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COASTAL VULNERABILITY ASSESSMENT THROUGH COMPLEMENTARY MONITORING TECHNOLOGIES: THE CASE OF RICCIONE

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EXTENDED ABSTRACT

È noto come il monitoraggio sia alla base per studi di pianificazione e gestione costiera, per verifiche degli effetti di interventi e per previsioni sullo stato futuro. Sono diversi i parametri che vanno considerati nella definizione e nella pianificazione di un monitoraggio, quali la sua estensione, la durata del programma di monitoraggio, la precisione necessaria dei dati planimetrici ed altimetrici, la frequenza con la quale si necessita di dati e, forse uno dei più determinanti, il budget disponibile. In questo ambito il paper presenta i primi risultati del monitoraggio con tecniche integrate di un tratto di costa presso il comune di Riccione, nell'ambito del progetto di ricerca STIMARE, finanziato dal MATTM.

Il sito è protetto da opere di difesa 'non convenzionali', e sono in corso attività di monitoraggio della linea di riva mediante videocamere, utilizzando un sistema di hardware a bassissimo costo, con componentistica Raspberry Pi, e lo sviluppo di software on site per il rilievo, la rettifica e la georeferenziazione dei dati. Il monitoraggio della morfologia della spiaggia emersa e sommersa viene effettuato tramite rilievi topo-batimetrici (terrestial laser scanner, fotogrammetria da UAV, multibeam da ASV), permettendo di ottenere modelli digitali del terreno (DTM) ad altissima risoluzione. Il confronto tra rilievi successivi acquisiti con tecniche diverse darà informazioni sulla risposta del tratto costiero al regime di moto ondoso in diverse condizioni, sugli effetti delle opere sul fondale, sia nel nearfield che nel farfield, con la possibilità di quantificare i volumi di sabbia erosi o accumulati.

I due approcci di monitoraggio sono quindi complementari nei tempi e nella precisione, i rilievi diretti forniscono dati ad alta precisione spaziale ma non acquisiti in continuo per motivi di budget e di logistica, mentre il videomonitoraggio dà indicazioni meno precise della sola linea di riva, (utilizzata come proxy per la descrizione della dinamica costiera) ma con informazioni acquisite in continuo. Il progetto si propone di verificare la complementarietà e integrazione delle diverse tecniche adottate nel monitoraggio, e la possibile applicazione anche ad altri tratti costieri ai fini di valutazioni di vulnerabilità.

ABSTRACT

Monitoring is known to be the basis for coastal planning and management studies, for verifying the interventions effects and for forecasting the future state of beaches. There are several proxies that must be considered in the definition of a monitoring plan, such as the spatial and temporal extension of the monitoring activities, the types of data and their required accuracy values, the acquisition frequency of the data and perhaps the available budget to invest are among the most important aspects. The present paper presents the first results of the monitoring activity with integrated and complementary techniques applied to a stretch of coast near the city of Riccione, North Italy, within the framework of the research project STIMARE, financed by the MATTM and of the project POR FESR TAO.

The site is protected by non-traditional defense works, and the on-going activities aim to monitor the shoreline evolution by using videocameras, with a low-cost hardware system, based on Raspberry Pi components, and the development of on-site software for the survey, correction and georeferencing of data. The monitoring of the emergence and submerged beach is carried out by means of topographic and bathymetric surveys (terrestrial laser scanner, UAV photogrammetry, ASV multibeam), allowing a very high-resolution digital terrain model (DTM) to be obtained. The comparison between successive surveys acquired with different techniques provides information on the response of the coastal stretch to the local regime of waves and currents and on the effects of the defense structures on the seabed, both in the nearfield and in the farfield, with the possibility of quantifying the volumes of eroded or accumulated sand.

Finally, the two monitoring approaches are shown to be complementary in terms of time and precision: direct surveys provide data with high spatial precision but not continuous acquisition due to budget and logistics reasons, while video monitoring provides only information on the shoreline, (used as a proxy for the description of coastal dynamics) but with data continuously acquired. The project aims to verify the complementarity and integration of the different techniques adopted in monitoring, and the possible feasibility in other coastal stretches with the purpose of assessing vulnerability.

***Keywords**: coastal risk, video monitoring, coastal protection, Riccione (Italy).*

INTRODUCTION

The integration of different monitoring techniques is an essential tool in coastal studies, aiming at observing the physical phenomena at a wide range of space and time scale (Tarragone *et alii*, 2015; Montefalcone *et alii*, 2019; Bonaldo *et alii*, 2019). Coastal management needs a huge amount of quantities and typologies of data and information in order to rely on tools for the risk assessment (Archetti & Lamberti, 2003; Scarascia Mugnozza, 2019).

Video monitoring is a useful tool for coastal management. It allows monitoring of the coastline evolution and its shift in response to waves regime, and it supports risk analyses connected to storm surges (Holman *et alii*, 2003), with the advantage to be synoptic and non-invasive and to collect data continuously in time (Takewaka & Nakamura, 2000; Davidson *et alii*, 2004; Kroon *et alii*, 2007; Van Koningsveld, 2007; Archetti, 2009; Archetti & Romagnoli, 2011). The standard systems normally sample once per hour and their final products can show variations of the observed parameters over different time scales (Plant & Holman, 1997; Holman & Stanley, 2007). The advantages of remote sensing through video systems favoured a wide spread of this technique in coastal monitoring over the world for proper management of the coastal areas and for the setup of early warning systems (Archetti & Zanuttigh, 2010), having large use also in research fields (Morris *et alii*, 2001; Alexander & Holman, 2004; Almar *et alii*, 2008; Archetti *et alii*, 2016).

On the other side, the shoreline position is not an exhaustive indicator of coastal evolution and tendency, being often subjected to anthropic interventions (Montanari *et alii*, 2016). In a wider perspective, observations on the coastal evolution should include monitoring of the shoreface and the nearshore, where most of the natural variability occurs in response to changes in the wave regime.

In the last years, remote sensing techniques have seen a fast development in environmental monitoring, due to the extreme practicality, accuracy and the low impact on the environment. Especially in subaerial coastal environments, laser scanner technology and photogrammetry are very useful for the three-dimensional reconstruction of the morphologies. TLS (Terrestrial Laser Scanner) is an extremely accurate instrument and, thanks to the laser light, it allows to distinguish data related to vegetation, soil or sand and other element of different material, being very useful in monitoring coastal natural system (Fabbri *et alii*, 2017; Montreuil *et alii*, 2013). On the other hand, surveys can be very time-consuming and require technical personnel and expensive instrumentation. Digital photogrammetry allows to detect areas in an easy and fast way by managing images according to the Structure from Motions (SfM) approach (Snavely *et alii*, 2008) and the use of simple software. Photogrammetry can be also a very low-cost technique, especially with terrestrial method (Westobyet *et alii*, 2012; Pikeli *et alii*, 2015) or via low-cost UAV (Unmanned Aerial Vehicle) (Cook, 2016; Casella *et alii*, 2014), very useful for geoscience applications. As for nearshore areas, the recent development of multibeam echosounders proves this technique to be the most effective and reliable system to generate high-resolution submarine DEMs, comparable over time and with measurements collected onshore (Bosman *et alii*, 2015 and 2020).

In this paper, we describe the data of the first topo-bathymetric survey of the Riccione beach, obtained by means of a TLS for the emerged beach and a multibeam system via ASV (Autonomous Surface Vehicle) for the submerged one. This survey will be compared with the results of similar, previous and next surveys carried out in the same area, by using also different techniques, to provide information on the local coastal evolution and morpho-dynamics and to check the repeatability and integration of different approaches. Activities are performed in the framework of the project STIMARE (Archetti *et alii*, 2019, http://www.progettostimare.it/).

MATERIALS AND METHODS

In this study, we make use of a low-cost videomonitoring technique in order to quantify the coastal retreat and flooding dynamics through image processing of the shoreline evolution and run-up and to calibrate an evolution numerical model including morpho-dynamics processes (Sancho *et alii*, 2002). The instrumentation consists of a Raspberry Pi and a camera with a maximum resolution of 8 MP. The Raspberry Pi is a small and affordable computer, which allows controlling the camera acquisition through a simple programming language. For the present installation, we used Python and Shell scripts to construct a robust system to upload images to a remote server. Strong efforts have been made to make the connection fault-tolerant and capable to recover interrupted uploads of the acquired images, in the event of intermittent connection up-downs. For this reason, a system with a FIFO (First In First Out) queue has been implemented to guarantee consistent network streams over time without data loss. The queuing system is implemented using two folders. The first folder contains the images that have been acquired but not yet uploaded, ordered by their acquisition time. The second folder contains the images already uploaded to the remote server. The system checks every hour if there are images in the first folder and in case executes the upload process, that starts uploading the image with the older date. As soon as an image has been successfully uploaded to the remote server it is moved from the first folder to the second one, and then the upload process continues with the next image. This guarantees that the queue state is persistent also in the event of unexpected reboot of the operating system.

As in many applications related to monitoring systems, in our installation it is compulsory to avoid loss of data and to guarantee continuous time coverage of the time-series images. Besides that, huge attention has been paid to keep the video monitoring system simple and easily maintainable, through an opened socket-channel that allows the remote station to be accessible from everywhere. Uploaded images were then checked on the collecting server and finally sent to the image analysis sub-process.

Acquisitions consist of 10-minutes images each hour with a sampling frequency of 2 Hz (for a total of 1200 photograms) and a resolution of 2 MP (1640 x 1232 pixels). After the acquisition, the video system extrapolates the timex (i.e., time exposure image), which is the average of the RGB pixels of all the acquired photograms, and sends it to a remote server as described before. This process runs operatively in situ. Further analyses are then performed offline through a software developed in MATLAB for image processing. The offline processing is necessary for the rectification of the timex, the shoreline detection and the run-up evaluation (the latter only for intense meteorological events). The rectified timex is obtained through a projective transformation from image coordinates (i.e., in pixels) to local external coordinates (i.e., in meters) as detailed in the next section, i.e. through the measurements of ground control points (GCPs) with known image and local external coordinates.

The shoreline is obtained through a semi-automatic detection procedure which uses advanced image segmentation techniques on the rectified timex. The image segmentation is based on algorithms developed by Li *et alii* (2004), which clusters the image starting from foreground and background points indicated by the user and separates an area of interest from the background. The foreground points individuate the area of interest (in our case, the beach), while the background points indicate the background area (in our case, the seaside and added noise like people and sky). Further functions detect the boundary which separates beach and water, which represents the shoreline in sea calm conditions.

In case of intense meteorological events we can obtain a first evaluation of the maximum averaged wave run-up extension (Damiani *et alii*, 2018). The method is the same as that described for the shoreline detection (i.e., image segmentation with image clustering techniques), but the detected line which separates the water from the sand during intense events represents the quantitative estimation of the averaged run-up extension during the 10-minute acquisitions. Once the image processing steps (in situ and offline) provide the shoreline detection in metric coordinates, the following analysis can be performed:
i) the comparison of the semi-automatically detected shoreline position with the one obtained through GPS measurements, with the aim of processing validation;
ii) the quantification of the shoreline displacement after an intense meteorological event;
iii) the quantification of the run-up extension during a storm surge event.

A topo-bathymetric survey has been carried out by using TLS and ASV (Figure 1a, Figure 1b) with a multibeam system in May 2019. A DTM has been created by surveying the emerged beach using a FARO Laser Scanner CAM2 Focus3D, a very accurate instrument based on "Phase Shift" technology for measuring distances (6 mm resolution over a range of about 20 m) (Fabbri *et alii*, 2017). The TLS (Terrestrial Laser Scanning) scans have been merged and georeferenced by means of vertical chessboard targets (self-detected by software in the post-processing phases). Positioning has been made by a differential GPS Leica Viva GS14 (GNSS-NRTK positioning) that provides a very accurate measurement, 5 cm error at most. After scans filtering and processing a single point cloud has been created, then meshed to interpolate small gaps of missing points and, finally, it has been transformed in a very-high resolution DTM (grid at 0.01 x 0.01 m^2). The high-resolution multi-beam bathymetric survey has been performed in the submerged beach (from 0.4 m to -7 m) through an ASV (Autonomous Surface Vehicle) equipped with a multibeam system PicoMB-120 positioned by means of an RTK station (Figure 1c). This survey has been integrated with direct depth acquisition along GPS transects from about -1 m to the coastline and allowed to obtain a DTM gridded at 0.10x0.10 m^2.

Fig. 1 - a) TSL survey; b) ASV used for multibeam bathymetric surveys; c) RTK-GPS system.

In the future new bathymetric surveys will be performed also with the ASV made by Proambiente, the OpenSWAP (https://www.openswap.it/). It is a small and easily deployable catamaran, customized for the purpose of morpho-bathymetric surveys with an interferometric multibeam. This ASV allows complete control over the mission through a powerful scripting language that gives access to the whole catamaran HW/SW. Besides that, it is able to follow a planned path with great precision, with an error between planned and actual path below 30 cm. This allows to repeat the same acquisition survey at planned time intervals to check for minimal variations over time and thus enabling to study with great precision the sea-bottom dynamics (See Fig. 2).

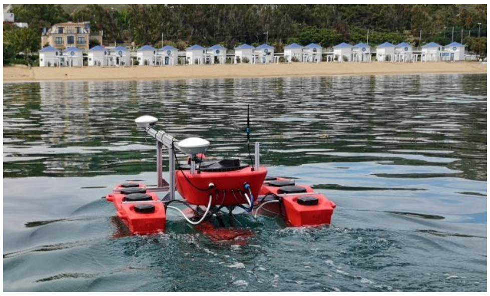

Fig. 2 - OpenSWAP in operation with a Klein Hydrochart 3500 multibeam installed between the two hulls.

THE STUDY CASE

The study site is Riccione, a touristic sea town in the Emilia-Romagna region in Italy: the location of the video-monitoring system is reported in Figure 3.The video system has been installed in July 2019 and has been operative for two months. During the installation of the video-monitoring station, several ground control points (GCPs) have been acquired with a differential GPS Leica Viva GS14 (GNSS - NRTK positioning) with centimetric precision. Moreover, two cross-shore transects and the shoreline have been measured for comparison with the shoreline detected through video processing.

As the municipality of Riccione and its beach are very popular with tourists during the summer season, the acquired timex images show high noise levels in the shoreline detection due to the presence of bathers and installations of sunshades on the beach. Nevertheless, choosing an appropriate time during the day (i.e., at the end of the day) for images capturing and processing, this problem is partly solved, and useful data are obtained.

Figure 3a shows the rectified image collected on July 17th 2019 and the comparison between the shoreline detection through MATLAB and the shoreline measured by GPS. As it will be extensively detailed later, this date was selected among the available database in order to make a first exercise of the methodology in the field. As largely described in literature, the video-analysis allows to compare shorelines at different moments; the detected shoreline being an isodepth or isoline with associated elevation of the simultaneous sea water level (SWL). It follows that the comparison of shorelines collected during comparable SWL, can give information on the shoreline displacement.

For the comparison of two or more shorelines and to give a value of distance among them, we estimate the root mean square error (RMSE) and the bias (as the shorelines distance averaged in the observed beach area). The RMSE gives the absolute distance between the computed shorelines, while the bias gives information about the shoreline variability. The latter is taken along the direction perpendicular to the mean inclination of the shoreline with respect to the metric coordinates. The comparison and statistics of two shoreline distances has been made between i) shoreline detected simultaneously through different methodologies, in order to validate them; ii) shorelines detected with the same methodology at different times, in order to observe and quantify the coast evolution. Figure 4a shows the comparison of the shoreline position between the shoreline measured by the GPS and the one detected through video analysis on July 17th. The result shows an overall overlap between the two lines, with a bias of 0.14 m and RMSE equal to 1.41 m (Figure 4b), mainly due to the low accuracy resulting where the coast is occupied by seaside facilities, which add noise to the image and prevent an optical access to the shoreline. The analysis will be repeated during winter time, far from the touristic season.

Fig. 3 - Aerial view of the study site, with indication of the Raspberry Pi location and of the monitored coastal tract.

The use of GCPs provides data enough to perform an error analysis for the evaluation of the uncertainty due to rectification process. We used six chessboard targets and two fixed GCPs for testing the uncertainty of the rectification process, while all the other GCPs were used as training test (i.e., to evaluate the transformation parameters). Figure 5 shows the comparison between the transformed and measured points. The maximum displacement was 0.97 m at the image sides, while the minimum displacement was 0.05 m at the center of the figure. The uncertainty is estimated as the average of the test GCPs and results to be 0.43 m.

PRELIMINARY RESULTS

The first analysis regarded the shoreline evolution during the two months in which the monitoring system was installed (July 17th - September 10th, 2019). The data for the significant wave height and tidal level were provided by the Regional Nausicaa wave buoy (https://simc.arpae.it/dext3r/) and the National Tide Gauge Network (https://www.mareografico.it), respectively. The Nausicaa buoy (located in Cesenatico 8-km-offshore and at a water depth of 10 m) is 33 km far from the study site, while the tidal level was obtained by weight-averaging the data from the existing tide gauges located at Ancona (77 km south of Riccione) and Marina di Ravenna (64 km north of Riccione).

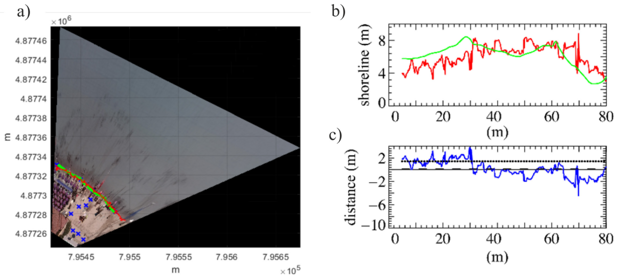

Fig. 4 - a) Rectified timex with the shorelines automatically detected trough video monitoring (then processed with MATLAB) and measured with GPS survey, and GCPs. b) Comparison between GPS and MATLAB-detected shorelines. c) Displacement, RMSE and bias between the two shorelines.

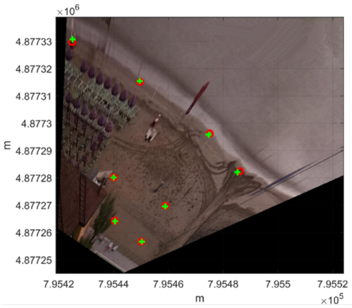

Fig. 5 - Comparison between GCPs measured with GPS and transformed with the rectification software.

We have considered an event of small storm occurred in the time frame July 26th and 28th. The time series of the significant wave height H_s and the sea level from tide gauges during the considered timeframe (between July 26th and 29th) are shown in Figure 6; maximum recorded H_s was 1.04 m propagating from 49°N with T_p 4.4 s. Figure 6 shows the two shorelines detected, the first before the small storm event (red line at 12:00 am GMT on July 26th) and the second shoreline detected through video processing after the peak of the storm event (blue line in Fig. 7, detected on July 28th at 8:00 am GMT). The images were carefully selected in order to correspond to moment with comparable SWL (see Figure 6b). The last image in figure (Fig. 7c) shows a shoreline displacement after the storm, with a bias of - 0.48 m, with the same order of magnitude of the error, which indicates a coastline retreat (on average) observed with the video monitoring station between July 26th and 28th. The images for the evaluation of the maximum run-up are taken before and after the sea level peak in the considered period and shown in Figure 8. Results show an average shoreline displacement in relation to the run-up (during the peak of the analyzed period) of 2.64 m, with local value of maximum shoreline displacement of 9.20 m, in correspondence of a drainage channel, with lowered morphology.

Regarding the topo-bathymetric surveys, they have been georeferenced in the same coordinate reference system

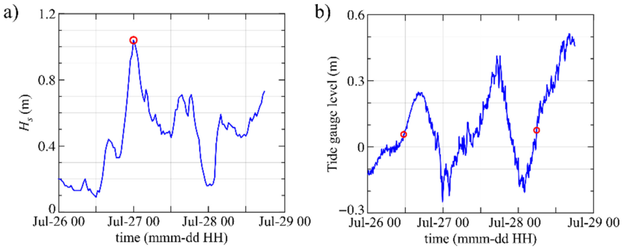

Fig. 6 - a) Significant wave height H_s measured during the consideredtime frame (peak indicated by the red circle). b) Tide gauge level estimated for Riccione from the National Tidal Network data (red circles indicate dates at the beginning and at the end of the analyzed period).

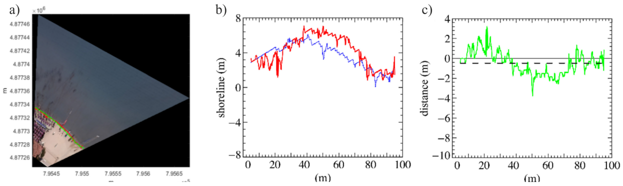

Fig. 7 - a) Rectified timex with the shorelines at the beginning (July 26th) and at the end (July 28th) of the observed period. b) Shoreline comparison. c) Shoreline displacement and bias.

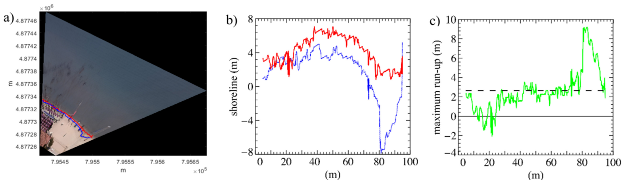

Fig. 8 - a) Detection of the run-up extension during the wave height peak (July 27th) on the rectified timex. b) Detected shoreline before the peak wave (July 26th) and at the peak wave (July 27th). c) Maximum run-up extension due to the peak wave height (July 27th), point-by-point and averaged on the horizontal (as the shoreline bias).

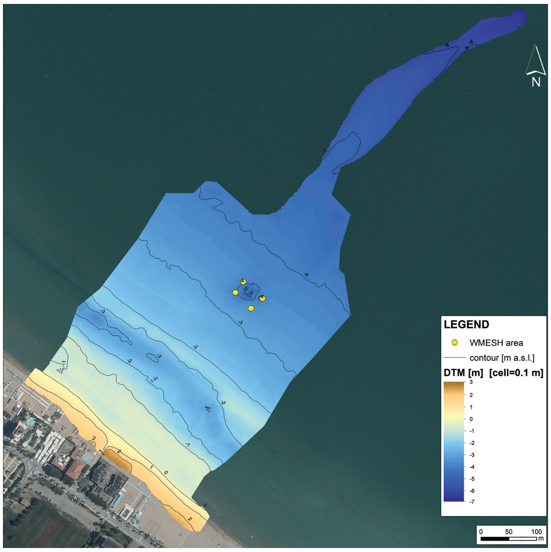

Fig. 9 - Merged DTM of the surveyed emerged and submerged beach. Yellow dots indicate the position of submerged coastal protection structures.

(ETRF2000-UTM32(2008.0)) and referred to the same topographic benchmark (of the Emilia-Romagna Coastal Geodetic Network) to obtain the orthometric height (m a. s. l.).

Thus, they have been merged to obtain a single 3D model of the studied beach area gridded at 0.10 x 0.10 m^2 (Figure 9) that will be also the topo-bathymetric input for numerical models. Particular attention was given to the correlation between the topographic and bathymetric surveys, in order to eliminate any possible errors related to the use of different methodologies (Mancini *et alii*, 2013; Giambastiani *et alii*, 2016; Scarelli *et alii*, 2017).

In the next steps of the project, the results of similar surveys that will be carried out with different techniques (such as UAV photogrammetric survey) will be compared and integrated in order to reconstruct the overall evolution of the coastal tract under study. Moreover, comparisons with other multibeam bathymetries previously acquired by ARPAE in 2017 and 2018 (in the same area with similar operative conditions) are currently in progress.

CONCLUSIONS

Preliminary results of two different monitoring techniques adopted in the framework of the STIMARE project are here presented with application on the study site of Riccione (IT). The two monitoring approaches are complementary in terms of temporal acquisition and precision: direct surveys provide data with high spatial precision but not acquired continuously for budget and logistics reasons, while video monitoring provides less precise indications of the shoreline alone (used as a proxy for the description of coastal dynamics) but with information acquired continuously. The comparison between following surveys will provide information on the response of the coastline to waves in different conditions and on the effects of the coastal protection structures on the seabed, both in the near field and in the far field, with the possibility of quantifying the locally eroded or accumulated sediment.

Concerning the performances of low-cost video station, made with Raspberry Pi, we obtained good results: routines to make a timex every hour, to detect the shoreline and to orthorectify the images have been developed and they are operative on site. The resolution used in the experiments is 2 MPixel and will be increased in the future development. The error in the orthorectification process of the images is low (0.43 m) and will be reduced in the future by using a third-order polynomial transformation (rubber sheet); the shoreline detection on images shows a medium-good quality, when compared with direct measurements.

Through video analysis we have analyzed, as test of the system, the impact of a small intensity storm event occurred last summer. Complementary, repeated surveys of the emerged and submerged beach through different techniques will provide accurate description of the site and of its evolution at the mid-term, evidencing the impact of the submerged coastal protection structures.

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