IDENTIFICATION OF SEAFLOOR HABITATS IN COASTAL SHELF WATERS USING A MULTIBEAM ECHOSOUNDER

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Abstract

Modern, high-resolution multibeam sonar systems are capable of mapping acoustic backscattering strength coinciding with fine bathymetry, which improves substantially the capability of sonars to discriminate different types of seafloor habitats. As part of the Coastal Water Habitat Mapping project of the CRC for Coastal Zone, Estuary and Waterway Management, a set of bathymetry and acoustic backscattering data has been collected in different regions of the Australian coastal shelf in 2003-2004, using a state-of-the-art, 450-kHz RESON SeaBat 8125 multibeam echosounder. The surveyed sites included a sediment dominant area of Sydney harbour and regions of seagrass and sand found in the Recherche Archipelago. The analysis results show that the seafloor can be characterized by specific angular dependence of acoustic backscattering and statistical distribution of the backscattering energy, however, caution is needed when using these methods for habitat mapping. Preliminary conclusions are made in the paper with regard to the efficiency and adequacy of seafloor habitat mapping using high-resolution multibeam sonar systems.

Introduction

Multibeam sonar systems (MBSS) have rapidly evolved over the last few decades, and are currently the most advanced and efficient tool for remote observations and characterization of the seafloor [1]. In addition to high-resolution bathymetry, MBSS can also provide valuable information about seafloor properties [2-4]. These properties can be used to help classify the seafloor into different habitat types [5-8]. Most of the seafloor classification techniques developed for MBSS are based on analysis of bathymetry and/or backscatter data. As part of the Coastal Water Habitat Mapping (CWHM) project of the Coastal CRC, a set of bathymetry and acoustic backscattering data has been collected in different regions of the Australian coastal shelf in 2003-2004, using a state-of-the-art, 455-kHz RESON SeaBat 8125 multibeam echosounder. The data is being used in the investigation of the important seafloor properties that can be obtained from MBSS for seafloor classification. This paper summarises the techniques used so far and presents the preliminary results and conclusions.

Seafloor classification by MBSS

Detailed analysis of the backscatter signals from multibeam systems is the subject of current international research and development activities. These studies are aimed at obtaining more information about seafloor properties and benthic habitats from acoustic data. Although several researchers and other programs have focused on the practical implementation of MBSS, few discussions exist regarding the suitable methodologies to classify data from MBSS. Of the various techniques that have been used to classify MBSS data, they can be broadly categorised into one of four methodologies:

1. Textural analysis [9]
2. Angular dependence of acoustic backscatter [10]
3. Power spectral analysis of echo amplitudes [11]
4. Echo peak probability density function (PDF) analysis [12]

Textural analysis and angular dependence of acoustic backscatter are the most widely used and developed techniques, and, so far, have been the focus of this study. A brief explanation of these methodologies is now given.

Textural analysis

Textural analysis is widely used in processing MBSS data for classification since the methods are similar to those that have been utilized previously in the processing of side-scan sonar images. In the simplest case, a human operator examines an image of acoustic backscatter amplitude for patterns and subjectively segments the seafloor based on these patterns and ground truth data [2, 3]. Automation of this procedure could provide more objectivity and reproducible map products. There are various 2D spatial statistics that can be employed to do this. The most common analysis is based on determination of statistical features of the so-called grey-level co-occurrence matrices (GLCM) [9]. However, this study's initial objective is to determine the important seafloor properties that could be used for classification before employing automatic procedures.

Before performing texture analysis, the backscatter data is usually corrected for the angular dependence of acoustic backscattering and for inequality of the MBSS sensitivity at different angles of incidence. An improper correction of the backscatter angular dependence may produce large errors in the estimates of the basic statistic characteristics, such as mean intensity, standard deviation, and higher-order moments, derived from backscatter images. The simplest model of well-known Lambert's Law is frequently applied for the angular compensation of backscatter intensity [13]. However, this model is not accurate enough for many classes of seafloor cover, especially at near-nadir (steep incidence) angles. Hellequin *et al.* [14] employed a simple composite model that treated the angular dependence of backscattering using the tangent plane (Kirchhoff) high-frequency approximation for near-nadir incidence angles and a Lambert-like term dominating at larger incidence angles:

$$BS(\theta) = 10\text{Log}[A\exp(-\alpha\theta^2) + B\cos^{\beta}\theta] \quad (1)$$

Where, BS is the backscattering strength and θ is the angle of incidence. The coefficients A, B, α, and β are estimated by least-mean-square fitting of the model function to the average angular dependence of backscatter intensity observed across representative (or training) areas. However, this model is not sufficient to fully correct for angular dependence of backscatter strength.

Angular dependence of acoustic backscatter

The angular dependence of backscattering strength is an important characteristic that distinguishes different types of the seafloor cover. So instead of removing angular information in MBSS data, as done in texture analysis, another approach in seafloor classification is to utilise this information [10]. In practice, though, it is difficult to define replicas of the angular dependence for every type of the seafloor and classify the bottom surface by searching for the best-fit replica for the measured backscatter data. Therefore, the whole angular range is usually divided into a small number of specific domains according to the physical peculiarities of acoustic scattering at different angles.

The bottom backscattering model formulated by Jackson *et al.* [15] distinguishes three domains. At near vertical incidence, backscattering from large smooth roughness dominates the volume scattering and backscattering from small-scale roughness. The tangent plane (Kirchhoff) approximation is an appropriate approach to modelling the angular dependence within this domain. At moderate incidence angles, Bragg scattering from small-scale roughness and volume inhomogeneities is the primary mechanism that can be modelled using a composite model approach based on the small-perturbation approximation. At small grazing angles below the critical angle, the volume scattering becomes negligible, which reduces the backscatter intensity especially at lower frequencies. Jackson's model gives reasonable numerical estimates of the backscattering coefficient for certain types of the seafloor cover, such as silt, sand, gravel, and some others, at not too high frequencies of tens of kHz.

Modern high-resolution MBSS operate at higher frequencies of hundreds of kHz, at which the wavelength of transmitted signals becomes comparable with or even smaller than the typical dimension of the seafloor roughness. The operational frequency of SeaBat 8125 is 455kHz and hence the wavelength is about 3 mm, which is much less than the roughness scale of gravel, rocks, and seagrass. In that case, Jackson's model is not correct at large and moderate angles of incidence.

The most comprehensive procedure of angular dependence classification involves determination of the domain boundaries and calculation of certain characteristic values, such as the mean backscatter intensity, angular dependence slopes and second derivatives, within each domain. Figure 1 gives an example of angular dependence classification with 10 selected characteristics. In practice, though, some of the angular dependence parameters are not robust enough for adequate recognition of the seafloor type and therefore only a few parameters are used for seafloor classification, which usually are the main backscatter intensities measured within certain angular intervals belonging to different domains.

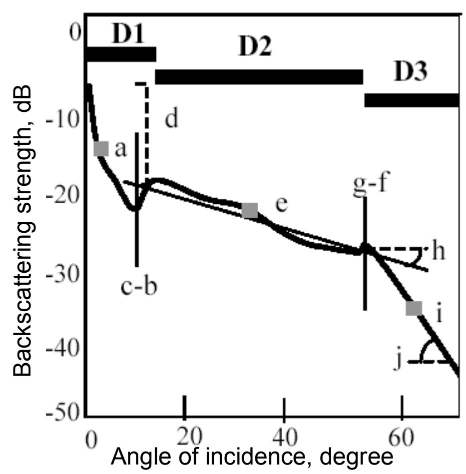

Figure 1. Three main domains (D1, D2, D3) of angular response curves and the parameters extracted to describe each domain (from [15]). Parameters estimated: **a** - mean BS intensity for **D1** ($0\text{-}10^0$); **b** - 2-d derivative at **c**; **c** - location of boundary **D1-D2**; **d** - dB range of **D1**; **e** - mean BS intensity for **D2** ($15\text{-}50^0$); **f** - 2-d derivative of **g**; **g** - location of boundary **D2-D3**; **h** - slope **D2**; **i** - mean BS intensity for **D3** ($55\text{-}70^0$); **j** - slope **D3**.

Coastal Water Habitat Mapping (CWHM) Project

The work presented here is part of the CWHM Project, which is an initiative of the Coastal CRC. The three-year multi-million dollar project will develop and apply technologies for rapid and cost effective assessment of shallow water marine habitats around Australia and overseas. The project is a joint venture between scientists, universities, government agencies and private enterprise, and constitutes an extension to the

Coastal CRC. At present, it is the largest single program of shallow water benthic habitat mapping in Australia. Together with the Coastal CRC's established capacity in ecosystem health monitoring, science for coastal planning and community engagement, it will establish benchmarks in shallow water habitat mapping, a field of growing focus in Australia.

Method

Study areas

The work presented here comes from data collected from the Sow and Pigs area in Sydney harbour in New South Wales, and in the Recherche Archipelago off Esperance in Western Australia. The seabed type in Sow and Pigs area in Sydney harbour is mainly mud and muddy sand with shell debris found near the reef in the centre. Whereas, the seabed habitat in Recherche Archipelago is much more variable and includes, among others, sand, seagrass, rhodolith, reef and soft coral.

Data collection and processing

Multibeam bathymetric and backscatter data was collected in Sydney harbour between 30 July – 4 August 2003, and in the Recherche Archipelago between 29 October – 6 November 2003 using a RESON SeaBat 8125. Specifications of the SeaBat 8125 sonar system are given in Table 1, and the settings selected for the surveys in Sydney harbour and the Recherche Archipelago are given Table 2.

Table 1. RESON SeaBat 8125 Sonar Specifications

Operating Frequency	455 kHz
Swath Coverage	120º (3.5 X Water Depth)
Beam Width, Along Track	1.0º
Beam Width, Across Track	0.5º (at Nadir)
Number of Horizontal Beams	240
Range Resolution	1.0 cm
Maximum Ping (update) rate	40 pings s^{-1}

Table 2. RESON SeaBat 8125 settings used for surveys of Sydney harbour and the Recherche Archipelago

Setting	***Sydney***	***Recherche***
Ping rate	20.6 pings s^{-1}*	11.6 pings s^{-1}*
Transmit power	6*	9*
Pulse length	46 µs	51 µs
Receiver gain	26	9
Gain mode	TVG	TVG
Auto gain	off	off

* Subject to changes in depth.

In Sydney the sonar head was mounted on the bow, whereas, in the Recherche Archipelago the sonar head was installed underneath on the vessel. Estimates of the surface backscatter coefficient (as defined by Medwin and Clay [17]) were calculated from the snippet data and corrected for spreading loss, absorption loss and footprint size. Multibeam data was ground-truthed using grab samples in Sydney harbour and by direct observation in the Recherche Archipelago. Data from Sydney harbour was prepared also for the Shallow Survey Conference ’03 as common dataset.

Results

Recherche Archipelago

The results obtained from Recherche Archipelago highlight the potential for using Multibeam systems to characterise the seafloor. Figure 2 shows a swath from a single line with backscatter intensity (corrected for the angular dependence off-nadir using Lambert-like law) draped over the 3-D bathymetric map of a sloped seabed area off the Recherche Archipelago. Seagrass patches, identified from direct observations, are clearly seen at the upper section of the slope characterised by a high backscatter strength. Whereas, the sand at the bottom of the slope produces a substantially weaker backscatter signal. However, problems with processing multibeam data are also shown here, for example, the slightly brighter band in the middle of the track is due to stronger backscattering at near-vertical angles of incidence due to inadequate angular correction.

The distinct difference in acoustic properties between sand and seagrass habitats is confirmed further in Figure 3, which shows the angular dependence of the backscatter strength for sand and seagrass found in the Recherche Archipelago. It is evident that sand shows the classic angular dependence curve with backscatter decreasing rapidly with the increase of incidence angle [18]. Whereas, the seafloor roughness structure created by seagrass causes almost isotropic backscattering that remains relatively uniform as incident angle increases.

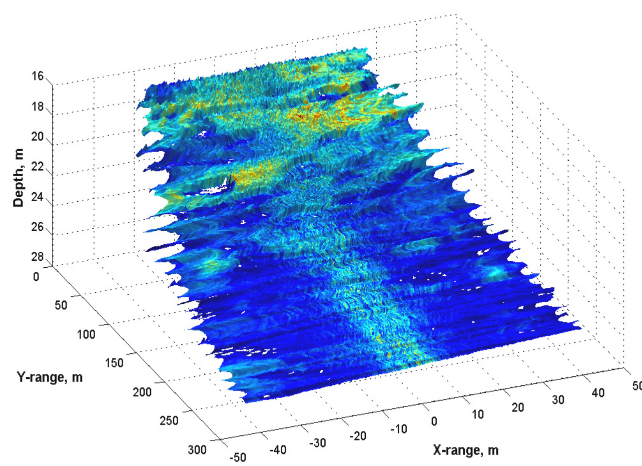

Figure 2. Backscatter intensity draped over the 3-D bathymetric map as recorded from a single swath of multibeam sonar taken in the Recherche Archipelago.

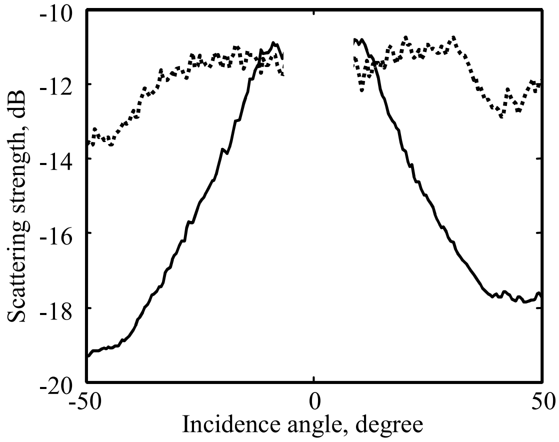

Figure 3. Backscattering strength against incident angle for sand (solid line) and seagrass (dashed line) taken from multibeam sonar data collected in the Recherche Archipelago. The values within $\pm 7^0$ around nadir were not measured due to initial longitudinal tilt in the deployment of the sonar head.

Sydney harbour

The results obtained from Sydney harbour demonstrate some of the problems with using multibeam systems to map benthic habitats. Figures 4, 5 and 6 show three different swathes recorded in Sydney harbour with backscatter intensity (not corrected for angular dependence) draped over the 3-D bathymetric map; and, respective plots of their angular dependence of backscatter derived for the first and last third parts of the swath. Grab samples taken (shown as the white dots) identify all the areas shown here as muddy sand. It is well established that the backscatter strength for this sediment type will sharply decrease with incident angle [18]. The angular dependence of backscatter strength measured over a patch of muddy sand (shown in Fig.4a) is steep, as expected (Fig.4b), even though the seafloor surface is not smooth. However, Figure 5 shows a significantly less sharp drop in backscattering strength with the angle increase measured over a different patch of the similar sediment type. This variation in angular dependence is shown in mid swath in Figure 6.

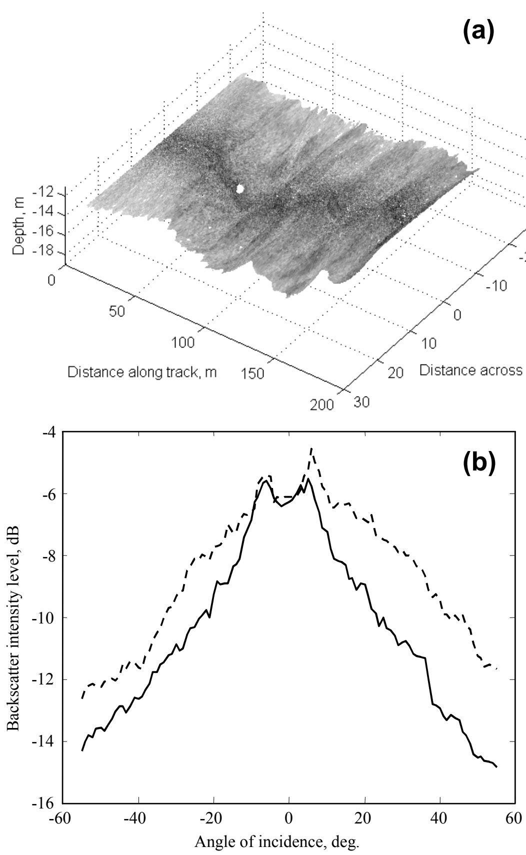

Figure 4. Backscatter intensity recorded from a single swath in Sydney harbour (a) draped over the 3-D bathymetric map with the white dot indicating the grab sample; (b) plotted against angle of incidence, solid lines represent first third and dashed line represent last third of the track.

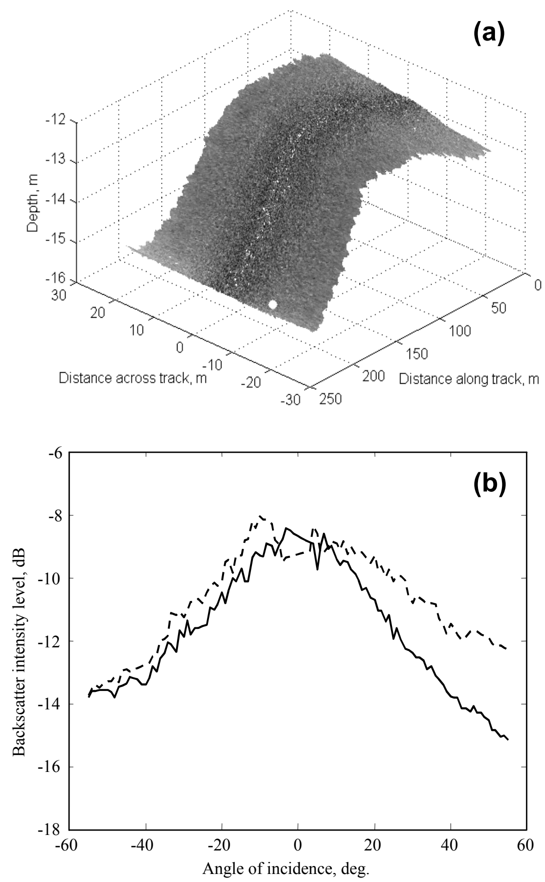

Figure 5. Backscatter intensity recorded from a single swath in Sydney harbour (a) draped over the 3-D bathymetric map with the white dot indicating the grab sample; (b) plotted against angle of incidence, solid lines represent first third and dashed line represent last third of the track.

The examples given in Figs 4, 5, and 6 demonstrate that grab samples taken sparsely over the surveyed area may not identify the actual properties of the seafloor and their spatial variation. At this time, it is unclear whether these grab samples do not account for certain important properties of sediments, such as gas content in the near-surface layer, or the sampling separation is too large for tracking spatial change in the seafloor properties. In the case of Figure 6 it is very likely that there is actually a change of seafloor type that falls between ground truth samples. Unless these differences can be accounted for and understood, adequate interpretation of measured angular dependence with regard to seafloor types is problematic, which limits the use of angular dependence in seafloor classification.

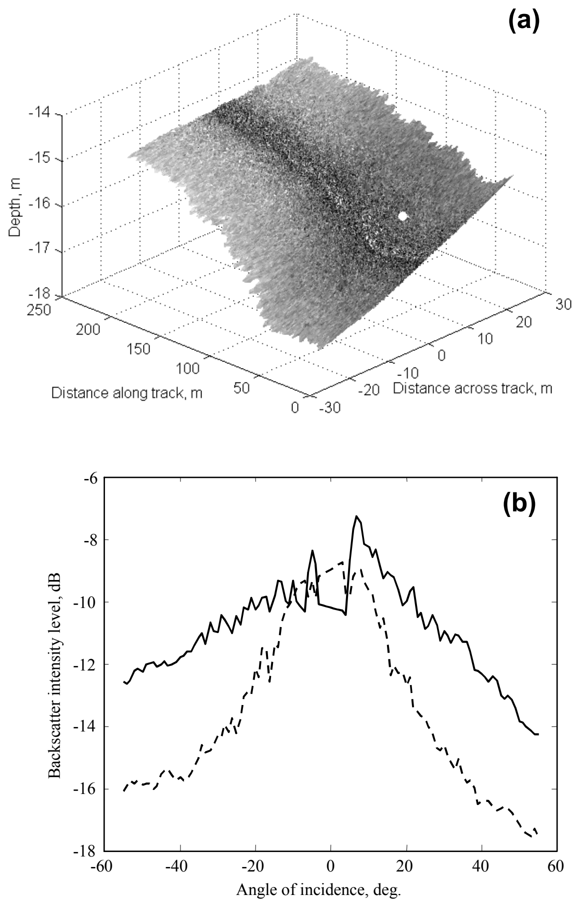

Figure 6. Backscatter intensity recorded from a single swath in Sydney harbour (a) draped over the 3-D bathymetric map with the white dot indicating the grab sample; (b) plotted against angle of incidence, solid lines represent first third and dashed line represent last third of the track.

Conclusions

Preliminary results are promising and suggest multibeam systems can be effective for mapping seafloor characteristics, but more work needs to be done. It appeared that some of the approaches to MBSS seafloor classification developed earlier for older systems could not be utilised or should be substantially modified for modern systems operating at very high frequencies. Problems with methods used here include:

- Correcting for angular dependence of backscatter intensity for building backscatter imagery of large, "multi-swath" areas is still not resolved.
- Accurate measurements of the angular dependence of backscatter require a well calibrated multibeam sonar.
- Problems in heterogeneous areas, i.e. how to determine the averaging interval in both along and across track directions?
- Identifying the important seafloor properties that can be obtained from MBSS for seafloor classification. For instance, topographic derivatives, such as bottom roughness, which are not angular dependent, may prove more robust than backscatter strength in habitat mapping.

These issues as well as other methods used to classify MBSS data (as mentioned previously) will be investigated further. The CWHM project aims to establish the optimal approach to utilising high-resolution MBSS in benthic habitat mapping. Although more work is required, the initial results confirm that MBSS offers the greatest potential in characterising and mapping the seafloor. Through further understanding of the operation of the MBSS and the physics of acoustic scattering from the seafloor at high frequencies this potential can be realised in much more efficient way.

Acknowledgements

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