ARTICLE

Identifying potential upper mesophotic coral ecosystems in Masinloc, Zambales, Philippines using recreational-grade side scan sonars

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Recreational-grade side scan sonars (RGSSS) have become available in recent years. They provide high-resolution imagery similar to more expensive models but have limited depth coverage. RGSSS have been used in mapping of benthic communities in rivers and shallow reefs; however, their ability to identify potential upper mesophotic coral ecosystems has not been explored. In this study we use a dual frequency RGSSS operating at 86/455 kHz to generate a bathymetric chart and substrate map showing the distribution of rocky/coraline substrates and loose sediments. Ground truthing utilized drop camera images of the seafloor and limited diver observations. The survey covered a total area of 2.34 km^2 with a depth range of 1.5–117 m. Rocky/coralline substrate covered 0.86 km^2, while loose sediments covered 0.74 km^2; the remaining area is unclassified due to the loss of sound signals at depths greater than 40 m. The accuracy in discriminating hard-bottom habitats from loose sediments is 89% with a kappa coefficient of 0.78, which shows that RGSSS can be used in mapping the upper mesophotic zone (30-40 m). However, the user must be aware of certain limitations such as (1) the lack of a manufacturer-supported georeferencing tool, means that the geometric error of the sonar image may be magnified, and (2) the lack of standard procedures for processing this type of sonar images.

KEYWORDS

mesophotic coral ecosystem, side scan sonar, low-cost, recreational-grade, Masinloc

INTRODUCTION

Mesophotic coral ecosystems (MCEs) are characterized by the presence of light-dependent corals and associated communities found at depths of 30–150 m (Hinderstein et al. 2010). They represent a direct extension of shallow-water reef ecosystems (Kahng et al. 2010) and may serve as refugia for corals and other species during times of environmental stress as well as larval supply for some shallow-water species (Lesser et al. 2009; Hinderstein et al. 2010).

MCEs remain relatively unexplored compared to shallow reefs primarily because they are located at depths beyond recreational scuba diving and thus pose logistical difficulties (Lesser et al. 2009; Kahng et al. 2010; Bridge et al. 2011; Turner et al. 2017).

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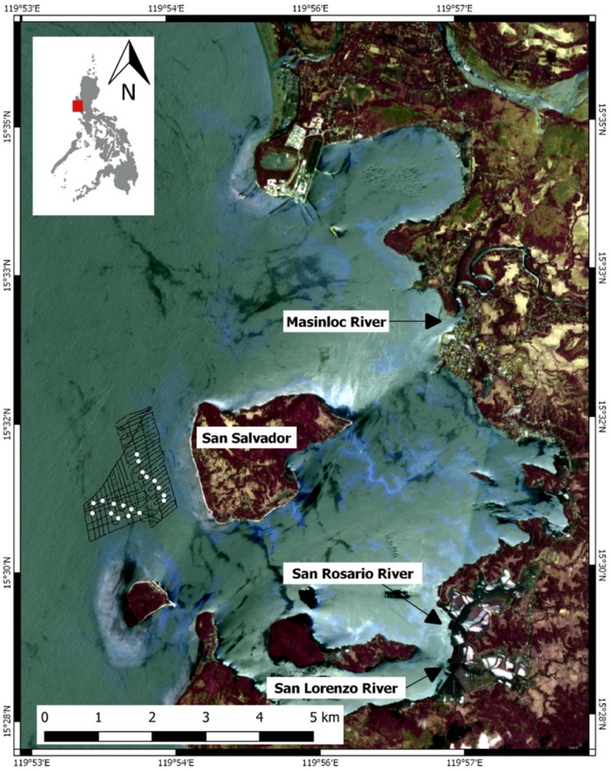

Figure 1: Location map of the study site showing the survey track lines. White dots represent the location of the ground truth points. Base map is a Sentinel 2 image with natural color combination.

Technological advancements in acoustic mapping systems such as multibeam echo-sounder, side scan sonar (SSS), and sub-bottom profilers and the development of submerged mapping platforms such as remotely operated vehicles and autonomous underwater vehicles have made MCEs more accessible (Locker et al. 2010; Bridge et al. 2011; Abbey et al. 2013).

The almost photo-realistic acoustic images produced by SSS make them suitable for identification and interpretation of bed features (Buscombe et al. 2016; Buscombe 2017). SSS work by transmitting a high-frequency acoustic beam from their array of transducers perpendicular to the ship's track and recording the amplitude of the returning echo (Johnson and Helferty 1990; Blondel 2009). SSS became commercially available in the late 1960s (Gonzalez-Socoloske and Olivera-Gomez 2012) and have been used for imaging benthic environments and locating sunken vessels (Kaeser et al. 2012). Traditional SSS systems are expensive ($20,000+) and require a high level of expertise to operate and specialized software for image processing (Kaeser et al. 2012), thereby limiting their use to certain individuals or organizations. Low-cost, recreational-grade side scan sonars (RGSSS) have recently been developed for leisure activities and quickly became popular among aquatic scientists due to their high-resolution imagery available at a cheaper price. Various studies have already been conducted on their use for habitat mapping and object detection (Kaeser and Litts 2010; Flowers and Hightower 2013; Gocolowski et al. 2013; Kingon 2016; Kitchingman et al. 2013; Powers et al. 2013; Froehlich et al. 2015; Buscombe et al. 2016; Cheek et al. 2016; Dunlop et al. 2016; Smit and Kaeser 2016; Kaeser and Litts 2008; Gonzales-Socoloske et al. 2009; Collins et al. 2010; Havens et al. 2010; Bilkovic et al. 2014; Sterret et al. 2015). However, there are no published reports on their use in mapping MCEs. Mesophotic reef research in the Philippines has only recently started and focused primarily on ecology (Cabaitan et al. in press; Abesamis et al. 2018; Quimpo et al. 2018; Nacorda et al 2018). Here we aim to explore the use of RGSSS in mapping the upper MCEs with Masinloc, Zambales, as a case study.

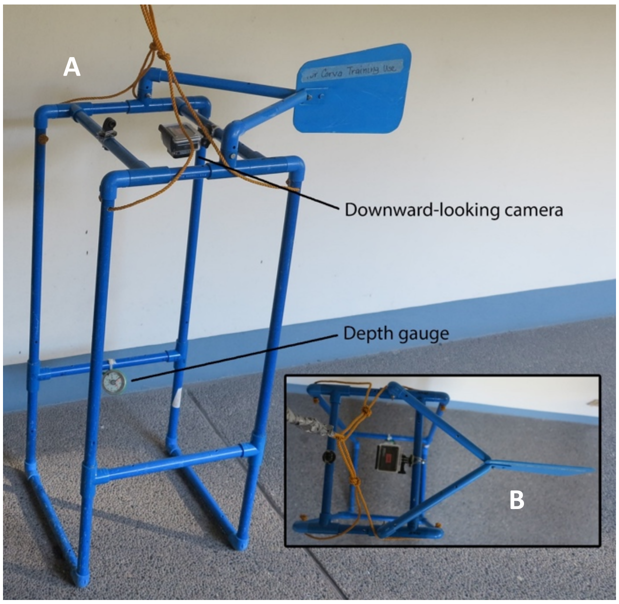

Figure 2: (A) Remotely deployed video system (RDV) with an attached pressure gauge. (B) A housed GoPro camera attached to the RDV framework.

MATERIALS AND METHODS

Study site

Masinloc is located in the province of Zambales situated along the northwestern coast of Luzon (fig. 1). The estimated area covered by coral based on spaceborne remote sensing technique is 1,029 hectares (David 2018, personal communication). The municipality of Masinloc has well-developed reefs in Brgy. San Salvador. They are of fringing type with a vast reef flat with steep drop-offs along the reef crest. Spur and groove formations are also common along the reef crest (Reulegio et al. 2012). The San Salvador coral reef is also in fair condition with an average live coral cover of 27% dominated by *Acropora* (Belen 2013).

Sonar survey

A Humminbird 698 SSS unit with an operating frequency of 86/455 kHz was used to collect single-beam bathymetric data and sonar images of the seafloor on June 27–28, 2017 (fig. 1). The sonar was positioned vertically by using a custom mount at the starboard side of the midportion of the boat and submerged at least 30 cm from the surface or just below the boat's keel. The sonar unit was set to record bathymetric measurements every second. The study site has an approximately 1 m tidal range. Due to the rough sea condition during the survey and the lack of a heave sensor, tide correction was not applied. Track lines were laid perpendicularly to the coast with a spacing of ~80 m with a few tie lines. The side scan survey was done simultaneously with the bathymetric survey, and the range of the SSS was set to 70 m. Boat speed was maintained below 5 kts, and SSS recordings were made only during a straight-line motion.

Map production

A higher-resolution bathymetric chart is important for a meaningful interpretation of the sonar images. Single beam bathymetric readings were extracted from the sonar unit, and false readings such as zero and negative readings were removed. A Hypack 2016 software was used for processing; the triangulation method was used for interpolation.

Raw sonar images are written as .son, which is a proprietary file format for Humminbird. The files were converted to extended triton format by Son2XTF software and processed in the Sidescan Target and Mosaicing function of Hypack 2016. The water column was removed, and time-varying gain was applied

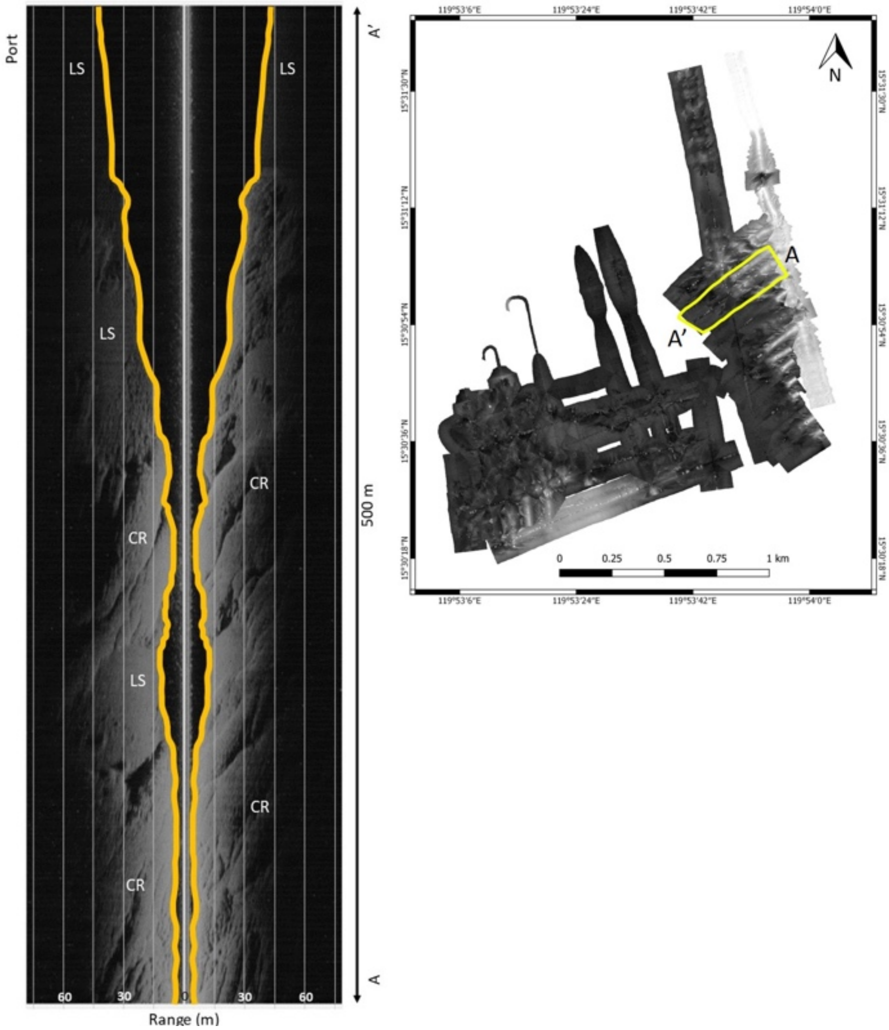

Figure 3: Sample of an interpreted SSS image. Coralline/rocky (CR) substrates appear as bright and rough regions while loose sediments (LS) appear as darker and smooth regions. Yellow line shows the boundary between the water column and the sea floor. The right figure shows the mocaicked SSS image. Yellow box indicates the location of the interpreted image.

to each file. The end-product from Hypack is a slant-range corrected and georeferenced sonar image, hereinafter referred to as sonar image maps (SIMs) (Kaeser and Litts 2010). The resolution of the SIMs was set to 30 cm and loaded into the QGIS software 2.14.22, where the substrate types were visually identified and manually delineated. Humminbird SSS units can produce high-resolution imagery (10 cm); however, no significant difference in terms of image quality was observed when the resolution of the SIMs was set to 10 cm (Kaeser et al. 2012).

Ground truth and benthic survey

Ground truthing was performed on November 28–29, 2017, and the points were selected on the bases of depth and the extent of the SIMs (figs. 1 and 4). A total of 18 points were selected between the 30 m contour and the end of the SIMs. The separation distance between ground truthing points was set to be ~200 m and was set to be away from the delineated substrate boundaries. A customized drop-camera system, hereinafter referred to as a remotely deployed video system (RDV), which utilizes a polyvinyl chloride frame, and a GoPro camera was then used to take photographs of the seafloor (fig. 2). To establish the extent or continuity of coral cover, diver-based data collection was also conducted but was limited only to two sites due to safety consideration. The two dive sites were selected on the basis of seafloor morphology, where ground truth point 7 (GP7) represents a steep seafloor and ground truth point 9 (GP9) a gentler seafloor. Photo-quadrats (1 x 1 m) were taken at every other meter of a 20 m transect line at GP7 and GP9 (fig. 4) and processed in Coral Point Count with Excel extensions (Kohler and Gill 2006). The overall benthic composition (i.e., whether coral or algae dominated) was then determined from the image by using 25 gridded scoring points per image.

RESULTS AND DISCUSSION

The rocky/coralline substrate covered 0.86 km^2, while loose sediments covered 0.74 km^2 of the study area (figs. 3, 4, and 5). These substrates were identified from the SIMs based on backscatter intensity. Rocky/coralline substrates have rough surfaces that are likely to have small facets facing toward the sonar resulting in higher backscatter intensities (Blondel 2009). This implies that this type of substrate appears to be more "textured" because of large variations in adjacent pixel values in the SIMs (Buscombe et al. 2016). By contrast, loose sediments appear as "smooth" surfaces due to similar pixel values. The remaining 0.74 km^2 of the survey area is unclassified due to the loss of sound signals from the SSS at depths greater than 40 m.

Previous studies (Kaeser and Litts 2010; Kaeser et al. 2012; Buscombe et al. 2016; Buscombe 2017) have already demonstrated that RGSSS are effective tools for substrate mapping in fluvial systems. RGSSS can be used also to create valid benthic imagery of nearshore marine habitats up to a depth of 20 m (Kingon 2013). In our study only two substrates were

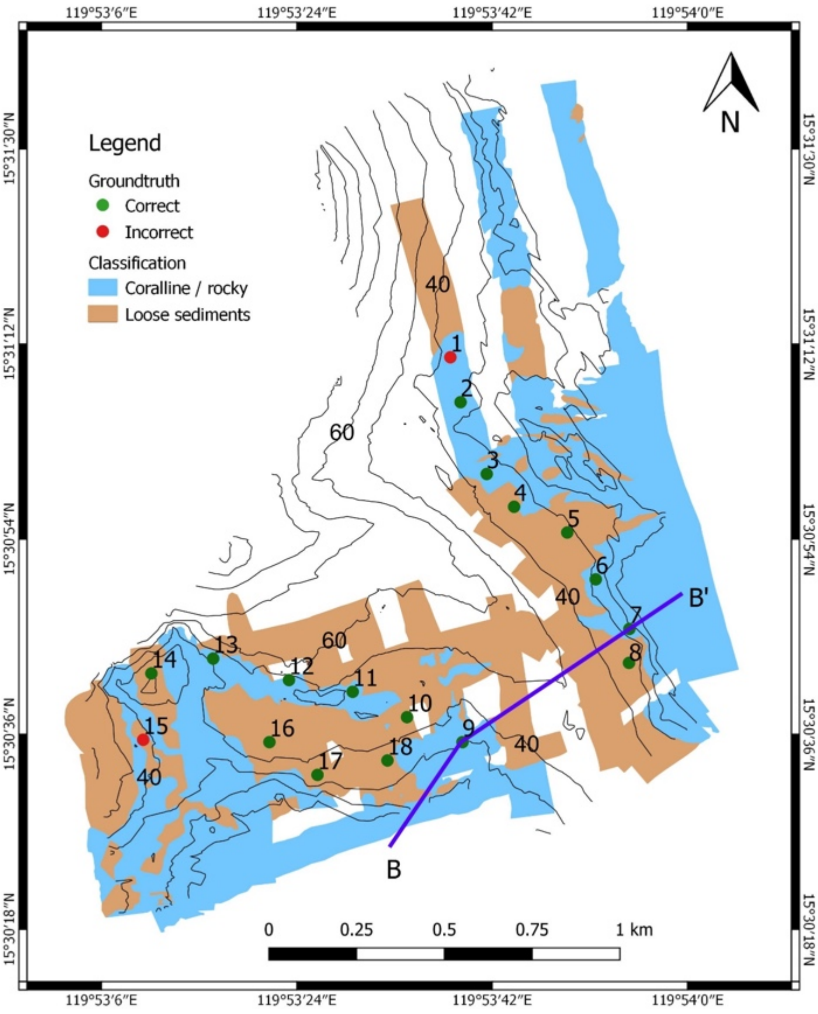

Figure 4: Substrate map generated from the SSS images. Black lines show 10 m contours. Dots show ground truthing points. Green dots show the predicted substrate is the same with the observed substrate; and red shows otherwise. Line B-B' is the location of the cross section in Figure 7.

used in the classification of the sonar images (rocky/coralline and loose sediments) primarily because the areas of interest are hard-bottom habitats. These hard-bottom habitats are inhabited by sessile benthic organisms such as corals, sponges, and algae, which in turn provide additional structure for motile invertebrates and fishes to colonize (Kingon 2013). Thus they are where MCEs are expected to thrive.

The ground truth survey consists of nine points for rocky/coralline substrate and another nine points for loose sediments (fig. 4). Outcropping rocks are easily distinguishable in areas surrounded by loose sediments (Blondel 2009). Discrete boundaries are formed and are traceable throughout the SIMs. Thus the limited number of ground truth points can still adequately determine the accuracy of the map generated. Table 1 represents the classification error matrix resulting from the ground truth points. The overall classification accuracy is 89% and was calculated by dividing the total number of correctly classified substrate by the total number of ground truth points (Lillesand et al. 2015). Both producer's and user's accuracy for both substrates are also 89%. Producer's accuracy represents the map maker's ability to correctly identifying substrates appearing in the SIMs (Kaeser et al. 2012) and was calculated by dividing the number of correctly classified points in each category by the number of ground truth points for that category (Lillesand et al. 2015). By contrast, user's accuracy represents the proportion of classified areas on the map matching those in the field (Kaeser et al. 2012) and was calculated by dividing the total number of correctly classified points in each category by the total number of points classified for that category. The kappa coefficient (κ) was also calculated. It is an indicator of the extent to which the percentage correct values of an error matrix are due to "true" agreement rather than "chance" or "random" agreement (Lillesand et al. 2015). The calculated κ is 0.78, suggesting that the map classification was significantly better than random (Kaeser et al. 2012).

A major source of error in SSS images is that they are subject to geometric error, distortions that lead to inaccurate geographic representation, and this may be amplified by lack of high-quality positioning and boat attitude measurements by RGSSS (Buscombe 2017). There is no manufacturer-supported venue for georeferencing RGSSS, and there are no standard procedures in processing this type of data (Hook 2011), further contributing to the geometric error. Thus the selection of the ground truthing points to be located away from the delineated substrate boundaries was necessary to avoid underestimating the accuracy of the SSS images.

Diver-based depth measurements at GP7 and GP9 were 30 m and 31 m, respectively. Benthic composition of GP7 is dominated by dead scleractinian corals (56.1%) followed by live scleractinian (29.5%), while GP9 is dominated by algae (38.8%) followed by dead scleractinians (25.9%) and live scleractinians (16.0%) (fig. 6). The dominance of algae and lower live coral cover in GP9 might be related to the greater sediment retention potential of the gentler seafloor.

Table 1: Error matrix of the substrate map.

		Reference image			
		CR	LS	Total	User's accuracy (%)
Classified image	CR	8	1	9	89
	LS	1	8	9	89
	Total	9	9	18	
	Producer's accuracy (%)	89	89	Overall accuracy = 89% Kappa coefficient = 0.78	

Figure 5: Representative photos taken by the remotely deployed video system for the substrate classes identified. Left photo shows coralline/rocky substrate while the middle and right photos show the loose sediments.

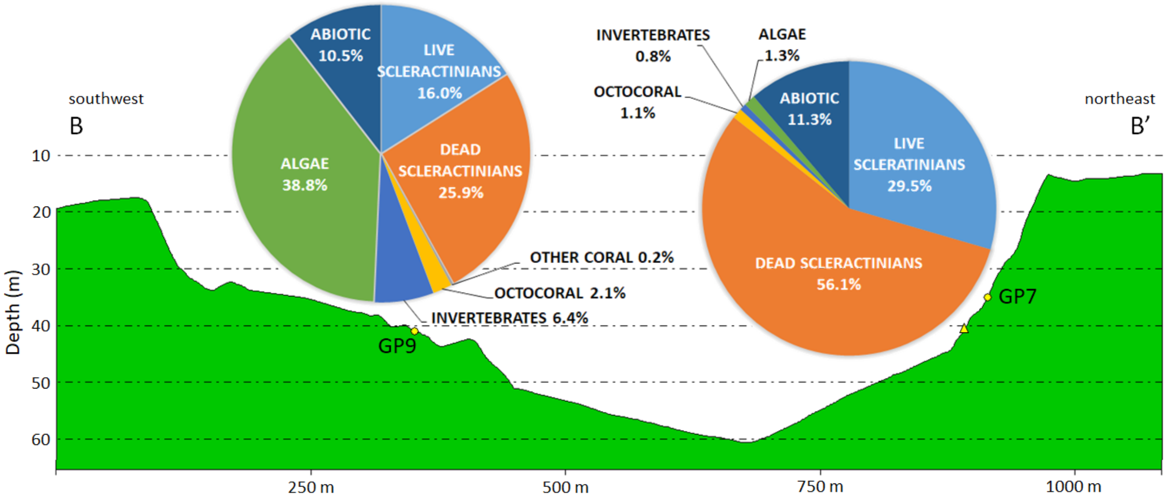

Figure 6: Bathymetric profile along line B-B' in Figure 5 with the overall benthic composition of GP7 and GP9. Yellow circles along the cross section represent the GPS readings for GP7 and GP9 above water. The yellow triangle represents the most likely location of the dive survey conducted in GP7.

CONCLUSIONS AND RECOMMENDATIONS

Low-cost RGSSS are lightweight and portable equipment that provides high-resolution imagery. RGSSS can be used to identify potential upper MCEs with an overall accuracy of 89%. However, the user must be aware of the limitations of the equipment. The images are prone to geometric error especially because there is no standardized procedure in processing the images produced by this type of sonar. Various authors have suggested different ways of georeferencing the image (Kaeser and Litts 2010; Hook 2011; Froehlich et al. 2015; Buscombe et al. 2015; Buscombe 2017). Here we used Hypack 2016 because it allows the user to delineate manually the seafloor instead of relying on algorithms to detect the seafloor boundary. Rocky/coralline substrates can be accurately identified because of their "rough" texture in the sonar image, and they form a distinct traceable boundary between the surrounding loose sendiments.

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CONTRIBUTION OF INDIVIDUAL AUTHORS

PCM Flores performed the sonar survey, processed and analysed the sonar recordings, produced the maps, and wrote majority of the paper. FP Siringan was lead researcher. RL

Albelda wrote the biology part of the methodology, and results and discussion, and performed the analysis of the data collected from the ground truthing data. KTB Go performed the groundtruthing. PC Cabaitan led the research for the biology component research of this study.

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