

Seabed habitat classification

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Introduction.

As the exploitation of marine biological resources increases, effective marine environmental management becomes important for a sustainable environment. Base maps of biological as well as physical and geological resources are required for effective marine environmental management. The practice of resource mapping making use of satellite remote sensing and airborne platforms is well established for terrestrial management. On the other hand, marine biological resource mapping is not readily available except in part from that derived for surface waters from satellite based ocean colour mapping. While acoustic techniques have been used for some time in pelagic biomass assessment, only recently have acoustic techniques been applied to marine biological resource mapping of benthic communities. Examples include Magorrian *et al.* (1995), Greenstreet *et al.* (1997), Davies *et al.* (1997) and Sorensen *et al.* (1998) using the RoxAnn system, and Prager *et al.* (1995) using the QTC-view system.

This paper describes methods used to classify the bottom type from echosounder records obtained during a survey of fisheries resources in the North West Shelf region of Western Australia. The survey formed part of the CSIRO Division of Marine Research management program in the area. It is a continuation of the management program which has been ongoing since 1986 with main objective being to measure changes in abundance of benthos and fish species in the intervening years (Whitelaw, 1998). In line with the main objective, it is a secondary objective to assess a post processing method for bottom classifications from acoustic data provided by a stand-alone SIMRAD EK 500 echosounder. This paper focuses on the process of bottom classification using analysis of first and second bottom echoes to provide assessments of bottom type along the vessel's track. The approach is similar to that used in the commercial RoxAnn system. In grouping bottom types however, multivariate analysis is adopted instead of the allocation system normally used in the RoxAnn system. Attention is also given to the extent to which bottom classification derived along the vessel track can be extended into unsampled areas.

Surveys.

The survey was carried out between the 7th of August 1997 to the 1st of September 1997 from the FRV *Southern Surveyor* in the North West Shelf region, Western Australia, between 114°30'E and 119°E and between 18°30'S and 21°S. Moving from west to east, the survey encompassed three experimental management zones; Barrow Island, Legendre and Port Hedland respectively from west to east (Whitelaw, 1998). Trawl stations were based upon a stratified random design. Fig. 1 shows the transects used and the bathymetry.

Acoustic data were collected along the track from the FRV *Southern Surveyor* with a calibrated SIMRAD EK500 scientific echosounder with hull-mounted transducers of three different frequencies. The three operating frequencies were 12 kHz (single beam with 14/17° full angle), 38 kHz (split beam with 7° full angle) and 120 kHz (split beam with 10.5° full angle). This paper deals with the analysis of data from the 12 and 38 kHz hull mounted transducers.

Photographic surveys of the seabed were taken in trawl stations using a Photosea 1000 underwater camera. The camera together with its frame was attached to the mouth of the net. The elapsed time at each station, from when the trawl reached the bottom until it left the bottom, was 30 minutes. Pictures were taken at half minute intervals, yielding around 60 pictures from each station. The pictures were processed on board to allow underway monitoring and adjustment of photographic parameters.

Acoustic data quality control.

ECHO software developed by the CSIRO Division of Marine Research was used for quality control of the acoustic data on a Sun workstation (Waring *et al.*, 1994; Kloser *et al.*, 1998). The ECHO software enables the specification of background and spike noise thresholds, correction for calibration and absorption changes, removal of corrupted data and editing of bottom lines (Kloser *et al.*, 1996; Kloser *et al.*, 1998). With the ECHO software, regions containing acoustic noise due to aeration and spike noise above the seabed due to a time jitter were excluded from further analysis.

Acoustic data analysis.

Two key factors in the RoxAnn system are the so-called E1 and E2 parameters. E1 is derived from an integration of the tail of the first acoustic bottom return and E2 is derived from an integration of the complete second acoustic bottom return. The rationale of this is that the energy in the tail of the first acoustic bottom returns (E1) arises from the roughness of the seabed and that of the entire second acoustic bottom returns (E2) arises from the acoustic impedance mismatch of the seabed and the water column (Chivers *et al.*, 1990; Chivers and Burns, 1992). This parameter is customarily taken to represent the "hardness" of the seabed. Heald and Pace (1996) provide theoretical expressions derived from scattering theory for E1 and E2.

As water depth increases, the spreading of the acoustic beam causes longer bottom echo tails to arise (Fig. 2). The time taken from the arrival of the wavefront at the centre of the acoustic beam until the -3dB point has passed increases with depth. This results in an increase in the pulse length of the return signal with depth ($t_2 > t_1$).

Using the ECHO software, the bottom roughness parameter was computed by averaging over 0.05 nmi the integration of the tail of the first acoustic bottom returns from bottom locked data provided by the SIMRAD EK 500 echosounder. Similarly, the bottom hardness parameter was computed by averaging over 0.05 nmi the integration of the complete second acoustic bottom returns. The following expression is used by the ECHO software to compute both bottom roughness and bottom hardness parameters.

$$E = 4p1852^2 \frac{\sum_{l=1}^p \left(2 \sum_{k=1}^d s_{v(k,l)} \right)}{p} \quad (1)$$

where d is the number of s_v values within the tail of the first acoustic bottom return and that within the complete second acoustic bottom return respectively for the bottom roughness and bottom hardness parameters, s_v is backscattering coefficient, and p is the number of pings within a horizontal interval of 0.05 nmi. The final indices E1 and E2 used, as shown in Fig. 4, were the logarithm of the bottom roughness and bottom hardness parameters obtained from equation (1).

$$\begin{aligned} & E1 = \log_{10}(E) \\ \text{and} & E2 = \log_{10}(E) \end{aligned} \quad (2)$$

To remove the effect depicted in Fig. 2, a simple regression fit was determined and applied to the bottom roughness index E1 to remove the trend with depth (Fig. 3).

A scatter plot of E2 versus E1 for 12 kHz data is shown in Fig. 4. Although the range of variation of E1 is from 5 to 9, E1 appears to cluster in a range varying from 5.5 to 7. Unlike E1, E2 seems to vary uniformly between 4.5 and 7.5. This indicates that there is more variation in bottom hardness than there is in bottom roughness. Sorensen *et al.* (1998) on the other hand show otherwise and a quite distinct separation of E1 into three separate clusters. In this study however, the separation of this kind is not very obvious even for E2 where the spread of values is greater. Their results arose from a wider variety of bottom types than appear to be represented in the current work.

Autocorrelation.

The spacings between transects shown in Fig. 1 varied from zero to 50 nmi and were generally of order 20 nmi. Although it was thought desirable to produce a map of bottom types over the whole study area encompassed by the survey, the results obtained suggest that only along track assessments may be made. This conclusion is based upon autocorrelation analysis of along-track E1 and E2 results. Fig. 5 gives a representative example of E1 values at 38 kHz of one particular transect. This and other results indicate that autocorrelation characteristic lengths derived from along-track measurements were in general much less than average transects spacings. It would appear that the spatial variability of E1 and E2 involves distances much smaller than the transect separation necessary on the survey. The autocorrelation of other bottom parameters from all frequencies showed the similar autocorrelation characteristic length. This suggests that a full 2-D bottom type structure of the whole study area is not possible.

Photograph analysis.

The distance between the camera and the seabed for each shot is not accurately known. A full photograph analysis yielding wavelength and amplitude of sandwaves, coverage area, abundance etc (Smith and Hamilton, 1983; Wadley, 1998 (pers. com.)) is not accessible. In the present work, a descriptive analysis of the photographic records was undertaken. The descriptors used were smoothness or roughness of the seabed surface, presence or absence of sandwaves, and presence or absence of the epi-benthos, especially underwater plants. While the first two descriptors are useful to infer the bottom roughness, the last one is helpful to deduce the bottom hardness. The rationale of the last descriptor is that the underwater plants are likely to grow in a strong/hard base to support them. Using these descriptors, three different bottom types of the study area are determined namely soft/smooth, hard/smooth, and hard/rough. Categorisation of this kind appears to agree with that derived from the method combining acoustics and multivariate analysis.

Classification.

The RoxAnn system calls for an operator to allocate specific areas on the E1, E2 plot. We present here an alternative approach to classification using multivariate analysis. This enables the classification of bottom types from E1 and E2 data and also provides for the possibility of the inclusion of other meaningful parameters as well. In addition, Greenstreet *et al.* (1997) found inconsistency in the allocation system of the RoxAnn technique in

boundaries between different bottom types. The parameters used in this study for seabed classification were E1, E2 from 12 and 38 kHz data, and their associated depths. We are at present exploring the extent to which Principal Component Analysis (PCA) can aid in integrating the data now available. In addition, data at 12 kHz will shortly be included and further testing of the PCA technique will be undertaken. The PCA was performed on the high-dimensional spectral data set formed by those parameters to produce three principal components as outlined below. Examples of the use of PCA for bottom classification technique include, among others, the QTC-view system (Prager *et al.*, 1995) and Kavli *et al.* (1994). PCA involves a linear combination of the original features or in other words a rotation of the original axes to the new coordinate axes which are orthogonal (Bailey and Gatrell, 1995). As such, it seeks the eigenvectors of the standardised covariance of the high-dimensional spectral data set. The corresponding eigenvalues are then the variances of the observations in the new coordinate axes (Bailey and Gatrell, 1995).

Of these new feature variables, 3 with the largest eigenvalues are retained. The criteria used to retain important principal components is based on eigenvalues which are greater than 1. The first three principal components retained account for 89.04% of the total variation with first, second and third principal component accounting individually for 41.49%, 26.12% and 21.43% respectively (Table 1). As shown in Table 2, while the first principal component (PC1) comprises E1_{12kHz}, E2_{12kHz}, E1_{38kHz} and E2_{38kHz} by respectively 45.56%, 67.57%, 47.89% and 41.86%, PC2 comprises most of the rest of those in PC1, and PC3 mostly comprises D by 91.58%. Fig. 6 shows a 3-D scatter plot of new score variables in new coordinate systems (Principal Components (PC) 1, 2 and 3).

Table 1. Variance of each component and cumulative variance.

Component	Eigenvalues		
	Total	% of Variance	Cumulative %
1	2.074	41.485	41.485
2	1.306	26.121	67.606
3	1.072	21.431	89.037
4	0.297	5.943	94.980
5	0.251	5.020	100.000

Table 2. Component loading and variance of each feature variable on the three retained principal components.

Feature variable	Component					
	1		2		3	
	Component loading	Variance [%]	Component loading	Variance [%]	Component loading	Variance [%]
E1 _{12kHz}	0.675	45.6	-0.618	38.2	-0.161	2.6
E2 _{12kHz}	0.822	67.6	0.424	18.0	0.103	1.1
E1 _{38kHz}	0.692	47.9	-0.524	27.5	0.346	12.0
E2 _{38kHz}	0.647	41.9	0.683	46.6	-0.015	0.0
D	-0.215	4.6	0.051	0.3	0.957	91.6

The three new retained score variables are then subjected to a nonhierarchical classification, the K-mean technique (Bailey and Gatrell, 1995), to provide clusters corresponding to separable seabed categories. The K-mean functions by first arbitrarily partitioning the score variables in 4 initial clusters, 3 determined from photographs and 1 reserved for outliers, and then proceeding through the score variables, assigning a score variable to the cluster whose

centroid is nearest. The distance used is the normalised Euclidean distance. The next step is to recalculate the centroid for the cluster receiving the new member and also for that losing the member. The last step is to repeat the previous steps for the remaining score variables until no more reassignments take place (Bailey and Gatrell, 1995). The Euclidean distances of the four classes are given in Table 3. Fig. 7 shows scatter plots of new score variables in new coordinate systems (PC1 versus PC2 and PC1 versus PC3) together with 4 classes. Stars are outliers, circles are hard/smooth, squares are hard/rough, and triangles are soft/smooth. Fig. 8 shows the segmentation of bottom types along the vessel's track.

Table 3. Euclidean distances between classes. 1=outliers; 2=hard/smooth; 3=hard/rough; 4=soft/smooth.

Class	1	2	3
2	4.867		
3	3.300	1.611	
4	4.410	1.900	2.028

Conclusions.

The method presented in this paper has shown that a combination of the multiple bottom echoes technique of RoxAnn and multivariate analysis applied to the acoustic data provided by the stand-alone echosounder can be used for bottom classification. This requires that both first and second acoustic bottom echoes are available. In order to produce a full spatial coverage map of bottom types in this area, much closer transect spacings appear necessary. Photographs appear to agree with the bottom classification technique used in this study. For a full photograph analysis however, it is necessary to accurately know the distance between the camera and the seabed for each shot. Future work are to include 120 kHz data and to find the correlation, if any, between bottom types and fish communities above them.

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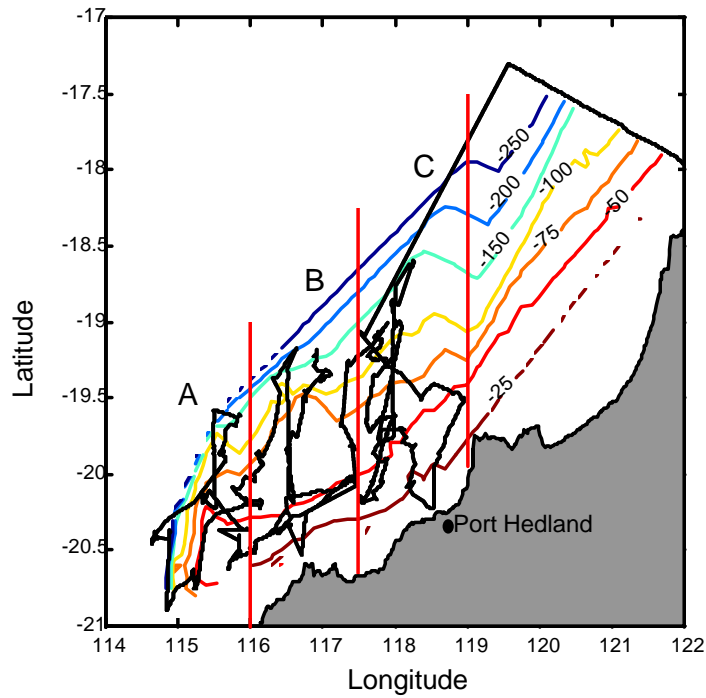


Fig. 1. The study area, bathymetry and transects used in the survey. A is the Barrow Island zone; B is the Legendre zone; C is the Port Hedland zone.

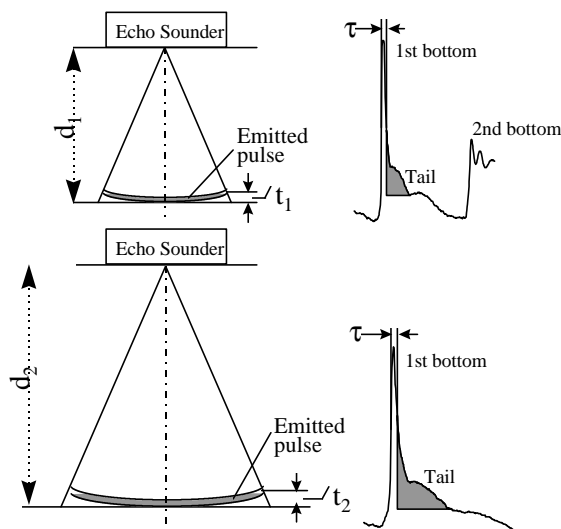


Fig. 2. Effect of spreading beam pattern on length of pulse of first acoustic bottom returns.

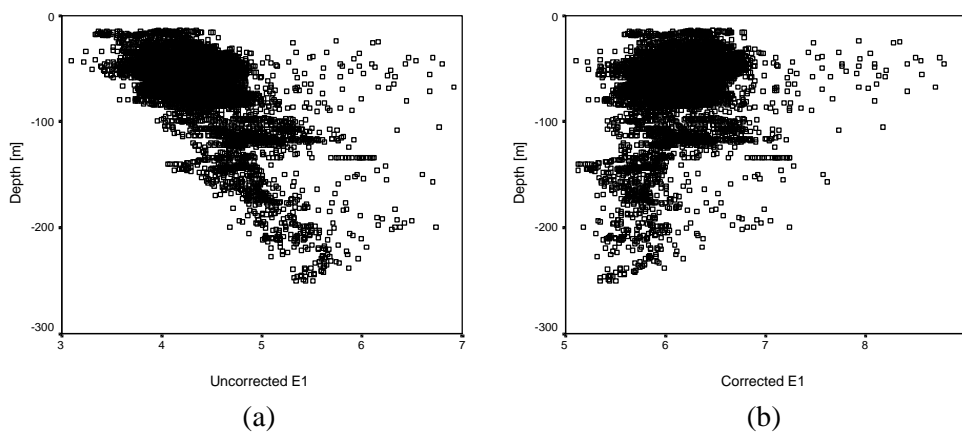


Fig. 3. Scatter plots of E1 at 12 kHz versus depth for (a) uncorrected E1 (b) corrected E1.

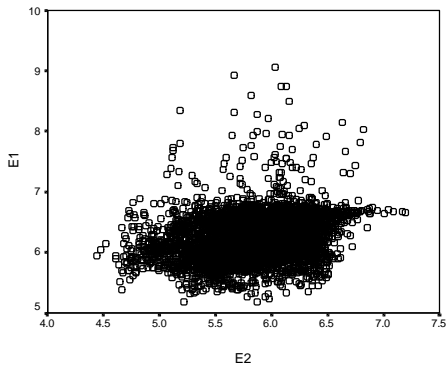


Fig. 4. Scatter plot of E2 versus E1 at 12 kHz.

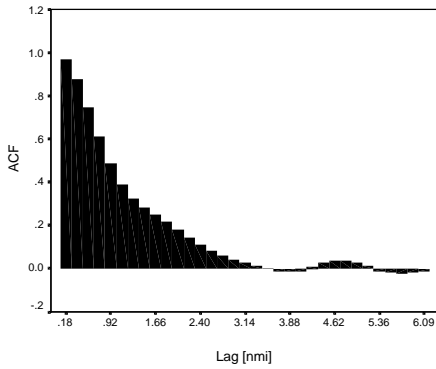


Fig. 5. Autocorrelation of E1 at 38 kHz for one particular transect.

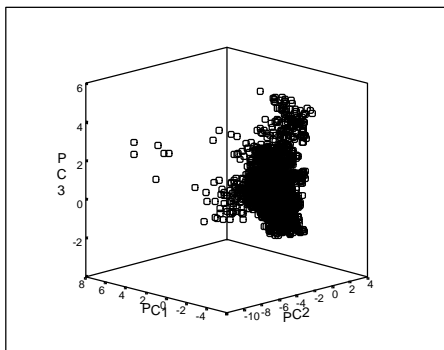


Fig. 6. 3-D scatter plot of score variables derived from principal component analysis in the first three principal components, PC1, PC2 and PC3, which accounts for 89.04% of the total variation of the original feature variables, E1 and E2 at 12 and 38 kHz, and depth.

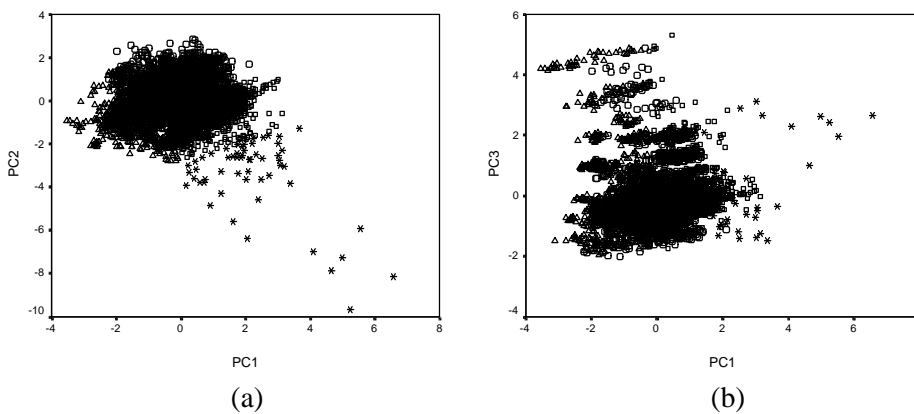


Fig. 7. Scatter plot of the score variables together with the four classes: (a) PC1 and PC2 (b) PC1 and PC3. * = outliers; o = hard/smooth; \square = hard/rough; Δ = soft/smooth.

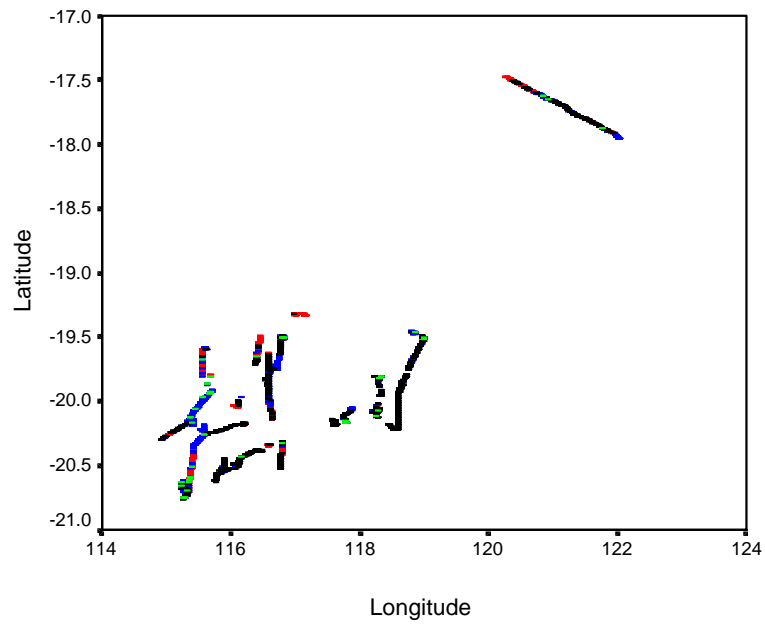


Fig. 8. Segmentation of bottom types in 4 different classes along the vessel's track. Green=outliers; black=hard/smooth; blue=hard/rough; red=soft/smooth.