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Investigating terrain changes around artificial reefs by using a multi-beam echosounder

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Although sidescan may be used for approximate delimitation of the boundaries of artificial reefs, multi-beam echosounding technology provides a superior alternative for obtaining quantitative information on sea-bottom morphology and terrain changes around individual reef units. The accuracy of depth measurements of the system used during our trials was around 0.20 m. This allows a grey-scale or colour-code bathymetric map to be drawn from surveying results to demonstrate scouring and sand ripples around reef units. Horizontal movements and subsidence of individual units may be identified from appropriate cross-sections. We found that terrain changes were highly correlated with the direction of local waves and currents. Average width and depth of scouring around concrete reef units and wrecks were approximately equal to the height and to half the height of each unit, respectively.

Keywords: artificial reefs, grey-scale bathymetric map, multi-beam echosounder, sand ripples, scouring.

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Introduction

For the past 20 years, the Taiwan Fishery Bureau has spent at least six million US dollars annually on the construction and deployment of concrete artificial reefs all around the island with the objective of preserving fishery resources. However, many of these reefs cannot be relocated, because they have subsided or have been partly covered by sand. Typhoons may sometimes move units horizontally. According to International Hydrographic Organization standards, some classes of nautical chart surveys must identify seabed features larger than 1 m^3. The distribution of artificial reefs after deployment therefore has to be investigated and marked on these charts. However, it is impossible to delimit the boundary of artificial reefs with traditional single beam echosoundings and the tow fish required for sidescan sonar is difficult to control. Moreover, interpreting sidescan images demands extensive experience and in practice it is hard to obtain quantitative information on sea bottom morphology and terrain changes around reefs. Shyue (1998) showed that, conversely, multi-beam echosounding (MBES) technology offers the potential of detecting fine-scale distribution of reef units. Shallow-water MBES has also been used in nautical chart surveying (Mol, 1994; Reed *et al.*, 1994; Huff *et al.*, 1996; Miller *et al.*, 1996), in pipeline-routing surveys (Hansen and Simonis, 1994; Clasper, 1996), in monitoring seabed morphology and composition (Cauwenberghe, 1996; Kammerer *et al.*, 1998), and in searching for sunken aircraft.

Scouring may be a major reason for reefs subsiding. Investigating scouring around a ship reef, Baynes and Szmant (1989) measured the heights from seabed to deck of the bow, stern, and amidships manually. However, this method provides limited information about spatial differences and is unsuitable for use in turbid waters; MBES therefore offers a better choice. In exploring changes in reef status, bathymetric surveys should be carried out continually. We endeavour to demonstrate horizontal movements of reef units based on two surveys undertaken approximately 4 months apart. Because sand transport can cause artificial reefs to lose their function by blanketing, we also investigate statistical characteristics of scouring and sand transport, and discuss local terrain changes around ship reefs in relation to wave and current regimes.

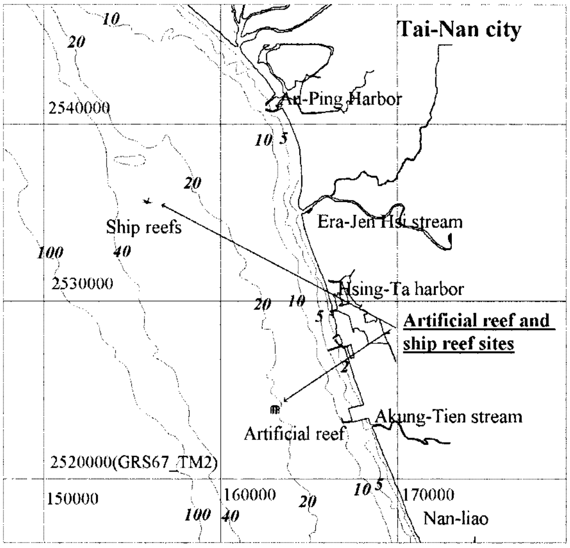

Figure 1. Map of the experimental sites for surveying concrete artificial reef units and ship reefs.

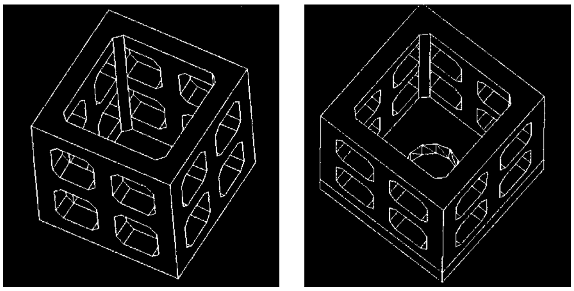

Figure 2. Schematic representation of the two types of concrete reef units deployed in the survey area.

Methods

MBES instantaneously collects multiple depth information. Each beam has a certain width and therefore its incident surface area on the sea bottom, or footprint, is a circle or ellipse, depending on its angle. If the beam is directly beneath the transducer, the footprint is a circle. Beam width multiplied by number of beams is the total beam angle. Swath width is a function of beam angle and water depth.

The system used was a Reson 9001, which has a total of 60 beams with a 1.5° beam width (beam angle 90°) and a swath width that is twice the water depth. The footprint will be approximately 0.45–0.80 m. According to the manual, 6.86 profiles are obtained per second when output baud rate is set to 9600. If vessel speed is maintained at 3 knots ($1.5\,\mathrm{m\ s^{-1}}$), a profile can be obtained every 0.22 m.

To compensate for ship motion and heading, a TSS DMS-05 motion sensor and a Sperry SR-180 gyrocompass were used. Ashtech Z-12 GPS receivers with sub-meter DGPS positioning accuracy were used. Reson 6042 software and hardware system and Hypack software were used for data collection and navigation. Offsets between sensors were directly measured from the vessel. Angular misalignment among transducer, motion sensor, and gyrocompass, together with latency, was calibrated by a patch test at sea. Sound speed profile measurement was done by SV plus a sound velocimeter from Applied Micro-system Ltd. After correcting for tide, sound velocity, ship motion, offsets, misalignment, and latency, 3-D sounding coordinates (north, east, water depth) were obtained. The depth of grid nodes was calculated using an interpolation algorithm from neighbouring soundings. A grey-scale or colour-code bathymetric map was then drawn.

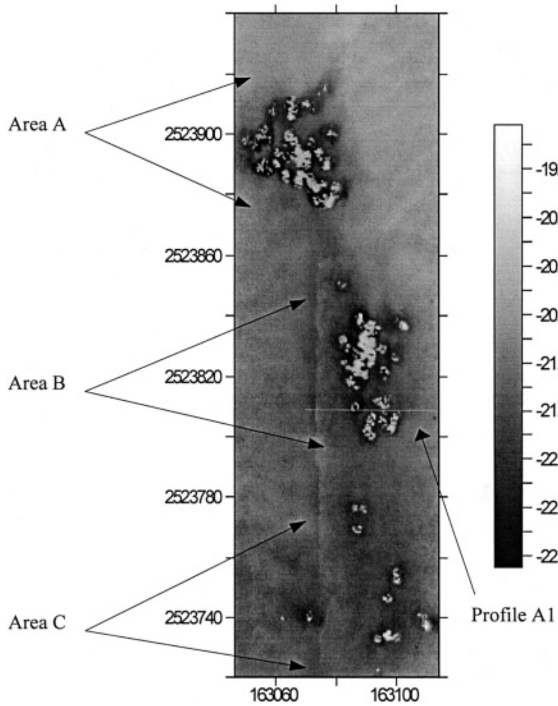

Figure 3. Grey-scale bathymetric map of the area where concrete reef units (light spots) had been deployed. Darker areas indicate scouring effects.

Two types of concrete artificial reef units were deployed at around 20 m depth off the coast of Kaohsiung County in November 1996 (Figure 1). The local seabed is flat with coarse sand and gravel. Both reefs were double layered ($2 \times 2 \times 2$ m) cubes with a total of 16 openings (0.61×0.61 m) in the 0.26 m thick vertical walls and open at the top. One type was also open at the bottom while the other type had a concrete bottom (total cube was $2 \times 2 \times 2.3$ m) with a circular hole of 0.7 m diameter (Figure 2).

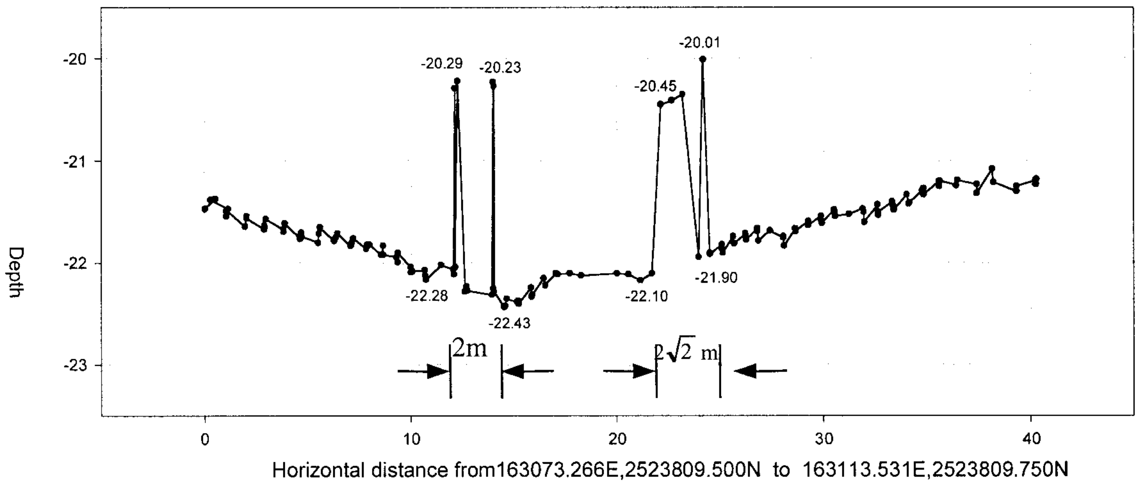

Figure 4. Depth profile along A1 (cf. Figure 2).

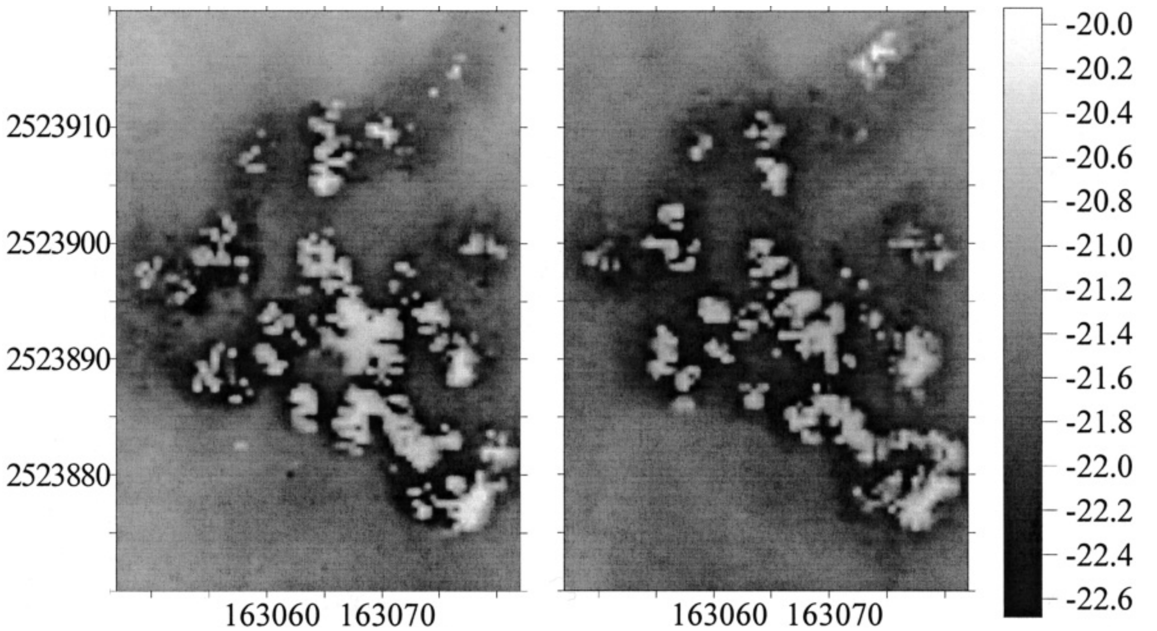

Figure 5. Bathymetric maps of Area A (cf. Figure 2) on 1 September 1998 (left) and on 23 December 1998 (right), before and after typhoon BABS passed through the area, respectively.

Two survey data sets were collected on 1 September 1998 and 23 December 1998, before and after typhoon BABS (maximum windspeed of 35 m s^{-1}) passed the Taiwan Strait, where the reefs were located, on 27 October 1998. To obtain detailed depth information, vessel speed was restricted to 2–4 knots and the distance between two neighbouring survey lines was set to 20 m for 200% coverage. The footprint was around 0.5 m. The results show that reef units were clustered into three areas: A, B, and C in Figure 3.

According to oceanographic observation records at 15 m depth near the reef area in autumn 1997, maximum current speed was 90.3 cm s^{-1}, with an azimuth of 179° (C-c. Shern, pers. comm.). Average speed of the rest current was 10.3 cm s^{-1}, with an azimuth of 135°, while average absolute current speed was 35.7 cm s^{-1}. Tidal current directions were parallel to the coast (NNW and SSE during flood and ebb, respectively). Eighty-nine percent of wave heights were in the range 20–60 cm, wave period was around 6–8 s, and predominant major wave direction was from the north.

MBES was also used to map ship reefs off the Tainan coast (Figure 1) at a depth of approximately 30 m (footprint around 0.7 m).

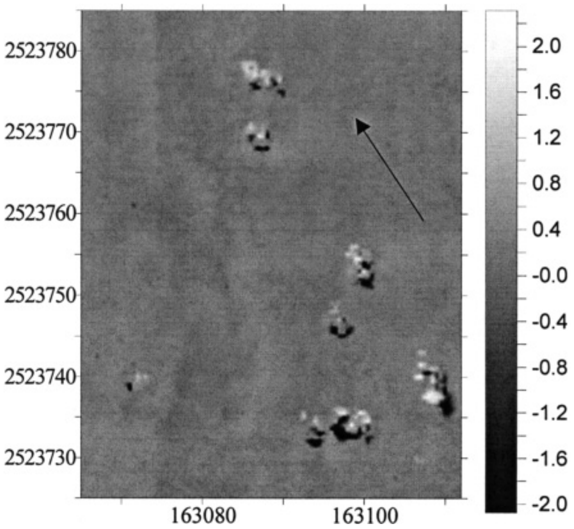

Figure 6. Bathymetric difference map of area C (cf. Figure 2) based on data collected during the two surveys. Arrow indicates direction of movement of individual units.

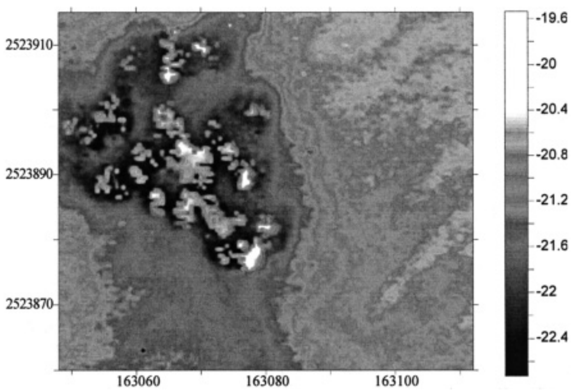

Figure 7. Bathymetric map of sand ripples around area A (cf. Figure 2).

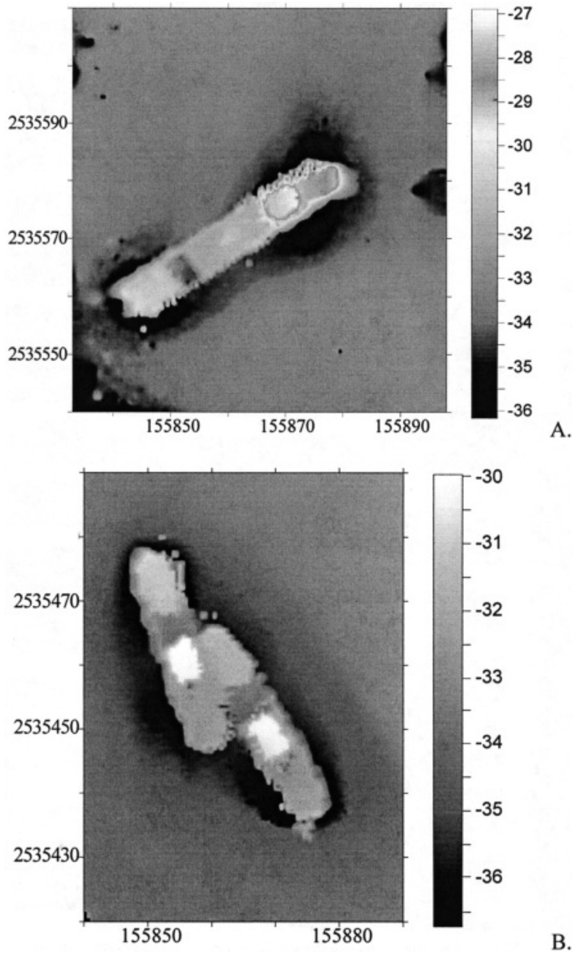

Figure 8. Bathymetric map of (A) one ship reef perpendicular and (B) two ship reefs parallel to the predominant current direction.

Table 1. Characteristics of gullies caused by scouring around concrete and ship reef units.

Type	Width (m) Range	Width (m) Average	Depth (m) Range	Depth (m) Average
Concrete	1.8–9.6	2.4	0.6–1.6	1.1
Ship	2.8–8.6	4.1	1.2–2.1	1.8

Results

The grey-scale bathymetric map of the concrete reef area depicts units in white with a black centre indicating the open top. Black areas around the units indicate scouring. Depth profile A1 passing through area B (Figure 3) identifies two units based on the horizontal distance between the bottom projections of the two objects seen (2 m and 2.2 m, respectively) and their height of approximately 2 m (Figure 4). In this way, the position of all units can be identified. The amount of subsidence experienced by a unit may be calculated by comparing profiles for September and December. However, the accuracy of MBES depth measurements must be taken into account. A cross-check survey indicated that the accuracy was around 0.2 m. Accordingly, subsidence of a unit may not be detectable if the depth difference between two profiles taken at different times is <0.2 m. Given this potential error, profile maps may still help to identify location, orientation, and amount of subsidence of individual units (Figure 5). Scouring was more pronounced after the typhoon had passed and the northern part of the reef area had become deeper by about 40–60 cm. The bathymetric difference map of area C between the two surveys (Figure 6) suggests that reef units have moved 2–3 m in a NW direction. Taking into account the positioning error of about 1 m for the DGPS used, the horizontal movement based on this bathymetric difference map appears significant. The direction of sand ripples around the reefs (Figure 7) was approximately parallel to the direction of current. Based on cross-sections perpendicular to the direction of the sand ripples, their width and height were 3.6 m and 0.24 m, respectively.

Of the ship reefs mapped, one was lying perpendicularly, while the other two lay parallel to the direction of the local current (Figure 8). Scouring was more pronounced at the bow and stern of the former than amidships [Figure 8(A)]. However, scouring around the two ships lying parallel to the current was much more widespread and pronounced [Figure 8(B)].

Discussion

These results show that MBES can be used efficiently not only to delimit the extent of artificial reefs, but also to locate individual units and to measure such aspects as orientation, horizontal movement, and subsidence. However, positioning accuracy and depth-measurement accuracy must be taken into account. The estimated horizontal movement of individual concrete reef units in this trial was about 2–3 m, which is well in excess of DGPS accuracy of 1 m. If smaller horizontal movements need to be identified, real-time kinematic (RTK) GPS technology may provide 10–20 cm positioning accuracy. The estimated depth-measurement accuracy of the MBES system used was approximately 0.2 m, which should suffice to confirm significant scouring around objects of the size deployed. However, multiple concrete reef units deployed closely together could not be distinguished from each other at this stage of the trials. Overlaying multiple surveys carried out at short temporal intervals might resolve this problem.

Bathymetric maps are useful for demonstrating width and height of scouring effects and of sand ripples around different types of reefs. Average width of the gullies around concrete and ship units was approximately equal to their height, whereas average depth was approximately equal to half the height of the units (Table 1). By overlaying two bathymetric maps and calculating difference maps, temporal terrain changes around reefs may be obtained in relation to predominant hydrographic features. Our results show that the direction of the sand ripples was approximately parallel to the direction of the main current.

MBES can also provide good information on shape, size, and orientation of ships on the seabed in relation to effects of scouring. It appears that ships placed perpendicular to the current experience less scouring overall, even though deep gullies may be formed at the bow and stern, as has also been observed by Baynes and Szmant (1989). This suggests that ship reefs are better deployed perpendicularly to the direction of the current to prevent excessive scouring and subsequent burial.

Acknowledgement

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