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Development of software for use in multi-frequency acoustic biomass assessments and ecological studies

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FISHERIES RESEARCH & DEVELOPMENT CORPORATION

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FRDC Project T93/237

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NON TECHNICAL SUMMARY

T93/237 Development of software for use in multi-frequency acoustic biomass assessments and ecological studies

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Objectives

The primary objective of the research is the development of multi-frequency-based methods of analysis for an expanding and diverse range of applications in Australia's fisheries and their associated ecosystems. This will be achieved by;

1. The development of software that will use multi-variate and image analysis analytical methods to analyse calibrated multi-frequency acoustic data for biomass assessment, species composition and bottom type studies.

2. Testing and validating these methods with field data on orange roughy and ecology/biomass studies in the SBT, SEF and Gulf of Carpentaria.

Non-technical Summary

The development of the ECHO software has enabled the collection and analysis of large multi-frequency acoustic data sets. The data can now be processed in a timely manner (via overlays) to quality assure and interpret underlying acoustic characteristics in the signals. From these analyses we can perform seabed and biomass processing on the individual frequencies. Alternatively the three frequencies can be mixed in a visual display that highlight distinct species groupings.

In the deep water orange roughy fishery the multi-frequency analysis clearly identified the dominant species groupings that occur. These combined echograms show that the community composition around the spawning aggregation is complex and not truly represented in commercial trawling operations. This will have a significant impact on the interpretation of acoustic biomass estimates. The ability to remotely sense the acoustical dominant species composition using multi-frequencies is a major advance in fisheries acoustic research. The

results from this study have changed the analysis method used in calculating the biomass of orange roughy on St Helens Hill and have been incorporated in subsequent biomass assessments, Koslow and Kloser (1998).

The ECHO software has enabled us to develop methods to remotely sense fisheries habitat as well as ensuring high data quality. The software developed in this study was used to process acoustic seabed data obtained from the FRDC South East Fishery research project, Bax and Williams (1998) using simple classification methods. This project and associated software development was used to provide data to the acoustic benthic habitat FRDC project 93/058, Pitcher *et al* (1998). This enabled the development of enhanced bottom classification methods. We have further developed the processing techniques in this report and demonstrated that the use of multiple frequencies can improve seabed misclassification rates from 27% at a single frequency to 8% at multiple frequencies. This could lead to a major advance in our ability to correctly classify different fisheries habitats and to monitor the long term stability of these habitats.

The ability to determine the mix species on the shelf with multiple frequencies and demersal catches was inconclusive. The complex nature of the scattering of the various species and the shadow zone for acoustics near the seabed may be hindering the technique. In the particular analysis presented here only two frequencies were used. To extend this method would require using all three frequencies and including information about the seabed to assist in the classification process as well as a greater number of demersal trawls with varying catch compositions.

Overall >112 Gbytes (end 1997) of data were collected and 30 % of this data processed using the ECHO software. The applications of multi-frequency acoustics have ranged from shelf seabed classification (South East Fishery, North West Shelf and the Gulf of Carpentaria), deep-water species identification in the orange roughy fishery, Southern Ocean pelagic ecosystem studies and a study of the feed of Tuna on the East Coast of Australia. The high quality calibrated data collected in this study will enable historical comparisons to be made in the future on the seabed type and water column nekton distribution and abundance in many regions of Australia that are subject to ongoing multiple use management needs.

The future development of the acoustic technique for biomass, ecology and habitat studies will continue well into the future. This future development will concentrate on developing algorithms to correct, interpret and quantify the acoustic returns to provide on survey information.

Keywords acoustics, software, shelf, habitat, orange roughy, deepwater

CONTENTS

1 BACKGROUND AND NEED

1.1 As in Proposal

Acoustic data are currently used extensively by international fisheries researchers for biomass estimation in stock assessments (walleye pollock in USA (Karp and Traynor 1989), cod and herring in Norway (Foote 1987)) and for habitat differentiation in ecological studies (Burns et al 1985). In Australia, single frequency acoustic data are currently used in stock assessments of fishes, including orange roughy, oreo dories and blue grenadier (Kloser 1989, Koslow et al 1992). In addition, the application of single frequency acoustic techniques to habitat differentiation is under investigation in both tropical and temperate fisheries (FRDC grant 93/58).

Due to the use of only single frequency data, present techniques have limited ability to distinguish fishes at a species level or to differentiate habitat types beyond coarse levels of substrate type (Anon 1992). Different acoustic targets may return the same signal strength at a single frequency due to differences in size and/or swim bladder type for fish or different roughness and hardness indices for bottom types. The use of two or more frequencies enables greater differentiation of fish species and bottom types through the use of multi-variate and image analysis analytical techniques (Simard 1992, Madureira 1993).

However at present the main impediment to adopting multi-frequency acoustic methods is the difficulty in managing the vast amount of data. Software development is required to collect the data and provide researchers with real time indicators of biomass, target strengths and bottom types at two or more frequencies. Further, software tools need to be developed to enable researchers to quickly ascertain the usefulness of the multi-frequency data for particular studies.

2. OBJECTIVES

Objectives

The primary objective of the research is the development of multi-frequency-based methods of analysis for an expanding and diverse range of applications in Australia's fisheries and their associated ecosystems. This will be achieved by:

1. The development of software that will use multi-variate and image analysis analytical methods to analyse calibrated multi-frequency acoustic data for biomass assessment, species composition and bottom type studies.

2. Testing and validating these methods with field data on orange roughy and ecology/biomass studies in the SBT, SEF and Gulf of Carpentaria.

3. METHODS

As in original proposal

The technology and hardware (Simrad EK500) are currently available to obtain calibrated volume reverberation throughout the water column and in-situ target strengths of fish and macro-zooplankton at two frequencies using 38 and 120kHz split-beam transducers. One set of transducers is currently mounted on the hull of *R.V. Southern Surveyor* for shallow water work and another set is being developed for deep water work mounted in a towed body. The data set produced using these transducers is large and a SUN UNIX computer is available to collect and archive the data. A shore-based computer with software developed at CSIRO Division of Fisheries is available to handle the basic one-frequency data set. Funds for purchase of a third frequency (12kHz) without split-beam technology to the system is requested in this proposal. The addition of a third frequency to the system will greatly enhance the discriminatory power of the technique.

In the first year, the proposal aims to develop software to collect the multi-frequency acoustic data and establish algorithms based on experience with single frequency acoustic systems. Currently algorithms are available for biomass assessment and bottom discrimination at one frequency and others are being developed by the CSIRO Division of Fisheries. These algorithms would be included to form a multi-frequency acoustic software toolkit. The resulting toolkit will enable acoustic data that will be collected on research cruises to be easily analysed and processed in line with a diverse usage.

Several opportunities for application of new methodology can be identified during the first year of the study period. CSIRO studies of the shelf SEF fishery during 1993 and 1994 and of the Gulf of Carpentaria in 1993. These studies working in shallow water will enable data to be easily collected and compared with other biomass and benthic samplers, such as trawling, benthic sleds and videos. Data will be collected from surveys of deep-water fisheries in the SEF in 1994 using a towed body and studies of SBT fishery ecology in the 0-400m range. At the end of the first year, procedures for collecting and analysing calibrated multi-frequency acoustic data collected on research cruises will be in place.

The second year will concentrate on analysing one complete data set by using and refining the software tools. The feasibility of extending the software tools to other fisheries will be assessed. Techniques to be tried on the data will include principal component analysis, clustering techniques and linear discriminate analysis as well as image analysis techniques. These techniques involve setting up environmental and acoustic descriptors of the multi-frequency echograms at various spatial scales. Such descriptors will include volume acoustic scattering, in-situ target strength profiles, school shape/size, height above bottom, weather conditions, time of day, geographic location, bottom depth and others. The image analysis techniques will include simple subtraction and addition of echo grams, overlays and pattern recognition using signal strength/shape characteristics at two or more frequencies. It is not envisaged that one technique alone will uniquely specify the schools, individual scatterers or bottom types. A classification within each method and across methods will be established so a multivariate analysis of the various techniques can be achieved. The results of the acoustic analyses will then be compared with other methods of species identification, biomass and benthic sampling methods and trends identified.

At the end of the second year algorithms will be in place that can process the data on board a research vessel and give real time acoustic indicators of change in biomass, broad species groupings and bottom types. The software tools with database will be incorporated into the acoustic system and will enable the user to easily analyse the multi-frequency data and customise it to specific fisheries. The routine nature of the technique will make it useful for long term biomass assessment and ecological studies.

Developed through project

During the process of the research several changes to the original methods became apparent. Firstly the effort required to, collect, manage and calibrate the acoustic data required significant resources. Extra resources were placed in this area to ensure good quality data was collected for future analyses. Secondly the application for the technique has also been applied to a deep-water scattering layer project to investigate its use for long term monitoring. Thirdly, it was decided to investigate the application of the software to a variety of studies rather than a detailed assessment of one alone. This would ensure that the software development was not limited in scope. The detailed oceanography, biology and acoustic analysis of these studies are being completed through the projects indicated in this report.

3.1 Software development methodology

3.1.1 Overview

Acoustic methods using echo integration are currently being used to manage fisheries worldwide. The theory and methods are well established and are detailed in many references recently summarised by MacLennan and Simmonds (1992). The technique generates large digitised data sets that require management, quality assurance and need to be readily available for processing and analysis. Automated computational techniques are required in areas such as noise filtering, bottom and surface exclusion, school pattern recognition and multi-frequency analysis. To perform these processes, flexible software is required (Foote 1991).

In the Australian context the CSIRO Division of Marine Research and the Australian Antarctic Division currently use acoustic methods to provide biomass assessments on resources such as orange roughy in the deep-water and krill in the Antarctic. These biomass surveys use Simrad EK500 scientific echo sounders at several frequencies, 12kHz, 38kHz, 120kHz and 200kHz, operating hull mounted and towed transducers. The acoustic data from these transducers are combined with navigational, pitch-roll, towed body depth and other vessel information. The amount of data collected can exceed a giga byte per day. Such large volumes require complex data management systems for archival storage and processing.

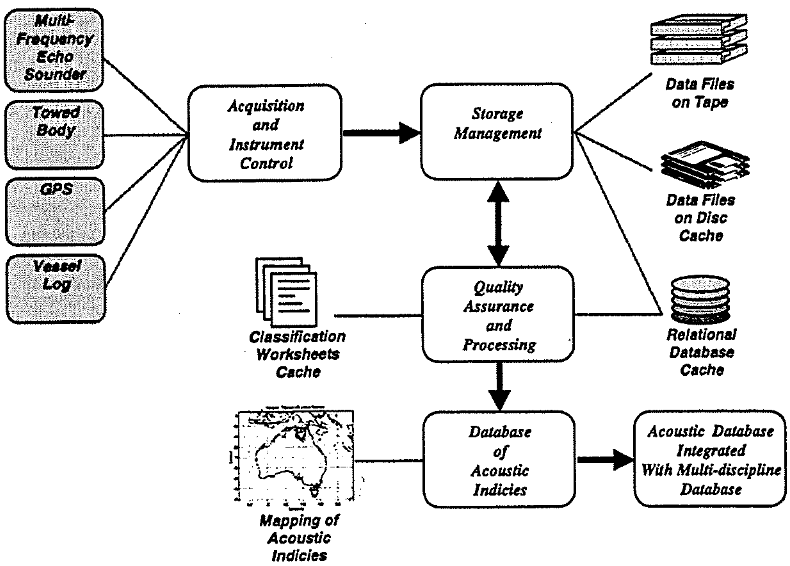
Normal incidence acoustic techniques can also be used to describe the nature of the seabed to increase our understanding of the physical and biological processes that relate to it. In our study of the Australian continental shelf we were setting out to describe the relationship of the benthic and bentho-pelagic fish and invertebrate communities to different seabed types. We collected calibrated normal incidence pulsed echo sounder acoustics at 12, 38 and 120 kHz. Each ping was digitised by the Simrad EK 500 echo sounder to include both the first and second echoes with an expansion of the bottom referenced first echo. To carry out such studies requires a wide dynamic range receiver that records each ping of information. Return bottom signals can be distinguished by a variety of shape characteristics from the enveloped and normalised energy transformed signals. Signal rise time, decay time, total energy and width are just a few such characteristics that can be extracted with dedicated software.

Early in the design phase of ECHO a stable development platform was required that would not be hardware limited. We chose a number of standard platforms such as a Sun Unix workstation, X-Windows user interface and Oracle database. The programming language C++ was chosen because of its object oriented structures that provide considerable flexibility when extending the program's capabilities. The software development of ECHO commenced in November 1992 as a collaborative project between the then CSIRO Division of Fisheries and the Australian Antarctic Division. The development of ECHO built on a modest program developed by CSIRO called ECHOX that ran on a PC. Over the past five years the software has matured and been extended to handle a variety of biomass and ecology applications. The development of the multi-frequency aspect of ECHO is a natural progression to further enhance our understanding of the marine environment.

ECHO was designed in three separate modules, Figure 3.1.1-1. These are:

- Acquisition and Instrument Control
- Storage Management and Quality
- Quality Assurance and Processing

Figure 3.1.1-1. An overview of ECHO system design



3.1.2 Software modules

3.1.2.1 Acquisition and Instrument Control

This module is designed to acquire and store data to disc. Preprocessing of the data before registration with the database is also required. Each instrument is provided with a dedicated program that understands its communication protocol. These interfacing programs pass the data on to an Acquisition Coordinator, which is primarily responsible for storage to disc. An additional facility allows co-operative programs to communicate with the Acquisition Coordinator and request that certain data telegrams be relayed to them when available. All monitors and real-time display programs use this communication mechanism. Specifically, the EK500 interfacing program communicates via an Ethernet connection with the instrument and provides facilities to remotely control the EK500, monitor the acquisition of data and display echograms in real-time.

3.1.2.2 Storage Management

The ECHO Storage Management System (ESMS) is responsible for the registration, management, retrieval and exporting of all acoustic data. An Oracle relational database is used to assist in the management of this information. Registration involves importing logged data into the database (either from an historical source or from the acquisition system). Data records are placed chronologically within uniquely named binary files, which are associated with the database according to cruise, survey, instrument, data type and data channel.

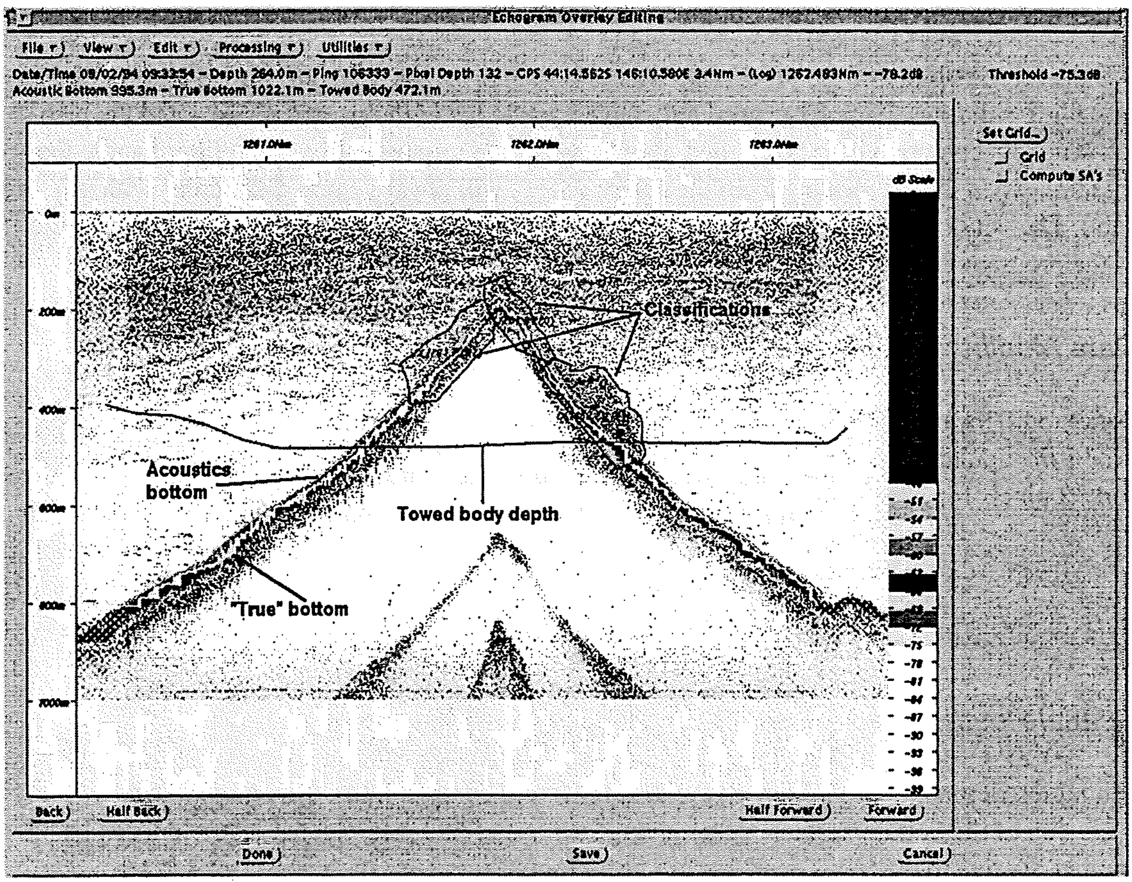
An inherent problem in managing acoustic data is that because of the large data volumes it is not always possible to store all data files to local disc. It is necessary to place registered data files on archival tapes. The ESMS was designed to keep track of the physical storage location of data files on archival tapes and local discs. To facilitate efficient retrievals, data files are grouped according to rules of likely retrieval before archival. Descriptive information is also provided for each tape, which assists users during retrieval.

ESMS provides a number of local disc "caches" that permit sections of data to be recalled from tape and stored locally on the workstation. Two types of caches are supported, volatile and non-volatile. Volatile caches provide a temporary storage space for applications to load their data that is automatically removed when the application registers that it is longer required. The user manages the non-volatile cache and data files are loaded on demand remaining in the cache until the user requests their removal.

3.1.2.3 Quality Assurance and Processing

While the ESMS can manage a wide variety of data types, processing is restricted to selected data types; ECHO is currently limited to the processing of echogram data files, Figure 3.1.2.3-1.

Figure 3.1.2.3-1 Example of the data quality and processing module



During the logging and registration with the ESMS data quality is not checked. It is necessary to assure the data quality before processing. This is achieved by applying calibration and filtering coefficients and defining regions of unwanted data (e.g. Bottom and surface exclusion); to assist with this a 'classification worksheet' has been designed. The classification worksheet also allows the user to attach special meaning to selected regions (e.g. a school of orange roughy) which is of critical importance for some processing techniques. Processing involves integration of the echogram data within defined layers or regions over a survey area. Layers may be locked to the transducer, sea surface or sea bottom. Results are written to files in a tabular format allowing for further analysis using spreadsheet or database software.

3.1.3 Data modifiers

Filters

Filtering is a general term used to describe a process that modifies the data set in some manner, or changes parameters associated with it. For echogram processing, we are concerned with only three types of filtering operations.

- Data Modifiers
- Spatial Restrictors

- Spatial Offsets

It is the responsibility of the processing structure to manage the creation and population of the cascading windows. Each filter need only have knowledge of the parent window and the ping for which its operation is to be applied. It is however the responsibility of the filter handle the situation when data is missing from the parent (edges will always cause difficulties with missing data). The windowing feature of the software has been allowed for in the underlining structure of the program but is yet to be implemented.

Data Modifiers

Data modifiers are filters that alter the intensity values of a data record. For echograms, this means manipulating the individual backscatter pixels. Such filters are often used to remove or correct pixels for noise or to apply compensations for known calibration offsets.

Data modification filters returns a new filtered record.

Spatial Restrictors

Spatial restrictors impose a limit on the data for future computations. This might mean exclusion of the bottom/surface, or removing sections of bad data. Spatial restrictors can be applied relative to the transducer, surface or bottom.

Spatial restrictors filters return a list of pixel exclusions. In the case of the echograms, this shall be a list of pixels pairs.

Spatial Offsets

Spatial offsets compute the vertical offsets required for offsetting the ping. Computation of towed body depths in an echogram is just such an application.

Processing Algorithms

Processing algorithms are unlike filters in that they are passive. They do not directly change the data, nor are their results passed onto other nodes within the processing structure. Computing the SA is a typical processing algorithm used in acoustics; this gives a measure of the backscatter strength within a given unit area.

Processing algorithms are self-contained. While they accept the data from the processing structure, they do not directly return anything.

Data Modifiers

Spike noise elimination

Noise thresholding

Absorption

Sound Speed correction

Bubble effects

Remapping of pixels to new scale

Image processing operations - Averaging/Edge detection

Spatial Restrictors

Surface locked Layers

Bottom locked layers

Transducer locked layers

Classification

Bottom exclusion

Surface exclusion

Bad data exclusion

Dead-Zone

Spatial Offsets

Layback correction

Processing Algorithms

SA's

TS's

Bottom detection/classification

School detection/classification

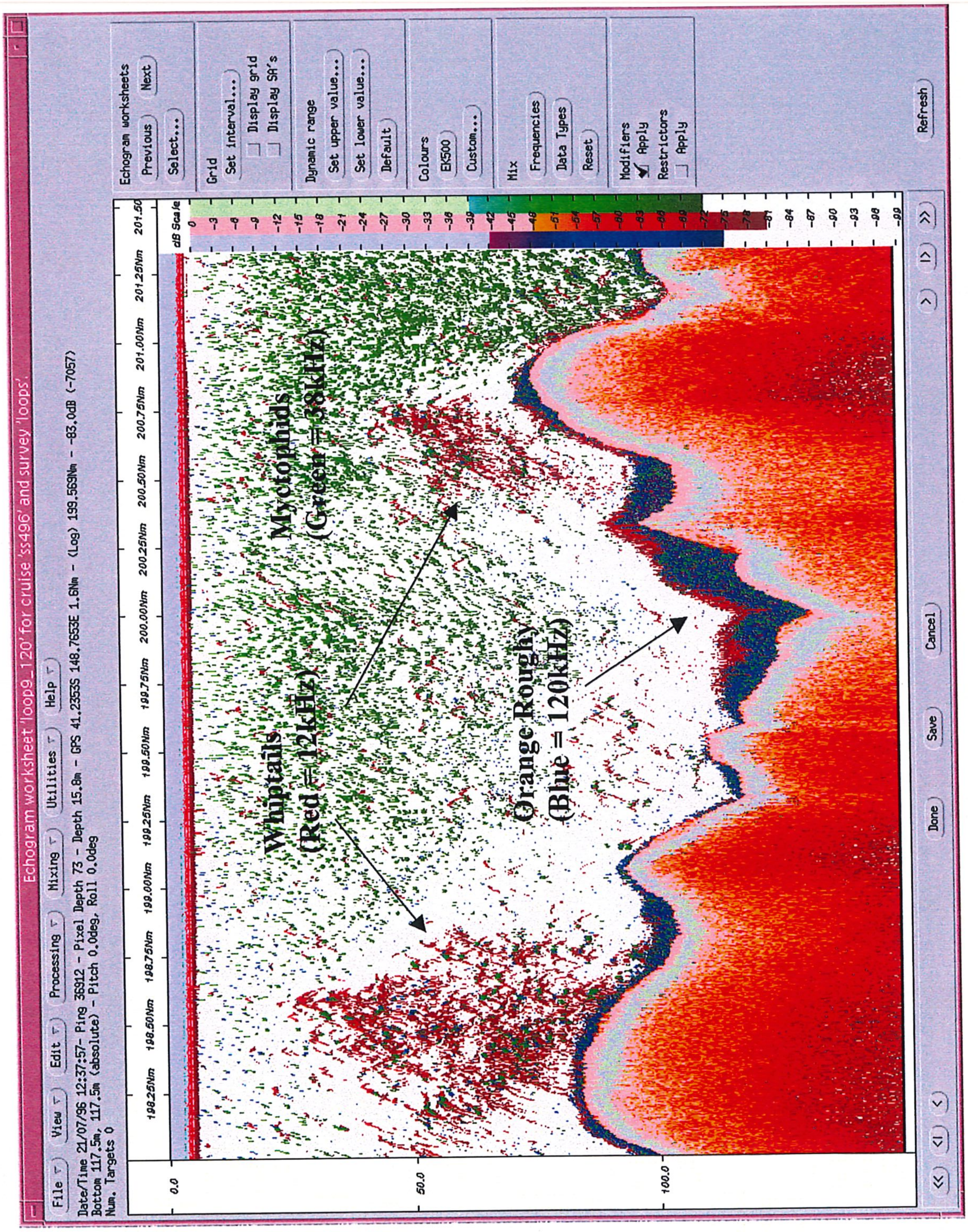
Noise quality

3.1.4 Multi-frequency visualisation

The general approach we have taken to visualise the multi-frequency data is to apply the various data modifiers on each frequency and then mix them according to an algorithm as dictated by the particular application. Presently an empirical mixing of the frequencies has proven most useful in extracting out features of interest. This is achieved by allocating each frequency a unique colour pallet with independent start range and dynamic range. Mixing of the three colours is then displayed as its own mixed pallet or by an algorithm of the individual colours. Figure 3.1.4-1.

To achieve this frequency mixing it is necessary to load the ping data for each frequency into separate buffers, time synchronisation of the echograms is checked at regular intervals. It is presently assumed that the vertical resolution of the echograms are the same. As our knowledge of the needs for analysis for the multifrequency data increase we plan to implement more application dependant frequency mixing and visualisation techniques.

Figure 3.1.4-1. Example of mixing three frequencies for a deep-water application.



3.2 Data collection and processing

3.2.1 Data collection and archive procedures

Data Collection

The collection of acoustic data is specified in detail in the document, ECHO user manual (Appendix A, Waring, 1995). This manual outlines how a user sets up the software and hardware.

Archive Procedures

There are two type of files that need to be archived, the raw data files generated during the logging of echogram data and the data files that are created when these raw data files are registered with the Oracle database.

Creation and Archiving of Raw Data Files

Using the Acquisition and Instrument Control module of the *ECHO* software, raw data files are created and stored initially on the logging computers' hard drive. During a voyage these files are routinely backed up onto exabyte tape using the archive tools provided with the *ECHO* logging software. The document tapearc.doc (Appendix A, Waring, 1993) has details on the tape utilities used for archiving of the raw data files.

Creation and Archiving of Registered Data Files

Before any quality checking or processing of the logged data can commence, the raw data files need to be registered with the Oracle database. Once raw files from a survey have been registered, the user can create, edit and process echogram worksheets.

The final step is to archive the registered data files using the esms_archive utility. This utility will make two exabyte tape copies of the registered data and then at the end of the cycle remove the files from the hard drive. The ESMS software will keep a track of the whereabouts of all registered files so that at any time it is known if required files are on hard drive or need to be extracted from the archive tapes. This happens automatically so if the files are not presently on the hard drive the user will be prompted to load the tape where the registered data files reside. Further details of the registration and archiving process can be found in the document egws_registration.doc, (Appendix A, Ryan, 1997).

3.2.2 Calibration methods

The acoustic equipment was calibrated at regular intervals with a standard -33.6 dB, 60 mm copper sphere for the 38 kHz transducer or a 42 mm sphere for all the transducers to obtain the on-axis echo integration constant (Foote, 1982). This technique combines the electrical and acoustic constants of the system, such as transmitter power, the transmitting and receiving efficiency of the transducer, and receiver gain. The manufacturer of the transducer measured the equivalent beam angle and tests on this value were confirmed for the towed system with a special calibration rig. The split-beam deep-tow transducers were also calibrated from 100 - 1000 m to correct for changes with depth in transducer sensitivity and to test for changes in beam pattern (Kloser, 1996). A calibration sphere suspended fore and aft 10 m under the towed body was lowered through the water column. The seawater propagation parameters of absorption and sound velocity were calculated from the formulae of Francois and Garrison (1982) and MacKenzie (1981), respectively, based upon temperature and salinity profiles obtained during the surveys with a Neil Brown conductivity-temperature-depth recorder (CTD).

In late 1996 an error was discovered in the Simrad software that affected the absolute calibration of the instrument. The Simrad software did not take into account the instrument delays and the TVG gain ramp through the target sphere. This was a surprise to many acousticians as Simrad quote the correct research paper that accounts for this change. The calibration error is more pronounced in deep water due to the longer pulse lengths and narrower bandwidths used. Our calibration data has been corrected by the appropriate amount as determined by the pulselength, bandwidth and sphere depth used for each calibration.

To test the beam pattern and depth related errors associated with the calibration process a special rig was constructed to mount our multi-frequency towed body in vertical mode. The test rig allowed us to measure the beam pattern plots of the 12, 38 and 120 kHz transducers at various distances ranging from 6 – 20 m.

3.2.3 Quality Assurance

Once the acoustic data has been registered with the database the user can subdivide the acoustic data into time portions of interest. To do this the user creates a worksheet that specifies a portion of acoustic data by a start and stop time and an associated sounder frequency. This enables the user to view the data and to make some quality assurance editing. The current changes implemented in the software are:

- Calibration
- Absorption
- Background and spike noise
- Bad data
- Bottom editing

Calibration

The Simrad EK500 is set up in a default mode prior to each survey according to the most recent calibration information (Table 12.8). A subsequent calibration would then be performed for the exact settings used during the particular survey and any inconsistencies noted. These calibration corrections were then entered into the echo software as required. The deep towed body transducers' calibration changed with depth and is was necessary to enter a calibration offset and slope as required, as per Tables 12.5 and 12.6.

Absorption

Absorption corrections are required on the various frequencies depending on the absorption profile obtained from CTD measurements at the specific locations. At times these corrections were large due to the large range of water temperatures that the vessel operated in, from temperate 10 degrees to tropical 30-degree surface waters.

Background and Spike Noise

Background noise Sv was measured each worksheet by obtaining the average Sv value below the bottom signal, where there was no acoustic reverberation signal, and subtracting this value from all Sv data, as described in Kloser (1996). Spike Sv noise occurred at very high values (commonly > -25 dB) due mainly to unsychronised vessel-mounted sounders or occasional high vibration and electrical noise from the deep-tow system. Spike Sv noise greater than the threshold was replaced by the Sv value immediately above in the water column. Large areas of data that were affected by vessel movement for the vessel-mounted transducer or electrical noise for the deep-tow transducer were removed by the bad data option.

Bad Data

On visual inspection of the echograms as specified in the worksheet it was possible to exclude portions of the data that were adversely affected by noise or vessel movement.

Bottom editing

Bottom editing was required when the automatic depth tracking in the Simrad EK500 failed to pick the correct bottom signal. These high-bottom signal values could corrupt the acoustic data. Using the ECHO program the bottom line could be redrawn with a mouse.

Processing Masks and Data Flow

Processing of the data can be realised by specifying a vertical depth range and a horizontal interval. The range can be referenced from the surface or by the first or second seabed echoes. This data is then processed within an editing session or can be automated to process a number of worksheets after the appropriate quality assurance process. The data once processed is placed into flat summary files for importing into a database or 4GL language such as Matlab. C Shell, nawk and awk scripts have been written to convert the flat files into formats suitable for a variety of packages.

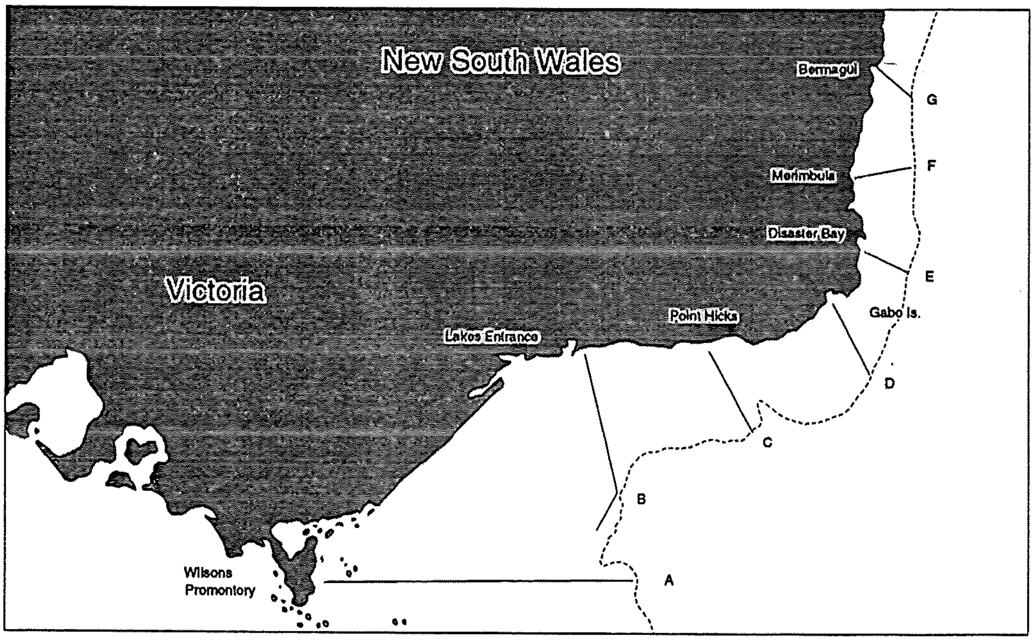
3.3 Application to fishery biomass and ecological studies

The methods for the data analysis reported here relate to the application of multi-frequency acoustic methods to nekton biomass/ species composition and seabed habitat studies. Combining the application of the methods and software development has allowed us to focus on the critical issues required. The software development has thus focused on supporting the needs of the particular studies and enhancing their results.

3.3.1 The association of acoustic data with shelf demersal trawl catches in the SEF.

The association between patterns of acoustic backscatter and near-bottom fish assemblages was investigated using data collected from the continental shelf off southeastern Australia. Data were collected along seven cross-shelf transects in depths from ~ 25 to 200 m. They covered an area from Wilsons Promontory, Transect A, to Bermagui, Transect G, (Figure 3.3.1-1) with data taken at five stations on each at approximately 25 m, 40 m, 80 m, 120 m, and 200 m depths. The data used for this analysis were from Southern Surveyor cruise 5/93, Legs 2 and 3 (Table 3.3.1-1).

Figure 3.3.1-1 Transects for demersal trawls.



Fish data came from a trawl carried out at each station in which the numbers and weights of each species caught were recorded. The 156 distinct species identified among the 38 trawls were collapsed into eight broad groups (Table 3.3.1-2), based on characteristics expected to affect acoustic reflectance: presence or absence of a swim bladder, demersal or semi-pelagic association with the seafloor, and large or small body size. Since acoustic backscatter values (Sa) provide an index of fish density based on numbers rather than size directly, catch numbers rather than weights of each species were used.

Acoustic data were recorded concurrently with trawling at two frequencies at each station: low (38 kHz) and high (120 kHz). The acoustic echoes were initially divided into four depth bands, 0-5 metres above the bottom, 5-10 metres, 10-15 metres and 15-20 metres. Backscatter (Sa) values have 0.005 nautical mile intervals along the acoustic transect, corresponding to approximately six pings at one second intervals, with between 134 and 491 values per acoustic transect. The 0-5 m depth band was adjusted for the 'dead zone' at the bottom, from which bottom signal interferes with signal from fish. Accordingly, data from the bottom 0.5 metres was ignored and the total for 0-5 m was taken as (total for 0.5-5 metres)*10/9.

The acoustic data were processed before analysis, by replacing missing values using linear interpolation, taking logarithms of Sa values, and, for some analyses, smoothing the data using a non-parametric smoother named "4253H, twice" (Velleman and Hoaglin, 1981). Univariate descriptors of the eight acoustic traces at each station were sought to describe general level, shape, trend and smoothness. A fractal dimension measure was used, as well as roughness measures based on square root or absolute value of second differences.

The fractal dimension measure was defined as follows. The length of a profile, in the Y-direction only, was measured using different step lengths, i.e. using every point, then every second point, every third point etc., averaging the results from measures starting at different points, with adjustments at the ends. This resulted in length for step length k being defined as:

$$\mathrm{L(k)} = \frac{n-1}{n-k}\frac{1}{k}\sum_{i=k+1}^{n} | Y_i - Y_{i-k} |$$

Then log L(k) was plotted against log of step length k, which generally produced a straight line with negative slope. This was checked each time. It did not work for smoothed data, where this plot was always curved, so unsmoothed data were used. The fractal dimension was defined to be one plus the absolute value of this slope (as estimated by simple linear regression), giving a number greater than 1, or equal to 1 for perfectly smooth traces, in which the length is constant for all step lengths – there are no bumps to be smoothed out by larger step lengths. In general, for one-dimensional curves, the maximum possible value of fractal dimension is 2. We obtained value up to 2.1, which suggest some modification of this measure may be desirable.

The aim of the analysis was to relate the two sets of data: fish abundance and acoustic Sa variables. There were 38 trawl stations each with up to 156 species (multivariate) observations, and acoustic traces for two frequencies and four depth bands, each trace consisting of a few hundred points. With only 38 stations, the number of variables must be reduced to many less than 38, so as to avoid over-fitting, i.e. obtaining a solution very specific to these data but not able to be generalised.

Three different approaches were used to associate patterns in the two data sets: 1) using data from all stations, 2) using data from only the deeper stations, 3) using stations with similar catch compositions.

Step 2 used a subset of stations in which there was greater consistency in the catch compositions. These stations also had better quality acoustic data, which probably resulted from data collection in smoother sea conditions. Distinctive catch compositions were sought, on the basis of actual species rather than the broad groups, in the hope of greater sensitivity. Particular attention was paid to catch compositions in which one species completely dominated the catch. Several measures of diversity and dominance were also examined: Shannon-Wiener diversity index, Species richness, species evenness, its complement which is a measure of dominance, Simpson's concentration, and a diversity index based on Simpson's concentration.

Step 3 attempted to compare acoustic traces from stations with similar catch compositions to try to discover any features, either of individual traces or of relationships between traces from the same station, which characterised certain catch compositions. Plots of the acoustic traces were examined, two frequencies superimposed on the same plot, with most attention on only the deepest depth band. Also examined were scatterplots (ignoring ordering of observations along the trace) of acoustic values at the two frequencies and the two deepest depths, plotted against each other.

Table 3.3.1-1. Stations information and comments on acoustic data quality. Depths 1 to 5 are approximately 25 m, 40 m, 80 m, 120 m and 200 m respectively. In the comments column, a refers to 0-5 m depth band, b to 5-10 m and c to 10-15 m depth band. The number is the frequency.

Station	Number of points in acoustic data	Transect	Depth	Data quality	Comments
85	303	A	1		
87	268	A	2		
102	134	B	2		
104	491	B	1		
106	326	C	1		b120, b38 driven by indiv schls hence high sd
108	333	C	2		
110	310	C	3		
127	346	E	4		
129	301	E	3		
130	357	E	2		
132	348	E	1		
140	461	E	1		
141	300	E	4		
142	369	E	5		
160	308	F	2	bad	a120 has suspicious amounts of data
161	360	F	5	good	
169	356	C	1	bad	c120, b38, c38 driven by discrete school
172	233	C	5	good	120 has many low signal noise spikes
174	209	C	5	good	120 has many low signal noise spikes
175	167	C	5	good	120 has many low signal noise spikes
176	168	C	5	good	120 has many low signal noise spikes
177	360	C	5	good	120 has many low signal noise spikes
201	280	D/E	5	good	120 has many low signal noise spikes
213	271	D	4	good	
215	339	D	3	good	
217	276	D	2	good	
224	340	E	1/2	120 bad, 38 good	
225	347	E	1/2	120 bad, 38 good	
230	317	E	1/2	120 bad, 38 good	
231	386	E	1/2	120 bad, 38 good	
239	248	E	2	good	
240	368	E	2	120 moderate, 38 good	
245	341	E	2	120 bad, 38 good	
246	299	E	2	120 bad, 38 good	a120 has suspicious amounts of high value data
251	358	G	5	120 good, 38 very good	

253	302	G	4	120 good, 38 very good	
255	320	G	3	120 good, 38 very good	
257	325	G	2	120 bad, 38 good	b120, c120, b38, c38 driven by discrete school

Table 3.3.1-2. Characteristics of the eight broad groups of species

Group	Spatial	Swim bladder	Size	Expected acoustic reflectance
1	Demersal	No	Large	Low
2	Demersal	No	Small	Low
3	Demersal	Yes	Large	High
4	Demersal	Yes	Small	Mod-High
5	Semi-pelagic	Yes	Large	Highest
6	Semi-pelagic	Yes	Small	Highest
7	Semi-pelagic	No	Large	Low
8	Semi-pelagic	No	Small	Low

3.3.2 The association of acoustic data with pelagic trawl catches

Summary of a report by Kloser et al (in Prep) on Combining multi-frequency acoustics and depth stratified trawls to describe nekton and macrozooplankton in the Southern Ocean.

The association between patterns of acoustic backscatter and pelagic biota was investigated using data collected from the deep open ocean off southern Tasmania. Multi-frequency acoustic data was collected continuously on a voyage in 1995 (SS9511) in a region of the Southern Ocean bounded by latitudes 40°S and 53°S and longitudes 140°E and 148°E (Kloser et al., in prep). The acoustic data recorded concurrently with trawling was at three frequencies at each station: very low (12 kHz), low (38 kHz) and high (120 kHz). Trawl samples were taken with a depth-stratified pelagic trawl, the 'MIDOC', that was targeted at acoustic layers between the surface and 300 m depth. The numbers, weights and lengths of each species caught were recorded separately from each of five depth strata per trawl. The multiple species were split into four broad groups based on characteristics expected to affect acoustic reflectance, primarily taxonomy, and presence or absence of a swim bladder: salps and pyrosomes (=gelatinous zooplankton), medusae, small micronektonic crustaceans (=krill) and micronektonic fishes. The Details of species swimbladder dimensions and position were also recorded. Again, numbers of each species were used for comparison with acoustic data.

Acoustic data were depth-corrected for noise and absorption and calibrated using acoustic backscattering data profiles.

3.3.3 Classification of fishery habitats using acoustics

Describing the nature of the seabed is important in obtaining an understanding of the physical and biological processes that relate to it. In our study of the Australian continental shelf we were setting out to describe the relationship of the benthic and bentho-pelagic fish and invertebrate communities to different seabed types. We collected calibrated normal incidence pulsed echo sounder acoustics at 12, 38 and 120 kHz. Each ping was digitised by the Simrad EK 500 echo sounder to include both the first and second echoes with an expansion of the bottom referenced first echo.

Our software package 'ECHO' was enhanced to acquire, store and quality assure the ping based seabed data. Quality assurance removes pings that are corrupted due to poor bottom detection, aeration in bad weather, excessive vessel movement and noise. Simple algorithms have been introduced to routinely process the first and second echoes and compensate for depth and noise. This data is imported to an Oracle database where it is combined with video, trawl, grab and sled information. It is then mapped as required to display an individual acoustic feature or a cluster of features. This type of analytical approach was performed for the South East Fishery data reported in Bax et al (1998) and Bax and Williams (1998).

3.3.3.1 Feature and smooth ping multi-frequency analysis

Summary of a report by Gordon, Jones and Kloser presented here and in Pitcher et al (1998)

The stored acoustic data were exported from the ECHO software in the form of pings at three frequencies from four replicate sites at each of three habitats. The habitats chosen were classified as Soft, Rougher, and Rough/Hard. The three frequencies were: 12Hz, 38Hz, and 120Hz. Each ping was recorded at 128 discrete points and there were 128 pings measured at each of the three frequencies for each of the rep x habitat combinations. The aim of this section is to present the statistical analyses used to assess the ability to distinguish between the three habitats based on multi frequency data compared to single frequency data.

We will consider the three frequencies as three separate data sets to examine the single frequency approach. For the multi frequency approach, we will merge the three frequency data sets to form a combined data set, as described below. The traditional statistical approaches to classifying data from a vector of features use the Mahalanobis distance and discriminant vectors. The Mahalanobis distance measures either the distance between the habitat feature means or the distance of individual pings to habitat means, and the discriminant vectors are linear combinations of the original feature vectors that maximise the between habitat variability relative to the between ping variability.

As a typical ping is a smooth function when plotted against the corresponding sequence of points in time, various extracted parameters of the smooth curve have been used in the past to form the feature vectors for classifying habitats. We plan to use the smooth curve as an underling component of the full set of points available for a ping and perform the classification of habitats without relying on using extracted features that may be subject to spurious data values and be unreliable when put into routine habitat classification.

In the following, the extracted features and the full smooth curve approach will be compared using a cross-validated miss-classification error rate. Here we calculate the Mahalanobis distance for the appropriate feature vectors on test subsets of the data relative to their complementary training subset means.

A brief description of the full smooth curve approach is now given. If we denote **B** as the between habitat covariance matrix and **W** the between ping within rep x habitat covariance matrix , then the discriminant functions are linear combinations of a feature vector **x** , written as **a'x**, where **a** are obtained as the eigenvectors of $\mathbf{W}^{-1}\mathbf{B}$. When this is applied to the smooth curve of points on a ping, you would expect the resulting pattern of elements of the **a** vector to similarly be smooth curves when plotted against the sequence of points at which the ping was measured. However, because of the high correlations between consecutive values on a ping, the **W** matrix does not lead to stable or smooth coefficient plots. Hence, we augment **W** with a penalty matrix $\lambda\Omega$, where Ω is a roughness penalty matrix and λ is a parameter which trades off staying close to the data **W** and having a smooth coefficient vector **a**. Consequently, the higher the value of λ, the smoother the coefficient vectors **a** will be, as rough versions of **W** correspond to smooth versions of $\mathbf{W}^{-1}$. In the multi-frequency approach, we want the coefficient vector a to reflect the smooth two dimensional surface of the pings considered as functions of points in time and level of ping frequency.

A summary of the 58 extracted features & groups of features for a ping is given in the table below:

Feature Group	Feature Type	Features
A	Statistics	Maximum, minimum, mean, variance, median, histogram, harmonic mean, skewness, kurtosis, interquartile range, mean absolute deviation, range
B	Shape	Ping shape
C	Pulse Parameters	Number of peaks, pulse width, rise time, fall time, slew rate, decay rate, maximum threshold, minimum threshold, differential threshold

D	LPC's	Linear prediction coefficients
E	Echo Integration	Above bottom, below bottom, peak, tail, tail to peak ratio

Detailed description of extracted ping features can be found in the report (Pitcher et al 1998)

From the above, the Peak and Tail echo integration features are proxies for acoustic Hardness and Roughness measures respectively.

The collection of 58 features will be called the "Extracted Features".

The following notation will be used:

Habitat Description	Label	Rep1	Rep2	Rep3	Rep4
Soft	1	a	b	c	d
Rough/Hard	2	m	n	o	p
Rougher	3	w	x	y	z

Frequency	Label
12Hz	1
38Hz	2
120Hz	3

Multi – Frequency Extracted Features were obtained by combining the three blocks of 58 columns from each of the three frequencies one after the other. Similarly, the multi – frequency version of a full smooth curve for a pin g was obtained by combining the three blocks of 128 points in time for each of the three frequencies one after the other.

When looking at all the 58 extracted features for any frequency, or the 174 features from the multi – frequency extracted feature set, as the groups of features have different scales, the columns were standardized by dividing by the value [MAX(ABS(x))+1] for each column.

For the full smooth curve approach, and a single frequency, Ω is given by $D_{128}' D_{128}$ where

$$D_{128} = (d_{ij}) = \begin{cases} 1, & j=i,i+2 \\ -2, & j=i+1 \\ 0, & \text{otherwise.} \end{cases}$$

For the full smooth curve approach considered from a multi – frequency approach, Ω is given by D'D

$$D = D_3 \otimes I_{128} + I_3 \otimes D_{128}$$

where D_3 and D_{128} are defined as above and I_3 and I_{128} are identity matrices of dimension 3 and 128 respectively, and $\otimes$ is the direct product operator for matrices.The augmented W used in the full smooth curve approach is given by

$$\text{Aug}(\mathbf{W}) = (1 - \lambda)\mathbf{W} + \lambda c\Omega$$

where c (= trace(W)/trace(Ω)) is used to allow the trace of Aug(W) be the same as the trace of W.

To calculate the cross-validated miss-classification rate, halves of reps from each habitat were set aside and the various discriminant analyses performed on the remaining halves. The data that was set aside was then classified using Mahalanobis distance, i.e. each withheld observation was assigned the class with the minimum Mahalanobis distance when referred to the mean and covariance matrix of the remaining data. The miss-classification error was calculated as the proportion of incorrectly classified observations when the 8 sets of half reps had been withheld.

3.3.4 Describing the feed of Tuna

This is a summary of a report by Young *et al* (in Prep) and describes the methods used for a study on the feed for Tuna and how the acoustic data was integrated with the oceanographic and biological information.

In May (18 - 31) 1996 the CSIRO fisheries research vessel, FRV Southern Surveyor, completed a survey of the main yellowfin tuna longline fishery off southeastern New South Wales, Australia. The physical oceanography of the area was described from two main hydrographic transects eastward from the shelf along latitudes 36° 25' and 37° 15' S. On each transect CTD casts, at intervals of between 5 and 20 n.miles, recorded temperature, salinity and nutrients to a depth of 1000 m. Fluorescence was measured to a depth of 100 m at each CTD station, and from the surface water layer while the ship was steaming. The oceanographic data were also used to ground-truth satellite images of sea surface temperature taken of the area during the period of each study.

A Simrad EK 500 scientific echo sounder was used to collect underway acoustics data to a depth of 400 m, the maximum depth to which we sampled. Frequencies of 12 and 38 and 120 kHz with wavelengths at 0.125, .0395, 0.0125 m respectively for a sound speed of 1500 m/s were used. The multiple frequencies were used to enable species identification based on target shape, size and density and swim bladder type and size as a function of depth. The Simrad EK500 echosounder was calibrated with a standard sphere as outlined by Foote (1987) and the data was processed and quality checked following Kloser (1996) using a program developed by Waring et al (1994). To avoid changing backscatter within a frequency due to vertical migration of organisms data were grouped by day and night. Day and night hours were specified by 1.5 hours either side of dawn and dusk to allow for the organisms to settle as visually observed on the echograms.

Net collections

Four types of nets were used to sample the fauna from microzooplankton (animals < 1mm in length) through macrozooplankton (animals from 1 to 20 mm) to micronekton (animals between 2 and 20 cm)(Omori and Ikeda 1984). At each hydrographic station the microzooplankton was sampled with three replicate drop nets (Heron 1982) of mesh size 100 µm and mouth area 0.25 m^2. This net sampled to 100 metres except on the shelf where it sampled to 60 metres. Macrozooplankton was sampled with a paired 70 cm bongo net (mesh size 500 µm) by day. Volume filtered was recorded with a flow meter. A submersible data logger attached to the frame transmitted depth, rate of descent and elapsed fishing time. The bongo net fished obliquely from the surface to 200 m and back again over approximately 20 minutes. Over the shelf the bongo was towed to just above the seabed. Micronekton were sampled at night using an IYGPT midwater trawl fitted with an opening/closing codend (midoc). The codend used an electronic timer to fire nets at pre-set times. Depth, mouth opening, headline height and board spread of the trawl were monitored acoustically. Sampling consisted of a 40 minute oblique tow to 400 m, followed by 15 minute stepped-oblique tows at depths of 400-300, 300-200, 200-100 and 100-0 metres. A square surface net (mouth area $1m^2$ and 500 µm mesh netting) fitted with a mechanical flow meter was deployed once with each bongo tow and between 2 to 4 times with each midwater trawl. Net samples were usually fixed in 10% seawater formalin buffered with sodium acetate. However, approximately half of the bongo and all of the surface tows were fixed in ethanol to preserve the otoliths of any larval fishes present.

3.3.5 Species identification in the deep-water orange roughy fishery.

Summary of a report by Kloser et al (in Prep) titled 'Deepwater species identification using multi-frequency acoustics'.

In late July 1996 the FRV Southern Surveyor conducted an acoustic survey of the orange roughy on St Helens Hill. Acoustic surveys of Orange Roughy are very sensitive to error in assessment of species composition, because orange roughy have relatively low acoustic reflectance due to a lack of a gas-filled swimbladder. Furthermore, because the target strength of orange roughy is similar to that of small feed fishes (i.e. myctophids) with swimbladders at 38 kHz, it has not been possible to differentiate between these two types of acoustic targets using split beam technology at this frequency. A major potential source of bias may be eliminated, therefore, if such targets can be discriminated using several frequencies.

To conduct the multi-frequency experiments on orange roughy a deeptow body was constructed and tested prior to the voyage, FRDC project 95/031, Koslow and Kloser, 1998. The deeptow body contained three frequencies at 12, 38 and 120 kHz, the 38 and 120 kHz transducers were split beam for echo location and beam compensation of single fish. The transducers on the deeptow body were calibrated as per Kloser (1996) by suspending a sphere underneath the transducers and lowering to 800 m. The calibration results from this calibration are given in Appendix D.

Species composition around the hill was investigated by following the depth contour of 700 – 900 m at a height of 100 m above using the multi-frequency towed body. This survey strategy ensured that all sectors of the hill could be sampled in a timely manner. In all 14 loops around the hill were conducted and the multi-frequency data were logged and processed using the composite routine developed in the ECHO software, as described in 3.1.4.

The species composition around the hill was also investigated by 21 demersal trawl tows conducted from a commercial vessel. The catches were sorted into dominant acoustic categories based on swim bladder and shape characteristics.

4. DETAILED RESULTS

4.1 Software Development

Appendix B outlines the modules used to drive the software package known as ECHO. These modules are described in the documentation outlined in Appendix A. The software package is used both at the CSIRO Division of Marine Research and the Australian Antarctic Division. Both organisations provide support and enhancements for the software for research activities. The software is maintained under the CVS source code control system. Daily management of the code occurs through a bug and enhancement list that are attached priorities as dictated by data analysis priorities. The web page address for monitoring development of the software and registering bugs or enhancements is http://www.marine.csiro.au/dmr/software/echo/echo.html. This web address also contains the theory of operation and data analysis modules. The software is continuing to be used throughout the organisation for a variety of projects ranging from fisheries biomass to seabed habitat studies. In total the software package has 118 055 lines of code that contain 308 159 words or 2 723 141 characters.

4.2 Data Collected

4.2.1 Data holdings

A great deal of time and effort has been entered into to collect quality calibrated multi-frequency acoustic data. This data set will be used well into the future for time series information and seabed habitat mapping when required. Appendix C gives a summary of all the data collected by the ECHO software and its approximate location. In total 112 giga bytes of raw data have been collected using the ECHO software and 30% of this data is registered for analysis. A detailed location map of data used for the multi-frequency trials is shown in Figures 4.2.1.1-4

Figure 4.2.1-1 Display of specific data holding around Australia

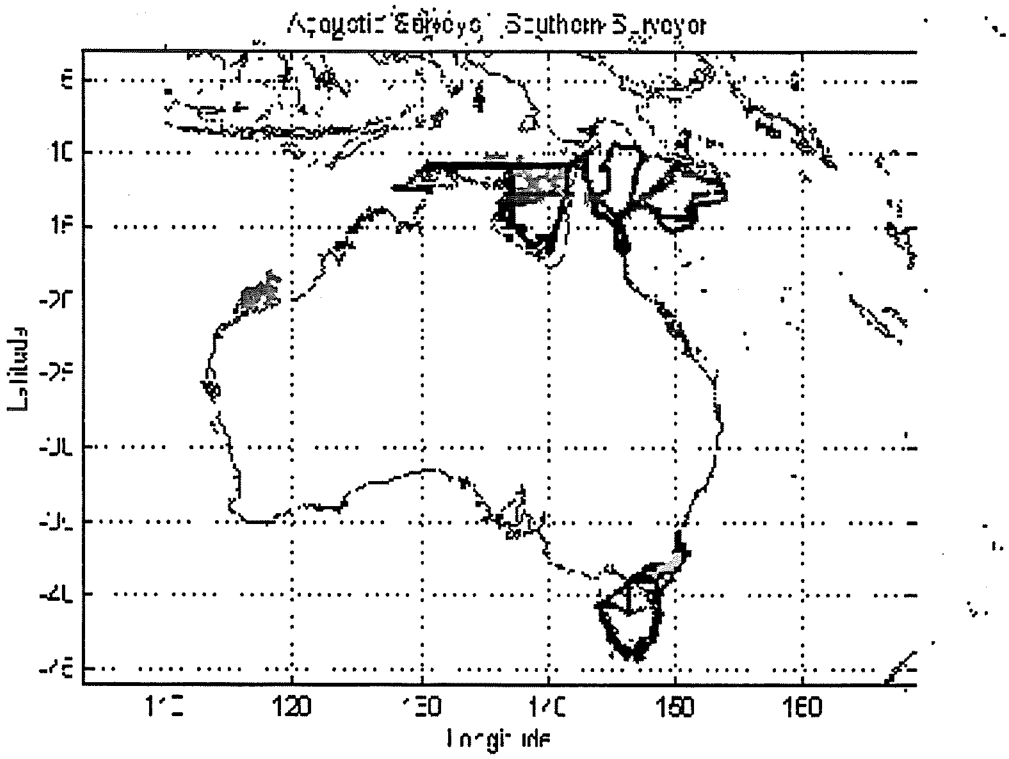


Figure 4.2.1-2 ss496 Ship Tracks

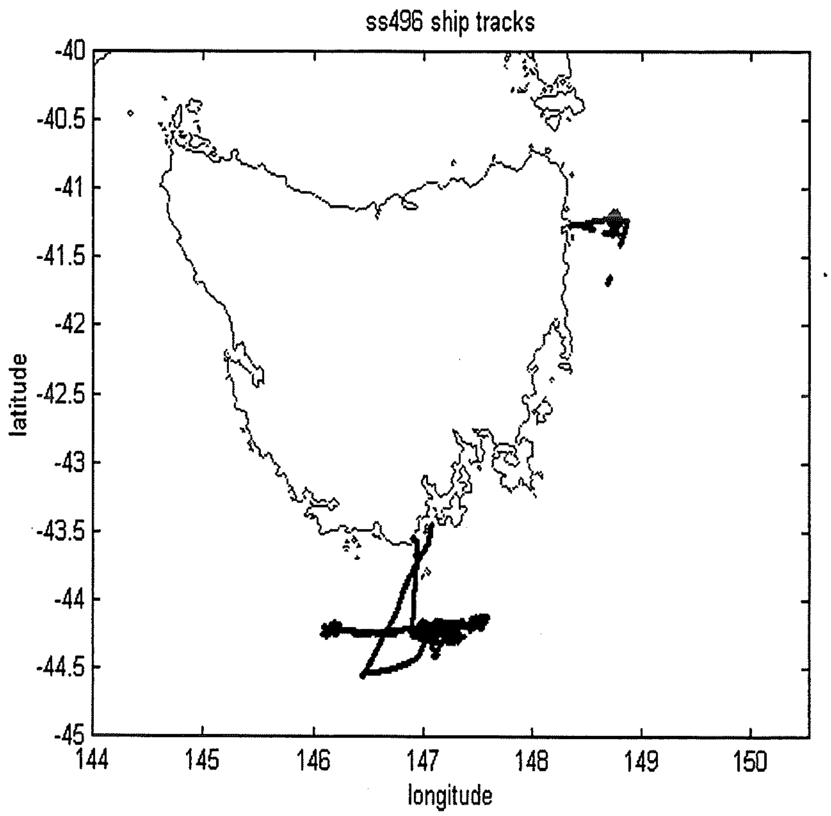


Figure 4.2.1-3 ss1195 Ship Tracks

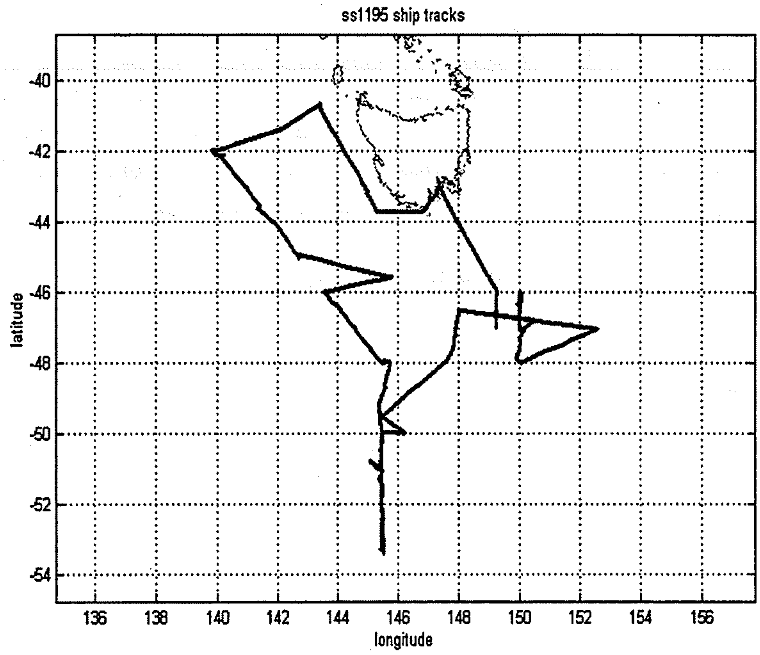
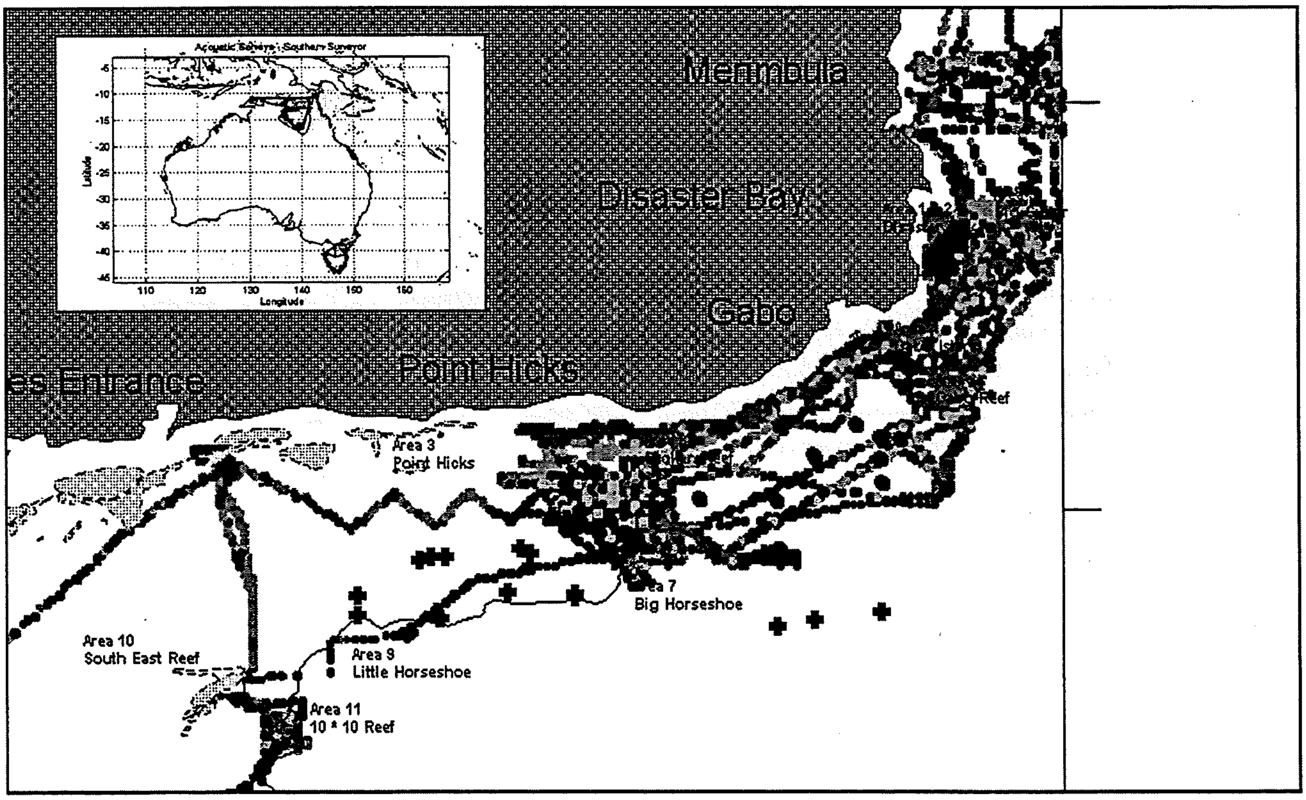


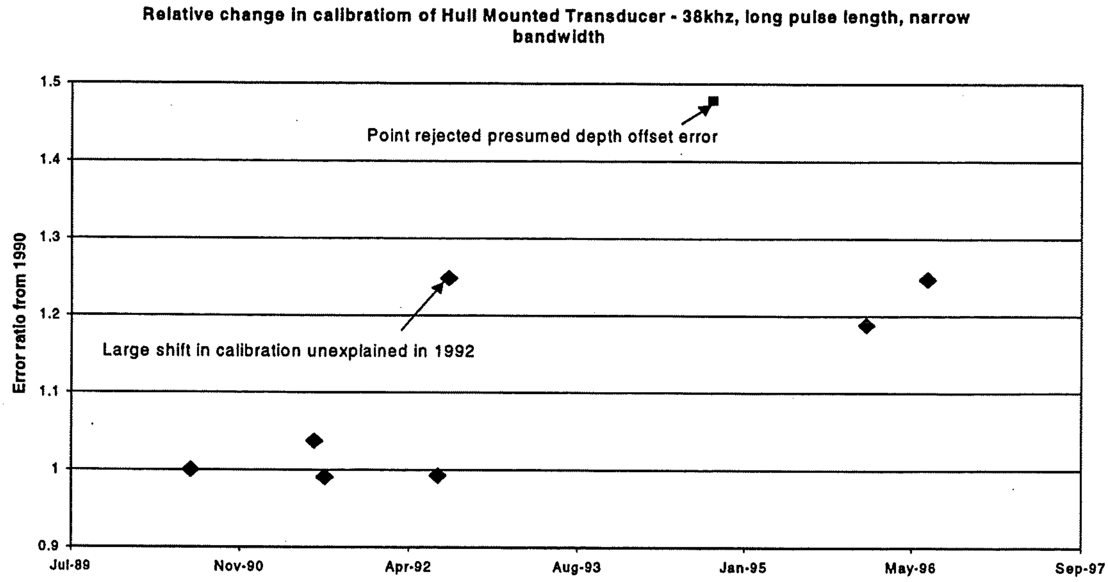
Figure 4.2.1-4 South-East Fishery Ship Tracks



4.2.2 Calibration results and instrument settings

Detailed calibration results are given in Appendix D and outline the transducer specifications and the instrument settings for both the vessel and towed transducers. To summarise the calibration settings Figure 4.2.2-1 below displays the stability of the 38 kHz vessel mounted transducer at one setting over a number of years. The large shift in calibration in 1992 has not been explained and may be due to hardware modifications. The shift in calibration in 1992 has been reproduced in subsequent calibrations and is thus seen as an actual change.

Figure 4.2.2-1. Stability of vessel mounted 38 kHz transducer over a six year period.



The deep-tow transducers are sensitive to depth and a plot of the up and down profiles for the three transducers shows hysteresis in the transducers. The hysteresis of the 38 kHz transducer has been well documented in, Kloser (1996). The results for calibration of the 12kHz, 38kHz and 120kHz transducers presented here (Figures 4.2.2-2, 4.2.2-3 and 4.2.2-4) are from one site and investigations are continuing into the transmitter to transducer matching that may be contributing to the hysteresis observed.

Figure 4.2.2-2 Results of deep water calibrations for the 120kHz transducers.

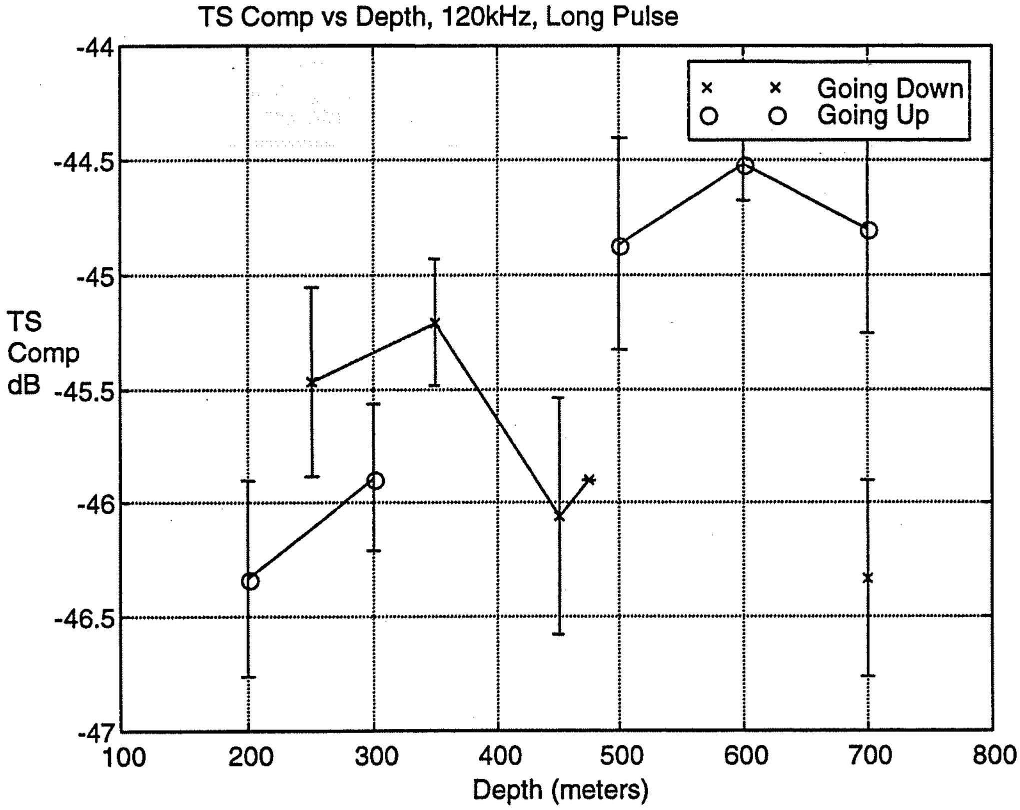


Figure 4.2.2-3 Results of deep water calibrations for the 38kHz transducers.

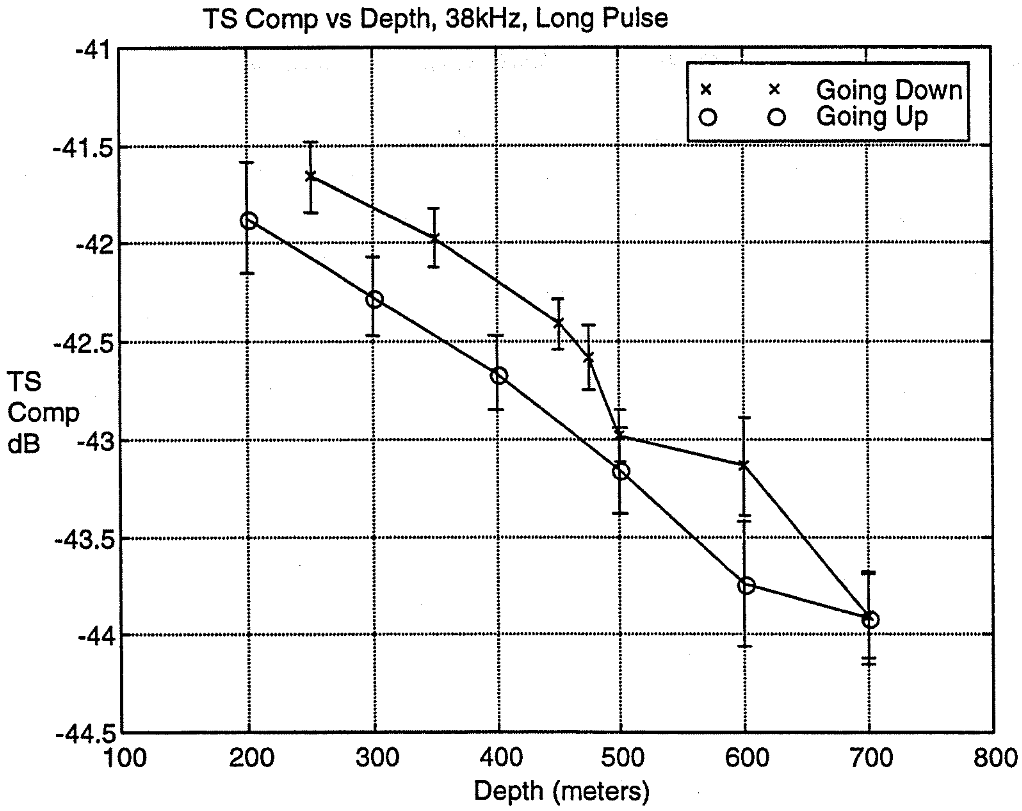
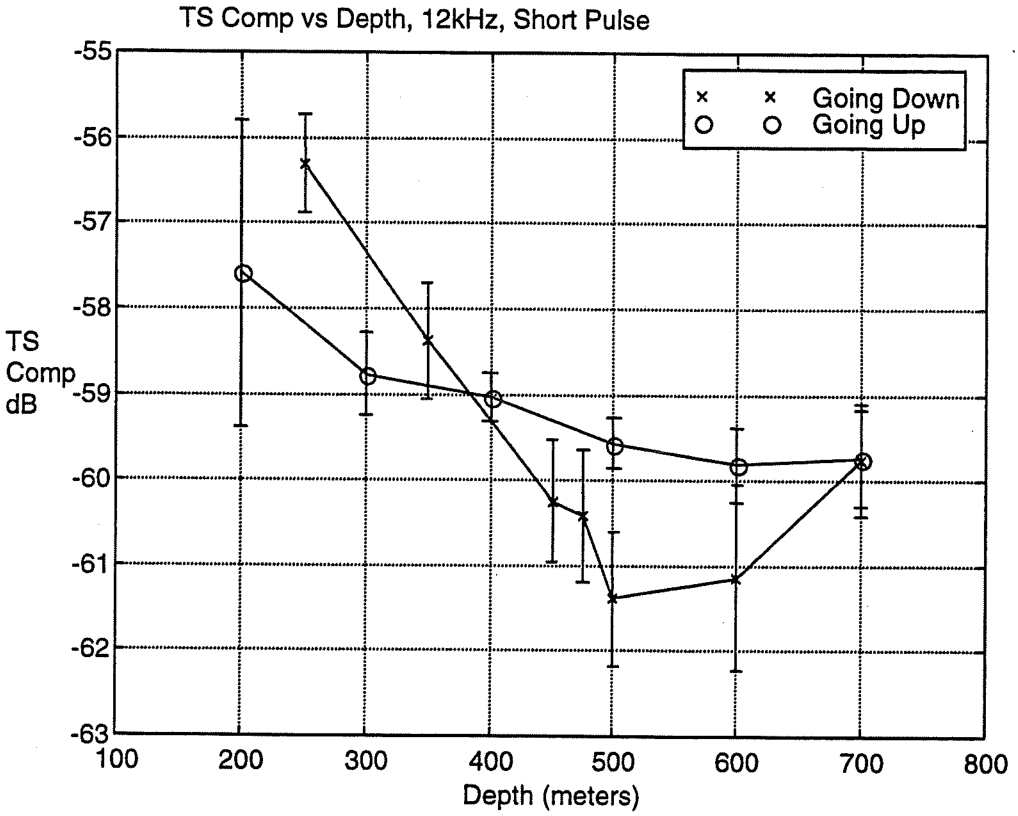


Figure 4.2.2-4 Results of deep water calibrations for the 12kHz transducers.



4.3 Data analysis of biomass and ecological studies

This section outlines the results from the application of multi-frequency methods using the ECHO software to collect archive and process the acoustic data. This section is to give the reader an understanding of the applications involved. It is not intended to go into depth into any one method (these are reported elsewhere) but rather give an overview of the techniques applied to date and how they have benefited the associated studies.

4.3.1 The association of acoustic data with shelf demersal trawl catches

Comparison of species compositions with their corresponding acoustic profiles (Haskard, CSIRO Biometrics internal report 97/7) did not show associations in any of the three approaches (using all data, deep stations only, stations with similar catch compositions). All the acoustic traces were very jagged, and the fractal dimension measure gave values of between 1.8 and 2.1 (all at the upper end of the range of 1 for a completely smooth curve, and the usual maximum of 2 for one-dimensional objects). Roughness measures based on second differences gave a similar ordering of roughness for the traces. Because of the very jagged nature of all the traces, none of these measures were helpful, and did not appear to relate to the catch composition in the eight broad groups of species.

When attempting to identify distinctly similar catch compositions, there were at best only a few pairs of similar stations, diversity and dominance measures were all highly correlated, and supported the same categorisations of stations. The acoustic traces for pairs of stations with similar catch compositions looked quite different. There were no characteristics, either of individual traces or of relationships between traces from the same transect, common to transects with similar catch compositions, but different across different catch compositions.

There are several possible reasons for the lack of clear relationships. Poor quality acoustic data, in which it was not possible to detect and remove noise, resulted from some stations sampled during bad sea conditions. Within the biological data there were not sufficiently large groups of stations with similar catch compositions; replicate trawls from an area or similar areas giving less variable catch compositions seem necessary to give a pattern to compare to. In addition, the eight broad groups of species probably inadequately defined fish assemblages in terms of their acoustic reflectivity. We assumed that acoustic reflectance for species within groups was more similar than that of species from different groups. However, some within-group variability was unaccounted for, eg size variation within a species, where one species may have belonged both the large and small size classes.

There are also a number of sampling problems associated with the exact positions from which samples are taken. Trawls sample only two to three metres off bottom (but may herd fish down from higher in the water column) whereas acoustic data typically integrate over a wider depth range. Benthic (bottom-hugging) species probably remain undetected by acoustics, and in any case are eliminated by the 'dead-zone' adjustment, but remain in the catch data. Also, many species—including some of our dominant deep species (redfish, 3-spine cardinalfish)-- may have a change in diel vertical distribution (swimming up in the water column at night). Thus, they may be detected by acoustics throughout the day, but only at certain times by trawl. Further, it is possible the transect actually observed by acoustics does not correspond well with the water body filtered by the trawl due to water current 'setting' the trawl gear to one side or other.

This analysis could be improved by using more carefully constructed groups of fishes from larger groups of stations with more-similar species compositions. Stations should be sampled at similar times of the day in areas where species composition is likely to be dominated by species that are close to the seafloor but not in the bottom 'dead-zone'.

4.3.2 The association of acoustic data with pelagic trawl catches

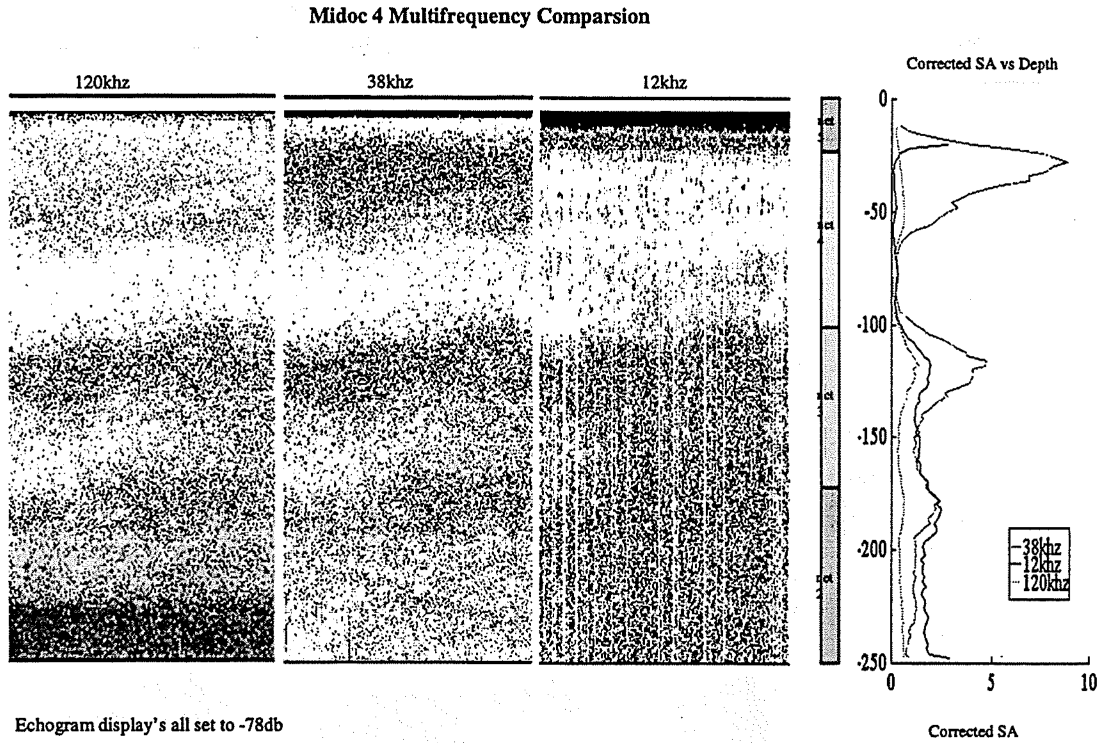
Six depth stratified MIDOC trawls were completed (Table 4.3.2-1). Trawl #1 was performed during the day and produced very small catches, whilst trawls #2 – 6 were at night and had relatively large catches for their short tow duration. Higher night time catch rates are attributable to high densities of migrating micronekton that ascend to feed in epipelagic waters at night. The primary species caught included the salps Thetys vagina and Iasis zonaria, and the pyrosome Pyrosoma atlanticum (=gelatinous zooplankton), the euphausid Euphausia tricantha, and myctophid fishes, predominantly Electrona antarctica, E. paucirastra, Gymnoscopelus piabilis, Lampichthys procerus, and Symbolophorus boops.

Table 4.3.2-1 2 Station Data from SS11\95 (MIDOC shots 1-6)

Station	Start Date	Time	Start	Start	Tow Direction	Wind Direction	Wind Speed	Sea Direction	Sea Height
Number		24 hr	Latitude	Longitude	(degs)	(degs)	(knots)	(degs)	(m)
37 (M1)	21/11/95	9:08	4207.65	14013.62	235	75	22	135	2
53 (M2)	23/11/95	1:56	4500.65	14243.44	355	221	17	200	1.5
66 (M3)	25/11/95	1:29	4758.05	14529.47	28	203	15	225	1
94 (M4)	28/11/95	1:32	5313.17	14529.6	216	311	13	315	0.5
118 (M5)	1/12/95	1:44	4956.76	14538.4	91	280	23	270	3
158 (M6)	6/12/95	2:11	4636.72	14910.8	110	305	11	315	0.5

As before, acoustic profiles were compared with trawl catch compositions. Here, however, this was done visually. An example for trawl # 4 shows acoustic echograms, the Sa data for each frequency data, the depth range sampled by each net (Figure 4.3.2-1), and the catch composition Figure 4.3.2-2.

Figure 4.3.2-1. Example of uncompensated echograms for MIDOC tow # 4 at 12, 38 and 120kHz, with compensated by noise and absorption Sa profiles. The depths sampled by the four nets are shown beside the echograms.



At the station where trawl #4 was taken there was a significant acoustic mark between approximately 20 and 60 m on the 38 kHz profile which was not detected by 12 kHz and only slightly by 120 kHz. The most common groups in the net fishing these depths were medusae and micronektonic fishes. Fishes in the 23-101 m layer were predominantly the myctophids Electrona paucirastra, E. antarctica and Gymnoscopelus piabilis. These species were absent between 23 m and the surface. Medusae were found in smaller numbers than fish throughout the water column between 100 m and the surface. The next mark observed on the acoustic profiles was between 100 and 150 m. In this depth range Electrona antarctica was the most abundant fish with G. piabilis also common; the euphausiid Euphausia tricantha was highly abundant.

Comparing all trawls and acoustic profiles in this manner indicate the following associations:

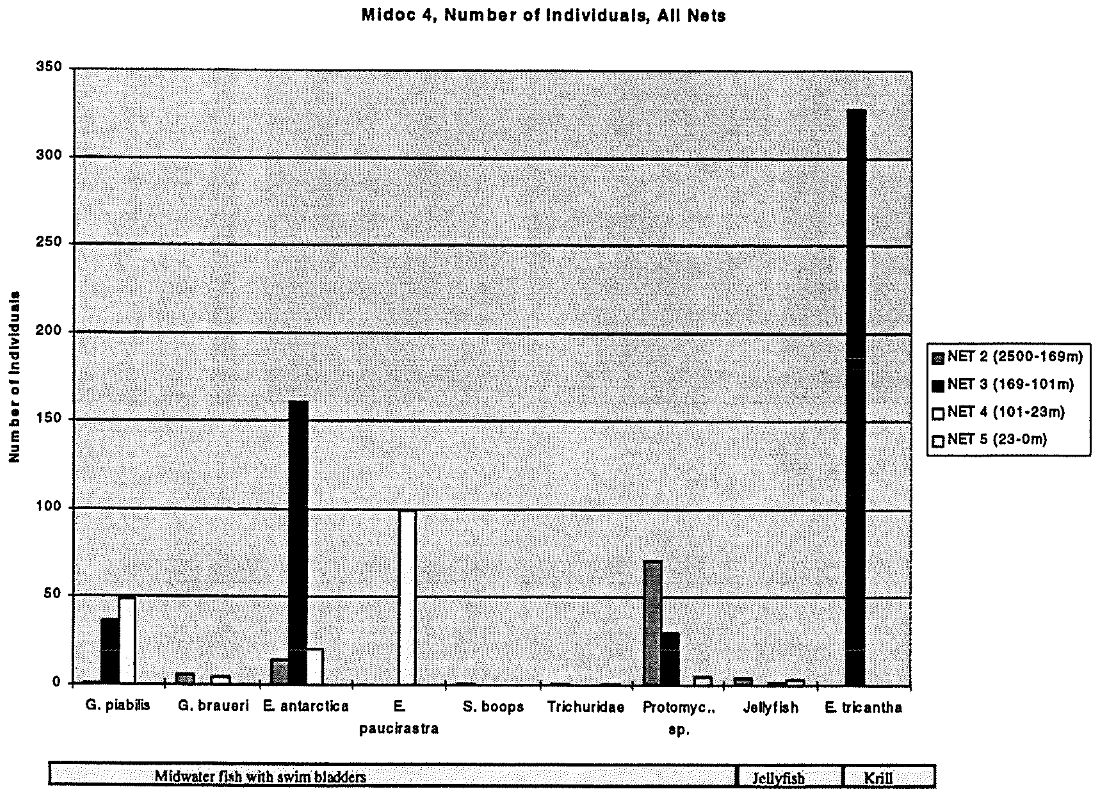
High peaks in 38kHz profiles were associated with micronektonic fishes at several stations. This is consistent with the high reflectance normally associated with the gas-filled swimbladders this suite of fishes uses for buoyancy. Peaks in 12 and 120kHz profiles also matched fish abundance in some samples, but these were not consistent or of the same magnitude as 38kHz peaks.

Extremely high densities (~1gm-3) of gelatinous zooplankton (mainly pyrosomes) in near surface waters at stations #3, 5, 6 did not produce backscatter at the three frequencies used.

Where pyrosomes and fish occurred together (near surface stations #2 and 6, and ~40-70 m at station #5) backscatter resulted in peaks of Sa in acoustic profiles. It is likely therefore, that fish contributed most of all of the backscatter detected. The same is likely to apply to data where medusae and fish occurred together.

High backscatter at 12 and 38kHz frequencies occurred at 100-150 m at station #4 where Euphasia tricantha was in high abundance. However, myctophids were also abundant in the same depths, and therefore it is unclear how much the euphausid contributed to the high Sa values.

Figure 4.3.2-2 Summary of the catch from the 4 depth stratified nets grouped into swimbladder type



The dominant acoustic backscatter is due to the gas-filled swimbladders of the mid-water fishes. Investigations are continuing regarding the expected frequency response at each frequency using models of various spherical and prolate spheroids as a function of depth.

4.3.3 Classifying fisheries habitats using acoustics

Presently, simple processing within the ECHO software on the first and second echoes show hardness and roughness features of the seabed. The 38kHz EK500 acoustic and 'TACOS' photographic records are from a deep reef transect and display the contrast as you go from the rough / hard on reef habitat to the smooth/soft off reef habitat.

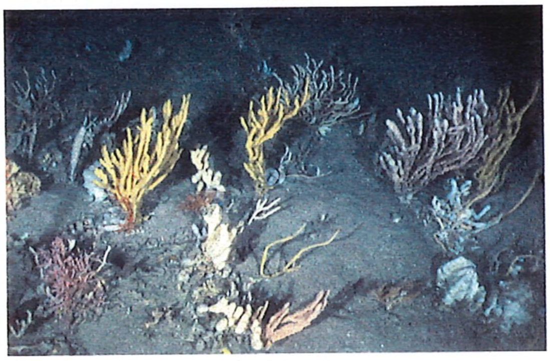
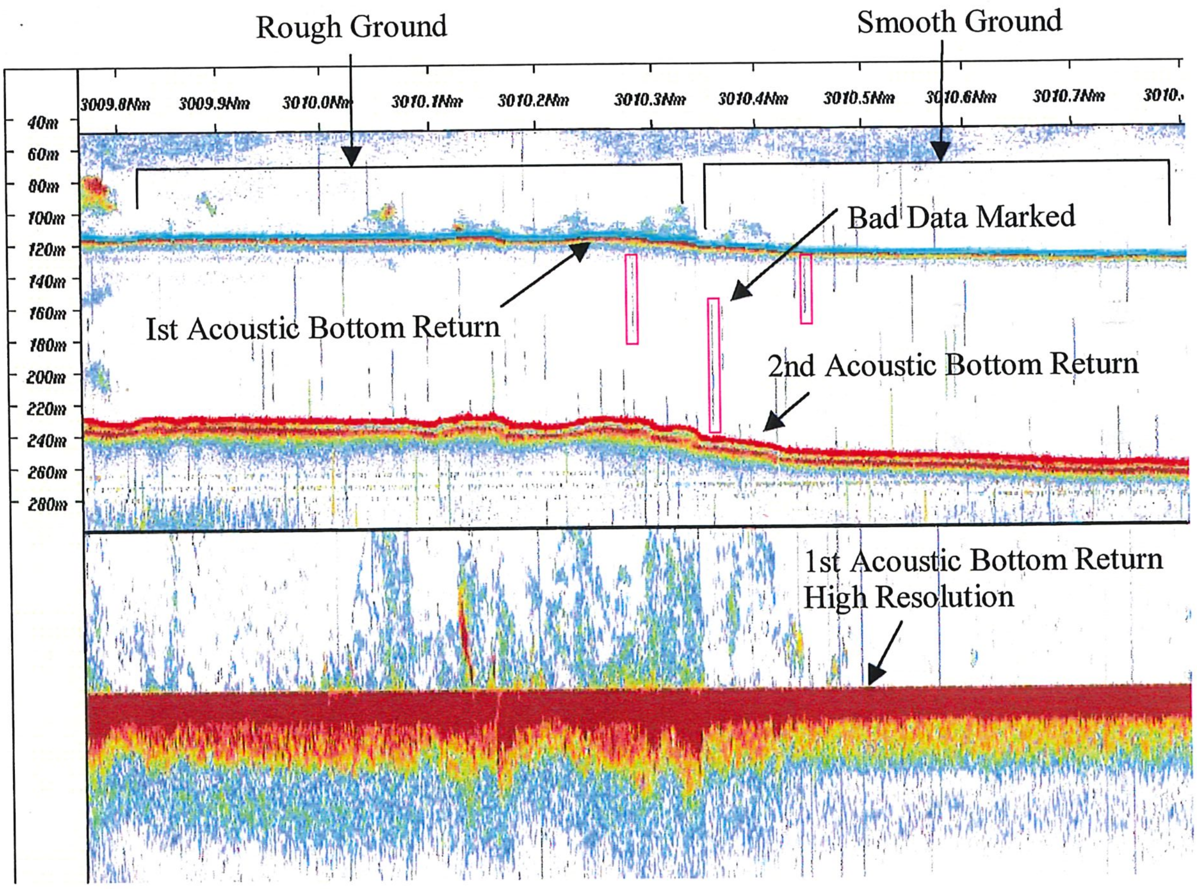


Figure 4.3.3-1 Rough/Hard Reef

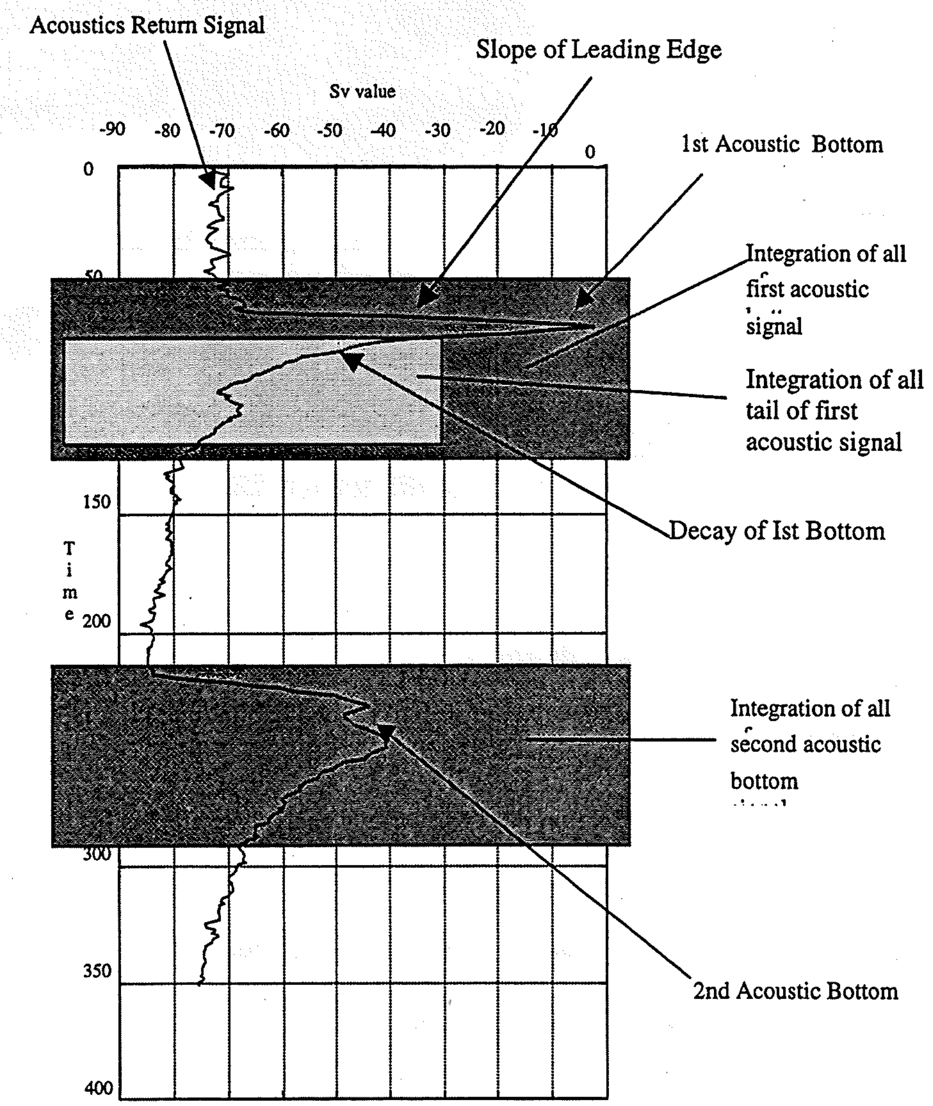
Figure 4.3.3-2 Smooth/Soft Off Reef

Figure 4.3.3-3 38kHz Echogram is showing Transition from Rough/Hard Reef to Smooth/Soft Off Reef Habitat.



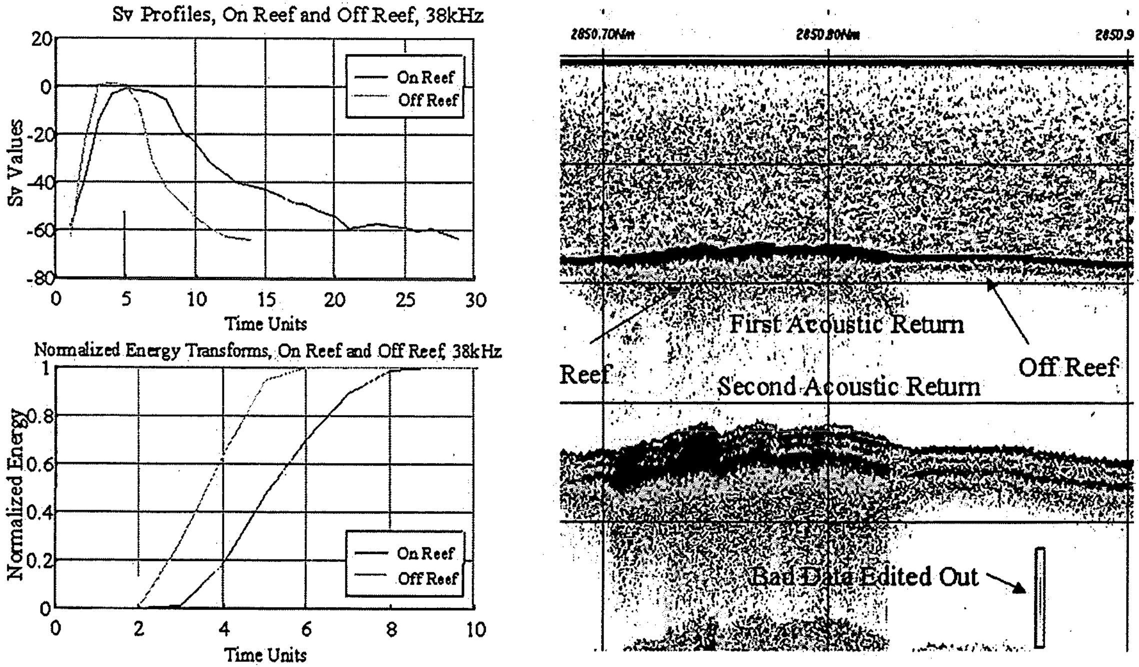
The hi-resolution bottom referenced data is currently exported to Matlab, normalised by depth and features extracted.

Figure 4.3.3-4 Investigation Into Characteristics of the Seafloor Bottom Echo Return Signal



Return bottom signals can be distinguished by a variety of shape characteristics from the enveloped and normalised energy transformed signals as displayed above. Signal rise time, decay time, total energy and width are just a few such characteristics that are being incorporated into our ECHO software.

Figure 4.3.3-5 Display of Raw Echogram Data With Profile of Bottom Return Signal and Normalised Energy Transformation



4.3.3.1 Multi-frequency seabed classification

The improved discrimination of the multi-frequency approach to seabed habitat mapping is summarised in Table 4.3.3.2-1.

Table 4.3.3.2-1 Cross-validation miss classification rates for various analysis strategies for single frequencies and then combining the frequencies.

Data	Freq 1	Freq 2	Freq 3	Multi-Freq
Peak/Tail	0.2728	0.2253	0.4902	0.1836
A	0.2201	0.1361	0.3802	0.1191
B	0.1862	0.1549	0.2572	0.1081
C	0.2337	0.2233	0.2650	0.1348
D	0.1784	0.2109	0.2331	0.1113
E	0.1810	0.1361	0.2363	0.1100
All Extracted	0.1621	0.0911	0.1999	0.0788
PCA(10)	0.1992	0.1087	0.2259	0.0827

Full Smooth(0)	0.1862	0.1016	0.1660	0.0801
Full Smooth(.5)	0.1751	0.0898	0.1647	0.0775
Full Smooth(.9)	0.1771	0.0977	0.1686	0.0833

From this particular data set it can be seen that an improved classification is achieved over the simulated RoxAnn method from an error rate of 18.4 % to the Full smooth(.5) curve approach of 7.8%. A summary of the classification tables for the full smooth curve analysis is given in Table 4.3.3.2-2. The preliminary result of this analysis will have a major impact on our ability to classify habitats. In the South East Fishery ecosystem study we have collected multi-frequency acoustic data over a four year period with associated biological data. Using the analysis methods outline here we will be able to reprocess our acoustic data in line with these methods using the ECHO software.

Table 4.3.3.2-2 Classification tables for Extracted Features and Full Smooth Curves are given below:

		Extracted Features			Full Smooth Curve		
	Pred\Obs	1	2	3	1	2	3
Freq 1	1	475	33	0	480	30	1
	2	17	390	90	20	388	112
	3	20	89	422	12	94	399
Freq 2	1	512	0	19	511	9	5
	2	0	449	58	1	448	68
	3	0	63	435	0	55	439
Freq 3	1	470	55	3	495	61	5
	2	41	346	96	15	353	72
	3	1	111	413	2	98	435
Multi-F	1	507	0	0	508	3	0
	2	3	458	62	4	451	54
	3	2	54	450	0	58	458

This improvement must be tempered by the limited data set used for this study. However the analysis has demonstrated that it is possible to achieve improved classification using the digitally recorded multi-frequency data. The ECHO software has enabled us to collect and archive this ping based digital data for subsequent processing.

4.3.4 Describing the feed of Tuna

A summary of the results from the application of acoustic methods to the feed of Tuna as reported by Young et al (in Prep) follows.

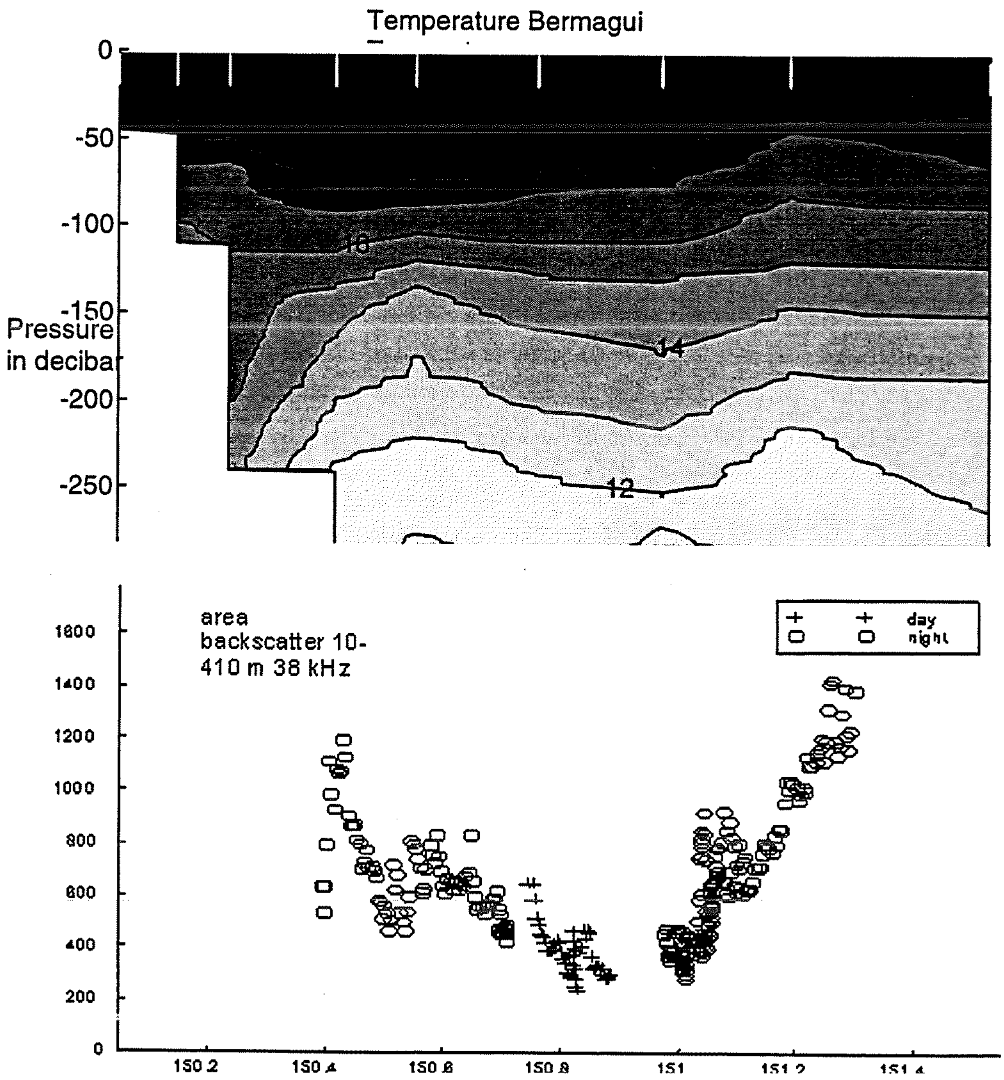
Physical Oceanography

The transect east of Bermagui identified a thin tongue of southward-flowing, tropical origin, East Australia Current water to a depth of ~ 50 m. To the south a warm-core eddy, ~ 60 n.miles in diameter was situated directly east of Green Cape between latitudes 36° 30' and 37° 30' S and within 10 n.miles of the shelf break. This eddy had recently separated from East Australia Current waters to the north as evidenced by previous satellite images of the area (CSIRO unpublished data). It had a mixed layer of 21°C water to a depth of 100 m and at 250 m had a temperature of 15° C and a salinity of 35. 4 ppt. At the western and southeastern edges of this eddy were relatively high concentrations of chlorophyll a. Underway sampling of fluorescence supported this observation and also that fluorescence was lowest in the centre of the eddy. A strong westerly current (~2 m.s) defined the upper boundary of the eddy (Young, Pers. obs.).

Acoustic data

Distribution of backscatter across the Bermagui and Green Cape transects showed a concentration of biomass over the shelf and shelf break, a decrease through the eddy increasing at the eastern edge of the eddy. The difference between the 12kHz and 38 kHz traces on the shelf edge are believed to be from the lanternfish (Lampanyctodes hectoris). The magnitude of the difference between the frequencies was restricted to the shelf break area and hence this particular species. The swimbladder characteristics of this species are being investigated to explain the large 12khz records. Off from the shelf break the 38kHz records show a significant correlation with the surface eddy for the Bermagui transect, Figure. 4.3.4-2. Work is still in progress to describe the relationship between the acoustic multi-frequency records, nekton and oceanography.

Figure 4.3.4-2 Temperature profile of the Bermagui Transect showing the warm core eddy and the corresponding acoustic backscatter for the 38kHz transducer.



Biomass of zooplankton and micronekton

Microzooplankton

Microzooplankton biomass ranged from 10.70 (± 1.30 SE) g per 100 m^3 in the eddy to 43.30 (± 10.10 SE) g per 100 m^3 over the slope. Biomass was significantly higher over the slope than in the eddy (ANOVA, n = 62, F = 5.70, p = 0.00) (Tukey, MSE = 0.02, DF = 58, p = 0.00).

Macrozooplankton (0-200m)

Macrozooplankton were sampled with the bongo net. Because one codend of the bongo net pair was preserved in formalin and the other in alcohol, we first compared the wet weight biomass of each side. Alcohol preserved samples had a significantly lower wet weight biomass (t-test, n = 76, p = 0.00). Alcohol preserved samples were therefore multiplied by 1.29. Following this correction, we found no significant difference in wet weight between left and right codends (t-test, n = 79, p = 0.43). Left and right codend samples were thus combined for all subsequent analyses.

Macrozooplankton biomass differed very little between the slope, eddy and frontal areas (all were ~ 10 g per 1000 m^3), but was significantly high over the shelf (22.62 (± 2.19 [se]) g per 1000 $m^{3)}$.

Surface macrozooplankton

Overall, the mean macrozooplankton biomass at the surface was 80.37 (± 8.06 [SE]) g per 1000 m^3. Within the eddy, however, biomass was significantly lower (24.60 ± 3.94 [se] g per 1000 m^3) than the other three areas (ANOVA, n = 91, DF = 3, F = 7.13, p = 0.00.

Micronekton

The micronekton catch was largely composed of fish, the composition of which changed between inshore and offshore waters. Inshore, jack mackerel (Trachurus declivis) dominated the catches whereas over the slope lanternfish (Lampanyctodes hectoris) was the most abundant fish taxon. It should be noted also that sonar soundings during the day over the shelf detected large schools of surface and subsurface schools of jack mackerel, identified as such by previous studies in the area (N. Bax, CSIRO, pers. comm.). Offshore a suite of myctophid species, dominated by Scopelopsis multipunctatus, and stomiatoid species made up the catches.

There was a trend toward higher biomass of micronekton over the slope (916.80 ± 488.13 SE g 10^5 m^{-3}) than in waters offshore (234.29 ± 7.43 SE g 10^5 m^{-3}). However, total micronekton biomass was not significantly different between areas (ANOVA, n = 21, DF = 3, F = 1.64, p = 0.22). Of the individual taxa, myctophids were significantly more abundant over the slope (ANOVA, p < 0.01) whereas Stomiiforme fishes and Crustacea were significantly more abundant offshore (ANOVA, p < 0.01).

Collectively, the net capture data showed consistently low values on the inside of the eddy with generally higher biomasses over the shelf break/slope region.

Stomach contents of yellow fin tuna

A total of 29 yellowfin tuna stomachs were collected from longline fishers working in the area during the period of the cruise. Their diet varied widely, but was dominated by fish, squid and crustaceans . Of the individual taxa, crab megalopa, species of mackerel and juvenile squid Notodarus gouldii dominated the tuna's diet. Midwater trawling indicated that the mackerel (Decapterus spp. and Trachurus declivis) were concentrated over the shelf /slope region whereas the crab megalopa and squid were more common offshore (CSIRO unpublished data).

Fishery data

Yellowfin tuna catches from the domestic longline fishery for May 1996 were significantly different between inshore and offshore waters (ANOVA, $n = 309$, $df = 4$, $F = 3.79$, $P = 0.005$). Catch per unit effort by weight and number showed higher catch rates closest to the shelf break than offshore (Tukey test, $p < 0.01$), although there was a trend of rising catches toward the eastern edge of the eddy. There was a small but not significant increase in mean weight (size) off the coast.

Japanese longliners are excluded from the area of the domestic fishery. However, examination of their catch records for the same period directly east of the domestic fishery showed very little in the way of yellowfin catches, although catches for southern bluefin tuna (Thunnus maccoyii) were high, perhaps reflecting the colder water out wide

Discussion

We found a persistent warm-core eddy extending below a depth of 400 m adjacent to the coast off southeastern New South Wales. The edges of the eddy were characterised by closely spaced upward-sloping isotherms and isohalines, changing horizontally in areas by as much as a degree per kilometre at the surface. At the eastern and western edges of the eddy fluorescence values were highest indicating upwelling in these areas. Acoustic backscatter showed a similar pattern with highest concentrations of biomass at the edges. Although not as clearly defined, net captures showed relatively higher biomasses over the shelf and slope than in the eddy proper. Examination of catch records of yellowfin tuna for May of that year showed that catch per unit effort was highest along the coast at the shelf/slope interface and was significantly higher than offshore. The presence of shelf-associated species in the stomachs of the tuna indicates that the captured fish were targeting the shelf/slope region.

Tuna distributions in relation to feed

The perception that tuna are aggregating in areas of greater potential feed is not new. For example, Roger (1994) found that the biomass of viable forage was a key factor in controlling the abundance and distribution of yellowfin in the tropics. Specifically, he found that the biomass of suitable plankton in "good" yellowfin fishing areas was seven times higher than in poor fishing areas. Fiedler and Barnard (1987) found that albacore tuna (Thunnus alalunga) and skipjack (Katsuwonus pelamis) were "feeding near mesoscale centres of high productivity where prey abundance may be enhanced" off California. Such investigations indicate that the tuna are responding to areas in which their prey were concentrated, a conclusion reached by the present study.

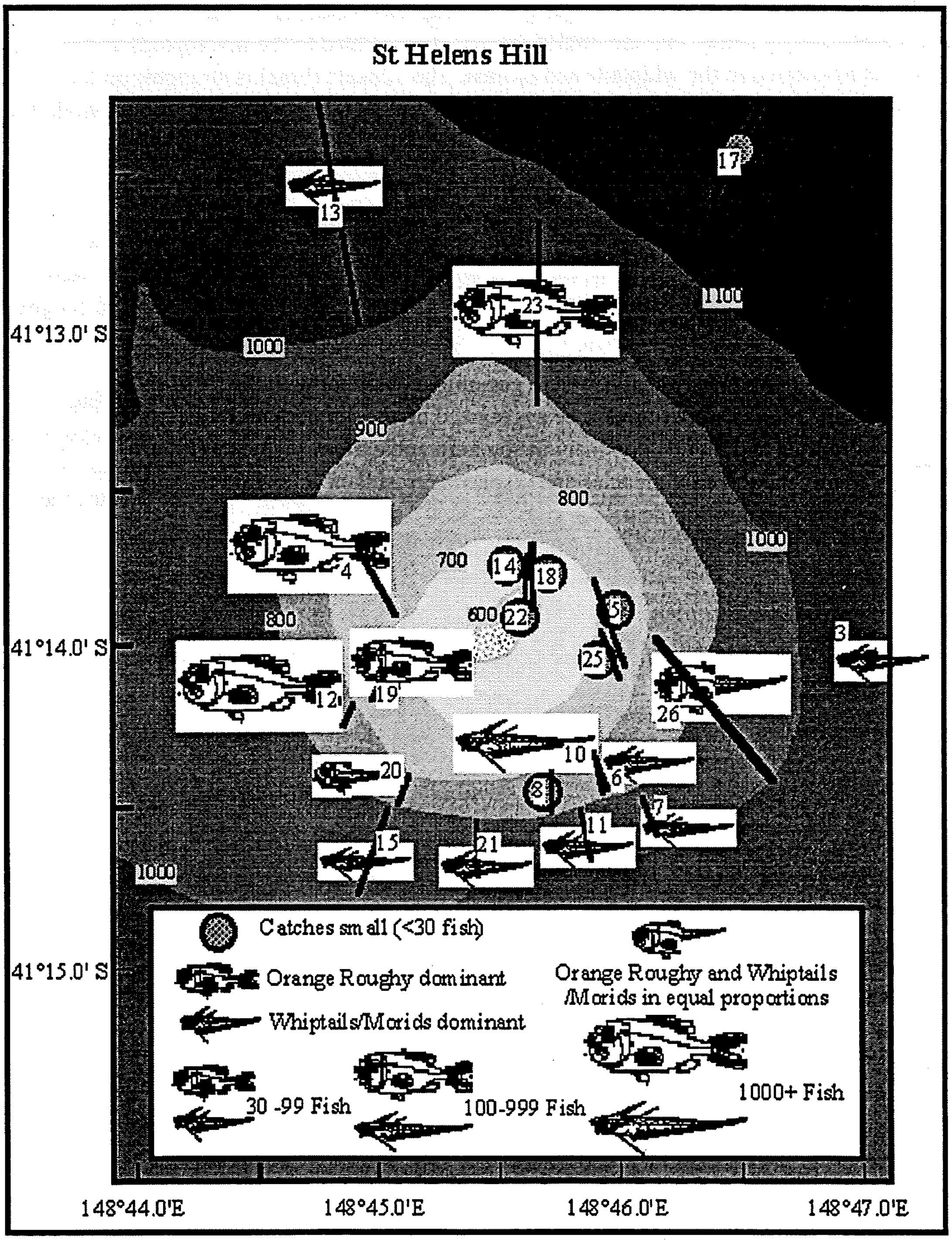
That the highest catch per unit effort data were closely linked to the productive area of the study ads further support to the relationship. It could be argued that these catches were a function of the inability of the boats to fish further seaward and not to the concentration of fish. However, there have been a number of studies which have shown that tuna fishers usually concentrate where catches were good (Calkins 1961, Keene and Pearcy 1976). By inference then fleet distribution should reflect fish distribution (Healey et al 1990).

4.3.5 Species identification in the deep water orange roughy fishery

Biological interpretation of species composition

Figure 4.3.5-1 shows the distribution of 21 demersal trawls with associated compositions around the hill. It can be seen from the figure that orange roughy are dominantly found on the North West sector of the hill whilst morids and whiptails dominate the South East sector of the hill.

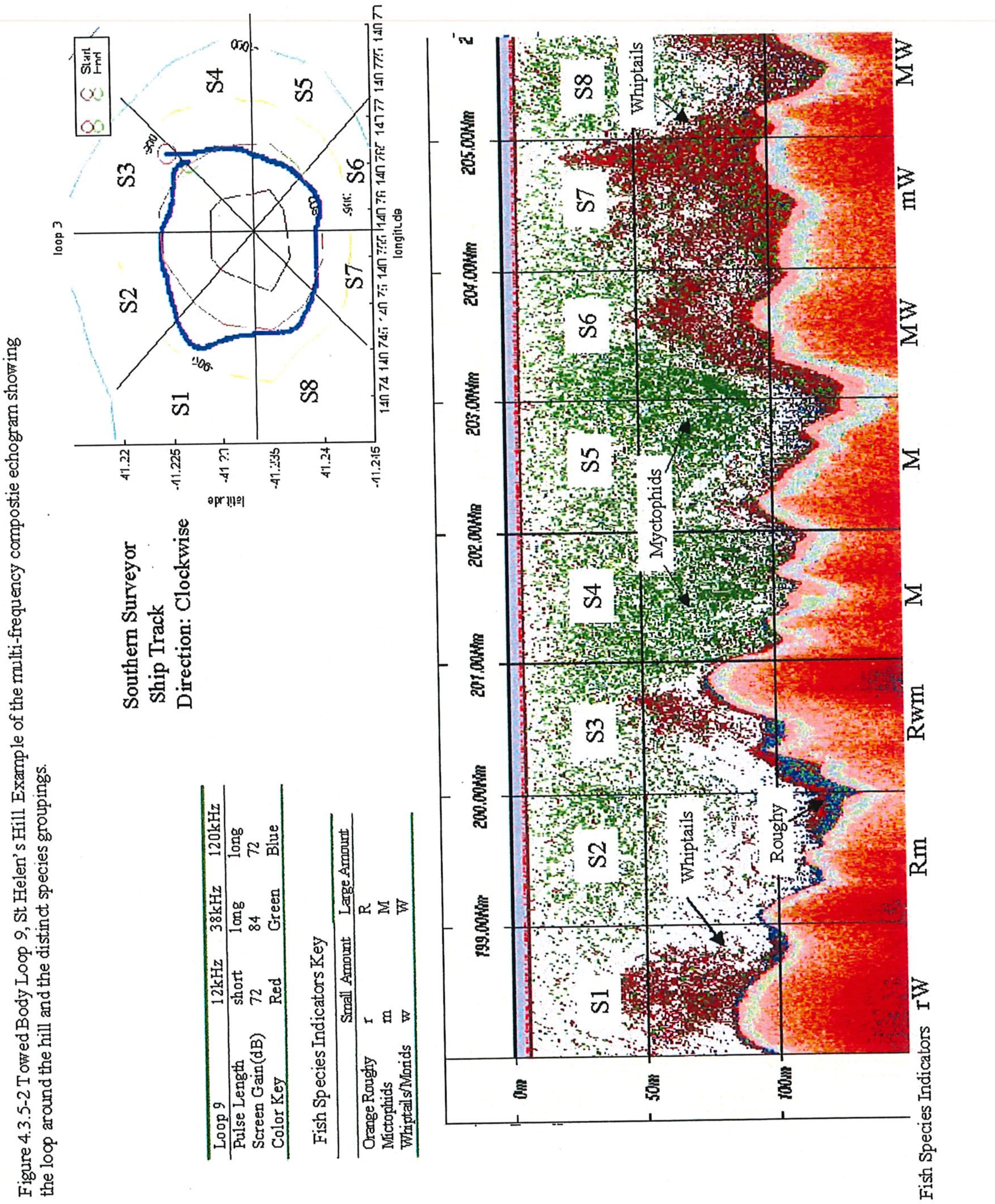
Figure 4.3.5-1. Summary of 21 demersal trawl tows performed around the hill separated into the dominant acoustic scatterers.



The composite multi-frequency acoustic data, Figure. 4.3.5-2, shows a loop around the deepwater seamount with the towed body at a depth of 600 – 650 m. The resultant three frequency echogram has been compressed to display the whole loop. The mixing of the three frequencies is optimised as outlined in section 3.1.4 to highlight the three distinct acoustic groups of orange roughy (large fish without swim bladder), myctophids (small fish with a swimbladder) and whiptails and morids (large fish with swim bladders). The echogram in Figure 4.3.5-2 clearly shows that the 38kHz (green) is associated to the myctophids and the 12 kHz (red) is associated to the whiptails and morids. The 120kHz (blue) is strongest on the orange roughy that have been forced close to the bottom due to the towed transducer. Modelling work on the reflection of fish at depth due to gas-filled bladders is continuing in order to convert the qualitative display into a quantitative estimate of the different acoustic fish groups. This colour Figure shows the ship track for the loop with the bathymetry of the hill as an underlay. For the purposes of the analysis, the hill has been divided into 8 sectors as shown. The composite 12, 38 and 120 kHz (red, green, blue) echogram is also shown for the loop. Each sector has been ascribed a species mixture of myctophids, whiptalis/morids and orange roughy. This mixture was based on the intensity of the colour and the area of coverage.

Results of the multi-frequency analysis were generally consistent with the trawl sampling, insofar as orange roughy were found to be aggregated on the northern and western sectors of the hill with macrourids and morids dominant in southern and eastern segments (Figure 4.3.5-1). The ability to mix the three frequencies and display the resultant echogram demonstrates the power of the software development.

Figure 4.3.5-2. Example of the multi-frequency composite echogram showing the loop around the hill and the distinct species groupings.



5. BENEFITS

As in original proposal

The direct benefits of the software development are as a research tool, and it has application to a wide number of fisheries. The beneficiaries of the research will be the fisheries involved in biomass assessment and ecological studies. This software development will provide a measure of biomass and bottom type change at two or more frequencies that is independent of trawling and benthic sampling. In the short term, the software development will be applied to the following biomass assessment and ecological studies.

1. Deep water orange roughy fishery.

2. Southern blue fin tuna fishery.

3. Gulf of Carpentaria fishery.

4. South East Fishery.

The flow of benefits from the research relates to two key areas. Firstly, a more precise estimation of fish biomass will lead to better management of fish stocks. This will be achieved through a better understanding of species composition that contribute to acoustic signals. Initially orange roughy will be targeted but applications to other species such as blue grenadier, gemfish, oreos and jack mackerel can be identified. Secondly, the software development will greatly assist researchers in long term ecological studies such as the SBT, South East and Gulf of Carpentaria fisheries.

How the areas have benefited

The research project has greatly enhanced the application of acoustic methods to a wide range of applications. The relative ease at which raw data can be processed makes it an attractive option. Specifically the software has been integral to the following studies reported here.

1. Deep water orange roughy fishery.
   The results from the multi-frequency analysis of the deepwater survey of Orange roughy on St Helens hill clearly shows three distinct species groups. An independent assessment of species composition is now possible using multi-frequency acoustics.

2. Southern blue fin tuna fishery.
   The application of the software was used to describe the feed for tuna. This work is still being analysed but has proven useful to describe the distribution of nekton in relation to oceanographic features.

3. Gulf of Carpentaria fishery.
   Data was collected for the Gulf of Carpentaria cruises but has not been analysed to date. This data will be analysed as the need arises.

4. South East Fishery.
   Detailed habitat maps have been produced for the SEF project using the ECHO software. Investigation are continuing through the FRDC funded South East Fishery habitat study to further analyse the acoustic data in relation to the benthic and fish communities.

5. Deep scattering layers
   Although not in the original proposal, the software has been applied to study deep scattering layers in the southern ocean. This work will improve our understanding of the distribution and abundance of deep water ecosystems.

6. INTELLECTUAL PROPERTY

The ECHO software was originally developed by CSIRO Division of Marine Research in conjunction with the Australian Antarctic Division. This software is owned by the CSIRO Division of Marine Research whilst the Australian Antarctic Division has exclusive access to the code to develop the software for their own research objectives. For this project the software has been maintained and extended to process multi-frequency echograms. The data collected in this proposal will be used for other long-term biomass and ecology studies.

7. FURTHER DEVELOPMENTS

The software development project is seen as a research tool and will continue to be developed in line with research objectives. Currently the code will be extended to improve the data modifiers and bottom feature extraction routines. Also data window routines are being planned to improve the signal recognition capabilities for seabed classification, image processing and school recognition.

8. STAFF

Name	Skills relevant to project
Rudy Kloser	Principal investigator, Acoustician
Tony Koslow	Biological Oceanographer
Kathy Haskard	Statistician
Alan Williams	Fisheries Ecologist
*Jason Waring	Senior Software Developer
*Paul Sakov	Software Developer, Acoustician
Tim Ryan	Data analyst
Scott Gordon	Acoustic signal processing
Peter Jones	Statastician, Mathamatician
Jock Young	Biological Oceanographer
Alan Poole	Acoustic technician

* Jason Waring wrote the original ECHO software for single frequency applications with the foundations in the software to extend its use to multiple frequencies. Kath Whitfield-Massom also worked on the code for a year, 1996. Most of the advances in the multi-frequency visualisation have occurred over the past six months due to the efforts of Paul Sakov and Jason Waring. Code has also been maintained and developed by the Australian Antarctic Division (Tim Pauly, Gordon Keith and Tim Barlow). Code has been exchanged between CSIRO and The Antarctic Division at various times to assist each other's research effort.

9. APPENDIX A

ECHO Software Development

A list of documentation that is held at CSIRO Division of Marine Research to describe and run the ECHO software. A web address to manage the maintenance and development of the software is available internally at http://www.marine.csiro.au/dmr/software/echo/echo.html

Design

1. Waring, J. 1997 Design note for the Echogram Processing Structure

2. Waring, J. 1993 Quality Control and Assurance

3. Waring, J. 1993. ECHO Design Considerations.

Operation

1. Sakov, P. 1997 Raw storage file format.

2. Waring, J. 1993 Tape archival utilities

3. Waring, J . R. 1995 ECHO User Manual

4. Waring, J. R. 1993. ECHO User Reference Manual

5. Ryan, T. 1997. Registration of data into ECHO.

Data Management

1. Ryan, T. 1997. Data Management, Analysis and Mapping of Acoustic Seafloor Indices.

10. APPENDIX B

ECHO Software Modules

A list of the software modules in ECHO and a brief description is given below. In total the modules contain 118 055 lines of code with 308 159 words or 2 723 141 characters.

Data Acquisition

da_coord	Coordinates the interfacing, dissemination and storage of acquired data.
ek_table_convert	Converts ek_table configuration files to binary
ek_template files.	
ekdisc_da	Reads EK500 log files and dispatches the telegrams to the coordinator.
ekmonitor	Displays the number of packets of each data type acquired since instrument communication was established.
eknet_da	Dedicated ethernet based interfacing program for the EK500.
ekpreview	Controls the data acquisition and display of EK500 data. A scrolling echogram is provided.

Post Processing

echox_to_egws	Converts EchoX overlays files to Echogram Worksheet files.
egws	Quality assures and processes data associated with Echogram Worksheets. egws also provides facilities for creating, deleting and editing the worksheets.
egws_export	Export the contents of an Echogram Worksheet to an ASCII form.
egws_import	Imports ASCII Echogram Worksheets to the database as a normal Echogram worksheet.
egws_process	Processes echogram data defined by an Echogram Worksheet and a Processing Mask. No graphical user interface required.
ekimport	Import Simrad EK500 log files into the ESMS.
esms_admin	Administration utility for defining Cruises, Surveys, Vessels, Registration Caches, Caches, Media Devices and Instruments.

esms_archive	Archives data to media (e.g. tape) that is currently resident in registration caches.
esms_export	Exports selected data types from the ESMS as structured ASCII files.
esms_extract	Extracts selected data from the archive media. The data files are placed in the Caches.
esms_info	Displays which data type are available in the a particular cruise/survey.
esms_register	Registers Raw Storage datafiles with the ESMS.
rs_admin	Raw storage administration tool.
tbimport	Towed body import utility. Southern Surveyor specific.

Miscellaneous tools

echo2matlab	Converts ECHO Processing files to a Matlab compatible form (very limited).
ekdepths	Extracts the depth at the occurance of each navigation telegram in a Simrad EK500 data file.
ekfile_start	Determines the seed date/time for a Simrad EK500 data file.
ekms	Extracts all motion sensor information from a Simrad EK500 data file.
eksimulate	Uses Simrad EK500 data files to ?simulate? a data stream from the EK500. Interfaces to the coordinator.
ekstrip	Removes telegrams of a specified header type from Simrad EK500 data files.
ektestpat	Builds a simply test pattern file from an existing Simrad EK500 data file.
free_ipc_key	Deallocates Unix IPC keys that might not have been cleaned up correctly.
tbtimes	Determines the seed date/time for the sourthern surveyor data files.

11. APPENDIX C

Acoustic Data Collection

Summary of Acoustic Data collected by the ECHO software – RV Southern Surveyor. In total 112 Giga bytes of data has been collected with about 30% of this data registered with the database for processing.

Table 11.1

Cruise Label	*Cruise Start*	*Cruise End*	*Registered*	*Cruise Location(s)*
ss294				
ss697				
ss291 leg 1	29-JUN-91	15-JUL-91	Biomass	South and East Coast of Tasmania, Around Maatsuker Island and Flinders Island
ss291 leg 2	18-JUL-91	3-AUG-91		St Helen's Hill
ss291 leg 3	6-AUG-91	10-AUG-91		Tasman Sea approx. 40 miles east of Maria Island
ss192 leg1	05-FEB-92	12-FEB-92	Biomass	Continental slope south of Tasmania
ss392 leg 1	15-JUL-92	24-JUL-92	Biomass	St Helen's Hill Orange Roughy Survey
ss392 leg 2	25-JUL-92	13-AUG-92		West Coast of Tasmania Blue Grenadier Survey
ss492	03-NOV-92	02-DEC-92	Biomass	Productivity of mid-slope region off southern Tasmania. Acoustic and net sampling methods off southern Tasmania.
ss393	7-APR-93	22-APR-93	Biomass	Central and western continental shelf south of Tasmania.
ss593	14-JUL-93	24-AUG-93	Biomass	Leg1: Southern fishing zone. Leg2&3:Eastern Bass Strait and southern NSW. Leg4: Southern NSW and eastern Victorian Waters.
ss793	28-OCT-93	28-NOV-93	Biomass	Leg1: Gulf of Carpentaria. Leg2: Weipa to Cairns
ss194	02-FEB-94	15-FEB-94	Biomass	
ss394	18-MAY-94	31-MAY-94		Oceanic and shelf water off eastern Tasmania.
ss594 leg1	18-AUG-94	23-AUG-94		West Coast of Tasmania Blue Grenadier Survey
ss594 leg2	23-AUG-94	8-SEP-94		Ecosystem structure in the South East Fishery region
ss594 leg3	13-SEP-94	22-SEP-94		Ecosystem structure in the South East Fishery region
ss195	14-JAN-95	2-FEB-95		South and West of Tasmania
ss295	13-FEB-95	9-MAR-91		Gulf of Carpentaria, West of Weipa.
ss595	16-JUN-95	23-JUN-95		Gulf of Carpentaria, West of Weipa
ss895	18-AUG-95	10-SEP-95	Biomass	North West Shelf Study Area
ss1095	10-OCT-95	5-NOV-95	Ecology	Gulf of Carpentaria, West of Weipa
ss1195	15-NOV-95	07-DEC-95	Biomass	West and South of Tasmania
ss196	9-APR-96	15-APR-96	Trials	DSTO Cruise. SE Coast of Tasmania
ss296	14-APR-96	12-MAY-96	Habitat	East Cost of Tasmania and SEF study region
ss396	13-MAY-96	28-MAY-96	Habitat	East of Eden, East of Tasmania
ss496	16-JUL-96	30-JUL-96	Biomass	St Helen's Hill, Southern Hills
ss596	13-NOV-96	18-NOV-96	Habitat	
ss696	20-NOV-96	19-DEC-96	Habitat	East Cost of Tasmania and SEF study region
ss197	20-JAN-97	1-FEB-97	Habitat	Seamount on continental shelf off Tasmania
ss297	12-FEB-97	12-MAR-97	Ecology	Prawn grounds, Torres Strait

ss597	17-APR-97	30-APR-97	Habitat	DSTO Cairns
ss797	7-AUG-97	2-SEP-97		North West Shelf

12. APPENDIX D

Calibration Summary

The Simrad EK500 is the main acoustic instrument connected to transducers located on the vessel and on deep water towed transducers. The specifications of the transducers are detailed in Table 12.1.

Table 12.1. Transducer Information

Transducer	*Manufacturer*	*Locations*	*Equivalent Beamwidth*	*Beamwidth*
120Khz	Simrad	Hull	-18.5	11.2
38kHz	Simrad	Hull	-20.7	7.1
12kHz	Simrad	Hull	-13.2	16/17.5
120kHz	Simrad	Towed Body	-20.6	7
38Khz	EDO western	Towed Body	-21.1	6.5
12kHz	MASA	Towed Body	-10	40
38kHz	Simrad	Pole	-20.7	7.3

Table 12.2. Definition of Pulse Length Names for Three Frequencies – Simrad EK500

	Pulse Length (ms^{-1})		
Frequency	Short	Medium	Long
12 kHz	1	3	10
38kHz	0.3	1	3
120kHz	.1	.3	1

Table 12.3. Definition of Pulse Length Names for Three Frequencies – Towed Body

	Pulse Length (ms^{-1})	
Frequency	Short	Long
12 kHz	1	3
38kHz	.3	1
120kHz	.3	1

Table 12.4. Definition of Bandwidth Names for Three Frequencies – Simrad EK500

	Bandwidth (kHz)	
Frequency	Wide	Narrow
12 kHz	1.2	0.12
38kHz	3.8	0.38
120kHz	12	1.2

A summary of all the calibration results for the vessel mounted transducers for various combinations of pulse lengths and bandwidths are given in Table 12.5.

Table 12.5. Summary of Hull Mounted Surface Calibration Results.

Date	*Frequency*	*Pulse Length*	*Bandwidth*	*Depth to Sphere*	*SVc*	*TSc*
Jul-90	38	short	wide	15.3	26.8*	26.8
Jul-90	38	medium	wide	15.4	27.9*	27.9
Jul-90	38	medium	narrow	15.6	27.7*	27.7
Jul-90	38	long	narrow	15.8	27.4*	27.4
Jul-91	38	long	narrow	14.9	27.7	27.3
Aug-91	38	long	narrow	14.9	27.8	27.4
Jul-92	38	long	narrow	14.5	27.8	
Jul-92	38	medium	wide	14	27.6	27.7
Aug-92	38	long	narrow	14.6	27.3	26.9
Oct-94	120	long	narrow	21.09	22.4	
Oct-94	120	medium	wide	21.09	22.6	
Oct-94	38	medium	wide	21.09	27.2	
Oct-94	38	long	narrow	21.09	26.8	
Nov-94	120	medium	wide	19.74	22	22.1
Nov-94	120	short	wide	19.74	22.4	22
Nov-94	120	long	narrow	19.8	22.2	22.2
Jan-96	120	long	narrow	18.96	22.8	22.6
Jan-96	38	medium	wide	18.6	27.3	27.1
Jan-96	38	short	wide	18.7	27	26.4
Jan-96	38	long	narrow	19.5	27.3	26.9
Jan-96	38	long	wide	19.1	27.5	27.4
Jan-96	120	medium	wide	18.96	22.8	22.6
Jan-96	120	short	wide	18.93	23	22.8
Jan-96	12	medium	wide	18.5	13.4	N/A
Mar-96	12	medium	wide	16.5	13.2	N/A
Mar-96	38	medium	wide	17	27.1	
Mar-96	120	long	narrow	17.01	22.6	22.4
Aug-96	12	medium	wide	16.5	13.2	N/A
Jul-96	38	long	narrow	19.2	27.2	26.8

* To compare these 1990 SVc results with other years, 0.35 should be added to these SVc values. This has arisen because the Ideal Beamwidth was set to 20.0 whereas for subsequent years it was set to 20.7

Table 12.6. Summary of Towed Body Surface Calibration Results.

Date	*Frequency*	*Pulse Length*	*Bandwidth*	*Depth to Sphere*	*SVc*	*TSc*
1-Aug-96	38	medium	wide	6.3	29.3	29.1
1-Aug-96	120	medium	wide	6.2	20.5	20.8
1-Aug-96	120	long	narrow	6.1	24.1	23.8

Table 12.7. Towed Body TS Vs Depth Corrections.

EK500 Settings				Surface Calibration Results			Theoretical	Measured		ECHO Settings	
Freq	Pulse Length	Svc_set	TSc_set	Svc	TSc	Sphere Depth	TS Sphere	Slope	Intercept	TS Intercept	Sv Intercept
38	Long	-	-	-	-	-	-42.35	-0.0052	-40.8093	-	-
38	Medium	31.7	31.5	29.3	29.1	6.3	-42.35	-0.00492	-40.2808	2.0692	2.0692

120	Long	23	23	20.5	20.8	6.21	-39.5	-0.00276	-44.5109	-5.01	-4.41
120	Medium	23	23	24.1	23.8	6.15	-39.5	-0.00534	-37.0662	2.4338	3.0338
12	Long	18.5	18.5	no result	no result	no result	-42	0	-62.3	-20.3	-20.3
12	Medium	18.5	18.5	no result	no result	no result	-42	0	-60	-18	-18

Notes:

Svc_set: Sv value as set in EK500

TSc_set TS value as set in EK500

Svc Sv value determined from calibration

TSc TS value determined from calibration

TS Sphere Theoretical value of calibration target sphere

Slope Slope of Depth vs TS relationship

Intercept Intercept with y axis of Depth vs TS relationship

TS Intercept Value that is entered into echo software for correction purposes

Sv Intercept Value that is entered into echo software for correction purposes

Sv intercept and TS intercept should be set to the identical values if the difference between Sv_set and TS_set is the same as the difference between Svc and TSc calibration results. This is the case for the 38kHz. In this instance

TS Intercept = Intercept – TS Sphere

TS Intercept = -40.2808 - -42.35 = 2.0692 = Sv Intercept

For the 120kHz the Svc and TSc have been set to the same value. For this case for long pulse length:

TS Intercept = -44.5109 - -39.5 = -5.01

but for Sv Intercept Sv Intercept = Intercept – TS Sphere – 2 * (Svc – TSc)

Sv Intercept = -44.5109 - -39.5 - 2*(20.5-20.8)

Sv Intercept = -4.41

The TS Slope and Sv slope are assumed to be the same so in the Echo worksheet calibration table the value of slope from table 12.7 can be entered into both the TS Slope and Sv Slope fields.

12kHz slope and intercept values were not calculated from the plot of TS Comp vs Depth since the plot was not linear. For this frequency the average towed body depth was calculated for all the loops of Sthelens Hill and this depth was used to find the corresponding TS Comp value on the plot of TS Comp vs depth.

Table 12.8. Instrument settings at commencement of cruise

Cruise	Freq	Date	Transducer Location	Power	absorption set	pulse length	bandwidth	Sv gain	TSc
ss9305	120	15-Jul-93	Hull	no info	no info	long	narrow	22.4	no info
ss9305	38	15-Jul-93	Hull	no info	no info	long	narrow	27.8	no info
ss9405	38	18-Aug-94	Hull	2000	10	medium	wide	27.8	27.4
ss9405	12	18-Aug-94	Hull	4000	1	medium	wide	13.3	13.3
ss9405	120	18-Aug-94	Hull	2000	37	long	narrow	22.4	22.1
ss9511	120	20-Nov-95	Hull	2000	40	long	narrow	22.6	no info
ss9511	38	20-Nov-95	Hull	4000	10	medium	wide	27.8	no info
ss9511	12	20-Nov-95	Hull	2000	1	short	wide	11.7	no info
ss9602	38	16-Apr-94	Hull	no info	9	medium	wide	27.2	27.1
ss9602	12	16-Apr-94	Hull	no info	1	medium	wide	13.3	no info
ss9602	120	16-Apr-94	Hull	no info	43	long	narrow	22.7	22.5
ss9603	38	16-Apr-94	Hull	no info	9	medium	wide	27.2	27.1
ss9603	12	16-Apr-94	Hull	no info	1	medium	wide	13.3	no info
ss9603	120	16-Apr-94	Hull	no info	43	long	narrow	22.7	22.5
ss9604	38	16-Jul-96	Towed Body	2000	9	medium	wide	26.5	26.5
ss9604	38	16-Jul-96	Hull	2000	9	long	narrow	27.2	27
ss9604	12	16-Jul-96	Hull	2000	1	medium	wide	18.5	18.5
ss9604	120	16-Jul-96	Hull	1000	42	long	narrow	22.7	22.5
ss9604	38	17-Jul-96	Towed Body	2000	9	medium	wide	26.5	26.5
ss9604	38	19-Jul-96	Towed Body	2000	9	medium	wide	31.7	31.5
ss9604	12	19-Jul-96	Towed Body	2000	1	medium	wide	18.5*	18.5*
ss9604	120	19	Towed Body	500	42	long	narrow	23	23

notes: Sound Velocity was set to 1498 m s^{-1} for all cruises except for ss9604 Towed Body from 16-Jul-96 to 19-Jul-96 where the EK500_2 was set to 1444 ms^{-1}

* ss9604, 12kHz hull was set to 18.5 while calibration results showed that it should have been set at 13.2

13. APPENDIX E

Matlab Processing Files

Biomass

The following scripts are kept at f:/matlab/toolbox/biomass.

bio.m	fuction script to calculate the biomass of the hull mounted data for survey data.
bio_all	macro style m file to run survey_biomass.m for all surveys.
calc_biomass	script to calculate the biomass
contour_bio_layers_hull.m	macro style script to contour up biomass at each integration interval for the six hull mounted surveys from 1990 to 1996.
contour_bio_layers.m	macro style script to contour up biomass at each integration interval for the five towed surveys from 1990 to 1996.
contour_hull_surveys.m	macro style script to contour up Sa values for the six hull mounted surveys from 1990 to 1996.
contour_tb_surveys.m	macro style script to contour up the Sa values for the five towed body surveys from 1990 to 1996.
contour_ss496_surveys.m	macro style script to contour up the hull mounted and towed body Sa value surveys for 1996.
correct_layers.m	function to apply corrections to the layers matrix according to cruise,survey_number and transducer location.
correct_sa.m	function to apply Simrad TVG corrections to the sa values depending in cruise,survey_number and transducer location.
correct_ss190_hull.m	script to 1) set dz height according to the mean of 1991,1992 and 1993 and 2) make corrections for absorption and noise (this was automatically done in ECHO in subsequent years.
correct_tb_position	script to pass corrected towed body positions into the layers matrix
create_bio_layers_tb.m	script to produces a vector of sa values that are attributed only to the roughy contribution. For a given sa value find out what depth range and sector of the survey area it lies in. using the appropriate species compostion file, find the proportion of orange roughy in the depth range of our sa value.

create_mat.m	script to create a mat file with all the desired variables for north, south and combined sectors of St Helens Hill.
create_mat_all_surveys	macro style m file to run create_mat.m for all surveys.
decode_layers.m	script to separate out the various variables from the layers matrix.
dz_contribution.m	script to summarize and compare the contribution of the dz to the total Sa. For each survey year load up the biomass_survey_year_survey_num.mat file for each sector calculate the mean sa and mean dz and print to the screen with tab delimiters so that it can be readily imported into excel.
final_plots	script to plot up the final outputs for Sthelens hill surveys.
fixlay	Load a composite echo layer processing file. convert a 0.1 nm log file into a bottom contour file suitable for StHelens.m to perform biomass calculations.
pelagic.m	Estimates the contribution of pelagic biota to the acoustic signal of depth contoured 100 m by 150 m height data.
pelagic_dz.m	Estimates the contribution of pelagic biota to the acoustic signal.of depth contoured 100 m by 150 m height data.
pelagic_sa.m	Estimates the contribution of pelagic biota to the acoustic signal of depth contoured 100 m by 150 m heigh data.
plot_all_ship_tracks.m	script to plot up all the ships tracks for all the surveys includes different color for ships track in northern and southern sectors.
plot_biomass_results.m	script to provide summary plots of the output of survey_biomass.m
plot_pelagic_profiles.m	script to plot up all the pelagic profiles for all surveys.
plot_survey_summaries_hull.m	script to create summary plots of survey data for Sthelens Hill for the surveys ss190 to ss496
remove_nans.m	script to remove rows which contain nans either of mean bottom depth sa or dz sa's
set_area.m	function to set to NaN's any layers.dat values outside a defined area of interest
set_north.m	function to remove any rows in layers that are NOT in the northern sector
set_south.m	function to remove any rows in layers that are NOT in the southern sector.

shiptrack_over_bathy	plot up the contour of the hill bathymetry for ss496 with shiptrack over the top
summary_plot.m	script to take the relevant values in sa_hull.txt and bio_hull.txt and plot out just the total biomass and sa values (with error bars) for all survey years.
summary_plot_tb.m	script to take the relevant values in sa_tb.txt and bio_tb.txt and plot out just the total biomass and sa values (with error bars) for all survey years.
summary_plots.m	script to provide summary plots of biomass and sa's for surveys 1990 to 1996.
summary_results_hull.m	script to summarise results for survey_biomass for all years results are saved in sa_hull.txt and bio_hull.txt.
summary_results_tb.m	script to summarise results for survey_biomass for all years.results are save in sa_tb.txt and bio_tb.txt.
survey_biomass.m	script to calculate the biomass of the hull mounted data for survey data.
survey_biomass_all_surveys	macro style m file to run survey_biomass.m for all surveys.
survey_times_bar_graph.m	script to plot out the time of survey for the surveys from 1990 to 1996.
tb_posn.m	script to calculate lat and lons for the the tb for ss496, sthelens hill
layback.m	script to allow the user work out the layback of the tb by viewing bathymetry plots of tb and hull data for a user specified transect

Biomass/Low_Level_Functions

The following scripts are kept at f:/matlab/toolbox/biomass/Low_Level_Functions.

compsig	Compute the Composition sigma.
l_decode_bottom	Extracts the mean bottom depths at each integration interval of an echo processing file.
l_decode_dz	Extracts the dead zone SA and dead zone heights at each integration interval of an echo processing file.
l_decode_header	Extracts header information from the header file. This describes how the processing of the layers was performed.
l_decode_hills	Builds a list of start and stop indexes for each hill.

l_decode_log	Extracts the vessel log information, and computes the difference between integration intervals, and the total length of each transect.
l_decode_nav	Decode the navigation information from a composite Echo processing file.
l_decode_pings	Decode the number of pings from a composite Echo processing file.
l_decode_sa	Decode the SA information from a composite Echo processing file
l_decode_transects	Decode the identifier information from a composite Echo processing file.
l_depth_partition	Create a vector of indexes.
l_hull_area	Compute an effective area for each contour interval weighting each transect area by the number of transects per hill.
l_strata_area	Compute the mean biomass for each contour level.
l_strata_biomass	Compute the Biomass for each species.
l_strata_mean	Compute the mean value of the parameter x for each strata.
l_strata_sa	Computes the Mean Sa and the variance for each strata.
l_summary	Write summary support of the results
l_trans_area	Compute an effective area for each contour interval. The area is computed as a quadrant of pi/2.
l_weight_sa	Compute the 'weighted' Sa's.
l_weights	Compute the Layer weights for each transects section.

Echo Utilities

The following scripts are kept at f:/matlab/toolbox/echoutil

absorp	- calculates the sound speed and absorption
calerror	- calculates the calibration error from Simrad
noise	- noise refered to 1m
noisecal	- noise refered to 1m in dB re 1 uPa
noise_sa	- more noise calc looks like the same as above

sa_calc	- calculates the Sa for a given Sv and depth of integration
sserror	- sound velocity error
sv_error	returns the error for vessel and toed transducers
sv	- calculates the Sv for a given Sa and depth of integration
tvg20log	- TVG gain calculation
fish_per_sample_vol.m	convert an sa value into number of fish per sample volume

General

The following scripts are kept at f:/matlab/toolbox/general

nanmax	Maximum value of matrix columns or two matrices, ignoring NaNs
nanmin	Minimum value of matrix columns or two matrices, ignoring NaNs
nanmean	Mean value of matrix columns, ignoring NaNs
nanstd	Standard deviation ignoring NaNs.
nansum	Sum of matrix columns, ignoring NaNs
nanrange	Finds min and max values, ignoring NaNs.
subset	Plot up two variables, x,y. Using the zoom function zoom into the desired area. At this point run subset.m to ouput only x and y data that is associated with the plot currently being view.

14. APPENDIX F

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