



Cooperative Research Centre for Coastal Zone, Estuary & Waterway Management

Technical Report 86



Photo: Gary Kendrick, University of Western Australia

Overview of coastal water habitat mapping research for the Coastal CRC

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Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management

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Synthesis of research outputs from Sydney Harbour, Cockburn Sound, Recherché, Moreton Bay and Fitzroy Estuary/Keppel Bay sites

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1 Introduction

This technical report summarises results of research conducted within the Coastal Water Habitat Mapping (CWHM) project of the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management. This research aimed to develop acoustic techniques for the discrimination and mapping of seafloor habitats in coastal zones using the acoustic (echo sounder) and ground-truthing (video observations and grab/core samples of sediments) data collected in a number of areas on the coastal shelf around Australia. The study was based primarily on multibeam sonar observation of the seafloor using a Reson Seabat 8125 240-beam echo sounder. In most survey areas, multibeam sonar observation of the seafloor was accompanied by acoustic measurements with a single-beam Simrad EQ-60 echo sounder.

The principal objective of this study was to develop cost-effective and robust techniques for fast, large-scale assessment of the seafloor cover in coastal shelf zones and for classification and mapping of seafloor habitats. The methods developed for habitat discriminations were based on utilising high-resolution bathymetry and seafloor acoustic backscatter intensity that can be collected concurrently using modern high-frequency multibeam sonar systems. The research focus was to establish bathymetry (seafloor terrain) and acoustic backscatter characteristics and/or their combinations, which would be robust enough for discrimination of different seafloor habitats typical of Australian coastal waters.

While methods for processing bathymetry data collected with multibeam systems and terrain analysis for seafloor classification are well established, processing and interpretation of backscatter data obtained from high-frequency systems encounters specific problems that must be solved to enhance the capability of multibeam data analysis to acoustically characterise and map seafloor habitats.

Those problems comprise two issues: (1) difficulties arising from the technical and operational complexity of such systems, such as complex dependence of system characteristics affecting backscatter measurements through the system configurations, settings and environmental conditions; and (2) problems of physical interpretation of stochastic backscatter intensity data collected at high frequencies at different angles of incidence on the seafloor. The latter includes the angular dependence of backscatter intensity, which influences not only the mean values (first-order statistical moment) but also the higher statistical moments and shape of the probability density function (PDF) from returns across track. Hence, knowing statistical characteristics of seafloor acoustic backscatter

at different angles of incidence for different types of seafloor cover is essential for the discrimination of seafloor habitats and the accurate tracing of boundaries between them.

The problems mentioned above apply for every coastal zone area surveyed with the multibeam system in the CWHM project, and therefore the common principal research objective for each investigated area was to develop techniques for building acoustic backscatter imagery of the seafloor that would be independent of the experimental design (i.e. system settings, arrangement of swath tracks, sea depth, etc.) and independent of the angle at which seafloor acoustic backscatter was measured. At the same time, the angular dependence is one of the fundamental backscatter characteristics that portray roughness and acoustic impedance of the seafloor surface. Hence it was essential to retrieve the angular characteristics from backscatter data and use them, along with the angular corrected backscatter imagery, for seafloor classification and mapping. Results of the research conducted to build such a technique based on analysis of backscatter data from different sites are discussed in Section 2 of the report.

The coastal shelf areas studied in the CWHM project comprise different sets of seafloor habitats typical for environmental conditions in those areas. The characteristics of sonar data collected in each area were somewhat different, and therefore backscatter data analysis and interpretation also involved specific questions to be addressed and specific seafloor backscatter features to be studied. Results of sonar data analysis specific for the surveyed coastal shelf areas are discussed in Section 3. Conclusions on the results obtained and methods developed are given in Section 4

A number of papers based on the material given in this report have been presented at various national and international conferences and published in the refereed conference proceedings. A paper summarising the results of the CWHM project discussed in this report has been prepared and is intended for submission to one of the internationally recognised scientific journals, such as the *IEEE Ocean Engineering Journal* or the *Acta Acustica Journal* of the European Acoustical Association.

2 Common research objectives and outcomes

Multibeam sonar systems (MBS) are recognised as the most effective tools available to remotely characterise and map the seafloor as they provide co-located high-resolution bathymetry and acoustic backscatter from a wide swath across a vessel's track. While the production of bathymetry maps from MBS is well developed, analysis of MBS backscatter has not yet reached its full potential. Methods for analysis of MBS backscatter data have been developed in the CWHM project in order to determine the backscatter features that adequately characterise the seafloor cover. Part of this work involves correction of the backscatter images to make them independent of incident angle to enable further segmentation and classification of the areas on the seafloor acoustically observed along multiple overlapping MBS swath tracks. To develop such techniques we considered the effects of incident angle on high frequency backscatter intensity from a range of different habitats investigated in different coastal shelf areas within the CWHM project.

Acoustic backscatter strength is highly dependent on incident angle due to different mechanisms of scattering within different angular domains, which basically are: near-nadir (typically from 0° to 10°), moderate (20° – 40°) and oblique ($>50^\circ$) angles of incidence. At near-nadir angles, specular backscattering dominates the contribution of backscattering from the small-scale roughness of the seafloor surface and from volume inhomogeneities in the sediment.

Since the horizontal scale of spatial change in the local slope can be larger than the beam footprint of high-frequency narrow-beam systems, backscatter samples of the seafloor by consecutive pings may be statistically dependent, and therefore the stochastic variation of backscatter energy may not satisfy the Rayleigh distribution for Gaussian processes. Moreover, a large difference between the specular and off-specular backscatter strength results in large dispersion of backscatter intensity measured at near-nadir angles.

At oblique angles of incidence, the contribution of specular scattering is negligible if the large-scale slope of the surface roughness is not very large. In this regime, backscattering from the small-scale roughness and sediment volume contribute most to the backscatter energy. If the correlation length of small-scale roughness and the typical size of volume inhomogeneities are generally smaller than the beam footprint, then the total backscatter energy tends to be distributed according to the Rayleigh law for a Gaussian process with statistically independent contributors. The transition between these two domains can be seen at the moderate angles.

In addition to a stronger backscatter return at near-nadir angles, the angular dependence of backscatter strength also appears in larger variations near the nadir, which makes the backscatter images much noisier in the inner part of swath tracks. Attempts made at correcting the angular dependence through theoretical models seem to be inadequate, especially for the modern high-frequency multibeam systems. This is mainly due to the lack of a universal backscattering model suitable for every seabed type, which has led to many authors using an empirical approach based on removing the spatially averaged angular response derived for a single swath track (Beaudoin *et al.*, 2002; Hughes Clark, 1994). However, as the distribution of backscatter is known to change with the incident angle, removing only the mean response does not completely compensate angular effects in MBS backscatter images.

An example of the difference between the statistical distributions (PDFs) of backscatter strength at different angles of incidence for different types of seafloor cover is demonstrated in the left panels of Figure 1.

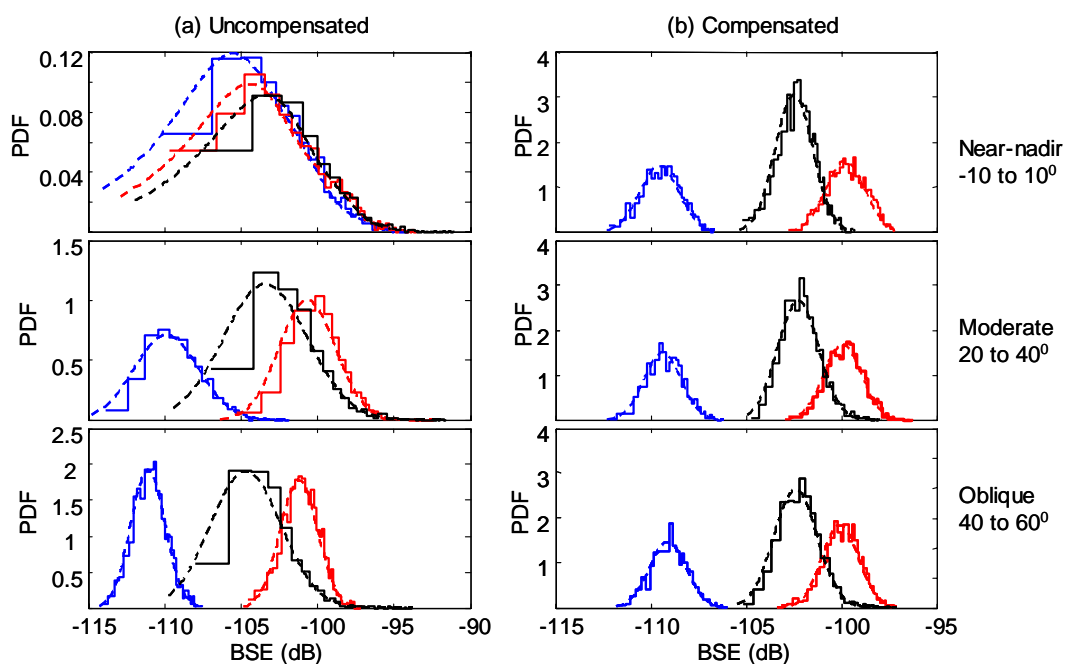


Figure 1. Backscatter intensity histograms (solid lines) and their best fit to theoretical probability density functions (dashed lines) for sand (blue), rhodolith (red) and rock (black) in different angular domains for backscatter data not corrected (a) and corrected (b) for angular dependence

One can see in the top left panel that the dispersion of backscatter intensity at near-nadir angles of incidence is large and the difference between the mean values calculated for different seafloor covers is small so that different habitats cannot be discriminated by acoustic backscatter. In contrast to vertical angles of

incidence, the distributions of backscatter from different habitats at oblique angles are well separated from each other and therefore the seafloor type can be identified by the mean backscatter value. At moderate angles of incidence the PDFs are insufficiently narrow so that misclassification of rhodolith and rock is probable when using the mean value as a classifier.

The effects of angular dependence on seafloor backscatter images derived from MBS data for these three different seafloor types are clearly seen in Figure 2 (top panels). All three images have noticeable banding effect along the central track line corresponding to the vertical angles of incidence. Change of the mean backscatter intensity across swath is evident for sand: backscatter is much stronger around the nadir and weaker at the most oblique angles (outermost beams). For the rhodolith cover, the mean backscatter value is nearly uniform across swath, but larger dispersion around the nadir becomes apparent as a narrow band along the central line. The angular dependence of both mean value and standard deviation is also seen in the backscatter image of the rock area.

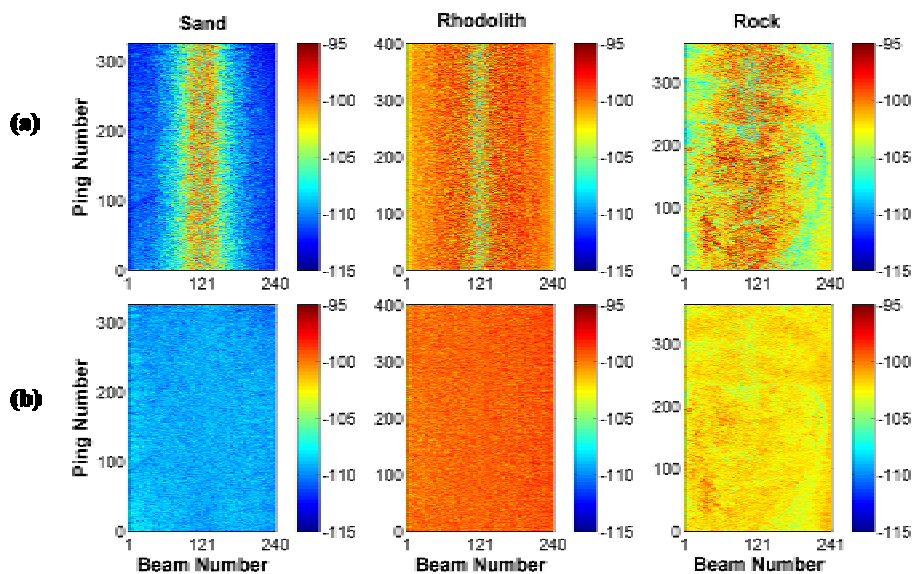


Figure 2. Backscatter strength images of sand, rhodolith and rock: (a) before and (b) after compensation for angular dependence

The algorithm for processing MBS data developed and implemented in the CWHM project is outlined by Gavrilov *et al.* (2005) and Parnum *et al.* (2005, 2006) and described in detail in the appendix. Further development of the algorithm involved elaboration of a new procedure for angular backscatter correction based on a more comprehensive analysis of backscatter statistical characteristics. The new procedure of angular correction equalises the

backscatter intensity values to a reference level which is characteristic for the seafloor type observed with MBS.

In the semi-empirical algorithm developed by the Centre for Marine Science and Technology, Curtin University of Technology, an average angular characteristic of backscatter and its standard deviation is calculated within a spatial window of a predefined length moving along the swath track. The average angular characteristic is subtracted from the backscatter intensity values (represented in the logarithmic scale) within the spatial window and the resulting values are normalised to equalise the standard deviation at different angles of incidence.

The absolute value of backscatter intensity and the dispersion of variations are then restored using the reference average backscatter level and standard deviation within a 2-degree angular span around a reference angle of incidence of 30 degrees. If the sliding spatial window crosses a boundary between two different types of seafloor cover (different habitats), which is examined by an abrupt increase of the standard deviation, the window length is automatically shortened in such a way that the current window ends at the boundary and the new window starts from the boundary.

The angular characteristics are initially assumed to be symmetrical relative to the nadir and the average angular response is calculated for a symmetric angular response. However, if the standard deviation of backscatter intensity is essentially asymmetric and an abrupt increase of the standard deviation at the reference angle occurs on the starboard and port sides at different positions of the sliding window, the algorithm infers that the boundary between different seafloor types is diagonal to the swath track. In that case, the boundary is reconstructed along the line that intersects the swath track at the points where the transition is localised at the reference angles independently on the starboard and port sides. The correction for asymmetry is made within the spatial window that contains a diagonal boundary.

Higher statistical moments (such as skewness and kurtosis) of backscatter intensity domains were also investigated within different angular domains, but they did not show any dependence or provide useful information for seafloor discrimination.

The results of angular correction of backscatter data, using the new algorithm developed in the CWHM project are shown in Figures 1 and 2, right and bottom panels respectively. The PDFs of backscatter intensity after angular correction (Figure 1, right panels) became similar in different angular domains, but distinctly separated for different seafloor types. In the backscatter data corrected for

angular dependence, different habitats can be easily discriminated by the mean backscatter intensity. The width of PDFs, that is, the standard deviation of backscatter, also became identical in different angular domains. This resulted in a nearly complete equalisation of backscatter images with respect to the angle of incidence after angular correction (Figure 2, bottom panels). The images of homogeneous areas of sand and rhodolith (bottom left and middle panels) became flat, as they should appear, but different in colour (or brightness) mirroring the difference in the seafloor roughness of sand and rhodolith. The rock backscatter image (bottom right panel) became equalised with respect to the incidence angle, but preserved the texture features distinctive for reefs and rocks.

The efficiency of the angular correction algorithm is demonstrated in Figure 3 given as an example of one of the worst scenarios for acoustic segmentation of the seafloor when the boundaries between different habitats have a complex contour and are diagonal to the swath track. Even for such scenario, the backscatter processing method was capable of removing angular artefacts and depicting boundaries between habitats.

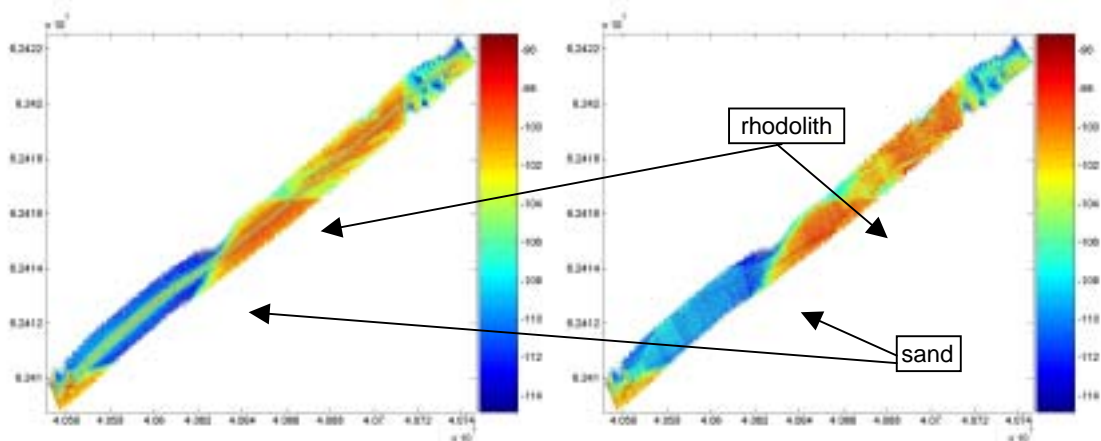


Figure 3. Backscatter intensity along a swath line crossing boundaries between different habitats before (left) and after (right) correction for angular dependence

The robustness of the methods developed in the CWHM project for MBS data processing allowed us to considerably improve the capability of MBS observations to acoustically classify and map habitats on the seafloor.

An example of seafloor segmentation and classification using MBS data collected along multiple overlapping swath tracks over the seafloor off the Recherché Archipelago is shown in Figure 4.

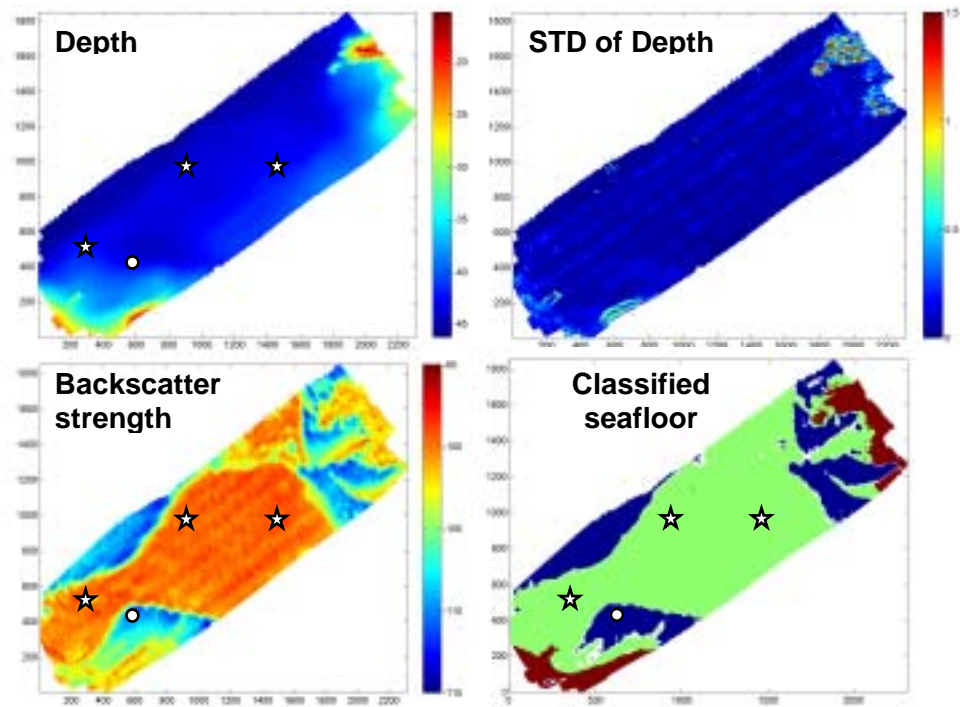


Figure 4. Example of seafloor discrimination and classification using backscatter – bathymetry analysis for the seafloor area in the Recherché Archipelago region
(Grab samples: o – sand, ★ - rhodolith; Acoustic segmentation: sand – blue, rhodolith – green, rock – brown)

In addition to the mean backscatter intensity corrected for angular dependence (bottom left), the seafloor relief (top left) and standard deviation of its roughness (top right) were used to contour the habitats on the seafloor. A decision tree analysis was applied to multi-parameter space of MBS samples to classify the seafloor. The result of habitat mapping is demonstrated in the bottom right panel of Figure 4. Acoustic mapping of the seafloor is consistent with the ground-truthing grab samples of the bottom sediment (circles and stars).

3 Site-specific research goals

3.1 Cockburn Sound

Cockburn Sound is a shallow-water coastal region located between the mainland south of Fremantle and Garden Island in Western Australia. The research program of the CWHM project in this area was focused primarily on testing the capability of acoustic techniques to distinguish marine vegetation on a sandy/muddy seabed and to assess its distribution and density. This region was also used as a case study area for elaboration of experimental design for acoustic surveys of the seafloor and for examination of various technical and environmental factors that could influence survey results. Details of the experimental studies conducted in Cockburn Sound are given in the milestone technical report by Siwabessy *et al.* (2005).

Figure 5 shows the acoustic backscatter intensity from a sloping seabed in Cockburn Sound. A spot of considerably higher backscatter intensity is distinct in the eastern part of this area. Underwater video examination of the seafloor showed that the MBS backscatter image accurately portrayed a patch of seagrass growing on sand in this area.

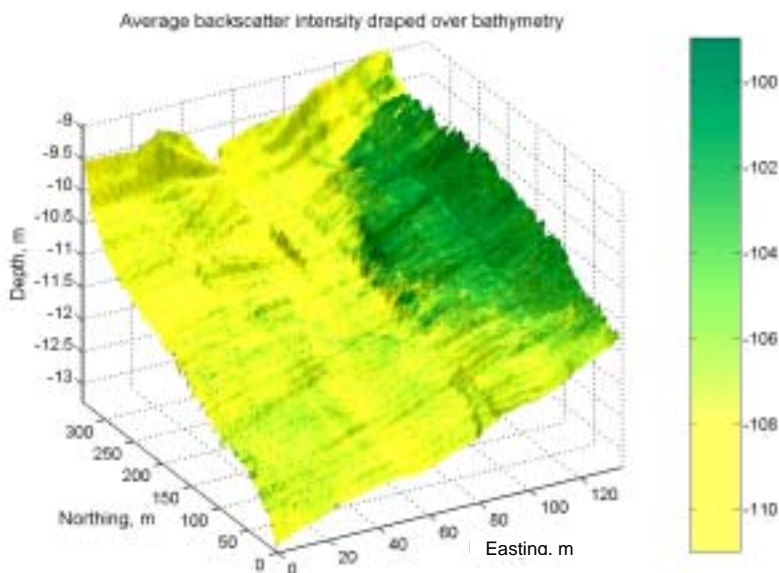


Figure 5. Backscatter intensity (shown in colour) draped over bathymetry in one of the areas surveyed in Cockburn Sound

The green area in the eastern part is a patch of seagrass growing on sand (yellow)

It was found that the angular dependence of backscatter from seagrass was utterly different from that of sand and mud. In contrast to small-grain sediments, acoustic backscatter from a dense seagrass cover is almost independent of the angle of incidence, that is, seagrass scatters acoustic waves in all directions, and backscattering is noticeably stronger at all angles including vertical incidence. This is clearly seen in Figure 6, which shows the angular dependence of backscatter measured for sand and seagrass.

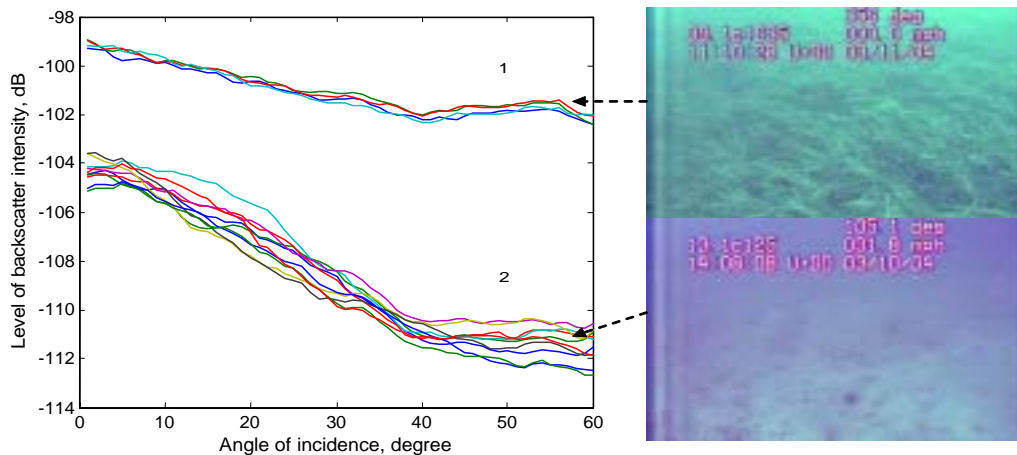


Figure 6. Angular dependence of backscattering intensity from seagrass (1) and sand (2) measured in Cockburn Sound, Western Australia in the CWHM project, along with photographs of the seafloor taken for ground-truthing acoustic observations

It can also be seen in Figure 6 that the mean angular response of backscatter derived from fifty consecutive sonar pings was steady for both sand and seagrass, even if sea depth was considerably varying across the area. This means that the backscatter processing algorithm properly compensates the intensity of backscattered signals for acoustic transmission losses that depend strongly on sea depth, which is important for robust acoustic recognition of seafloor habitats regardless of oceanographic conditions.

Figure 7 depicts three stages of backscatter analysis. The left panel shows the intensity of backscatter from a sandy bottom covered with sparse seagrass patches. In this image composed from five swath lines, the backscatter intensity values are corrected for system settings and transmission losses, but not corrected for angular dependence, which becomes apparent as red and yellow bands of strong backscatter along the central lines of swath tracks. Seagrass patches can be recognised in this image as red spots, but cannot be unambiguously contoured because of artefacts due to angular dependence.

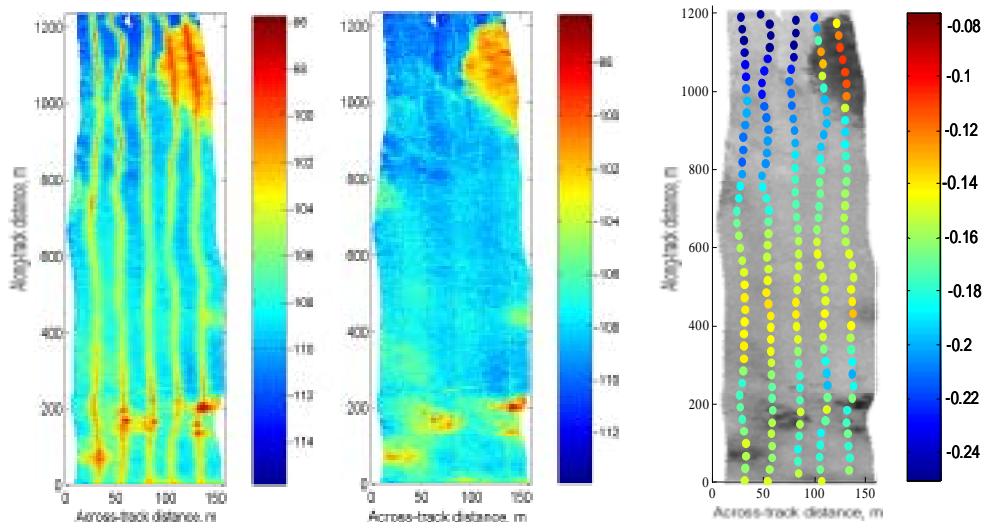


Figure 7. Backscatter intensity image of the seafloor built from five overlapping swath lines, before (left) and after (middle) correction for angular dependence

Colour-coded dots draped over the grey-scale backscatter intensity image in the right panel demonstrates the mean slope of angular dependence within $5\text{--}40^\circ$ measured at the central points of each 50-ping section of swath lines

The central panel of Figure 7 shows the result of angular correction. In this equalised image, the artefacts of angular dependence disappeared and seagrass patches became distinct and therefore can be properly contoured. In the right panel, the colour-coded dots superimposed on a grey-scale backscatter intensity image of the same area indicate the slope of angular dependence measured around the spot location by averaging fifty consecutive pings. These data provide an extra layer to the backscatter characteristic map for more comprehensive classification of the seafloor.

3.2 Recherché Archipelago

The seafloor in the region around the Recherché Archipelago is characterised by complex relief with multiple reefs of different steepness and a mixture of different habitats, such as sand and rhodolith sediment, seagrass, algae and rocks, occupying flat and ridged areas on the seafloor. This complicates building appropriate maps of seafloor habitats using MBS data. Moreover, the sea is usually rough in this area due to persistent swell waves coming from the Southern Ocean, which make it essential to provide accurate navigation and motion tracking of the vessel surveying the seafloor with a multibeam sonar system. Details of the MBS data collected in the Recherché Archipelago area are given in the milestone project report by Siwabessy (2005).

An example of seafloor relief in one of the surveyed areas is shown in Figure 8 along with the backscatter intensity draped over bathymetry. Ground-truthing of MBS acoustic observation was performed via underwater video observations and grab samples of sediments. This figure shows that analysis of MBS backscatter data satisfactorily depicts habitats on the seafloor even if bathymetry over the area is very uneven.

The angular dependence of backscatter was also used to assess small-scale roughness of the seafloor and to classify habitats. The dots superimposed on the backscatter intensity image in Figure 9 show the centres of seafloor areas where the average angular response was measured, and the colour of dots corresponds to the mean slope of the angular dependence at moderate angles of incidence. The seafloor in both the southernmost and northernmost parts of this area is flat and covered with sand. However, in the northern part sparse algae aggregations grow on sand, which strongly influences the backscatter intensity and its angular dependence. In the backscatter image (Figure 8) the presence of algae on sand can be recognised by a highly textured surface of different colours (or brightness in Figure 9). The angular dependence of backscatter over this area tends to be nearly flat, while in the southern part it is as steep as almost 2 dB per degree.

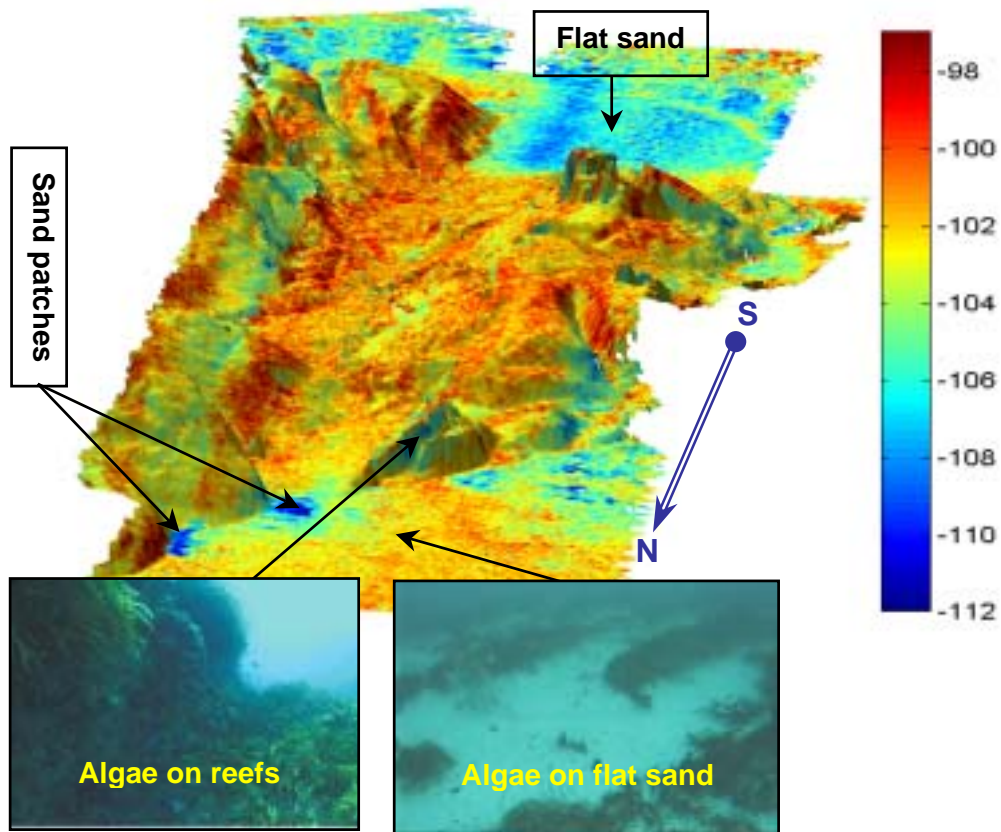


Figure 8. An example of seafloor relief and acoustic backscatter intensity derived from MBS data in the region of Lion Island of Recherche Archipelago

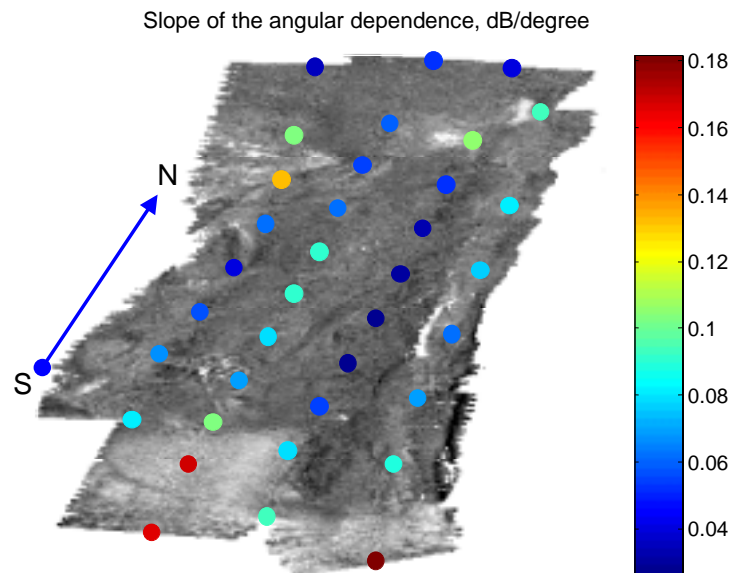


Figure 9. Colour-coded least-mean-square slope of backscatter angular response measured at different locations across the surveyed area and displayed on the grey-scale backscatter mosaic. The LMS slope was determined within a 10–35° angular domain

The seafloor around the Woody Island Group was the main area investigated in the Recherché Archipelago region. Figure 10 shows a colour-coded image of backscatter intensity from the seafloor in this area. The locations of grab samples of seafloor sediments taken across the area are shown by black dots on the map in Figure 10. The numbers given at the sample location indicate the sediment type determined from the grab samples.

Aggregations of rhodolith sediments (3) can be apparently identified and contoured in the backscatter image of the seafloor. Acoustic backscatter from this type of sediment is much stronger and more variable than that from sand (11), which is clearly seen from a comparison of the backscatter histograms for sand and rhodolith shown in the top panels. The intensity of backscatter from seagrass (6) and reefs (2 and 4) is also stronger and more variable than that from sand. Certain distinction between backscatter images of seagrass and rhodolith can be found in the shapes of backscatter distribution. The PDF of seagrass backscatter is much more asymmetric with more contribution from lower values, which was likely due to an irregularity of the seagrass cover growing on the sediment. The distinction between reef and rhodolith areas is much less evident from the comparison of backscatter characteristics. For such cases, a terrain analysis may provide more characteristics (such as the mean local slope, topography variation index, etc.) to discriminate the seafloor types of similar acoustic backscatter characteristics.

Overview of coastal water habitat mapping research for the Coastal CRC

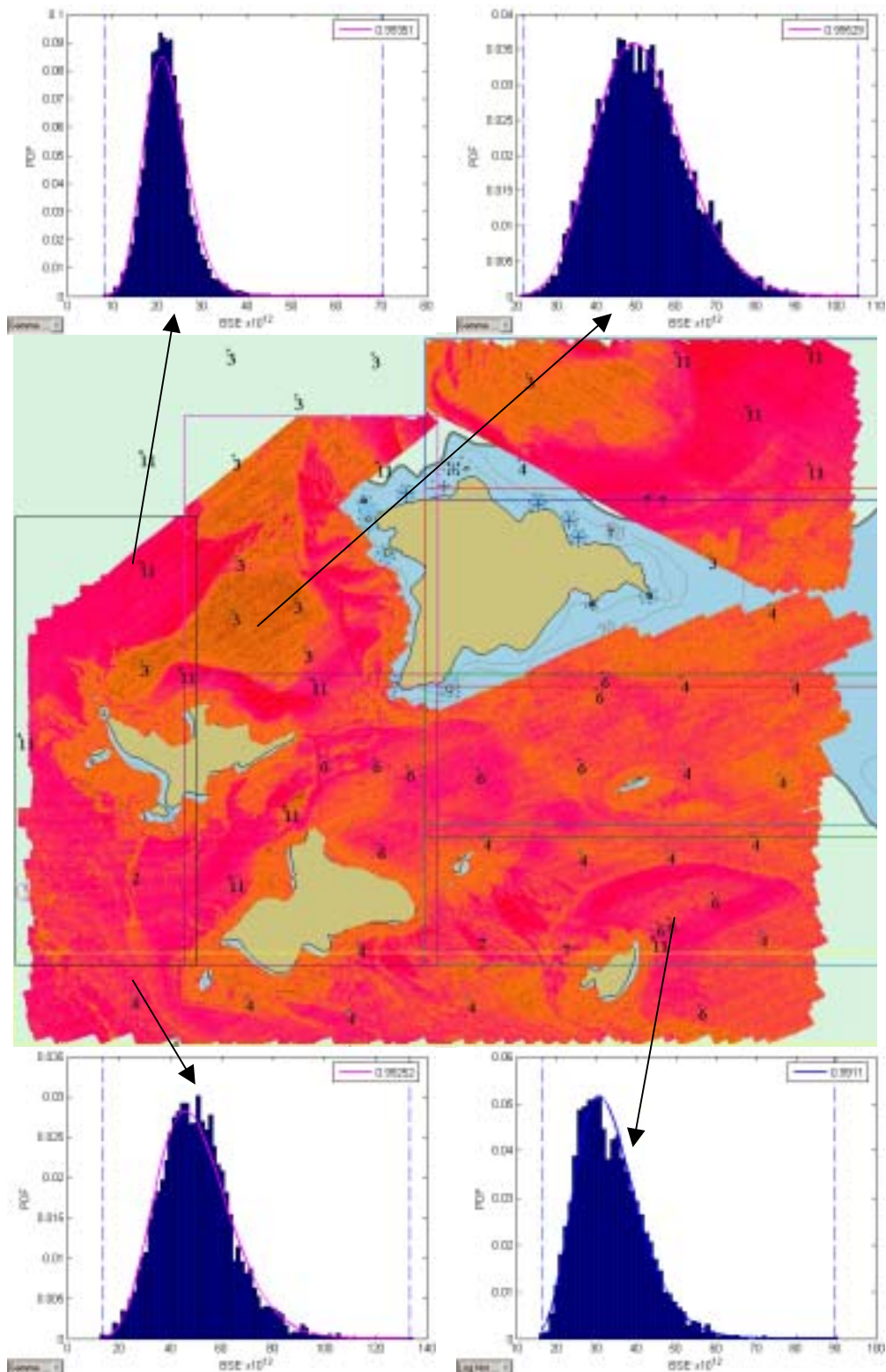


Figure 10. Acoustic backscatter image of the seafloor in the Woody Island study area

The numbers stand for the habitats classified as: 2 – high profile reef; 3 – rhodolith; 4 – low profile reef; 6 – medium seagrass; 7 – sparse seagrass; 11 – sand; 13 – sand dunes. Histograms and their best-fit approximation by model distributions show the mean values and variation of backscatter intensity from four different classes of the seafloor (before correction for angular dependence)

3.3 Moreton Bay

One of the specific objectives of seafloor investigation with sonar systems in the Moreton Bay region was to examine the capability of acoustic observation to distinguish sparse and low tropical seagrass growing on sandy and muddy sediments. A comparison of the performance of single- and multibeam systems with respect to discrimination of seafloor habitats was another objective of the study in this area.

Figure 11 shows MBS-derived bathymetry (left panel) and backscatter intensity image (right panel) of the seafloor in one of the areas surveyed around North Peel Island. Seafloor classification results derived from single beam sonar data are superimposed on the bathymetry and backscatter images for comparison.

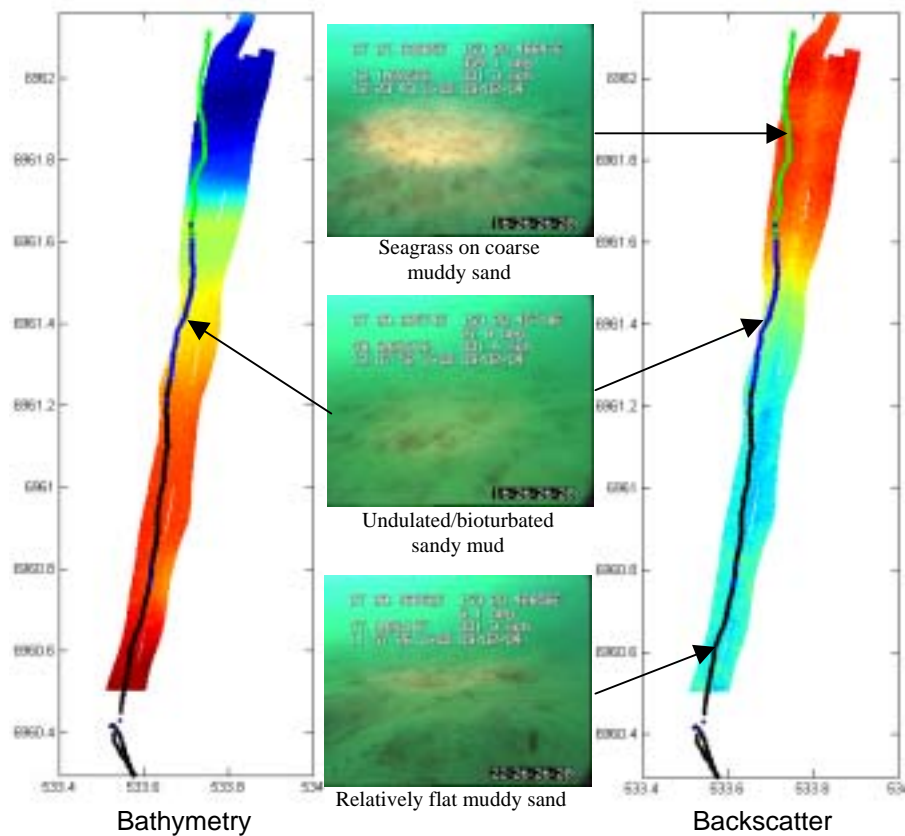


Figure 11. Comparison of multibeam and single beam acoustic classification of the seafloor in the North Peel Island area

The seabed classes derived from single beam data are as follows: C1 shown in black – relatively flat muddy sand; C2 shown in blue – very rough, undulated sandy mud; and C3 shown in green – coarse muddy sand covered with sparse medium tropical seagrass

Three distinct classes of the seabed referred to as C1, C2 and C3 were discriminated from RoxAnn backscatter analysis of the single beam sonar data. These three different classes are shown along the single beam track line by different colours: C1 as black, C2 as blue, and C3 as green.

Class C3 was localised within the zone of high backscatter intensity observed with the multibeam system in the northern part of the area. Underwater video observation showed that the seafloor in this zone was covered with sparse and medium tropical seagrass, which significantly increased backscatter strength of the seafloor and made it almost independent of the angle of incidence (green angular response shown in Figure 12).

Classes C2 and C3 were distinguished over the seafloor area in which the MBS backscatter intensity was relatively low. The difference between backscatter characteristics of these two classes becomes apparent when comparing the angular dependence (Figure 12) and the distribution (Figure 13) of backscatter from these types of the seafloor. Backscatter strength of bottom class C2 is slightly higher but much more variable than that of bottom class C3. The PDF of backscatter from bottom class C2 is somewhat wider and essentially asymmetric due to distortion resulted from the contribution of high backscatter values. Such irregularly distributed backscatter strength was most likely due to large undulation of the seafloor surface in the central part of the area, which was also observed in underwater video recordings.

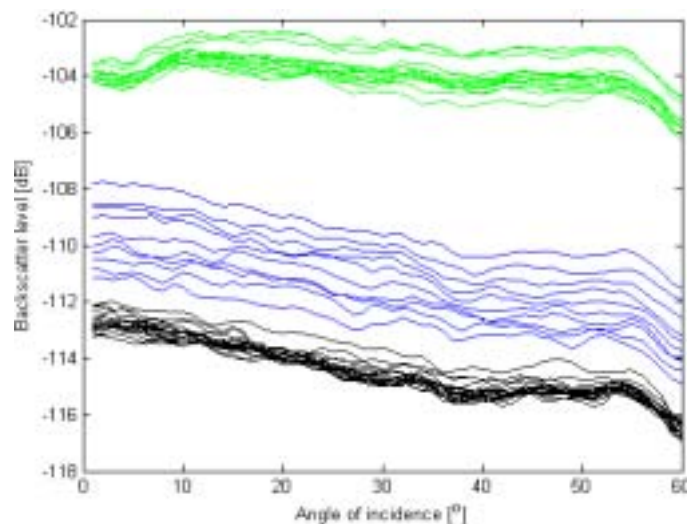


Figure 12. Angular dependence of backscatter intensity level measured for the seabed classes shown in Figure 11

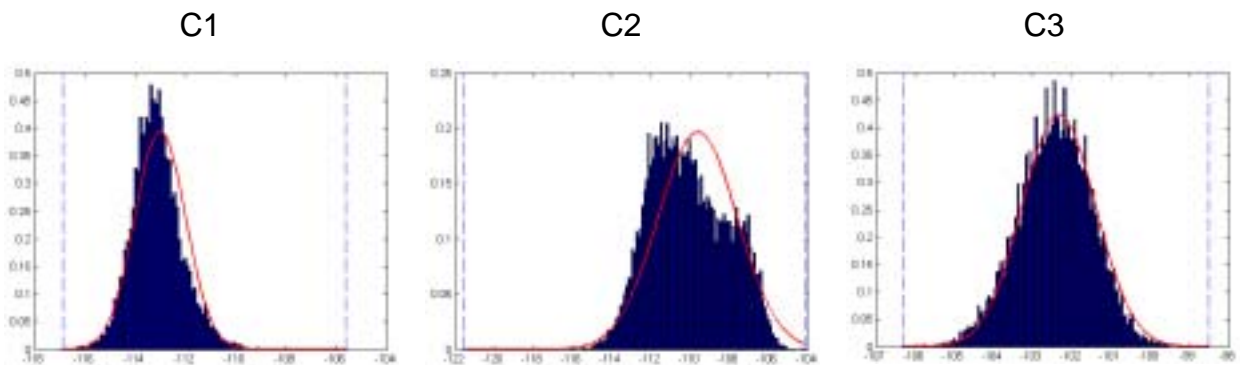


Figure 13. Distribution of backscatter intensity from three seabed classes shown in Figure 11 and their best-fit approximation by modelling PDFs

3.4 Fitzroy Estuary/Keppel Bay

The main objective of acoustic studies in the Fitzroy Estuary and Keppel Bay areas was to examine the capability of sonar technologies to monitor bottom habitats in very turbid waters where direct video observation was either problematical or even impossible. Monitoring of the bottom features that resulted from sediment dynamics was another specific subject of research by acoustic means.

The water in Keppel Bay was generally turbid. The underwater visibility around Port Alma was as poor as half a metre and somewhat better, about 3.5 m, around the Centre Banks. The presence of large dunes in the Centre Banks area is apparent from both bathymetry and backscatter intensity images shown in Figure 14. In the western part of the area that appears darker in the backscatter mosaic, the seafloor was generally flat and covered primarily with muddy sand of small grain size which typically forms a smooth surface of weak acoustic backscattering properties. Higher backscatter levels (brighter image areas) were observed in the eastern part of the area and along the crests of submerged dunes. It appeared from grab samples that the sediment in dunes and in the eastern area contained a large amount of shell debris which is a good scatterer of acoustic waves at high frequencies. Thus the experiment showed that dynamics of sediments could be acoustically monitored through MBS observation of the configuration and contents of sediment dunes.

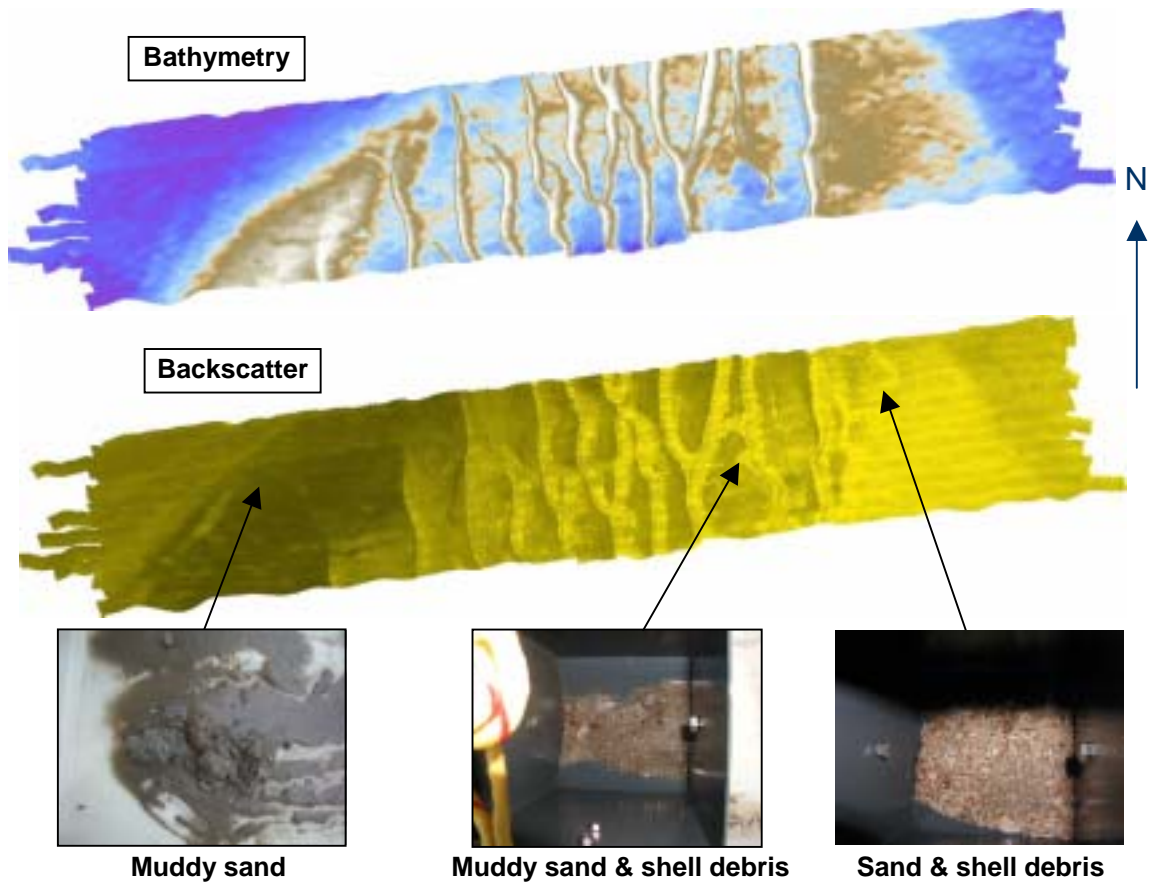


Figure 14. Bathymetry, acoustic backscatter mosaic and grab samples of sediments collected over the Centre Banks region, Keppel Bay

3.5 Sydney Harbour

The Sydney Harbour area is characterised by complex seabed relief with various features of both natural and artificial origin. Seafloor habitats in this area include sand, mud, rock and marine vegetation (both seagrass and algae). The top sediment layer in some areas of the seafloor is very likely saturated with gas, which may strongly influence acoustic properties of the seafloor including the backscattering strength. The presence and concentration of gas in the sediment are not apparent from underwater video observation and require specific instrumentation for gas content to be measured. This makes it more complicated to interpret results of acoustic observation based on the correlation between acoustic data and underwater video observation.

Figure 15 shows an example of an MBS-derived bathymetry and backscatter intensity image of the seafloor in one of the areas surveyed in Sydney Harbour. This area can be divided generally in two parts: shallower water (5–7 m) with strong seafloor backscattering, and deeper water (12–16 m) with weak backscattering. The seafloor in the shallower area contains rock outcrops, gravel and individual rocks that form a rough and acoustically hard surface, which results in strong and irregular acoustic backscattering. In the deeper southern part of the area, the seafloor is relatively flat and covered primarily with sand, which results in much weaker acoustic backscattering. However, there are two depressions of the seafloor in the central part of the area which are as deep and sandy as the southern flat part but exhibiting backscatter properties as strong as the shallow area of rock outcrops. Such an ambiguity can likely be explained by the presence of gas and/or shell debris in the sediment in those seafloor depressions.

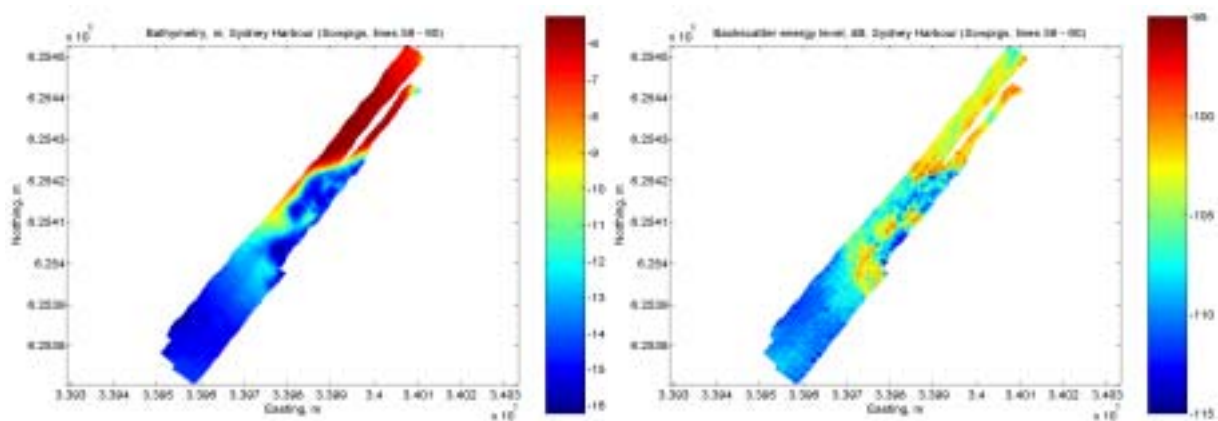


Figure 15. Bathymetry map and backscatter intensity image of one of the seafloor areas surveyed with the MBS system in Sydney Harbour

The difference between the acoustic backscatter strength of rock outcrops and sand is clearly seen in the backscatter image of the seafloor shown in Figure 16, along with selected frames of an underwater video recording made along the MBS swath track. The transition from sand to rock outcrops on the seafloor was observed in the video data in the southern part of the track. This transition can also be clearly distinguished in the acoustic backscatter data.

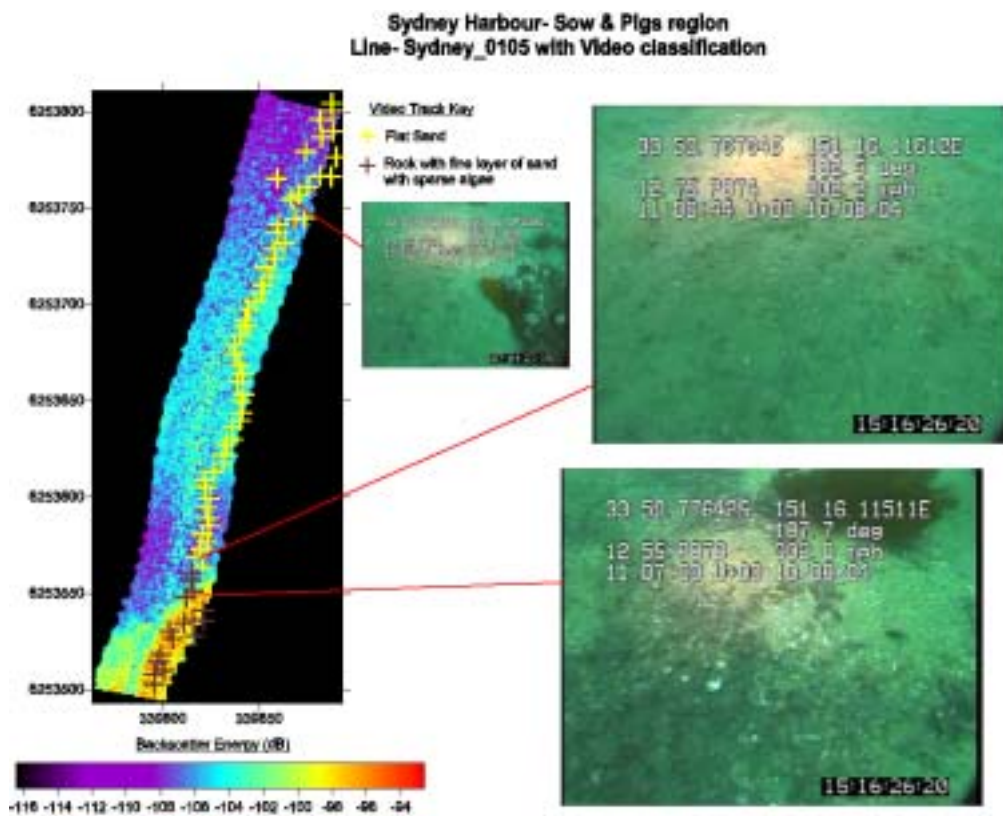


Figure 16. Gridded, angle-corrected backscatter intensity level along line 105 of the second survey in Sydney Harbour in October 2004, and selected frames of video recording that show spatial variations of the seafloor cover

4 Conclusions

A method for the processing and analysis of high-frequency multibeam sonar data has been developed in the CWHM project to build georeferenced bathymetry maps and backscatter mosaics of the seafloor in shallow-water coastal shelf regions. This new technique has been applied to classification and mapping of seafloor habitats in several regions on the Australian coastal shelf. The method appeared to be quite universal with respect to discrimination, acoustic classification and mapping of different seafloor habitats typical of the Australian coastal zone, such as flat and undulated sediments consisting of sand and mud, coarse sediments (rhodolith, rock and shell debris), rock outcrops and coral reefs, and marine vegetation on the seafloor (seagrass and algae).

Acoustic discrimination of the seafloor was consistent with ground-truthing underwater video observation and grab samples of sediment in the majority of the coastal shelf areas surveyed at the experimental sites of the CWHM project.

In addition to common classes, seafloor habitats in each study region revealed particular features of which acoustic backscatter characteristics were also specific. This means that full-coverage remote acoustic observation and classification of the seafloor with multibeam sonar systems in any specific region should be supported with direct video observation and/or sedimentary probes at certain selected locations, even though an efficient, robust and reasonably universal method for seafloor acoustic classification is available.

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Appendix: Algorithms and computer programs for processing multibeam sonar data

Common remarks

These technical notes describe the algorithms and software tools that have been developed by the Centre for Marine Science and Technology, Curtin University of Technology, for processing of multibeam sonar data as part of the Coastal Water Habitat Mapping project of the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management.

The algorithms developed for multibeam sonar data processing were implemented in Matlab, which allowed us to create a platform-independent software package and have the source codes open for further modification and adaptation to new multibeam systems and data formats. The current version of the Matlab Multibeam Data Processing (MMDP) toolbox is universal with respect to processing of multibeam sonar data from all existing multibeam systems that are capable of collecting snippet (backscatter waveform) data and exporting all data in the eXtended Triton Format (XTF) binary data files.

Basic structure of the library

The Matlab library for multibeam sonar data processing consists of three major parts. The first set of Matlab programs and functions performs conversion of all data collected by a multibeam sonar system, including motion and navigation data, from XTF binary data files into Matlab data files.

The second, major component of the Matlab library contains the programs and functions that process multibeam sonar data to calculate bathymetry and the acoustic backscatter strength of the seafloor over the surveyed area.

Matlab programs in the third part of the library implement known and enhanced algorithms for segmentation of seafloor properties by acoustic backscatter and bathymetry data.

A set of Matlab functions that implement a graphic user interface for program control was also developed in CMST to simplify operation of all Matlab programs for multibeam sonar data processing.

In these notes, only the data processing component of the library is described.

Backscatter processing algorithms and computer programs

The Matlab functions for processing multibeam sonar data perform the following operations:

1. Calculation of georeferenced bathymetry corrected for ship's motion, static offsets in system settings, and dynamic and static offsets in system timing.
2. Calculation of acoustic backscatter intensity from the snippet data collected by the multibeam system at the points coinciding with bathymetry samples. Two backscatter intensity characteristics are calculated from the snippet data: (i) peak intensity, which is the squared maximum of backscatter pulses, and (ii) backscatter energy, which is the integral of squared backscatter pulses (see Figure A1 for detail).
3. Radiometric correction. Both peak and integral backscatter intensity values are corrected for transmit power and receive gain in order to obtain backscatter characteristics independent of system settings. The backscatter energy is also normalised to the transmit pulse width, which converts the backscatter energy into the average backscatter intensity independent on the pulse width selected by a system operator.
4. Removal of time varying gain (TVG) correction by the system hardware. If the TVG mode is selected in system settings, a special Matlab function compensates the system TVG correction based on the system setting of the spreading and absorption loss. This procedure converts the TVG-corrected backscatter data, depending on the system setting by an operator, into the actual backscatter level received on the sonar array.
5. Calculation of the seafloor surface backscatter coefficient and the true angle of incidence. This Matlab program calculates the surface backscatter coefficient and the angle of incidence for each beam and each ping corrected for the transmission (spreading and absorption) loss and for the beam footprint size and insonified seafloor area for average and peak intensity respectively (see Figures A1 and A2 for detail). The transmission losses are derived from the slant range to the bottom along each beam and from the acoustic absorption coefficient calculated in a special Matlab function based on the water temperature and salinity data. The true angle of incidence is derived from beam angles relative to the sea surface allowing for ship's motion and from the local slope of the seafloor surface derived from bathymetry.

6. Angular correction of backscatter strength. The algorithm for angular correction is discussed in detail in Section 2 of the report.
7. Combining swath lines and data gridding. This Matlab program implements common procedures for data gridding, such as the Delaunay triangulation method for bathymetry and the local median filtration method for backscatter. The grid size can be selected by the user.

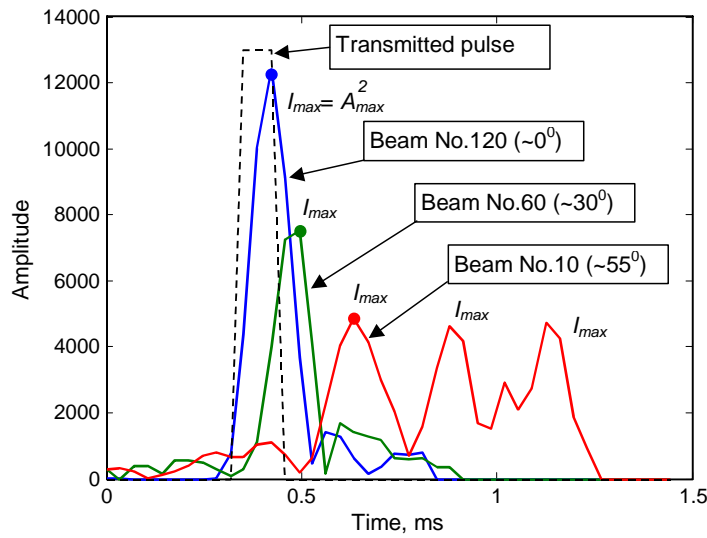


Figure A1. Pulse form of the snippet signals (envelopes of acoustic backscatter signals on the sonar receive array) along the innermost, moderate slant and outermost beams

The average backscatter intensity I_{aver} is derived from backscatter energy as:

$$I_{aver} = \frac{\sum A_n^2 \times T_S}{T_P}, \text{ where } A_n \text{ are samples of the acoustic pressure amplitude in the}$$

snippet signal; T_S is the sampling interval; and T_P is the transmit pulse length.

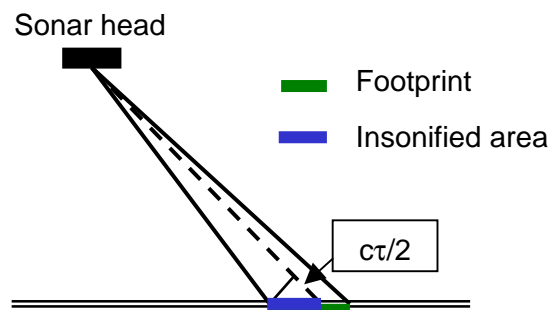


Figure A2. Footprint of an individual receive beam and insonified area on the seafloor

C is the sound speed and τ is the length of transmitted pulses

Figure A3 shows a block diagram of the full algorithm.

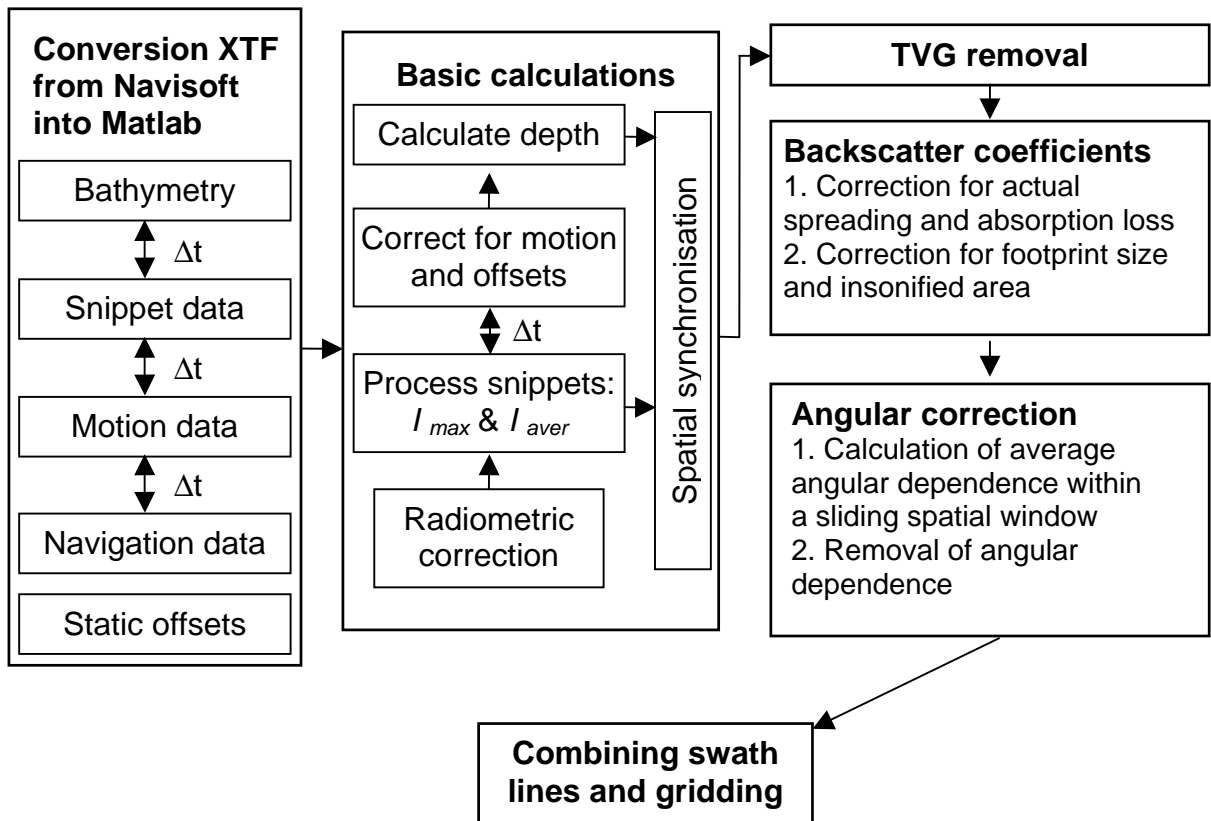


Figure A3. Block diagram of MBS data processing algorithm developed within the CWHM project