

ACOUSTIC MAPPING OF ESTUARINE BENTHIC HABITATS:

RESULTS OF A TRIAL IN WALLIS LAKE, N.S.W.

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EXECUTIVE SUMMARY

A collaborative field trial of the Quester-Tangent View Series 5 single beam acoustic benthic mapping system was conducted in Wallis Lake by Geoscience Australia and Quester Tangent Corporation, with the assistance of NSW Department of Infrastructure, Planning and Natural Resources, Great Lakes Council and Curtin University. The survey, in June 2002, involved acquisition of the acoustic backscatter data from the northern channels and basins of Wallis Lake. Quester-Tangent software (IMPACT v3) was used to classify acoustic signals (echograms) that returned from the lake bottom into statistically different acoustic classes. The classification was based on characteristics of the echograms, which were further reduced using a principal component analysis (PCA) algorithm. An algorithm then divided the data into logical clusters, each cluster representing a unique acoustic class. Six acoustically different substrate types were identified in the Wallis Lake survey area.

In conjunction with the acoustic survey, ground-truthing was undertaken to identify the sedimentological and biological features of the lake floor that influenced the shape of the return echograms. Samples of lake-bottom sediment were collected from over 100 sites (located by DGPS) by snorkel divers, and pole-coring. For each sample, laboratory measurements were made of grain size, wet bulk density, total organic carbon, CaCO_3 content. Mass of coarse fraction (mainly shell) material was recorded for samples taken in December. At most sampling sites, diver observations provided information about the morphology of the lake bed, such as density of animal burrows, and seagrass species and coverage; and at several sites photographs of the substrate were taken. A scheme of simple ranked indices was developed to reflect the relative density of each of these site features.

Statistical cluster analysis and multi-dimensional scaling were utilised to identify any physical similarities between groups of ground-truthing sites. The analysis revealed four distinct and mappable substrate types in the study area. These comprised dense, shelly sands, low density mud without shells, low density shelly mud, and poorly sorted muddy sand. Very little relationship between seagrass distribution and sediment type was detected. Cluster analyses and multi-dimensional scaling were also used to indicate the degree of association between acoustic classes and both sediment parameters and observed biophysical features. Ground-truthing sample sites were coded for acoustic class, based on their proximity to the acoustic survey track lines. The analysis revealed that, based on the parameters measured, not all of the six acoustic classes were uniquely linked to distinct sedimentological facies, indicating that factors other than the sediment parameters influence the return acoustic signal. However, the well recognised estuarine sedimentary environments, such as marine sands and muddy basin sediments, are clearly delineated.

Much of the seagrass-dominated environments are limited to the shallow-water margins of the basin and channel areas. The wide central basin areas, such as Pipers Bay and the area west of Wallis Island, were dominated by very fine sediments with varying concentrations of shell material, and densely populated by various infaunal organisms. The channel areas, which form intricate networks in northern Wallis Lake, were the deepest areas in the lake, and comprised relatively dense sandy muds and muddy sands, and also featured a high concentration of shell material. The marine tidal delta was also a distinct and mappable habitat, with clean well sorted sand, and dense seagrass beds.

The Quester-Tangent View Series 5 system demonstrated the ability to rapidly survey a relatively large and diverse area, to produce a coherent map of spatially homogenous acoustic classes. Although not all of the acoustic substrate classes could be identified in sedimentological terms, useful linkages were made between the acoustic classes and known estuarine sedimentary environments, illustrating that the Quester-Tangent acoustic mapping

system is a useful tool for coastal management and research. The spatial interpretation of the Wallis Lake Quester-Tangent data represents the first quantification of non-seagrass habitats in the deeper areas of the lake, and provides a useful indication of benthic habitat diversity and abundance. For future studies, a more quantitative measure of faunal burrow size and density, and also other sedimentary bedforms, is recommended. Other unmeasured features of the lake bed may also have influenced the echograms, for example gas bubbles produced by plants or evolved from within surficial organic-rich muds.

INTRODUCTION

Shallow coastal waterways such as estuaries support a large and growing tourist industry, are important fisheries habitats, and are also key areas for the conservation of marine biodiversity. However, the Australian coastal zone is under increasing pressure from continuous population drift to the coastal fringe (NLWRA, 2002). Because of this, there is a pressing need to find new ways to cost-effectively manage the habitats in and around coastal waterways. The first fundamental step in the implementation of wise management plans is mapping of estuarine habitats or their surrogates, at a scale and accuracy suitable to local or regional planning. In response to this growing demand, a range of remote and automated techniques are being developed and applied to various natural environments, to complement traditional field mapping methods. For example, much work is being done with classified satellite and airborne sensor images, for the mapping of habitats such as seagrasses (Dekker *et al.*, 2003), and both vegetated and non-vegetated intertidal habitats (Rainey *et al.*, 2003). However, seabed habitats covered by more than a few metres of water are often problematic to airborne and spaceborne sensors, due to the potentially low water clarity often observed in estuaries. Acoustic methods of sensing variation in the geological and biological features of the seabed provide a potential method for classifying benthic habitats, when used in conjunction with other sampling methods (Penrose & Siwabessy 2001). The acoustic systems are especially useful in environments where the seabed cannot be reliably detected by satellite or airborne sensors. Additionally, new insights into the distribution of benthic habitats can be gained, as seabed structure and animal communities are frequently not well described due to the difficulty of sampling broad areas of seabed by traditional methods. The speed with which such surveys can be undertaken (and repeated) thus represents an attractive tool for environmental managers.

Geoscience Australia recently conducted a collaborative field trial to investigate the potential of a new, cost effective acoustic-based system of shallow-water habitat mapping, developed by Quester-Tangent Corporation, a Canadian marine survey company. Acoustic mapping systems insonify the seabed in order to discriminate seabed types on the basis of characteristics of the return echo, which is a function of substrate sediments, morphology, and biological features such as benthic vegetation and fauna (Fig. 1). Acoustic systems also provide high-resolution bathymetric data. This information is of great potential use as a thematic layer for mapping the distribution of sediment types, locating (and delineating) specific substrate features, and also for the mapping and monitoring of benthic habitats.

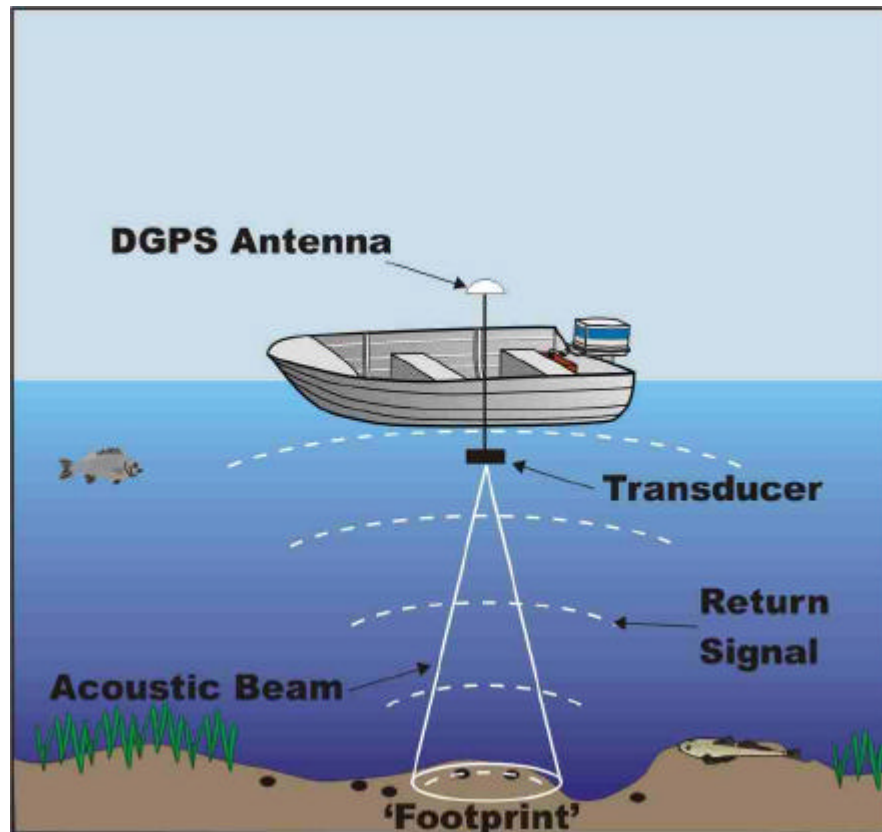


Figure 1: Cartoon representation of a single-beam acoustic mapping system, which relies on a submerged transducer head to emit an acoustic signal, and detect the return echo from the 'footprint' of insonified seabed.

The new acoustic-based habitat mapping systems promise rapid and economical techniques with which to classify shallow water substrates, at an unprecedented sensitivity and scale (Hamilton *et al.*, 1999, Van Lancker *et al.*, 2003). This report presents the results of a trial of the Quester-Tangent View Series 5 acoustic backscatter system in the very shallow water environment of Wallis Lake, an estuary on the central NSW coast of Australia.

Previous studies in Wallis Lake have focused on the intertidal to supratidal regions. Biological surveys have tended to be shore-based, and have also mainly targeted seagrass areas (Webb, McKeown & Associates, 1999). It is the intention of this study to investigate the potential of another tool (an acoustic bottom classification system) for the discrimination of marine habitats such as seagrass beds, and for the first time, delineate other infaunal and epifaunal habitat types in the deeper, and often more turbid, muddy basin and channel areas.

Aims

The major aims of this field survey were:

- 1) To trial the Quester Tangent Corporation (QTC) View Series 5 acoustic mapping and classification system, in order to assess its potential to discriminate variations in the shallow water benthos of Wallis Lake, based on comparison with existing habitat data, and detailed ground-truthing data collected in the field.
- 2) To provide a useful interpretation of the acoustic classification and ground-truthing data, in the form of a map of benthic habitat types in northern Wallis Lake. The deeper water and more turbid environments are of particular interest, as these cannot easily be surveyed by traditional diver or video-based methods, and are not visible to conventional airborne or spaceborne environmental sensors.

Location

Wallis Lake is located adjacent to the coastal township of Forster, approximately 310 km north of Sydney (Fig. 2). It is a relatively large estuary, comprising approximately 94 km² of enclosed waters, and is an excellent example of the wave-dominated estuaries to be found along the coast of NSW and Victoria (Ryan *et al.* 2003). Wallis Lake forms part of the Great Lakes system of coastal lagoons, which also include Port Stephens, the Myall Lakes system, and Smiths Lake (Thom *et al.*, 1992, Roy *et al.*, 1997).

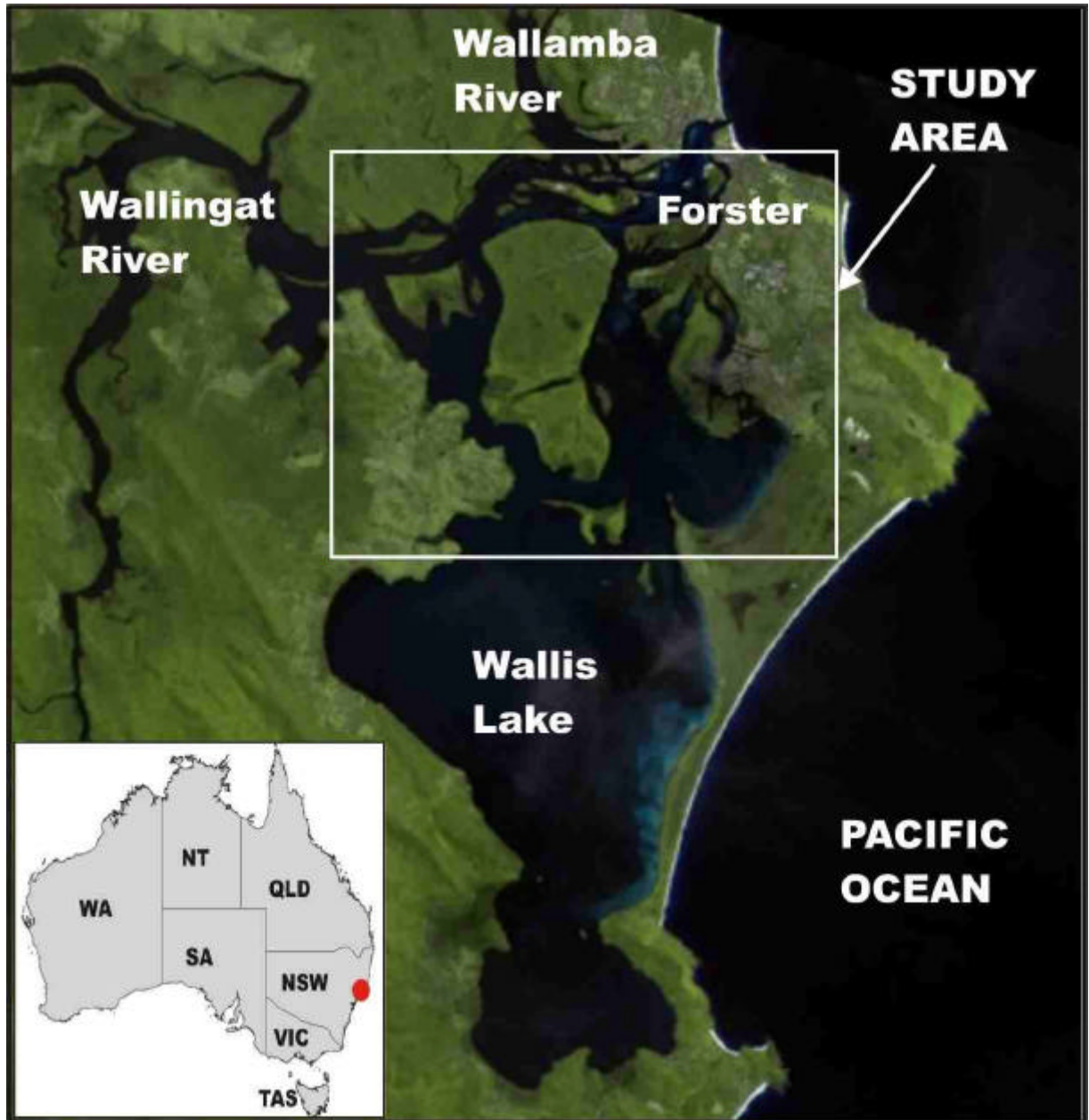


Figure 2 - Location of Wallis Lake estuary, northern New South Wales, and an *Aster* satellite image depicting the study area, and the morphology of the lake system (image © Commonwealth of Australia - ACRES, Geoscience Australia).

The Wallis Lake estuary is a complex system of lakes, rivers and interconnecting channels. Benthic habitats include extensive shallow sand banks (1 – 2 m deep), seagrass and macroalgal beds (Laegdsgaard 2001), relatively deep channels (maximum depth 8 m, see Appendix 3), and sheltered muddy basins with both clear and turbid water conditions. The entrance of the estuary is permanently open, maintained by twin artificial training breakwaters, which also have the effect of attenuating the tidal range within the estuarine

basin to an average of 18 cm (Nielsen & Gordon, 1986). The catchment of Wallis Lake has a warm temperate climate, with a strong marine sub-tropical influence, resulting in a relatively high humidity and rainfall of around 1200 mm/yr (Webb, McKeown & Associates, 1999).

Wallis Lake has been the focus of a variety of sedimentological, biological and hydrodynamic studies in recent years. This work has included mapping of seagrass habitats (West *et al.*, 1985, Dekker *et al.*, 2003), environmental reconstruction from sediment cores (Roy *et al.*, 1997), and identification of sediment biomarkers and nutrient fluxes related to urban, industrial and agricultural activities in the catchment (Logan *et al.*, 2001, Smith *et al.*, 2001). The lake comprises a diverse range of estuarine habitats (Webb, McKeown & Associates, 1999, Heap *et al.*, 2001), making it an ideal estuary for the evaluation of the Quester-Tangent 5 benthic mapping system. Additionally, a number of environmental issues have arisen in the recent past, in association with the diverse tourist and commercial uses of the estuary (Wilcox 1999). These factors highlight the need for better informed management practices based upon sound environmental information.

MATERIALS AND METHODS

Acoustic Survey and Data Processing

The QTC View Series 5 is a single-beam system, which acquires point-based data positioned along the ship-track. The system comprises an echosounder, transducer, sounder interface module, a differential global positioning system (DGPS), and a laptop computer. Software included applications for navigation, data logging, post-processing, and statistical classification (Fig. 3).

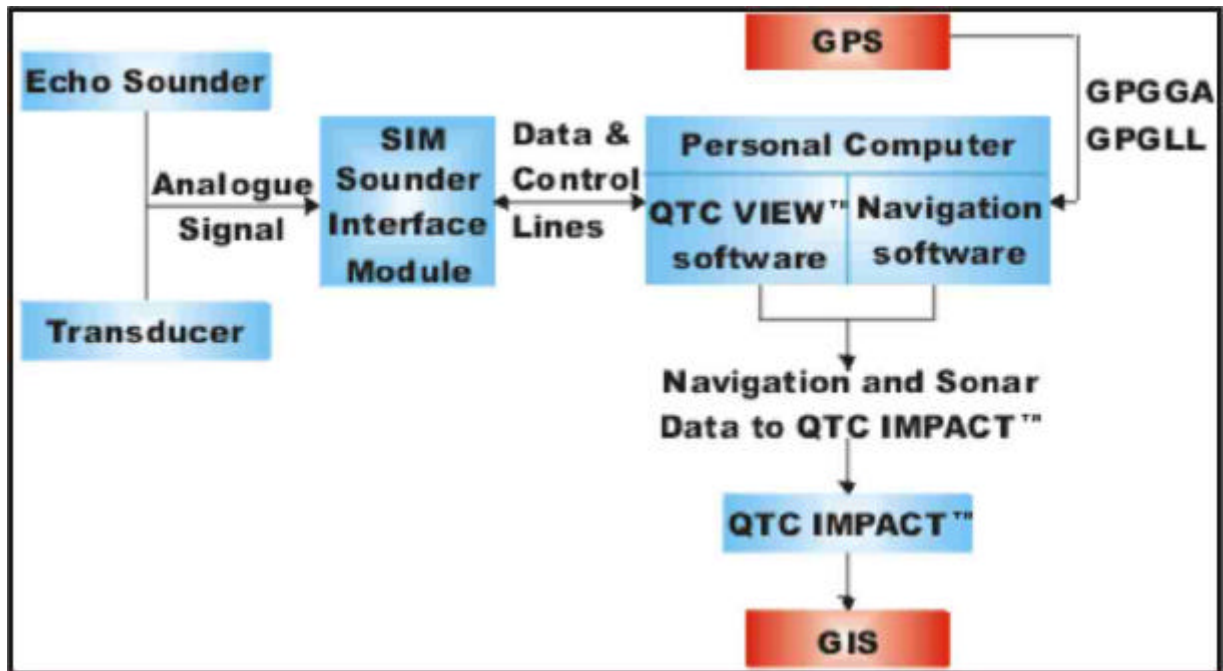


Figure 3 - Components and signal pathways of the QTC View 5 system used in the trial. The blue boxes indicate hardware and software components included in the system (Qvester Tangent Corporation, 2003).

The system is highly portable, and in this field trial it was mounted upon a low-draught 6 m punt (Fig. 4). Transects were undertaken at a speed of approximately 5 knots (the maximum speed of the vessel), although greater speeds of survey are achievable if cavitation of the transducer head is avoided. A differential global positioning system (DGPS) was used to accurately record the position of every acoustic sample (or 'ping') along the trackline. The hardware was mounted on the side of the boat using an aluminium pole, with the transducer face about 25 cm below the lake surface, and the DGPS antenna mounted on top of the pole (to minimise spatial offset). A Suzuki 2025 echosounder was used, with a frequency of 200 kHz, and a pulse duration of 0.3 ms at the minimum power and depth range setting. The transducer had a 42 x 16 degree beam width, which insonified a 'footprint' (Fig. 1) of approximately 1 square metre of the seabed at a depth of 3 metres, the average depth of most areas surveyed (Appendix 3). A 10 dB attenuator was placed inline between the echosounder, and the QTC Version 5 sounder interface module, to help prevent clipping at the input of the sounder interface. Data were acquired using a Compac Evo notebook computer installed in an expansion base station containing the NIDAQ data acquisition card. Navigation data was collected using QTC ISAHPC software. All of the equipment was powered by a single deep-cycle lead acid 12-volt battery. A 12V DC to 120V AC inverter was used to power the computer. High-resolution bathymetric data were also recorded.



Figure 4 - Installation of the QTC system. The transducer and DGPS antenna were installed on an aluminium pole mounted upon the side of the boat.

Three surveys were conducted in the period from June 11 to June 13, 2002. A total of 76,593 acoustic 'samples', or digitised echograms, were acquired, covering the majority of the northern channels of Wallis Lake, including Pipers Bay, the area west of Wallis Island, and the connecting channels. Samples were spaced approximately every 2 m along the ship track (Fig. 5).

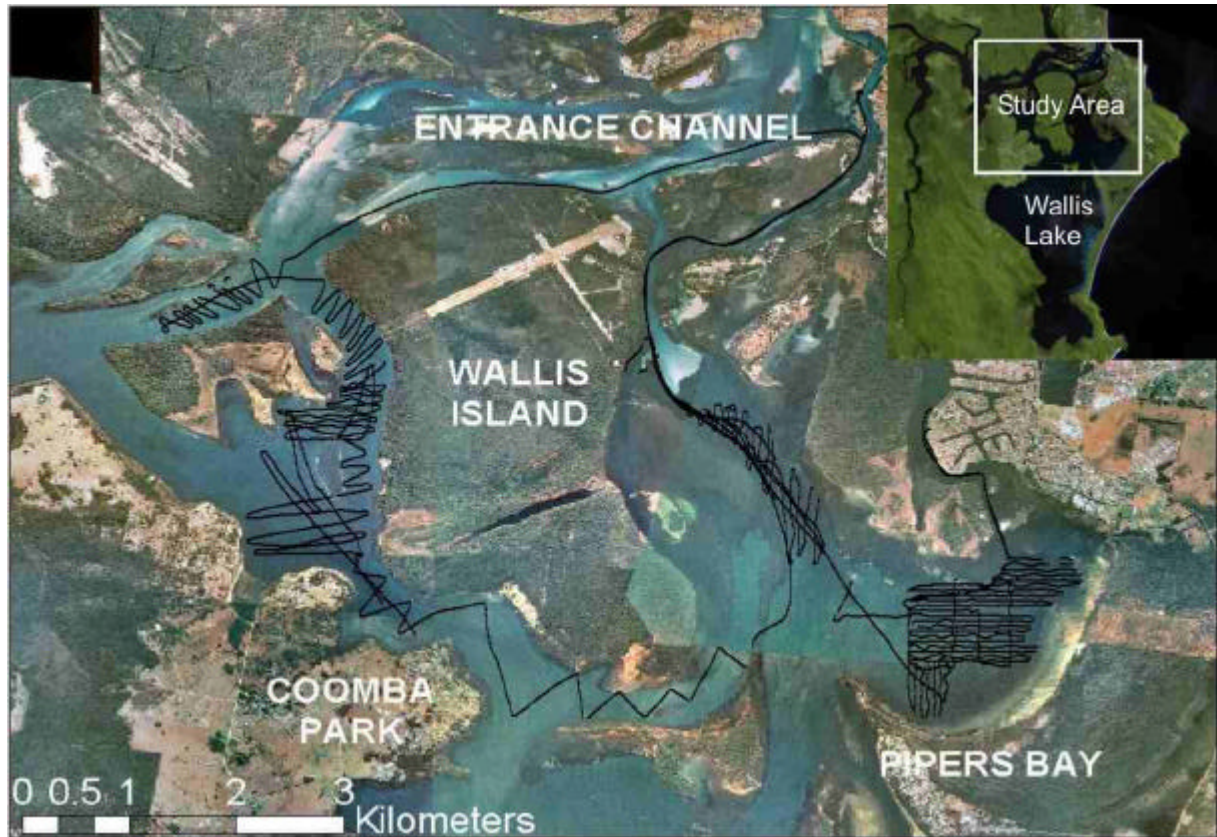


Figure 5 - The path followed by the vessel during acquisition of the acoustic data, plotted upon a colour aerial photograph. See inset in the top right for location of the sampling area within Wallis Lake. Aerial photographs courtesy of Land and Property Information, NSW.

QTC Impact Version 3 software was used to classify the echograms that returned from the lake bottom into statistically significant ‘acoustic’ classes (Quester-Tangent Corporation, 2003). Impact identifies 166 separate characteristics of the return echograms, and then reduces these to three Q-values using a principal component analysis (PCA) algorithm. A k-means iterative clustering algorithm then divides this Q-space into logical clusters, representing unique acoustic classes. Confidence values are provided for each data point assigned to a class. All data with confidence values of less than 95% were discarded.

Ground Truthing of the Acoustic Data

Ground truthing was undertaken to identify the sedimentological, morphological and biological features of the benthos that may have influenced the shape of the return echograms (Fig. 6). The ground truthing survey was conducted in June 2002, in association with the QTC acoustic mapping, and also in December 2002. Sample sites were identified in a GIS that comprised the classified acoustic data, and a scanned and georectified aerial photograph (see below). Sites were selected on the basis of their proximity to the sections of QTC track lines that represent unique acoustic classes, and were located in the field using a DGPS to minimise spatial error (Fig. 6).

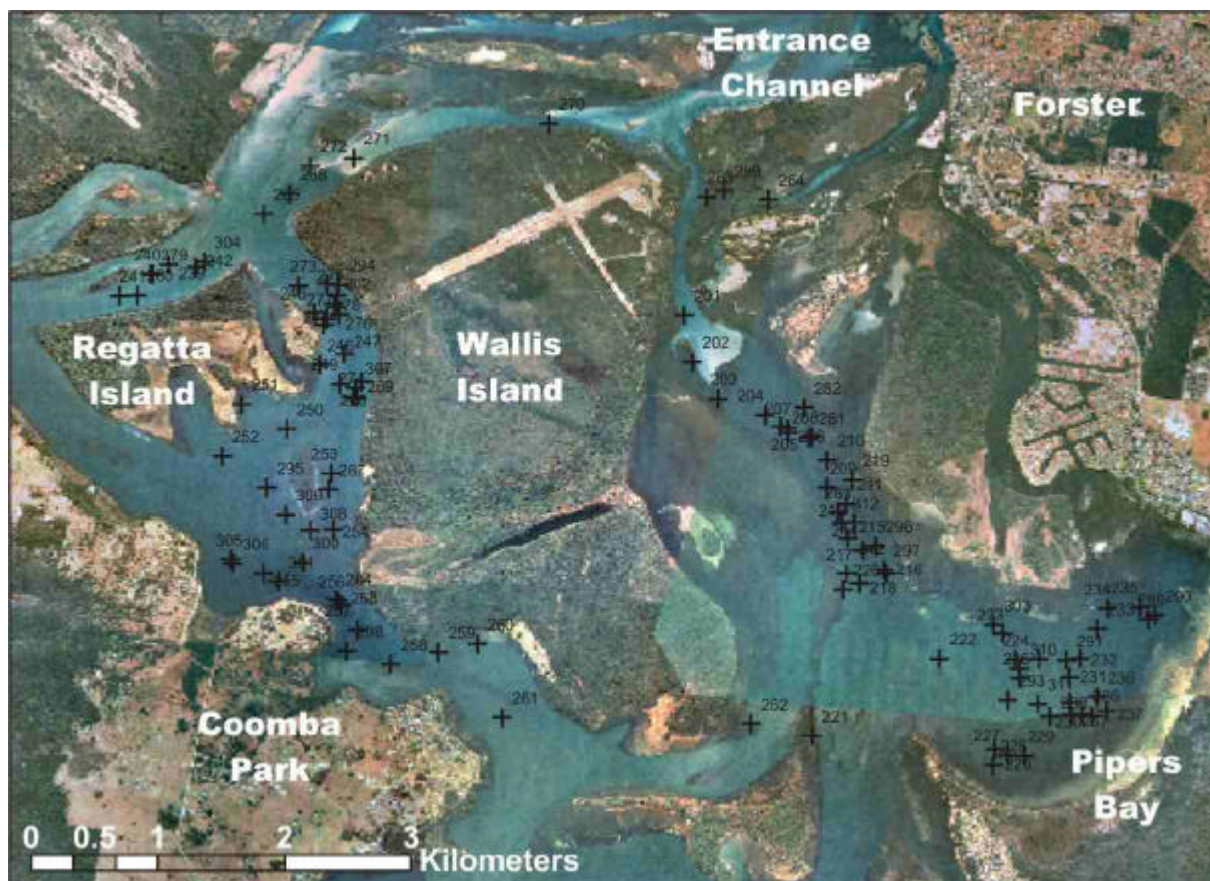


Figure 6 - Distribution of ground-truthing sample sites around Wallis Lake. Aerial photographs courtesy of Land and Property Information, NSW.

Samples of the top 2 cm of bottom sediment were collected from 83 sites by snorkel divers, and with a pole corer (Fig. 6). For each sample, laboratory measurements were made of grain size and sorting, including proportion of mud, porosity, and wet bulk density (Table 1, Appendix 4 and 5). The mass of the coarse fraction (>2 mm diameter) was measured in 43 samples collected during the second survey (December 2002) only. These samples were collected by divers using a 5 litre dredge. This fraction predominantly comprised mollusc shells and shell fragments.

Table 1 - Sedimentological variables measured in substrate samples collected at each of the ground-truthing sites.

Sediment Feature	Methods & Unit of Measurement
Mean Grain Size	Malvern Laser Size Analyser (μm)
Mean Grain Size (Sorting)	Malvern Laser Size Analyser (μm)
% < 63 microns	Malvern Laser Size Analyser (μm)
Porosity	Water Content per cm^3 , volume %
Wet bulk density	Sediment Density per cm^3
Shell Mass (Second survey only)	Mass of >2mm diameter shell material in a 5 litre sediment sample
Total Organic Carbon	Rock-Eval Instrument, Weight %
Sediment CaCO_3 Content	CO_2 Gas Evolution Method

At 62 of the sample sites, visual observations were made of bottom samples retrieved by divers or a grab sampler. Diver observations were made of faunal burrow types and frequency, and extent of seagrass cover. To provide a semi-quantitative assessment of these site features, a scheme of rankings was developed to reflect the relative abundance or density of each site feature (Table 2, Appendix 5). Photographs were taken (where possible), using a

Sea & Sea Motor Marine MX-10 underwater camera, however water clarity conditions were generally unsuitable for photography.

Table 2 – Ranked indices representing diver observations for each ground-truthing site.

Parameter	Scores
Faunal Burrows	0 = None 3 = Sparse small burrows 5 = Sparse large burrows 7 = Abundant burrows
Seagrass Cover (based on Dekker <i>et al.</i> , 2003)	0 = None 4 = Sparse Vegetation 8 = Dense Vegetation

A vegetation index map developed by Dekker *et al.*, (2003), was utilised in order to provide a consistent measure of seagrass and macrophyte distribution and density, to supplement the ground-truthing data for seagrasses. The vegetation map was produced by optical modelling of Landsat TM7 imagery, and validated using a field spectroradiometer. For the purpose of this study, the interpreted substrate vegetation cover was simplified into an index representing seagrass/macrophyte cover (based upon known seagrass growth characteristics), in order to reflect the relative density of seagrasses and macrophytes (Laegdsgaard, 2001). These simplified indices were manually linked to ground-truthing sites using *ArcGIS 8.3* software. The final map used for interpretations in this study has been included in Appendix 1. The software packages *Primer 5* (Clarke and Gorley, 2001), and *Grapher 4* (Golden Software, 2003) were used for all statistical analyses of sediment and site observation data.

GIS Representation

The Wallis Lake acoustic classification data, ground truthing coordinates, and base images were incorporated as layers into a GIS, using *ArcGIS 8.3* software. The relevant 1:25000 colour aerial photographs (flown on 22nd August, 1997) were purchased from Land and Property Information, NSW. The photos were scanned and georectified using camera calibration information, and ground control points. The resulting images were resampled to a spatial resolution of 1.5 metres, and ‘mosaiced’ to produce a seamless high-resolution image of the middle and northern sections of Wallis Lake. Colour-balancing difficulties arose from sun-glint brightness variations between photos, especially over water. The higher spatial resolution and natural colour in the digitised photographs, however, made feature identification relatively easy. The acoustic backscatter data, and ground-truthing sites were overlain on the aerial photograph, to provide a useful spatial display of the study area (Figs. 5, 6, 9, 13, and Appendix 2).

RESULTS

Processing and Classification of the Acoustic Data

All of the acoustic survey data were merged into a single file for the final classification. Principal components analysis of the return echograms in the combined Wallis Lake dataset revealed six statistically significant acoustic classes (Fig. 7).

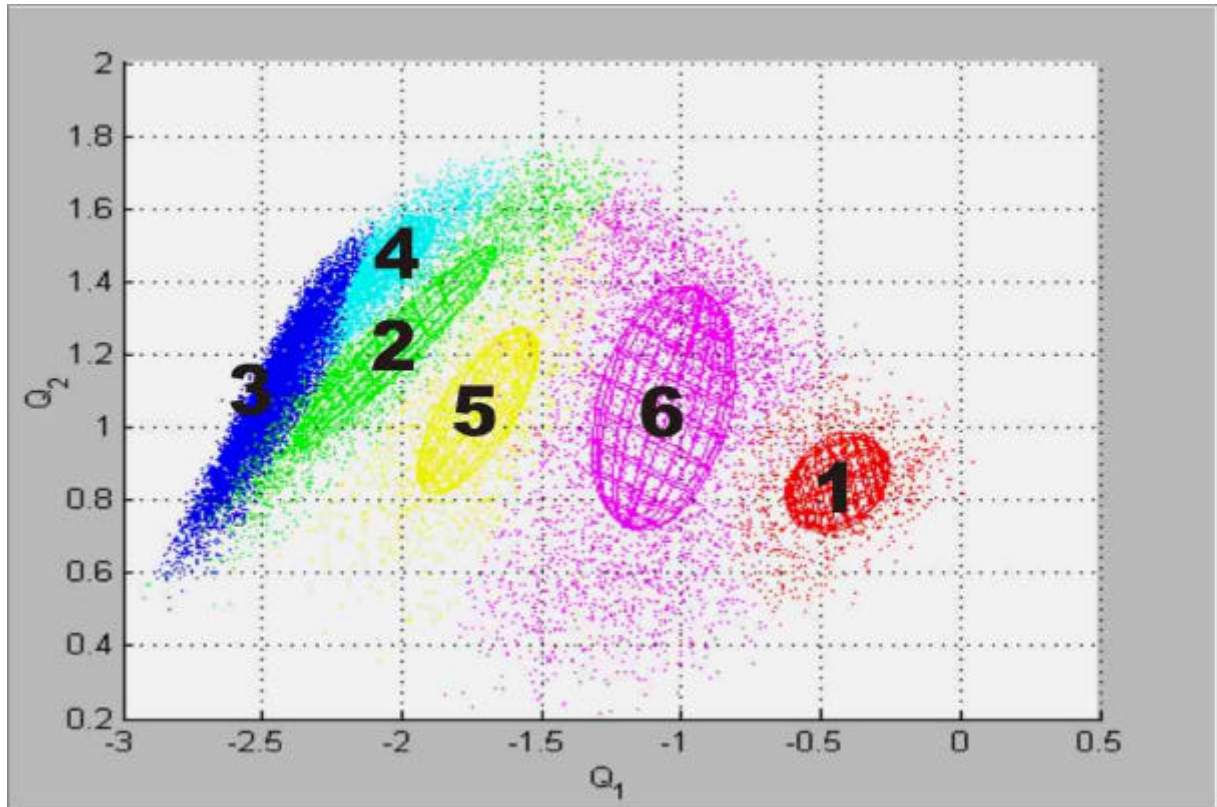


Figure 7: Clusters identified in the Wallis Lake acoustic dataset, based upon a Principal Components Analysis (using QTC Impact software). The ellipsoidal shapes (representing 95% confidence limits) include data points that make up the six acoustic classes (Class 1 = Red, Class 2 = Green, Class 3 = Blue, Class 4 = Cyan, Class 5 = Yellow, Class 6 = Pink).

Some of these acoustic classes show a loose correlation with water depth, as indicated by the classified plot of acoustic signal acquisition time, and depth (Fig. 8, Appendix 3). The QTC system accounts for the influence of changes in depth on the return echogram by transformation of the full waveform to a predetermined reference depth, which was set at 2 metres (the average depth was 3 metres).

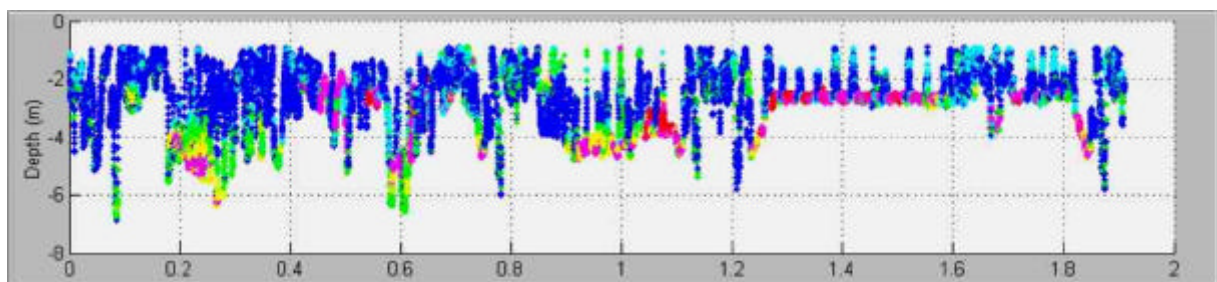


Figure 8: The complete Wallis Lake acoustic dataset plotted as depth against acquisition time (in days). Different colours represent acoustic classes as indicated in Figure 7 (Class 1 = Red, Class 2 = Green, Class 3 = Blue, Class

4 = Cyan, Class 5 = Yellow, Class 6 = Pink). All classes are located in a range of water depths, to varying degrees.

In Figure 9, and Appendix 2, the QTC acoustic classification of the lake-bed is displayed as colour-coded points overlain on the aerial photograph. The density of points along each survey track is shown in the inset enlargement. Some areas are spatially homogenous, while other areas or sections of survey track show a mixture of classes.

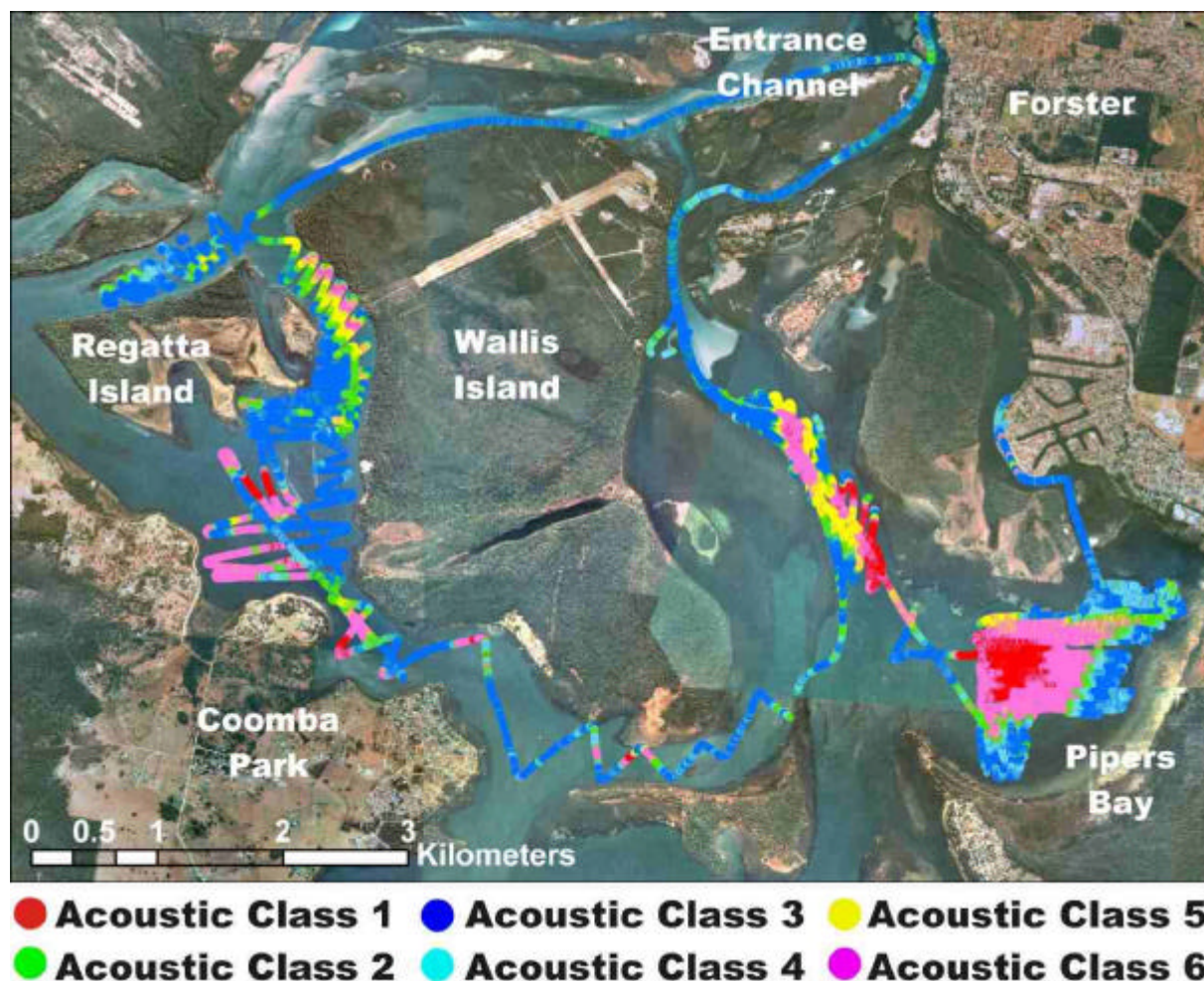


Figure 9 – Spatial representation of the acoustic data, coded for acoustic class, and plotted on a digital aerial photograph. Aerial photographs courtesy of Land and Property Information, NSW.

In Pipers Bay (Fig. 9, Appendix 2), the closer spacing and crossover of survey lines helps to establish the consistency of the classification. Spatially homogenous acoustic classes are indicated. An inner zone of class 1 is surrounded by a wide zone of class 6, and outer zones comprising classes 2, 4, 3, and 4. Transitions between zones are typically not abrupt, but are marked by mixtures of adjacent classes (Fig. 9). Near the shallower margins of the lake, however, there is a possible relationship between the slope of the substrate, and variability in representation of acoustic classes (Hamilton *et al.*, 1999).

Analysis of the Ground-truthing Dataset

To identify natural grouping in the sediment and site observation datasets, cluster analysis and multi-dimensional scaling (MDS) analyses were employed, using the statistical package Primer 5 (Clarke, 1993, Clarke and Gorley, 2001). For all analyses, the parameters of water depth, wet bulk density, % total organic carbon (%TOC), shell mass, mean grainsize and sorting were used. The sediment sample data was fourth-root transformed (to obtain a normal distribution of data). A normalised Euclidean distance similarity matrix was computed (the data were not standardised). The hierarchical cluster analysis and the non-metric Multi-Dimensional Scaling were both applied to the same similarity matrix.

Results of Cluster Analysis and Multi-Dimensional Scaling

The sediment cluster analysis dendrogram (Fig. 10) depicts the major hierarchical groupings within the sediment samples. Cluster analysis measures the degree of relatedness of samples, represented as simple euclidean distance (on the Y-axis).

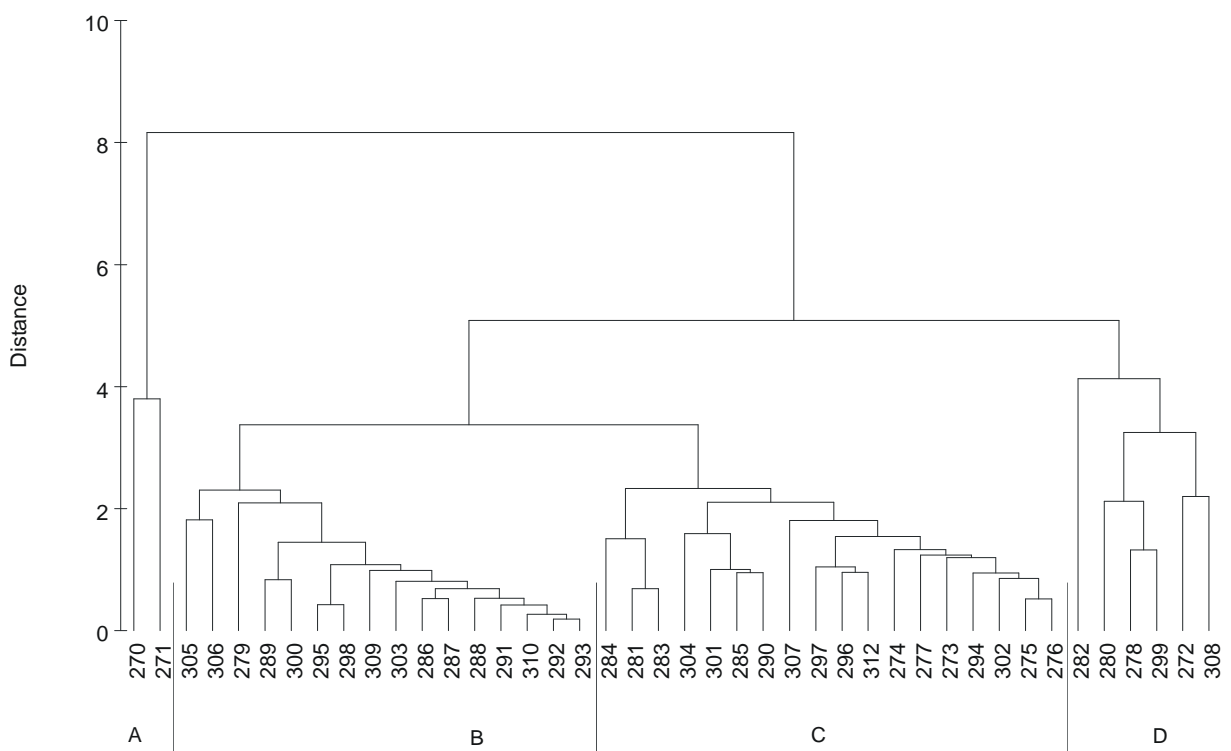


Figure 10 - Cluster analysis dendrogram of the sediment data (Table 1). Ground-truthing sample site numbers are shown on the x-axis. The four main cluster subgroups have been labelled Groups A-D. See Table 3 (on page 15) for the main characteristics of cluster subgroups.

The four obvious groups (or populations) in the data (Fig. 10) have been arbitrarily assigned labels, groups A-D. Group A comprises only two samples, however these are highly distinct from all other sample groups (e.g. a large separation in Euclidean space). To complement the cluster analysis, an MDS plot has been generated (Fig. 11).

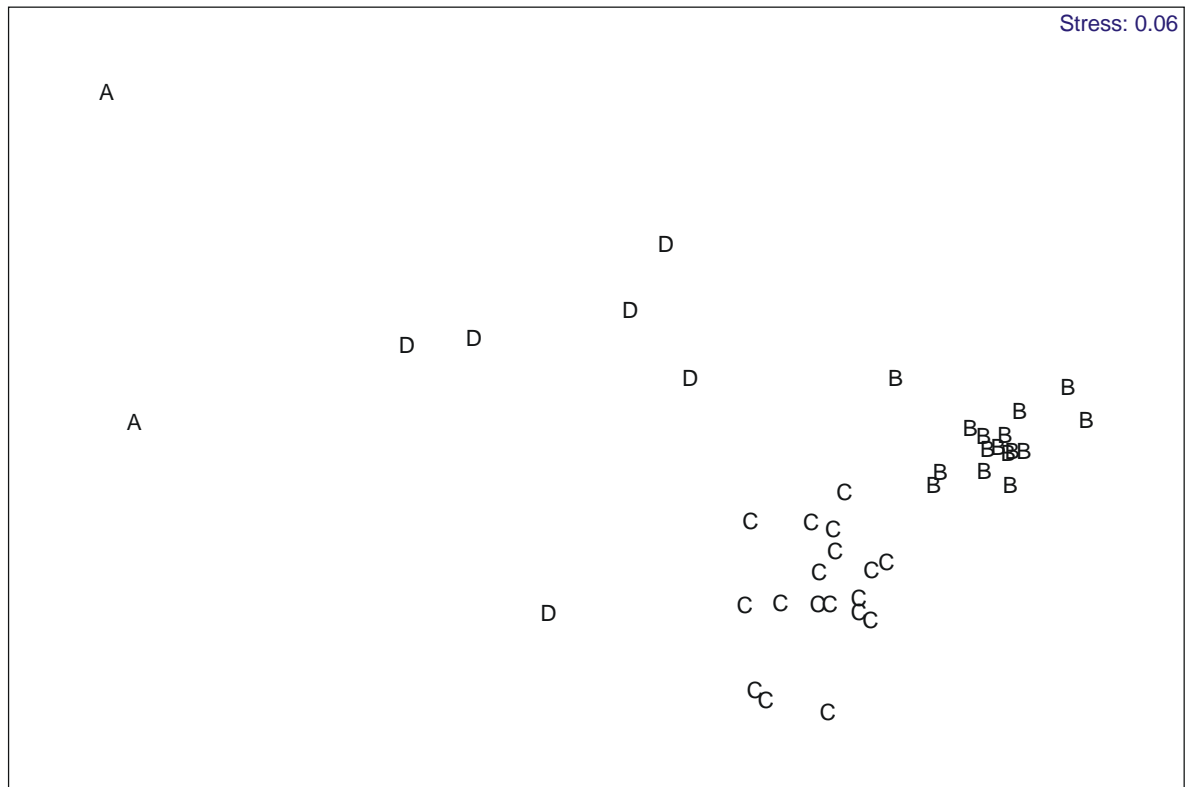


Figure 11 – Multi-dimensional scaling plot (MDS) of the sediment data (Table 1). The four main cluster subgroups, identified in Figure 10a, have been labelled Groups A-D. See Table 3 for the main characteristics of cluster subgroups.

This two-dimensional representation of multi-dimensional space indicates that the sediment groups B and C are internally homogenous groups of samples, and have similar physical properties. Groups A and D are less distinctly associated with other groups (Fig. 11).

To identify the sedimentary characteristics that determine the nature of groups A-D (Figs. 10 - 11), the sediment parameters for each cluster group have been depicted as box and whisker plots, showing the median, upper and lower quartiles, and the maximum and minimum for the parameters %TOC, wet bulk density, shell mass, mean grainsize and sorting (Fig. 12).

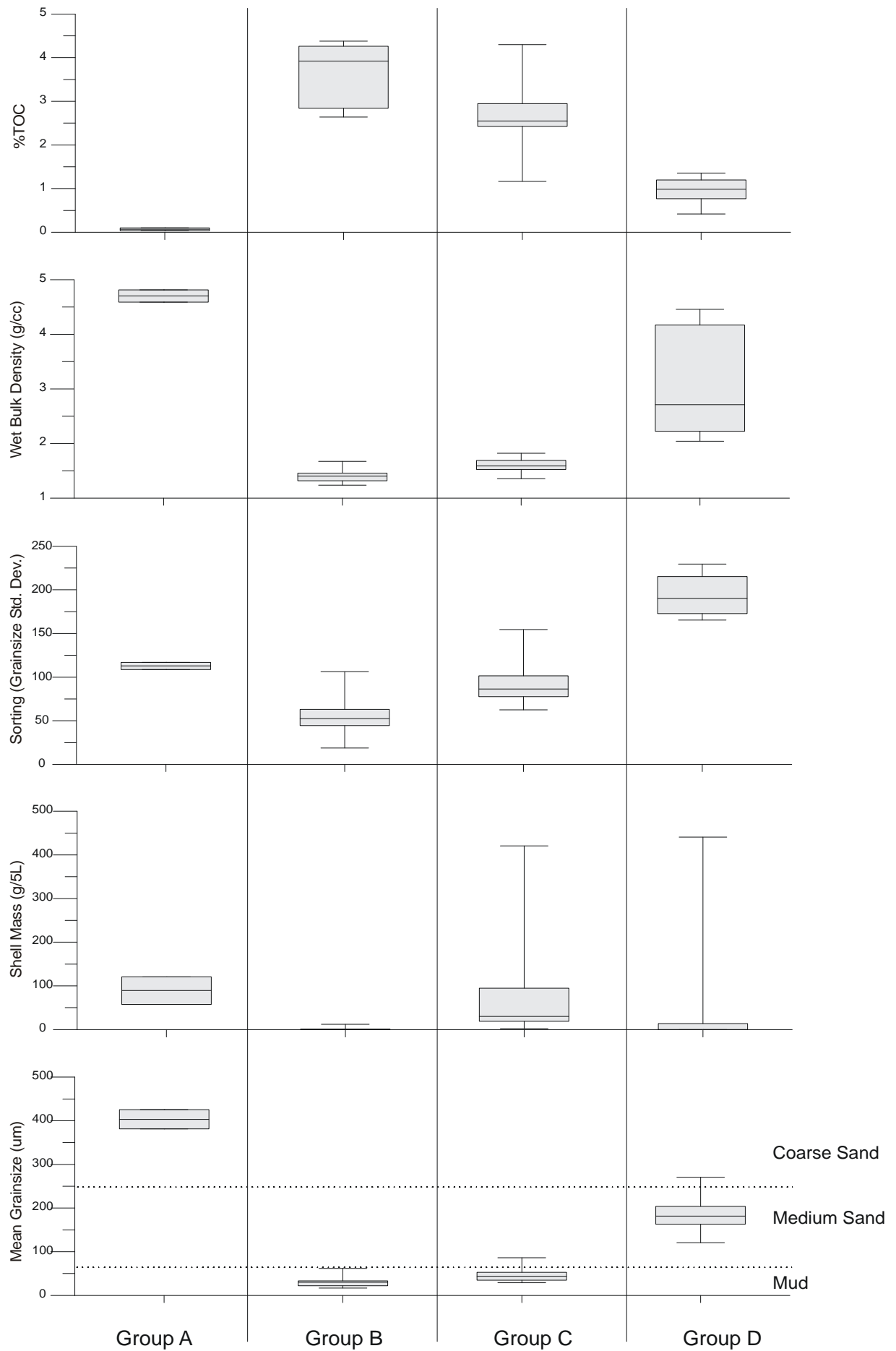


Figure 12 – Box and whisker plots for each of the 4 groups identified in the dendrogram of the sediment data (Fig. 10). The grey box indicates the upper and lower quartile, the centre line indicates the median, and the bars indicate the maximum and minimum.

The distinctive sedimentological features of each cluster group (and the mean depth), as shown in Figure 12, have been summarised in Table 3.

Table 3 – Summarised sedimentological characteristics of the groups identified in Figure 10 and 11. See Appendix 3 for a bathymetric map of Wallis Lake.

Group	Characteristics	Average Depth (m)
A	Coarse shelly sand, high density, ~0% TOC	2.5
B	Mud, no shell, low density, high TOC (~2.5-4.5%)	2.5
C	Shelly Mud, low density, high TOC (~1.5-4.5%)	4.1
D	Medium Sand, low shell, poorly sorted, medium density, low TOC (~0.5-1.5%)	2.6

Additionally, the spatial distribution of the grouped sample sites (colour coded for cluster groups) are shown on the Wallis Lake base map (Figure 13).

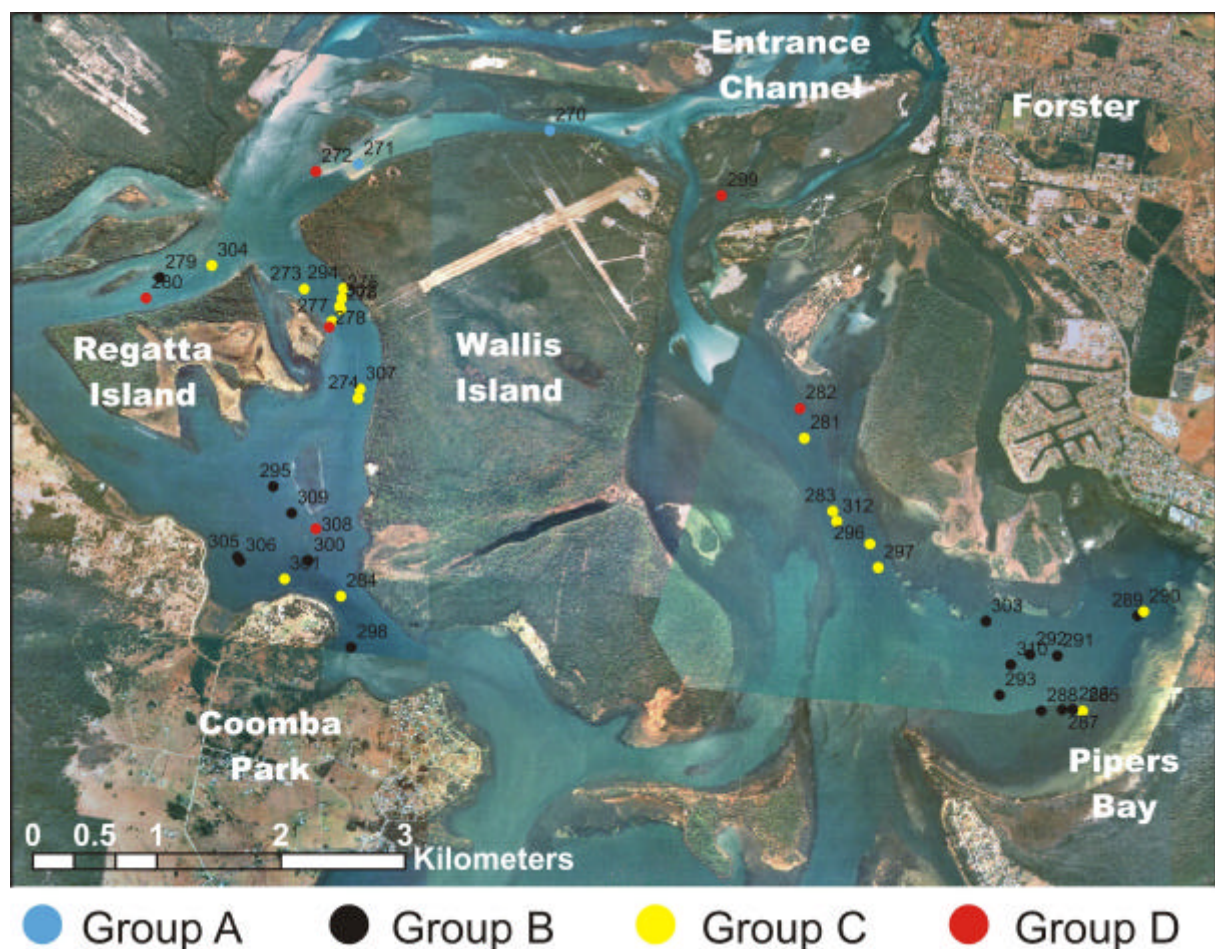


Figure 13 – Spatial distribution of the four cluster groups of sediment data as identified in Figure 10. Sample site codes are also shown. December 2002 sediment data.

The highly distinctive cluster group A appears to be clean, coarse sand, associated with the entrance channel (e.g. sites 270 and 271, Fig. 13, Table 3, Appendix 4). The entrance channel feature was poorly sampled as it appeared to be mostly homogenous, and was not a primary target for the acoustic mapping procedure. Groups B and C, closely clustered samples, represent estuarine muds, their distinctness from each other is based on presence or absence of shell material. Group B occurs in the central basin areas, whereas group C mostly occurs in the deeper channel areas (Fig. 13, Table 3). Group D is highly varied, comprising a poorly

sorted muddy sand, and appears to be associated with the seagrass-rich margins of the channels and basins in Wallis Lake.

Distribution of Seagrasses, Macrophytes and Faunal Burrows

To demonstrate any potential relationships between seagrasses or macrophytes, animal burrows, and the sediment cluster groups, the site observation values for each sample (Table 2) were used to label the sediment MDS plot of Fig. 11 Figure 14 has sites labelled for the seagrass index (Dekker *et al.*, 2003), and figure 15 has been labelled for the faunal burrow index.

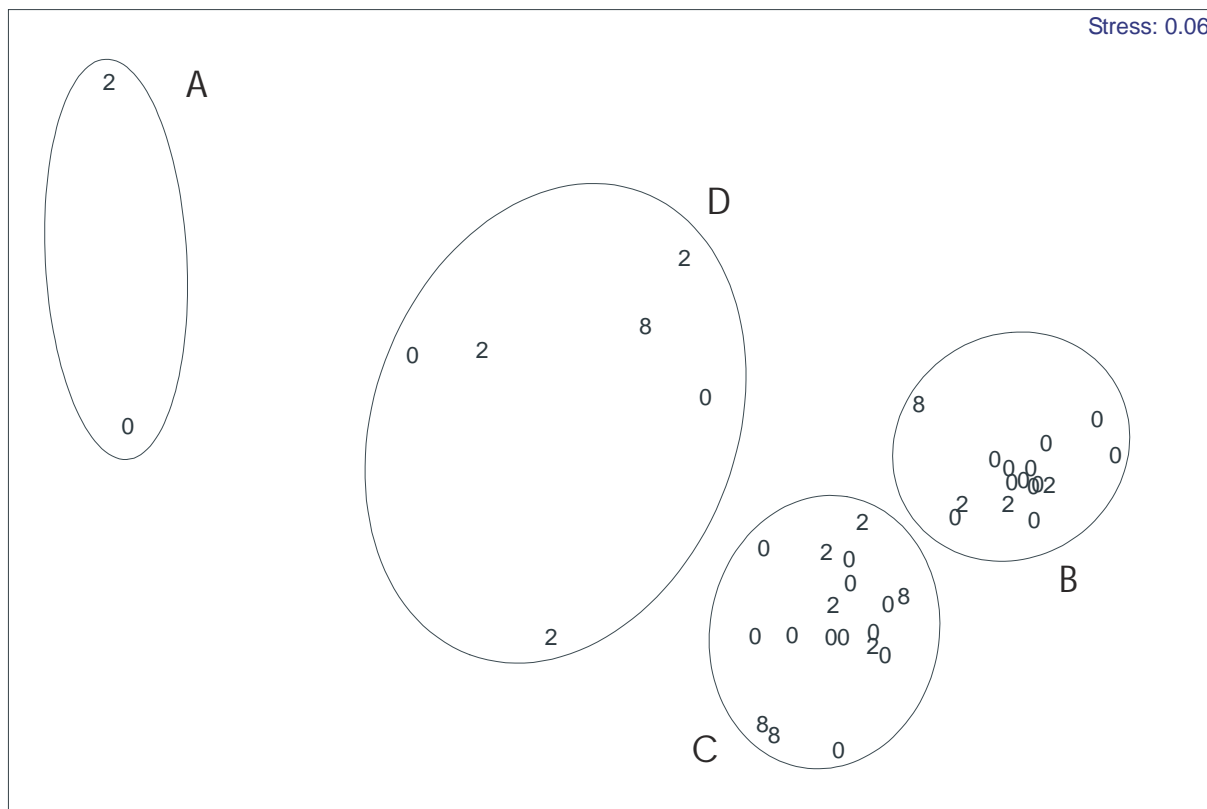


Figure 14 – MDS plot (Fig. 11) labelled with the CSIRO Seagrass Index (Table 2, Dekker *et al.*, 2003). 0 = no vegetation, 2 = sparse vegetation, 8 = dense vegetation.

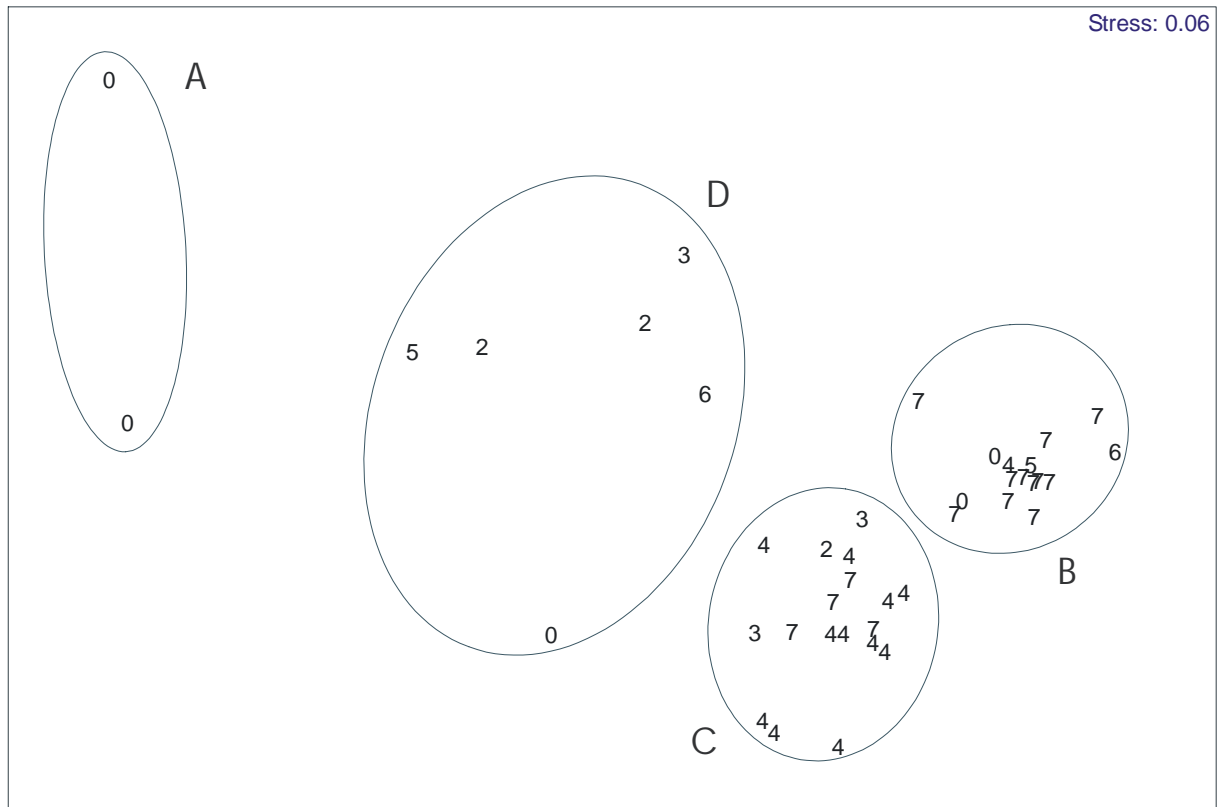


Figure 14 reveals very little relationship between seagrass distribution and sediment type, although sediment groups B and C tend to have some seagrass cover. Figure 15, however, shows a strong relationship between the muddy sediments (groups B and C, Table 3) and abundance of faunal burrows (e.g. Fig. 16).

Example Photographs of Wallis Lake Benthic Habitats

Photographs were taken at a number of visual observation sites. Figure 16 is an example of the muddy, burrowed sites (in Fig. 10 Group B), Figure 17 depicts sandy mud with shell material (Fig. 10 Group C), Figure 18 shows marine sands (Fig. 10 group A), and Figure 19 (Fig. 10 Group D) shows a sandy seagrass site. Few photographs were of suitable quality for presentation, due to the highly turbid conditions (resulting in optical backscatter of the flash) in many parts of Wallis Lake.

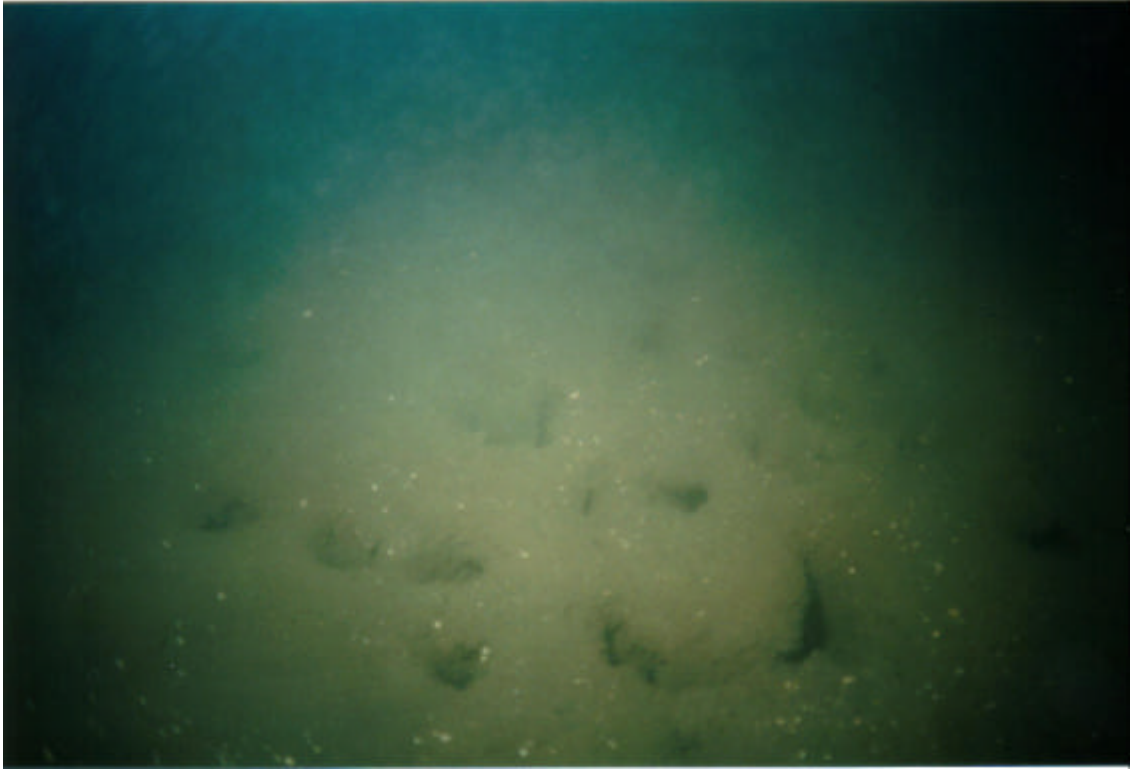


Figure 16 – Mud sediments with abundant animal burrows, and some shell material (burrow diameter = 2.5 cm).

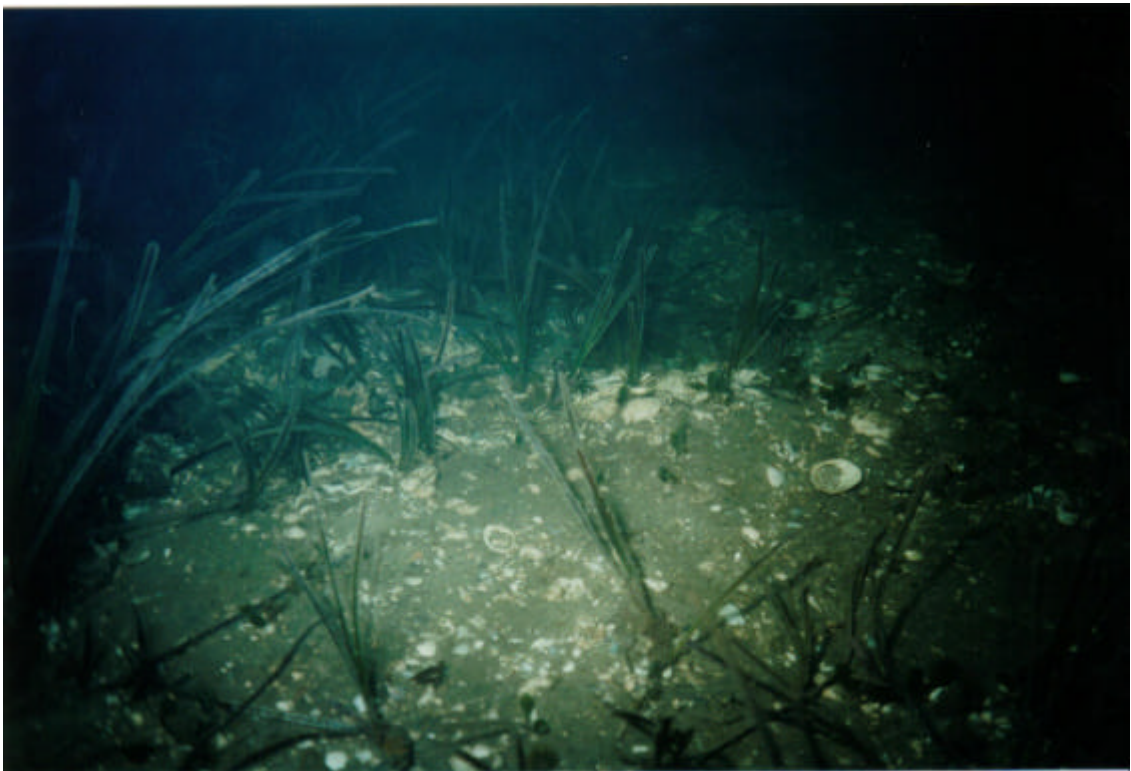


Figure 17 – Sandy muds with shell material, and some sparse seagrasses (field of view is approximately 50 cm wide).



Figure 18 – Well sorted marine sands, exposed at low tide (field of view is approximately 1 m wide).

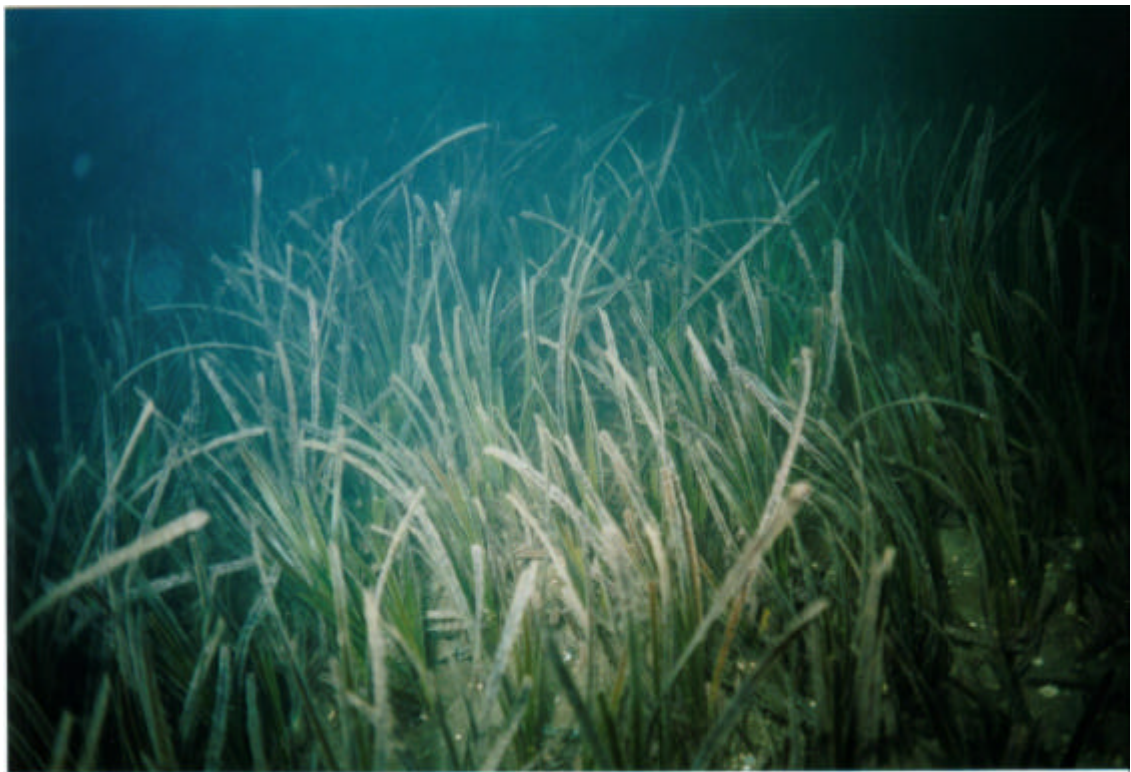


Figure 19 – Dense *Zostera* seagrass on a sandy substrate (field of view is approximately 50 cm wide).

Linking the Acoustic Classification with the Ground-truthing Dataset

To evaluate the usefulness of the Quester-Tangent mapping system for environmental monitoring, it is necessary to compare the results of the acoustic analysis with the data collected using traditional ‘ground-truthing’ techniques. The cluster analysis and MDS of the sediment data (Figs. 10 and 11) were labelled with acoustic class to investigate the degree of association between acoustic classes and the sedimentological features of each sample site (to produce Figs. 20 and 21).

Each of the ground-truthing sample sites was linked to the acoustic classes (Figure 9). Samples were manually checked for their proximity to the QTC track lines, and those collected on or within 3 m of extensive sections of track of each respective acoustic class (or adjacent to a crossover of two track lines of the same class) were coded by the relevant class (e.g. Classes 1 to 6). Samples without a clear association with any acoustic class were not labelled on the output plots. The cluster and MDS plots were then re-run (Figs. 20 and 21).

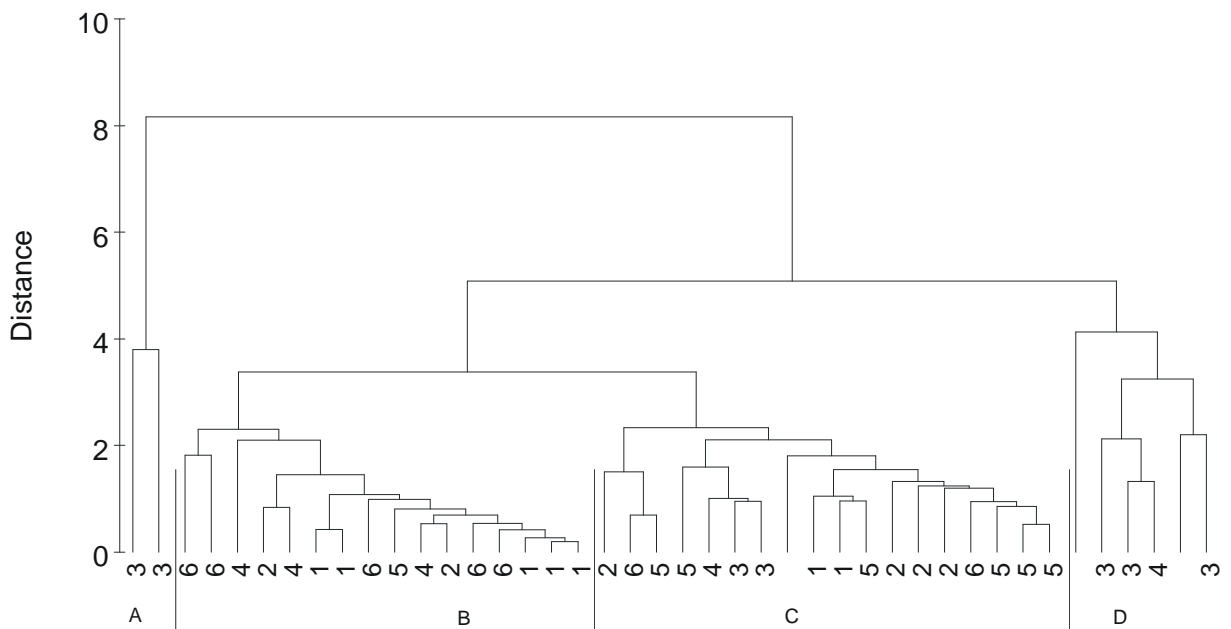


Figure 20 – Cluster analysis dendrogram of the sediment data (Table 1). Each sample is coded for acoustic class (Figure 7) on the x-axis. The four main cluster subgroups have been labelled Groups A-D. See Table 3 for the main characteristics of cluster subgroups.

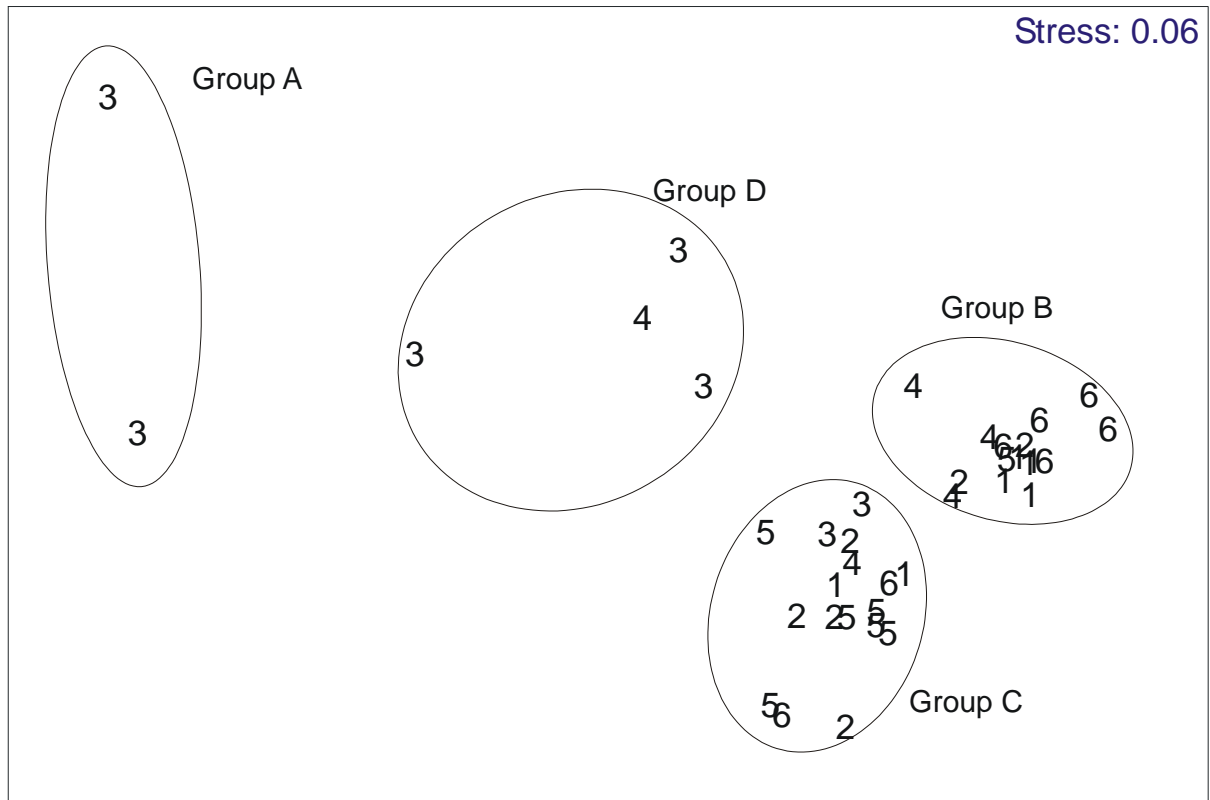


Figure 21 – Multi-dimensional scaling plot (MDS) of the sediment data (Table 1), also coded for acoustic class. The four main cluster subgroups, identified in Figure 10, have been circled (Groups A-D). See Table 3 for the main characteristics of cluster subgroups.

The cluster analysis and MDS plot (Figs. 20 and 21) is identical to that shown in Figures 10 and 11, however each sample is coded by the acoustic class within which it occurs (rather than the site identification numbers). The cluster analysis and MDS plots indicate that not all sediment cluster groups have a strong relationship with acoustic classes (identified in Fig. 9). Sediment group A, although it comprises only two samples, is 100% linked to acoustic class 3. Group B shows a relationship with acoustic classes 1 and 6, whereas group C comprises mainly acoustic class 5 and class 2 samples. Group D is also a small group, however it is dominated by acoustic class 3.

DISCUSSION

Summary of Findings

Single-beam acoustic mapping and classification of the benthic habitats of northern Wallis Lake indicate that there are up to six acoustically significant substrate classes. However, analysis of field and ground-truthing data, using advanced statistical techniques, was able to differentiate only four sedimentologically distinct and mappable sediment facies in the study area.

Cluster analysis and multi-dimensional scaling (MDS) of the sediment and site observation data were used to differentiate the four main types of depositional environments in the survey area, labelled as groups A, B, C, and D. Group A, a coarse shelly sand, is associated with the northern channel area (Fig. 13). Group B, comprising burrowed mud without shell material, is found almost exclusively within the centre of Pipers Bay and the embayment west of Wallis Island (Fig. 13). Group C differs from group B due to the presence of shell material, and also occurs in deeper channel sites (Table 3, Fig. 13). Group D is poorly sorted medium sand, and tends to occur on the margins of channels, possibly associated with seagrass beds (Fig. 13).

The distribution of seagrasses (primarily genera *Zostera*, *Posidonia*, and *Halophila*) was found to be independent of sediment grainsize (Appendix 1 and 4), and, although typically highly heterogenous, was linked with sediment groups C and D more so than with groups A and B (Fig. 14). The distribution of un-differentiated faunal burrows is strongly linked to sediment groups B and C, both of which comprise muddy sediment (Fig. 15). Faunal burrows were totally absent from group A.

A large proportion of the subtidal habitats of Wallis Lake have now, for the first time, been accurately quantified. The sedimentary environments found in northern Wallis Lake are strongly comparable to pre-existing conceptual models of estuarine facies in New South Wales (Roy *et al.*, 2001, Ryan *et al.*, 2003). The following table summarises the relationships between the sedimentary habitats found within Wallis Lake, the acoustic classification, and pre-established estuarine facies models (Table 4).

Table 4 – Relationship between sediment group, acoustic classification, seagrass distribution, faunal burrow distribution and pre-established estuarine facies models.

Sediment Group (Table 3)	Acoustic Classes (Fig. 9)	Seagrass Association (Fig. 14)	Faunal Burrow Association (Fig. 15)	Comparable Facies (Roy <i>et al.</i>, 2001)
A	3	Low	None	Marine tidal delta
B	1, 6	Low	High	Central muddy basin
C	5, 2	High	High	Central basin/channels, with molluscs
D	3	High	Mod.	Marginal subtidal

The major division apparent in both the sediment data and the acoustic classification appears to be caused by higher-density sandy sediments, and lower-density muddy sediments. The muddy material likely originated from upper catchment sedimentary rocks, and delivered via the main tributary rivers (the Wallamba, Wallingat, Wang Wauk and Coolongolook rivers) in

the form of fluvial muds, sands, and gravels (Webb, McKeown & Associates, 1999). Coarse shell material (comprising carbonate particles greater than 2 mm diameter) was found to be acoustically significant (Fig. 20 and 21), and also predominantly occurred in deeper areas (Appendix 3). This material appears to have been derived from mollusc habitats within the lake, and/or from beach and nearshore deposits that have been transported into the estuary (Roy *et al.*, 1997).

Much of the seagrass and macrophyte dominated environments, which are also the most well studied subaquatic habitats in the lake, are limited to the shallow-water margins of the basin and channel areas (Webb, McKeown & Associates, 1999).

The wide central basin areas (e.g. those described by Roy *et al.*, 2001), such as Pipers Bay and the area west of Wallis Island, are dominated by very fine sediments with varying concentrations of shell material, and densely populated by various infaunal organisms (as indicated by burrows and mounds on the lake floor). The channel areas, which form intricate networks in northern Wallis Lake, are the deepest areas in the lake (probably due to current scouring), and comprise relatively dense sandy muds and muddy sands, and also feature a high concentration of shell material (possibly allocthonous material deposited in the channels by currents). The marine tidal delta is also a highly distinct and mappable habitat, being clean well-sorted sand, and features many dense seagrass beds. Much of the sand in the channel areas and basin margins may be reworked Pleistocene coastal sand deposits (Roy *et al.*, 1997). The fluvial (or bayhead) delta, described by Roy *et al.*, (2001) and Ryan *et al.*, (2003), was not adequately surveyed in this study.

Additional Considerations

Larger scale benthic structures, such as bedforms (e.g. sand dunes, muddy ‘depressions’, and various animal burrows and mounds) could be better assessed for their influence on the acoustic signals using empirical measurements (e.g. video transects). Also, a quantitative measure of burrow size and density (e.g. quadrat-based measurements of size and density) could possibly provide a better indicator of the acoustic character of muddy depositional environments, and explain why similar muddy sediments display more than one acoustic class.

Single-beam acoustic mapping and classification systems are also problematic, in that substrates that are sloped at more than about 7° may reflect returning signals away from the sensor, and affect the classification (Hamilton *et al.*, 1999). This process may have influenced some of the acoustic return signals around the Lake margins.

Muddy sites that have a relatively low organic content and high density may produce echograms similar to samples with a significantly higher sand content. Other unmeasured features of the lake bed may also have influenced the echograms. These may include accumulations of dead vegetation (e.g. seagrass wrack), gas bubbles (O₂) produced by thick covers of macrophytes and benthic micro algal mats, and gas bubbles (e.g. CH₄ or CO₂) evolved from within surficial organic-rich muds (Froelich *et al.*, 1979).

CONCLUSIONS AND RECOMMENDATIONS

The Quester-Tangent View Series 5 system demonstrated the ability to rapidly survey a relatively large and diverse estuarine area, to produce a coherent map of spatially homogenous acoustic classes. Although multi-beam acoustic mapping techniques are capable of providing high resolution bathymetry, few of these systems allow the rapid classification of substrate type. Additionally, multi-beam systems are of less advantage in very shallow water due to beam width restrictions, and are also typically far more expensive and difficult to mount on survey vessels in comparison to single beam systems (Penrose and Siwabessy 2001).

The analysis revealed that, based on the parameters measured, not all of the six acoustic classes were uniquely linked to distinct sedimentological facies, indicating that factors other than the sediment parameters influence the return acoustic signal. Although not all of the acoustic substrate classes could be identified in sedimentological terms, useful linkages were made between the acoustic classes and known estuarine sedimentary environments (such as marine sands and muddy basin sediments), illustrating that the Quester-Tangent acoustic mapping system is a useful tool for coastal management and research. The spatial interpretation of the Wallis Lake Quester-Tangent data represents the first quantification of non-seagrass habitats in the deeper areas of the lake, provides a useful indication of benthic habitat diversity and abundance, and clearly delineates the well-described estuarine sedimentary environments in the area (Roy *et al.*, 2001).

The relative ease of surveying, and the potential to use small and fast survey vessels, shows that single-beam systems are of great use to estuarine managers and researchers. However, it is suggested that significant resources should be directed toward adequate ground-truthing procedures (based upon sediment, vegetation and bedform morphological assessment) during the first survey, in order to provide a useful basis for comparison during repeat surveys. In this way, repeat surveys using the same equipment and settings will provide valuable information about environmental change in the sub-marine environment (Van Lancker *et al.*, 2003). A more quantitative assessment of larger scale bedforms (e.g. burrows or sand dunes), using biological sampling techniques such as quadrats, may also have provided better information on the important larger-scale features. Other confounding factors, such as photosynthetic production of gas bubbles, might be assessed by night or low-light conditions surveys.

In addition to the trial of the new Quester Tangent Series 5 system, some useful information about the substrate of Wallis Lake was obtained. The study may provide a useful indication of habitat abundance and diversity for future environmental management purposes (Fig. 13). Further ecological sampling may also provide valuable information about the nature, distribution and abundance of infaunal and epifaunal species and communities, which may in turn be linked to acoustic backscatter information (Freeman *et al.*, 2002).

ACKNOWLEDGEMENTS

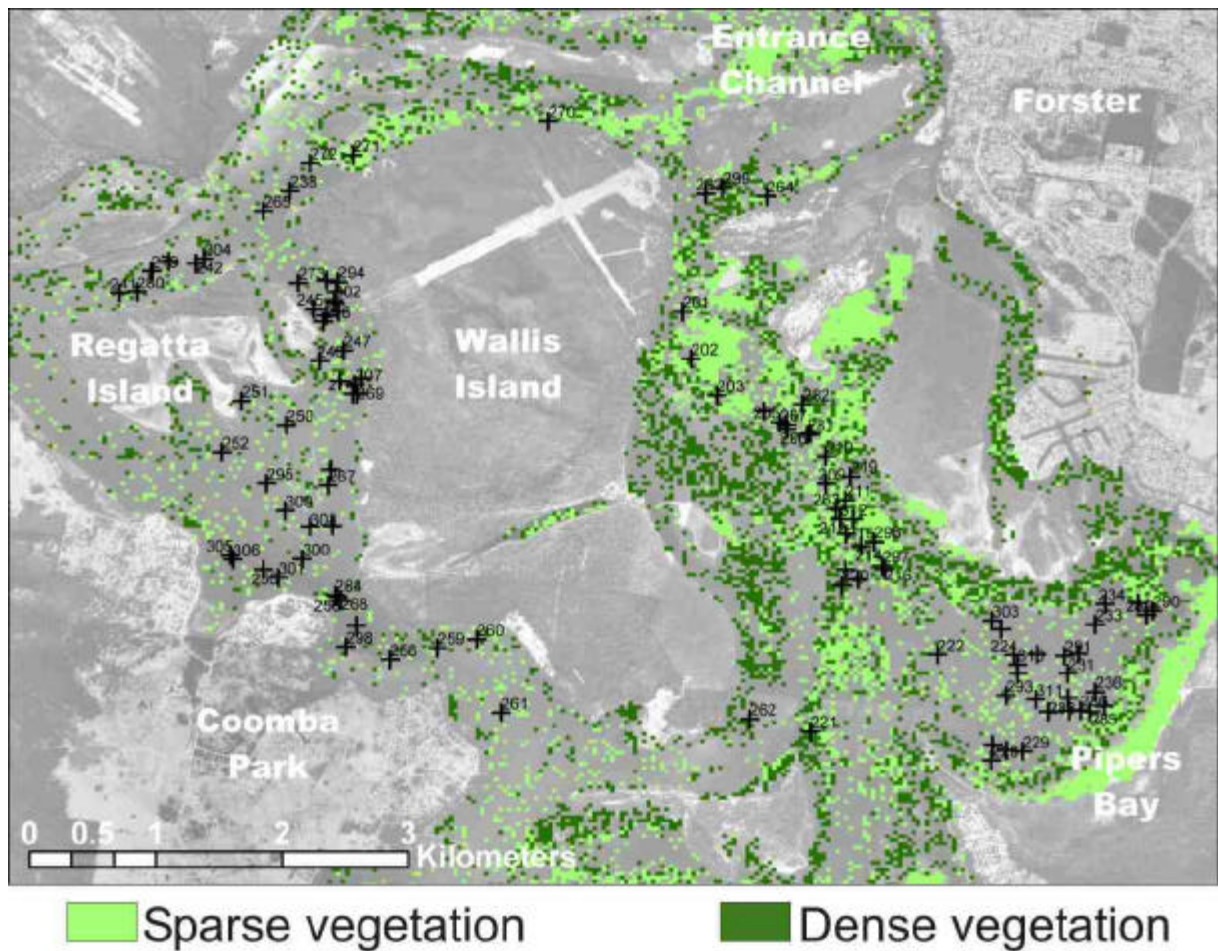
The authors would like to acknowledge the support, communication and discussion with numerous members of the CRC for Coastal Zone, Estuary and Waterway Management. Many thanks to Quester-Tangent Corporation (<http://www.questertangent.com>) for demonstration the QTC Version 5 system, Gerard Tuckerman of the Great Lakes Council for supporting the field operation, Joanne Wilson and Peter Evans of the NSW Department of Infrastructure, Planning and Natural Resources for help with initial field interpretations and supplying a boat, John Ryan and Colin Tindall of GA for fieldwork assistance, Les Hamilton of Defence Science and Technology Organisation for constructive review, John Penrose of Curtin University, Lynda Radke of GA for review and advice on statistical techniques, Tony Watson and Alex McLachlan of GA for sediment analysis, and Mick Collins of Graeme Barclay Oysters Pty. Ltd. for invaluable assistance in navigation and boat driving.

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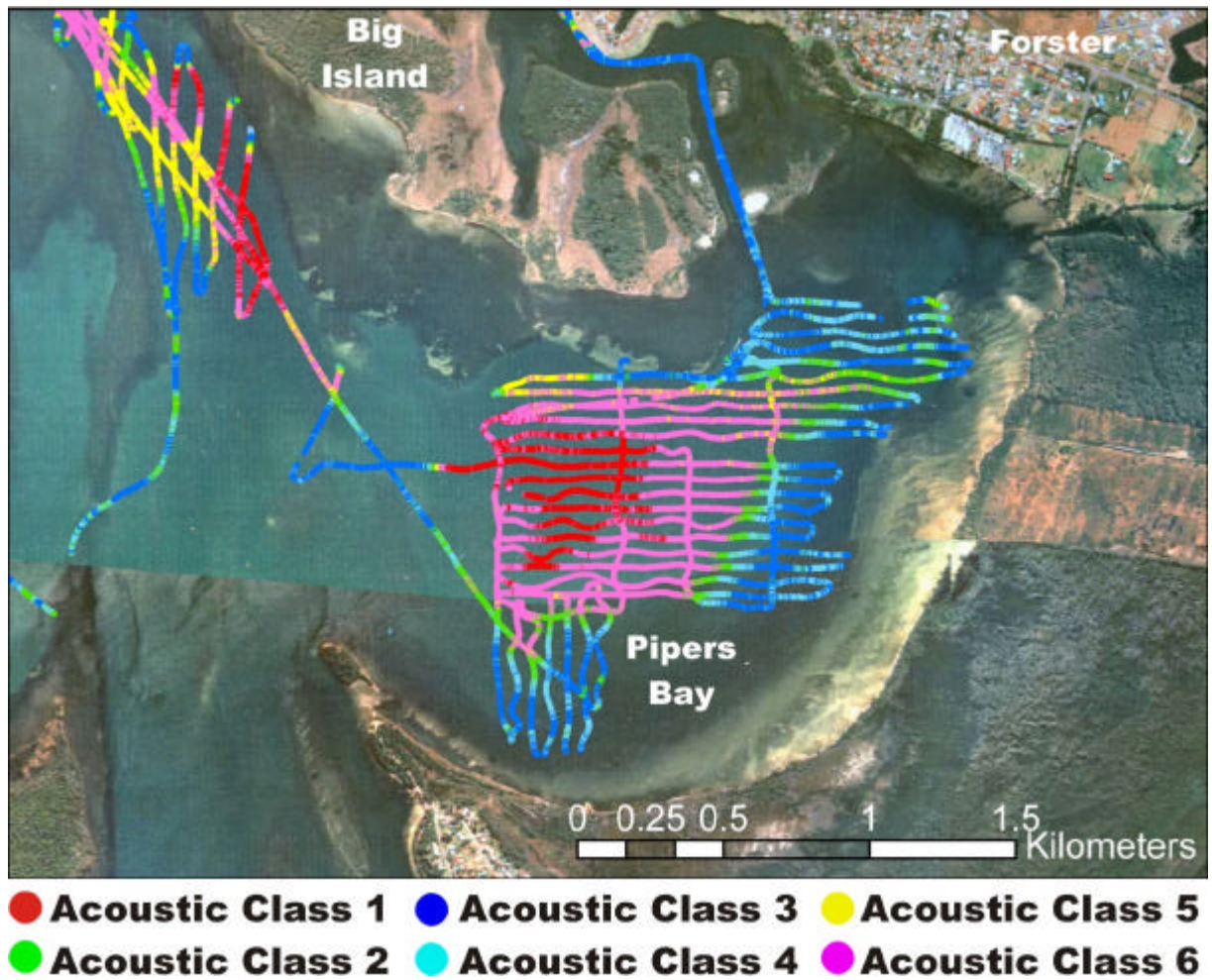
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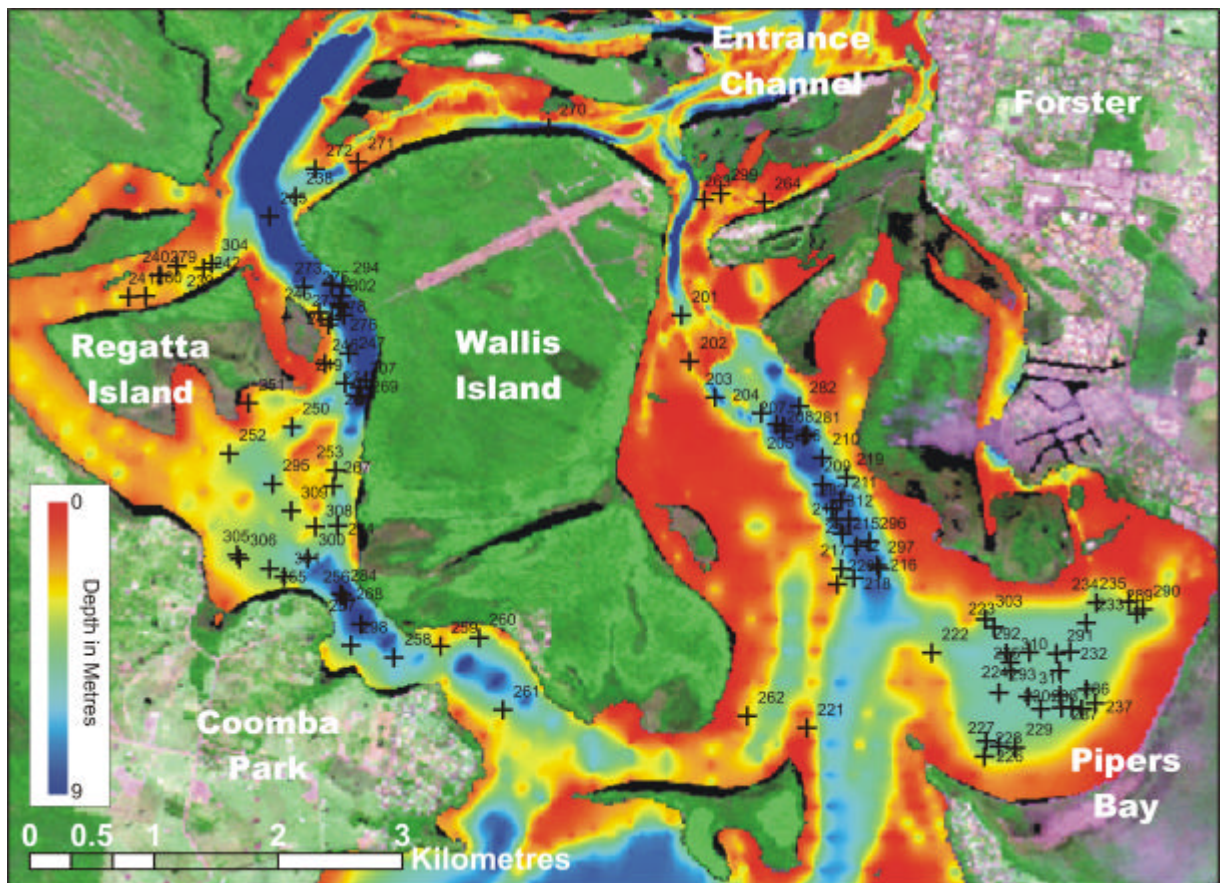
APPENDIX



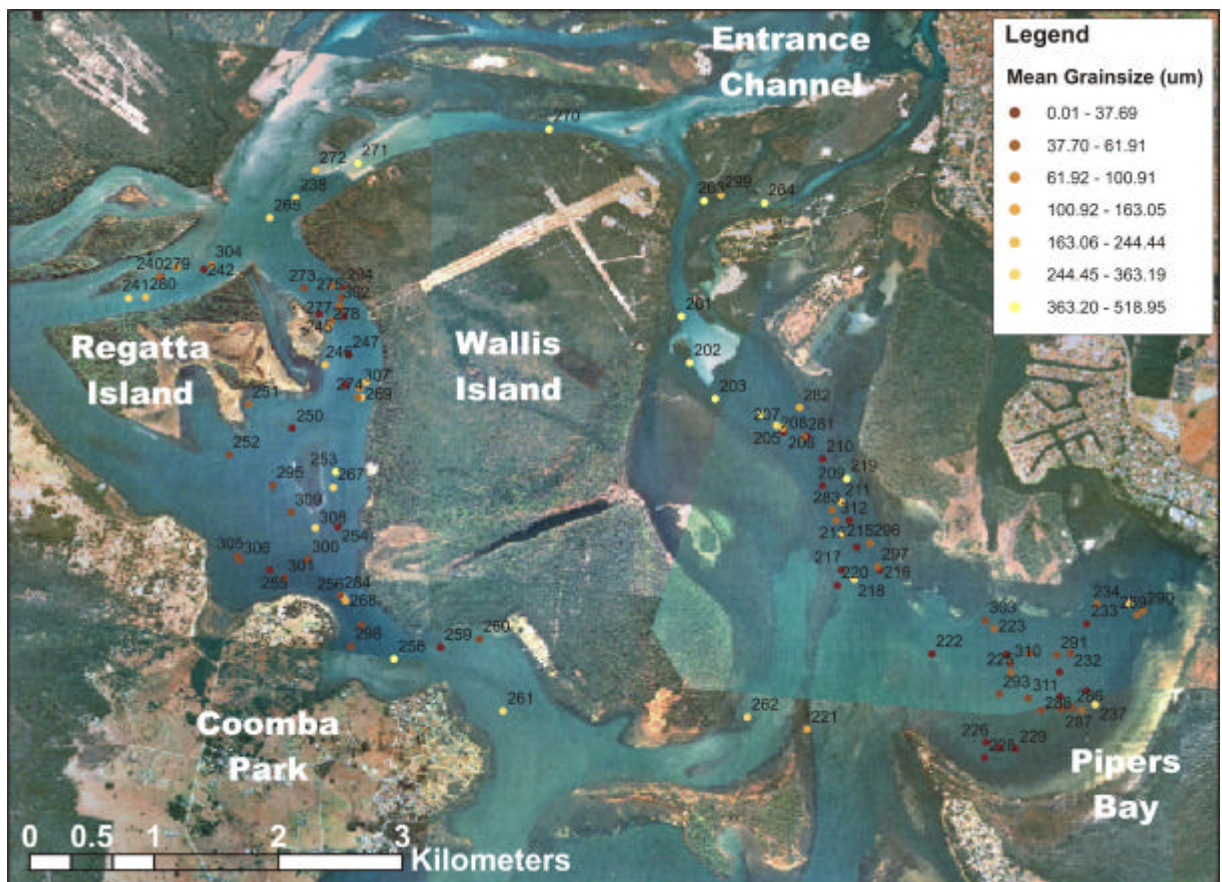
Appendix 1 - Modified seagrass density map, adapted and simplified from Dekker *et al.*, 2003. Sample site locations are included as black crosses.



Appendix 2 - Spatial representation of the acoustic data, coded for acoustic class, and plotted on a digital aerial photograph of Pipers Bay. Aerial photographs courtesy of Land and Property Information, NSW.



Appendix 3 – Bathymetry of Wallis Lake. Bathymetric grid provided by the New South Wales Department of Infrastructure, Planning and Natural Resources, 2003 (formerly NSW Department of Land and Water Conservation). Sample site locations are included as black crosses.



Appendix 4 – Spatial distribution of sample sites, showing mean sediment grainsize (as determined by a Malvern laser size analyser).

Appendix 5 - Raw sedimentological and geochemical data for the ground-truthing sites in Wallis Lake. Acoustic class is only provided for ground-truthing sites that occurred in areas of low acoustic heterogeneity, and within 3 metres of the ship track.

WPT	Lat (dd)	Long (dd)	Date	Depth	Burrows	Seagrass (CSIRO)	%_Porosity	Wet_Dens	%_TOC	Shell_Mass	Sed_63um	Mean_GS	Std_Dev	%_CaCO3	Assigned Class
201	-32.208	152.493	11-Jun-02	2.3	0	8	40.24	5.16	0.10		0.00	452.39	128.44	2.50	3
202	-32.212	152.493	11-Jun-02		0	2	34.28	6.04	0.04		0.00	450.37	128.81	2.50	3
203	-32.214	152.495	11-Jun-02	3.5	0	8	53.12	3.52	0.24		2.33	376.30	131.88	2.50	3
204	-32.215	152.499	11-Jun-02	2.2	0	2	39.98	4.98	0.24		0.00	452.33	139.48	2.50	
205	-32.216	152.500	11-Jun-02	4.1	0	0	84.52	1.67	2.51		17.64	323.64	227.52	12.00	5
206	-32.217	152.500	11-Jun-02	4.4	0	8									6
207	-32.216	152.500	11-Jun-02	4.2	0	0	86.37	1.60	3.06		36.91	222.94	208.90	7.00	6
208	-32.217	152.502	11-Jun-02	4.2	0	0									5
209	-32.221	152.503	11-Jun-02	4.5	0	2									
210	-32.219	152.503	11-Jun-02	2.9	0	0									3
211	-32.222	152.504	11-Jun-02	4.1	0	8	82.63	1.67	3.12		36.10	239.57	230.19	14.00	6
212	-32.224	152.505	11-Jun-02	3.9	0	8	80.45	1.79	2.14		33.93	293.12	306.59	30.00	5
213	-32.223	152.505	11-Jun-02	3.9	0	0									
214	-32.225	152.506	11-Jun-02	3.9	0	0									5
215	-32.225	152.506	11-Jun-02	3.7	0	8	88.93	1.43	4.03		74.09	85.89	144.91	2.50	1
216	-32.227	152.507	11-Jun-02	3.7	0	0									
217	-32.227	152.504	11-Jun-02	2.0	0	8									3
218	-32.227	152.505	11-Jun-02	2.7	0	8	78.25	1.88	1.95		26.82	318.88	219.86	2.50	3
219	-32.220	152.505	11-Jun-02	2.3	0	2	41.70	4.95	0.10		1.99	418.10	131.72	0.00	3
220	-32.228	152.504	11-Jun-02	1.5	0	0									
221	-32.238	152.502	13-Jun-02	4.6	2	0	84.33	1.65	3.02		61.66	121.88	163.55	5.00	
222	-32.233	152.511	13-Jun-02	1.7	6	0									3
223	-32.231	152.516	13-Jun-02	2.8	6	0	96.83	1.21	4.36		83.57	40.69	65.41	0.00	
224	-32.233	152.516	13-Jun-02	2.5	6	8									1
225	-32.234	152.517	13-Jun-02	2.6	6	2	96.68	1.20	4.53		82.46	42.48	69.74	0.00	1
226	-32.239	152.515	13-Jun-02	2.8	0	0									4
227	-32.240	152.516	13-Jun-02	2.7	4	0									4
228	-32.240	152.515	13-Jun-02	2.0	5	2									3
229	-32.240	152.517	13-Jun-02	2.2	5	2									3
230	-32.236	152.520	13-Jun-02	2.8	5	0									6
231	-32.234	152.520	13-Jun-02	2.7	5	0									6
232	-32.233	152.521	13-Jun-02	2.8	7	0	96.66	1.21	4.50		86.95	34.95	59.58	0.00	6
233	-32.231	152.522	13-Jun-02		0	2									
234	-32.229	152.523	13-Jun-02	2.7	4	8	96.06	1.21	4.59		80.57	44.76	67.19	0.00	3
235	-32.229	152.525	13-Jun-02	1.6	0	8	74.04	2.11	1.09		27.45	338.54	271.13	2.50	
236	-32.235	152.522	13-Jun-02	2.7	7	2									4
237	-32.236	152.523	13-Jun-02	1.9	6	4	79.38	1.74	1.78		19.01	322.28	192.25	2.50	3

238	-32.200	152.465	14-Jun-02	2.4	5	2	59.27	3.03	0.44		4.66	363.19	132.29	2.50	3
239	-32.205	152.456	14-Jun-02	1.5	5	0	82.27	1.68	2.92		63.11	100.91	151.42	0.00	
240	-32.205	152.455	14-Jun-02	1.5	5	8									2
241	-32.207	152.453	14-Jun-02	1.8	2	2	59.05	3.06	0.59		17.51	301.82	167.97	0.00	3
242	-32.205	152.458	14-Jun-02	2.4	2	2									
243	-32.206	152.467	14-Jun-02	4.9	5	0	85.50	1.56	2.84		85.86	41.06	88.52	2.50	6
244	-32.208	152.468	14-Jun-02	4.5	0	0									5
245	-32.208	152.467	14-Jun-02	1.5	5	4									3
246	-32.212	152.467	14-Jun-02	1.5	5	0	77.10	1.95			31.82	220.26	172.38	0.00	3
247	-32.211	152.469	14-Jun-02	3.6	4	0									
248	-32.213	152.470	14-Jun-02	6.4	4	2	79.45	1.72	2.37		43.92	244.44	265.43	9.00	
249	-32.213	152.468	14-Jun-02	2.0	6	2									3
250	-32.216	152.465	14-Jun-02	3.5	6	0									3
251	-32.215	152.461	14-Jun-02	1.8	5	0	89.53	1.40	2.39		79.70	58.88	104.67	0.00	2
252	-32.218	152.460	14-Jun-02	2.4	4	0	89.05	1.45	2.81		86.21	37.22	70.74	0.00	6
253	-32.220	152.468	14-Jun-02	3.0	4	0	62.38	2.97	0.68		2.45	418.22	154.14	2.50	3
254	-32.224	152.468	14-Jun-02	2.4	4	2									3
255	-32.227	152.463	14-Jun-02	2.4	3	0									6
256	-32.229	152.468	14-Jun-02	6.4	4	2	81.44	1.75	3.32		38.69	292.46	308.77	2.50	2
257	-32.231	152.470	14-Jun-02	4.9	5	0	90.87	1.40	2.87		91.72	26.02	53.13	0.00	6
258	-32.233	152.472	14-Jun-02	3.0	5	0	46.03	4.36	0.25		0.00	518.95	170.40	5.00	3
259	-32.232	152.475	14-Jun-02	2.1	5	2									3
260	-32.232	152.478	14-Jun-02	2.7	7	0	89.88	1.39	2.85		90.08	28.14	50.83	0.00	1
261	-32.237	152.480	14-Jun-02	2.1	6	0	79.16	1.95	2.23		27.55	309.86	228.34	2.50	3
262	-32.237	152.498	14-Jun-02	1.2	0	8	73.39	2.15	1.58		15.97	308.71	164.89	2.50	
263	-32.200	152.494	14-Jun-02	2.1	2	4	63.87	2.49	0.29		4.60	396.27	135.20	2.50	3
264	-32.200	152.499	14-Jun-02	2.4	0	0	37.94	5.37	0.13		0.00	404.35	102.16	2.50	3
265	-32.201	152.463	15-Jun-02	3.0	6	0	66.91	2.15	1.63		16.30	320.53	175.10	2.50	2
266	-32.213	152.470	15-Jun-02	6.4	4	2	81.82	1.68	2.19		41.85	191.42	181.64	2.50	
267	-32.221	152.468	15-Jun-02	6.4	6	2	55.68	2.55	1.07		8.19	325.79	134.76	2.50	3
268	-32.229	152.469	15-Jun-02	6.0	0	0	87.87	1.50	2.50		63.11	132.44	196.81	2.50	2
269	-32.214	152.470	15-Jun-02	5.5	7	2	77.58	1.74	1.97		43.62	210.76	207.93	2.50	2
270	-32.195	152.483	03-Dec-02	4.0	0	0	64.47	4.82	0.10	121.00	0.00	425.17	108.51	2.50	3
271	-32.197	152.469	03-Dec-02	1.0	0	2	45.31	4.59	0.04	58.00	0.00	381.47	116.91	2.50	3
272	-32.198	152.466	03-Dec-02	3.3	2	2	49.30	4.17	0.77	0.00	43.98	181.09	179.73	2.50	
273	-32.206	152.465	03-Dec-02	4.8	4	0	87.13	1.58	1.17	8.00	86.77	37.69	77.73	2.50	
274	-32.214	152.469	03-Dec-02	5.2	7	0	76.26	1.82	2.53	20.00	87.38	44.30	101.27	2.50	2
275	-32.207	152.468	03-Dec-02	4.9	4	0	87.33	1.58	2.70	33.00	90.63	28.79	62.53	2.50	
276	-32.208	152.468	03-Dec-02	4.7	7	0	91.74	1.59	2.44	19.00	87.39	34.92	73.22	2.50	5
277	-32.209	152.467	03-Dec-02	3.6	4	0	85.90	1.74	2.03	2.00	83.47	46.96	93.90	2.50	2
278	-32.209	152.467	03-Dec-02	2.4	6	0	78.62	2.04	1.36	0.00	48.79	163.05	172.77	2.50	3
279	-32.205	152.455	03-Dec-02	1.7	7	8	86.00	1.67	4.14	3.00	74.19	61.91	106.12	0.00	4
280	-32.207	152.454	03-Dec-02	1.7	3	2	66.42	2.59	0.86	0.00	49.61	182.37	200.57	0.00	3

281	-32.217	152.502	03-Dec-02	4.3	4	8	85.90	1.69	2.71	421.00	83.81	45.97	85.76	24.00	
282	-32.215	152.501	03-Dec-02	4.4	0	2	64.27	2.83	1.20	441.00	61.59	120.87	165.32	12.00	
283	-32.222	152.504	03-Dec-02	4.5	4	8	89.69	1.56	2.43	394.00	82.81	55.94	112.13	19.00	
284	-32.229	152.468	03-Dec-02	6.1	4	0	91.94	1.73	2.71	267.00	92.27	30.09	78.53	7.00	2
285	-32.237	152.522	03-Dec-02	2.1	3	2	90.10	1.43	2.55	36.00	85.93	43.66	87.12	2.50	3
286	-32.237	152.521	03-Dec-02	2.6	0	0	84.77	1.33	3.62	0.00	89.53	33.02	62.95	0.00	4
287	-32.237	152.520	03-Dec-02	2.6	5	0	85.18	1.24	4.33	0.00	91.89	27.45	50.09	0.00	2
288	-32.237	152.519	03-Dec-02	2.6	7	2	92.05	1.27	3.98	0.00	94.19	23.13	44.43	0.00	6
289	-32.230	152.526	03-Dec-02	2.7	0	2	92.25	1.40	4.26	8.00	83.96	41.93	72.10	0.00	2
290	-32.230	152.526	03-Dec-02	2.5	2	2	83.33	1.36	3.52	88.00	81.59	52.80	99.44	2.50	3
291	-32.233	152.520	03-Dec-02	2.6	4	0	90.10	1.32	4.18	0.00	87.56	34.26	59.81	0.00	6
292	-32.233	152.518	03-Dec-02	2.6	7	0	95.84	1.31	4.32	0.00	89.57	30.50	52.84	0.00	1
293	-32.236	152.516	04-Dec-02	2.7	7	0	96.25	1.40	4.38	0.00	89.82	30.22	52.18	0.00	1
294	-32.206	152.468	04-Dec-02	4.5	4	0	86.20	1.68	2.95	2.00	88.25	34.29	74.34	2.50	6
295	-32.221	152.463	04-Dec-02	2.6	7	2	91.74	1.44	2.84	1.00	92.65	23.50	47.32	0.00	1
296	-32.225	152.506	04-Dec-02	3.7	4	8	92.15	1.47	4.30	10.00	85.78	41.39	78.76	2.50	1
297	-32.226	152.507	04-Dec-02	3.8	7	2	94.20	1.53	4.06	27.00	82.38	60.84	124.99	2.50	1
298	-32.232	152.469	04-Dec-02	2.7	7	0	96.15	1.40	2.89	1.00	94.26	20.69	39.45	0.00	
299	-32.199	152.496	04-Dec-02	1.7	2	8	68.16	2.22	1.11	0.00	47.22	203.82	215.26	2.50	4
300	-32.226	152.466	04-Dec-02	2.9	7	0	90.10	1.44	2.64	12.00	91.71	30.03	70.75	0.00	4
301	-32.227	152.464	04-Dec-02	2.8	7	0	86.00	1.59	2.55	106.00	90.44	32.87	76.31	2.50	4
302	-32.207	152.468	04-Dec-02	4.8	4	0	92.66	1.64	2.50	26.00	85.58	44.53	101.54	2.50	5
303	-32.230	152.515	04-Dec-02	2.8	7	0	95.53	1.46	2.76	0.00	88.27	32.09	53.21	0.00	5
304	-32.205	152.459	04-Dec-02	2.5	4	0	94.10	1.63	2.18	89.00	73.99	79.28	154.23	2.50	5
305	-32.226	152.461	04-Dec-02	2.1	7	0	93.28	1.53	2.74	0.00	96.14	16.62	18.90	2.50	6
306	-32.226	152.461	04-Dec-02	1.9	6	0	93.38	1.47	3.09	0.00	95.65	17.09	20.36	0.00	
307	-32.213	152.470	04-Dec-02	5.4	3	0	86.51	1.71	2.41	24.00	75.80	86.19	154.46	2.50	
308	-32.224	152.466	04-Dec-02	2.0	5	0	55.76	4.46	0.42	14.00	32.81	270.66	229.36	2.50	3
309	-32.222	152.465	04-Dec-02	1.9	7	0	94.61	1.43	4.10	0.00	94.41	21.79	48.71	0.00	6
310	-32.233	152.517	04-Dec-02	2.6	7	0	94.30	1.33	3.87	0.00	89.40	31.33	56.39	0.00	1
311	-32.236	152.518	04-Dec-02	2.5	5	2			3.64	0.00	91.22	28.26	50.21	0.00	6
312	-32.223	152.504	04-Dec-02	4.0	4	2	93.79	1.47	4.02	95.00	85.89	42.79	83.29	2.50	5