DEPARTMENT OF DEFENCE
DEFENCE SCIENCE & TECHNOLOGY ORGANISATION
DSTO

Acoustic Seabed Classification Systems

L.J. Hamilton

DSTO-TN-0401

Acoustic Seabed Classification Systems

L.J. Hamilton

Maritime Operations Division
Aeronautical and Maritime Research Laboratory

DSTO-TN-0401

ABSTRACT

In the last decade acoustic bottom classification devices have been developed which can routinely provide inferences of seabed texture and grain size or habitat while a vessel is underway. These devices can be attached to existing echosounders on vessels without affecting sounder operation, or to inexpensive fish finding echosounders, enabling real-time indications of bottom type after initial system calibration is made. Aspects of these acoustic bottom classification systems are broadly described. Topics covered are principles of operation, trials of the RoxAnn and QTC View systems, other commercially available systems, algorithms, usage, and approaches to classification. Data processing and calibration methods used by various authors are listed. It is important to note that acoustic seabed classification systems are essentially empirical devices which may work well for some bottoms but not others. To enable their more informed usage, some of the performance strengths and limitations of acoustic bottom classification systems are outlined.

RELEASE LIMITATION

Approved for public release

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE & TECHNOLOGY ORGANISATION
DSTO

AQ F02-04-0647

Published by

DSTO Aeronautical and Maritime Research Laboratory
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

AR-012-069
November 2001

APPROVED FOR PUBLIC RELEASE

Acoustic Seabed Classification Systems

Executive Summary

Many spheres of operation have a requirement for assessments of seabed bottom type, e.g. defence (mine countermeasures), environmental (habitat mapping and protection), economic (fisheries, mining), and maritime (dredging of harbours and channels). In the past this could only be done with time consuming point sample taking or diver and video observations. Samples must still be taken, but in the last decade acoustic bottom classification devices have been developed which can routinely provide estimates of seabed texture and grain size or habitat while a vessel is underway. These devices can be attached to existing echosounders on vessels without affecting sounder operation, or to inexpensive fish finding echosounders, enabling real-time indications of bottom type after initial system calibration is made. Calibration is made by visiting areas with known bottom type, and noting or recording the system response at these sites. Classifications are therefore not absolute, and are also a function of echosounder characteristics e.g. frequency and beamwidth. It is the general experience that useful classifications can be obtained with these acoustic systems if due care is taken, although performance is subject to a range of degradation effects, and calibration is not always easy or unambiguous.

There are two principal types of acoustic bottom classification systems, one using multiple echo energy methods, and the other using a first echo shape approach. General information on use and performance of these different systems is scattered over a wide variety of reports and there is not yet a common pool of knowledge on them which can be readily accessed by potential users. This report attempts to provide some of the background necessary for informed use of acoustic bottom classification systems through broad descriptions of algorithms, usage, data processing and calibration methods, and an assessment of their strengths and weaknesses. It is not a rigorous exposition and makes no claims to completeness.

Contents

1. Introduction

1.1 The requirement for seabed classification

Many spheres of maritime operations have a requirement for assessments of seabed bottom type, e.g. defence (mine countermeasures), environmental (habitat mapping and protection), economic (fisheries, mining), and maritime (dredging of harbours and channels). In the past this could only be done with time consuming point sample taking or diver and video observations. Samples must still be taken, but in the last decade acoustic bottom classification devices have been developed which can routinely provide estimates of seabed texture and grain size or habitat while a vessel is underway. This is achieved by attaching signal processing systems in parallel with the transducers of vertical incidence echosounders on ships, which operate at tens to hundreds of kilohertz.

These devices can be attached to existing echosounders on vessels without affecting sounder operation, or to inexpensive fish finding echosounders, enabling real-time indications of bottom type after initial system calibration is made. Calibration is made by visiting areas with known bottom type, and noting or recording the system response at these sites. Classifications are therefore not absolute, and are also a function of echosounder characteristics e.g. frequency, pulse length, pulse shape, and beamwidth. It is the general experience that useful classifications can be obtained with these acoustic systems if due care is taken, although performance is subject to a range of degradation effects, and calibration is not always easy or unambiguous.

There are two principal types of commercially available acoustic bottom systems, one using multiple echo energy methods, and the other using a first echo shape approach. This report non-rigorously describes algorithms, usage, data processing and calibration methods for these two types of systems. An assessment is made of the strengths and weaknesses of acoustic bottom classification systems, and methods are suggested on how to improve the classifications obtained from them. However, no claim to completeness is made for matters covered. Actual methods of software and hardware usage are documented in manufacturer's handbooks, and are not repeated here, and mathematical and theoretical details relating to acoustical backscatter and classification are omitted. Note that acoustic bottom classification systems are also known as *acoustic ground discrimination systems.*

1.2 Defence requirements

Several different types of defence systems and activities require knowledge of seabed properties for optimal operation. The required seabed properties can be grouped into geotechnical (mechanical) and acoustical types. A few examples follow.

Minehunting sonars require knowledge of seabed properties such as acoustic backscatter strength to predict probability of mine detection for different bottom types; and to tune or select the type of acoustic frequency or system best suited for particular bottom types. This application is the primary reason for the present work. Acoustic backscatter strength is a function of grain size and larger scale roughness elements e.g. sand ripples and shell beds. Sonars utilising bottom bounce paths require knowledge of acoustic attenuation coefficients of the seabed and backscatter or seabed reverberation for prediction of detection range and target strength. Amphibious operations require knowledge of bottom geotechnical properties such as trafficability, bearing strength, location of underwater obstacles and rough topography. Engineering structures such as noise ranges and tracking ranges require knowledge of bottom acoustical and geotechnical parameters for optimal acoustical and mechanical design considerations. Moored structures require details of geotechnical parameters.

2. Methods of characterising the bottom

Various methods of characterising the bottom may be adopted depending on the purpose of the classification e.g. for sediment characterisation, object detection, searches for buried objects or palaeochannels, searches for subsurface mineral deposits, and so on.

2.1 Mechanical sampling and probing

Mechanical sampling is the best way to get information on the seabed, but is costly in terms of time and effort. Grabs, cores, and divers are used to obtain sediment samples for assessments of sediment properties in the field, and for subsequent geological and engineering measurements e.g. grain size analyses, measurements of bulk properties (e.g. sediment density), chemical analyses, and estimates of bearing strength (ability to carry a load) and shear strength (resistance to deformation). As a particular RAN example, visual descriptions of wet sediments are made by RAN agencies in the field using simple methods prescribed by the Hydrographic Office (1991). Assessment of these visual descriptions has shown them to be reliable and repeatable, and able to be broadly related to grainsize triangles (Hamilton 1999). Quantitative estimates of acoustic reflectivity and backscatter strength may be modelled from grainsize, bulk density, and other parameters (Applied Physics Laboratory 1994). Expendable and non-expendable probes known as penetrometers which are fitted with accelerometers may be dropped into the bottom to estimate bearing strength profiles, which are used to predict mine burial on impact. Measurements of grainsize, bearing strength, and shear strength of the sediment can also be used for this purpose.

2.2 Remote Sensing Methods

Remote sensing methods for inference of seabed properties may utilise acoustics, optics (diver reports, photography, video, LADS, LANDSAT visible imagery); radar (detection of surface and sub-bottom features e.g. sand waves; ground penetrating radar for mine detection in dry soil); and electro-magnetics (detection of subsurface layers). See Anon (1996) and Kvitek et al (1999) for discussion on a wide range of remote systems useful for habitat mapping in particular. The present document is concerned with vertical incidence acoustic systems attached to conventional (single beam) echosounders (Fig. 1), which obtain essentially point classifications of the seabed below the transducer. Acoustic examinations of the seabed surface may also use sidescan and multibeam swathe type sonar systems, and depending on frequency can also obtain subsurface information e.g. by use of seismic systems, parametric sonars, and chirp sonars.

Although referred to as vertical incidence to separate them from multibeam or sidescan swathe type sonar systems, acoustic bottom classification systems utilise information on both specular return and backscatter, and provide best information for wider angle beams e.g. 12 to 50°. Acoustic bottom classification essentially provides point coverage and classification along track, however successive along track points with similar classification can be joined in charts and displays to show locally homogenous areas, a process described by Spina et al (1999) as "line segmentation". Acoustic bottom classification values are actually integrations wholly or partly over a circular area under the transducer (Fig. 2), with the area of the circle being a function of water depth and transducer beamwidth, but the width of the circular area is usually much less than the swathe width of sidescan sonar, and can be viewed as point coverage. Note that sidescan and vertical incidence systems operate at mutually exclusive grazing angles, and might not 'see' the same bottom properties.

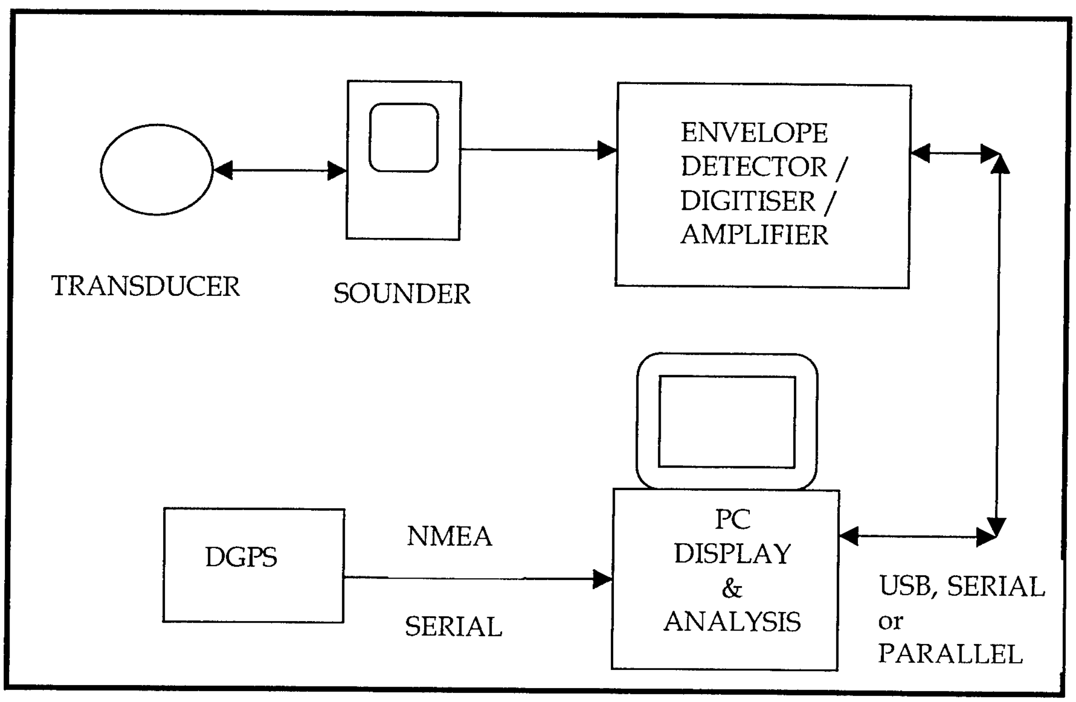

Figure 1. Schematic of an acoustic bottom classification system. Arrows show one-way or two-way information transfer.

3. Background to acoustic bottom classification

3.1 Principles of operation for acoustic bottom classification systems

The general empirical basis for acoustic bottom seabed classification is well established, although a full theoretical basis to describe interaction of the incident ping with the bottom is not. Acoustic bottom classification systems use wide beam echosounders (beamwidth typically 12-55°) to obtain information on seabed acoustic "hardness" (acoustic reflection coefficient) and acoustic "roughness" (as a backscatter coefficient). Pace et al (1998) discuss inversion approaches which could enable seabed geoacoustic parameters to be estimated from normal incidence data. SACLANTCEN have developed the BORIS model to return the time series response of the seafloor similar to the signal received by echosounders. However, it is doubtful whether inversions will allow reliable estimates of bottom type for the complicated and variegated seabed types experienced in the real world. Shell components in particular can cause unpredictable returns, and particular echo shapes need not have a unique cause.

3.1.1 Wavefront curvature and echo shape

Because of wavefront curvature a ping from an echosounder with a wide angle beam ensonifies first a circle on the seabed, then progressively ensonifies annuli of increasing radii and lower grazing angles (Fig. 2). If an amplitude envelope detector is used, then the signal recorded over a sampling interval is the total specular and backscatter return from some particular annulus. Echo shapes and energies depend on bottom acoustic hardness and roughness. The first part of the resulting echo shape (Fig. 3) is a peak dominantly from specular return, and the second part is a decaying tail principally from incoherent backscatter contributions. A smooth flat bottom returns the incident ping with its shape largely unchanged, but greater penetration into softer sediments attenuates the signal strength more than acoustically harder sediments. Rougher sediment surfaces provide more backscattered energy from the outer parts of the beam than smoother surfaces (which simply reflect the energy away from the direction of the transducer), so that a rougher surface is expected to have a lower peak and a longer tail than a smoother surface of the same composition. The length and energy of the tail provide a direct measure of acoustic roughness of the sediment surface. The echo shape is also a function of echosounder characteristics such as frequency, ping length, ping shape, and beam width. Acoustic penetration into the bottom and presence of subsurface reflectors can also affect echo shape through volume reverberation. Acquisition and classification of echo envelopes allows the bottom type to be inferred from the energy and/or shape characteristics of the echoes, by processes described in Section 3.2.

In reality the situation is more complicated as harder surfaces such as rock tend to have greater roughness and more random orientation of seabed facets than other sediments, resulting in widely varying return shapes and energies which can have an average signal strength resembling that of mud, if suitable averaging techniques are not used (Hamilton et al 1999). This phenomenon was noted many years ago in deep sea work, and has been "rediscovered" for acoustic bottom applications. "Regarding the reflection of sound by the ocean bottom, experimental studies ... have shown that sound reflection is determined by the parameters of the sediment only at comparatively low frequencies. At frequencies above a few kilohertz, bottom relief plays a dominating role. Reflection from a very rough rocky bottom may appear to be less than that from a muddy sediment" (Brekhovskikh and Lysanov 1982; section 1.9). Similarly, losses due to roughness effects can cause sand with ripples, sandwaves, holes, and scours to appear to some acoustic measures to have the same properties as mud. Suitable averaging of echoes can overcome much of this variability, however acoustic bottom classification results are sometimes ambiguous, a point which must always be remembered.

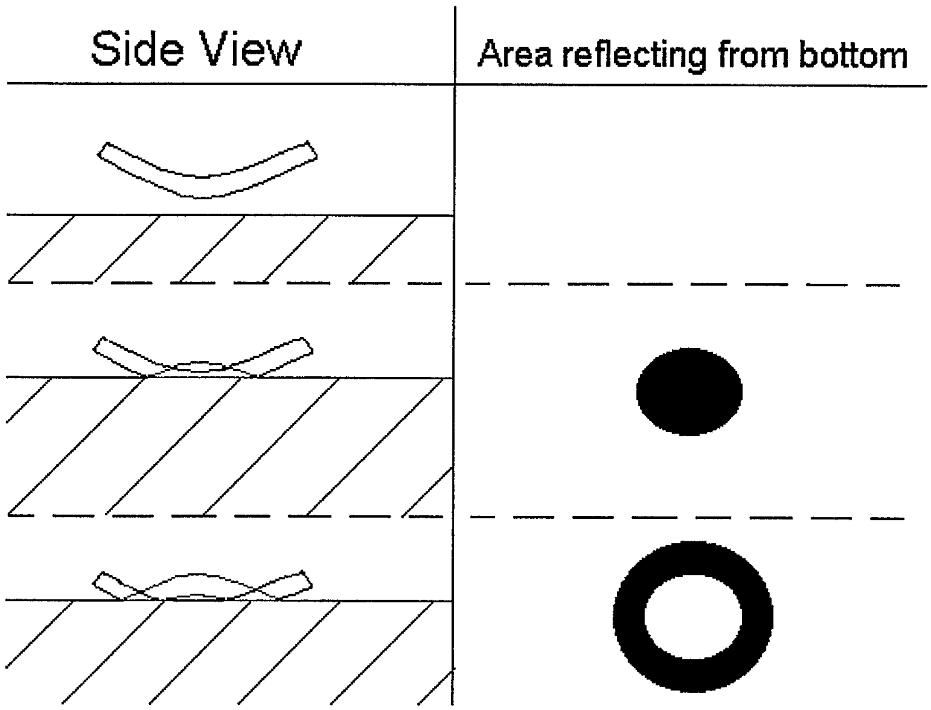

Figure 2. Interaction of an echosounder ping with the seabed (figure supplied by Andrew Balkin). The left hand side of the figure depicts the energy of the ping as it reflects from a horizontal seabed, and the right hand side shows the cross-section of the ping that is in contact with the seabed at the particular instant. In the centre frames, the back edge of the ping has not reached the seafloor, and a circle is ensonified. In the bottom frames, the back edge of the ping has already reached the seafloor, and an annulus is ensonified.

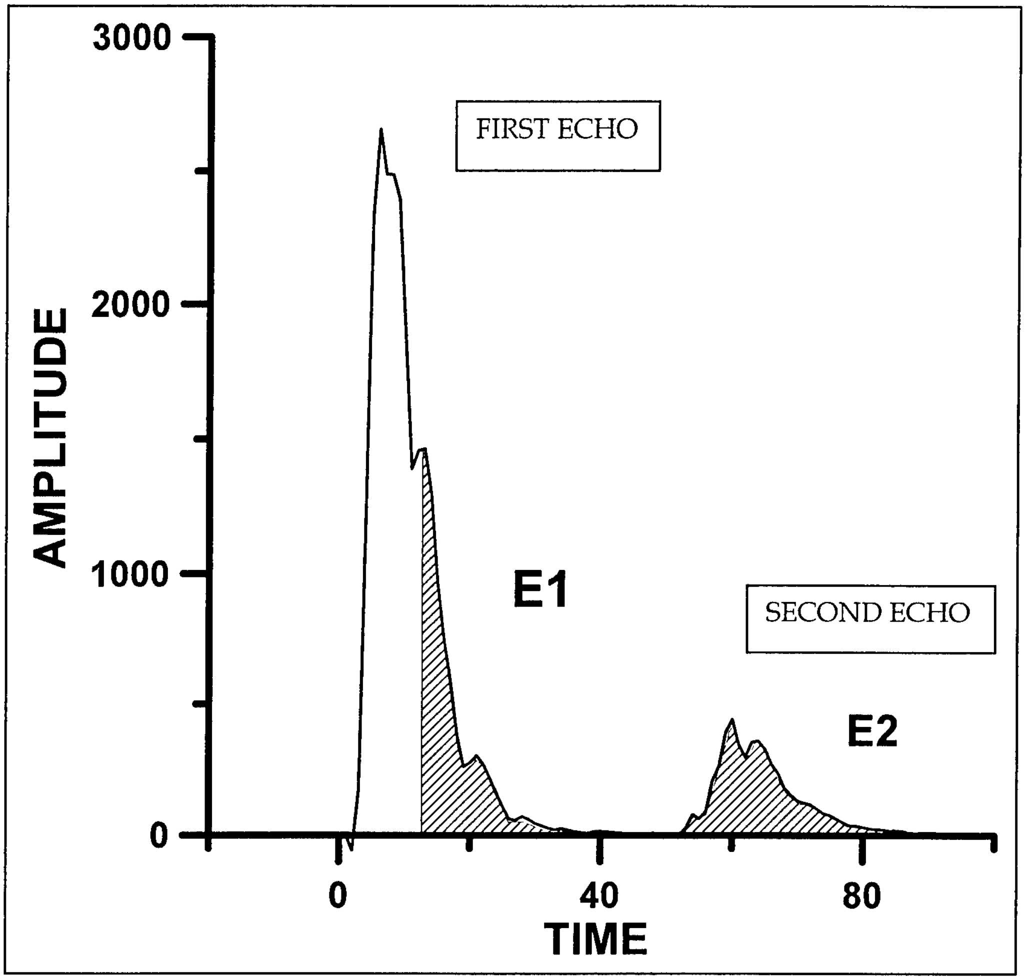

Figure 3. The parts of the first and second bottom returns used by the RoxAnn system. Energy of the shaded regions is integrated to form two indices - E1 (for the tail of the first echo – summation begins one pulse length from the echo start) and E2 (for all the second echo).

3.1.2 The need for a reference depth

The shape and power of the returned signal can change significantly with depth, even if the bottom type remains the same. Examples are given in Caughey et al (1994), Caughey and Kirlin (1996), and Fig. 4. The returns for a particular bottom type are expanded (dilated) along the time axis for a deeper bottom, and compressed in time for a shallower bottom, so that returns from the same bottom sediment type lying at different depths do not have the same shape. This occurs because signals are sampled or digitised at equal time intervals rather than at equal angles (Caughey et al 1994). More samples are obtained from one particular angle to another for a deeper bottom compared to a shallower bottom. Before the echoes can be processed they must be transformed to a reference depth e.g. average survey depth. Normalising echosounder waveforms to a reference depth allows signal sampling to correspond to a standard set of incidence angles, as opposed to a set of linearly spaced times (Caughey et al 1994). For a particular echosounder this conveniently removes the need to allow for beam patterns, and for the backscatter function changing with angle of incidence. Algorithms for the reference depth correction are given in Section 5.2. Spherical spreading corrections are also applied. Absorption can usually be neglected for short ranges for lower frequencies e.g. 50 kHz, but becomes increasingly significant at higher frequencies. Since the signal to noise ratio decreases with increasing depth, large depth variations over an area could influence these corrections adversely.

3.1.3 Averaging of returns

Return echo shapes can vary markedly over a small time interval, even for the same bottom type. As a result of ship and sensor movements and natural variability the returns from any particular angle are of a random nature, sometimes adding and sometimes subtracting as bottom facets lying at slightly different angles and depths are encountered. Echoes are also subject to noise, natural variability, and echosounder instability. To obtain acoustic signal stability ten pings are usually averaged. Over rougher terrain simple averaging may not help ping stability, and can act to reduce overall ping levels from their 'true' value, causing rocky surfaces to be classed as muds, a drawback of some commercial systems (Hamilton et al 1999). In this circumstance a smaller number of pings could be averaged or a different averaging method used e.g. Hamilton et al (1999) suggested using the average of the one-third highest values in a ping set, under the assumption that higher energy returns are least affected by roughness effects. A system developed by Biosonics allows selection of the highest value in a ping set, or averaging of values over a selected threshold (Burczynski 1999). However the current version v1.9 of the Biosonics system does not have depth normalisation - see Section 3.2.3 of the present document.

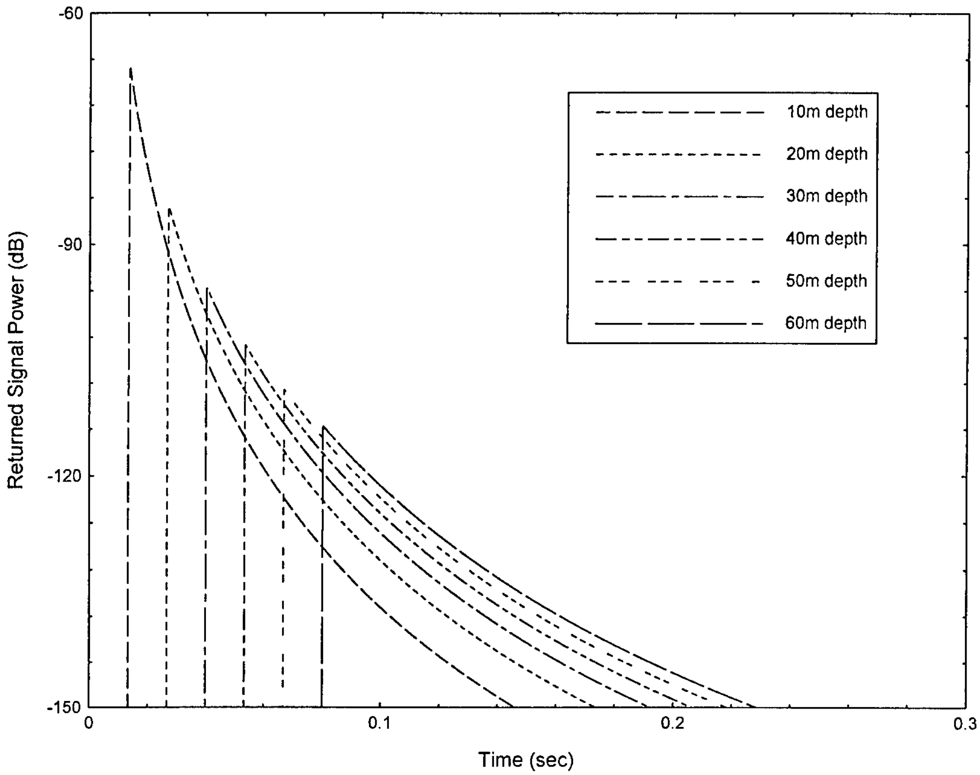

Figure 4. Effect of depth on echo shape for a very short ping. From Clarke and Hamilton (1999).

3.2 Practical approaches to acoustic bottom classification

Both single and multi-echo approaches to bottom classification are used by COTS (Commercial Off The Shelf) acoustic bottom classification systems, and shape and/or energy parameters are employed to characterise the echo properties. An experimental comparison of the two types of systems as embodied by RoxAnn and QTC-view has been made by Hamilton et al (1999).

3.2.1 The RoxAnn multi-echo energy approach

RoxAnn is a well known commercial system particularly used by the fishing industry which has been in use for a decade. The RoxAnn system uses a patented multi-echo energy classification method, where the energy of the second echo is used as one of two classification parameters, being a measure of acoustic "hardness" or reflectivity of the seabed (Burns et al 1989). The other parameter is the energy of the tail of the first echo, a measure of acoustic roughness or backscatter of the seabed, as noted in Section 3.1 (see Fig. 3).

The first echo is a direct reflection from the seabed, and the second has reflected twice at the seabed and once at the sea surface (and the vessel). The second echo has a transducer/bottom/sea surface/bottom/transducer path, i.e. it has interacted once with the sea surface (and hull of the vessel) and twice with the bottom. The double bottom interaction of the second echo causes it to be strongly affected by the acoustic bottom hardness, with roughness effects becoming secondary. In principle E1 and E2 are related dominantly to acoustic roughness and hardness respectively, although each contains components of both.

The two parameters are plotted against each other, and different pairings of the two parameters are expected to be related to different bottom types. The user must determine which parameter combinations are related to particular bottom types by taking bottom samples. The approach is purely empirical, but works very well for flatter bottoms (Hamilton et al 1999). Some rationale is given for this approach by noting that smaller scale sediment roughness may be physically related to grainsize (McKinney and Anderson 1964). McKinney and Anderson (1964) expected backscatter to be a function of particle size and bottom relief, and proposed sediment particle size influenced the size of bottom relief. Burns et al (1989) state this as "harder ground has a greater capability of exhibiting roughness", effectively the rationale assumed for RoxAnn operation. However these relations are lost over rougher topographies (Hamilton et al 1999). E1 and E2 are often referred to as "hardness" and "roughness", implying measures of mechanical hardness and geometrical or physical roughness, but they are simply acoustic indices with some unknown relation to seabed conditions. E1 is a bottom backscatter index, and E2 is related to acoustic reflectivity.

Over rougher bottoms e.g. those with ripples, the energy lost to the second echo by backscatter can lead to lower than expected values of RoxAnn acoustical "hardness" for a particular sediment type, so that careful calibration against sediment samples is needed to obtain inferences of bottom type from the acoustics. See Hamilton et al (1999) for more details. Depending on beam angle, unreliable E2 values are returned even for small slope values, a problem not widely appreciated. Voulgaris and Collins (1990) quote Jagodzinski (1960) as follows: "the second echo cannot be received unless the inclination of the bottom is smaller than the half beam width of the receiving oscillator. As a result the second echo may in some cases not be recorded, especially in the case of rocky bottoms or features such as sandwaves where the inclination changes rapidly on either side of the sand wave". (Phil Chapple of DSTO notes that this may be quarter beam-width rather than half, depending on the definition of beamwidth).

For Mine CounterMeasures (MCM) use the acoustical roughness estimate could be used by itself as a broad indicator of backscattering strength, without reference to the acoustical hardness parameter. The difficulty with this is that E1 measurements for different frequencies and systems are not always linearly related, except in very broad terms. Since MCM often use simple 1 to 4 scales to describe the bottom, the problem is reduced for this application, as broad roughness classes can be used.

RoxAnn classification

Burns et al (1989) introduced the "RoxAnn Squared" display concept, which uses coloured boxes with sides aligned parallel to E1 and E2 axes to classify the data, where data in a box are expected to be related to a particular bottom type. Squares are arbitrarily user defined. RoxAnn squares for different bottoms can sometimes overlap or occupy the same portions of RoxAnn space e.g. sand waves may be classed as "sand and rocks" (Voulgaris and Collins 1990). From Rukavina (1997): "it is important to note that where the bottom variability is at a smaller scale than the footprint, because RoxAnn integrates over the footprint it cannot distinguish e.g. ... clay and boulders from a uniform gravel with the same average acoustic properties. Also the footprint size varies with depth". Note that Hamilton et al (1999) found that polygons (inclined parallelograms) aligned with the overall E1-E2 data trend formed optimum classifiers, rather than "RoxAnn squares".

There are no standardised methods for processing of RoxAnn data (see Section 7.1), but the methods of Hamilton et al (1999) in Section 7.1.3 may be of general interest.

3.2.2 The Quester Tangent Corporation first echo shape approach

The QTC-View 4 system examines shape characteristics of the first echo, known as Q-values (Q1, Q2, Q3) (Prager et al 1995). QTC-View version 4 originally normalised the first echo to unity peak amplitude before calculating shape parameters (Caughey et al

1994). It is not known if this is still the case. Energy parameters are now also used (Quester Tangent Corporation 1998b), although their form is unknown, and may simply be normalised cumulative energy sums. Various first echo shape parameters are calculated in both time and frequency domains, such as half width, Fourier transform coefficients, spectral moments, and wavelet transform coefficients. The Q-values are chosen automatically by principal component analysis by the QTC software from a possible total of 166 parameters (and may be combinations of these 166), with their mathematical or physical meaning unknown to the user. In supervised classification mode, QTC software automatically provides bottom classes by comparisons against user chosen portions of the data set, generally associated with groundtruth. In unsupervised mode, QTC principal component and cluster analysis automatically provides classifications. The software provides a percentage confidence estimate of each ping set classification. If extra calibration sites are added, calibration is performed again, and the new Q-values could differ from the original. All QTC data are assigned to a derived class, with no unknown or doubtful class provided. The worth of the unsupervised approach depends on good choices of the acoustical parameters input to the clustering, while supervised classification requires good choice of sample sites.

The first reaction to the QTC-View type of approach is often that it is unscientific, since it is empirical, and since details of the classifying parameters may not be known, but for flatter bottoms it works very well. Since it uses only the first echo it is less subject to noise, variability, and energy losses due to roughness effects than a multi-echo approach. A drawback for RAN operations is that bottom type can be classified, but a direct backscatter measurement is not presently supplied, although presumably the manufacturer could be asked to calculate one. A limited number of bottom types corresponding to mud, sand, gravel, and rock could be used to form the classification catalogue, to infer a broad backscatter classification, but quantitative relation to backscatter measurements from other systems is then unknown.

QTC parameters

The QTC parameters have not been disclosed. For those wishing to implement a first echo approach themselves, this should not be a problem, since any number of parameters can be calculated in both time and frequency domains, and examined for suitability for waveform classification. General details have been published to indicate the approaches used by QTC. Mayer (2000) describes initial work where the first four moments of the waveform were computed. Comparing the second and fourth moments allowed some seabed types to be differentiated. Also "It is clear that the integrated waveforms from various sediment types have recognizable differences". Use of integrated curves follows an approach of Lurton and Pouliquen (1992a, 1992b). Differences were quantified by calculating three features, these being the normalised cumulative energy to the peak amplitude, to the pulse length, and energy to rise time normalised by energy to half the peak time. The definition of rise time was not stated. Typically in the approximation of a step function, it is the time required for a signal to change from a specified low value to a specified high value. Usually these are 10% and 90% of the step height. Probability density functions of these three features were examined and a weighting matrix was formed for each feature in terms of its ability to identify a particular seabed type.

One QTC implementation produced 166 parameters from five algorithms: a histogram of the distribution of the amplitudes in the echo; quantiles of the distribution of the amplitudes in the echo; integrals of the amplitudes to various times in the echo and ratios of these integrals; Fourier spectrum amplitude coefficients; and wavelet coefficients (Prager et al 1995). Quester Tangent Corporation (1995) also list the five algorithms as Histogram, Quantile, Integrated Energy Slope, Wavelet packet coefficients, and Spectral coefficient algorithms. Presumably the transforms are used to calculate spectral moments and other spectral measures of shape. Quester Tangent Corporation have developed techniques using wavelet transforms to characterise the signature of the echo. Wavelets were found to give more consistent classification than other measures. "Subtle changes in echo shape are reflected in a few key components of the wavelet-transformed data" (Caughey et al 1994). Data are normalised to peak amplitude and virtual (reference) depth. Samples (2 ms) are included before the bottom pick, providing the ability to detect vegetation or groundfish (Prager et al 1995). Principal component analysis and clustering are used to provide unsupervised classification, or supervised methods can be used.

3.2.3 Other Systems

More COTS systems are coming onto the market, and digital echosounders are also available.

BioSonics VBT-Seabed Classifier (Burczynski 1999)

The VBT-Seabed Classifier collects data in a template database, implementing four classification methods. These are (1) first echo normalisation and cumulative energy curves (Pouliquen and Lurton 1992), (2) ratio of energies of the tail of the first echo to the second echo (the RoxAnn method, after Orlowski 1984), (3) first echo division or partition, and (4) fractal dimension. For (3) an equivalent to the RoxAnn E2 parameter is formed as the energy under the first part of the first echo, which lasts for the duration of the transmitted pulse. E1 is the energy under the tail of the first echo, as for the RoxAnn method. For (4), E1 is one parameter, and a second parameter is formed as the fractal dimension of the first echo shape. "According to Euclidian geometry, a simple geometrical form can have dimensions of 0 (zero: point), 1 (line), 2 (surface), 3 (volume geometrical figure)". Harder bottoms should have more energetic (higher peak amplitude) returns, and the greater departure from a straight line, so that this parameter is essentially a proxy for E2. Fuzzy C-means clustering of parameters can be performed. Use of different methods is a good way to show up both anomalies and similarities in classification. However, for methods (2) to (4) there may essentially be only two parameters, namely E1 and E2 proxies.

Good echo averaging methods are used by Biosonics. In a ping set the weakest and strongest echo energies are recorded. It is assumed the strongest echo is most specular and is most suitable for classification. Echoes above some energy threshold between the highest and lowest levels of a ping set can be specified for classification. Hamilton et al (1999) recommended similar methods. In addition, data before the start of the echo can be recorded to show vegetation, as for QTC-view.

See http://www.biosonicsinc.com/product_pages/vbt_classifier.html for further information.

Dommisse and Urban (2001) report that the VBT system (v1.9) ***does not employ depth normalisation***. This would make it suitable for acoustic bottom classification only if the bottom depth is constant over the entire survey area. In addition interpretation of the the VBT bottom pick method as described in Dommisse and Urban (2001) indicates it is not robust to depth changes. The VBT system's performance is likely compromised for all but completely flat bottoms until these aspects are remedied.

SAVEWS

A system known as SAVEWS (Submerged Aquatic Vegetation Early Warning System) has been developed by the U.S. Army Engineer Waterways Experiment Station to characterise vegetation in shallow water environments. SAVEWS uses a BioSonics DT4000 digital hydroacoustic sounder with a narrow-beam transducer (Sabol and Burczynski 1998). The system records the depths of the tops of vegetation, usually appearing as "a jagged pattern". The pattern is interpreted visually or automatically. Koniwinski et al (1999) have used this system.

ECHOplus

ECHOplus is a digital version of RoxAnn produced by SEA (Advanced Products) Ltd. The system attempts to compensate for frequency, depth, power level, and pulse length, making it unique among acoustic bottom classifiers. Pulse amplitude and length are measured on every transmission and outputs are scaled accordingly. Absorption corrections are factored in. This means that in principle it can be used with any echosounder (with frequency 20 to 230 kHz), and that changes in system settings are automatically accounted for. ECHOplus has the facility to input and process two frequencies simultaneously. This would seem to be an advanced system. It has been trialled by SEA personnel (Bates and Whitehead 2001). "The results exhibit excellent correlation between acoustic bottom classes and ground truth data". A potential drawback for scientific use is that the various compensations may unwittingly affect the parameters being measured. There is also no justification for assuming linearity between acoustic parameters measured with different frequencies or echosounder characteristics.

CSIRO multifrequency system

CSIRO is the Commonwealth Scientific and Industrial Research Organisation, Australia. Siwabessy et al (2000) and Kloser et al (2001) describe a multi-frequency system developed for biomass estimates and seabed classification, based on a SIMRAD scientific echosounder operating at 12, 38, and 120 kHz. RoxAnn E1 and E2 parameters are formed for each frequency (the log of E1 is used instead of E1), but RoxAnn squares are not used. A Principal Components Analysis is used to combine the three E1 data sets, and the three E2 data sets. Apparently only the first principal components are used, being the average of the three sets of measurements for E1, and for E2. The first PCA of E1 and E2 described more than 70% of the total variation of the original E1 and E2 respectively. Training sets of E1-E2 values are input to a k-means clustering algorithm as seeds for known classes. Four seabed classes labelled as hard-rough, soft-rough, soft-smooth, and hard-smooth were able to be formed in two separate areas. The k-means iterative relocation technique used presumably precludes real-time classification. In essence this is a RoxAnn system with a predefined number of classes and a limited classification scheme. Tests of the system are described in Kloser et al (2001).

4. Trials Of COTS And Other Systems

Several commercial systems were purchased or trialled to gain experience with this type of equipment, and to assess their suitability for RAN usage. The commercial systems generally gave acceptable acoustic bottom classifications over flatter bottoms, although modifications to the manufacturer prescribed operating and processing procedures were required (Hamilton et al 1999). Some observed classification problems could not be fully investigated or overcome because of the particular approach employed by the manufacturer for classification, or because of the unknown proprietary nature of algorithms. For example it was observed that two systems using completely different physical principles both classed reef areas as soft muds, although there was no mention of this phenomenon in the manufacturers' literature. Development of a low cost in house system was instigated to examine such problems, and to provide a solution meeting the particular needs of the RAN.

4.1 RoxAnn system

4.1.1 Reports of RoxAnn trials by others

Many papers have been written on results obtained with RoxAnn. Only a few are discussed briefly.

Effectiveness at resolving bottom types and bedforms

> Voulgaris and Collins (1990) and Collins and Voulgaris (1993) found RoxAnn™ capable of discriminating between the mean characteristics of various <u>featureless</u> seabed types for a particular location. However their classification diagrammes for E1-E2 showed that <u>bottoms with bedforms caused ambiguities</u> e.g. sand/rocks/ripples overlapped the signatures of rocks and of sand/rocks. Sand ripples overlapped the classification for rocks and for sand/rocks. A jump in RoxAnn™ values often seemed to occur when bottom type changed, but the reason was unknown. Roughness increased in areas covered with seaweed. Laboratory examination over artificial beds showed RoxAnn™ could discriminate between several artificial sand, gravel, and hard surfaces (however one gravel size gave lower E2 hardness values than sand, while another gravel size gave the same E2 value as sand but higher E1).

Repeatibility of RoxAnn™ data

> Schlagentweit (1993) found that <u>reproducibility was obtained only if constant ship speed was maintained</u>, attributed to changes in aeration and engine noise. There was a "modest correlation" between datasets for 40 and 208 kHz (and with ground truth data - see his Fig 7). The system was not evaluated in rough seas, which could affect E2 in particular.

Hearn et al (1993) found substantial variability in the E1 and E2 values recorded for similar observed surface bottom types. They attributed this to layering of mud and sand in different subsurface thicknesses, but had no evidence to prove this.

Oskarsson (19--) found consistently high repeatibility of data. "To our judgement the correct use of the RoxAnn™ system in combination with conventional survey methods has the potential to make a significant improvement of the possibility to map the Oresound Bridge corridor". They obtained extensive video and bottom sample data.

Collins and Voulgaris (1993) found a dependence on echosounder frequency and with time, attributed to echosounder signal output instability.

Murphy et al (1995) found calibration along an east-west portion of a track was different from the rest of the track and all north-south transects. "Overall, diver observations and grab samples verified that the range of classification directly reflected subtle variations of sediment, size, and constituents, which correlated very well with submerged dune formation".

Inconsistencies in RoxAnn data have been attributed to echosounder instabilities, seastate (since the second echo has one interaction with the sea surface), pitch and roll (although RoxAnn hardware has an "electronic gimbal" which is believed to reject signal acquisition over some particular pitch and roll conditions to ensure beams are not too far off vertical), bottom slope (Voulgaris and Collins 1990), and depth changes (Collins and Voulgaris 1993). Kloser et al (2001) found a depth bias in a 120 kHz RoxAnn system.

4.1.2 Discussion of points in the literature

Although many papers on RoxAnn have been produced, it is rather difficult to assess the value of RoxAnn from them. Many papers describing RoxAnn™ are enthusiastic but provide little quantitative evaluation of performance, apparently assuming that changes in the RoxAnn™ display were useful indicators which could be ground-truthed in the future or believed at first sight. It appears RoxAnn™ cannot always discriminate between some seabed types and bottoms with bedforms e.g. sand ripples overlapped the classification for rocks (and sand/rocks) for a survey by Voulgaris and Collins (1990). In the absence of bedforms RoxAnn™ may provide information about bottom changes, but it may not always be possible to tell what the changes mean. Bottoms must first be classified with conventional surveys and techniques, after which RoxAnn™ data can possibly be used to fill in the gaps, but with ambiguities. Use of different echosounder frequencies for a survey might be of assistance in resolving ambiguities, but might also introduce more discrepancies. The RoxAnn™ system appears useful, but only if results are analysed with care, and with proper regard to the capabilities of the instrument. Use of RoxAnn™ to gather data is routine, but interpretation of results is not necessarily straightforward.

From the DSTO trials reported next, it can be said that RoxAnn works i.e. provides useful classifications, if (1) adherence to ship speed restrictions are employed, (2) if the bottom is relatively flat (this is a function both of bottom slope and beamwidth), and (3) the depth range is not large. However it can be difficult to calibrate.

4.1.3 DSTO trials of RoxAnn

A RoxAnn system was trialled off Cairns and in Sydney Harbour. A bottom classification for both Sydney Harbour and the Cairns area initially proved difficult, even with many bottom samples, and this seems to be a common experience of RoxAnn users. It seems the system can provide useful bottom classifications for flatter bottoms in particular if enough bottom samples are taken, and if only a broad classification with four or five classes is sought. Use over a limited range of depths is also likely to provide better results than over a large range. However a reliable bottom classification cannot be guaranteed.

It was found from the Cairns data that the system provided consistent results only if a constant survey speed was used, as also found by Schlagentweit (1993), although the manufacturer's advertising claimed that any speed was suitable. This was largely a function of vessel noise and aeration affecting the lower energy E2 parameter, and would not apply to every vessel. Data obtained when stationary were not self consistent. This indicates RoxAnn should be tuned and operated while surveying at constant speed. RoxAnn users should examine data for speed dependence.

Similar directional effects to those observed by Murphy et al (1995) were seen. This implies surveys should include intersecting along-slope and cross-slope transects to check for such effects. E1 also varied markedly for some repeated inshore tracks in depths less than 10 m.

The RoxAnn classification off Cairns was not very good compared to a QTC classification (Hamilton et al 1999), but a RoxAnn classification of Sydney Harbour yielded apparently very good results (Fig. 5) appearing well allied to groundtruth (Fig. 6). Reasonably constant speed was used, and the harbour depths do not have as great a range as the Cairns data.

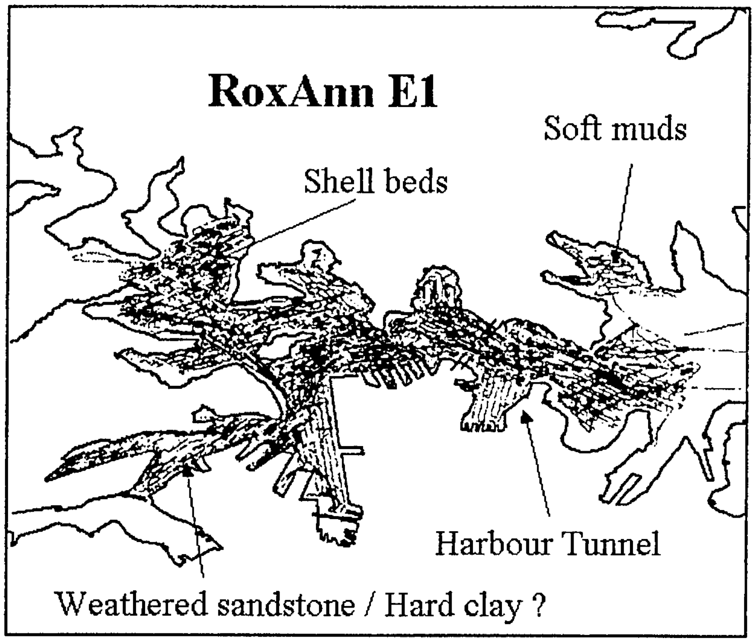

Figure 5a. Chart of RoxAnn E1 values in Sydney Harbour, representing backscatter. Light greens, cyans, and dark blue are lower backscatter values representing soft muds. Purple, red, and yellow are higher backscatter values, representing a range of seabed types. Note the Harbour tunnel appearing as a near vertical blue band, the highest backscatter category. The high backscatter axis along the main channel is caused in places by scouring actions of shipping exposing shell beds.

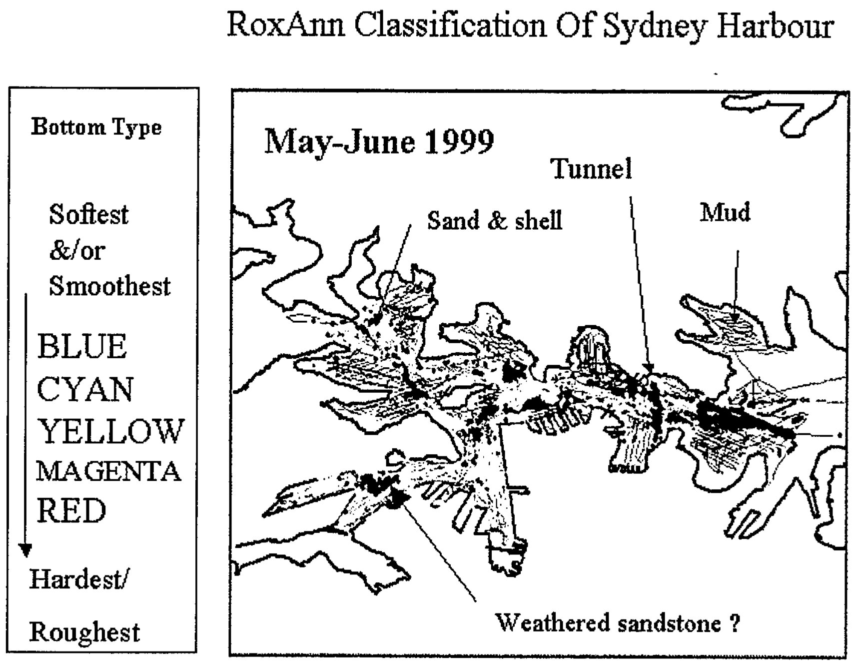

Figure 5b. A RoxAnn classification of Sydney Harbour sediments. Note the axes of highly reflective sediments (yellows and magentas) along the shipping channels. The harbour tunnel stands out clearly as a near vertical red band. From Hamilton (1999a).

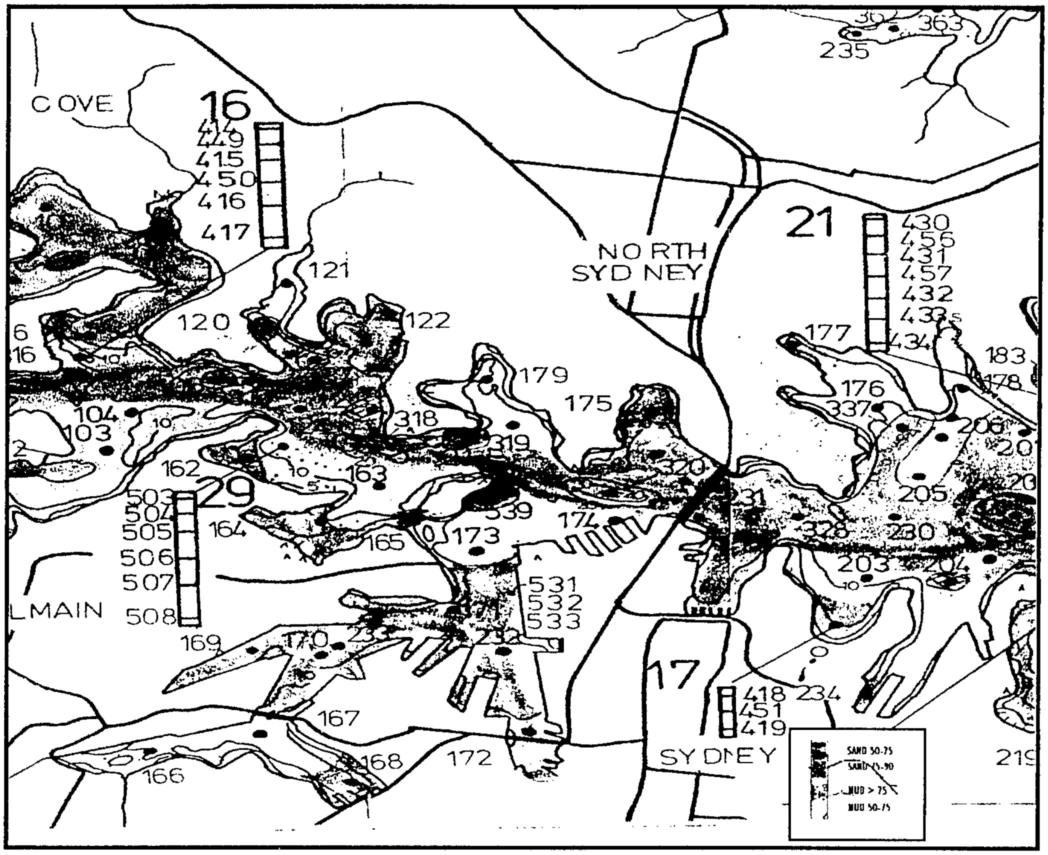

Figure 6. Broad grainsize distribution in Sydney Harbour (after Irvine 1980). Orange shows mud content over 75%, green has mud content of 50-75%, magenta has sand content 50-75%, and blue is sand of 75-90% by weight of sediment. Compare with the RoxAnn data of Figures 5a and 5b.

Performance over rough terrain

E2 oscillated between very low and very high values when traversing local topographic highs or outcrops, which could be expected to be hard, with E1 not appearing to experience such effects (see Fig. 2 of Hamilton et al 1999). Voulgaris and Collins (1990) quote Jagodzinski (1960) as follows: "the second echo cannot be received unless the inclination of the bottom is smaller than the half beam width of the receiving oscillator. As a result the second echo may in some cases not be recorded, especially in the case of rocky bottoms or features such as sandwaves where the inclination changes rapidly on either side of the sand wave". (Phil Chapple of DSTO notes that this may be quarter beam-width rather than half, depending on the definition of beamwidth). Outcrops will generally also have smaller scale roughness, which could further diminish the second echo (Burns et al 1989). This indicates E2 on the average will be lower over rough terrain than expected, causing the data envelope to bend in the positive E1 direction for high E1. Examples can be seen in Voulgaris and Collins (1990), causing class overlaps for sand ripples, sandwaves, sand/rocks/ripples, and rocks. E2 appears an unreliable classifier over rough topography. Sometimes however, this lowering of E2 may allow a particular bottom type to be distinguished from other bottom types, providing it does not overlap with other classes.

Use of backscatter or reflection coefficient alone to classify bottom type

RoxAnn data indicates that use of average backscatter intensity alone over one particular range of grazing angles (E1 in the case of RoxAnn) to characterise the bottom type is not likely to work. The second RoxAnn parameter (E2) is needed to separate different bottom types, although it is not always successful at doing this. Conversely use of reflection coefficients alone may not be sufficient for classification, since E2 alone is not generally sufficient. These important points are not generally known, judging by recent conference abstracts in JASA reporting attempts at acoustic bottom classification by use of reflection coefficients alone.

4.2 QTC-View system

QTC is supplied with different levels of capability, depending on the software purchased with it. The basic model provides supervised classification only, and does not store raw echo data, except in calibration mode. Sites known to have different properties must be visited first in calibration mode, to establish a classification catalogue.

4.2.1 Reports of QTC trials by others

Reports of QTC trials have mostly been made in association with the manufacturer, and are highly complimentary of QTC View's classification abilities. Indications in Quester Tangent Corporation (1995) are that QTC may experience similar class overlaps to RoxAnn e.g. mud with scours was apparently identified as gravel/cobbles/rocks. DSTO trials reported in the following section showed that QTC was susceptible to slope effects in reef areas, which were classed as mud, and methods were suggested to improve the QTC stacking algorithms.

4.2.2 DSTO trials of QTC View

QTC-View loaned one of their systems to DSTO for a TTCP trial off Cairns. Supervised classifications were made by Roland Poeckert (then of Defence Research Establishment Atlantic (DREA), Canada) for five sites where bottom samples were taken. Unsupervised classification was not trialled by the TTCP group, but is reported in Quester Tangent Corporation (1998) with a dual frequency classification of the Cairns data. A confidence estimate supplied for each classification appeared to be meaningful, highest confidences occurring in the geographic centre of classes. The supervised classes correlated very well with trends of grainsize contours, although obvious misclassifications occurred over some reef areas. Outcrops in two areas were classed as rough muds, even though the QTC classification confidence values were mostly over 80%. That the RoxAnn E2 parameter was erratic over rough terrain suggests something similar is happening for QTC shape parameters.

QTC formed spatially well defined classes, without marked patchiness or inconsistencies. Most of over 108 crossings were consistent, but some disagreements occurred. For a data subset Quester Tangent Corporation (1998) found pitch and roll sometimes affected 120 kHz data, which was obtained with a wider beam than 38 kHz (10.5 compared to 7°). For both frequencies choice of normalization or reference depth sometimes affected classifications.

The QTC-View 4 system employed did not appear to experience ship speed effects, and gave a superior calibration to RoxAnn surveys of the same area with comparatively little user effort. For a data subset Quester Tangent Corporation (1998) found speed had only a slight influence on classification. It is not known if QTC experiences speed effects on other vessels, however RoxAnn results support this finding since RoxAnn E1 derived from the first echo showed little or no speed dependence, and QTC 4 uses only the first echo.

For classification of flatter bottoms in the Cairns area, QTC-View 4 appeared to be a highly effective system. See Hamilton et al (1999) for more information.

4.3 EchoListener logging and echogram display system

An EchoListener device manufactured by SonarData of Tasmania was purchased for use as a logging device. The EchoListener was developed to detect fish schools, not for acoustic bottom classification, and did not come with software for bottom classification, or for calculation of acoustic bottom parameters, although plans are being made to incorporate these facilities. However it is useful because it digitally acquires and stores bottom echo information and displays real-time echo data as echograms (the echo level through the column for pings are displayed as contiguous colour coded thin vertical bars) in a visually pleasing display. Fish schools can be seen in the echograms and a broad assessment of bottom type can be made from the length of the echogram after the bottom is reached, and by presence or absence of the second echo. Although DSTO did not purchase the EchoListener software packages, software is necessary to georeference EchoListener data. Sonardata supply a demonstration conversion programme which does not output time or position information with the raw echogram data. The EchoListener format was acquired from Sonardata and a programme written to decode the format and to output echo files with timing and navigation data.

The EchoListener has a choice of two gain settings (5 and 550), and wide or narrow band frequency selection. Pulse amplitude and pulse length are measured and recorded on every transmission. The system is relatively easy to install and use, and made a good impression. If it was sold without the software for detection and display of fish schools in the water column it would form a good cost effective data logger, but does presently have drawbacks. Use of only one effective gain (the low gain usually was too small for bottom classification) and a low dynamic range for bottom classification requirements might restrict its usefulness. A later model not trialled by DSTO does have more dynamic range.

Clustering of even one parameter calculated with the DSTO software, corresponding to a roughness measure (Fig. 7), for Sydney Harbour EchoListener waveform data provided classifications visually well correlated with known bottom types (Fig. 6) and a RoxAnn classification (Fig. 5). The parameter is simply the time from the start of the pulse to the peak height. Exploitation of this time is made in satellite altimetric inferences of wave height. "If the ocean surface is roughened by the presence of waves, the leading edge of the transmitted pulse will interact with the crests of the waves a small time before interacting with the troughs. As a result, the leading edge of the return will be broadened in comparison to the flat ocean case. As the wave height increases, this broadening of the leading edge of the return pulse increases. Therefore, the slope of the leading edge of the return pulse can be used as a measure of the wave height". ... "The slope of the leading edge of the pulse clearly decreases as the significant wave height increases" (Dobson and Monaldo 1995; also reproduced in Young 1999).

For more details of EchoListener, see the maker's web site www.sonardata.com .

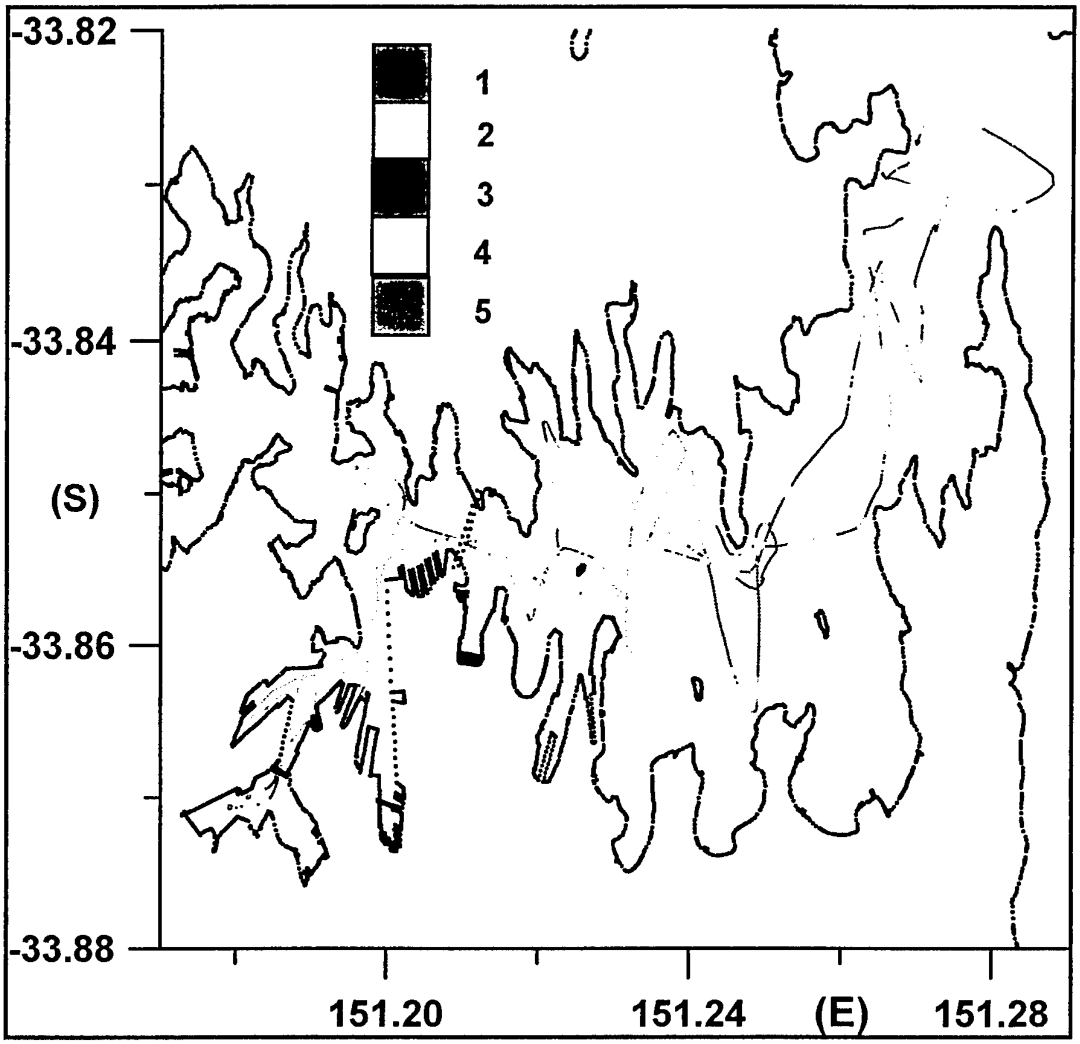

Figure 7. Seabed roughness classification for Sydney Harbour from clustering of time to peak height. The echoes were captured and stored digitally by an EchoListener manufactured by SonarData Tasmania attached to a 50 kHz Furuno LS-6000 echosounder, and processed by DSTO software. Class numbers increase with time, and with roughness. Classes 4 and 5 indicate rock platforms or harder bottoms. Note the change to class 3 near headlands. Compare with the RoxAnn backscatter classes of Fig. 5a.

4.4 BioSonics VBT-Seabed system

Two conference abstracts including BioSonics authors deal with the BioSonics system. Hedgepeth et al (1999) tested the capability of the Biosonics system at two frequencies and two beamwidths. Results were not obtained for the present report. Hedgepeth et al (1998) reported testing of the BioSonics Visual Bottom Typer software to categorize sediments using data libraries and two locations. The extended abstract shows some results for partition of the first echo as co-plots of two acoustic parameters, but no results for the other three BioSonics two-parameter classification methods listed in section 3.2.3. Plots indicate good separation of mud from sand and from rock, and some separation of sand from rock, but with rock mostly overlapping part of the sand signature. The first echo partitioning shows some discrimination, but may possibly need refinement. A comment of the present author is that the beamwidths used of 6 and 9 degrees may be too small to adequately detect the backscatter tail of the first echo, although E1 appears to have good range.

Since the current version of the VBT system (v1.9) ***does not employ depth normalisation*** (Dommisse and Urban 2001) it can only be used for acoustic bottom classification if depth is constant over an entire survey. In addition the VBT bottom pick method as described in Dommisse and Urban (2001) does not appear robust to changes in bottom depth. The VBT system's performance is likely compromised for all but completely flat bottoms until these aspects are remedied.

4.5 DSTO System

A low cost system is being developed by DSTO to automatically and routinely provide real-time estimates of seabed backscatter suitable for MCM operations. Main hardware comprises a conventional 50 kHz Furuno LS-6000 'fishfinder' echosounder, an electronics circuit to acquire echo analogue waveform data, and a COTS analog to digital device (a Data Translation Data Acquisition Module DTE9804) connected to the USB port of a laptop PC running Windows. USB (Universal Serial Bus) is a high speed communications port available on PCs using Windows 98. A DGPS navigation input is also required. Visual Basic software built around the digitiser acquisition and display software is used to drive the system.

A backscatter classification of Sydney harbour data (Fig. 8) acquired by the DSTO system using four classes made using the method of natural breaks (i.e. clustering) compares favourably with another indicator of bottom roughness, time to peak height, acquired by DSTO processing of data gathered by an EchoListener system earlier in the year (Fig. 7). In effect the two data acquisition systems cross-validate each other, although note that pre-processing algorithms used on the two data sets are the same.

The primary purpose of the system is to provide real-time assessments of acoustic bottom backscatter suitable for MCM purposes. However there are strong indications that a real-time acoustic bottom classification capability could also be added, based on simple parameters with known derivation and physical meaning (see Fig. 11 and associated discussion). Post processing of data by clustering techniques can provide classification, but this approach is not suitable for routine or real-time operations, and does not give cross-platform compatibility. The latter point has not been addressed by commercial systems. Use of physical parameters with known meaning could address this requirement.

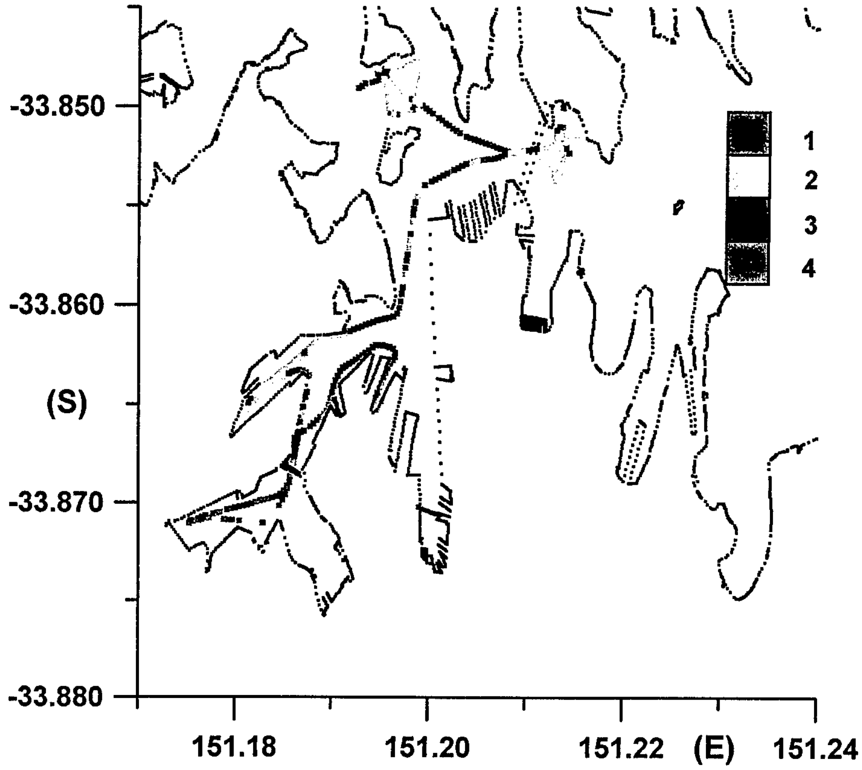

Figure 8. Backscatter classification as four classes from data obtained in Sydney Harbour on 10-May-2001 using the DSTO 50 kHz prototype backscatter system. Class numbers increase with backscatter. Compare with the time to peak height data of Fig. 7.

5. Algorithms

To perform acoustic bottom classification, a sequence of operations is carried out. First the echo (or echoes for multiecho systems) must be accurately found, a process known as bottom pick. The echoes are then transformed to a reference depth by making time and energy corrections. Smoothing and averaging of ping sets is employed to remove noise and provide acoustic stability. These last two points were introduced in Section 3.1. Echoes are then classified by various schemes, utilising shape and/or energy characteristics.

5.1 Picking the bottom

The start of the first echo or return, corresponding to the bottom depth, must first be found accurately. No algorithms were found in the literature for this, and in the presence of noise and noise spikes it proved to be not all that straightforward a process. Determinations of bottom depth alone are much simpler, since simple threshold criteria can be used to find the approximate depth within acceptable error, subject to the observations by de Moustier (2000) on the effect of ping shape on depth determination, and choice of threshold on false alarm rates or missed detections. For bottom classification the complete waveform must be obtained accurately. A robust bottom pick algorithm was devised and implemented. An example of its goodness of bottom pick in the presence of strong spiking is shown in Fig. 9.

The steps involved are as follows: find the background noise level, step backwards from the end of the ping record (to help to avoid spikes) and find the most energetic peak above the noise (calculated as a running average of three or more values), accept the peak only if it exceeds some threshold of the maximum possible amplitude range less the noise and also if it exceeds a width criterion (to eliminate spikes and obviously bad data), step backwards from the peak to find the start of the echo, step forwards from the peak to find the end of the echo, using tests such as x of y observations must be above/below some multiple of the noise level to define the start/end of the echo. Calculations avoid the ringing time at the start of the record after the pulse transmission, the duration of which must be determined for each transducer. Quester Tangent Corporation (1995) use a correlation technique for bottom pick. Using more than one bottom pick method could provide more robust self checking depth determination, at the expense of processing time.

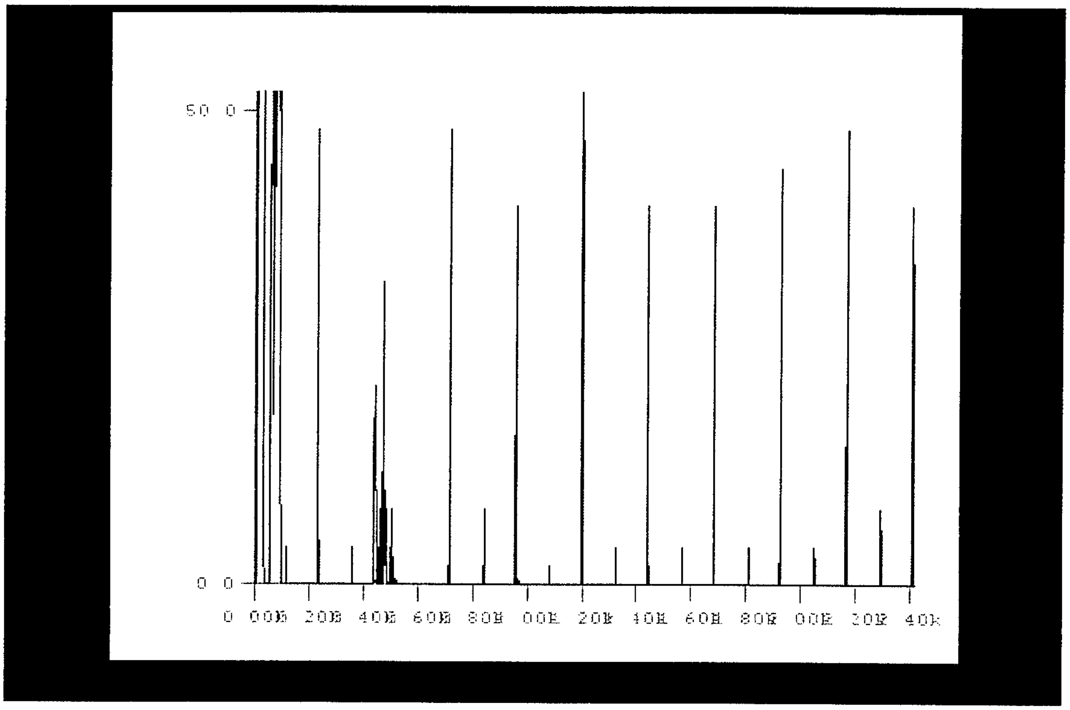

Figure 9. Example of correct bottom pick and echo selection (the green signal) for a low energy signal in the presence of noise spikes (blue).

5.2 Transformation to a reference depth

To transform a returned signal to a reference depth, time and power corrections need to be made (see section 3.1.2). The time correction is first made to adjust the length of the returned ping. The power correction then corrects the effect of spherical spreading. These corrections are required because signals are sampled or digitised at equal time intervals rather than at equal angles (Caughey et al 1994). Fig. 4 shows the effect of depth changes on a short rectangular ping. Normalising echosounder waveforms to a reference depth followed by resampling allows signal sampling to correspond to a standard set of incidence angles, as opposed to a set of linearly spaced times (Caughey et al 1994).

5.2.1 Time Correction

The time correction employed enables returns from the actual depth d and the reference depth d_0 to maintain the same time/angle relationship (Caughey et al 1994). Sampling at the same angles for different depths removes the need to allow for beam patterns, and the need to allow for the bottom backscatter function changing with incidence angle.

The time correction is $\gamma = \dfrac{d}{d_o}$ eq(1) (Caughey et al 1994)

where d = The actual depth.
d_o = The reference depth.

Therefore $t' = \dfrac{t}{\gamma} = \dfrac{d_o t}{d}$ eq(2)

where t' = The corrected time.
t = The time from the uncorrected signal.

Interpolation is then performed at times corresponding to reference depth sample times.

5.2.2 Power Correction (spreading losses and absorption)

An echo sounder ping experiences both spherical spreading loss and absorption losses. The amount of absorption is dependent on the distance travelled through the water, and the temperature, salinity, and pressure of the water. For a temperature of 20°C, salinity of 35, and depth of 10m, the absorption at 10, 30, 50, and 100 kHz is 0.761, 5.19, 13.0, and 38.0 dB/km respectively (see Francois and Garrison 1982).

From Clarke and Hamilton (1999): Since the path length from the transmitter to the sea floor is the same length as the path length from the sea floor to the receiver for the first return (i.e. the same transmit and receive angles α - see figure 10), the energy correction due to spherical spreading is:

$$E' = \frac{(2r)^2}{(2r_0)^2} E$$

where E = The actual received energy.

E' = The corrected received energy.

r = The actual path length to the sea floor.

r_o = The path length to the reference depth sea floor for the same angle α.

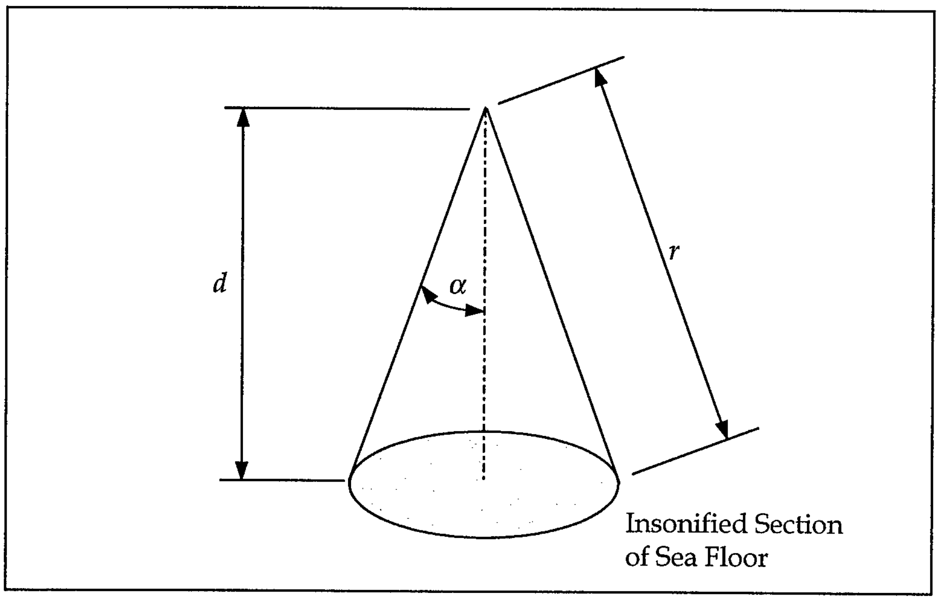

Figure 10. Geometry of the Pulse Insonifing the Sea Floor (from Clarke and Hamilton 1999)

Since $r = \dfrac{d}{Cos\alpha}$ and $r_0 = \dfrac{d_0}{Cos\alpha}$

The energy correction can be written as:

$$E' = \left(\frac{d}{d_o}\right)^2 E \qquad \text{eq(3)}$$

5.3 Smoothing and averaging

A number of pulses (a ping set) are averaged by some means to provide acoustic stability, and to allow for variability over rougher bottoms. This has been covered in Sections 3.1, 3.1.3, and 3.2.3. Additional smoothing to reduce noise can be accomplished by any of the usual means e.g. three-point weighted averages:
Amp(ii) = 0.25 x Amp(ii-1) + 0.5 x Amp(ii) + 0.25 x Amp(ii+1),
or more sophisticated low pass filters. Median filters are effective means of removing spikes (Hamilton 1998b).

5.4 Classification methods

5.4.1 Multiecho

Several two-parameter methods are in use, all using the energy of the tail of the first echo as one parameter, corresponding to bottom roughness. See Section 3.2.3 on the Biosonics VBT-Seabed classifier. The particular two energy-parameter multiecho RoxAnn approach to acoustic bottom classification (section 3.2.1) is patented. However, variations of the method could be employed e.g. there are more parameters available from the second echo than total energy. Although the multiecho approach is not robust over rough bottoms, and the second echo is susceptible to noise, second echo parameters are extremely useful. Even the presence of multiple echoes immediately indicates harder bottoms than cases without.

5.4.2 Single echo

Echo shape libraries

Libraries of first echo pulse shapes corresponding to particular bottoms can be compiled, and measures of curve fit can be employed to find matches. Cumulative curves can also be used as reference curves. To smooth signals and enable more reliable averaging Lurton and Pouliquen (1992a, 1992b) replaced individual echo envelopes by normalised cumulative summations as a function of time. Some success was obtained in classification using direct comparisons of cumulative energy curves against reference cumulative energy curves, although mud and rock responses were highly similar for some parts of the curves. An abstract by Schneider and Hedgepeth (1999) mentions the use of Generalized Additive Models (nonlinear regression models) to find relating functions between echo parameters. They noted that since transitions between bottom types can occur in any number of ways, that building a library from known bottoms might be the easiest and most practicable method of classification.

Clustering

First echo shape parameters may be used in clustering approaches, the method used by QTC-View (Caughey et al 1994). It is common practice to reduce multi-parameter sets to three or fewer parameters using Principal Component Analysis (PCA) or other methods (see Murtagh 1985, 1986 for algorithms and code), in order to provide visualisations of the data, to enable quicker processing by clustering and other means, and to avoid redundant parameters and reduce noise. When the degree of contribution of particular parameters to classification is unknown, clustering of more than three parameters (whether principal components or raw) provides more robust classifications than three alone as QTC does. Some clustering techniques can handle elongated clusters, and others cannot, so that it may be useful to employ different types of clustering algorithms, and to compare charts of the different classifications for obvious anomalies, and for agreements. A good introduction to clustering techniques is provided by Kaufman and Rousseeuw (1990). Clustering is a post-processing process.

Acoustic parameters for first echo classification

See "QTC parameters" in Section 3.2.2. Any number of shape and energy parameters can be calculated for the time and frequency domains e.g. echo half width, peak height, total energy, statistical moments, Fourier Transform coefficients, wavelet transform coefficients (see Torrence and Campo 1998 for algorithms and code), skewness, kurtosis, centroids, time to peak height, rise time, and cumulative energy sums. Spectral moments may be used directly, and to calculate other spectral parameters such as half-width. Fractal dimension has been used (Burczynski 1999; Tegowski and Lubniewski 2000), and wavelet zero-crossing techniques have been trialled (see the list of papers for the 4th European Conference on Underwater Acoustics, Rome, 1998 for titles by Lubniewski and Stepnowski - fractals, and by Tujaka – wavelet zero-crossing). It is obviously an advantage to know which parameters are the effective classifiers, and why.

Simpler Methods

Although the PCA and unsupervised clustering methods give useful results, these are applied in post-processing, and a solution able to give classification in real-time is far preferable. Supervised classification methods eliminate the immediate need for extensive post-processing, and can be routinely used once known areas of ground have been visited. An even simpler method is to provide a two parameter RoxAnn type of classification, and non-RoxAnn parameters with known physical meaning are being sought for this purpose. Choosing one parameter to correspond with the MCM requirement for backscatter measurements leaves the second parameter to be determined. Peak height of the second echo could be used in place of total energy, but a first echo parameter is being sought to escape the noise and bottom slope degradation effects experienced by the second echo, and to avoid extra complexity in circuitry and software. It does not seem difficult to find first echo parameters suitable for the purpose, but full trials of their suitability have not been made. Fig. 11 is a two-parameter classification with the ordinate related to peak energy, and the abscissa the time to peak height. Even this unsophisticated classification shows some separation of bottom types. The first echo partition method of Orlowski (1984) has been implemented by BioSonics (2000), although results in section 4.4 indicate it may not be an ideal method. Bakiera and Stepnowski (1996) discuss first echo division. Orlowski (1984) also suggested using the ratio of energies of first and second echoes as an empirical index of the nature of the seabed.

There is an observation that the tail of the first echo is less susceptible to degradation by ship movements than the first part of the first echo (e.g. Burczynski 1999), meaning that first echo classification methods using the first part of the first echo might not be good. However the success of QTC indicates that simple ping set averaging effectively removes such effects.

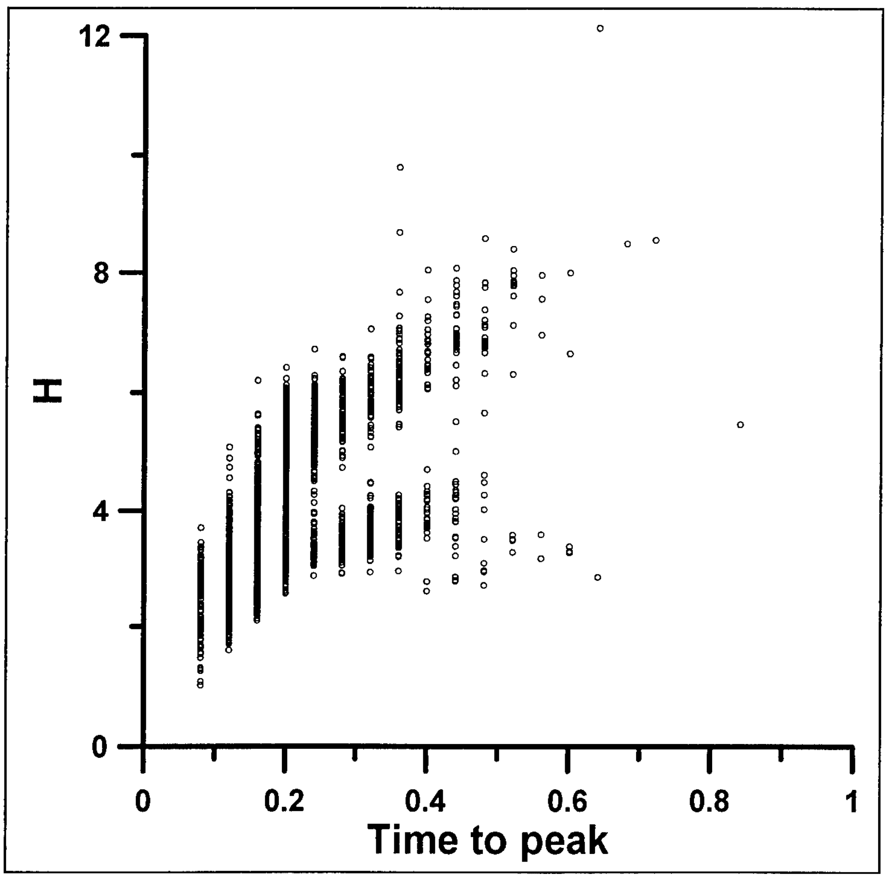

Figure 11. A two-parameter first echo classification of echoes from Sydney Harbour for a peak energy parameter vs time to peak height.

6. Using ABCs

Some of the basic points for usage of ABCs given in previous sections are now summarised.

6.1 Basic points of usage

SHIP SPEED. A first essential point is to use constant survey speed until and unless it can be determined that the same classifications are obtained over the same piece of ground at different ship speeds. The RoxAnn E2 parameter in particular is sometimes highly susceptible to self noise and other effects. Any RoxAnn values taken over groundtruth sites should be done at this speed also, meaning that several passes of each calibration site might have to be made to get enough data. Ship speed may have to be low enough to ensure the desired sampling density is obtained.

AERATION. A second point is to avoid bubbles and ship wakes e.g. from own ship turns, and make sure that there is no aeration of the sensor, or too much turbulence about the sensor. Points one and two can mean doing surveys at some slow, constant speed. Some sounders (e.g. the Furuno LS-6000) have a scope facility, good for assessing noise (electrical and flow noise).

LIMITED DEPTH RANGE. Thirdly, if it is possible, try to use ABCs over a fairly limited range of depths. Data are transferred internally to a reference depth (see Section 5.2), and the transformations necessary may be adversely affected by larger depth ranges. Use of a limited depth range also avoids problems with signal to noise values decreasing with depth. Lower frequencies may have to be used for deeper bottoms. Note also that systems have a minimum depth at which they can function, which depends on factors such as frequency and pulse length, and is typically about 5 m for 50 kHz. Quester Tangent Corporation have recently developed a system to work in very shallow water.

SLOPES AND ROUGH AREAS. A fourth factor which impinges onto data processing is to examine data over rougher areas, slopes, and outcrops for stability and dropouts. When crossing over slopes and outcrops the second echo may not be fully received, or may not be received at all, leading to apparently different RoxAnn signatures over different parts of the outcrop which are really artefacts. With high data rates this can be allowed for, but with low data rates, not much can be done except elimination of affected data. In enclosed areas, note that reflections from banks and walls, wharves, and other vessel hulls may adversely affect echo reception, particularly for the second echo. Expecting RoxAnn or any acoustic bottom classification system to reliably differentiate between different types of rocky or rough surfaces is probably expecting too much. Slope variations over rocky and reef bottoms affect the second echo unpredictably, leading to high variability, and making it an uncertain classifier. See Hamilton et al (1999) for further remarks. Simple examinations by the author for

Sydney Harbour data show that even small slopes, expressed as point to point depth changes, are a major problem for RoxAnn. Discrepancies between two RoxAnn systems operating at different frequencies were largely removed when simple slope criteria were implemented, such as removing successive data points with depth changes more than some particular criterion. Expect that in some areas good results can not be obtained by ABCs.

NAVIGATION. Use the highest precision navigation available for both the ABC and groundtruth. It is very difficult to match the two up otherwise (see Hull and Nunny 1998 for a discussion).

BEAMWIDTH. Choose an echo-sounder of sufficient beamwidth to receive the tail or backscatter part of the echo. Beamwidths of 12° and less may be too narrow for good acoustic bottom classification. Some recent references have used very narrow beams, but all this can hope to achieve is measurement of reflection coefficients, which RoxAnn indicates is unlikely to be sufficient for a full classification.

DIRECTIONAL EFFECTS. Areas can be surveyed with a grid of tracks or criss-crossing tracks to check classification reliability, in case slopes and other factors cause directional effects.

These combined factors may make ABC systems appear unduly complicated, but once systems are up and running, operation is usually quite routine. Awareness of potential problems allows them to be checked for or avoided. As Rukavina (1997) and Hamilton et al (1999) have noted, ABCs (of the RoxAnn variety) are perhaps best used in a reconnaissance mode to find areas with similar and dissimilar acoustic properties, with groundtruthing made later, or as areas with new acoustic properties are found.

6.2 Groundtruth and metadata

The following material is mostly from Hamilton (1998a). Groundtruth data are necessary to obtain system calibration. Metadata are defined as data necessary to obtain and support the final primary classifications. Metadata are necessary for data interpretation and assessment of reliability of the final classification products provided by the systems. The required metadata are a function of system characteristics, and the particular use to which the systems are put. Generally as much raw data, including waveforms, and supporting notes and documentation should be retained as possible. There are several reasons for this:

(1) improved algorithms may be derived in the future
(2) problems may be found with existing algorithms or methods
(3) one person's classification may not suit the requirements of another
(4) new groundtruth may be obtained at a later date

(5) the manufacturer's prescriptions for instrument capability, calibration, or usage may prove to be inadequate
(6) factors of importance might only become apparent after a survey
(7) Kloser et al (2001) make the important point that parameters from black box systems not recording raw waveforms are subject to errors, perhaps for days at a time, e.g. as a result of aeration or sea state, but there may be no way of knowing this afterwards.

To determine the type of metadata and groundtruth, a knowledge of what type of information the systems provide is needed, with some idea of how the systems work, what factors are likely to affect their performance, and what the systems are to be used for. The metadata needed are dictated by the particular purposes of a survey e.g. the applications of fisheries and engineering may be totally different, and so will the metadata. However we can state some basic requirements and the reasons for them in terms of system characteristics and successful operation and usage.

Some obvious requirements are indications of **small and large scale bottom roughness**. Small scale roughness is determined by grain size, and larger scale roughness could be caused by vegetation, animal activity (mounds and burrows and their size, cementation), presence of coral reefs, rocks, sandwaves and ripples, outcrops, and so on. Grain size can be determined from grab samples, cores, or box cores. Generally box cores provide more reliable information on surficial sediments, including evidence of animal behaviour. Note that because of the averaging employed over the relatively wide footprint of ABCs, and the way in which they operate, side scan sonar are more useful to detect smaller isolated features such as coral bommies or rocks. ABCs give information on overall texture, not features.

From the bottom samples the following should be considered a minimum requirement: **a visual description, grain size distribution and porosity**, and the following are desirable: **bulk density, carbonate content, plasticity, bearing strength**. For some purposes a visual description of the sample is more useful than the quantitative parameters. Photography and especially **video** provide information on the larger scale roughness, general habitat, and number and type of features per some unit area. Longer video transects may be useful to show bottom type boundaries. CSIRO Australia are developing methods to characterise video images of the bottom, particularly for habitat. Divers can provide good information. Penetrometers can be used to determine bottom properties. **Bathymetry** provides largest roughness scales. Historical groundtruth for an area may be available as **published charts or tables, or in databases**, and references to such sources should form part of the metadata to assist others.

If the final classifications and classification products such as charts are considered to be the primary data, then types of metadata can be grouped as follows:

(A) raw acoustic data and derived acoustic parameters,

(B) groundtruth and other environmental data,
(C) processing methods, basis of the classification, supporting documentation
(D) equipment characteristics.

Particular metadata for these groupings are:

(A) waveforms; the basic parameters from which the classifications were derived (the E1/E2 pairs for RoxAnn; the three Q factors and percentage sureties for QTC-VIEW)

(B) groundtruth (grain size distribution, porosity, visual description of the bottom sample, other parameters such as carbonate content, bulk density); environmental parameters: bathymetry (supplied by the ABCs), seastate (logged pitch and roll data could be useful) - has more effect for narrow beams, Sound speed profiles

(C) the basis of the classification
for RoxAnn the RoxAnn classification polygons and associated class names;
for QTC whether classification was supervised or unsupervised, the bottom type inferred for each class, the portions of the data set used for supervised classification;
a description of any special processing methods such as averaging, smoothing;
reasons for acceptance/rejection of data;
persons/organisations who made the classification;
publications referring to the data interpretation and processing

(D) system description and settings e.g. manufacturer, make, model, hardware/software version, ping rates, frequency/frequencies, beam-width, pulse length, gain settings and depth range
Navigation: type, manufacturer, spheroid
Ship speed (can be derived from ABC time and position)
Vessel and Organisation

7. Calibration and Data Processing Methods

Calibration and data processing are virtually one and the same. A calibration must be performed each time a system is installed in a vessel, if the gain or depth range of the echosounder or system are changed, or if the vessel enters an area having different geology from the initial calibration area. Note however that the ECHOplus classifier system attempts to account for system changes. Systems may be calibrated for energy by using spherical targets with known properties. This is important for fish biomass estimates, but not for acoustic bottom classification.

For classification the systems rely on establishing empirical relations between *ad hoc* acoustic parameters and sediment sample properties. System calibration and classification then become a function of the bottom sampling strategy, a key point which cannot be over-emphasised. Classification can also depend on the purpose of the user e.g. a mapping of fish habitat could produce a different classification from a mapping allied to grainsize. Video groundtruth is often best but the field of view is too restrictive.

Being acoustic the systems are subject to noise and variability. Because of their empirical nature, classifications made using different acoustic bottom classification systems have an unknown relation to each other. Even for the same system and vessel, classifications could differ over time with changes in transducer characteristics with age or fouling, or in background noise, regardless of any changes to the environment.

We shall class calibration methods as **direct** and **indirect**. Direct methods are applied by classing particular portions of the ABC parameter space, and generally seek quantitative calibrations: explicit correlations of portions of the parameter space are sought with bottom properties such as grainsize bounds or vegetation indices obtained at calibration sites. Indirect methods may classify in parameter or geographical space e.g. the RoxAnn space may simply be arbitrarily classed by rectangles of equal size, and the geographical class distributions so formed are then examined for obvious trends. A second example of an indirect method is that of applying image processing methods to RoxAnn data in geographical space, and then using groundtruth to assign meaning to the geographical classes (Greenstreet et al 1998; Fox et al 1999). The geographical classes so formed should be transferred back to RoxAnn space to check for outliers and errors. Indirect methods may be more appropriate for habitat assessments, where explicit separation of classes or groundtruth might not exist. For indirect methods Geographic Information Systems (GIS) could be used to overlay acoustic classes and groundtruth to check for correspondences or otherwise.

7.1 RoxAnn

7.1.1 Removal of RoxAnn default values

It doesn't seem to be generally appreciated that RoxAnn outputs default lower level values for E1 and E2 when values are below the detection threshold of a particular system, and similarly outputs default upper level values when some particular level is exceeded. The literature contains no mentions of this. Examples may be seen in E1-E2 plots of Greenstreet et al (1998), where they apparently went unnoticed. Default values form useful and usable information in some circumstances, however they will affect some classification methods, and should be removed if parameter regressions are sought.

7.1.2 RoxAnn squares

RoxAnn E1-E2 data are usually arbitrarily classified by drawing "RoxAnn squares" in E1-E2 space corresponding to properties of geographic areas having similar groundtruth (Burns et al 1989) - see Section 3.2.1. To obtain RoxAnn squares, Voulgaris and Collins (1990) classified areas indicated from bottom observations to be similar by means and standard deviations of E1 and E2 for the areas plotted in RoxAnn space. Note that Hamilton et al (1999) found that polygons (inclined parallelograms) aligned with the overall E1-E2 data trend formed optimum classifiers, rather than "RoxAnn squares".

7.1.3 Replay-display method

Hamilton et al (1999) used a procedure opposite to that of Voulgaris and Collins (1990), and did not make assumptions about homogeneity of bottom properties, noting that these could change with factors not readily apparent to routine observations of sample properties e.g. compaction. Statistics were automatically calculated for RoxAnn data within selected radii of bottom sample positions, and for ship speeds above a critical value, and plotted in RoxAnn space as rectangles, with e.g. one corner the E1-E2 medians, and the other the E1-E2 modes, with rectangle outlines for similar sediment samples colour coded (the mode-median method). Visual descriptions of wet samples were assigned to the rectangles for each calibration site, with % grain size found usually to be of secondary usefulness. Medians are often a better indicator of acoustic data values than averages in the presence of noise for low data numbers (Hamilton 1998b). A measure of site variability is provided by the degree of separation of opposite rectangle corners.

With respect to this procedure of starting calibration from E1-E2 groupings for groundtruth sites, rather than from observed bottom properties, Hull and Nunny

(1998) quote results from Broffey (1996): "Attempts to calibrate RoxAnn prior to a survey by successively running the instrument over several areas of apparently known and uniform sediment types have met with little success". Presumably this is caused by variability, roughness factors such as sand ripples, and possibly vessel speed effects (which were not investigated).

Large scatter was observed in RoxAnn parameters at some Cairns sites (as for Voulgaris and Collins 1990; Hearn et al 1993). A visual estimate of the usefulness of the RoxAnn™ data as calibration data had to be made for each bottom sample site. A separate programme was used to cycle through and display E1, E2, depth and ship-speed data within a user selected radius of groundtruth positions as time series (the replay method), together with histogrammes of E1 and E2 (Fig. 12). This allowed calibration sites with bimodality or large spread in E1 or E2 to be flagged. Histograms have been similarly used by Hull and Nunny (1998), who also discuss positioning errors in ground-truthing. In general the methods of Hull and Nunny (1998) are similar to those used by the present author.

Using the mode-median and replay methods it proved possible to make an initial very broad RoxAnn square classification for Cairns data, albeit with some difficulty (Hamilton et al 1999). Sixteen trial groups were manually determined, but these were reduced to eight, and then essentially to five. Charting the sixteen groups separately showed several groups separated in E1-E2 space lay on the same sections of track. Some covered so little geographical area they could be absorbed into other groups without loss of information. Classes could only be very broadly defined in terms of bottom properties. For the Cairns data, RoxAnn was apparently relatively insensitive in terms of E2 for mud content over about 20%.

Two displays used by Hamilton (1998a) for RoxAnn investigations are shown as Figs. 12 and 13. Portions of the top four displays of Fig. 13 are mouse selectable, and when selected are highlighted on the track plot and E1-E2 plot.

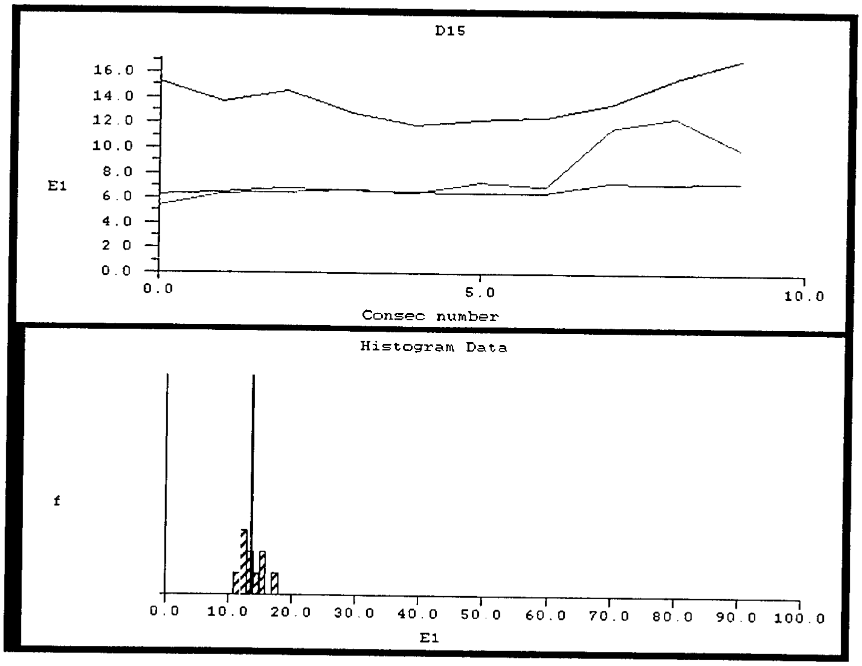

Figure 12. Time series display of RoxAnn data within a user selected radius of a calibration site (E1 blue, depth red, and ship-speed yellow), with a histogram of the E1 values (where the vertical bars are mode, median, and mean of E1)

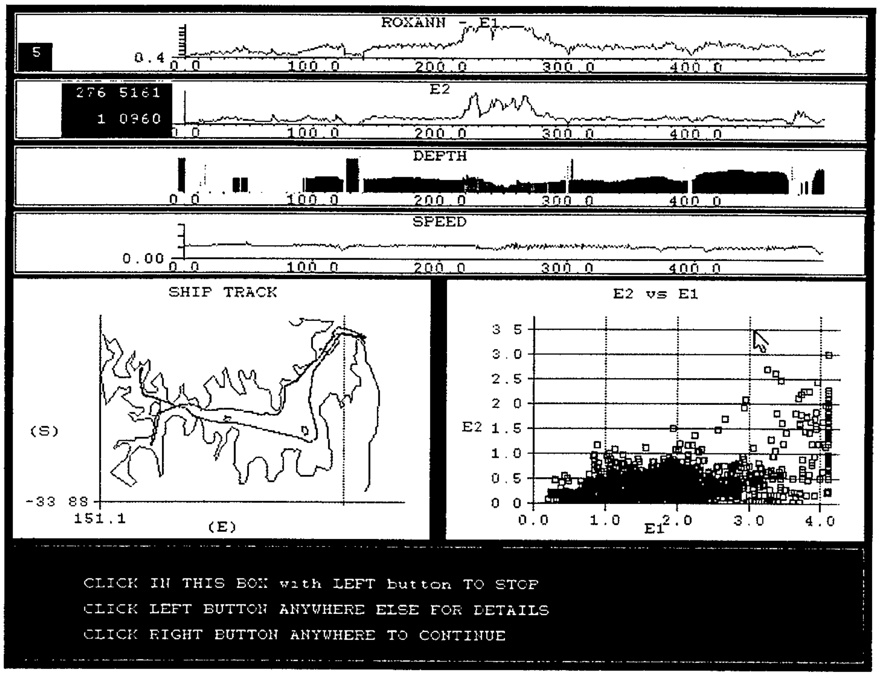

Figure 13. Display of RoxAnn E1, E2, depth and ship-speed data for a user selected number of data points (500 in this case) as four time series, track plot, and E1-E2 scatter plot. In the track plot and E1-E2 scatter plot, green and magenta points are the 500 points currently on display in the top four panels, and blue points are for prior data already cycled through. Magenta points were highlighted by the user via mouse selection on the E2 panel near point 274 (they are for a rock platform near a headland at the northeastern extremity of the track).

7.1.4 Indirect calibration methods

Indirectly comparing RoxAnn data and broad grainsize distributions may be the most painless way to check RoxAnn functioning and obtain calibration in many instances. It seems to be the common experience that many samples are required to obtain a good RoxAnn calibration, and that calibration is not always obtained easily even then. Classes formed by arbitrary RoxAnn squares initially of the same dimensions can simply be plotted in geographical space to check for obvious broad relations with groundtruth, without a full calibration necessarily being sought. This method may seem arbitrary and perhaps inaccurate, but when the RoxAnn space is continuous (with no obvious clusters), it may be the only real option. RoxAnn squares can then be refined in a feedback process. The image processing methods of section 7.1.7 provide a possible improvement on using arbitrary squares, whereby the RoxAnn space can be covered by a smoothly varying colour (or grey) scale, so that less subjective geographical examinations can be made without artificial step boundaries.

7.1.5 Untrained classification and clustering in E1-E2 space

E1 and E2 can be plotted separately to examine variation over the survey area. Classification of E1 (and E2) by the method of natural breaks (one-parameter clustering) can be very useful in some cases (e.g. see Fig. 8 for clustering of a backscatter parameter).

Some authors refer to untrained RoxAnn classifications, meaning that the RoxAnn E1-E2 space is examined visually or by clustering for data groupings, rather than trying to form RoxAnn squares directly from groundtruth. This method can be very effective, as data do sometimes form obvious clusters or outlying groups. However, sometimes the RoxAnn space is occupied by an essentially continuous data cloud, without obvious clusters, and there is no obvious way to form a classification. Also, some clusters in the overall data cloud may simply be the result of observing one particular bottom type more times than another, and excluding nearby points with lesser density from a cluster may not be the physically correct thing to do. Whether or not the RoxAnn data cloud appears continuous, as it usually does, E1-E2 clustering is not a good approach, and it is better to segment the whole E1-E2 space in some manner e.g. by RoxAnn squares, as described in section 7.1.4, or by the image processing methods of section 7.1.7.

7.1.6 Interactive tools

Mayer et al (1997), Mayer (2000) describe a suite of software tools for display and processing of multibeam, sidescan, and vertical incidence sonar data. In the examples it appears that ellipses may be drawn round RoxAnn data in E1-E2 space (it is not known if other polygons can be drawn). RoxAnn data grouped in this manner can be displayed in geographic space as different classes. A problem just highlighted in 7.1.5

is that RoxAnn data sometimes doesn't have obvious clusters, in which case good segmentation will not be provided by ellipses (or other shapes), and class overlaps may occur.

7.1.7 Image processing methods

Fox et al (1998)

Fox et al (1998) used the image processing methods of Sotheran et al (1997) to examine RoxAnn data. Data were scanned for errors and interpolated to a regular E1-E2 grid. Gridded E1 and E2 data were scaled as 0-255 and displayed in geographic space as a greyscale image. Each pixel represented 50m x 50m. A linear histogram stretch was applied to use the full range of 0-255, then a principal component transformation was applied to produce the first two principal components. "This transformation acts to spread the pixel values across the data space, removing the correlation between E1 and E2 and thus helping to increase the information visible within the image". Unsupervised classification was performed on the first two principal components using a K-means classification. The classification map formed was used to choose 80 video groundtruthing sites (training areas), designed to sample each of 10 acoustic classes evenly. A Gaussian classifier then assigned likely bottom types to every pixel based on the training sets. A Fisher Linear Discriminant classifier was also used as a comparison method. Maps based on the two classifiers showed similar types in a broad sense. At the very least, the two classifiers succeeded in describing "rock" versus "sand". This being so, the final maps were described as predictive, and not viewed as absolute.

Greenstreet et al (1997)

To compare seasonal surveys of an area made with the same RoxAnn system, Greenstreet et al (1997) used spatial interpolation schemes combined with image processing methods. The two surveys followed approximately the same tracks. Cutting through the many processing and decision making steps involved, the essentials of the method are that E1 and E2 from area surveys were interpolated to regular geographic grids. Each survey was processed separately. The interpolated (collocated) E1 and E2 values were scaled as 0-255 and the extreme 5% of data at each end of the scale were reset to the upper and lower scaling bounds. A False Colour Composite Image (FCCI) was produced for each survey using 0, E2, E1 as RGB colour parameters, and unsupervised classification was performed on the FCCI to divide the survey area into clusters of similar RGB values. Successive smoothing, interpolation, mapping, and re-mapping caused loss of data and resolution at each step.

Good features of the image processing techniques

The 0-255 scaling and FCCI techniques provide initial continuous colour (or greyscale) codings for geographical data, without arbitrary divisions of the RoxAnn parameter space, or resulting step boundaries. Subsequent classification in geographical space may have the potential to more easily identify different bottom types, including those having overlapping RoxAnn acoustic signatures. Classifying RoxAnn data on a regular grid in geographic space, rather than clustering in RoxAnn space, avoids the problem of producing a classification based merely on sample density in RoxAnn space, rather than on bottom type. Greenstreet et al (1997; p957) noted this problem for their bottom grab samples, these being evenly spaced throughout their study area, rather than there being the same number of samples for each bottom type. A similar problem exists with acoustic data.

Drawbacks of the image processing techniques

The techniques are only suitable for geographically well distributed data. Original data are not preserved. Spatial interpolation between tracks implies a knowledge of bottom type there which does not exist, while along track smoothing to achieve regular pixel sizes may remove real changes. It might be useful to feedback FCCI clusterings to RoxAnn space to check and adjust for obvious FCCI cluster outliers and overlaps revealed in RoxAnn space. There is no need to remove 10% of data as Greenstreet et al (1997) did, a hangover from image processing methods used to reduce noise, just remove the RoxAnn default values described in section 7.1.1. Although the overall FCCI techniques appear useful, they are highly complex compared to the simplicity of the original two parameter RoxAnn data, and results may not justify the effort.

7.2 QTC

To check supervised QTC classifications made from five calibration sites, Hamilton et al (1999) determined the QTC class for all groundtruth sites as the class with the highest population (the mode) within 100 m and 200 m of a site. As an assessment of variability, a confidence was assigned to the mode as the percentage of the total number of QTC points the mode represented (this is not the ping classification confidence figure given by the QTC system). Statistics of mud, sand, and gravel grainsize weight percentages were then formed for each supervised class from all bottom samples in that class. For the Cairns area each QTC class had consistent quantitative grainsize properties, which were basically the same as those for the five calibration sites, but large spread occurred in individual grainsize values in three of five classes. Some outliers had low numbers of QTC points or were samples from previous surveys. Removing outliers significantly reduced the spread in mud/sand/gravel for one station. These simple evaluation methods for grainsize were quite effective in giving quantitative indications of QTC system performance, and in providing a quantitative type of calibration. This is an example of a 'direct' calibration.

In addition QTC classifications were overplotted on maps of grainsize, and were observed to have the same trends. This is an example of an 'indirect' calibration technique. Difference maps can be constructed using image processing techniques and GIS to obtain more quantitative estimates of relations between groundtruth and classifications (e.g. Fox et al 1998).

Overlaps of Q-values can occur for supervised classification, leading to some ambiguities, even for bottoms with very different appearance (Hamilton et al 1999). Ideally overlaps should not exist, or should be removed e.g. by forming an overlap class if the data cloud shows this is feasible.

Quester Tangent Corporation are investigating use of multi-statistical methods to seek correlations of QTC classes with various kinds of groundtruth properties, but to the present author it is not clear that their methods have always achieved useful results. Multi-statistical methods are likely to become more important as QTC refine their techniques.

7.3 General processing

7.3.1 Allowance for slope effects

Particularly for multiecho methods, it is necessary to scan for successive points, or for sets of points, with 'large' depth changes. Very large depth changes are indicative of errors e.g. due to crossing bubble wakes, and should be removed at early stages of the processing. Other changes due to bottom slope must also either be removed or checked for acoustic data stability and reliability. For vessel speeds of about 4 to 5 knots, and a classification about every five seconds, 'large' changes may be 0.8 m or less, according to RoxAnn data from Sydney Harbour obtained at beamwidths of 50°. This equates to a bottom slope of 4.5 degrees, quite a low value. Some confirmation is provided by a detailed analysis of slope effects on the QTC-View system (von Szalay and McConnaughey 2001). They found slopes above only 5-8° caused misclassifications for two 38 kHz QTC-View systems with beamwidths of 7°x7° and 9°x13°.

7.3.2 Variability in displayed classification

When individual points along track were plotted as Roxann™ classification square colours, some portions of track would alternate between two classes as successive points were plotted, even though the calibrations for that portion of track were uniform and clear cut, not being for data at the edges of RoxAnn squares. This was attributed to high variability in the Roxann™ data. To overcome this median values of E1 and E2 for along track segments were formed to smooth results. Over rough topography high variability can indicate natural bottom changes in properties, or limitations in RoxAnn second echo reception. In the latter case simple averaging may not help ping stability, and can act to reduce overall ping levels from their 'true' value, a drawback of some commercial systems (Hamilton et al 1999). Other forms of ping set averaging can be used for these cases - see Section 3.1.3.

Because of noise and variability close spaced points can be displayed as the same screen pixel, which is successively overwritten with different classes (colours) to give a false smoothing dependent on display resolution. Displaying medians of data for selected numbers of points along track can overcome this problem.

7.3.3 Geographical class overlaps

Hamilton et al (1999) found it necessary during RoxAnn calibration to plot each apparently separate class on separate maps, to check for geographical overlaps and inconsistencies, and to find out why they occurred.

7.3.4 Other points

-check track crossings for consistency

-check that tracks with different directions give the same classification

-check that ship speed / seastate does not affect classification

-check performance in areas of steeper or rapidly changing slopes

-check that changing the reference depth does not significantly affect classification. If it does, then classifications could be unreliable.

-repeat surveys of an area should form calibrations over the same pieces of ground. Duplicate tracks should preferably be followed, although the benefits of this can be outweighed by small slope changes and acoustic variability.

8. Strengths and weaknesses of acoustic bottom classification

8.1 General Strengths of Acoustic Bottom Classification systems (ABCs)

ABCs provide remote, real-time, routine data acquisition without interfering with normal vessel operations (subject to ship speed requirements where self-noise and aeration require constant vessel speed or operation within a range of speeds).

Basic units are comparatively cheap, and can be used with inexpensive purpose bought echosounders if necessary (although they also need a PC, DGPS, and external power supply, either DC or AC).

They are quite easy to set up and use, and are "portable" between vessels.

They may lessen the need for bottom sample taking (or they may not!).

8.2 General Weaknesses of ABCs

Systems use patented algorithms, or unknown proprietary algorithms, so that users are reliant on manufacturers for improvements and upgrades. This makes it difficult to advance the field of research. Still, anyone can make their own system, and based on RoxAnn as few as two parameters can do the job. QTC use 166 parameters, but how many parameters are there in a Fourier or Wavelet Transform?

Some systems have arbitrary or undisclosed parameters. Different manufacturers use different parameters. Parameters sometimes have no clear physical relation to the environment, and most if not all parameters currently used are system dependent. Consequently classifications made by a particular system have unknown relations to those made by other systems.

Constant vessel speed must be used for some vessels to provide a constant noise background, and usable signal to noise levels.

Averaging (stacking) of ping sets is not always well done - see Section 3.1.3.

ABCs ensonify different areas at different depths, so depth changes may change results even for the same bottom types. A postulated example from Rukavina (1997) is as follows: "it is important to note that where the bottom variability is at a smaller scale than the footprint, because RoxAnn integrates over the footprint it cannot distinguish e.g. ... clay and boulders from a uniform gravel with the same average acoustic properties. Also the footprint size varies with depth".

Signal to noise ratio decreases with increasing depth, so that a wide range of depths in an area may cause poor classifications. A wide depth range can also affect the reference depth corrections.

ABCs are subject to bottom slope effects, especially for second echo methods. They may not provide reliable results near the sides of channels, over deep holes, or outcrops.

Some don't record or display waveforms.

Most ABCs only work at one or two frequencies which must usually be chosen or purpose built to fit the vessel's sounder.

ABCs are affected by bubbles, wakes, acoustic noise, transducer fouling (which may degrade echo reception), seastate (through sea surface roughness for multiecho systems, and pitch and roll) and many other factors. Effects of wakes means they may not be able to be used in busy harbours, or have to be used at night. They can not be used in surf zones.

For multiecho systems, the sounder must be set to twice the maximum depth expected, so as to receive the second echo.

Results are frequency dependent.

They may give spurious or misleading results for some terrains e.g. areas with scours, and areas with rapidly changing topography.

8.3 Particular considerations for RoxAnn and QTC

8.3.1 QTC

The single echo QTC system requires complex processing, and employs arbitrary and empirical classification methods. QTC should experience fewer slope effects than multi-echo systems, has a 'simple' 3D display, and provides a classification in terms of a few known bottom types. However, a number of sites with known bottom type must be visited before classifications can be obtained in real-time, and QTC does not give indications of acoustic properties of roughness and hardness, just a classification and confidence estimate. The QTC data space is possibly not continuous. This disadvantage could possibly be offset if only simple bottom classification is sought e.g. mud, sand, gravel, rock, but forcing all bottom data to particular bottom types as QTC does could be misleading.

The QTC View system has the advantage of being easy to calibrate, but the disadvantage of only being able to show in real-time particular bottom types corresponding to the properties of the calibration sites, and of not showing indications of acoustic bottom properties such as hardness and roughness.

In unsupervised post-processing QTC can provide classifications automatically, even without groundtruth (although the meaning of the classes may not be known).

QTC may be good for habitat assessment, and this is no accident. Samples are included before the bottom pick, providing the ability to detect vegetation.

QTC requires a pre-existing catalogue of sites before real-time displays of bottom type are possible. A new type of bottom might cause difficulties to QTC.

8.3.2 RoxAnn

The multi-echo RoxAnn system uses two simple physically meaningful parameters, but requires complex circuitry with high gain for the second echo detection and noise removal, and the weaker second echo is subject to extra slope and noise effects, including non-detection over slopes. The sounder must be set to twice the maximum depth expected, so as to receive the second echo.

The RoxAnn system has the advantage of being able to indicate bottoms with differing acoustic responses in real-time without the need for prior calibration, enabling bottom sample sites to be chosen to match. It has the disadvantage of not always being easy to calibrate in terms of bottom type, often requiring much groundtruth and user intervention and interpretation. It does not work reliably over slopes and rougher bottoms because of effects on the second echo.

8.4 Desirable features of ABCs

From the foregoing sections, a list of ideal capabilities that might be required by ABCs could be as follows:

- real-time operation, including displays of classified ship track on a chart (simple or complex), along track bathymetry, ship speed, key parameters
- choice of ping averaging to suit the terrain, perhaps able to be automatically implemented
- high ping processing rates
- DGPS navigation or better
- use of known physically based and universal system independent parameters
- a ping set variability index or parameter variability index
- a slope index or display of ping set to ping set depth change
- a classification confidence for clustering type classifiers
- low cost
- a backscatter index for MCM
- able to interface with different frequency echosounders
- able to automatically allow for changes in gain, depth setting
- facility to display raw pings in real-time
- storage of raw traces
- ability to manually change or select the reference depth
- ability to run and output real-time results in uncalibrated mode
- choice of more than one classification method
- small size and weight, portability

9. The way ahead?

9.1 Improved performance and classification

Combination of classification methods

Since classification is largely empirical, use of two or more classification methods is recommended as a form of self-checking to look for similarities and anomalies. To some extent the Biosonics VBT system provides this facility. It has a real-time two-parameter RoxAnn type capability, and the ability to combine other parameters in post-processing by fuzzy clustering. However the VBT system (version v1.9) does not employ depth normalisation, and the VBT system's performance is likely compromised for all but completely flat bottoms until these aspects are remedied (see section 4.4).

The best approach in this vein at present would appear to be to combine the methods of the two types of systems most commonly used, RoxAnn and QTC-View. A particular attraction of the RoxAnn system is that it need not be calibrated to provide discrimination between bottom types, so that an unknown area can be examined without prior surveys or knowledge of the area being necessary. Use of physically based known parameters is also an advantage. A RoxAnn type approach could provide real-time indications of different bottom types, allowing groundtruth to be obtained for different bottom types as they are encountered, and also allowing a library of sites to be selected for QTC-View. QTC post-processing (or delayed processing once a library is set up) could then provide an alternative classification in terms of ping shapes. Although RoxAnn and QTC-View are used as COTS examples, the real-time part of this combined system need not be RoxAnn, nor a multiecho system, and another first echo system could be used in place of QTC-View.

For the real-time part of the combined system, two-parameter or three-parameter classifications based on the first echo could be sought, where the parameters have known physical meaning, and the complications of the second echo are avoided (e.g. see Fig. 11). The alternative two-parameter VBT classifications may have achieved this, but until VBT implements depth normalisation, it cannot be a generally useful system for acoustic bottom classification.

Allowance for changes in sounder settings and frequency

ECHOplus has the ability to input any (constant) frequency, not only one set frequency, an obvious advantage. Echoplus also implements automatic allowance for changes in echosounder settings (power, pulse length) during surveys. The system measures output power and pulse length for each ping, allowing attempts at parameter normalisations between different echosounders for its RoxAnn type outputs. How effectively is unknown.

Quantitative estimates of performance

More quantitative evaluations of performance of vertical incidence systems need to be obtained. GIS techniques are one way of achieving this e.g. with sidescan sonar imagery used as groundtruth e.g. Fox et al (1998).

Slope effects on RoxAnn and other systems have not been quantified e.g. in terms of a variability index dependent on rms slope and beamwidth. Simple examinations by the author for Sydney Harbour data show that even small slopes, expressed as point to point depth changes, are a major problem for RoxAnn. Discrepancies between two RoxAnn systems operating at different frequencies were largely removed when simple slope criteria were implemented, such as removing successive data points with depth changes more than some particular criterion. Some work on slope effects is being done by Urban (2001).

Improving Performance Over Rough Terrain

Obvious misclassification over rough terrain can be monitored by simple depth correlations. Rock or coral bottoms provide maximum echo fluctuations in shape and energy level (McKinney and Anderson 1964; Lurton and Pouliquen 1992a, 1992b). McKinney and Anderson (1964) found scattering over coral areas to vary wildly and randomly. Hamilton et al (1999) suggested variability in ping sets as a characteristic to help identify such areas. Simple averaging of pings will not necessarily achieve signal stability. More reliable parameter values could perhaps be formed as e.g. averages of the one-third highest values for ping sets, since higher values for such areas should be least affected. Comparison of stacking made with different numbers of pings could be made automatically for along track segments to check for, and flag, areas of high variability. Stacking techniques could then be adjusted accordingly e.g. by using smaller number of pings, or threshold algorithms.

Concept of RoxAnn Squares

Hamilton et al (1999) found that the simplistic notion of RoxAnn squares should be replaced by the concept of classification polygons (inclined parallelograms), aligned with the overall RoxAnn data envelope.

Classification overlaps

ABC classes for very different bottoms can overlap. Addition of a third RoxAnn parameter e.g. variability might help to distinguish between such cases. An overlap class could be formed for QTC.

Variability as a parameter

Use of variability in E1 and E2 e.g. as standard deviations for track segments introduces third and fourth RoxAnn parameters, which could possibly be much more indicative of biological/geological provinces than E1-E2 alone. Normalised deviations in E1 and E2 could be graded as Low, Medium, or High. Variability estimates for the three QTC parameters might also be useful. Simple variability indicators for ping sets are Maximum-Minimum, Median-Average etc, and these can be normalised, e.g. (Maximum-Minimum)/Median, Standard_deviation/Median. Some bottoms can be distinguished directly from others by variability index.

Use of grainsize triangles

The author has experimented with plotting E1 and E2 on grainsize triangles to check for obvious correspondences with bottom sample properties, with limited success. In the reverse procedure, an average phi size was determined for each bottom sample (using three size ranges and phi sizes for Mud of 7, for Sand of 1.5, for Gravel of -3 phi) and plotted in E1-E2 space. Hull and Nunny (1998) plotted % grain size in RoxAnn space, and also sand grain population mode as phi units. A similar procedure could be used for classes, particularly those from QTC.

9.2 Data fusion

Quite a deal of work has been done recently on combining normal incidence data with sidescan and multibeam backscatter information. Normal incidence data is valuable to sidescan sonar imagery, since backscatter alone is not usually able to characterise seabed type, as can be deduced from RoxAnn results. However, a little addressed question is that of data fusion between vertical incidence systems themselves. A technical problem exists in obtaining comparable classification results from different vessels, since vessels may be fitted with different types of echosounders operating at different frequencies. In addition, pulse shapes, power, pinglength, transducer shapes and beam patterns may be different, to mention a few parameters.

Work done by the author indicates that quantitative transforms can be obtained between different RoxAnn classifications made for an area, for all or part of the data sets, if critical factors such as variations in bottom slope are allowed for. Greenstreet et al (1998) examined ways of comparing RoxAnn seasonal surveys of an area using image processing methods, but their work is flawed (default lower and upper bounds were not explicitly removed, and there is no need to lose 10% of data), and does not provide direct quantitative comparisons. There is scope for work in this area.

Only one paper to date has compared or fused the results from different types of vertical incidence systems (Hamilton et al 1999), although more work is presently underway (Urban 2001). The analysis of Hamilton et al (1999) indicated that the single-echo shape approach of QTC-View 4 and the double-echo energy approach of RoxAnn could provide equivalent classifications, although RoxAnn variability was difficult to overcome. A quantitative transform from QTC space to RoxAnn space was obtained.

If vessels resurvey an area, then data fusion could be made easier if calibration is made at the sites used by the previous survey(s).

9.3 Data archival

Data archival has received increasing attention in recent years, with many research grants contingent on a good data archival plan. A workshop sponsored by DSTO and the University of Sydney in April 1998 addressed the question of what data should be archived for normal incidence systems. Some information has been given in Section 6. Data archival considerations will become increasingly important as data volumes increase, and as data fusion is sought between measurements made at different times, or with different systems. See Hamilton (1998a) for reference to the workshop.

10. Discussion

This document has broadly discussed some of the more basic considerations relevant to usage of acoustic bottom classification systems. Acoustic bottom classification systems cannot be used as standalone instruments for bottom classification, as noted in the literature. Classification of the sediment or habitat type ultimately requires that sediment samples or other groundtruth be taken. System calibration and classification are empirical processes, and are a function of the bottom sampling strategy, a key point which cannot be over-emphasised. Classification of an area by users using different sites for groundtruth may differ from each other. Classification can also depend on the purpose of the user e.g. a mapping of fish habitat could produce a different classification from a mapping allied to grainsize.

Because of slope effects, and signal to noise considerations arising with increasing depth and changes in self noise with ship speed, it seems likely a single echo classification approach would generally yield better results than a multi-echo approach. Nevertheless the RoxAnn multi-echo energy approach can work very well for flatter bottoms, and is useful for its simplicity, ability to show changes in seabed type without prior calibration, and other factors. An experimental comparison of RoxAnn and QTC-View has been made by Hamilton et al (1999).

Some very complicated analysis methods have been applied to extract information from acoustic bottom classification data. However, not too much should be expected from these systems. Variability in the acoustic measurements is the dominating factor in the reliability of classifications, whether it be environmental or acoustic. Small changes in bottom slope, including artefacts of vessel motions, can greatly affect shapes and energies of echoes, particularly multiples. With the noise, instability, variability, and the averaging necessary to allow for these effects, broad classifications may be all that is possible. Most ABC users find only three to five useful classes.

With careful data processing and well selected groundtruth, ABCs can provide useful results. However classifications are frequency dependent, and misclassifications can occur. It is important to note that acoustic seabed classification systems are essentially empirical devices which may work well for some bottoms but not others. Increasing knowledge of their performance strengths and limitations will enable their more informed use. For example the Biosonics VBT system (version v1.9) does not employ depth normalisation (Dommisse and Urban 2001), so that its ability to function as an acoustic bottom classification system over all but completely flat bottoms is questionable. Biosonics have acknowledged this and are working on a solution (Michaela Dommisse, personal communication).

11. References

Anon (1996). Coral Remote Sensing Workshop. Proceedings and Recommendations. Sept 17-18, 1996. Sheraton, Brickell Avenue, Miami, Florida.

Applied Physics Laboratory (1994). *APL-UW High Frequency Ocean Environmental Acoustic Models Handbook.* Technical Report APL-UW TR-9407, October 1994. Applied Physics Laboratory, University of Washington, Seattle.

Bakiera, D. and Stepnowski, A. (1996). Method of the sea bottom classification with a division of the first echo signal. Proceedings of the XIIIth Symposium on Hydroacoustics, Gdynia-Jurata, 55-60.

Bates, C.R. and Whitehead, E.J. (2001). ECHOplus measurements in Hopavagen Bay, Norway. The Oceanography Society, Biennial Scientific Meeting, April 2001.

Broffey, M. (1996). A study of coastal processes and material transportation at Kingsdown, Kent. Dept. of Ocean Sciences, University of Plymouth, Year 3 Dissertation. [Referenced by Hull and Nunny 1998]

Brekhovskikh, L. and Lysanov, Y. (1982). Fundamentals of ocean acoustics. Ed. L. Felsen. Springer Series in Electrophysics Volume 8. Springer-Verlag, Berlin.

Burczynski, J. (1999). Bottom classification. BioSonics Inc., 4027 Leary Way NW, Seattle WA 98107, USA.
[See http://www.biosonicsinc.com/product_pages/vbt_classifier.html]

Burns D.R., Queen C.B., Sisk H., Mullarkey W. and Chivers R.C. (1989). Rapid and convenient acoustic sea-bed discrimination for fisheries applications. *Proceedings of the Institute of Acoustics,* **11**, Part 3, 169-178.

Caughey, D.A. and R. L. Kirlin (1996). Blind Deconvolution of Echo Sounder Envelopes, Presented ICASS 96. 1996 International Conference on Acoustics, Speech and Signal Processing, page 3150. May 7-10. 1996. Marriott Marquis Hotel, Atlanta, Georgia. Institute of Electrical and Electronics Engineers Signal Processing Society.

Caughey D., Prager B., and Klymak J. (1994). Sea Bottom Classification from Echo Sounding Data. Contractor's Report 94-56 prepared for Defence Research Establishment Pacific, Canada. Document number SC93-019-FR-001, Quester Tangent Corporation, Marine Technology Centre, 99-9865 West Saanich Road, Sidney, British Columbia, V8L 3S1, Canada. 35pp

Clarke P.A. and Hamilton L.J. (1999). Analysis of Echo Sounder Returns for Acoustic Bottom Classification. DSTO General Document DSTO-GD-0215. 42pp.

Collins M.B. and Voulgaris G. (1993). Empirical field and laboratory evaluation of a real-time acoustic sea bed surveying system. Proceedings of the Institute of Acoustics, Vol. 15, Part 2, 343-351.

de Moustier, C. (2000). Bottom detection methods. Lecture 11. Ocean Mapping Group of New Brunswick. In Volume 1 of Fourth Asia-Pacific Coastal Multibeam Training Course, 14-19 August, 2000, Cairns.

Dobson, E.B. and F.M. Monaldo (1995). Significant wave height from altimeters. *In* "Oceanographic Applications of Remote Sensing", eds. M. Ikeda and F.W. Dobson, Chapter 14, pp223-236. CRC Press, Boca Raton.

Dommisse, M. and D. Urban. (2001). A trial of the VBT seabed classification system for habitat mapping around Kodiak Alaska. Unpublished manuscript.

Fox, D., M. Amend, A. Merems, B. Miller, and J. Golden (1998). 1998 Nearshore Rocky Reef Assessment. Newport, Oregon: Oregon Department of Fish and Wildlife, Marine Program. 54pp.

Francois, R.E. and G.R. Garrison (1982). Sound absorption based on ocean measurements: Part I: Pure water and magnesium sulfate contributions. J. Acoust. Soc. Am. 72(3), 896-907.

Greenstreet S.P.R., Tuck I.D., Grewar G.N., Armstrong E., Reid D.G., and Wright P.J. (1997). An assessment of the acoustic survey technique, RoxAnn, as a means of mapping seabed habitat. ICES Journal of Marine Science, **54**: 939-959.

Hamilton L.J. (1998a). Metadata Requirements For RoxAnn And QTC-View. Managing Seabed Data from Acoustic Classification Devices, a workshop organized by DSTO and the University of Sydney. University of Sydney, 1st April 1998.
[http://www.es.usyd.edu.au/geology/centres/osi/acuclass/abstracts.html]

Hamilton L.J. (1998b). Calibration and interpretation of acoustic backscatter measurements of suspended sediment concentration profiles in Sydney Harbour. Acoustics Australia, **26**, No. 3, 87-93.

Hamilton L.J. (1999a). RoxAnn™ Acoustic Seabed Classification of Sydney Harbour. *In* Shallow Survey 99 Conference Proceedings. International Conference On High Resolution Surveys In Shallow Water. Sydney, Australia. 18-20 October 1999. DSTO, Australia. [On Compact Disc]

Hamilton L.J. (1999b). Classification, grainsize relations, and sediment distributions inferred from visual sediment descriptions on RAN Hydrographic Office bathymetry charts of the northern Great Barrier Reef lagoon. Australian Journal of Earth Sciences 46(4), 501-514.

Hamilton L.J., Mulhearn P.J. and R. Poeckert. (1999). A Comparison Of *RoxAnn* And *QTC-View* Acoustic Bottom Classification System Performance For The Cairns Area, Great Barrier Reef, Australia. Continental Shelf Research 19(12), 1577-1597.

G.J.Heald and N. G. Pace (1996). An Analysis of 1st and 2nd Backscatter for Seabed classification. Proceedings of the 3rd European Conference on Underwater Acoustics.

Hearn S.J., Williamson H.J., Ockenden M.C. and Waters C.B. (1993). Fine resolution acoustic mapping related to sediment erosion shear strength. Proceedings of the Institute of Acoustics, Vol. 15, Part 2, 41-48.

Hedgepeth, J., Sullivan, C., Moszynski, M., Schneider, P. (1999). Categorizing bottom substrate type in shallow water. Abstract. Paper ID 76. Shallow Water Fisheries Sonar

Conference, September 7-9, 1999, Seattle, USA. [To be published in a special issue of Aquatic Living Resources]

Hedgepeth, J., Sullivan, C., Sullivan, R., Schneider, P. (1998). Verification of a library for categorizing bottom substrate type. Extended abstract. 3aUW7. Journal of the Acoustical Society of America 103, No. 5, Pt. 2, p2934. May 1998.

Hull, J. and R. Nunny (1998). Mapping intertidal sediment distributions using the RoxAnn system, Dornoch Firth, NE Scotland. *In*: Black, K.S., Paterson, D.M. & Cramp, A. (eds) *Sedimentary Processes in the Intertidal Zone*. Geological Society, London, Special Publications, **139**, 273-282.

Hydrographic Office (1991). Symbols and Abbreviations Used On Admiralty Charts. HO Publication Chart 5011, Edition 1. Hydrographic Department, Ministry Of Defence, Taunton, Somerset, U.K. 75pp.

Jagodzinski Z. (1960). Multiple echoes in echosounders and the probability of detection of small targets. *International Hydrographic Review*, **37**(1), 63-68.

Kaufman, L. And P.J. Rousseeuw (1990). Finding Groups In Data: An Introduction To Cluster Analysis. Wiley series in probability and mathematical statistics. New York: John Wiley. 342pp.

Kloser, R.J., Bax, N.J., Ryan, T., Williams, A. and Barker, B.A. (2001). Remote sensing of seabed types in the Australian South East Fishery; development and application of normal incident acoustic techniques and associated 'ground truthing'. Marine and Freshwater Research 52(4), 475-490.

Koniwinski, J., McKinney, A., Sagan, J. and J. Burns (1999). Hydroacoustic mapping of submerged aquatic vegetation in the lower St. Johns River, Florida. Poster presentation. South Eastern Estuarine Research Society, Spring 1999 Meeting, 8-9 April, Jacksonville, Florida. (The authors affiliation: St. Johns River Water Management District, PO Box 1429, Palatka FL 32178)

Kvitek, R., Iampietro, P., Sandoval, E., Castleton, M., Bretz, C., Manouki, T. and Green, A. (1999). Early Implementation of Nearshore Ecosystem Database Project. Final Report. Task 2: Habitat metadata catalog. Task 3: Review of procedures, protocols, technologies and providers for nearshore marine habitat mapping. SIVA Resource Centre, Institute for Earth Systems Science and Policy, California State University, Monterey Bay 100 Campus Center, Seaside, CA 93955, USA. 131pp.
[http://seafloor.Monterey.edu/~cahabmap/html%202%20web/finalreport.htm]

Lurton X. and Pouliquen E. (1992a). Automated sea-bed classification system for echo-sounders. *IEEE Oceans '92 Conference Proceedings*, Vol. 1, 317-321.

Lurton X. and Pouliquen E. (1992b). Sea-bed identification using echo sounder signals. *In* Proceedings of the European Conference on Underwater Acoustics, Luxembourg, 14-18 September 1992.

McKinney C.M. and Anderson C.D. (1964). Measurements of backscattering of sound from the ocean bottom. *Journal of the Acoustical Society of America*, **36**, No. 1, 158-163.

Mayer, L. (2000). Normal incidence classification methods. Lecture 19. Ocean Mapping Group of New Brunswick. In Volume 2 of Fourth Asia-Pacific Coastal Multibeam Training Course, 14-19 August, 2000, Cairns.

Mayer, L.A., Djikastra, S., Hughes Clarke, J., Patron, M., and C. Ware. (1997). Interactive tools for the exploration and analysis of multibeam and other seafloor acoustic data. P355-362, In: High Frequency Acoustics In Shallow Water, eds. N.G. Pace, E. Pouliquen, O. Bergem and A.P. Lyons. Proceedings of a conference held in Lerici, (SP) Italy, 30 June to 4 July, 1997. (Saclantcen Conference Proceedings Series CP-45).

Murphy L., Leary T. and Williamson A. (1995). Standardizing seabed classification techniques. Sea Technology, July 1995, pp15-19.

Murtagh, P. (1985). Multidimensional clustering algorithms. Physica-Verlag, Heidelberg (ISBN 3 7051 0008 4).

Murtagh, P. (1986). Multivariate data analysis software and references. ST-ECF/ESA/ESO, Garching-bei-Muenchen, January 1986. Revisions to May 1991.
[Internet location: http://newb6.u-strasbg.fr/~fmurtagh/mda-sw/]

Orlowski A. (1984). Applications of multiple echoes energy measurement for evaluation of sea bottom type. Oceanologia 19, 61-78.

Oskarsson O. (19--). RoxAnn seabed analysis. Oresound Strait Bridge Project. Marin Matteknik AB.

Pace N.G, Zerr B., Pouliquen E. and Canepa G. (1998). Overview of progress towards area seabed classification. UDT Europe 98. 23-25 June 1998. Wembley Conference Centre, London, U.K. pp41-45.

Pouliquen, E. and Lurton, X. (1992). Sea-bed identification using echo-sounder signals. Proceedings of the European Conference on Underwater Acoustics. Elsevier Applied Science. London and New York. September 1992. P535-539.

Prager B.T., Caughey D.A., and Poeckert R.H. (1995). Bottom classification: operational results from QTC View. *"OCEANS '95 - Challenges of Our Changing Global Environment" Conference,* San Diego, California USA. October 1995.

Quester Tangent Corporation (1995). *Echo Sounder Seabed Classification Results.* Document SR-25-1, April 1995. Quester Tangent Corporation, Sidney, B.C., Canada.

Quester Tangent Corporation (1998a). *Acoustic Seabed Classification: MAST '97 Results,* Final report. Document SC75-123-PR03-R02. Quester Tangent Corporation, Sidney, B.C., Canada.

Quester Tangent Corporation (1998b). QTC VIEW Operator's Manual and Reference, SR-33-OM01-R02. Quester Tangent Corporation, Sidney, B.C., Canada.

Rukavina N.A. (1997). Substrate mapping in the Great Lakes nearshore zone with a RoxAnn acoustic sea-bed classification system. *Canadian Coastal Conference 1997,* 12pp.

Sabol, B.M. and Burczynski, J. (1998). Digital echo sounder system for characterising vegetation in shallow-water environments. Proceedings of the Fourth European Conference On Underwater Acoustics, Rome. Eds A. Alipii and G.B. Canelli. Pp165-171.

Schlagentweit G.E.O. (1993). Real-time acoustic bottom classification. A field evaluation of RoxAnn. *Oceans 93*, pp III-214 to III-219.

Schneider, P. and J. Hedgepeth. (1999). Generalized additive models for classifying sea-bottom types. Poster abstract. 4pAO12. March 18. Journal of the Acoustical Society of America, 105, No. 2, Pt. 2, p1266.
[http://asa/aip.org/web2/asa/abstracts/search6/asa1382.html]

Sotheran I.S., R.L. Foster-Smith, and J. Davies. (1997). Mapping marine benthic habitats using image processing techniques within a raster-based geographic information system. Estuarine and Coastal Shelf Science, 44A, 25-31.

Spina F., Zerr B. and Pace N.G. (1999). Automatic Approaches For NATO MCM Sea Floor Classification. UDT Europe 1999 Conference Proceedings, Nice, 29 June-1 July.

Tegowski, J. and Lubniewski, Z. (2000). The use of fractal properties of echo signals for acoustical classification of bottom sediments. Acustica, 86, 276-282.

Torrence, C. and G. P. Compo. (1998). A Practical Guide to Wavelet Analysis. Bull. Amer. Meteor. Soc., 79, 61-78. [See http://paos.colorado.edu/research/wavelets for algorithms and code]

Siwabessy, P.J., Penrose, J.D., Fox, D.R. and R.J. Kloser (2000). Bottom classification in the continental shelf: a case study for the north-west and south-east shelf of Australia. Australian Acoustical Society Conference, Joondalup, Australia. November 2000.

Urban, J.D. (2001). Comparison of Biosonics VBT and QTC-view acoustic bottom classification performance in the Kodiak area of Alaska, USA. Abstract. The Geology of Marine Habitat, a special symposium at the GAC/MAC meeting, St. John's, Newfoundland. May 27-31, 2001. Sponsored by the Marine Geosciences Division (MGSD) of the Geological Association of Canada.
[http://www.pgc.emr.ca/~mgd/habitat.htm]

von Szalay, P.G. and McConnaughey, R.A. (2001). The effect of slope and vessel speed on the performance of a single beam acoustic seabed classification system. Fisheries Research, 14pp (in press).

Voulgaris, G. and Collins, M.B. (1990). USP RoxAnn ground discrimination system: a preliminary evaluation. ARE Portland UTH Tech Memo 36/90. RE005314. University of Southampton, Department of Oceanography, Marine Consultancy Services, Technical Report No: SUDO/TEC/90/5C. 33pp + 39 figs + 3 charts.

Wong, H. and Chesterman, W.D. (1968). Bottom backscattering near grazing incidence in shallow water. *Journal of the Acoustical Society of America*, **44**, No. 6, 1713-1718.

Young, I.R. (1999). Wind generated ocean waves. Elsevier Ocean Engineering Book Series. Volume 2. Eds. R. Bhattacharyya & M.E. McCormick. Amsterdam.

DISTRIBUTION LIST

Acoustic Bottom Classification Systems

L.J. Hamilton

AUSTRALIA

DEFENCE ORGANISATION

Task Sponsor : MWCSS Project Director, R3-3-X016, Russell Offices, Department of Defence, Canberra, ACT, 2600

S&T Program

Chief Defence Scientist
FAS Science Policy
AS Science Corporate Management
Director General Science Policy Development
} shared copy

Counsellor Defence Science, London (Doc Data Sheet)
Counsellor Defence Science, Washington (Doc Data Sheet)
Scientific Adviser to MRDC Thailand (Doc Data Sheet)
Scientific Adviser Joint
Navy Scientific Adviser
Scientific Adviser - Army (Doc Data Sheet and distribution list only)
Air Force Scientific Adviser
Director Trials

Aeronautical and Maritime Research Laboratory

Director
Chief of Maritime Operations Division
Research Leader: Dr A. Theobald
Group Head: Dr D. H. Cato
Task Manager: Dr P.J. Mulhearn
Mr C. Andrew
Dr S. Anstee
Dr B. Ferguson
Dr P. C. Chapple
Mr L. J. Hamilton (Author) (2 copies)
Dr R. Neill
Dr J. Vrbancich

DSTO Library and Archives
Library Fishermans Bend (Doc Data Sheet only)
Library Maribyrnong (Doc Data Sheet only)
Library Salisbury
Australian Archives
Library, MOD, Pyrmont
Library, MOD, HMAS Stirling
US Defense Technical Information Center, 2 copies
UK Defence Research Information Centre, 2 copies
Canada Defence Scientific Information Service, 1 copy
NZ Defence Information Centre, 1 copy
National Library of Australia, 1 copy

Capability Systems Staff
Director General Maritime Development
Director General C3I Development (Doc Data Sheet only)
Director General Aerospace Development (Doc Data Sheet only)

Knowledge Staff
Director General Command, Control, Communications and Computers (DGC4) (Doc Data Sheet only)

Navy
COMAUSNAVMCDGRP, HMAS Waterhen, Waverton, NSW, 2060
COMAUSNAVHYDROGRP, Australian Hydrographic Office, Wollongong, NSW 2500 (Locked Bag 8801, South Coast Mail Centre NSW 2521)
Director, Oceanography & Meteorology, Maritime Headquarters, Garden Is.
Minehunter Coastal Project Director, Department of Defence, Campbell Park, (CP2-3-16), CANBERRA, ACT, 2600
DDMWD, A-3-02, Russell Offices, Canberra ACT 2600
OIC, Mine Warfare School, HMAS Waterhen, WAVERTON NSW 2060
Australian Project Officer, MWDDEA 5807/5819, Maritime Headquarters Annex, Garden Island, NSW 2000
LCDR R. MCMillan, MWCSS Project, HMAS Waterhen, Waverton, NSW 2060
Route Survey Office, HMAS Waterhen, Waverton, NSW 2060

Army
ASNSO ABCA, Puckapunyal, (4 copies)
SO (Science), DJFHQ (L), MILPO Enoggera, Queensland 4051 (Doc Data Sheet only)

Intelligence Program
DGSTA Defence Intelligence Organisation
Manager, Information Centre, Defence Intelligence Organisation

Corporate Support Program
OIC TRS, Defence Regional Library, Canberra (Doc Data Sheet only)

UNIVERSITIES AND COLLEGES
Australian Defence Force Academy
Library
Head of Aerospace and Mechanical Engineering
Hargrave Library, Monash University (Doc Data Sheet only)
Librarian, Flinders University
Dr M. Dommisse, School of Geography and Information Science, P.O. BOX 11A, Clayton, VIC 3800
S. Gordon, CSIRO Marine Research, PO Box 120, Cleveland QLD 4163
Dr C. Jenkins, Dept of Geology & Geophysics, University of Sydney, NSW 2006
R. Kloser, CSIRO Marine Research, GPO Box 1538, Hobart, Tasmania 7001

OTHER ORGANISATIONS
NASA (Canberra)
Info Australia (formerly AGPS)

OUTSIDE AUSTRALIA

ABSTRACTING AND INFORMATION ORGANISATIONS
Library, Chemical Abstracts Reference Service
Engineering Societies Library, US
Materials Information, Cambridge Scientific Abstracts, US
Documents Librarian, The Center for Research Libraries, US

INFORMATION EXCHANGE AGREEMENT PARTNERS
Acquisitions Unit, Science Reference and Information Service, UK
Library - Exchange Desk, National Institute of Standards and Technology, US

CMDR C. Butler, Office of Naval Research International Field Office – Europe, 223 Old Marylebone Rd, London NW1 5TH, UK
Dr R. Kuwahara, Defence Research Establisment Atlantic, Dartmouth, NS, Canada
Dr R. Holtkamp, DOTSE, Auckland Naval Base, Devenport, Auckland, NZ
NATO SACLANT Center Library, La Spezia, Italy
Dr M. D. Richardson, NRL, Stennis Space Center, MS 39529-5004, USA
Dr. Douglas Todoroff, Office of Naval Research, 800 North Quincy Street, Arlington, VA 22217-5660, USA
Dr P. Valent, NRL, Stennis Space Center, MS 39529-5004, USA

SPARES (5 copies)

Total No. of Copies 75

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)
Acoustic Seabed Classification Systems	Document (U) Title (U) Abstract (U)
4. AUTHOR(S) L.J. Hamilton	5. CORPORATE AUTHOR Aeronautical and Maritime Research Laboratory 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TN-0401	AR 012-069	Technical Note	November 2001

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
460/6/114	NAV 08/026	MWCSSPD	66	60

13. URL on the World Wide	14. RELEASE AUTHORITY
http://www.dsto.defence.gov.au/corporate/reports/DSTO-TN-0401.pdf	Chief, Maritime Operations Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, SALISBURY, SA 5108

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CASUAL ANNOUNCEMENT Yes

18. DEFTEST DESCRIPTORS

Acoustic bottom classification, Acoustic equipment, Acoustic measurement, Ocean bottom

19. ABSTRACT
In the last decade acoustic bottom classification devices have been developed which can routinely provide inferences of seabed texture and grain size or habitat while a vessel is underway. These devices can be attached to existing echosounders on vessels without affecting sounder operation, or to inexpensive fish finding echosounders, enabling real-time indications of bottom type after initial system calibration is made. Aspects of these acoustic bottom classification systems are broadly described. Topics covered are principles of operation, trials of the RoxAnn and QTC View systems, other commercially available systems, algorithms, usage, and approaches to classification. Data processing and calibration methods used by various authors are listed. It is important to note that acoustic seabed classification systems are essentially empirical devices which may work well for some bottoms but not others. To enable their more informed usage, some of the performance strengths and limitations of acoustic bottom classification systems are outlined.