Marine Information Technology

Curriculum Report

Title: **An Innovative method to optimize the Side-Scan Sonar mapping and unveil the Blind Band**

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“I declare that the assignment here submitted is original except for source material explicitly acknowledged, and that the same or related material has not been previously submitted for another course. I also acknowledge that I am aware of University policy and regulations on honesty in academic work, and of the disciplinary guidelines and procedures applicable to breaches of such policy and regulations.”

Signature: **Date: 23/6/2020**

Abstract

For the past few years, the mapping of the marine habitats in the Mediterranean has shown a need for concern to environmental managers, stakeholders, scientists for conservation purposes. Side-scan sonar (SSS), is one of the most recognized and effective tools in underwater mapping. However, the acoustic data (sonograms) interpretation requires extensive field calibration, as well as ground-truthing. A couple of techniques including sampling techniques have been used in time past, and these include scuba diving observations, grabs, Remotely Operated Vehicle (ROV) underwater video recordings. These techniques are known to be time consuming, expensive and provide sporadic information. However in this study, the use of a camera, attached to the Side Scan Sonar, to take underwater videos was tested. The oceanographic survey, 'PosidCorse', was carried out along the eastern coast of Corsica and optical and acoustic data were acquired using a GoPro^{TM} camera and a Klein 3000^{TM} Side Scan Sonar. Five profiles were carried out between 10 and 50 m depth, and this was about 20 km of data acquisition. The vertical images were recorded with camera that was fixed under the SSS and it was positioned facing downwards, and photo mosaics of good quality which correspond to the total sonogram's blind band were done. 94% of different bottom types and main habitats were acquired; and the structures were linked to anthropic, biological and hydrodynamics conditions and activities. The link between underwater videos and acoustic data has shown to be cost-effective and non-destructive method for ground-truthing in marine habitat mapping.

Introduction

Loss of marine coastal habitats like the seagrass meadows, corraligenous assemblages, coral reefs have been identified in a couple of regions of biosphere (Waycott et al., 2009; De'eath et al., 2012; Ponti et al., 2014). Trawling, coastal development, eutrophication, and competition with invasive species are the main causes for the loss of seagrass meadows in the Mediterranean Sea (Boudouresqu et al., 2009; Pergent et al., 2015). The mapping of these coastal benthic communities is necessary for conservation purposes and as well as environmental policies (Gilman, 2002). Common underwater mapping methods include optical sensors (aerial photographs and satellite images), which works better for shallow depths of about 15 m, and acoustic sensors (multi-beam echosounder and side-scan sonar) in deeper waters (Godet et al., 2009; Vela et al., 2008; Brown et al., 2011; Bonacorsi et al., 2013).

No matter the kind of sensor used, remote-sensing systems will always require field data (process of ground truthing) (Elefteriou and McIntyre, 2005; Anderson, 2007; Coggan et al., 2007; Van Rein et al., 2009; Brown et al., 2011) to validate the remote-sensing data. However, the acquisition of data is expensive and time-consuming (Kenny et al., 2003). In a survey of shallow water (0 – 10 m), a direct observation using echo sounder and a GPS is fast and accurate based on location and biosensors (Vela et al., 2008).

In surveys involving intermediate depths (-10 to -40 m), scuba diving is engaged. The data acquired per unit time is however not large enough and the cost is high; also, the accuracy is inadequate in terms of location (Leriche et al., 2006; Holon et al., 2015). For depths greater than 50 m, two common techniques used are blind samples with cores or grabs, which are effective for soft bottom and use of tools like underwater video cameras, Remotely Operated Vehicles (ROVs) and submarines (Pergent et al., 2017).

In recent years, underwater video images were used to calibrate side scan sonars, multibeam echosounder data and optical sensors (Smith et al., 2007, 2015; Lefebvre et al., 2009). While ground-truthing data provides sporadic information over a small part of the seafloor, sensors are able to provide a broad surface area data. Therefore, the aim of this study is to test the chances of acquiring field data continuously using a side-scan sonar, with camera attached in order to aid the mapping interpretation (Pergent et al., 2017).

Material and Methods

The study area is along the eastern coast of Corsica (Natura 2000 site Grand erbier de la Cote Orientale), whose depth ranges between 10 and 50 m depth. The acoustic data were acquired during the PosidCorse survey which was conducted during summer 2015. Two types of equipment used are the;

- Side-scan sonar (Klein 3000™), which provides acoustic data (sonogram) for the seabed (texture, grey color) and
- GoPro™ camera (HD Hero3 Black Edition) with a Subspace Picture™ underwater housing, which is fixed under the side-scan sonar.

The GoPro™ camera was faced down under the side-scan sonar to take vertical images which corresponds to the blind band (Fig 2). Five profiles were generated between 10 and 50 m depth, which accumulates to a 20 km data acquisition with a side-scan sonar range between 25 and 50 m

(Table 1). The speed of the vessel used ranged from 4.5 to 6.0 km/hr. there were different resolutions of the camera and the numbers of frame per second were tested. Just a field of view (medium) was used (127°). Also, different habitats and bottom types were studied (Cymodocea nodosa beds, Posidonia oceanica meadows, photophilous algae, sandy and rocky bottom, and beach rocks).

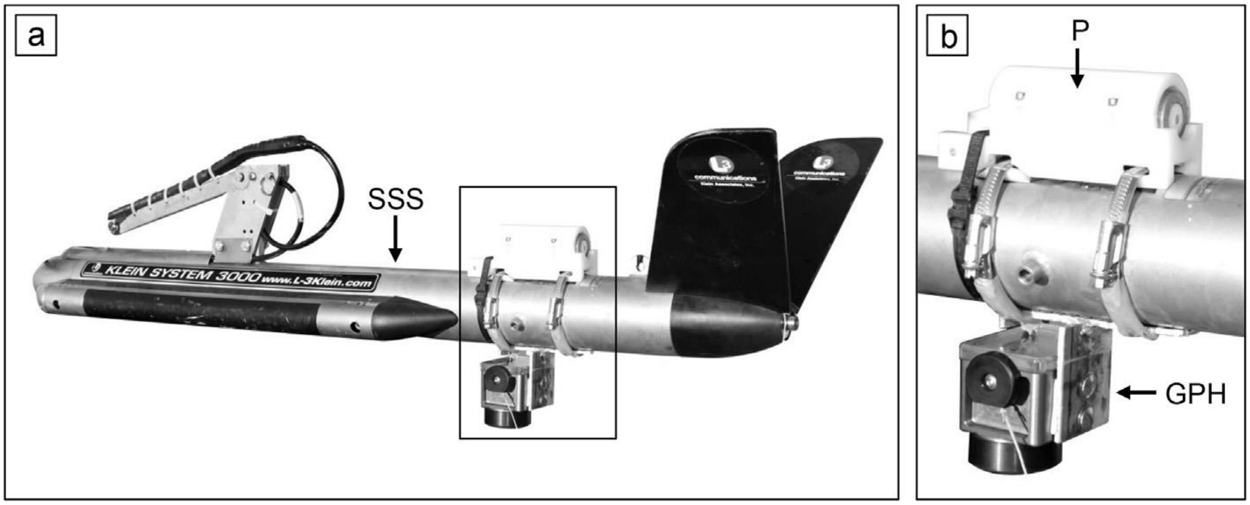

Fig. 1. (a) Klein 3000 ™ side-scan sonar (SSS) and (b) the pinger (P) with the GoPro™ camera in its housing (GPH) fixed on the towfish (Pergent, et al., 2017).

Videos from the GoPro camera were imported into the software Microsoft Image Composite Editor (ICE) environment, with version 2.0.3.0. this was done to make high quality panoramic image mosaic that correspond to the part of the ground that fell on the blind band. The options of the import step allow the selection of interval of the original video so to match the time process and to define the photo mosaic length. The ICE software auto-detect mode is used to analyze the video, analyze the images on the focal plane at each moment, stitch the images together and finally compose a photo mosaic (Pergent et al., 2017)..

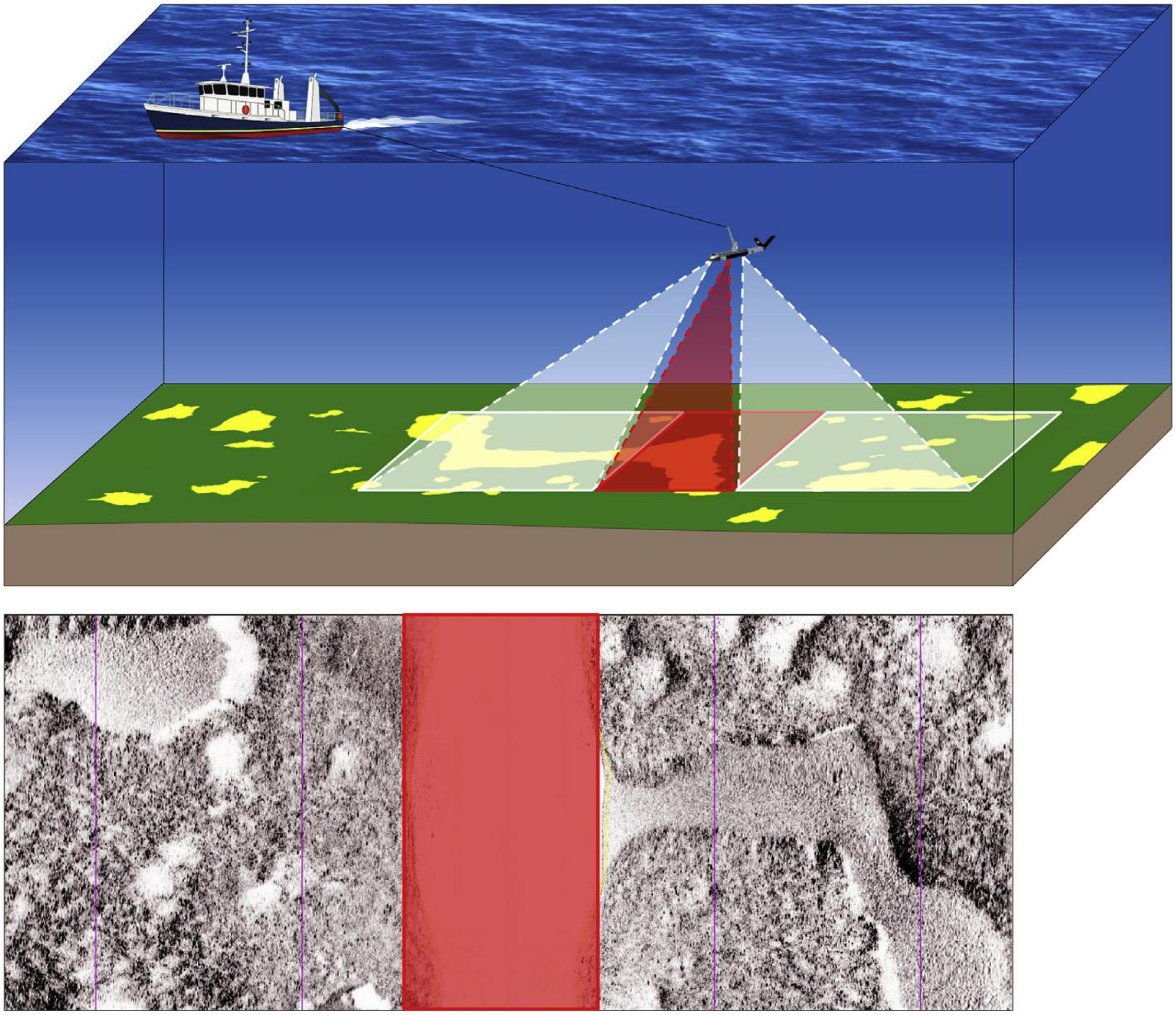

Fig. 2. Data recorded by the two devices, GoPro™ camera in the central part (red band) and side-scan sonar on either side (white bands). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) (Pergent, et al., 2017).

Table 1
Characteristics of transects using the GoPro™ camera and Klein 3000 side-scan sonar. fps ¼ frame per second (Pergent, et al., 2017).

Transect	Length (m)	Time duration (min)	Bottom depth (m)	Sonar range (m)	Tow elevation (m)	GoPro resolution (pixels)	Frames (fps)
L3-102	1700	20	10–12	25	2.5–3.3	1920 × 1080	60
L3-110	1600	21	10–16	25	2.5–4.9	1920 × 1080	60
L3-128	2800	29	20–45	25	2.5–4.0	1920 × 1080	60
L4-152	8100	84	10–50	25	2.5–2.8	2048 × 1536	30
L4-166	6200	68	10–20	50	3.9–5.4	1920 × 1080	60

Table 2
Percentage of bottom types and main habitats identified along GoPro transects (Pergent, et al., 2017).

Habitats and bottom types	Transect				
	L3-102	L3-110	L3-128	L4-152	L4-166
Cymodocea nodosa	38.0%			5.0%	
Posidonia oceanica		79.2%	30.7%	45.3%	96.4%
Dead matte				6.7%	1.1%
Soft bottom	62.0%	13.8%	12.5%	10.6%	2.5%
Rocky bottom		7.0%		0.3%	
Pebbles				0.5%	
Rhodolith beds			34.4%	24.8%	
Undefined habitats			22.4%	6.8%	

Results

The GoPro camera allows the discrimination of different bottom types and the main habitats, and even if the results are not satisfactory in deep parts (Table 2). Also, it made it possible to identify particular structures that are related to the water movement (intermates, ripple marks, accumulation of Posidonia dead leaves), to biological activity (bioturbation of the sediment like the burrows), anthropic activity (plastic bag, waste, boat hull and so on). Quite a number of burrows were identified, which were likened to Cymodocea nodosa beds; they also correspond to the activity of decapod crustaceans, like the Pestarella tyrrhena Petagna 1792 and the Upogebia pusilla Petagna 1792 (Pergent et al., 2017).

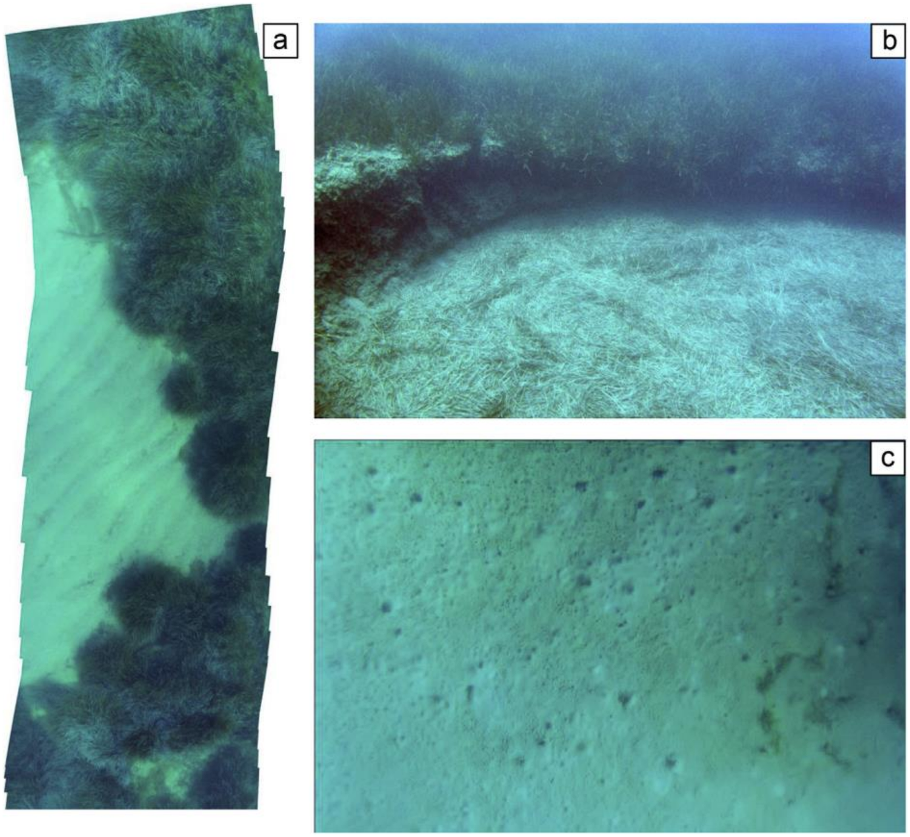

Fig. 3. (a) Photo mosaic made by Microsoft© ICE, a part of the transect L3-1101 showing P. oceanica meadow and soft bottom with Ripple marks, (b) accumulation of P. oceanica dead leaves in an intermatte (c) and crustacean burrows in C. nodosa beds (Pergent, et al., 2017).

In another case, the substrate on which the Posidonia oceanica meadow grows (whether soft bottom and/or rocky bottom), it appears clearly on the images from the GoPro camera, which is an information not always shown by sonograms, and was really helpful for the interpretation of the acoustic data. In the Natura 2000 zone, the seagrass settled on rocky substrate which is unusual in a continuous habitat in the region and it represents small areas which were confirmed by the videos.

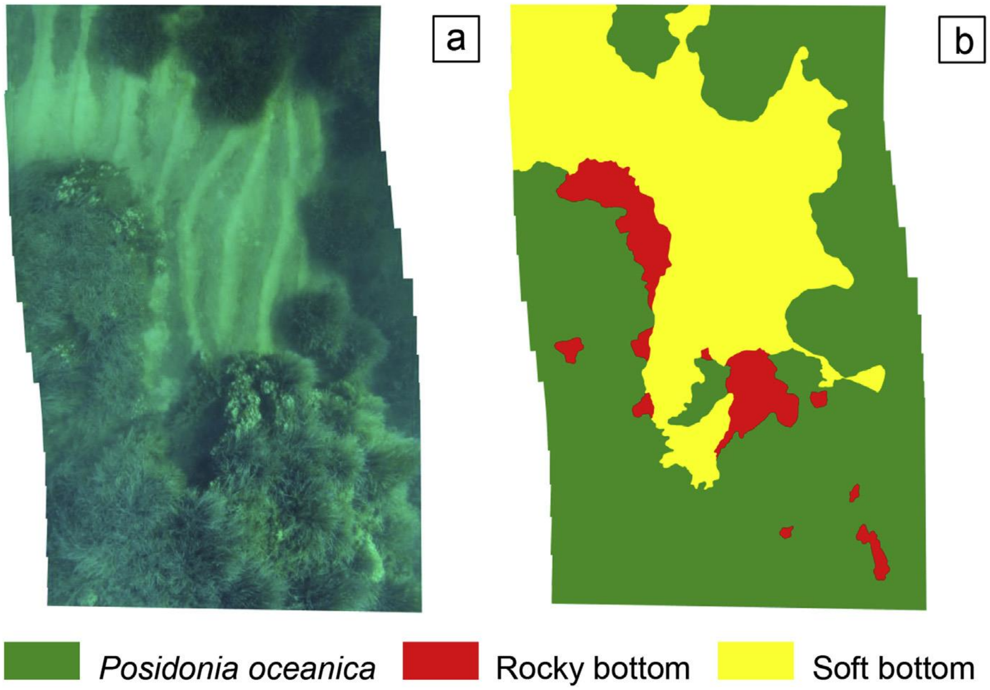

Fig. 4. Photo mosaic of Posidonia oceanica on rocky and soft bottom (a) and the mapping interpretation (b) (Pergent, et al., 2017).

Therefore, the association of the acoustic data (sonogram) and the camera images give a wide range of information which serves as basis for underwater mapping. The advantages of this includes;

i. allowing an accurate validation or calibration of the acoustic data and a precise identification of the bottom type and/or the corresponding habitat (Fig 3);
ii. it gives an indication of the nature of the substrate (Fig 4) and also
iii. gives information on the ‘blind band’ which was not covered by the side-scan sonar.

The last feature helps to prevent a subjective interpolation. This novel method also helps to map accurately the location of the boundaries of the habitats, on either side of the blind band (Fig 5a), and as well to detect small features that are present in the band (Fig 5b) (Pergent et al., 2017).

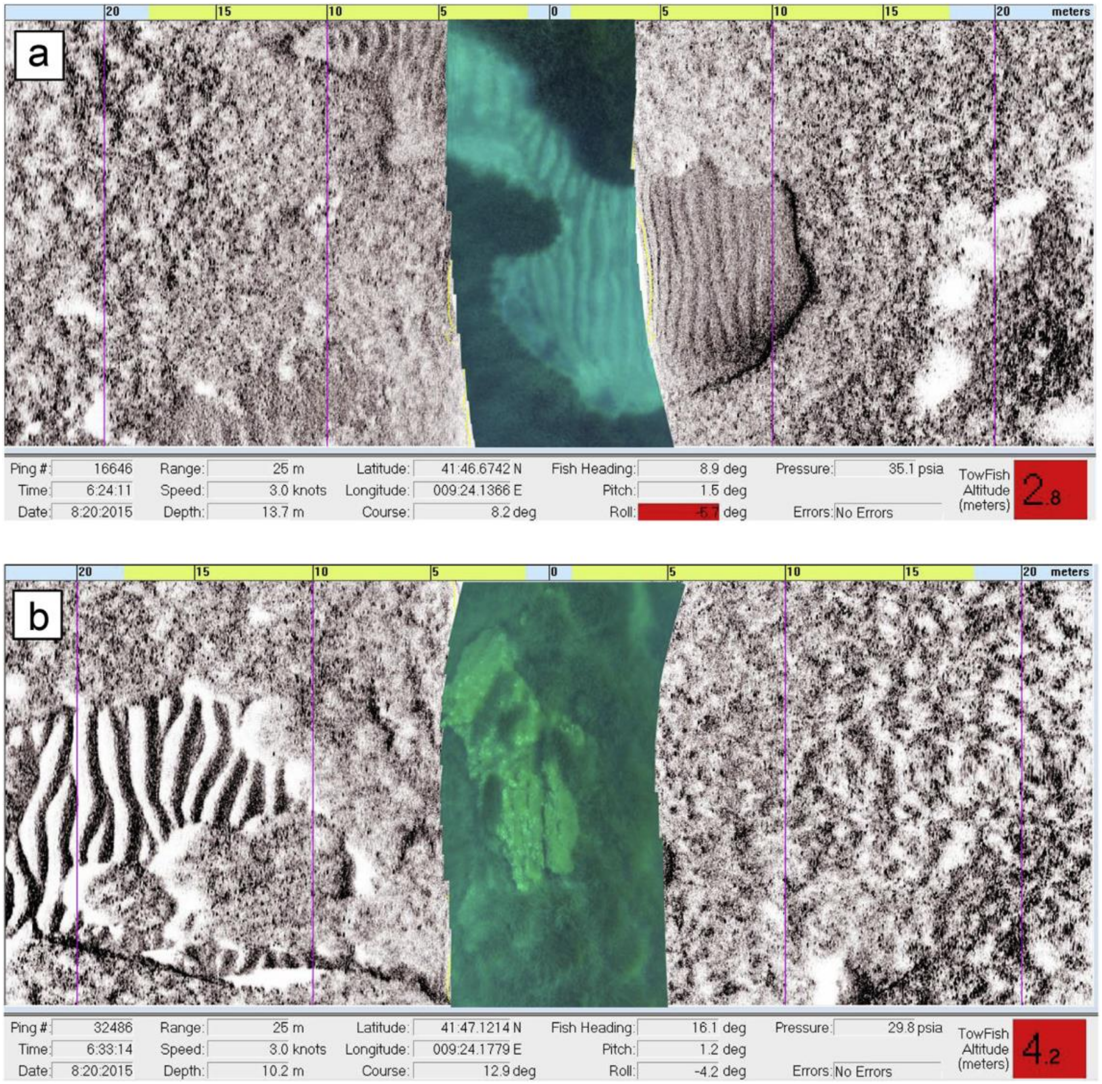

Fig. 5. Association between acoustic data (sonograms) and photo mosaic from GoPro camera: (a) limit of sand with ripple mark and (b) rock with meadow on both sides (Pergent, et al., 2017).

Discussion

The use of acoustic sensors help to give a wide range of information which characterize the seabed (including assemblages, bathymetry and the types of bottom). However, these data require validation and calibration before they can be used as a basis for precision mapping. In the use of the side-scan sonar data, the validation requires experience and is based on the reference sonar images for identification of characteristic textures and spectral signatures (e.g sonogram atlas; Clabaut et al., 2007; Clabaut and Augris, 2014). Nonetheless, the ground-truthing is essential to validate the interpretations (MESH, 2008); these data are either acquired in the course of the oceanographic survey, and it is expected to interrupt the data acquisition by the side-scan sonar

(Bonacorsi et al., 2012; 2013), or at the end of the survey, which involves the repeated use of the seagoing research facilities and an accurate GPS to make it easy to revisit the places to be verified (Andromede Oceanologie et Stareso, 2012; Pasqualini et al., 2000). Unfortunately, the operations require a significant cost.

For past few years, use of underwater cameras has been on the rise, because;

i. They allow good discrimination of assemblages and species (Rooper, 2008; Van Overmeeren et al., 2009; Hamilton et al., 2011; Pelletier et al., 2011; Bonacorsi et al., 2012; Chabanet et al., 2012; Sane et al., 2016)
ii. They also provide raw data banks, that can be stored and reinterpreted for purposes of monitoring over time (Barker et al., 1999; Lam et al., 2006; Lirman et al., 2007; Tyne et al., 2010; Pelletier et al., 2012), and
iii. They do not affect or degrade the environment, compared to the popular sampling methods like the grab or edge.

In this study, the coupling of the GoPro camera and the side-scan sonar was tested to validate the acoustic data for mapping main habitats and bottom types which occur between 10 and 50 m depth. The method made it possible to calibrate continuously in real time, of the sonograms acquired with up to 94% identification of habitats and the bottom types that are present (Table 2). It further provided a means to identify the nature of substrate where the habitats have developed, and also to show specific structures that are related to the water movement, biological and anthropic activities (Fig 3).

Further, the blind band, which is directly below the sonar was properly surveyed for the first time (Fig 5), while previous methods involves the use of specific algorithms during the processing of the sonograms or use the manual interpolation.

From the previous images and video acquired by many towed systems (Rooper, 2008; Rende et al., 2015), the recordings during the study were always affected by pitch and roll. The fins where the side scan sonars are situated provide an effective stabilization and gives a good image quality. The light-weight, small-sized camera housing, that is fixed at the rear of the side-scan sonar allows no hydrodynamic turbulence or effect on the movement. The videos that were acquired at the speeds of 4.5 to 6 km/h give good quality of photo mosaics for the videos of 60 fps, even if there are occasional blurring and distortion.

During the photo mosaics using the Microsoft ICE software, the time lapse mode of the GoPro camera with acquisition frequency of 0.5 fps gives a very satisfactory results and it prevents the problem of blurring due to the high coverage of the seagrass meadow and movement of leaves ('canopy effect') and also facilitates the stage of stitching up the different photographs (Rende et al., 2015).

To optimize the results and allow a wider application of this novel technique in underwater mapping, there are some limitations to be taken care of. One is the battery life, which is just 2 h and will have to be extended to prevent bringing up the sonar repeatedly. Also, the sensitivity of the side scan sonar is important because it limits the depth of acquisition to 50 m (in the Mediterranean and other areas with low turbidity. It also imposes a limited height of the tow fish over the bottom (2 – 5 m), and therefore limits the range of the sonar to just 50 m. however, the sensitivity of the camera is being developed; and today, it is 6400 ISO and could go further.

Finally, use of a wider field of view (170°) should be tested, even if there will be greater distortion at the edges of the image. The distortions could be corrected by calibration and correction procedures (Bouguet, 2010 in Rende et al., 2015). Also, installation of powerful light sources in order to increase the depth and the height for the photograph acquisition, using remotely controlled underwater systems is also envisaged for greater depths (Ludvigsen et al., 2007). However, due to how bulky the equipment is, it's use on the side scan sonar might be difficult for now (Pergent, et al., 2017).

References

Anderson, J.T., 2007. Acoustic seabed classification of marine physical and biological landscapes: Introduction. In: Anderson, J.T., Holliday, D.V., Kloser, R.J., Reid, D., Simard, Y. (Eds.), Acoustic Seabed Classification of Marine Physical and Biological Landscapes. ICES Cooperative Research Report, Copenhagen, pp. 1e6.

Androm_ede Oc_eanologie et Stareso, 2012. Inventaires biologiques et analyse _ecologique des habitats marins patrimoniaux du site Natura 2000 « Cap Rossu, Scandola, Pointe de la Revelatta, Canyon de Calvi » FR 940201. Androm_ede Oc_eanologie et Stareso/Agence Des Aires Marines Prot_eg_ees, pp. 339.

Barker, B.A., Helmond, I., Bax, N.J., Williams, A., Davenport, S., Wadley, V.A., 1999. A vessel-towed camera platform for surveying seafloor habitats of the continental shelf. Cont. Shelf Res. 19, 1161e1170.

Bonacorsi, M., Pergent-Martini, C., Clabaut, P., Pergent, G., 2012. Coralligenous ‘‘atolls’’: discovery of a new morphotype in the Western Mediterranean Sea. Comptes Rendus Biol. 335, 668e672.

Bonacorsi, M., Pergent-Martini, C., Clabaut, P., Jouet, G., Pergent, G., 2013. Optimization and comparison of underwater mapping methods. In: Marmaris, Turkey, Ozhan, E. (Eds.), Proceedings of the Global Congress on ICM: Lessons Learned to Address New Challenges, EMECS 10-MEDCOAST 2013 Joint Conference, 30 Oct - 03 Nov 2013, vol. 2. MEDCOAST Mediterranean Coastal Foundation, Dalyan, Mugla, Turkey, pp. 907e918.

Boudouresque, C.F., Bernard, G., Pergent, G., Shili, A., Verlaque, M., 2009. Regression of Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and stress: a critical review. Bot. Mar. 52, 395e418.

Bouguet, J.Y., 2010. Camera, calibration. Toolbox for matlab. Available online. http://www.vision.caltech.edu/bouguetj/calib_doc/index.html.

Brown, C., Smith, S., Lawton, P., Anderson, J., 2011. Benthic habitat mapping: a review of progress towards improved understanding of the spatial ecology of the seafloor using bacoustic techniques. Estuar. Coast. Shelf Sci. 92 (3), 502e520.

Chabanet, P., Loiseau, N., Join, J.-L., Ponton, D., 2012. VideoSolo, an autonomous video system for high-frequency monitoring of aquatic biota, applied to coral reef fishes in the Glorios Islands (SWIO). J. Exp. Mar. Biol. Ecol. 430e431, 10e16.

Clabaut, P., Augris, C., Pasqualini, V., Pergent, G., Pergent-Martini, C., 2007. Identification et caract_erisation des herbiers _a Posidonia oceanica par sonar a balayage lat_eral : vers une base de donn_ees m_editerran_eenne ? In: Pergent- Martini, C., El Asmi, S., Le Ravallec, C. (Eds.), Proceedings of the 3rd Mediterranean Symposium on Marine Vegetation (Marseilles, France, 27-29 March 2007). RAC/SPA publ., Tunis, pp. 48e55.

Clabaut, P., Augris, C., 2014. Les fonds marins c^otiers de Corse. Cartographie biomorphos _edimentaire. _Ed. Quae. 25 feuilles, _echelle 1/20 000, livret d'accompagnement, 80 pp.

Coggan, R., Populus, J., White, J., Sheehan, K., Fitzpatrick, F., Piel, S., 2007. Review of Standards and Protocols for Seabed Habitat Mapping. Mapping European Seabed Habitats (MESH), p. 210.

De'ath, G., Fabricius, K.E., Sweatman, H., Puotinen, M., 2012. The 27eyear decline of coral cover on the Great Barrier Reef and its causes. Proc. Natl. Acad. Sci. U. S. A. 109 (44), 17995e17999.

Elefteriou, A., McIntyre, A. (Eds.), 2005. Methods for the Study of Marine Benthos, third ed. Blackwell Science Ltd., Oxford, UK, p. 418.

Godet, L., Fournier, J., Toupoint, N., Olivier, F., 2009. Mapping and monitoring intertidal benthic habitats: a review of techniques and a proposal for a new visual methodology for the European coasts. Prog. Phys. Geogr. 33 (3), 378e402.

Gilman, E., 2002. Guidelines for coastal and marine site-planning and examples of planning and management intervention tools. Ocean Coast. Manag. 45, 377e404.

Hamilton, L.J., Parnum, I., 2011. Acoustic seabed segmentation from direct statistical clustering of entire multibeam sonar backscatter curves. Cont. Shelf Res. 31, 138e148.

Holon, F., Mouquet, N., Boissery, P., Bouchoucha, M., Delaruelle, G., Tribot, A.-S., Deter, J., 2015. Fine-scale cartography of human impacts along French Mediterranean coasts: a relevant map for the management of marine ecosystems. PLoS One 10 (8), e0135473.

Kenny, A.J., Cato, I., Desprez, M., Fader, G., SchuÅNttenhelm, R.T.E., Side, J., 2003. An overview of seabed-mapping technologies in the context of marine habitat classification. ICES J. Mar. Sci. 60, 411e418.

Lam, K., Shin, P.K.S., Bradbeer, R., Randall, D., Ku, K.K.K., Hodgson, P., Cheung, S.G., 2006. A comparison of video and point intercept transect methods for monitoring subtropical coral communities. J. Exp. Mar. Biol. Ecol. 333, 115e128.

Lefebvre, A., Thompson, C.E.L., Collins, K.J., Amos, C.L., 2009. Use of a high-resolution profiling sonar and a towed video camera to map a Zostera marina bed, Solent, UK. Estuarine. Coast. Shelf Sci. 82 (2), 323e334.

Leriche, A., Pasqualini, V., Boudouresque, C.F., Bernard, G., Bonhomme, P., Clabaut, P., Denis, J., 2006. Spatial, temporal and structural variations of a Posidonia oceanica seagrass meadow facing human activities. Aquat. Bot. 84, 287e293.

Lirman, D., Gracias, N.R., Gintert, B.E., Gleason, A.C.R., Reid, R.P., Negahdaripour, S. Kramer, P., 2007. Development and application of a video-mosaic survey technology to document the status of coral reef communities. Environ. Monit. Assess. 125 (1e3), 59e73.

Ludvigsen, M., Sortland, B., Johnsen, G., Singh, H., 2007. Applications of georeferenced underwater photo mosaics in marine biology and archaeology. Oceanography 20 (4), 140e149.

Mapping European Seabed Habitats (MESH), 2008. The MESH Blue Book. The Joint Nature Conservation Committee, Peterborough, UK, p. 23.

Pasqualini, V., Clabaut, P., Pergent, G., Benyoussef, L., Pergent-Martini, C., 2000. Contribution of side scan sonar to the management of Mediterranean littoral ecosystems. Int. J. Remote Sens. 21 (2), 367e378.

Pelletier, D., Leleu, K., Mou-Tham, G., Guillemot, N., Chabanet, P., 2011. Comparison of visual census and high definition video transects for monitoring coral reef fish assemblages. Fish. Res. 107, 84e93.

Pelletier, D., Leleu, K., Mallet, D., Mou-Tham, G., Herv_e, G., Boureau, M., Guilpart, N., 2012. Remote high-definition rotating video enables fast spatial survey of marine underwater macrofauna and habitats. PLoS One 7 (2), e30536.

Pergent, G., Pergent-Martini, C., Bein, A., Dedeken, M., Oberti, P., Orsini, A., Santucci, J.F., Short, F., 2015. Dynamic of Posidonia oceanica seagrass meadows in the northwestern Mediterranean: could climate change be to blame? Comptes Rendus Biol. 338 (7), 484e493.

Pergent, G., Monnier, B., Clabaut, P., Gascon, G., Pergent-Martini, C., & Valette-Sansevin, A. (2017). Innovative method for optimizing Side-Scan Sonar mapping: The blind band unveiled. *Estuarine, Coastal and Shelf Science*, 77-83.

Ponti, M., Perlini, R.A., Ventra, V., Grech, D., Abbiati, M., Cerrano, C., 2014. Ecological shifts in Mediterranean coralligenous assemblages related to gorgonian forest loss. PLoS One 9 (7), e102782.

Rende, S.F., Irving, A.D., Bacci, T., Parlagreco, L., Bruno, F., De Filippo, F., Montefalcone, M., Penna, M., Trabucco, B., Di Mento, R., Cicero, A.M., 2015. Advances in micro-cartography: a two-dimensional photo mosaicing technique for seagrass monitoring. Estuarine. Coast. Shelf Sci. 167, 475e486.

Rooper, C.N., 2008. Underwater Video Sleds: Versatile and Cost Effective Tools for Habitat Mapping. Marine Habitat Mapping Technology for Alaska. Alaska Sea Grant College Program. University of Alaska Fairbanks.

Sa~n_e, E., Chiocci, F.L., Basso, D., Martorelli, E., 2016. Environmental factors controlling the distribution of rhodoliths: an integrated study based on seafloor sampling, ROV and side scan sonar data, offshore the W-Pontine Archipelago. Cont. Shelf Res. 129, 10e22.

Smith, C.J., Banks, A.C., Papadopoulou, K.-N., 2007. Improving the quantitative estimation of trawling impacts from sidescan-sonar and underwater-video imagery. ICES J. Mar. Sci. 64, 1692e1701.

Smith, J., O'Brien, P.E., Stark, J.S., Johnstone, G.J., Riddle, M.J., 2015. Integrating multibeam sonar and underwater video data to map benthic habitats in an East Antarctic nearshore environment. Estuarine. Coast. Shelf Sci. 164, 520e536.

Tyne, J., Loneragen, N., Krutzen, M., Allen, S., Bejder, L., 2010. An integrated data management and video system for sampling aquatic benthos. Mar. Freshw. Res. 61 (9), 1023e1028.

van Overmeeren, R., Craeymeersch, J., van Dalfsen, J., Fey, F., van Heteren, S., Meesters, E., 2009. Acoustic habitat and shellfish mapping and monitoring in shallow coastal water e sidescan sonar experiences in The Netherlands. Estuarine. Coast. Shelf Sci. 85, 437e448.

Van Rein, H.B., Brown, C.J., Quinn, R., Breen, J., 2009. A review of sublittoralmonitoring methods in temperate waters: a focus on scale. Underwater technology. Int. J. Soc. Underw. 28 (3), 99e113.

Vela, A., Pasqualini, V., Leoni, V., Djelouli, A., Langar, H., Pergent, G., Pergent- Martini, C., Ferrat, L., Ridha, M., Djabou, H., 2008. Use of SPOT 5 and IKONOS imagery for mapping biocenoses in a Tunisian coastal lagoon (Mediterranean Sea). Estuarine. Coast. Shelf Sci. 79 (4), 591e598.

Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S. Calladine, A., Fourqurean, J.W., Heck Jr., K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T., Williams, S.L., 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc. Natl. Acad. Sci. U. S. A. 106 (30), 12377e12381.