

# **Cost Effective Marine Habitat Mapping from Small Vessels using GIS, Sidescan Sonar and Video.**

**Andrew Neil Bickers**

Ph.D. Student / Engineer

Marine Science Group, School of Plant Biology, University of Western Australia, Hackett Drive, Crawley, WA 6009.

*andyb@cyllene.uwa.edu.au*

## **Abstract**

High frequency sidescan sonar has been popular for mapping and visualisation of the sea floor since the early 1980's. In the past decade the availability of affordable portable personal computer based digital acquisition and processing software has breathed new life into this technology. Similar improvement in video technology has bred underwater video systems that are reliable, small and inexpensive. This evolution has been supported by the rapid exploitation of Global Positioning Systems (GPS) and Geographical Information System (GIS) technology.

Here I describe the packaging of all these technologies into a cost-effective system for mapping shallow water continental shelf habitats. This paper details the fusion of commercially available sidescan equipment and third party software with video system hardware and software developed by the author into a portable package that can be deployed efficiently from vessels as small as 7 m. GIS software such as ArcGIS™ was used intensively for navigation, interpretation and visualisation during both data acquisition and processing.

The utility of surveying using the combined sidescan and towed video system is demonstrated by mapping coastal benthic habitats from the Recherche Archipelago, Western Australia. Over 60 km<sup>2</sup> was mapped for as part of a larger Fisheries Research Development Council (FRDC) project characterising the fish habitats of the Recherche Archipelago. The results demonstrate how accurate and efficient seabed mapping can be performed in shallow water and details of the required infrastructure and capital outlay are provided.

## **Introduction**

The nearshore benthic marine environments of Australia contain a diverse range of habitats including temperate and tropical reefs, seagrass meadows and a variety of vegetated and unvegetated sediments. Effective environmental management of these areas requires the production of base maps of physical and biological resources. Much effort has recently been directed towards the mapping and classification of marine areas in terms of their diversity and spatial distribution of habitats. Scientists often assess habitats to understand the distribution and relative abundance of marine resources (Stanbury & Starr, 1999). Habitat is normally defined as the place in which a species lives (e.g. rocky sub-tidal habitat) or as being characterised by the dominant life form (e.g. kelp forest habitat) (Kvitek, et al., 1999; Greene, et al., 1999). Resource management agencies are becoming ever more reliant on maps of habitat type at different scales to predict the real or potential distribution of species or communities that are difficult to survey directly (Davies, et al., 1997). Marine habitat mapping is also identified by the Australian Government (IMCRA, 1998) as an important component of micro-scale regionalisation, through assessment of the spatial extent and boundaries of ecological units. This mapping is currently underway in many coastal regions to assess the current and potential impacts of coastal developments on the near shore marine environment (e.g. mining, port developments and aquaculture).

Due to the poor propagation of electro-optical waves in water, the use of hydro-acoustics is widely accepted as the only way to map the seafloor on a broad scale at any significant depth (Blondel, 1997). This differs markedly from the techniques used in the production of habitat maps in terrestrial systems which are typically produced by cost effective optical and radar remote sensing techniques deployed using planes or satellites. Video systems may provide an easily interpretable record of the seabed, but their field of view is limited and dependant upon sea state and water conditions. New airborne electro-optical techniques such as CASI and LIDAR have significantly improved survey speeds, but are limited by resolution, cost and water penetration. (Kvitek, et al., 1999).

Various hydro-acoustic (sonar) systems are used in mapping the surface of the seabed. All rely on analysis of the timing, strength and angle of the reflected waves received from a transmitted sonic pulse incident on the seafloor. Where single beam echo sounders in combination with digital acoustic ground discrimination systems can provide water depth and indices relating to the nature of the substrate below the vessel, multibeam and sidescan sonars provide continuous information about the seabed over a wide swath. Sidescan sonar provides little information about the bathymetry of the area surveyed, but the acoustic 'backscatter' recorded is of a high resolution and infers much

about the texture of the seabed. Although multibeam systems can be used to provide both bathymetry and information about the substrate, the textural information obtained is generally of a lower resolution than for sidescan. Records obtained from both types of systems require processing and interpretation and, with accurate vessel positioning, successive swaths can be mosaicked into composite acoustic images of the seabed.

Sidescan sonar is a proven technology which has historically been used for detection and monitoring of objects on the seabed. In the last ten years however, it has become commonly employed in broad scale characterisation of the seabed itself. This usually involves either visual or automated segmentation of the acoustic image into discernibly different textural regions which are then related to habitat type or dominant biota. As with most remote sensing techniques, the objects of interest may be below the resolving capabilities of the equipment and supplementary data is required to accurately identify the substrate and community of each area. This supplementary data can take many forms, depending on the accuracy and type of information that is required, but is commonly obtained by diver, grab or video (Kvitek, et al., 1999; Blondel, 1997).

It is important to note that the improved availability of accurate positioning from the Global Positioning System (GPS) satellite array and the development of personal computer based sonar acquisition and processing systems at reasonable cost, has allowed the exploitation of these technologies by agencies and institutions that it would not have previously been available to. The advent of desktop and portable Geographical Information Systems (GIS) means that biological and physical data referenced to geographic coordinates can now be merged, layered, analysed and displayed at many scales (Kvitek, et al., 1999; Stanbury & Starr, 1999).

The aim of the research described here was to provide a continuous map of the distribution and boundaries of the main types of benthic habitats and dominant communities of the area surrounding the Woody Island group in the Recherche Archipelago, Western Australia using sidescan sonar and video techniques.

The results demonstrate how accurate and efficient seabed mapping can be performed in shallow water from vessels as small as 7 m without large capital outlay and infrastructure.

## **Methods**

A combination of sidescan, video, GPS and GIS was used by the University of Western Australia in this study to perform benthic mapping of shallow continental shelf habitats. The system is based on a traditional analogue sidescan system combined with a contemporary digital acquisition and processing system. Classification of the sidescan imagery

into habitat types is supported with independent data sourced from georeferenced towed video. The utility of this combination is tested by mapping coastal benthic habitats from the Recherche Archipelago, Western Australia.

The Recherche Archipelago is located on the South coast of Western Australia. This region of open coast comprises about 150 islands and 1500 known 'extrusions' and comprises large zones of unsurveyed territory. The islands are scattered over 470 km of coastline, no further than 60 km offshore and in depths of up to 80 m. In this area the continental shelf encroaches on the mainland to within as little as 50 km (Clarke, 1952). Islands are formed from granite and gneiss which are similar to the isolated often dome shaped hills that dominate the coastline of the area (Myers, 1990). These islands are separated from each other and the mainland by sandy habitats, punctuated unpredictably by reefs which are often inundated by sand. More sheltered sandy areas typically support dense seagrass communities with the shallower reefs being dominated by algae. Reefs found in deeper water may be colonised by sponges, bryozoans and ascidians.

This study was carried out during May 2003 in calm to moderate conditions with seas and swell to 1m and winds to 20 knots. Two days of sidescan sonar survey were undertaken followed by a day of video validation. Classifications of points from a previous drop video survey were also used.

The following sections outline the acquisition, processing, analysis and display methods for the sidescan and video data.

### ***Sidescan Sonar Acquisition and Processing***

Sidescan sonars utilise two sensors each ensonifying a 'swath' of seafloor each side of a towed torpedo-shaped 'fish'. These transducers produce a thin fan shaped beam that is concentrated on the seabed in a line that runs from below the fish, perpendicularly out to the maximum range on each side. The forward motion of the device allows the beams to cover a wide swath of the seabed (Figure 1). The two transducers simultaneously emit a sonic pulse at a particular frequency. As the transmitted pulse interacts with the seafloor at angles off normal, most of the energy is reflected away from the transducer. The small amount of this backscattered energy that is received, is amplified and recorded by a digital acquisition system. This recording occurs over an extended period allowing for returns to be obtained out to the selected maximum ground range. The line of data obtained after each pulse, is considered a function of time. Using the speed of sound in water the distance from the fish for each position along this line can be predicted (Fish & Carr, 1991). Signal levels are digitally sampled and as the transducers move forward

subsequent lines of data are built up to form an acoustic image of the area. This image is a record of the instantaneous intensity of the backscatter and is affected by the following factors in decreasing order of importance.

- Sonar frequency (higher frequencies give higher resolution but attenuate more quickly with range than lower frequencies).
  - The geometric relationship between the transducer and the target object (slope).
  - Physical characteristics of the surface (texture)
  - Nature of the surface (composition, density)
- (after Kvitek, et al., 1999)

The unprocessed signal shown in Figure 2 shows a number of distinct areas. The nadir is shown as a black central line. This is an artifact of the emitted pulse. The water column below the fish is shown by the lighter area each side of the nadir and the width of this is dependant on the altitude of the fish above the seabed. The imagery each side of the water column represents the texture of the substrate and its benthos. Areas of that produce a stronger return are shown as darker.

Although this image yields much information about the composition and communities of the seabed it can be subjected to further processing. The water column is removed by 'bottom tracking' and 'slant range' geometric distortions which compress the record of areas near the transducer are corrected. Corrections can also be made to the data to compensate for radiometric distortions related to the attenuation of signal with distance and grazing angle (Fish & Carr, 1991; Blondel, 1997). As the position and heading of the vessel for each ping is recorded from the GPS, the processed data can be displayed correctly in geographical space. Compensation can also be made for the 'layback', which is the distance the towed body trails behind the GPS antenna mounted on the vessel. A fully processed example is shown in Figure 3. Multiple vessel tracks can be processed into a full coverage mosaic of the area surveyed.

The equipment used in surveys described here is comprised of a standard Edgetech 272T 100 kHz towed fish and 260TH surface unit. This type of system has a maximum range of 200 m per side (dependant on depth) and good quality images can be obtained at speeds of up to 6 or 7 knots. Although this unit is capable of providing a thermal paper chart output, signals are routed to a laptop based digital acquisition system. This commercially available system is supplied by ChesapeakeTechnologies of Mountain View, California in the form of three programs- SonarWiz, SonarWeb and Real Time Mosaicking (RTM). In order to maintain versatility the laptop, sounder and GPS are mounted in a ruggedised plastic case and can be powered by a 12v deep cycle lead acid battery.

While surveying, SonarWiz software is used to acquire sidescan data through an analogue to digital card mounted in the laptop. For each survey track this provides an industry standard XTF™ file containing position, heading, depth obtained from single beam echo sounder and backscatter amplitude information for each ping. There are a maximum of 4096 samples recorded per channel for each ping in 256 (8 bit) quantised levels. RTM software displays the positioned sonar output in real-time and ArcPad is used to provide live navigational capabilities. The screen grab shown in Figure 4 shows an example of the sonar acquisition software, RTM and ArcPad running simultaneously.

Postprocessing and mosaicking is completed using SonarWeb software, producing a composite image with a resolution of typically 1 m per pixel. This fully processed sidescan mosaic is then segmented visually into areas of different texture, patterning or morphology. Suitable tracks for video data collection are identified that will sample representative examples of the acoustically distinct regions of the sidescan mosaic. Areas to be sampled are chosen to include transitions, boundaries and patchy areas as well as areas of specific interest. Centres of visually similar regions are also commonly sampled as these can assist in gaining an idea of the differences in density of benthos compared with the periphery of the same region. Quite rapidly a ‘library’ of identifiable textures is created which reduces the need to sample similar textures again.

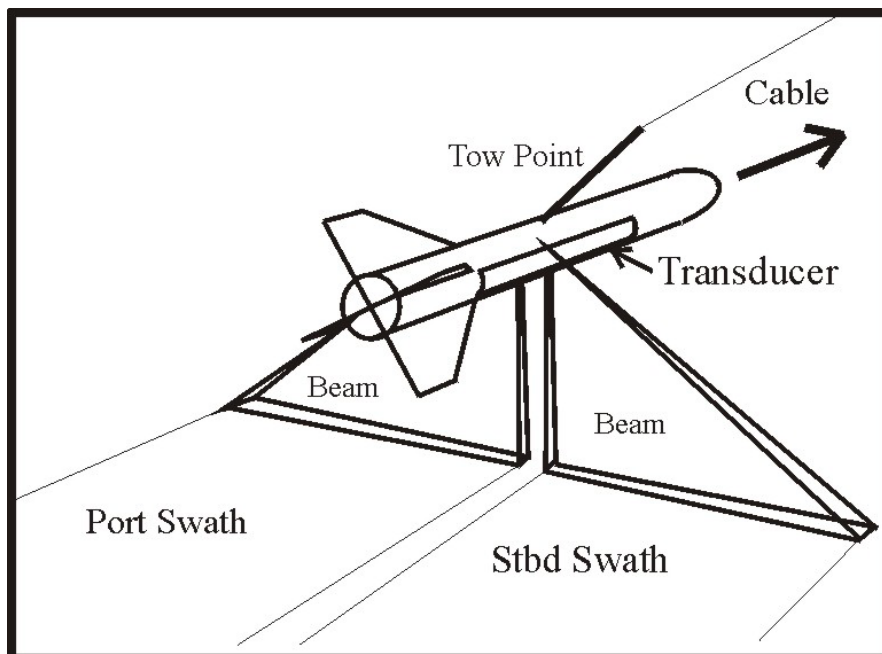


Figure 1: Sidescan sonar operation showing swath extent.

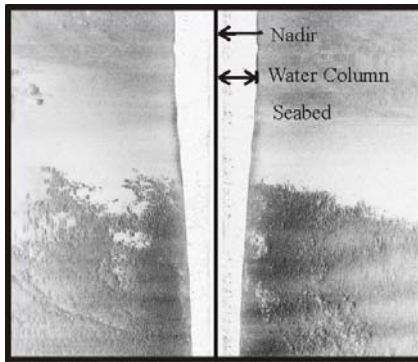


Figure 2: Unprocessed sidescan record showing water column, nadir and backscatter information.

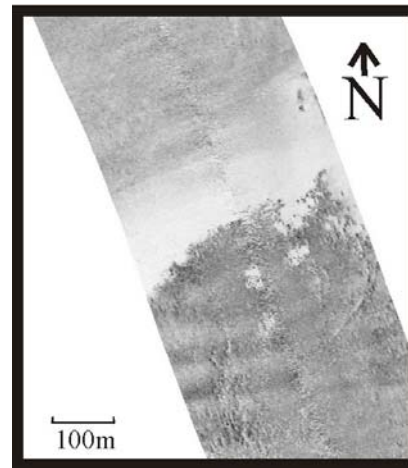


Figure 3: Fully processed sidescan record of Figure 2 with water column removed.

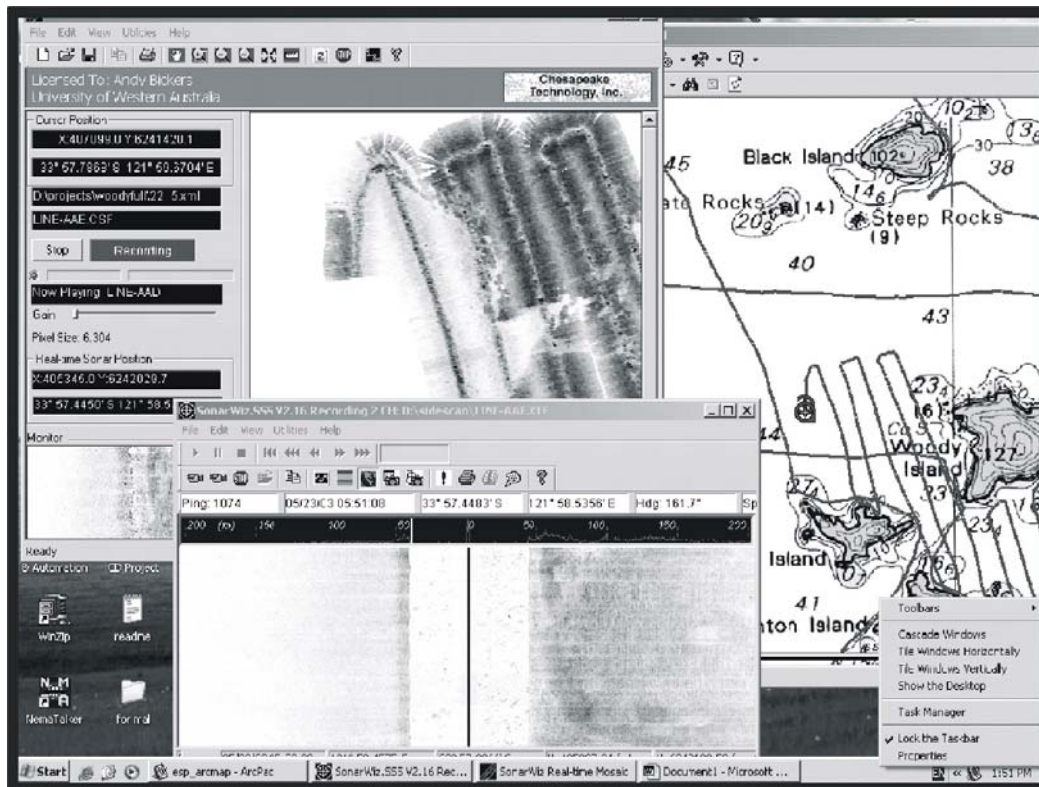


Figure 4: Screen view of sidescan survey in operation showing navigation and live acquisition and mosaicking.

### ***Video Acquisition and Processing***

Video is an efficient means of gaining a permanent record of both the substrate and epibenthos. A towed camera system is used that provides live video to the surface via a cable. On deck, the hardware used for the sidescan is also used for the video system. To assist in obtaining

and recording accurate positioning of the camera a number of innovations have been made that exploit the processing and interfacing capabilities of a personal computer. ArcPad is used to provide live vessel positioning, using both the digitised chart and the processed sidescan mosaic as a backdrop. This ensures that the areas, boundaries and transitions that are to be videoed can be accurately targeted. The availability of live video on the surface allows real time confirmation of the location of boundaries and changes in habitat type or benthic and community structure that have been observed on the acoustic image.

In order to accurately georeference the video, in house software developed in Visual Basic by the author is used to read National Marine Electronics Association (NMEA) strings from the GPS and single beam echo sounder and perform the following functions.

- Record depth, vessel position, heading and other GPS data in user definable time increments to a text file with respect to a unique alphanumeric identifier.
- Estimate layback as a function of the depth and calculate the position of the camera using this estimate, vessel position and an implementation of Vincentys algorithm (Vincenty, 1975).
- Send commands to video text overlay unit to imprint this information continuously on the video image (Figure 5).

The utility of this system is that videos can be visually classified with reference to a unique positional identifier displayed on the screen. This links the video to positions and other data recorded in the text file. Classifications of benthic habitat or community type made from the video can then be added to the text file with relation to their recorded position, unique identifier or time. Most GIS systems can then import this classified file as X-Y data into a track log. The information that is associated with each point, such as habitat classification, is used to form a table of attributes related to each recorded position.



Figure 5: Example frame of video with text overlay showing unique identifiers and depth.

### ***Analysis and Data Display Methods***

The use of GIS is fundamental to the combination, display and analysis of the sidescan and video data. The processed sidescan mosaic and classified video tracks can be added as layers to any existing available data sets for the surveyed area. These data sets may be as simple as a digital chart, coastline or point, contour or 3D bathymetry, but can include any physical or biological information obtained from previous surveys. It is essential however that the data is georeferenced and that the datum and coordinate system is known so the information can be converted or displayed in a common form.

Most GIS systems can display points or polygons coloured with respect to a column of data in the attribute table. The points overlaid on a portion of sidescan mosaic in Figure 6 are represented according to the broad habitat classification made during video processing. The inset image shows at the same location the areas segmented from the sidescan record. These have been labeled with a habitat class based on the overlaid video track. This illustrates how video transects allow identification of the areas distinguishable in the sidescan record. Although the use of the processed sidescan data can determine much about the spatial extent and boundaries of habitat and community types, reference to the higher resolution raw sidescan record may also be necessary for accurate identification.

Classification and visualisation can be aided with the use of a function such as “Hyperlink” in ArcGIS that allows logical addresses of video clips or still images to be referenced to points along the video track.

The still or video images can then be invoked by placing the cursor over the referenced points. Third party software such as Image Mapper™ is also available that will output maps of data layers with points and hyperlinks in an HTML format that can be viewed on any web browser.

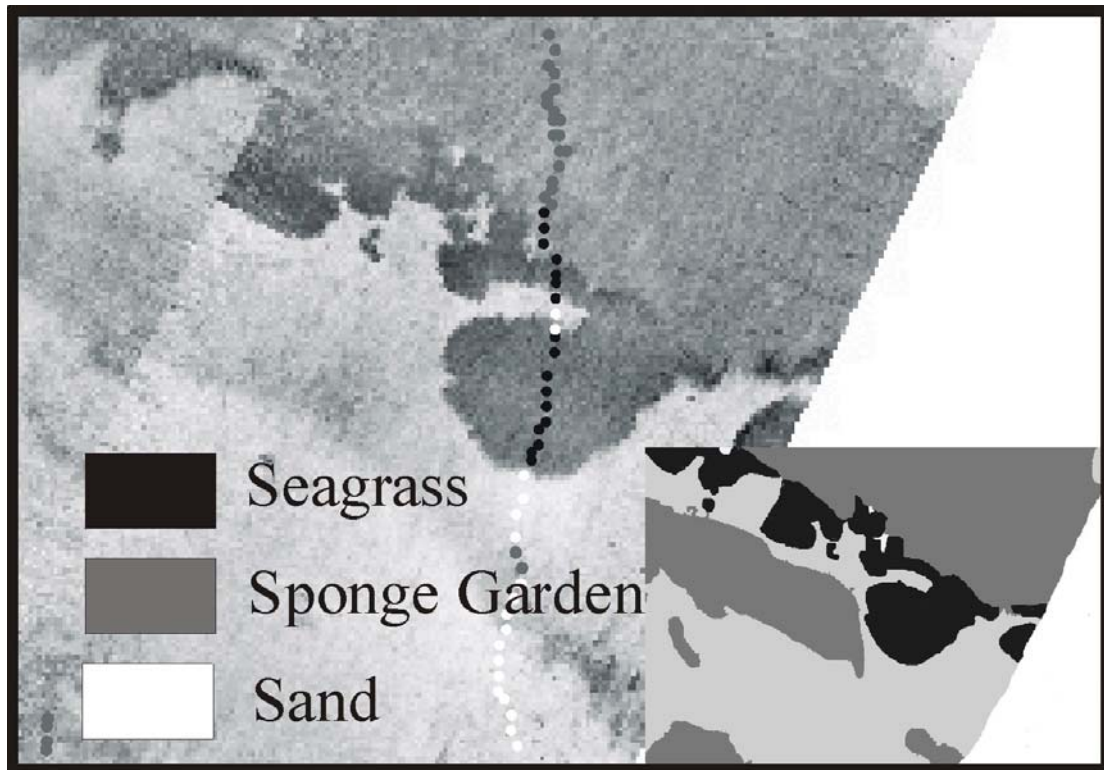


Figure 6: An example of an interpretation of sidescan and video to create a habitat map. The video track classified according to habitat type is overlaid on the processed and segmented sidescan record to allow classification of the sidescan record (inset).

## Results

During habitat mapping in the Recherche Archipelago, certain habitats and community structures have been found to be easily identifiable from the sidescan record. The series of images in Figure 7 displays examples of these as they appear on the sidescan record. The raw unprocessed images are shown, as during processing some of the detail may be lost. The data for all these images was obtained at the maximum range of 200 m per side and at towing speeds averaging over 6 knots. Low returns are shown as a light tone, darkening as the backscattered signal strengthens. The typical resolution of these files is 1 to 2m in the along track direction and 0.1 to 0.2m in the across track, depending on speed.

Seagrass meadows are distinguished on the sidescan record by a characteristic coarse irregular texture with a strong return (Figure 7a). It is thought that the gas filled cavities of seagrass are partly responsible for this (McCarthy, 1997). The uniform texture and robust return of rhodolith beds are also easily distinguished on the sidescan record. Rhodolith beds formed by aggregations of ball shaped autonomous calcareous red algae are evident as the darker areas in Figure 7b and stand out clearly from the surrounding sand. The smooth surface of the sand provides poor backscatter and most of the incident sonic pulse is reflected away from the transducers. This provides a stark contrast to the hard textured surface of the rhodoliths which provide a strong backscatter return. Isolated bommies, reefs and edges of islands appear clearly on the sidescan record (Figure 7c). Note that shadows (shown as light areas) are formed behind features of high relief due to the angle of acoustic illumination and areas of steep slope are characterised by low return. Sand ripples of various wavelengths are also identifiable, although is this dependant on their wavelength and amplitude as well as the resolution of the data and the sea condition. The area magnified in the inset on Figure 7d shows sand ripples of approximately 2 to 4 m wavelength. The texture of rippled surfaces can serve as a good reflector for the acoustic beam. On images that have been recorded or processed at lower resolutions, regions that have been rippled by physical effects often appear darker than adjacent similar sediments with a smooth surface (Figure 7e).

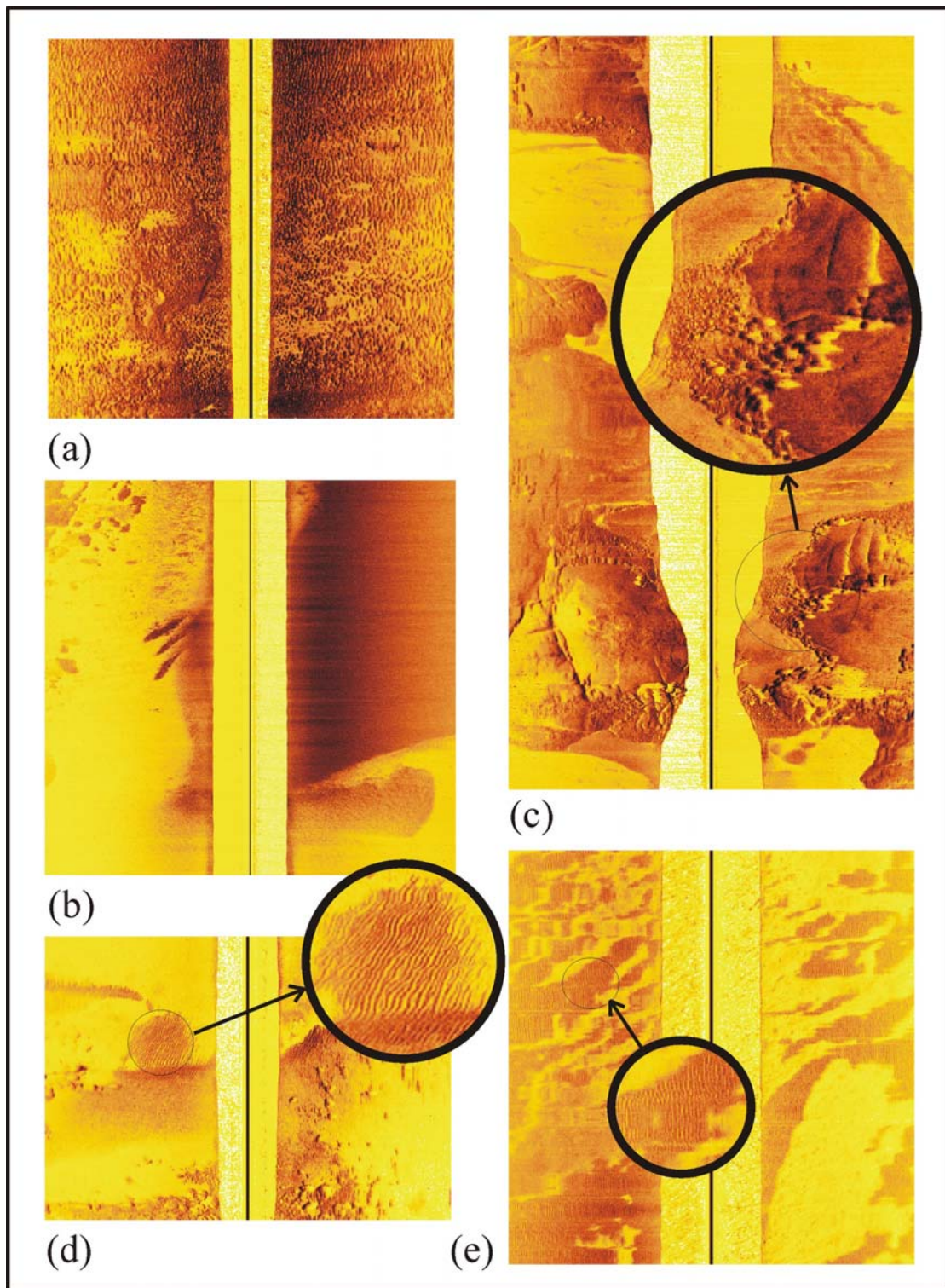


Figure 7: Examples of unprocessed sidescan images from the Recherche Archipelago taken at 100 kHz showing examples of different biota and habitats. a) Seagrass; b) Rhodoliths; c) Reef; d) Sand ripples; e) Sand ripples.

The marine habitats of coastal Western Australia are formed by complex and dynamic combinations of substrate and community types and are often not easy classified. An example of this is found in the low limestone reef pavements which are commonly inundated by sand. Areas such as these can be populated by a variety of organisms and communities including sponges, ascidians, bryozoans and macroalgae which are typically dependent on a hard substrate. Seagrasses, especially *Halophila spp.* are also often found on reefs with a more permanent inundation. This poses a considerable problem for both classification and identification of the sidescan record. Although we can now identify the different characteristic texture and transitions onto areas of these low reefs from the acoustic return from the benthos, the need for validation of both the habitats and communities is much greater. Penrose & Siwabessy (2001) and Cochrane and Lafferty (2001) also report this as being an issue.

The images in Figure 8 illustrate the process of classifying an area from the sidescan mosaic, raw sidescan data and geo-referenced video. The fully processed mosaic (Figure 8a) represents 16 hours of sidescan tow over approximately 60 square km of an area surrounding the Woody Island group in the Recherche Archipelago, Western Australia. Tracks shown in red are those for which towed video has been obtained and the points in blue are drop video locations from a previous survey. The raw sidescan for the area marked A on the mosaic is illustrated in Figure 8b. An example of a classified video track named w16, collected over the transitions shown in area marked B is shown in detail in Figure 8c. This has been classified as being seagrass, low profile reef or sand by analysis of the video. A still image (Figure 8d) illustrates the low profile reef at point 125 of this track. Both the positional references (track name and point number) are shown together with the depth of 32.7 m on the second line down of the text overlay. The classification of habitats along the video track supports the labeling of distinguishable regions in the raw sidescan image. At this point the other data sets available for the area were considered including those shown in Figure 9. The collection and merging into a common platform of available information is a vital step in the classification process. Examination of all the available information with reference to the sidescan and video data in this way, allows broad classification of the area into a habitat map (Figure 8e).

This map shows a draft classification of the area in terms of broad habitat/community types. Classes were chosen on the basis of those easily distinguishable from the sidescan record. These classifications are very coarse, but with further processing of the video and sidescan, a map can be produced, identifying in more detail the biota and physical attributes of areas.

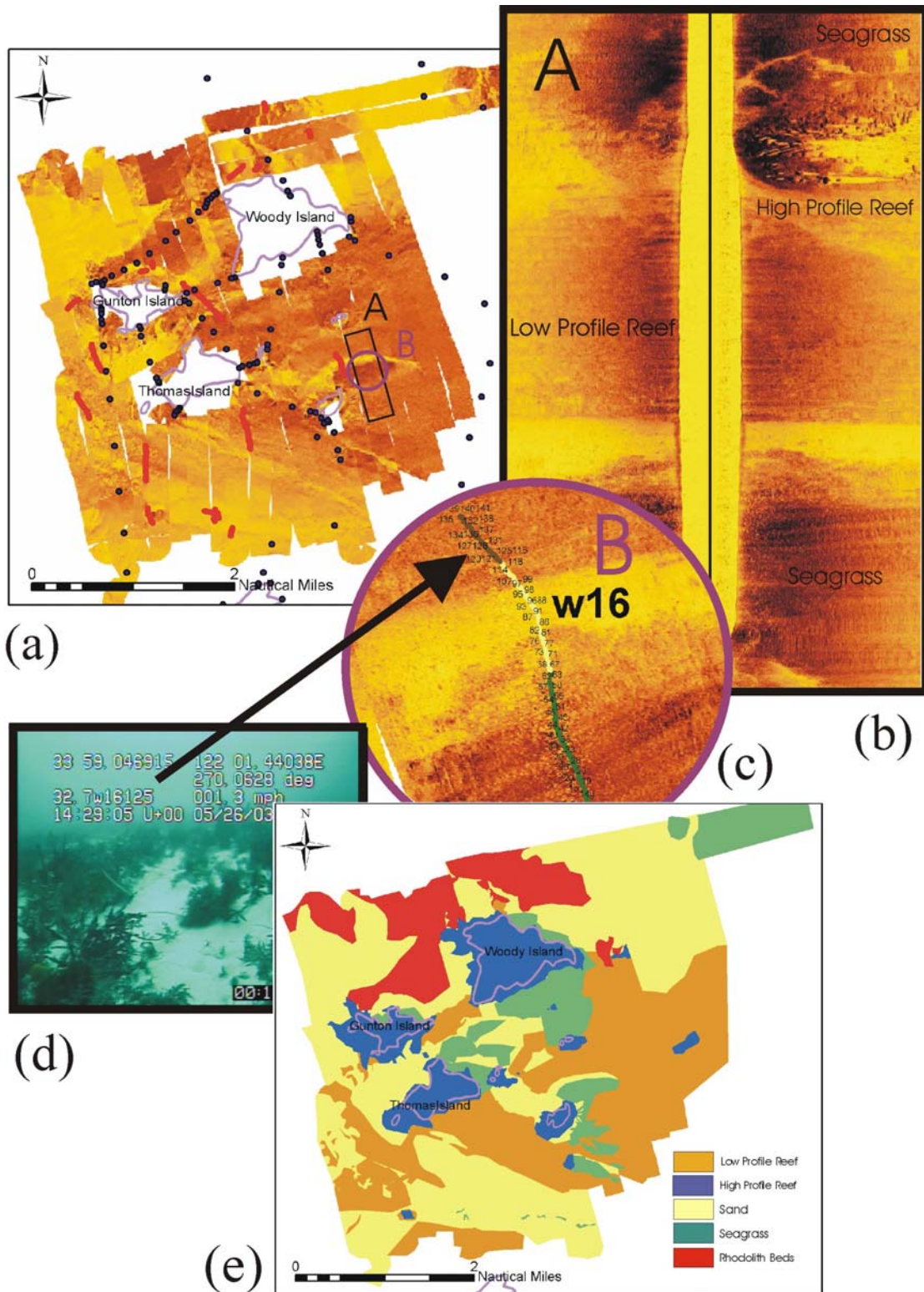


Figure 8: An example of the stages of creation of a habitat map from sidescan and video data. a) Sidescan mosaic; b) Raw sidescan data; c) Section of sidescan mosaic with overlaid classified video track; d) Frame of video showing text overlay; e) Classified habitat map.

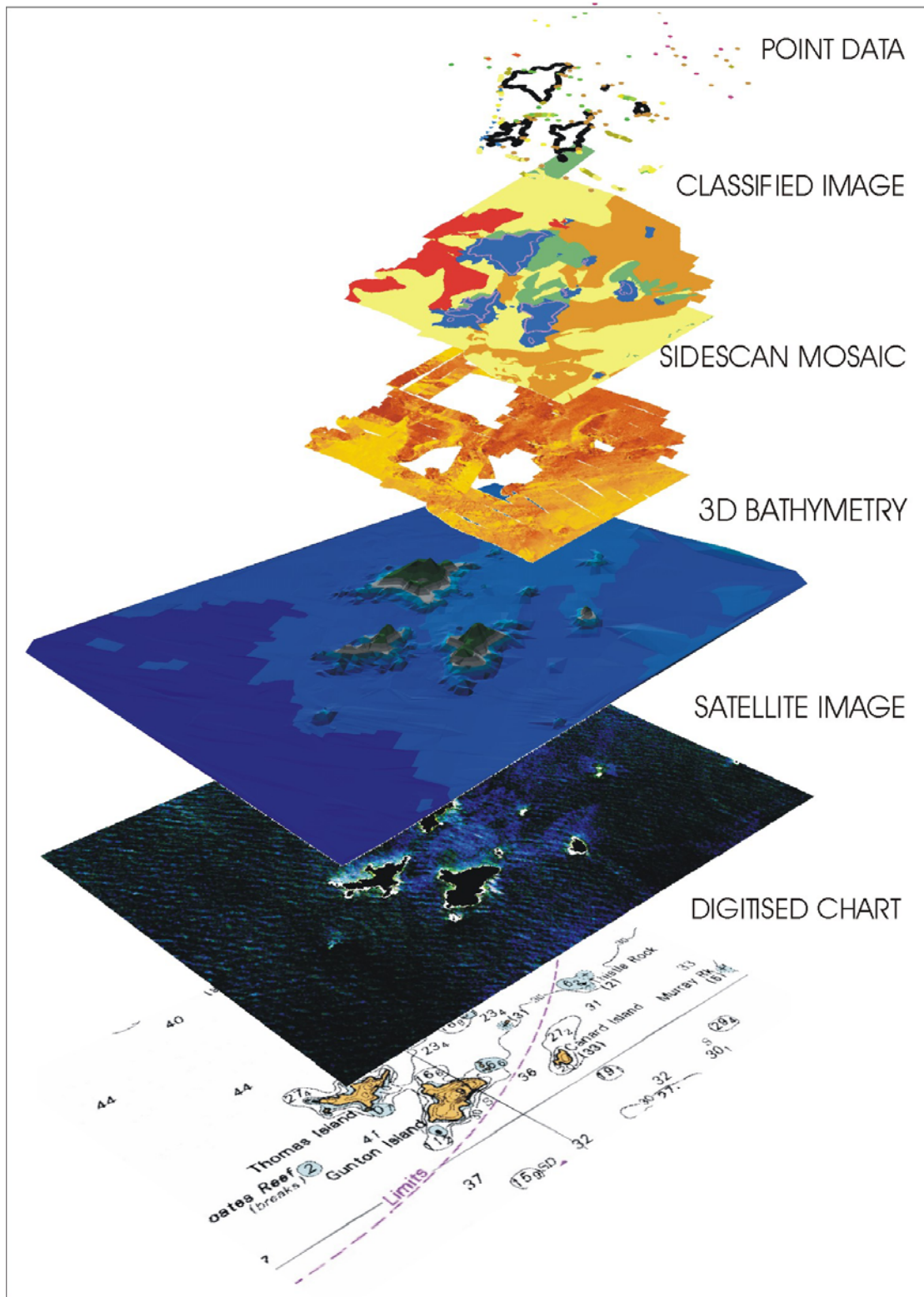


Figure 9: Data sets used in the creation of the habitat map.

## Discussion

The combined package of sidescan sonar, towed video and real-time DGPS linked through GIS and other acquisition software has proved

to be an efficient method of performing shallow water habitat mapping in the coastal environments of Western Australia. The availability of accurate GPS positioning and cost effective desktop computer based acquisition and processing equipment means older and lower end sidescan equipment can be used to provide accurate maps of the seabed at resolutions adequate to differentiate marine habitats and communities. The results shown here were obtained from twenty year old equipment fitted with new transducers and electronics costing approximately \$AUD 15,000. A minimum capital investment of \$AUD 100,000 would be expected for new equipment and software with similar capabilities to that described here. Although this is an order of magnitude less than for a multibeam sounder system comparisons are difficult as sidescan systems only record depth below the vessel and the quality of backscatter obtained from multibeam systems is continuously improving. Survey rates for sidescan are dependant on depth and the quality of data that is required, but, based on experience, an average of 4 square km per hour can be achieved in waters of 20 m and over.

The addition of a towing point behind and above the propeller enables surveys to be carried out with vessels as small as 7 m, and the ability to run the equipment at 12 volts has also improved system versatility. The quality of the sidescan image is affected by the movement of the vessel however, and becomes unusable in poor weather conditions in smaller vessels.

Despite the increase in availability, versatility and resolution of sidescan systems, direct sampling to support image interpretation is still critical to the success and accuracy of any survey. The video system described here has a number of benefits. Operationally the requirement for space on small vessels is relieved as it uses the same above surface hardware as the sidescan system and the low camera weight means that it can be deployed and retrieved by hand. Survey speeds are however limited by the amount of cable deployed, and although depths over 60 m can be achieved, the drag on the cable and the effort required to retrieve the system are effectively limiting. The availability of the vessel's position live over a backdrop of the sidescan record or chart has been found to be of great benefit in accurately targeting areas of interest. Numerical referencing of the video image with respect to the vessels track log has also proved to be invaluable in post processing and classification of the video and sidescan data. GPS time can also be used to reference points along the video track.

Classification of the surveyed area requires analysis of the texture of the sidescan record at a number of scales. The raw sidescan image is the highest resolution record available and although the easiest to interpret, is not correctly spatially processed. Processing and mosaicking

the sidescan tracks produces a composite spatially correct image, but typically there will be some loss of detail due to reduction in resolution. The resolution of the mosaicked image output can be controlled, but the exponential increase in image size can be limiting. Here, the mosaicked images were used to generate the position of boundaries and transitions, using the raw images to accurately identify the habitat or community types.

Although the sidescan record was segmented and classified visually with reference to validation by video data in a style similar to McRea, et al., (1999), there are a number of commercially available packages designed to perform automated supervised or unsupervised classification on images. A wealth of literature is available pertaining to the segmentation and classification of generic and sidescan images (Jain, 1989). A discussion of this is considered outside the scope of this paper, but the author is currently working on a system of automated textural classification to be tested on both the raw and processed sidescan data. This will initially be based around the most commonly reported method of textural analysis using Grey Level Co-occurrence Matrices, but will extend to an investigation into more complex methods (Haralick, 1973; Shokr, 1991).

Although the equipment and methods described here are based around known and proven technology, their accuracy and usefulness has been augmented by being combined with GPS, and modern desktop based GIS systems in both the acquisition and processing phases. The system described has been found to be very successful in shallow water habitat mapping in Western Australia. Much of this success can be attributed to its portability and ease of support.

Here we have only considered using the sidescan sonar to obtain 'full coverage' of areas. Broad scale information about the area can be used to target areas for sidescan survey, just as the sidescan record itself, is used to target areas for higher resolution video sampling. Analysis of charts, oceanography, topography or bathymetry together with satellite or aerial photography can assist in the identification of boundaries of habitats for survey. For instance, in the areas of study in Western Australia, the water clarity is such that boundaries of rhodolith beds that have been identified by sidescan and video survey have been similarly identified by satellite imagery in greater than 30 m of water. It is proposed that sidescan sonar can be used as a validation tool for information relating to habitat extent obtained on a broader scale and that performing widely spaced transects may increase survey efficiency. Work is continuing in this area.

## **Acknowledgements**

The field work for this paper was carried out as part of the Fisheries Research Development Council project 'Characterising the Fish Habitats of the Recherche Archipelago, 2001/060'. The author would also like to thank the Esperance Community for their support in this research. In addition I would like to thank my supervisor Dr. Gary Kendrick for his objective guidance in writing this paper and my colleague Katrina Baxter for her assistance in the field. Much credit is also due to Alan Cameron of GSE rentals (UK), Chuck Harding of Edgetech (USA) and John Gann of Chesapeake Technologies (USA) for their excellent technical support.

## References

- Blondel, P., & Murton, B. J. 1997. *Handbook of Seafloor Sonar Imagery*. John Wiley and Sons, Chichester, 314pp.
- Clarke, E. d. C., & Tarlton, P. 1952. *Physiography and other notes on a part of the south coast of Western Australia*.
- Cochrane, G. R., & Lafferty, K. D. 2001. Use of acoustic classification of sidescan sonar data for mapping benthic habitat in the Northern Channel Islands, California. *Continental Shelf Research* 22(5): 683-690.
- Davies, J., Foster-Smith, R., & Sotheran, I. S. 1997. Marine Biological Mapping for Environment Mapping Using Ground Discrimination Systems and Geographic Information Systems. *Journal of the Society for Underwater Technology* 22(4): 167-172.
- Fish, J. P., & Carr, A. H. 1991. *Sound Underwater Images: A guide to the generation and interpretations of sidescan sonar images*. American Underwater Search and Survey Ltd., Lower Cape Publishing, 189pp.
- Greene, H. G., Yoklavich, M. M., Starr, R. M., O'Connell, V. M., Wakefield, W. W., Sullivan, D. E., McRea Jr, J. E., & Cailliet, G. M. 1999. A classification scheme for deep seafloor habitats. *Oceanologica Acta* 22(6): 663-678.
- Haralick, R. M., Shanmugam, K., & Dinstein, R. 1973. Textural features for image classifications. *IEEE Transactions Systems, Man and Cybernetics*, vol SMC-3: 610-621.
- IMCRA. 1998. Interim Marine and Coastal Regionalisation for Australia: an ecosystem based classification for marine and coastal environments. Version 3.3. *Interim Marine and Coastal Regionalisation for Australia*,

Technical Group, Environment Australia, Commonwealth Department of the Environment. Canberra, Australia

Jain, A. 1989. *Fundamentals of Digital Image Processing*. Prentice-Hall, New York, 410pp.

Kvitek, R., Iampietro, P., Sandoval, E., Castleton, M., Bretz, C., Manouki, T., & Green, A. 1999. *Final Report, Early Implementation of Near shore Ecosystem Database Project*. SIVA Resource Center, Monterey Bay, California.

McCarthy, E. 1997. Acoustic Characterization of Submerged Aquatic Vegetation. *Proceedings of the High Frequency Acoustics in Shallow Water Conference, 1997*, 363-369

McRea (Jr), J. E., Greene, H. G., O'Connell, V. M., & Wakefield, W. W. 1999. Mapping marine habitats with high resolution sonar. *Oceanologica Acta* 22(6): 679-686.

Myers, J. S. 1990. Western Gneiss Terrane. *Geological Survey, Western Australian Memoirs, Geology and Mineral Resources of Western Australia* (3): 13-32.

Penrose, J. D., & Siwabessy, P. J. W. 2001. *Acoustic Techniques for Seabed Classification: Report prepared for the Marine Conservation Branch of the Western Australian Department of Conservation and Land Management (2001-36)*. Curtin University of Technology, Perth.

Shokr, M. E. 1991. Evaluation of Second Order Texture Parameters for Sea Ice Classification From Radar Images. *Journal of Geophysical Research* 96(C6), 10: 625 - 610,640.

Stanbury, K. B., & Starr, R. M. 1999. Applications of Geographic Information Systems (GIS) to habitat assessment and marine resource management. *Oceanologica Acta* 22(6): 699-703.

Vincenty, T. 1975. Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. *Survey Review* 22(176): 88-93.