assessment using the Mediterranean seagrass Posidonia oceanica: A review. *Ecol. Indic.* 2009, *9*, 595–604. [CrossRef]
- 69. Diviacco, G.; Coppo, S. Atlante Degli Habitat Marini Della Liguria: Descrizione Cartografia Delle Praterie di Posidonia Oceanica e dei Principali Popolamenti Marini Costieri; Grafiche Amadeo: Imperia, Italy, 2006; p. 205.
- 70. De Pippo, T.; Donadio, C.; Pennetta, M.; Petrosino, C.; Terlizzi, F.; Valente, A. Coastal hazard assessment and mapping in Northern Campania, Italy. *Geomorphology* **2008**, *97*, 451–466. [CrossRef]
- 71. Aminti, P.L.; Pranzini, E. Indagine sperimentale per la ristrutturazione delle difese di Marina di Pisa. Studi Costieri 2000, 3, 57–70.
- 72. Pranzini, E. Shore protection in Italy: From hard to soft engineering and back. Ocean Coast. Manag. 2018, 156, 43–57. [CrossRef]
- 73. Tanner, W.F. Ripple mark indices and their uses. Sedimentology 1967, 9, 89–104. [CrossRef]
- US Army Corps of Engineers. Shore Protection Manual; Department of the Army, US Army Corps of Engineers: Washington DC, USA, 1984; Volume 2, p. 652.
- 75. Gerhard, E. Sedimentary Basins Evolution, Facies and Sediment Budget; Springer: Berlin/Heidelberg, Germany, 2000.
- 76. Bruun, P. The development of downdrift erosion. J. Coast. Res. 1995, 11, 1242–1257.
- 77. Cipriani, L.E.; Ferri, S.; Iannotta, P.; Paolieri, F.; Pranzini, E. Morfologia e dinamica dei sedimenti del litorale della Toscana settentrionale. *Studi Costieri* 2001, *4*, 119–156.
- 78. Aminti, P.; Cipriani, L.E.; Pranzini, E. Back to the Beach: Converting Seawalls into Gravel Beaches. In *Soft Shore Protection*; Springer: Dordrecht, The Netherlands, 2003; pp. 261–274.
- 79. Aucelli, P.C.; Aminti, P.L.; Amore, C.; Artom, C.; Bellotti, P.; Bozzano, A.; Caputo, C.; Castelliti, G.; Cipriani, L.E.; Cocco, E.; et al. Lo stato dei litorali italiani. *Studi Costieri* **2006**, *10*, 174.
- Migeon, S.; Cattaneo, A.; Hassoun, V.; Larroque, C.; Corradi, N.; Fanucci, F.; Dano, A.; Mercier de Lepinay, B.; Sage, F.; Gorini, C. Morphology, distribution and origin of recent submarine landslides of the Ligurian Margin (North-western Mediterranean): Some insights into geohazard assessment. *Mar. Geophys. Res.* 2011, *32*, 225–243. [CrossRef]
- 81. Brandolini, P.; Cappadonia, C.; Luberti, G.M.; Donadio, C.; Stamatopoulos, L.; Di Maggio, C.; Faccini, F.; Corrado, S.; Vergari, F.; Palliaga, G.; et al. Geomorphology of the Anthropocene in Mediterranean urban areas. *Prog. Phys. Geogr. Earth Environ.* **2020**, *44*, 461–494. [CrossRef]