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LASER SCANNER AND MULTIBEAM INTEGRATED SURVEY FOR THE ASSESMENT OF ROCKY SEA CLIFF GEOMORPHOLOGICAL HAZARD

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KEY WORDS: Laser scanner, Multibeam echosounder, Rocky coast, Geomorphologic hazard, Gallinara island, NW Italy

ABSTRACT:
Within land management of coastal zone, considering both emerged and submerged areas, a large amount of high resolution georeferenced spatial data is required. Remote sensing techniques fully satisfy these needs and allow to obtain all information in a single survey campaign. An integrated survey of laser scanner and multibeam techniques has been experienced along the rocky cliffs of the Gallinara Island (Western Liguria, Italy), in order to produce a geomorphological map addressed to hazard evaluation. The resulting data allowed obtaining significative geo-structural and morphological information to evaluate the quality of the sea cliffs and the definition of their susceptibility to instability.

1. INTRODUCTION

The rapid technological evolution of the survey techniques has led many researches to focus on their integration and on the management and elaboration of the huge amount of data produced (point clouds and digital terrain/surface models), paying attention to reach the necessary precision and resolution (Nex et al., 2014; Gagliolo et al., 2018; Passoni et al., 2018), in various application fields, from the analysis of the territory to the cultural heritage.
Within land planning and management strategies in coastal areas, the application of remote sensing techniques, such as multibeam, laser scanner and terrestrial or UAV photogrammetry, in support of geomorphological hazard assessment is of great interest and relevance (Faccini et al., 2005; Mills et al., 2005; Rosser et al., 2005; Brandolini et al., 2007a; 2009; 2013; 2015; 2017; 2018; Naylor et al., 2010; Mancini et al., 2013; Del Monte et al., 2015; Monteys et al., 2015; Troisi et al., 2015; Aguilar et al., 2016; Raso et al., 2016; 2017; Capra et al., 2017). In the framework of rocky coastal environment, where it is necessary to get detailed georeferenced data both at sea and inland, remote sensing techniques allow the acquisition of the whole information in a single and integrated survey campaign.
In the context of this topical issue, a survey of rocky coast and seabottom of Gallinara Island (Western Liguria, Italy; Fig. 1) was carried out with the aim to produce a geomorphological map of the emerged and submerged coastal zone (Brandolini et al., 2007b; Cevasco et al., 2013; Scarpati et al., 2013; Lucchetti et al., 2013; Brandolini et al., 2018). Gallinara, included in a regional park since 1989, is a small island with an extent of 0,11 km^2 and a maximum elevation of 87 m a.s.l. The island is mainly featured by the cropping out of quartzites and secondly by conglomerates belonging to "Quarziti of Monte Bignone" Formation (Upper Cretaceous).
The small extent of Gallinara, together with its particular meteomarine climate conditions, makes the island a large scale significative laboratory for testing the application of remote sensing technologies within coastal geomorphological investigations and management. Hence the final aim of this study is the production of a susceptibility map to rock coast instability.

Figure 1. Location of the study area and north-west view of Gallinara Island.

2. METHODS

2.1 Integrated survey

The integrated coastal survey has been performed using a Laser Scanner (LS) RIEGL mod. LMS-Z420i, a MultiBeam EchoSounder (MBES) R2Sonic 2024, two GPS 5700 TRIMBLE in RTK (Real Time Kinematic) base-rover configuration and an IMU IXBLUE mod. HYDRINS III.
The survey has been carried out in only two days, mainly from the seaside, not having access to the island, because private, except for the refuge port of public property. A boat properly equipped by the Teledyne Reson PDS2000 platform for the simultaneous acquisition of MBES and LS in profiler mode data (Fig. 2), circumnavigated the island. In the refuge port a static LS survey from the protective piers, integrated with RTK GPS positioning along transects in the area characterized by low water depth, where the boat was not able to enter, has been performed too. GPS positioning was also necessary to georeference both the cornerstones (four on the coast and one in the refuge port of the island) by means of a static survey, and the boat by placing the base receiver on the island's cornerstones and the rover on the boat, connected to the acquisition platform.
The RIEGL instrument, characterized by 1 km maximum range and a repeatability of 8 mm on a single measurement and 4 mm on average, allowed reaching precisions of the order of 1 cm

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during the static survey. The static LS survey has been performed in three different positions and three cylindrical targets reflectors were used, in addition to natural or anthropogenic targets, to improve the accuracy of the cloud registration phase. In profiler mode precision varies between 3 and 5 cm, depending on the angular precision of IMU and the distance from the cliff.
LS was also integrated with a camera so to associate the color to the resulting point cloud
The MBES instrument is characterized by a 256 beams of 0,5° x 1° beamwidth across and along track at 450 kHz. In order to investigate the portions of the bottom close to the free surface, the Multibeam was mounted on a joint angled at 30°, thus physically tilting the transducer to exploit the entire swath of the MBES.
The MBES system requires a preventive calibration phase both for the synchronization of the time scale of each instrument (IMU, MBES, LS) with respect to the GPS time and for the compensation of the Roll, Pitch and Yaw rotations due to the mechanical assembly of the system with respect to the ideal configuration. An analogous manual calibration procedure is necessary for the correction of the Roll, Pitch and Yaw parameters of the Laser Scanner Profiler.
The MBES control interface allows data filtering, which is essential both for the automatic removal of most noise in water often caused by navigation motion. Sound Velocity Probe (SVP) allow to reduce the depth measurement error. Despiking is recommended to be performed manually by an experienced operator, especially in presence of articulated geological structures.
Seabottom MBES, processed by the platform Teledyne Reson PDS2000, allowed to obtain a detailed submerged Digital Terrain Model (DTM) of 0,25x0,25 m resolution. The static LS data, processed with the software Riscan Pro by Riegl, and the profiles LS data, processed by the platform Teledyne Reson PDS2000, allowed to describe the emerged rocky coast at 2-4 cm resolution. The final result was the reconstruction of a continuous 3D model both for emerged and submerged coastal zone (Figs. 3, 4), that allows to extract information on site geology and geomorphology.

Figure 2. On board technical equipment for the integrated survey: 1) GPS-RTK; 2) IMU; 3) SVP; 4) MBES; 5) LS.

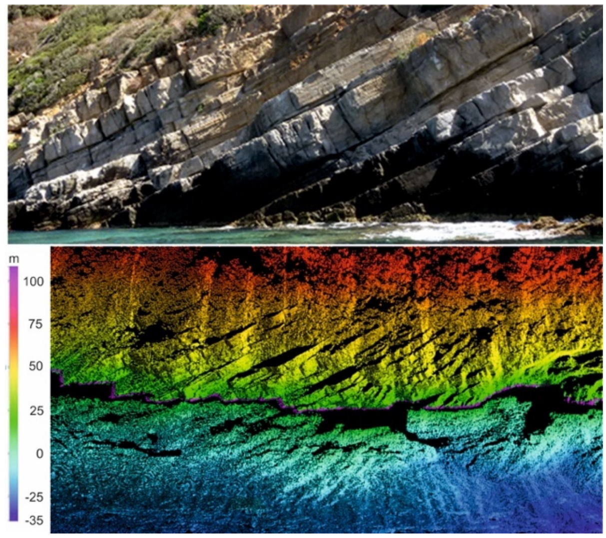

Figure 3. Example of clouds points continuity between Multibeam and Laser Scanner acquisition: comparison a current photo (A) and integrated survey (B).

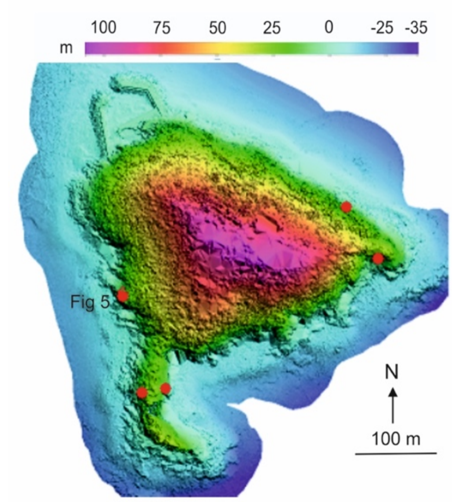

Figure 4. Gallinara Island DTM. The red dots indicate the SCMR test areas.

2.2 Geomorphological hazard mapping

The obtained data, checked and integrated with field observations and aerial photo interpretation, allowed to produce a geomorphological map following the guidelines of the new legend of the Italian Geomorphological Map proposed by AIGEO, the Italian Association of Physical Geography and Geomorphology (Mastronuzzi et al., 2017; Chelli et al., 2018).
Moreover, the processing of the collected data (e.g. characteristics of the outcrops and the joints) allowed the application of the "Sea Cliff Mass Rating" (SCMR) method for the evaluation of the quality and state of stability of sea cliffs (Lucchetti et al., 2013). SCMR partly takes in account the index Slope Mass Rating (SMR) by Romana (1993), introducing some new parameters related to the interaction of sea wave with cliff and seabottom (e.g. slope angle of the cliff; angle between the sea waves direction and the coast line; broken or breaking waves and the sea wave energy).
Finally, a susceptibility map of coastal instability, based on the correlation between SCMR and geomorphological data, has been produced according to the methods proposed by Lucchetti et al. (2014). Five classes of susceptibility of coastal instability (SCI) have been identified according to their quality and state of

stability. Moreover a sixth class, defined as “techno-coast", has been added to represent the harbor works and others man made interventions that have completely obliterated the sea cliff.

3. RESULTS AND FINAL REMARKS

Thanks to the effectiveness of the configuration adopted during the acquisition, MBES and LS have been correctly aligned and integrated in order to reconstruct in great detail the morphology of the Gallinara Island. Seabottom multibeam data allowed to obtain a detailed grid of 0,25x0,25 m of the submerged area, while emerged rocky coast were described at a 2-4 cm resolution by laser scanner data.

The 3D digital model of both emerged and submerged areas was reliable and useful for geomorphological and structural analysis of the entire island. Based on DTM data, together with field survey and aerial photo interpretation, geomorphological features of the island have been outlined: the whole perimeter of the island is mainly characterized by active rocky cliff with height up to about 30 m; an active coastal rock fall landslide is located in the southern sector affect by the main wave from SW (dominant) and SE; two flat surfaces, identifiable as quaternary marine terraces, are observable on the eastern and western promontories at an elevation of about 30-32 m.

The high resolution of DTM allowed to measure the attitude of the layers and the main discontinuities features of the bedrock (Fig. 5) used for the application of SCMR classification.

The application of SCMR classification was carried out in 5 representative areas of the island, identified as red dots in figure 4. Measurements, made on approximately 50 m for each area, highlighted the quality of the sea cliff in relation to bedrock condition and sea wave action.

The correlation between SCMR and geomorphological data allowed to produce the susceptibility map of coastal instability of the island perimeter. Very high susceptibility (SCI-4) has been found in the southern sector of the island within a wider sector with medium susceptibility (SCI-2). The remaining sea cliff are classified between low (SCI-1) and very low (SCI-0), except for a small sector identified with high susceptibility (SCI-3), affected by an active rock fall (Fig. 6)

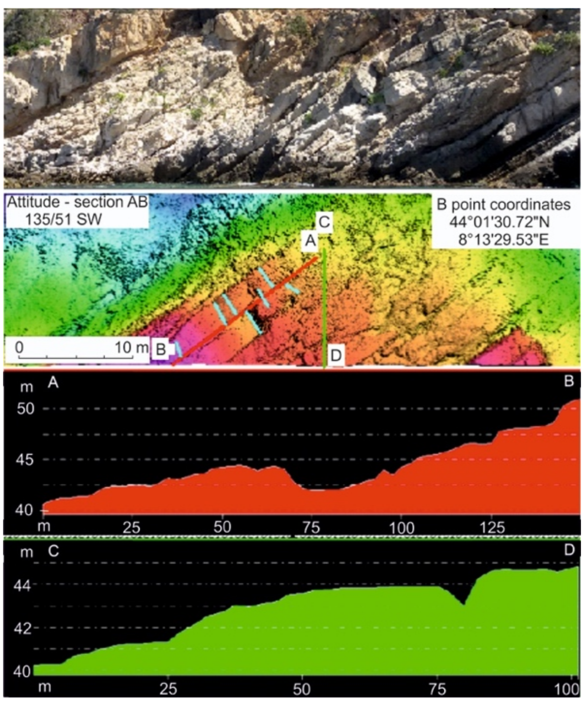

Figure 5. Example of attitude and joints measurement

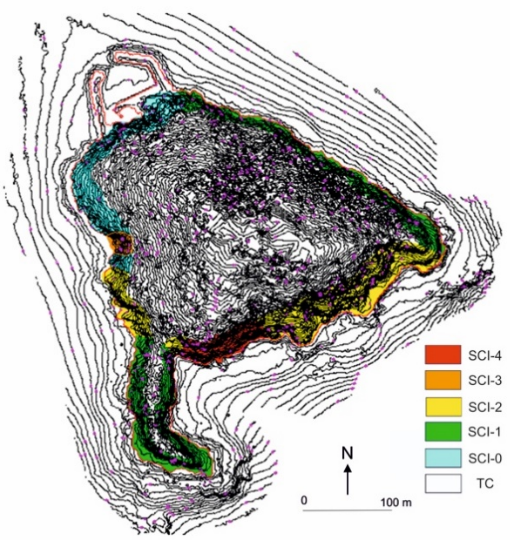

Figure 6. Susceptibility coastal instability (SCI) map: SCI-4 - very high susceptibility - active landslides and sea cliffs with SCMR = 0-20; SCI-3 - high susceptibility - deep seated gravitational slope deformation (D.S.G.S.D.) and sea cliffs with SCMR = 21-40; SCI-2 - medium susceptibility - sea cliffs with SCMR = 41-60; SCI-1 - low susceptibility - sea cliffs with SCMR = 61-80; SCI-0 - very low susceptibility - beaches and sea cliffs with SCMR = 81-100; TC - techno-coast.

In conclusion, the integrated remote sensing technologies showed to be very effective both in term of time, cost and accuracy of the result.

The application of an integrated survey based on MBES and LS techniques allowed detecting a large amount of high-accuracy and significant data in a single survey campaign, even in areas difficult to detect with direct traditional techniques. The results allowed assessing consistently the stability conditions of rocky coast, according to Lucchetti et al., highlighting the most hazardous areas along the south western sectors of Gallinara Island, which are exposed to dominant waves.

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