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Bottom Classification in the Continental Shelf: A Case Study for the North-west and South-east Shelf of Australia

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Abstract

Bottom classification has been conducted in the north-west and south-east continental shelf of Australia as a part of a CSIRO management program in those areas. Data used in this presentation were collected in the South East continental shelf of Australia from July to mid December 1996 and in the North West Shelf region of Western Australia between late July and mid August 1995, 1997. Acoustic data were collected by using a stand-alone EK 500 SIMRAD scientific echosounder operating three different frequencies; 12, 38 and 120kHz. Multiple echo energies were analysed using multivariate statistical tools to classify bottom features. The logarithm of the integration of the tail of the first bottom echo was used as a roughness index and the entire second bottom echo was used as a hardness index. A principal component analysis was used to identify echo components that provided the greatest contribution to seafloor classification. Class assignments were based on the iterative relocation technique. Results of bottom classifications on the two continental shelves and benthic assemblages overlaid to the acoustically derived bottom classification will be presented.

Introduction

The practice of resource mapping making extensive use of satellite remote sensing and airborne platforms is well established for terrestrial management. Marine biological resource mapping however is not readily available except in part from that derived for surface waters from satellite based ocean colour mapping. Perhaps the most fundamental reason is the sampling difficulty, which involves broad areas of seabed coverage, irregularities of seabed surface and depth.

Fishermen have traditionally used the first acoustic bottom echoes from a normal incidence echosounders for seabed characterisation. Only recently has attention been given to the potential use of acoustic bottom echoes from normal incidence echosounders for seabed classification in marine ecological applications. Commercial bottom classifiers available in the market that use normal incidence echosounders are the RoxAnn and QTC View systems. Both systems use shape and energy features contained in the range corrected acoustic bottom signals. Orlowski (1984) and Chivers *et al.* (1990) have used the energy features contained in the first and second acoustic bottom echoes as seabed descriptors, and Heald and Pace (1996) provide the theoretical background of relationships between energy features of the two echoes and seabed parameters. Lurton and Pouliquen (1992) and Collins *et al.* (1996) on the other hand use only a detailed analysis of the first acoustic bottom echoes. Only recently have studies on marine biological resource mapping of benthic communities used these acoustic techniques. Examples include Magorrian *et al.* (1995), Greenstreet *et al.* (1997), Kaiser *et al.* (1998), Sorensen *et al.* (1998) using the commercial RoxAnn system, Prager *et al.* (1995) using the commercial QTC-view system, and Bax *et al.* (1999), Siwabessy *et al.* (1999) and Kloser *et al.* (in press) using the RoxAnn-like technique of the energy features of the first and second acoustic bottom returns.

This paper describes methods used to classify the bottom type from echosounder records obtained during surveys of fisheries resources in the North-west continental shelf of Western Australia between late July and mid August 1995, 1997 and in the South-east continental shelf of Australia from July to mid December 1996. The approach used in this paper is similar to that used in the commercial RoxAnn system. In grouping bottom types however, multivariate analysis (PCA and CA) is adopted instead of the allocation system normally used in the RoxAnn system, called RoxAnn squares.

Reflection of acoustic wave from the bottom surface

Strictly speaking, acoustic waves incident on a boundary including seawater-seabed interface involve reflection and scattering at the boundary and transmission in the second medium. This process is determined primarily by the acoustic impedance ($Z = \rho c$) mismatch between media. In the simplest case of plane, normal incidence waves, the acoustic pressure reflection coefficient $\Re$ is defined as

$$\Re = \frac{p_i}{p_r} = \frac{Z_l - Z_u}{Z_l + Z_u} = \frac{\rho_l c_l - \rho_u c_u}{\rho_l c_l + \rho_u c_u} \qquad (1)$$

where p_i and p_r are respectively the incident and reflected wave pressures, Z is the acoustic impedances, ρ is the density of the media, c is the sound speed, and u and l denote upper and lower media respectively. Although this formulation is based on and valid for a fluid-fluid interface, it is still applicable to the liquid-solid boundary and is the first, simplest approximation for the seawater-seabed interface. Kloser *et al* (in press) have listed a number of factors causing the reflected bottom signals to be different from the incident acoustic pulses; (1) Acoustic impedance mismatch of the seawater-seabed interface leading to surface scattering of the main pulse. (2) Acoustic parameters of the instrument. (3) Acoustic signal penetration into the seabed leading to volume scattering of the main pulse. (4) Directional reflections at the seawater-seabed interface because of seabed roughness. (5) Time delay of oblique returns because of spherical spreading with changing depth. (6) Scattering response from the sea surface, subsurface bubbles and vessel hull for the second acoustic bottom return. (7) Seabed slopes. (8) Seawater acoustic absorption. (9) Acoustic noise.

Neglecting acoustic absorption, the following relationship holds for normal incident echosounders (Brekhovskikh and Lysanov, 1982; Orlowski, 1984)

$$4\pi \int_0^{\theta_0} m_s(\theta,\omega) \sin 2\theta d\theta \le \frac{\langle p^2 \rangle}{p_0^2} \le \Re^2 \qquad (2)$$

where $m_s(\theta,\omega)$ is the acoustic scattering coefficient, ω is the angular frequency, θ is the incident angle of the acoustic wave on the bottom, θ_0 is the half beamwidth, $\langle p^2 \rangle$ is the average square of the received pressure, p_0 is the received acoustic pressure from an ideal reflecting surface and $\Re$ is the acoustic pressure reflection coefficient of a smooth boundary.

For acoustic frequencies of interest in the present work, seabed surfaces are in general rough. It is therefore critical to consider the scale of the roughness with reference to the insonifying wavelength. $k\sigma$, where k is the acoustic wave number and σ is the rms deviation from the surface irregularities, is a common expression to scale the surface roughness. For $k\sigma << 1$, the normal incident backscattered return is coherent and the amplitude is determined by the reflection coefficient. For $k\sigma >> 1$, the magnitude of the coherent returns is much reduced. In addition, the distribution of the return signal from rough interfaces varies. Appropriate representations are Gaussian ($k\sigma << 1$) and Rayleigh ($k\sigma >> 1$). In general, signals of the acoustic bottom return comprise coherent and incoherent components (Brekhovskikh and Lysanov, 1982; Pace and Ceen, 1982; Orlowski, 1984) and the total average square of the returned acoustic pressure may be written as

$$\langle p^2 \rangle = p_c^2 + \sum_s p_{ic(s)}^2 \qquad (3)$$

where p_c is the received acoustic pressure due to the coherent returns, i.e. the reflected components and p_{ic} is the received acoustic pressure due to incoherent returns, i.e. the "scattered" component of the return signals. A tail present in the received signals significantly longer than the transmitted ones may be attributed to the incoherent component (Pace and Ceen, 1982). Applying the concept depicted in equation (2) into equation (3), Orlowski (1984) defines the total acoustic pressure reflection coefficient as

$$\langle \Re^2 \rangle = \Re_c^2 + 4\pi \int_0^{\theta_0} m_s(\theta) \sin\theta d\theta \qquad (4)$$

$$\langle \Re^2 \rangle = \Re_c^2 + \Re_{ic}^2 \qquad (5)$$

Backscatter of the first and second acoustic bottom returns

Focusing on the second term of equations (4) and (5), Heald and Pace (1996) try to relate energy features from the first acoustic bottom returns and roughness parameters. Figure 1 shows the geometry of the first backscatter return from the seabed. For an incremental area dA_1 far from the axis, the first backscatter return becomes incoherent. Total backscatter return is subject to the sum of all backscatter return from all areas. Following Heald and Pace (1996), the received acoustic pressure may be expressed as

$$p_{bs1}^2 = p_0^2 \int_{\theta_a}^{\theta_b} \frac{m_s(\theta_1) G^2(\theta_1)}{(R_0')^4} dA_1 \qquad (6)$$

where p_0 is the source pressure at a distance of 1 m from the source $dA_1 = 2\pi R_0'^2 \tan\theta_1 d\theta_1$, $R_0' = R_0\sqrt{(1 + \tan^2\theta_1)}$, $G(\theta_1)$ is the transducer gain and $m_s(\theta_1)$ is the acoustic scattering coefficient; $m_s(\theta_1) \propto \Re^2$ and $m_s(\theta_1) \propto (\sigma/T)^2$ where σ is the rms height of the surface roughness and T is the correlation length of the surface roughness. Heald and Pace (1996) further suggest that the integration limit of the intensity envelope of the first backscatter return from the seabed is in the region where the insonified area is an annulus when $ct/2 > c\tau/2$, i.e. $\sqrt{c(t-\tau)/R_0} \le \theta_1 \le \sqrt{c\tau/R_0}$.

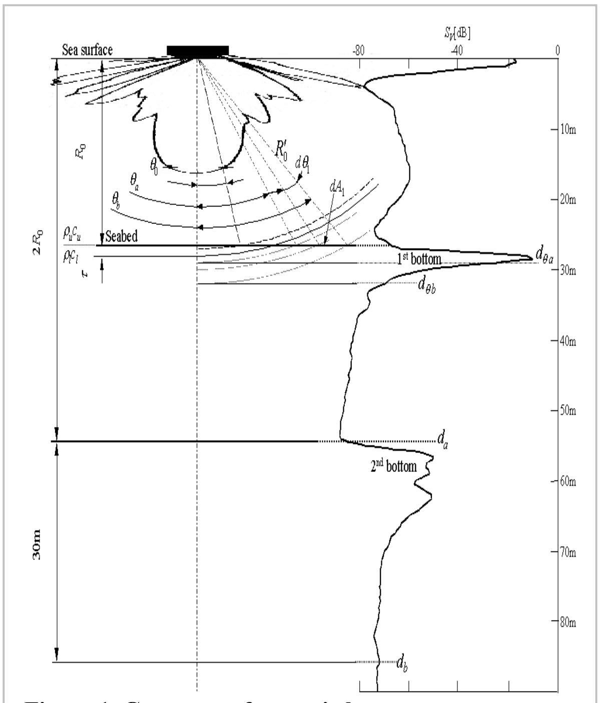


Figure 1. Geometry of acoustic bottom returns.

Orlowski (1984) used a monostatic geometry for treatments of the second backscatter return from the seabed whereas Heald and Pace (1996) used an on axis bistatic geometry. In the present work, the monostatic geometry is appropriate. Assuming the total acoustic pressure reflection coefficient is a best descriptor of the seabed hardness, the received acoustic pressure from the second backscatter return from the seabed must include coherent and incoherent components, i.e. the integration limit includes complete returned envelope. While the acoustic scattering coefficient $m_s(\theta_1)$ for the first acoustic bottom return is proportional to the square of the acoustic pressure reflection coefficient $\Re$, it is proportional to the 4th power of the acoustic pressure reflection coefficient $\Re$ for the second acoustic bottom return. For the second backscatter return from the seabed, the complete returned envelope is required and is obtained when $ct/2 \le c\tau/2$ and $ct/2 > c\tau/2$ (Heald and Pace, 1996).

Acoustic instrumentation and data analysis

A collection of acoustic bottom returns were conducted from the *RV Southern Surveyor* using a SIMRAD EK 500 echosounder operating three different frequencies, 12, 38 and 120 kHz. The 12 kHz transducer was a single beam unit whereas the 38 and 120 kHz transducers were split beam transducers. The echosounder was routinely calibrated with a 42 mm tungsten carbide calibration sphere. The volume reverberation signal S_v in logarithmic form implemented in the SIMRAD EK 500 echosounder is as follows

$$10\lg_{10}(s_v) = 10\lg_{10}(P_r) + 10\lg_{10}(r^2 10^{2\alpha r}) - 10\lg_{10}\left(\frac{P_t G_0^2 r_0^2 \lambda^2 c\tau\psi}{32\pi^2}\right) \quad (7)$$

Acoustic volume reverberation S_v data were continuously logged using *ECHO*, a software package developed by CSIRO Marine Research (Waring *et al.,* 1994; Kloser *et al.,* 1998).

Prior to analysis of the first and second acoustic bottom returns, recorded acoustic data were quality checked using the *ECHO* software. Faulty records mainly due to aeration usually caused by strong winds or sea-state or combination of the two were marked bad and excluded from further analysis. The RoxAnn E1 and E2 parameters were adopted. For analysis of acoustic bottom returns, the *ECHO* software provides several algorithms including a constant angular algorithm; see equation (6). This algorithm ensures that a constant angular sector of the incoherent field, irrespective of depth changes, is used for the integration of the first acoustic bottom backscatter. After several trials, the integration limit (θ_a and θ_b in equation (6) and Figure 1) after the falling edge of the acoustic pulse was between 27.4° and 40° for 12 kHz data and between 20° and 31.6° for 38 and 120 kHz data. Depths (after the bottom) corresponding to θ_a and θ_b varied with changing water depths and were estimated by

$$d_{\theta i} = R_0/\cos\theta_i - R_0 + \tau \quad (8)$$

where R_0 is the bottom depth in meters and τ is the pulse length offset in meters. A constant depth algorithm was used for the integration of the complete envelope of the second acoustic bottom backscatter. The integration limit was defined as starting from twice the water depth (d_a) and ending at twice the water depth plus 30 m (d_b); see Figure 1. To reduce variability between pings in the backscatter returns and to standardise on a unit of length sampled, the integration was averaged over an along-track interval of 0.05 nmi. The integration of acoustic volume reverberation resulted in area backscatter coefficients that stem from fisheries acoustics for biomass assessments and are adopted as a relative measure of acoustic energy for scattering from the seabed

$$\bar{s}_A = 1852^2 4\pi \frac{\sum_{p=1}^{m} \delta d \sum_{d=d_a}^{d_b} s_{v(dp)}}{m} \quad (9)$$

where s_v is the linear volume backscattering coefficient. E1 and E2 parameters are obtained by taking the logarithm of the corresponding $\bar{s}_A$ values.

Seabed classification

To reduce the dimensionality of the acoustic data, Principal Component Analysis (PCA) was applied to the E1 and E2 data sets separately. PCA is in general a data transformation technique. It attempts to reduce the dimensionality of a data set formed by a large number of interrelated variables but retains sample variation (information) in the data as much as possible. The process includes an orthogonal transformation from the axes representing the original variables into a new set of axes called principal components (PCs). The new axes or the PCs are uncorrelated one to another and are ordered in such a way that the first few PCs hold as much of the total variation as possible from all the original variables. While PCs from the geometric point of view are orthogonal projections of all the original variables, PCs algebraically are linear combinations of the original variables. In addition, a linear combination of variables is an essential concept in multivariate analysis and is indeed fundamental to PCA.

Cluster Analysis (CA) was then performed to the first few PCs, hopefully only the first PC, of E1 and E2. This study used the iterative relocation technique (*k*-means method) for cluster analysis. This technique employs either the fixed, prespecified number of classes or seeds of initial centroids of known classes or combination of the two. The latter was adopted in this study. Firstly, a training set comprising distinct types of the seabed based on underwater photographs (for North-west shelf (NWS) region) and reference sites (for South-east shelf (SEF) region) was set up. Results from the training set then became the seeds of the initial centroids. Using these seeds of initial centroids, the iterative relocation technique was eventually performed on the rest of the data.

Results

E1 results were obtained by implementing a constant angular algorithm in an attempt to ensure that the proportion of the tail sector being integrated is independent of depth (Figure 2(a)). Figure 2(a) is a representative example of a scatter plot of E1 parameter versus depth for 12 kHz data from the SEF data sets. In Figure 2(b), a scatterplot of E2 parameter against depth at the same for the same data sets. Again, E2 is independent of depth.

Results from PCA applied to the E1 and E2 parameters showed that only the first PC of E1 and E2 separately held most of the variation of the original E1 and E2 separately. It turns out that the first PC of the E1 and E2 parameters are simply the average of the original E1 and E2 respectively. The first PC of E1 and E2 accounted for more than 70% of the total variation of the original E1 and E2 respectively. This indicates a quite high correlation between E1 from the three frequencies and between E2 from the three frequencies as well.

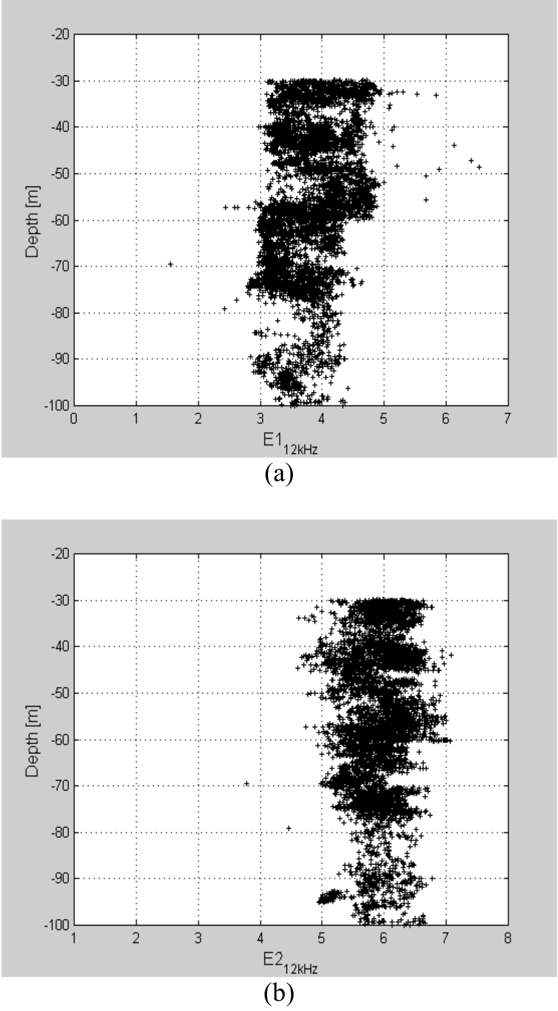


Figure 2. Scatterplot of (a) E1 versus Depth and (b) E2 versus Depth at 12 kHz from NWS data set.

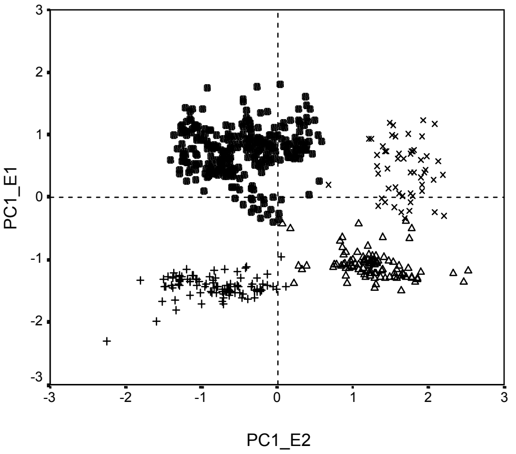
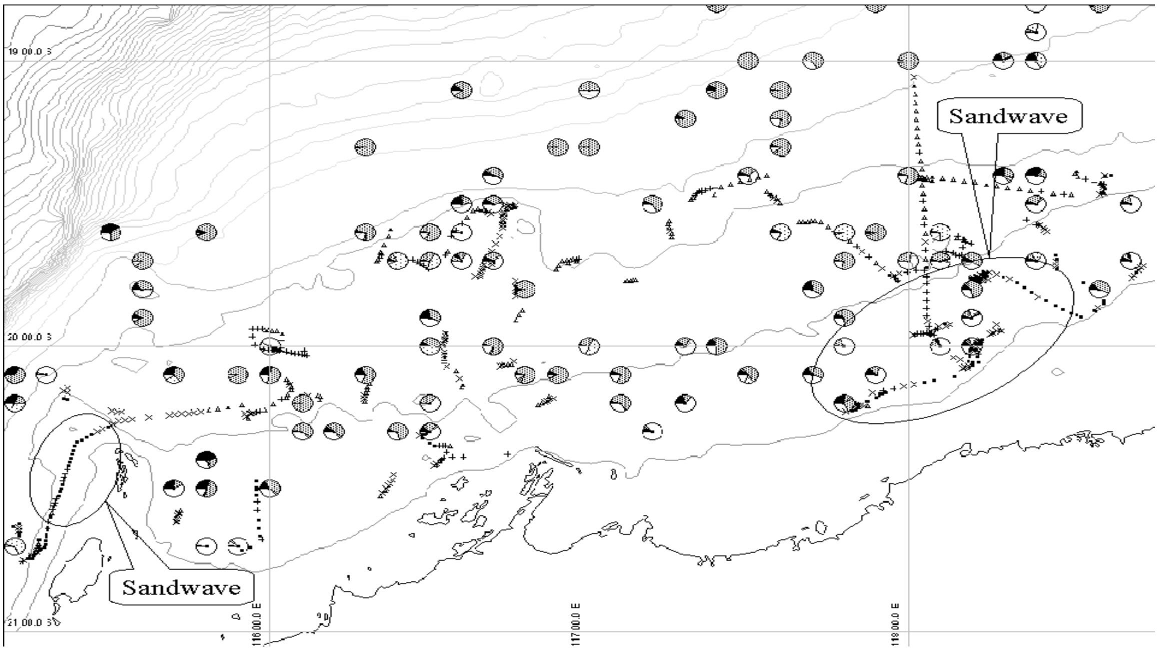
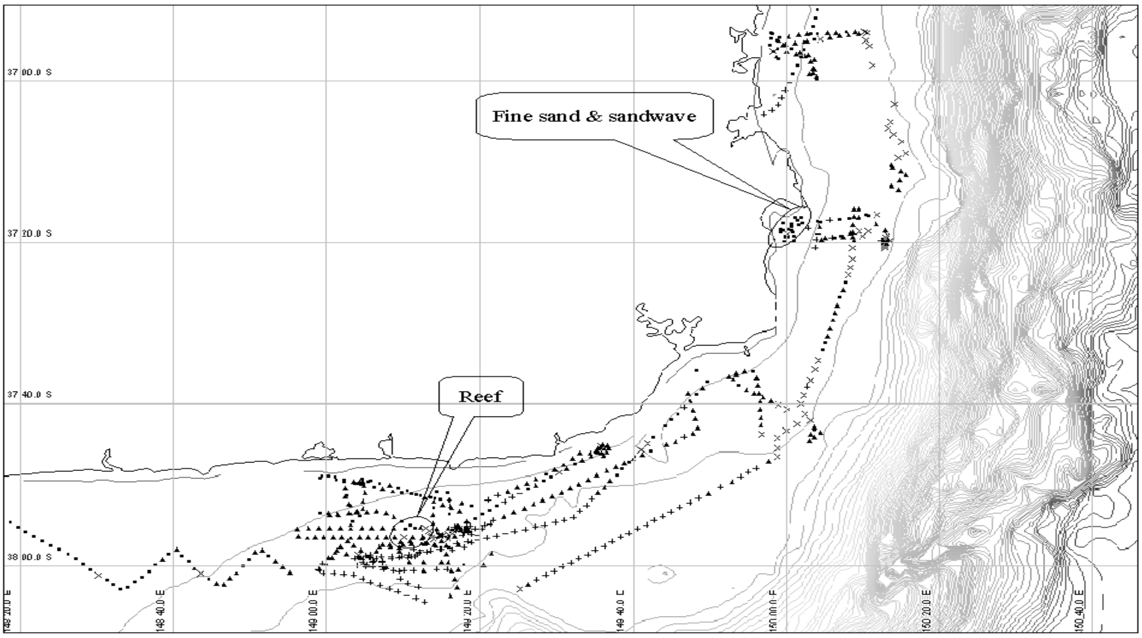


Figure 3. Scatterplot of PC1 of E1 vs PC1 of E2. × = Hard-Rough; ● = Soft-Rough; + = Soft-Smooth; Δ= Hard-Smooth.



(a) NWS region



(b) SEF region

Figure 4. Along-track segmentation of seabed types. For the along-track segmentation, × = Hard-Rough; • = Soft-Rough; + = Soft-Smooth; Δ= Hard-Smooth. For pie charts, □ = Hard-Rough; ⬚ = Soft-Rough; ▩ = Soft-Smooth; ■ = Hard-Smooth.

In their study of the assemblage of benthic habitats in the NWS region based on the underwater photographs, Sainsbury *et al.* (in prep.) suggested a classification involving 5 different benthic habitats. In the present work, two of the benthic habitats were not distinguishable acoustically. The acoustics results presented here support 4 distinct seabed types, based on the underwater photographs taken in the NWS region and on reference sites in the SEF region. Figure 3 shows a representative example of the training set comprising four distinct seabed types in the SEF region. It is evident that the four classes in Figure 3 are well separated. Segmentation of bottom types along the vessel's track is shown in Figure 4(a) for the NWS region and Figure 4(b) for the SEF region. For the

NWS region, benthic habitats from Sainsbury *et al.* (in prep.) are included in Figure 4(a).

Conclusions

The method that combines the multiple bottom echo techniques from normal incident echosounder and multivariate analysis can be used for seabed classification. There is general agreement between derived seabed types and available supportive information. Distances over which variations of along-track bottom types occurred were shorter in the NWS study area than in the SEF study area. This indicates that the local variations are greater in the NWS study area than in the SEF study area. This might be related to the fact that the NWS study area is located in the tropics whereas the SEF study area is in the temperate and higher latitude region. A high diversity and a moderate abundance of resources are characteristic of the tropical region. The temperate and higher latitude region is on the other hand characterised by a lower diversity and a higher abundance of resources. A higher local variation of the bottom type in the NWS study area might be an indication of a higher diversity of resources which is expected to occur in the tropics.

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