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Practical guide to acoustic techniques for benthic habitat classification

Photo: Gary Kendrick, University of Western Australia

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Curtin University of Technology

CRC for Coastal Zone Estuary & Waterway Management

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Practical guide to acoustic techniques for benthic habitat classification

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Summary

This document provides a short, practical guide to the use of acoustic techniques for assessing benthic habitats. Included in its contents are:

- a simple introduction to the use of acoustic techniques for seabed classification purposes
- an outline of different techniques available and their potential uses
- a simple summary of the types of processing undertaken
- the requirements and need for conducting correlating towed benthic video surveys with acoustic techniques
- practical issues related to the logistics, conduct and costs of surveys.

The three active acoustic techniques of single beam, sidescan and multibeam sonars are discussed for their application in determining seabed type and associated epibenthic fauna. Each technique may be used in some way to classify seabed type or describe epibenthic fauna. These classes are then correlated to ground-truthed data obtained from towed video or some other direct physical or observational sampling before being used in spatial mapping of seafloor communities or geology.

Single beam sonars are the simplest and easiest system to deploy and analyse. These typically look downward in a conical beam underneath a vessel's track so they sample along a line only. Sidescan sonars are more complex to deploy and analyse, sending out a fan-shaped beam across the vessel's trackline and listening to all echoes returned, thereby providing an 'image' of the seafloor. These images may be 'mosaicked' to cover a region, and image processing techniques are used to discriminate similar patches of seafloor. Multibeam sonars are the most complex of the systems, sending out a fan-shaped beam across the vessel's track and sampling it in many narrowly focussed beams to precisely measure bathymetry and provide information on seabed character from the nature of each beam's backscatter.

Sidescan and multibeam can be used to provide full spatial coverage of a targeted area; they can typically sample out to 3–7 times the water depth from the vessel's trackline. Analysis of single and multibeam systems can be used for bathymetry, with bathymetry derivatives such as slope and bottom roughness often providing detailed information on seabed type, or they can involve analysis of the returned echo character to discriminate seabed or epibenthic character. All sonar systems have been proven to discriminate seabed types although few analytical approaches can currently identify the community types or seabed classes they produce and so all sonar analyses must be ground-truthed.

Single beam systems are the simplest to implement in the field (i.e. they require the least expertise in operation), and large data sets may be collected by piggybacking systems onto unrelated work programs and operating systems autonomously or with a small supervisory component. Sidescan and multibeam data sets must be targeted in specific field programs and are typically complex operations involving detailed processing.

While the current generation of active acoustic systems can classify seafloor communities into broad classes and so provide large-scale spatial maps, they are not yet proven to be specific for any community, they require some level of ground-truthing and they involve relatively complex processing or specialised software. The automated analysis of sonar and linking of acoustic echo features to distinct seabed communities is an area of active investigation.

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1 Introduction

As a short, practical guide to the use of acoustic techniques for assessing benthic habitats, this document does not delve into technical issues related to theory or data interpretation and manipulation. Useful technical information and further references can be obtained from the publications of Hamilton or Penrose (as lead authors) on the website <http://www.coastal.crc.org.au/Publications/>.

This report is aimed at providing potential users of acoustic assessment techniques with information on the applicability, potential costs, possible products, conduct and limitations of the various methods available. Some acoustic techniques are comparatively simple, others complex, time-consuming and potentially costly. All techniques have limitations and may require careful consideration of hardware, calibrations, settings used in field trials, survey design, data quality and processing requirements. Like most endeavours, the choice of technique for any given survey requirement will be a compromise with the recognition that it is always wise to collect high-quality field data. We have attempted here to provide a document which gives guidance and background on what might be an applicable technique.

Several acoustic benthic classification systems sold come in 'black box' form, marketed as systems that output a graded set of values which purportedly correlate to different seabed types. Usually the seabed types need to be derived by the purchaser, by ground-truthing the system over known seabed communities or structures. While we do not evaluate specific systems here, we have attempted to indicate potential uses and shortcomings in such 'black box' systems.

Although not discussed at length, the use of passive acoustics in studying marine communities is also mentioned in the section on technique types. There are species which vocalise profusely, and thus offer a researcher a ready means to locate and census animals.

2 Types of techniques available and outputs

Four techniques are discussed in this document; three involve the active acoustic techniques (sending out a signal and deciphering its echoes) of single beam, sidescan and multibeam sonars. The relative footprint size of each technique is shown in Figure 1. A further technique of passive listening to vocalising animals is briefly discussed here, but as it is an experimental technique and not commonly commercially applied it is not discussed further.

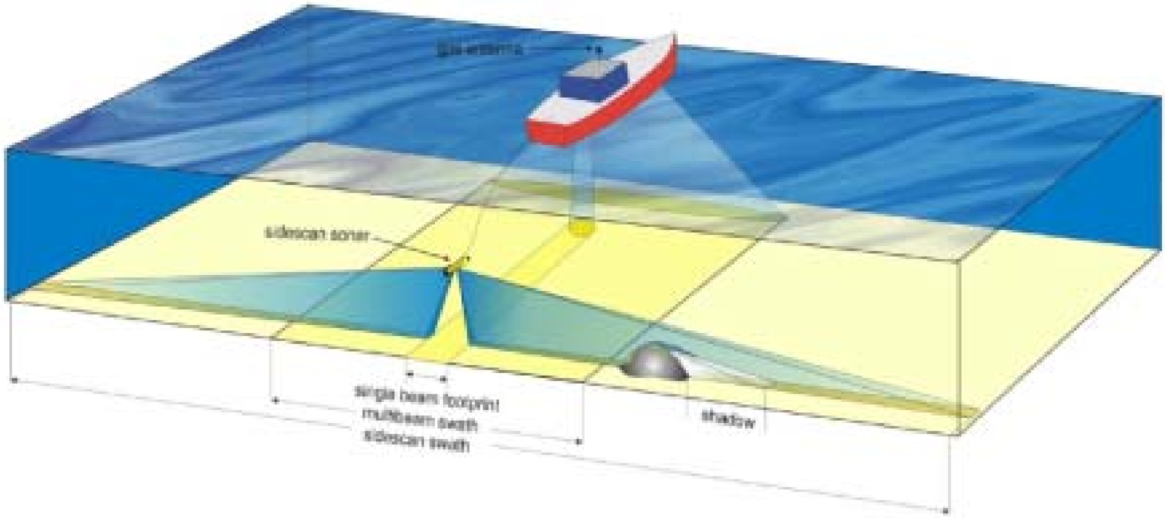

Figure 1. Comparison of coverage between acoustic mapping technologies

2.1 Single beam echo sounder

The simplest active acoustic technique for benthic habitat classification is a single beam system. Single beam sonars provide a variety of information about the reflective characteristics of the mid-water target and the seabed. They send a pulse of sound at a particular frequency (usually between 30 kHz and 200 kHz) that reflects from the seabed or in-water scatterers, and whose echo is received by a transducer. Information about the seabed type may be discerned from the nature of the sonar's echo, or in some instance its second echo (bounce off bottom, surface and bottom to receiver).

Fishermen have traditionally used acoustic bottom echoes from single beam sonars for seabed characterisation. One method they used to infer the presence of reef structures was to run parallel to the depth contours with the sounder set over what was assessed to be a sandy bottom, at a gain setting which was just less than sufficient to provide a second bottom return. When second returns were observed, with or without sudden changes in depth, it was inferred that the substrate contained hard, reef dominated structures. This became the essence of several systems later developed commercially to quantify acoustic bottom echoes for seabed classification in marine ecological applications.

Three commercial acoustic bottom classification systems available in the market are the RoxAnn system, the QTC View system and the more recent ECHO*plus* system. They extract shape, energy or both features contained in range-corrected acoustic bottom signals. In addition, several software packages such as Echo*view*, SeaBec or VBT (all commercially developed by SonarData, SIMRAD and BioSonic, respectively), and ECHO, developed by CSIRO Marine Research, offer seabed classification analysis from digital acoustic waveforms provided by single beam sounders. All techniques attempt to use characteristics of the received reflected acoustic signal to discern the target type.

Single beam commercial acoustic bottom classification systems use a wide beam angle (angle subtended by the outgoing pulse from the transducer head), typically 12–55°. These systems obtain information on seabed acoustic ‘hardness’ from an acoustic reflection coefficient (related to the energy received) and acoustic ‘roughness’ from a signal backscatter coefficient (related to the amount of scatter received). Due to wavefront curvature, acoustic waves excited by a transducer experience three different situations on reflection from the seabed (see Figure 2). Progressively, in time sequence, they will ensonify a circle with annuli of increasing radii and lower grazing angle on the seabed. The returned acoustic envelope at the transducer comprises two components; the total specular reflection and backscatter return from some particular annulus.

A peak in the first part of the returned acoustic envelope is due to coherent components from specular reflection and a decaying tail is due principally to incoherent contributions from some particular annulus. The shape of the returned acoustic envelope is thus a function of acoustic roughness; the rougher the seabed, the longer the reflected signal’s tail will be. The shape of the returned acoustic envelope is also a function of acoustic hardness and depends upon the outgoing signal’s frequency, pulse length and beam width plus the characteristic acoustic impedance of the seabed. The term ‘hardness’ is widely used in the literature and may be regarded as a descriptor of the contrast in acoustic impedance offered by the water–seabed interface, but users need to be wary as it does not necessarily correlate with bottom hardness.

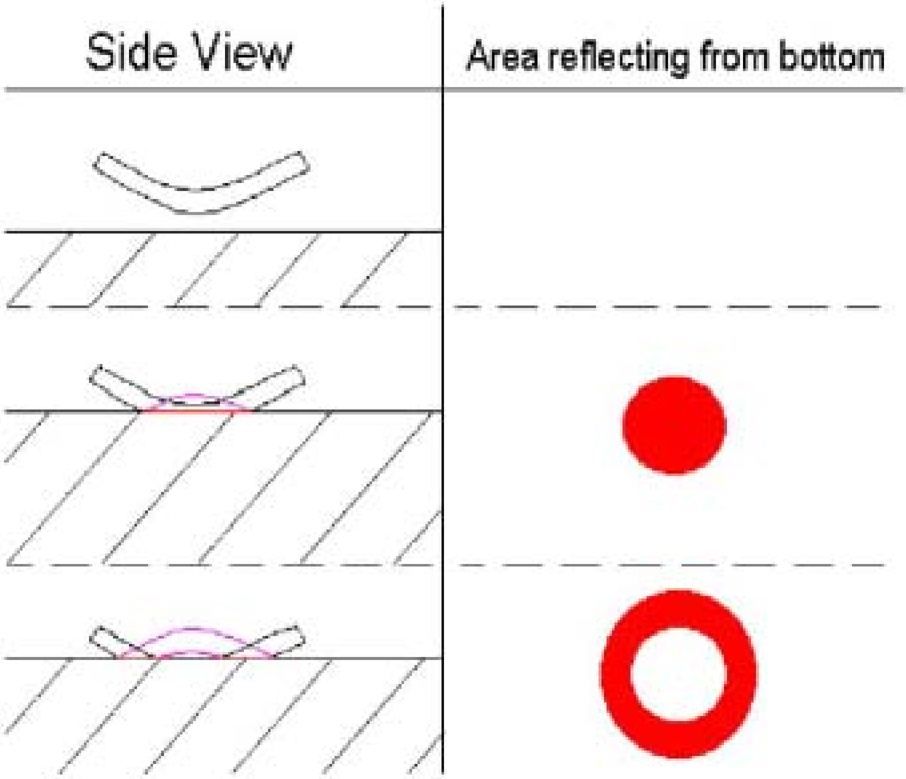

Figure 2. Interaction of an echo sounder ping with the seabed

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

2.2 Sidescan sonar

Sidescan sonars typically consist of two transducers mounted either side of a towed body or 'fish' (see Figure 3). Each transducer produces a thin, fan-shaped beam that is concentrated on a thin line running from below the fish perpendicular to the direction of vessel travel out to a maximum range that is restricted by frequency, power and transducer design. As the pulse of sound emitted by the transducer interacts with the seafloor at oblique angles, some of the energy is reflected away from the transducer and some is reflected back to the transducer.

The energy reflected back is known as the acoustic backscatter. This is recorded for an extended period of time after each ping, so forming a time series of amplitudes received off each side of the vessel/towfish's track. This time series is typically displayed corrected for range (based on signal travel time), with successive pings creating a mosaic image. The resulting image gives a ‘picture’ of the seabed, which can be of very high detail. The vessel’s position, speed of sound in water, and the height of the fish off the bottom are parameters used to predict the position on the seabed for any point on this time series, and hence to create a line of instantaneous backscatter amplitudes referenced to positions along the beam footprint on the seabed. In addition, corrections are made to the image to compensate for various geometric and radiometric distortions. Large features on the seafloor may create acoustic shadowing, where the outgoing sound wave is shielded by the feature, creating shadow zones in images.

Figure 3. Typical sidescan sonar fish

As the transducers travel through the water, the lines of data recorded from each subsequent ping produce an acoustic image of the area. This image is a record of the instantaneous intensity of the backscatter and is affected by sonar frequency and geometry, texture, composition and density of the target/seabed.

Sidescan systems are available from a number of manufacturers. These units vary in terms of frequency or combination of frequency and configuration (towed or vessel-mounted, digital or analogue). High-end systems also provide special features such as focussed beams, high tow speeds, chirp technology (wide frequency range), synthetic apertures or in the case of inferometric systems, the ability to obtain bathymetry.

2.3 Multibeam or swath mapping sonar

Multibeam sonars consist of many receiver beams across a vessel's track. As shown in Figure 4, a fan-shaped acoustic pulse that is wide 'across track' and narrow 'along track' is produced by the transducer. The receive array is located perpendicular to the transmit array and forms a large number of receive beams that are narrow across track and steered simultaneously at different across-track directions by a beam-forming process. Thus the system performs spatial filtration of acoustic signals backscattered from different portions of the seafloor along the swath. Modern shallow-water multibeam sonars, such as Simrad EM 3000 and Reson SeaBat 8125, operate at hundreds of kHz, transmit short pulses of several tens of microseconds, and form hundreds of beams of about one degree beam width. These narrow-beam, multibeam sonars operating at short pulse lengths (tens of µs) are capable of determining small features a few centimetres wide on the seafloor (in appropriate depths) with corresponding fine bathymetry details.

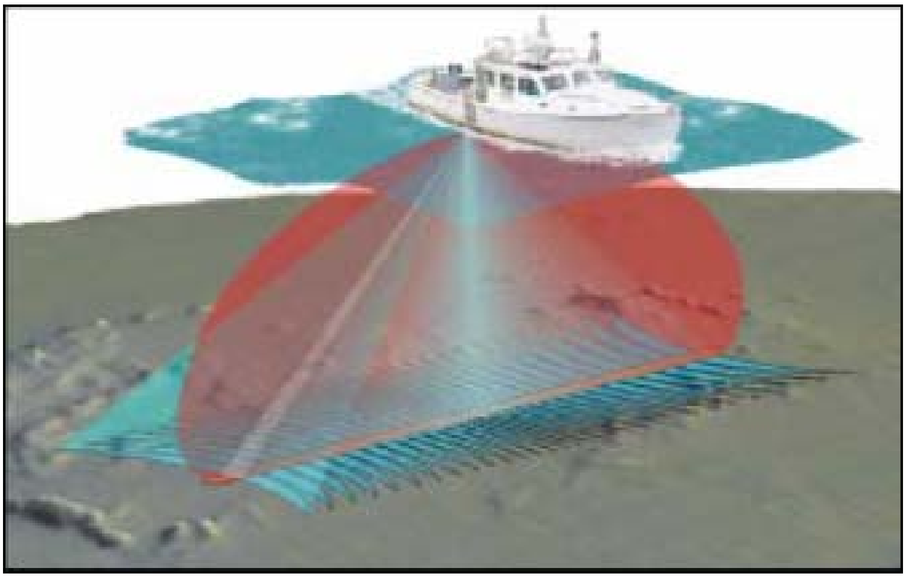

Figure 4. Typical geometry of the transmit and receive beams of multibeam sonars

The operation and analysis of multibeam sonars is much more complex than that of single beam and sidescan sonars. Multibeam sonars require navigational and attitude data (heading, heave, roll and pitch) of the vessel. Incorrect attitude data result in an irreparable distortion of the bathymetry and backscatter images, especially from the oblique beams of small grazing angles (outer beams) for which the ship's motion induces a large horizontal deviation of the footprint location. It is therefore mandatory for accompanying navigational and attitude data of the vessel to be collected and compensated for. An image of multibeam data uncorrected and corrected for vessel motion is shown in Figure 5.

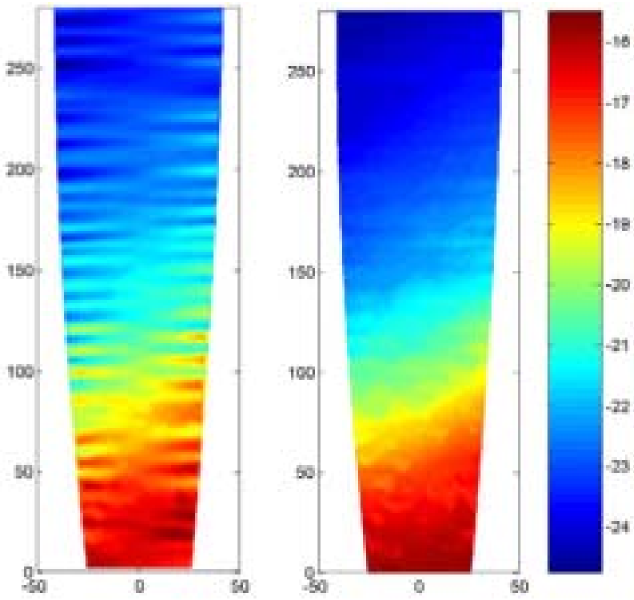

Figure 5. Bathymetry images before (left panel) and after (right panel) compensation for ship's motion
(from the results of the Coastal Water Habitat Mapping project of the Coastal CRC)

Acoustic refraction due to change of sound speed with depth is not of importance in single beam sonar because the acoustic rays normally travel straight down to the transducer. It is however crucial in multibeam and sidescan sonar, as acoustic rays also travel at angles off normal. Different sound speeds with depth will distort the acoustic ray trajectories (refraction) and hence the bathymetry images. A correction for the acoustic refraction is therefore essential, in particular for a condition where sound speed profile is time- and range-dependent.

2.4 Towed video systems

Towed video systems can take many forms, and ideally involve a video camera system with appropriate lighting towed at a constant height across the seafloor at a precisely known position in time (x-y-z-time), with each video image time- and position-stamped. Implementing such systems in practice is not easy and can easily involve cameras crashing into hard substrates or being towed too high. An example of a comparatively simple camera system developed by the University of Western Australia is presented here. It contains five devices: camera; lighting; differential GPS (DGPS); depth sounder; and PC (see Figure 6). An interface acquires information from DGPS and depth sounder, overlays them as text messages on the video data and saves to file.

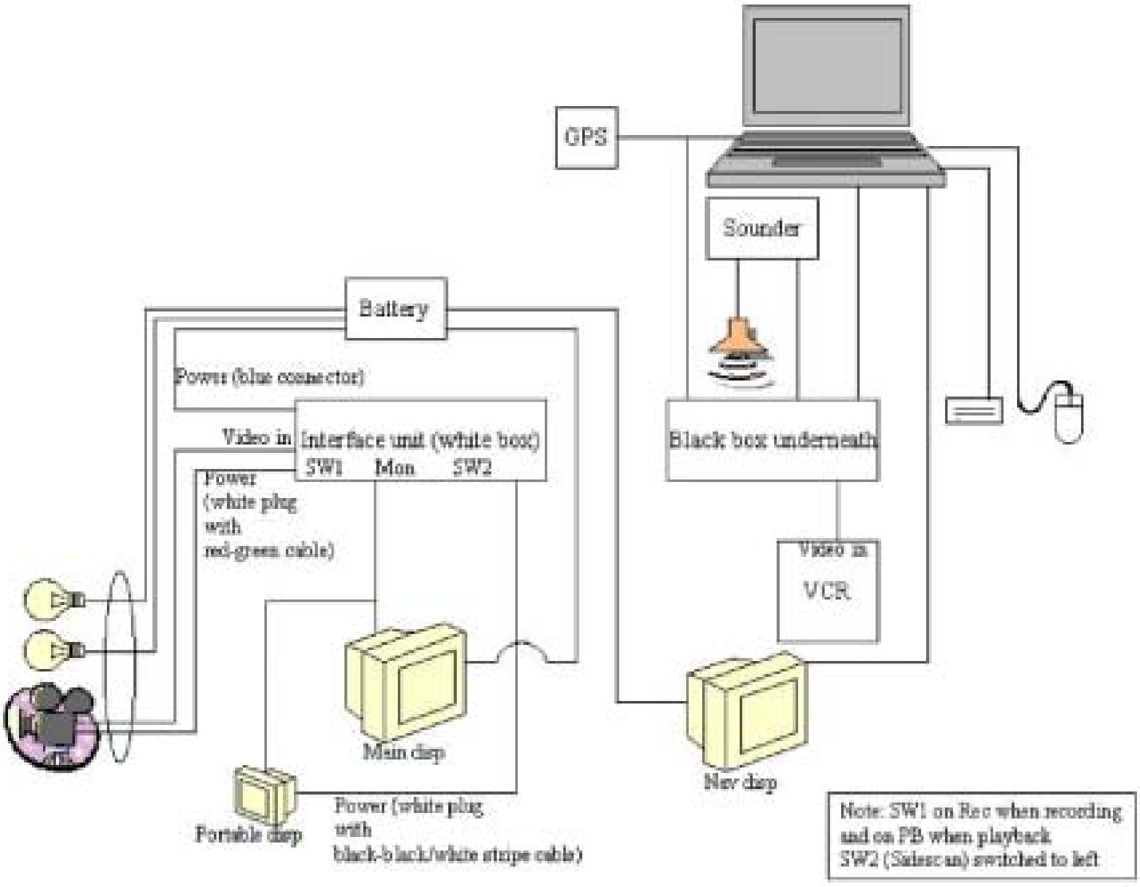

Figure 6. Schematic diagram of the UWA underwater video camera system

In the instance where this was used, the video data together with overlaid text messages was recorded with an off-the-shelf digital VCR. The system was operated by at least two persons; one holding the umbilical and the other watching the screen. The person holding the umbilical operated the camera from the stern of the boat (see Figure 7). This person was guided to bring the camera up or down by the person watching the screen, by adjusting the length of line deployed. The speed of the vessel was maintained typically at one knot. Video data provided by the system, together with grab-sampling data, offered ground-truth information to validate data collected by other means. One advantage of video data over grab-sampling data was that it also provided bottom relief information.

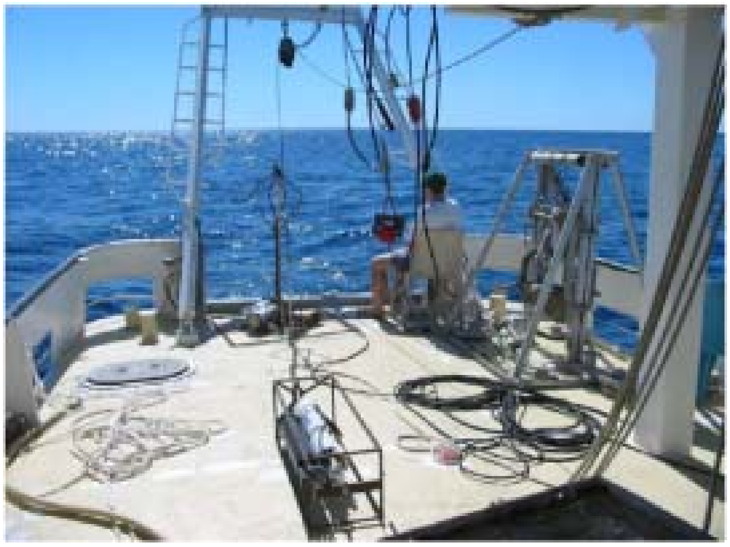

Figure 7. Operator enjoying the scene while holding the umbilical of the UWA underwater video camera

While a simple system such as described here provided invaluable information which could be used to ground-truth the remote acoustic techniques, its major shortfall was in estimating the position of the camera. Typically, a towed system will not be directly behind the vessel and the towline will not be straight. Thus small navigational errors creep into estimations of the camera's location, with these then compounded by tidal streams or vessel drift. For the high-resolution output of sidescan or multibeam systems, estimating position from a simple towed video system for overlay was difficult and proved a significant shortfall in processing, in that spatial correlation of camera and sonar data was often not good. Thus the system described has been elaborated to include a short baseline positioning system, which allows the location of the camera to be precisely located with respect to the vessel, thus fixed via the vessel's DGPS system.

Further enhancement of towed video systems involves the use of 3D cameras (typically stills) operated by an observer on the vessel or repetitively, coupled with laser calibration systems for photogrammetry analysis of observed fauna.

2.5 Passive acoustic systems

The ocean is a noisy environment, with biological and physical sources dominating ambient or background sea noise. Biological sources include invertebrates, fish and great whales. Animal calling may have many functions but is most commonly produced in relation to breeding and feeding activities. Many species of fish vocalise extensively during breeding periods, with individual calls audible out to kilometre ranges and many species calling *en masse* to produce choruses, which may be audible for tens of kilometres in range. Many great whales can routinely transmit signals which are audible for tens of kilometres on the continental shelf and hundreds of kilometres in ocean water depths.

A considerable amount of information can be gleaned from listening to animal calling. This includes species presence and absence for revealing time and space patterns, proxy measures of abundance, behavioural studies and, if multiple receivers are used, for tracking individuals. Converting counts of calling animals to abundance measures using acoustic techniques is a new technique and is fraught with difficulties which range from reliably estimating the range of callers to understanding the context of calls and population calling rates. Nevertheless, given advances in data collection capabilities and hardware, it is possible to routinely collect sea noise samples at high sampling resolution, and so obtain information on multiple species for long time periods (years) at low cost. This technique is in its infancy, is species-specific and is currently only being used in a developmental context by a few institutions (the Centre for Marine Science and Technology of Curtin University being one such institution).

3 Comparisons of techniques

The active acoustic techniques fall into three general categories as described above: single beam, sidescan and multibeam. The single beam data is the simplest to obtain and process. Sidescan data can be relatively easily collected and may be simple or complex to process, while multibeam data is complex to collect and process but gives the most detailed data in the form of 3D bathymetry for the survey region. Relative requirements, outputs and limitations of the three techniques are listed in Table 1.

Table 1. General comparison of active acoustic techniques in their typical configurations
The footprint size, output types and displays are hardware-specific. RT refers to real time display.

Technique	Typical footprint size	Sensors required	Types of output	Notes/limitations
Single beam	Within beam angle	Single transducer, GPS or DGPS	RT visual display of backscatter; logged data; RT graded seabed classification	Describes backscatter in beam below vessel only; if data logged further processing for seabed type/biomass can be made; simple and can operate remotely at low cost
Sidescan	3–7 x water depth	Towfish or hull-mounted transducer; GPS or DGPS	RT visual display; high quality ‘camera’ images of backscatter	Survey lines can be ‘mosaicked’ into an image and used to delineate benthos/ objects; but not precisely geo-referenced (error is survey-dependent)
Multibeam	3–7 x water depth	Hull-mounted transducer; gyrocompass; DGPS; motion sensor	RT visual display, pseudo sidescan image & 3D bathymetry possible but hardware-specific; data logged & post processed for bathymetry (data gridded at some resolution over survey area) or backscatter	Survey lines overlain and gridded at a resolution defined by hardware and survey; resolves 3D bathymetry to high precision; can have overlain backscatter images (pseudo sidescan or processed to remove angular dependence) for benthos delineation; most complex of techniques but gives most precise and comprehensive information
Towed video	<5 m	Towed camera system with lights; camera location system; GPS of DGPS	RT visual display; indication of benthic community type	Provides general ground-truthing for acoustic surveys; useless in low visibility environments; requires careful consideration of locating towed video system in space; very labour-intensive analysis

The nature of the survey requirements and available resources will dictate which type of survey is carried out. The issue of an optimal survey type for a required work program is not discussed here. In deciding on a survey technique it needs to be recognised that when conducting surveys it is better to obtain the highest quality data possible. Data collection may only represent a small faction of total survey costs, potentially being exceeded by costs associated with processing, interpretation, publication outputs or by having to repeat surveys because they were inadequate in the first place. Generally, in the long term a suitable initial investment in collecting comprehensive field data will save costs by reducing the need for follow-up surveys to fill gaps or expand techniques.

3.1 Comparisons of technique outputs

3.1.1 Single beam

An example of a single beam sounder output showing strong fish schools and a long and strong second echo are shown in Figure 8.

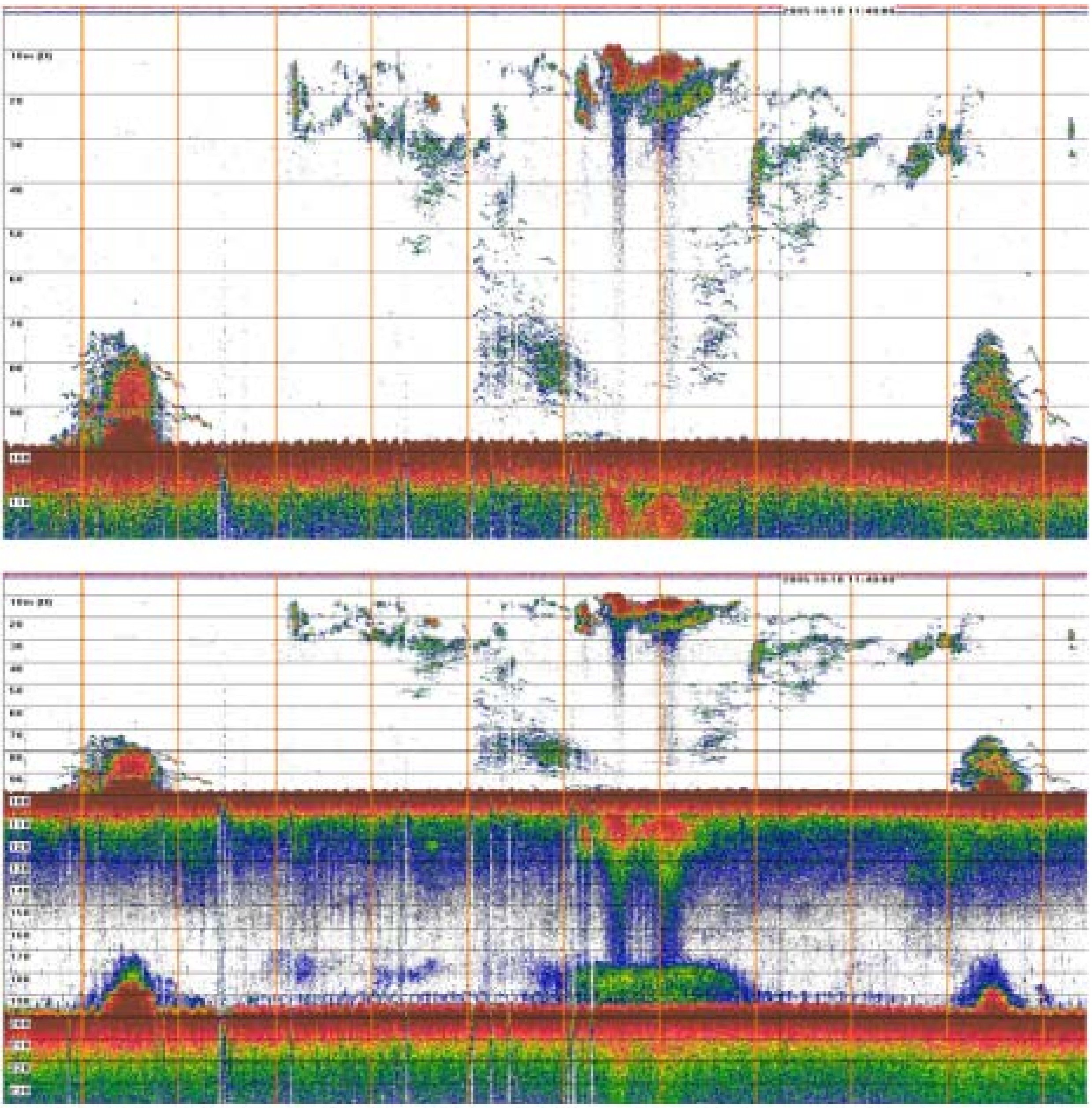

Figure 8. Example of single-beam sonar output showing (top) strong water column scatterers and (bottom) the same time-frame showing the strong second echo from a hard limestone bottom with a thin veneer of overlying sand

The resulting echo pings may be processed to discriminate seabed types. The RoxAnn (and its ECHO*plus* variant) and QTC View are widely used acoustic ground discrimination systems for benthic habitat classification. RoxAnn systems produce two parameters E1 and E2. E1 is the energy of the tail of the first acoustic bottom echo, often related to the roughness of the sediment, whereas E2 is the energy of the whole of the second acoustic bottom echo, often related to the hardness of the sediment. QTC View systems examine the shape of the first acoustic bottom echo only. They then use a series of algorithms to translate the shape of this echo into an array of 166 descriptive variables (many of which are potentially correlated). Principal Component Analysis reduces the dimension to three values termed Q1, Q2 and Q3. The RoxAnn and QTC systems use the outputs of their systems to cluster bottom types into similar regions. It is then up to the user to relate the clusters identified to seabed types through local knowledge or ground-truthing exercises.

A RoxAnn-like analytical technique was adopted and has been used at the Centre for Marine Science and Technology, Curtin University, to discriminate seabed types. Following the procedure described in Siwabessy (2001) and Siwabessy *et al* (2000), E1 and E2 parameters were derived from recorded acoustic waveforms using Echo*view* software. Maps of seabed roughness and seabed hardness along the track may be easily produced from E1 and E2 respectively (see Figure 10). Spatial interpolation is required to expand into unsampled areas. Introducing E1 and E2 into cluster analysis (Figure 9) may result in a map of acoustic habitat classes (see Figure 10, specifically 10b) that may be validated with ground-truth data. These defined habitat classes may then be spatially interpolated across a sampled region by some gridding process.

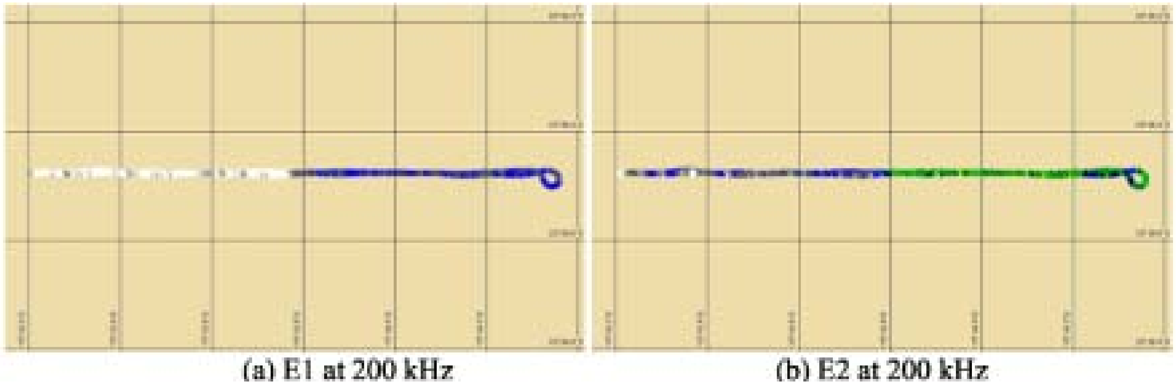

Figure 9. Trackplot of results from single-beam sonar showing a distinct separation between sand and seagras

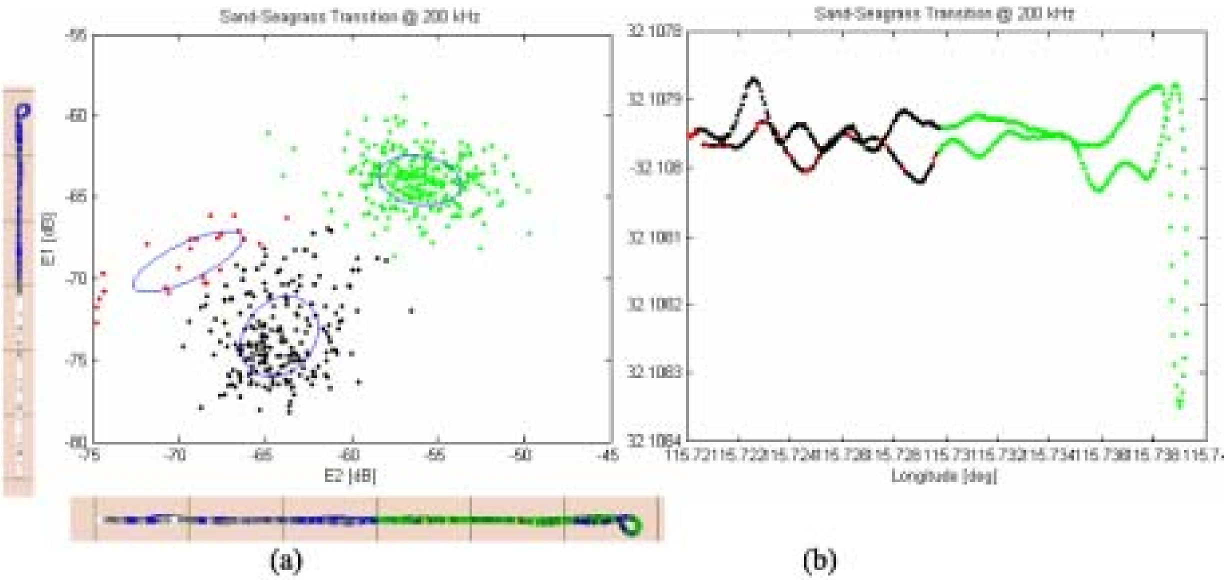

Figure 10. Scatterplot of E1 vs. E2 after cluster analysis (a) and seabed habitat classes along the track (b)
Black = sand; green = seagrass; red = bad data (due to aeration)

3.1.2 Sidescan

Sidescan sonars produce backscatter images from a time series of backscatter intensity of the acoustic returns across the track. Examples of raw waterfall sidescan records are shown in Figures 11 Figure 12. On these images it is possible to discriminate different types of seabed, including sand, coarse sediment, reef and seagrass. The stronger the backscatter, the darker is the image. The returns of sidescan records are not precisely geo-located. With proper ground-truthing, different features visible on the raw waterfall sidescan records may be routinely identified. With specialised mosaicking software which combines the images of many overlapping lines, the water column in the middle of sidescan records is removed and multiple lines are combined to produce a single backscatter image of an area. The different ground-truthed sidescan features can then be turned into benthic habitat maps.

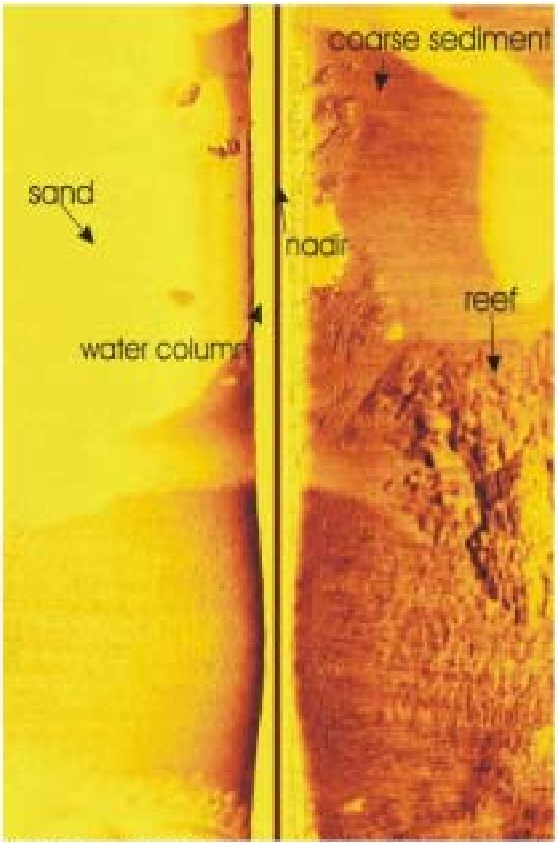

Figure 11. Example of raw 'waterfall' sidescan record

The nadir refers to the vessel's track. The clear area alongside the nadir is the water column return

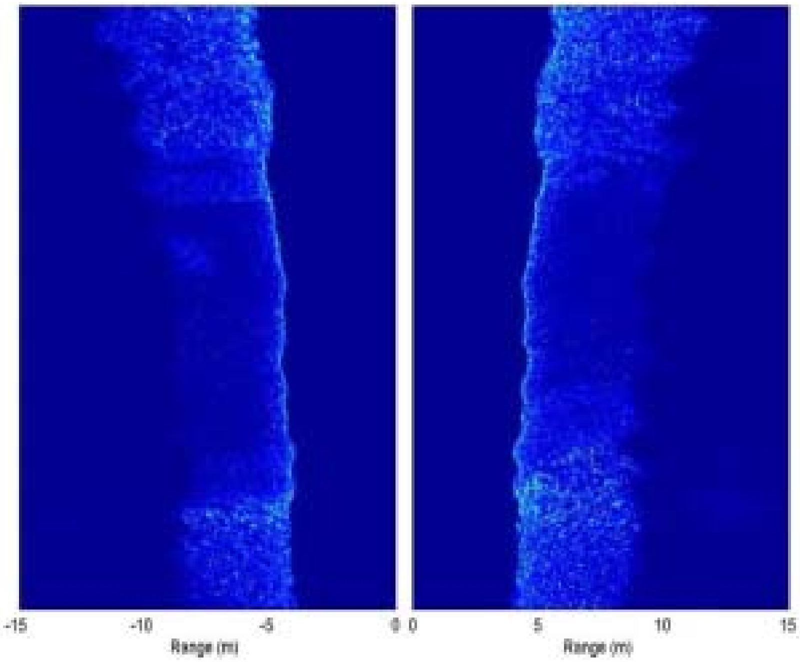

Figure 12. Example of sidescan output (synthesised from multibeam data) showing the water column aside nadir (uniform blue adjacent centre of plot), and seagrass (the textured portion of sidescan output at top and bottom of plot) with a sand patch in between (clear section through plot centre)

3.1.3 Multibeam

High-frequency, narrow-beam, multibeam sonars for shallow water surveys produce high-resolution bathymetry maps. Resolution may be to the order of centimetres, although to obtain this accuracy requires multiple, closely spaced transects and specialised high-resolution instruments (such as the Reson 8125). The high bathymetry resolution produced by the system allows for small-scale texture analysis of the seafloor relief and so allows determination of precisely located bottom roughness. Measures of bottom roughness can then be used as proxies for seabed type; that is, a reef variant, sand, coarse shell, mud or some other bottom type.

The most prevalent characteristics of bottom topography used to describe seafloor habitats are the average elevation, spatial derivatives of this, a topographic variability index (TVI), and a topographic amplitude index (TAI). Examples of these two indexes calculated for a coral reef backslope are shown in Figure 13. The different techniques reveal (real) different features, particularly in the deeper sections and on the steep slopes.

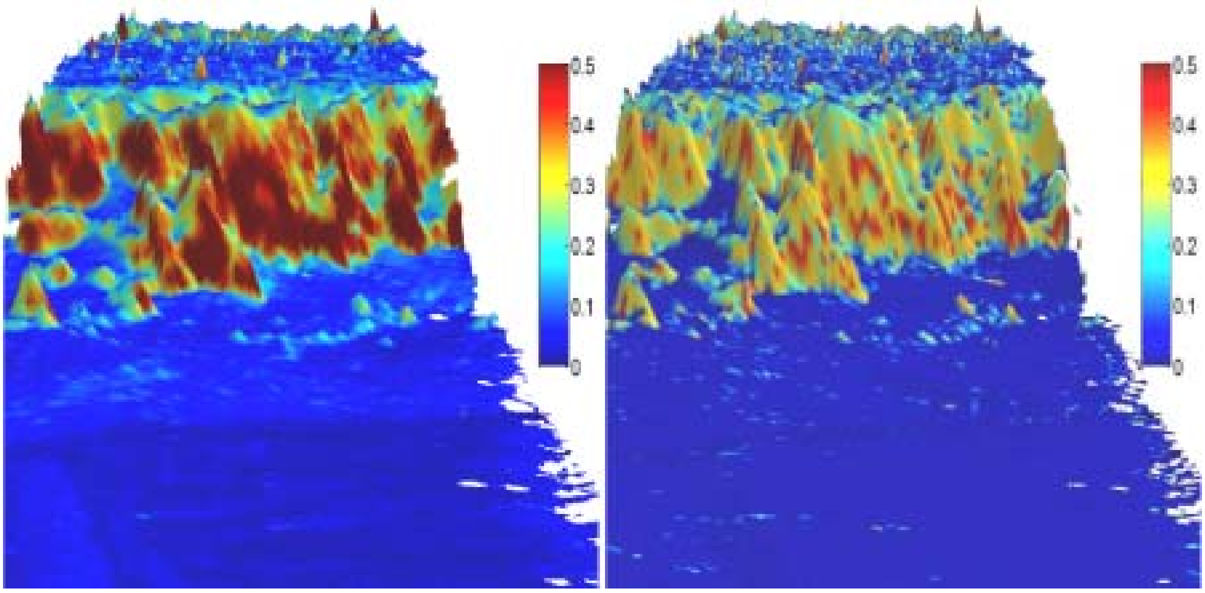

Figure 13. Slope (left panel) and TVI (right panel) draped over a 3D bathymetry of the Morinda Shoal region in Bowling Green Bay, Queensland
(from the results of the Coastal CRC's Coastal Water Habitat Mapping project)

The spatial resolution of multibeam sounders is depth-dependent. As the water depth increases, the spatial resolution becomes coarser, primarily because the beam width of the transducer insonifies an increasingly bigger area as the depth increases.

Multibeam sonar also produces sidescan (as shown in Figure 12) and backscatter images. Backscatter images are measures of various characteristics of the signal echo returned to the multibeam sounder (as opposed to bathymetry which is a measure of the depth at a known x-y point only). Processing backscatter from multibeam sonars requires the sonar to be capable of storing the section of signal reflected from the seabed. Currently the huge data rates associated with multibeam sounders generally preclude them from capturing and storing all the sonar signal from each beam (consider the Reson 8125 which has 240 beams each sampling 450 kHz with a 28 kHz bandwidth and up to tens of pings per second). Instead of attempting to capture all of the signal, some multibeams such as the Reson systems only capture and store a short segment located about the system-detected seafloor for each beam (termed 'snippets'). This greatly reduces the data storage requirements.

In principle, the nature of each echo within each beam received by the multibeam contains information on the nature of the scatterer, in this case the sea floor or the fauna above it. Complicating factors in interpreting multibeam backscatter are the nature of the particular sonar, the instrument settings and the variation in scattering from any object for signals hitting it at different angles. Since multibeam (and sidescan) sonars encompass a wide range of angles at which the beams are sampled, there is a strong angular dependence in scattering across the multibeam swath output for any particular seabed type. This variation with the angle of ensonification is itself a useful indicator of bottom type. At the high frequencies at which multibeam sonars operate, there currently do not appear to be any physical descriptions of scattering for real seabed types or epibenthic fauna. Therefore, the interpretation of multibeam 'angular dependence' and backscatter analysis is currently an empirical science.

Processing of multibeam backscatter data is more complicated than that of bathymetry data. As part of the Coastal Water Habitat Mapping project of the Coastal CRC, the Centre for Marine Science and Technology has developed an empirical approach to angular correction of backscatter intensity. It involves calculation of an average angular response for backscatter intensity level within a spatially sliding window along the trackline swath line, with a 50% overlap of windows. This average angular dependence is subtracted from the measured backscatter intensity level within each section of the swath line that spans the central half of the averaging window. The absolute level of backscatter is then reconstructed by adding the average level measured across the swath line within the interval of 30 ± 2°. This calculation is carried out separately for each side of the swathe line (i.e. both sides of the swath across the vessel's track are treated independently).

This technique results in backscatter images relatively free of angular dependence artefacts as shown in Figure 14. The angular dependence of backscattering strength is also retained in calculations as it provides an important characteristic that distinguishes different types of the seafloor cover, as can be seen on Figure 15 where it easily delineates sand and seagrass. The ground-truth images shown in Figure 15 are a typical output of the video sequences produced by the towed video system described in Section 2.4. Figure 16 shows a backscatter image draped over the bathymetry for the same area presented in Figure 14 along with single beam analysis of backscatter. In Figure 16 the single and multibeam systems clearly separate two different seabed habitat types, which were identified by video as sand and seagrass. The boundary that both systems draw falls along a similar line.

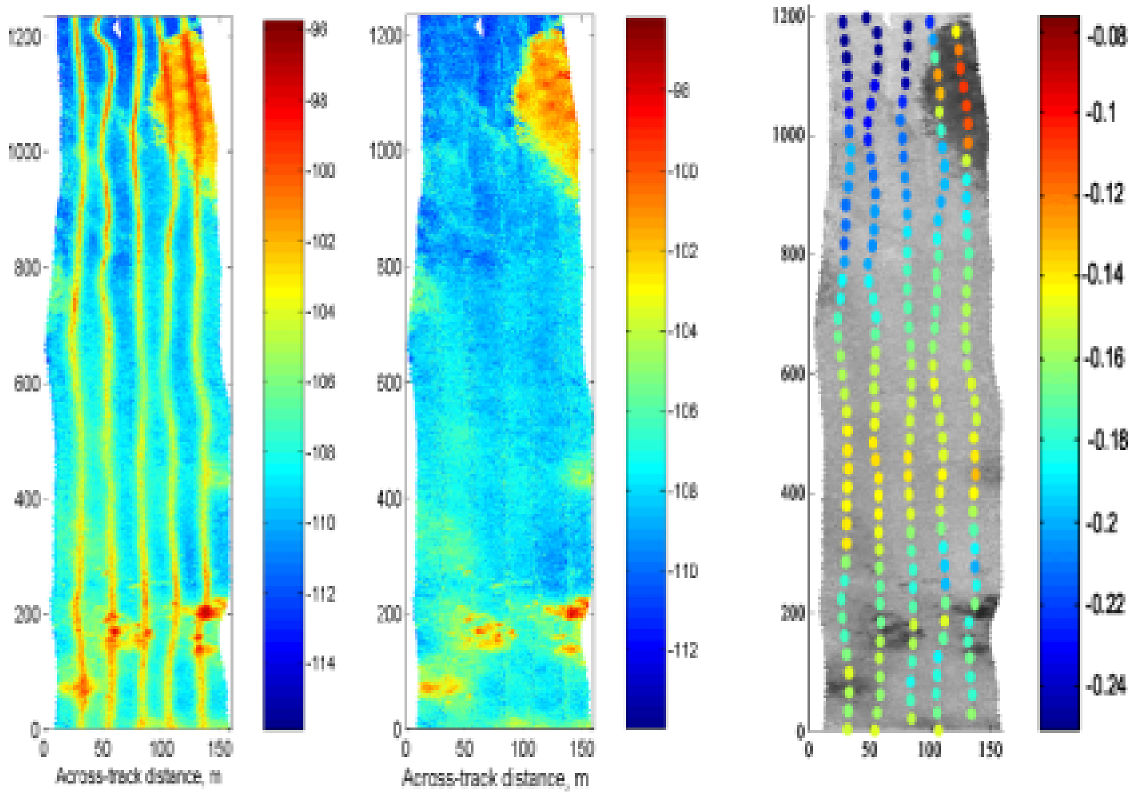

Figure 14. Backscatter intensity image of the seafloor built from five overlapping swath lines, before correction for angular dependence

Note strong angular dependence artefacts evident as the strong reflections from beams looking downward close to the vessel's track *(left panel*) and (*central panel*) the same region after correction for angular dependence. The *right panel* demonstrates the mean slope of angular dependence within 5–40^0 measured at the central points of each section of swath lines, superimposed on the grey-scale backscatter image. The seafloor in the surveyed area consisted mainly of sand. Note seagrass patches of various sizes clearly visible as yellow and red-coloured (dark) spots at the bottom and at the upper right corner of the area.

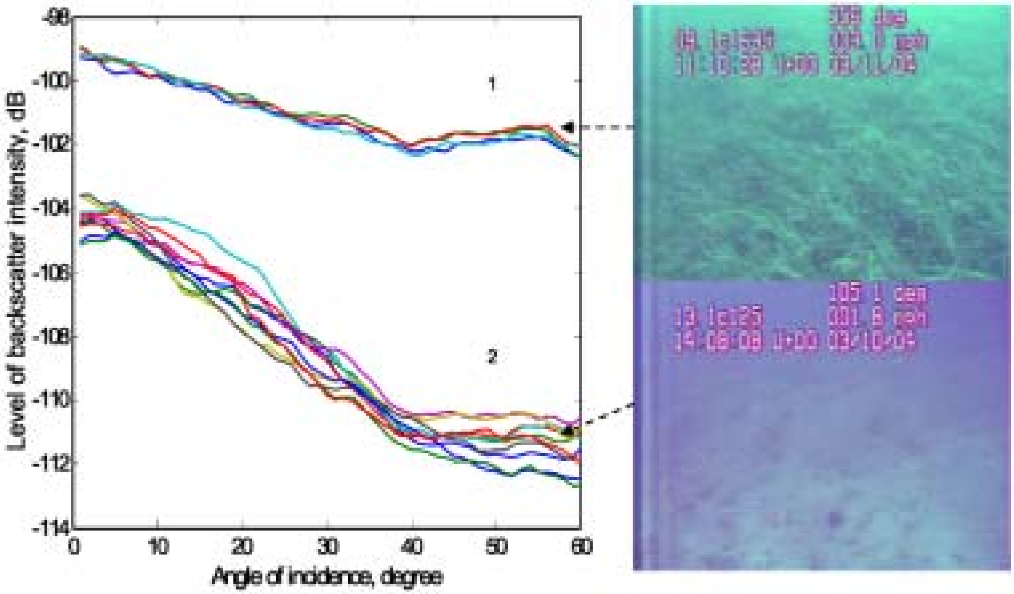

Figure 15. Angular dependence of backscattering strength from seagrass (1) and sand (2) measured in Cockburn Sound, Western Australia, along with photographs of the seafloor taken for ground-truthing acoustic observation
(part the Coastal Water Habitat Monitoring project; see Gavrilov *et al*., 2005)

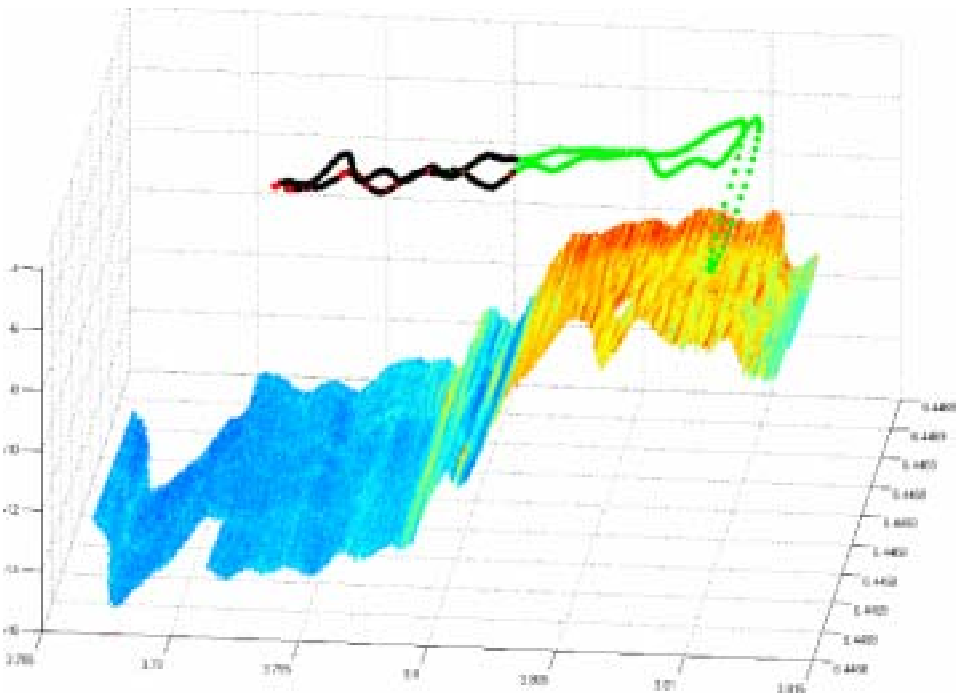

Figure 16. Comparison of results derived from the multibeam (as shown in Figure 15) and the single beam systems over a sand and seagrass bottom

4 Practical issues for surveys

A general summary of the requirements of each survey technique, with estimates of minimum labour costs for surveying and processing, is listed in Table 2. Of note here is that quality control of data sets and postprocessing can be a very protracted and demanding task, depending on the survey requirements, and that the person-day estimates given in Table 2 for postprocessing reflect only the simplest and minimum processing for each technique, and must therefore be considered as minimum times. The vessel sizes are given as estimates; *'safe'* means applicable to the marine environment concerned. The postprocessing requirements will vary for each technique depending on what is required out of the data set and the type of software used. Software availability and cost is a major issue for the more complex techniques. Data management and quality control are major factors for all techniques. All techniques currently require or will greatly benefit from some level of ground-truthing.

Table 2. General comparison of active acoustic practical issues and proportionate costs in person time, presented as x days for y persons for set up and field operations and person-days of analysis per survey-day for data processing (1 *Sud* = 1 survey day of 12 hours)

Technique	Vessel requirements*	Survey setup time	Field operators required	Postprocessing requirements
Single beam	Any safe vessel	Can be set up at vessel purchase ~ no setup costs; poles can be affixed in a morning (0.5 d, 1–2 p)	Can operate remotely (0 p per d) or with sporadic or continual supervision (1 p per day)	Seabed discrimination – figures from RoxAnn or QTC approach – immediate to ~0.5 d per *Sud*
Sidescan	Safe vessel >7 m	Towfish system requires little setup (0.5 d, 1 p); hull mount requires a) slipping (major cost); or b) side mount (1d, 2 p)	Comfortably with 2 p per d; can be operated with 1 p per day	Survey line images immediately available, mosaics ~1 d per *Sud* (software-dependent); describing community types ~2 d per *Sud*
Multibeam	*Sheltered waters 7–10 m okay; in exposed waters, safe vessel >15 m	Hull mount requires slipping or diver (major cost); pole mount or sonar well mount requires ~1.5 d, 2 p	Comfortably with 2 p per d; can be operated with 1 p per day; if real-time 3D bathymetry output, 2+ p per d	QC ~0.5 d per *Sud;* 3D bathymetry – immediate display with some software although ~2 d per *Sud* required for publication output; backscatter – open ended
Towed video	Any safe vessel capable of slow speed	0.5 d, 1 p – system is towed so no fixed mounts simplifies setup	2 p per day (1 monitor camera, 1 adjust line for depth compensation)	2 d per *Sud* for defining community types along tow

* The differentiation in vessel size is driven by the mounting requirements for the transducer, the large amount of electronics required, the space available for it and its protection from spray. Relatively small vessels can be used in sheltered waters if the electronics can be made compact in deck boxes. For offshore or extended work, vessels >15 m and with copious sheltered space for electronics are preferred.

4.1 Vessel requirements

Factors important in choosing a suitable vessel for a given survey include:

- daily charter rate
- ability to mount transducer appropriately
- ability to tow at slow speeds (some vessels simply cannot go slow) – slow speed is a requirement for surveys with towed sidecan or camera gear
- sufficient dry space near to the wheelhouse for electronics
- 240 V power
- appropriate vessel safety and comfort
- live aboard capability (where required)
- ability of vessel to maintain straight survey lines at the required speed (a function of the vessel design, required speed, particular sea conditions and the autopilot or helmsman's ability)
- capability, experience and reliability of vessel's crew.

All vessels used for surveys should be able to cope with sea conditions expected and meet appropriate survey and safety requirements. For all types of surveys, some space is required for system electronics. For multibeam surveys, the amount of space required for electronics is substantial and either a dedicated dry room for electronics or sufficient space in the vessel wheelhouse needs to be made available. Typically a multibeam survey will require access to two portable computers with three or four monitors, plus DGPS gear, sundry boxes of electronics and seemingly endless cables. The space requirements for electronics, transducer mounting configuration and vessel comfort are important factors in determining an appropriate vessel.

Surveys will require the setting up grids of transects or survey lines. The ability of a vessel to maintain a straight track line is important in the success of surveys; hence vessels should be able to reliably maintain a course. The selection of survey tracklines (see Section 5) will have an important bearing on the ability of a vessel to maintain a track. A knowledge of potential obstructions in running survey lines (e.g. fishing gear or moored vessels) may be an important consideration.

Many commercial vessels cannot go slower than 4–6 knots. For example, modern lobster fishing vessels are designed to travel at high speed for long ranges, carrying large pot loads. They generally have fixed pitch propellers designed for an optimum speed of >10 knots and thus have minimum speeds of 5+ knots. If towed gear such as sidescan or video systems are to be used then the minimum vessel speed should be ascertained before the charter to see if it does not exceed that required. A towed body needs to be held at a constant speed so as to maintain a constant depth. Thus vessels which must kick their propellers in and out of gear to maintain a suitable speed should be avoided, as this will result in the towfish depth continually changing. An ideal vessel in this regard is one with a variable pitch propeller, where the speed can be adjusted to as low as required.

An often underrated factor in considering a vessel charter is the selection of crew. Typically a fishing vessel skippered by its owner offers a considerable advantage to field programs in that professional fishers are extremely capable at sea, have an excellent knowledge of the marine environment and weather patterns in the areas they work, are usually keen to try new operations and are keen to learn about the marine environment. In chartering any vessel, the experience and skill of the crew are often more critical to the success of a field trip than the vessel itself. One factor which needs to be stressed to the crew of a chartered vessel is that acoustic surveys involve days of driving backwards and forwards along set lines. This can become monotonous for the vessel crew, so discussion on how this load can be spread amongst the crew should be decided before the charter begins. For longer trips some feedback system, where the vessel's crew can observe progress and results, is advantageous in maintaining crew enthusiasm.

4.2 Transducer mounting

Factors important in mounting transducers are:

- mounting away from vessel noise sources
- mounting in undisturbed water flow (i.e. no bubble streams from protuberances forward)
- transducer face mounted perpendicular to vessel vertical and in line with vessel horizontal and
- transducer pointed along fore and aft line of vessel (i.e. transducer not with a permanent tilt) OR offset to vessel's steaming axis
- mounting is rigid and does not flex (flexion reduces ability to correct for motion)
- knowledge of transducer location including: depth from the sea surface to face of transducer; offset from the vessel keel and fore and aft distance from some defined point of vessel, for systems with motion compensation.

The ideal location for vessel-mounted transducers is on the keel at the lowest point of the vessel and forward of the propellers. While this offers the best position as regards reducing vessel motion and offers undisturbed water flow about the transducer, it is also the most exposed position under the vessel and so will increase the chance of damage to the transducer if submerged objects are encountered. If the transducer is fitted permanently to the vessel hull, the manufacturer’s recommendations should be followed as to its placement.

For systems used regularly but not permanently fixed, a sonar well or moon pool (as is often found on larger research vessels) is the next best option for transducer mounting. Mounting the transducer in a well allows it to be rigidly mounted below the hull and the cable bought through the well or a pipe. A diver may be required to fit the transducer and bring the surface end of the transducer cable through the sonar well or pipe. Sealing the surface end of the cable may present problems, as sonar transducer surface connectors are generally not a waterproofed type which can be sealed with an appropriate bung. Water ingress during fitting of cables will cause faults in the long term, thus all efforts should be made to seal connectors if they must be submersed.

An example of the Reson 8125 sonar head mounted on a bracket for fitting inside the sonar well of a fishing vessel is shown in Figure 17. Hull-mounted transducers should always have some means of bringing the cable through the hull.

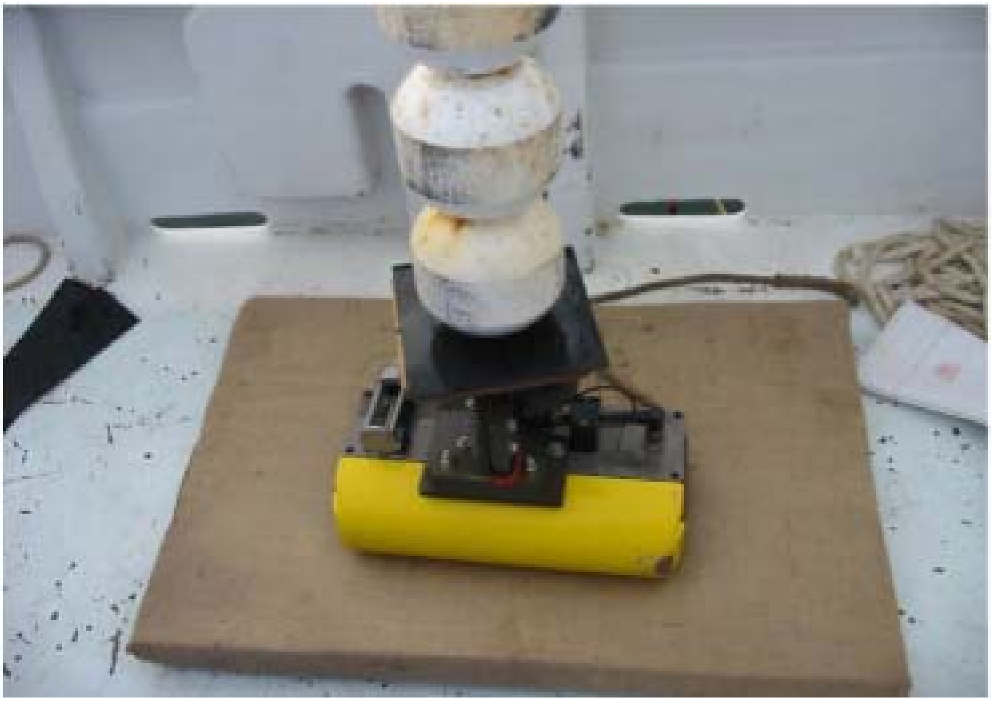

Figure 17. Reson 8125 transducer head (forward end) mounted for fitting in a large-diameter sonar well of a pilchard fishing vessel

Should the available vessel not have some facility for rigidly mounting the transducer to the hull, a pole arrangement is the next option. The manufacturers of some sonars (e.g. Reson) supply pole mounting systems. An example of a pole mounting system for a single beam sounder is shown in Figure 18 and for a swath mapping sonar system in Figure 19 (mounting as supplied by the manufacturer). The pole arrangement shown on Figure 18 cost approximately $2000 AUD to manufacture in 2002.

In all pole mounted systems it is crucial to align the transducers correctly, accurately measure the transducer offset and depth, and fix the system as rigidly as possible to the vessel, ideally by bolting through metal gunwales. Any flex in the mount or pole will degrade the ability to correct for motion compensation. An idea of the forces involved in steaming a pole mounted system can be gauged by the last plate in Figure 19. Our experience at using pole mounted systems is that the slower the tow speed the better, with speeds of 3–5 knots suitable for low frequencies (e.g. 38 kHz Simrad) and 4–7 knots for higher frequencies (such as 450 kHz Reson 8125).

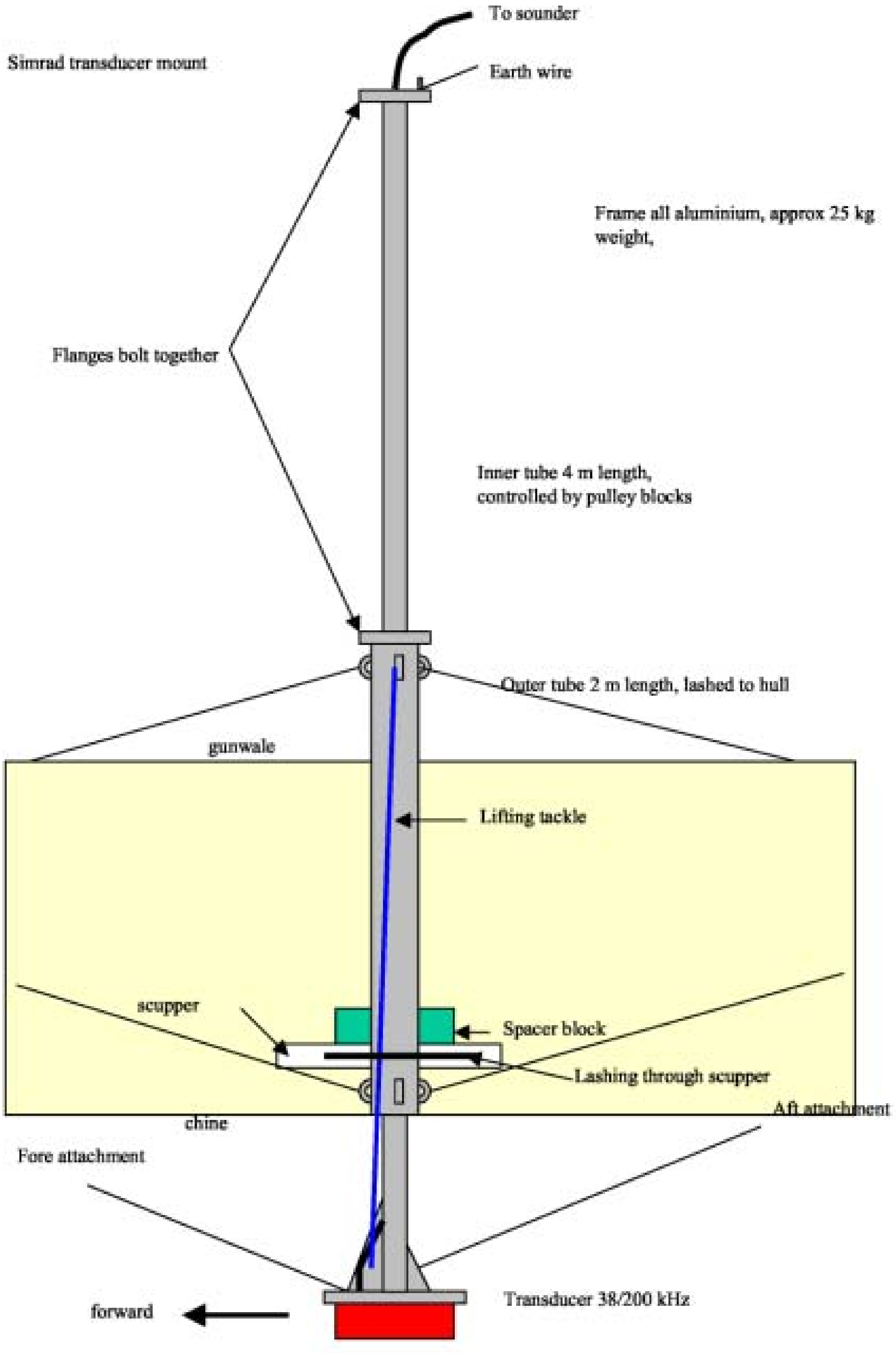

Figure 18. Example of a retractable side-mounted pole used on vessels of opportunity to 25 m length, with a Simrad transducer and lashed to gunwale

Figure 19. Images of a Reson 8125 pole mounted off the gunwale of three vessels

4.3 System configurations

4.3.1 Single beam echo sounder

The single beam is the simplest of the echo sounder systems in terms of field hardware. The requirements for a system are:

- appropriate frequency transducer
- echo sounder
- echo sounder data logging capability
- GPS system.

A scientific-grade echo sounder must have raw data file logging capability to be of any use for postprocessing. This capability may be on board the echo sounder (preferred) or via an attached logger which is placed in parallel with the transducer output/input (not preferred as the dynamic range may be less than that of the echo sounder).

The National Marine Electronics Association (NMEA) output of conventional GPS systems may be used if the features of interest are comparatively large, but if small-scale features are to be studied in detail (e.g. features of <500 m dimensions), differential GPS systems are preferred.

4.3.2 Sidescan sonar

The simplest sidescan system comprises the transducers in a towfish, and a GPS or DGPS interfaced to a surface deck unit to display and print data. The towfish is paid out using a known amount of cable and towed at an appropriate, constant speed. In this configuration the towfish position is estimated by the length of cable out, its tow depth and the GPS antenna location. This is a minimal system and would not provide accurate spatially located data due to movement of the towfish about all axes, its heading relative to the vessel's track and possible depth changes in the towfish (related to constancy of tow speed). More sophisticated systems will include:

- hardware to log raw data, as opposed to printed copies only
- towfish tracking systems, either short baseline pingers or more sophisticated tracking systems for deep towed sidescan
- towfish on-board motion and heading sensors to account for small changes in the axes and heading of the towfish
- towfish depth sensors
- active towfish depth and attitude control.

In some instances the towfish may be affixed to a vessel, either a surface vessel or, as is becoming more common, on an underwater vehicle. Again, if the spatial location of sidescan data is to be precisely known, then the orientation and movement of the towfish must be accounted for in time. A description of the hardware required for this is given below, in the multibeam section.

4.3.3 Multibeam or swath mapping sonar

A multibeam sonar is the most complex system to deploy. The system comprises:

- the sonar head, which has: a transmitter outputting a fan-shaped beam across the vessel's track (wide across-track but narrow along-track); and a receiving array of multiple elements, each of which looks at a different angle from the vertical and has an ellipsoidal beam pattern which is wide along-track and narrow across-track
- a sonar processor computer which allows the sonar settings to be manipulated
- a logging and navigation computer which logs the sensor and sonar data plus displays navigation tracks and real-time images of the sonar output
- a differential GPS
- a gyrocompass to allow real-time logging of the vessel's heading so the orientation of the sonar head to the sonar head track can be determined (to compensate for 'crabbing' of vessels across current)
- a motion sensor which allows logging of vessel heave, pitch and roll (used to correct for the orientation of the sonar head
- a sound velocity probe to measure sound speed at the sonar head
- a CTD profiler (optional but advised) to measure sound speed profiles with depth and thus correction for refraction.

A schematic diagram of the setup of the Reson 8125 system is shown in Figure 20. To simplify field deployments it is wise to fit all electronics into a single field box. This enables easy installation, keeps all the cables neatly mounted and ensures that specific cables are not forgotten. Images of the sensors associated with the Reson 8125 multibeam sounder and the electronics mounted in a single box are shown in Figure 21.

The gyrocompass needs to be mounted as close as possible to the fore and aft line along the vessel's keel. The motion sensor needs to be mounted fore and aft along the vessel's keel line and as close to the vessel's centre of gravity as possible.

The location of all sensors and the sonar head need to be positioned with respect to the vessel's centre of gravity. An example of the offsets for a configuration in a fishing vessel is shown in Figure 22.

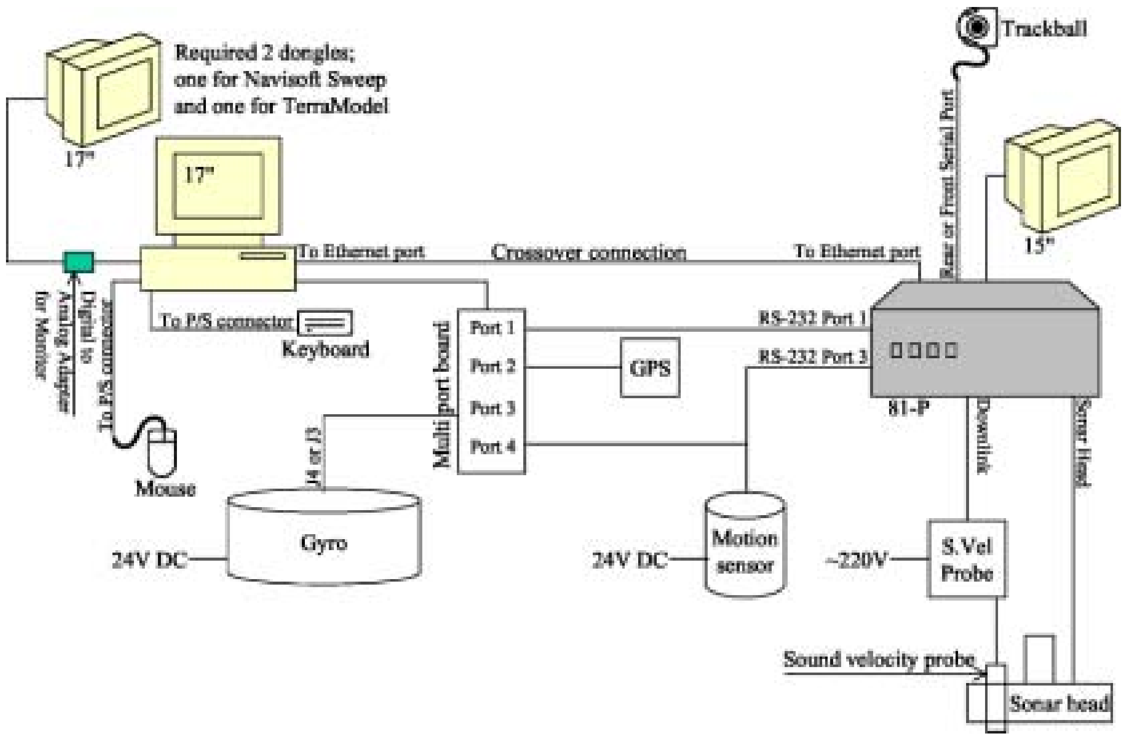

Figure 20. Schematic diagram of setup required for multibeam hardware aboard vessel

The sonar head and sonar acquisition processor are shown on the right.
A differential GPS unit is always required.

Figure 21. Images of a RESON SeaBat 8125 sonar system

Top left: gyrocompass (blue instrument) and motion sensor (black cylinder behind gyrocompass);
Top right: sonar PC (right), navigation and logging PC (left) and associated monitors;
Bottom left: all multibeam surface electronics housed in a field box, two other monitors cabled to the bridge

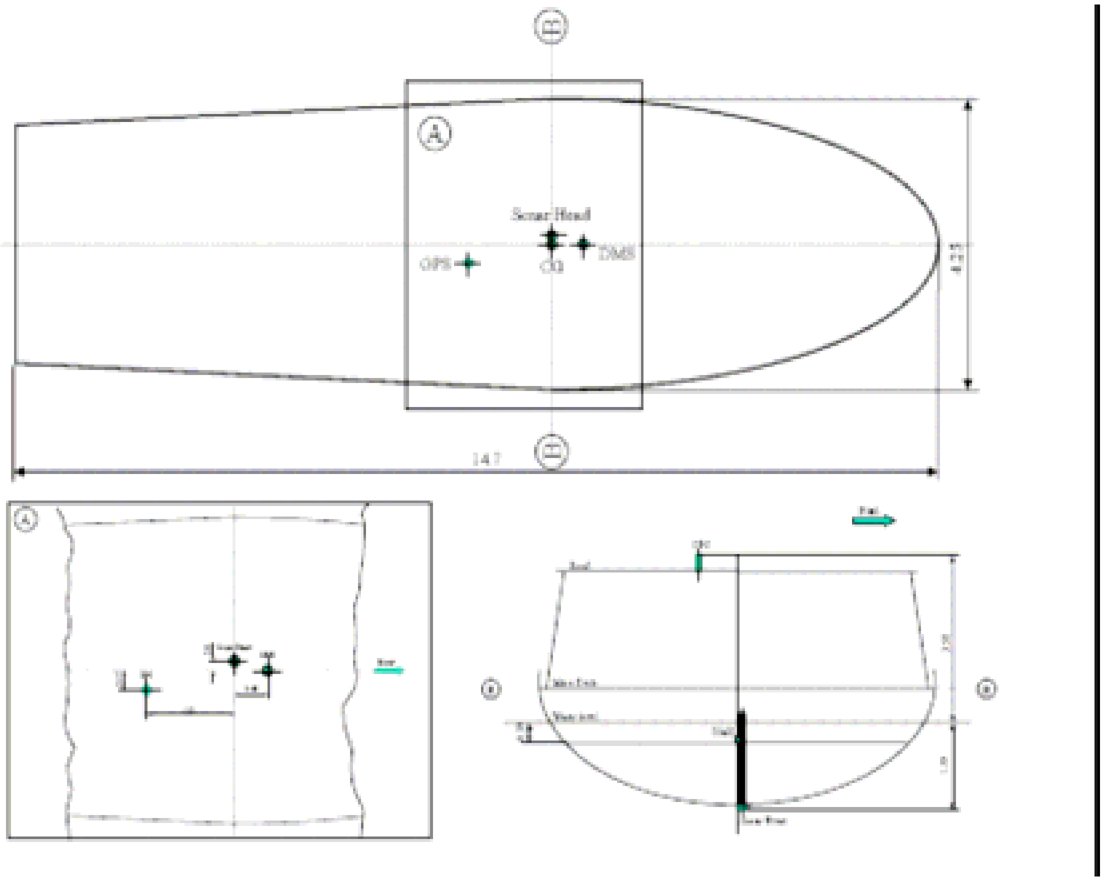

Figure 22. Layout of the various sensors on a vessel for a multibeam survey

The relative location of each element needs to be precisely known to allow motion correction to be applied to the swath beam.

5 Survey design and planning

Before any survey commences, a survey plan should be developed. This needs to be elaborated in a field itinerary, which also includes all details of gear, contacts, personnel, and specific safety instructions. Once a field plan is developed, it is nearly always worth sticking to it – if in doubt, stick with plan A.

5.1 Field Itinerary

All field programs should have a well developed field itinerary. This should include some or all of the following details:

- Trip title, document preparation date and name of person preparing itinerary
- Trip aims
- Field personnel and contacts (all phone numbers and addresses)
- Contacts – all contact details (and addresses where appropriate) for any individual, institutions or companies who will be actively involved in the field program or who may need to be contacted at short notice; includes logistics coordinators, technical assistance for gear, airlines, car rental hire companies, freight agents, hotels and motels and so on.
- Emergency contacts
- Vessel details and contacts – specifics of vessel/s, their call signs, vessel mobile numbers, skippers' names, owners' names, etc.
- A trip itinerary broken down by day, which includes all travel details (flight numbers and times, car rental reservation numbers, hotel/motel booking and contacts, freight consignment notes, etc.) and the planned daily field activities
- Specifics of field program –will vary depending on what is being undertaken but should include planning maps showing areas to work, proposed tracklines, and should include all locations as tables (i.e. trackline ends) with locations clearly stating the units and chart data used
- Gear specifics – some field programs may require special instrument settings, mountings, configurations, etc., these should be noted here for reference

- Specific safety procedures, hazard identification and emergency protocols and responses – specific safety procedures may need to be included
- Methodological protocols – details of some operations may need to be spelled out.

A complex field trip itinerary may require an index. When preparing an itinerary the readers may be:

- Field personnel
- Masters or skippers of vessels to be chartered who need to be informed in advance of where they are going and what they are to be doing; note that if positions are easily spelled out in the itinerary then they may be entered before vessel mobilisation begins
- Family of field personnel – family members will want to know where the field personnel are and how to contact them at any time, hence details of all contacts should be clearly spelled out
- Funding agencies – who may need to be satisfied that: (1) sufficient safety planning and contingencies have been made; or (2) that the trip plan resembles the work proposal.

Parts of the itinerary may need to be read on a vessel working at sea (e.g. gear positions, instrument settings or acoustic release codes), hence large fonts and open line spacing should be used for these sections.

The completion of a comprehensive field itinerary is essential for successful field programs. Having prepared many of these the author has often been taken aback when many days into a field program, after a slight change of plans, one of the field personnel has commented "but that's not what was planned", indicating that the itinerary has been well read and so acts as an important information source, communicating to all what is being done and why. All contacts need to be in the document, as often changes to schedules or gear repairs must be organised while at sea or at short notice, where phone books and diaries are not readily available. Multiple copies of itineraries need to be prepared and disseminated, to guarantee against losing them and to increase the chance that someone will have one handy when required.

5.2 Survey lines

For some sonar/vessel configurations, echo-sounder data may be collected on an *ad hoc* basis by piggybacking data collection while the vessel is undertaking other tasks. The echo-sounder data can either be collected autonomously, which has problems in that system settings usually need to be optimised according to the task and environment, or alternatively—and preferred—the system can be regularly monitored and adjusted by trained crew or science staff. In sophisticated systems on large vessels, facilities may be introduced to control a sonar remotely via email or telephone links. The advantage of running a sonar in this piggyback fashion is that comprehensive data sets may be collected with little field cost (only cost of gear installation and time commitment for crew to check systems). The disadvantages are that the system settings may not be optimal unless appropriately trained staff and detailed instructions are made available, that large quantities of data will be collected, that no control over where the vessel goes is possible, and that someone must eventually archive and analyse the data collected. Nevertheless, in the long term, *ad hoc* data collection may provide valuable data if a vessel routinely works in the same regions.

Designated acoustic surveys of a region require multiple transects or lines. These may be narrowly spaced to give complete or high resolution of a relatively small area, or widely spaced to give a low resolution of a large area. The type of coverage required, high or low resolution, is an issue of the science questions asked, or the information required, and is not dealt with here.

As far as bathymetry is concerned, a common practice in single beam surveys is to run survey lines perpendicular to the depth contours in order to obtain the best definition of slope. Single beam surveys will follow preset straight lines. This is not the case in multibeam surveys where the rule of thumb for bathymetry is to run survey lines parallel to the depth contours. The idea is to get the maximum swath coverage in the shortest time. However, the objectives of the survey, navigational requirements and weather conditions may dictate against running lines according to the depth contours, for multibeam or single beam survey. For example, the prevailing swell, currents or presence of a weather front may rule out some headings. Additionally, for a multibeam survey, if the objective is to look at changes in seabed habitat type along the track and if it happens that the changes are depth-dependent (normally the case), it is more appropriate to run the survey lines perpendicular to the depth contour rather than along them.

For multibeam or sidescan sonar surveys, lines may be generated in advance, or in consultation with the skipper on arrival at the particular area to be surveyed. Ideally, all lines are fully populated into the area of interest to guide the skipper. A 100% overlap between adjacent lines (or one side of the swath) is also ideally required for a multibeam or sidescan survey to avoid gaps between lines due to, among other factors, the roll of the vessel. Alternatively to pre-planning lines, survey lines may be drawn as the survey progresses. In this case, the operator draws the next line following the edge of the previous track. This allows flexibility in dealing with rapid depth changes which may not be known prior to the survey, or with good or poor weather or major bathymetry features (e.g. wrecks or steep ledges), all of which will change the swath overlap between lines required for collecting an optimal data set.

If the vessel skipper is experienced in maintaining the vessel's course, it is also possible to follow the edge of the previous multibeam swath track, thereby not requiring a survey line to be drawn. Again this allows for flexibility in dealing with unknown bathymetric features or prevailing weather or sea conditions. The navigational software used with a multibeam system may include survey line design tools. These may be dynamic, using results of one line to guide the location of the next line. For multibeam surveys the swath width is dependent on the water depth, thus parallel adjacent lines in deeper water can be further apart than adjacent lines in shallow water to achieve the same relative overlap between lines.

The sidescan image of the multibeam system and prior knowledge of the area help the operator to determine survey lines for towed video. Survey lines for towed video are selected in such a way that changes in seabed habitat type are optimised.

5.3 Instrument settings

Most sophisticated sonar systems have a large number of sonar parameters which may be altered by the user. The optimal combination of settings is dependent on the use of the sonar and the environment it is being used in. For the same sonar and environment, different combinations of settings may be needed for different tasks. Examples of the main settings available and their effect are listed below. Several examples are given, and these are specific to Simrad single beam and the Reson 8125 multibeam sonars.

Some of the main settings of sonar include:

- Signal type emitted – the majority of sonars use pure tones only, some more elaborate systems allow other signal types, notably swept tones or some form of pseudo random noise to be used
- Sonar frequency – some sonars have multiple frequencies available, a few new systems are 'broadband' in that they emit, receive and analyse

wide frequency band pulses; this has advantages in that a particular frequency will be optimal for 'seeing' a particular size or type of object, hence a broadband system increases the information returned

- Power output – usually the power output by the transducer can be changed, this needs to be set in conjunction with pulse length so that the received echoes do not saturate the receiver
- Receiver dynamic range (gain) – some systems allow the receiver dynamic range to be shifted, thus allowing maximum power to be used in shallow water
- Pulse length – typically chosen according to task; high resolution requires short pulse length but when lowering pulse length, once a certain pulse length is reached, the power output of the transducer begins to drop, so some systems are hardware-limited in the minimum pulse length available
- Range (or system listening time) – the system will need to listen for a certain time to hear echoes from the seafloor or distant scatterers (twice as long if the second echo is needed); this time depends on the two-way signal travel time (longer ranges require longer listening times and the listening time is then related to ping rate)
- Ping rate – number of pings per second, which is dictated by the sonar hardware and the listening time (range) needed.

Some sonars also have other settings, which are hardware-specific and related to how the system processes data internally.

The range settings—which involve listening time, transmitter power output and on more sophisticated systems also include receiver sensitivity—of single beam and multibeam systems depend on the water depth. The RoxAnn technique requires second bottom echoes to produce the RoxAnn E2 parameter. As such, the range of the single beam system used is set such that the second bottom echoes are provided (i.e. range is set to just greater than twice the water depth). The QTC View technique however requires only the first bottom echoes. In this case, the range (power) is set such that only the first bottom echoes are visible.

An example of multibeam system settings is presented for the Reson 8125, 450 kHz high-resolution system. The maximum range that Reson 8125 system provides is 120 m. The swath coverage of this system is 3.5 times the water depth within less than 60 m of the water depth. As the water depth exceeds 60 m, the swath coverage drops as the outer beams are lost due to insufficient power. The range of the multibeam system is set so that the optimum swath coverage is produced. Even in a single line where multibeam data are collected, the range of the multibeam system may change several times if extreme changes in water depth occur. This may happen if survey lines run across depth contours.

If bathymetry output is the only interest, the power and receiver gain are not as critical. Normally, the power is set quite high to provide a better bottom definition. However this kind of setting may saturate backscatter signals from seabeds. For seabed habitat mapping surveys or biomass estimation using backscatter, the echoes cannot be allowed to saturate the receiver. Thus irrespective of the systems deployed, single or multibeam sonar, where backscatter analysis is required the power and gain are set to a level so that the acoustic returns are not saturated (or do not overload and clip at the receiver). The power and the gain of systems are correlated. For single beam systems in water depths up to 20 m, the optimum power that provides unsaturated acoustic returns is typically less than 200 W. Between 20 m and 60 m of water depth, the typical power of the single beam is between 200 W and 500 W. For Reson 8125 multibeam system, the optimum power and gain settings for a depth less than 50 m without causing saturation in acoustic returns are Reson scales 6 and 7 respectively.

The pulse length determines the resolution of data: the shorter the pulse length, the better the resolution of data. However, the acoustic energy decreases as the pulse length decreases. The Reson 8125 multibeam system has a minimum pulse length of 11 µs and a maximum of 292 µs. The optimum pulse length recommended by the manufacturer is 51 µs. and the minimum is 33 µs. This optimum recommended pulse length is suitable only for bathymetry. Given a fixed sampling bandwidth (about the sonar centre frequency) of 28 kHz for both sidescan and snippets data output by the system, the minimum pulse length required from sampling theory is 70 µs. It is therefore recommended that the minimum pulse length suitable to produce sidescan and backscatter images using high resolution multibeam systems is 70 µs.

6 Effort required from example projects

The amount of data collected and the effort expended, from a series of acoustic surveys carried out during the duration of the Coastal Zone CRC program are described below (Table 3) to give an indication of the effort and results which can be achieved. All vessels utilised have been <25 m in length.

Table 3. Effort and costs associated with field collection in the form of vessel costs and personnel time

Place	Setup and test days / staff	Km surveyed (km^2 for multibeam) / survey-days / staff required			Downtime (days)	Vessel, transducer mounting
		Single beam	Multibeam	Towed video		
Sydney Harbour, NSW, 2003	2 / 3	67.5 / 4 / 1	67.5 / 4 / 3	Not used	0	AWB 440 DSTO vessel, ~12 m, bow mount
Recherche Archipelago, WA, 2003	2 / 6	Not used	306 / 5 / 3	Not used	2 (weather)	FV Firebird (pilchard fishing vessel) ~20 m, sonar well mount
Cockburn Sound, WA, 2004	1.5 / 6	130 / 2 / 2	172 / 2 / 3	Not used	0	FV Reliance II (lobster fishing vessel), side mounted
Bowling Green Bay, Qld, 2004	1 / 6	24 / 1 / 2	241 / 5 / 3	14 / 1 / 3	0	RV James Kirby (research vessel), side mount
Moreton Bay, Qld, 2004	1 / 5	33 / 1 / 2	197 / 6 / 2	14 / 1 / 3	1 (mechanical)	RV Tom Marshall (research vessel) side mount
Fitzroy Estuary, Qld, 2004	2 / 6	Not used	343 / 7.9 / 3	2 / 0.1 / 2	1 (gear recovery)	MV Rum Rambler, side mount
Sydney Harbour, NSW, 2004	1 / 5	110 / 3.8 / 1	170 / 3.8 / 4	4 / 0.3 / 4	0	AWB 440, DSTO vessel, bow mount
Recherche Archipelago, WA, 2004	2 / 6	Not used	903 / 10 / 2	Not used	2 (weather)	FV Firebird, fishing vessel, well mount

7 References

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