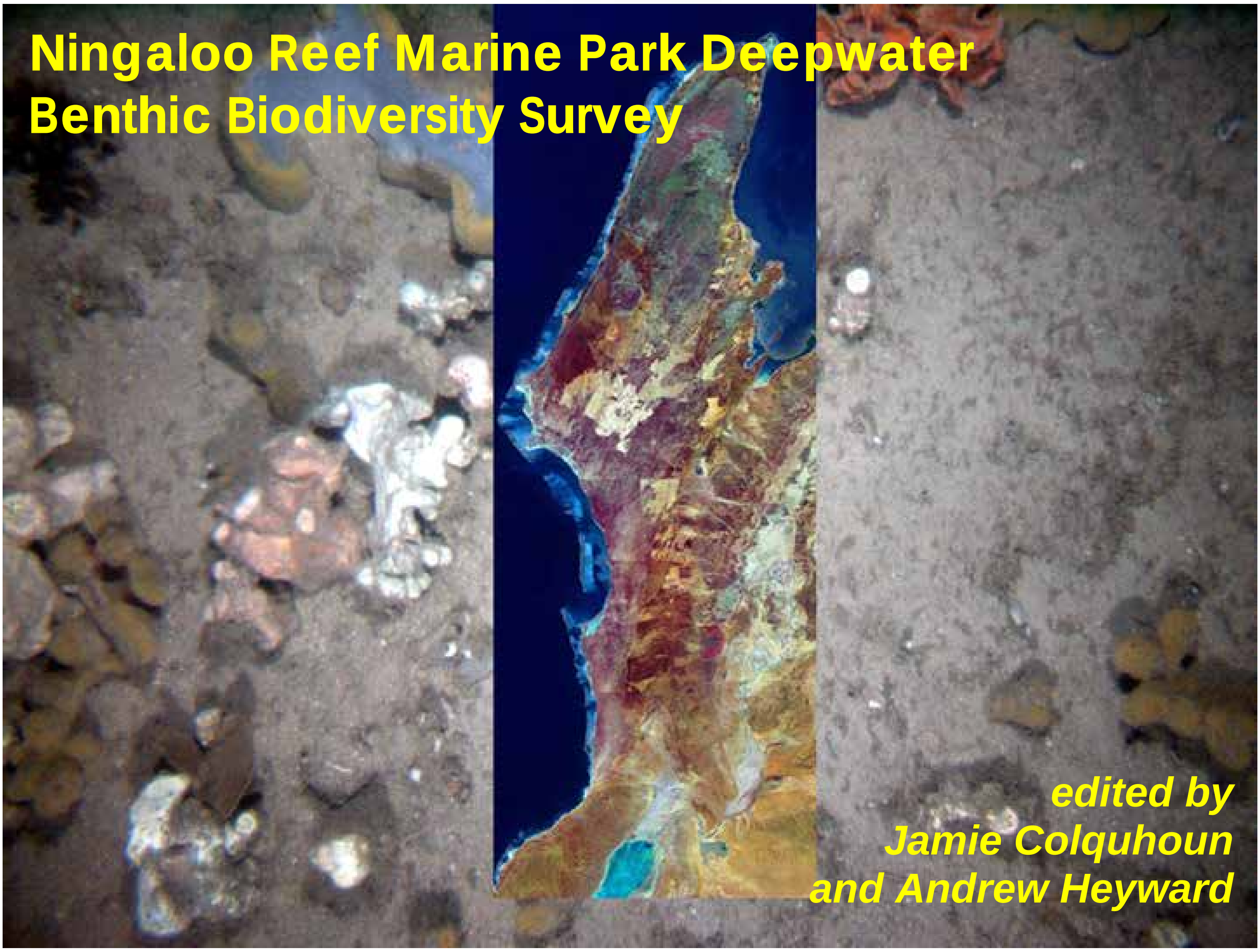

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Deepwater Communities at Ningaloo Marine Park

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Ningaloo Reef Marine Park Deepwater Benthic Biodiversity Survey

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EXECUTIVE SUMMARY

This report summarizes field and lab based activities undertaken during 2007 as part of the Ningaloo deeper water biodiversity project supported through WAMSI as Project 3.1.1. The Australian Institute of Marine Science is the lead organisation, but this is a collaborative, multidisciplinary project and the report represents a collation of the contributions from the partner organisations, each contributing different specialist research components, such as benthic mapping, acoustics, geology and taxonomy.

The principal activities during the 2007 deeper water biodiversity focussed on further data collection, undertaken during a month of ship-based field activities aboard the AIMS ship RV Cape Ferguson, to generate improved bathymetry and characterisation of the major habitats. During the year there was also significant effort on analysis of the fish and sediment data collections via post-graduate projects and preliminary analysis of the biodiversity collections by WA Museum.

In consultation with the Node 3 Leader, it was agreed to shift in 2007 from a moderately dense stratified sampling design, as used during the preliminary work undertaken in 2006, to sampling stations more widely spread along cross shelf transects located at approximately 5km intervals Consequently the 2007 field surveys provided very broad but somewhat coarse spatial coverage of the entire Ningaloo Marine Park, with the most significant effort focused on using towed video, sediment grabs, and single beam acoustics.

The 2007 field sampling saw a consolidation of approaches for acoustic mapping using single beam sonar, which standardized on consecutive cross shelf acoustic transects 500m apart, and the development and testing of an improved epibenthic sled, to deal with large organism sizes and high biomass sites, for collection of the biodiversity inventories. These methods proved effective and will be used as core tools to complete the sampling during 2008.

At the conclusion of the 2007 period, *in situ* video characterization of benthic habitats had been completed for 343 X 500m transects between NW Cape and Red Bluff, single beam coverage had been completed for approximately two thirds of the NMP, sediment grab collections had been completed for the length of the NMP and two series of collections had been delivered to the WA Museum to form the baseline for the Ningaloo offshore biodiversity database.

Acoustics

Single beam sonar data, collected using a Simrad EQ60 (38 and 200kHz) continued to be acquired to spatially compliment the 2006 data. Based on an analysis of interpolation reliability, the maximum spacing of 500m was used between cross shelf acoustic transects. Transects typically covered areas from the seaward edge of the reef, in around 30m depths, out to the WA NMP boundary, which was commonly a nominal 100m contour, although in places depths to 200m were mapped in the northern half, while depths were significantly less than 100m at the State boundary in the southern region.

Additional analysis was undertaken on both the 2006 and 2007 single beam data, together with the 2006 Multibeam data collected by Fugro Survey Ltd as part of the 2006 preliminary studies. Comparison of bathymetry and acoustic return parameters, including interpolation of the single beam data, analysis of mulitbeam backscatter and supervised classification of Roxanne E1 and E2 parameters, were used to generate classification maps of seabed habitat types. Three seabed classes, namely "rhodolith" or calcareous nodules, sand and "mixed" were found in the Mandu and Boat Passage areas. Three seabed classes delineated in the Red Bluff area corresponded to "algae", "sand" and "mixed", while in the Pt Coates area a fourth class, the "rhodolith" assemblage, was also delineated. Classification accuracy with these acoustic systems was high, varying between 72% and 90%, with the mulitbeam system given the higher values.

These results suggest that for broad scale mapping of major habitat types the acoustics are useful and should permit reasonably accurate estimate of gross habitat extent throughout the NMP. The use of single beam shall be maintained during the current project to cover as much of the NMP as possible, but the results also indicate that if resources can be found a comprehensive mulitbeam approach would deliver more reliable habitat maps.

Biodiversity Inventories

The field focus for sample collection during 2007 was to develop an improved sled design and establish an appropriate standardized sampling protocol. The 2006 sampling encountered areas with extremely high biomass and the original sled design and protocols, derived from the GBR Seabed Biodiversity project, caught too much material to process on some shots and under-sampled in other areas due to sled choking or filling.

A limited number of stations were sampled very successfully with the new sled in 2007 and delivered to the WA Museum after voucher processing under the Museum's guidance at sea. The WA Museum is undertaking taxonomic analysis of the Ningaloo deeper water samples and priority in 2007 was given to identify filter feeders, due to there perceived dominance in a number of the key habitats encountered.

Specimens were collected with an epibenthic sled at depths between 18 to 102m. All species of all phyla were collected, with sponges dominating the collection. Thirty-six sponge species were identified from the 12 stations sampled in 2007. These species were determined as dominant because they comprised a significant proportion of the total weight of biota collected from each station. In comparison, forty-five stations were sampled in 2006 and 39 sponge species were identified as dominant from these stations. Of these 75 species in total, only six were found to be common to both collecting years.

Within the 2007 sampling the majority of the dominant sponges were found at only one station (22 species), 11 species were found at two stations, one species was at 3 stations, and one species was found at seven of the 12 stations sampled. This interesting finding suggests that each station that has sponge habitat is dominated by a different sponge assemblage. Alternatively the species occurring at each station may be the same, but the dominant species, determined by weight, differ across stations. It is recommend that the 2008 sampling protocols endeavour, to the extent possible, to obtain comprehensive catch biomass data and well defined sled tow lengths, in order to assist in quantifying questions about spatial variation in sponge biomass. Additional taxonomic analysis remains to be done with the existing collections and further targeted quantitative sampling is planned for 2008.

Habitat Mapping

Broad scale habitat surveys, using real-time towed video categorization, were achieved along the full length of the NMP in 2007 on cross-shelf transects spaced 5km apart. Typically three stations, located at different depths along each cross shelf transect, were surveyed with replicated 500m video tows.

The major benthic habitats encountered were variations on fine and coarse sand environments which were ubiquitous throughout the NMP, extensive rubble zones which often consisted of calcareous algal rhodoliths, particularly extending beyond the reef slope across the shelf into 40-50m depths, limited areas where fleshy macroalgae were dominant, and localized but sometimes extensive consolidated rock and low relief ledge outcrops typically supporting medium to high density filter feeding communities with considerable diversity.

Latitudinal and depth related differences in composition of the sponge communities were apparent, as was patchiness in terms of abundance over spatial scales of 10s of meters to kilometres. Within any particular location along the NMP the abundance of the filter feeders was strongly associated with the presence of consolidated substrate, notably remnant geological ridge features, although video images frequently showed sponges growing on sand. The inference of this is that a thin sand veneer has covered consolidated substrate after the sponges became established.

The distribution of reef building corals was strongly attenuated with depth, with significant coral cover decreasing rapidly below 35-40m depth and becoming rare beyond 45-50m. These coral communities were mostly associated with the main reef slope areas, but were occasionally important on isolated offshore ridges and mounds which rose to 40m or less beneath the surface. These isolated features were most commonly encountered in the Pt Cloates area, where deeper water encrusting and plate corals occupied mound and ridge tops but gave way to filter feeders as depth increased down the sides of the feature.

An unusual observation was that while scleractinian corals could dominate down to depths of 35-40m in the northern half of the NMP, it was rare to see these at the southern end between Gnaraloo and Red Bluff. In that region there appeared to be a greater likelihood of sponges rather than corals being important components of the benthos even at depths of 30m.

Diverse and abundant sponge communities were documented in the southern half of the NMP for the first time in 2007. There is a suggestion from the sampling to date that while most of the existing sanctuary zones capture representative examples of the major habitats and biodiversity, the rich filter feeding communities encountered between Gnaraloo and Red Bluff may not be adequately represented at present. This area shall be targeted for additional sampling in 2008.

Geomorphology and Surface Sediments

Single and multibeam acoustic surveys, sediment grabs and dredged rock samples were used to investigate surficial sediments and seabed geomorphology of the deeper waters of NMP. The 2007 program saw completion of the major sediments grab collections, which began with the 2006 cruises, and significant progress on analysis of these samples and associated acoustic and tow video data.

The sediment sample collection provides broad coverage, in parallel with the video tow transects, across the entire NMP. The relationships determined at this scale may be used to inform our understanding of benthic habitat variability across the whole Marine Park. Acoustics combined with sedimentological and geomorphological data enabled the characterisation of different habitats according to depth, topography, substrate stability, hardness and roughness, grain size and suitability to support significant biota, from the base of the fore reef slope and seawards across the continental shelf.

The shelf within the northern NMP is narrow and preliminary results show a clear zonation of habitats across the shelf. There is a strong association between geomorphology and benthic habitats with communities taking advantage of the availability of Last Interglacial (LI, ca. 125 ka) substrates. The hard bottom is mainly composed of a fossilised limestone reef surface, karstified in places due to glacial lowstand subaerial exposure. In the shallower fore-reef slope, there is a thin veneer of Holocene coralgal growth on multiple back stepping spur and groove systems. Modern growth is largely determined by the antecedent LI topography. Between 30-40 m depth, even where hard substrates are still available, hard corals rapidly disappear, gradually replaced by a mixed deep-water benthic community. This transition, between the base of the fore reef slope and the inner shelf is characterised by reef and rhodolith gravel that supply the hard substrate for a diverse community dominated by crinoids, sponges, turf algae and Halimeda, with minor soft corals (gorgonians, sea whips), ascidians, and sea pens. There is an extensive middle–outer shelf sand plain where sediment thickness is variable overlying limestone pavement and low relief ridge systems. Here communities of sponges, crinoids, bryozoans, soft corals, sea pens and hydroids are patchy with higher abundance associated to exposed LI substrates. Rippled sands, with no epibenthos, are common on the inner-mid shelf, commonly associated with submarine fans adjacent to reef passes. Bioturbation is evident from echinoderm feeding traces, polychaetes and burrowing fish and a diverse infauna have reworked the sediments to build mounds and burrows. A number of ridges have been identified at various depths with prominent and extensive systems on the outer shelf (75-125 m). Exposed limestone substrates are sites of prolific growth with invertebrates growing affixed to the substrate. A more complex history of constructional and pre-existing antecedent topography exists at Cloates SZ, where Tertiary limestone surfaces, paleo still stand escarpments and shorelines, and stepwise LI fossil reefs, support a diverse coralgal and sponge community. South of Point

Cloates, the coastline veers eastward and there is a marked transition in bathymetry with a gentler and wider shelf to the south. Rhodolith and sandy habitats are more common in the southern part of the Marine Park. An offshore ridge system at the southern end towards Red Bluff again provides the hard substrate for a diverse sponge community.

Ningaloo Reef lies in a latitudinal transition zone of carbonate-producing communities where both photozoan-reef (warm-water/low nutrient) and heterozoan-carbonate ramp (cool-water/elevated nutrient) producers are found. Sediments are generated by growth of invertebrates and the importance of calcium carbonate secreting organisms to the surficial sediments is evident, with communities dominated by corals, red coralline algae, bryozoans, Halimeda, benthic forams, molluscs and planktonic forams. Sediments are almost wholly biogenic in origin consisting of older relict and reworked grains mixed with modern skeletal fragments. Depth consistent sediment facies can be recognised across the shelf on the basis of component composition and grain size characteristics. Inner shelf sediments are dominated by; hardground/rhodolith/coralline algal gravelly sands; modern skeletal rippled sands transported in submarine fans adjacent to reef passes; modern skeletal gravelly shelf sands dominated by a mixture of coralgal, molluscan, foraminiferal and bryozoan components; and modern seagrass/sublittoral fine sands in areas adjacent to lagoonal seagrass meadows. Grains composing whole skeletons or fragments, and gravel sized clasts are heavily encrusted by coralline algae. Middle shelf sediment is dominated by foraminiferal dominated relict skeletal sands, with initial observations indicating modern counterparts in shallower water depths suggesting deposition during lower sea-level in the Pleistocene. Subphotic sediments on the outer shelf and upper slope are a mixture of modern cool-water, poorly sorted, bryozoan/molluscan-dominated gravelly muddy sands with small benthic and planktonic foraminifera, sponge spicules and brachiopods. Relict grains again are common.

Fish Community Analysis

Significant progress was made during 2007 on analysis of the intial stereo BRUVs survey conducted in 2006. The 340 stereo BRUV samples collected from the reef slope across the shelf, at sites northwards from Pt Cloates, recorded 410 fish species from 63 families. Multivariate analyses of variance were used to detect differences in the fish assemblages between habiatas and depth zones. Sixty-eight fish species were found to be the dominant contributors to assemblage structure and had the major influence on patterns associated with depth and habiat groupings. Distinctive fish assemblages and fish size frequency partitioning was strongly correlated with different habitat and depth categories. Diversity appeared to decrease with increasing depth across the Ningaloo Reef shelf while average fish length increased. Habiat partitioning between species form the same family was common.

Depth range extensions for many species were noted, with a number of species usually observed by divers on shallow reefs seen up to 5km seawards of the reef crest and well below normal scientific diving depths. Species of butterfly fish (Chaetodontidae), parrot fish (Saridae) and wrasse (Labridae) normally seen in shallow coral and algal habitats were sometimes recorded in water up to 100m deep, which demonstrates linkage between shallow and deeper habitats for these species.

Data Management and Modelling

This research presents an interdisciplinary study and is using a Geographic Information System (GIS) to capture and manage the various data from seabed mapping techniques, using acoustics, traditional sedimentological and benthic sampling and towed video.

The ESRI™ suite of Geographical Information System (GIS) software ArcGIS™ is employed at AIMS as the preferred spatial data management system. AIMS utilises the add-on component Arc Spatial Data Engine (ArcSDE™) to provide a multi-user database environment incorporating the ORACLE™ database management system (DBMS). The ArcGIS software also interfaces directly with Microsoft Access™ Database (Access) format. The data collected as part of this study will be stored in the first instance in Access allowing a structured and relational storage system with the added advantage of ready spatial representation. This format is also widely used and is portable, allowing easy packaging of the data and associated maps etc for individual stakeholders. This will also assure secure access to the data until such time as this is no longer required. In the future, the data can be readily integrated into an enterprise database system such as the AIMS ORACLE/ArcSDE environment, which will allow extra functionality such as dynamic publication of data and maps to the Web.

Base spatial datasets have been provided primarily through the Western Australian Department of Environment and Conservation (DEC). These include high resolution aerial mosaics, marine and shoreline habitat information, coastal outlines and marine fauna observations. Multibeam surveys conducted by FUGRO have been included as both point and raster (gridded) GIS datasets. The GIS layers for the data collected in April – May 2006 are described below:

- Demersal Fish Assemblages Surveys using BRUVS – ArcGIS point shape file created with attributes including date, time and operational code for each camera deployment. Video samples from each deployment have also been added as an attribute to utilize the hyperlink functionality of ArcMap (the mapping component of ArcGIS). This allows the user to "click" on the location and launch the associated files application.
- Towed Video Surveys – ArcGIS point shape file created showing start and end points for each tow as well as an ArcGIS line shape file created showing the track. Attributes for each include date, time and operational codes for each tow. As for the BRUVS data, video files will be linked via an attribute and thus viewable from the ArcMap environment.
- Benthic Sled – ArcGIS point and line shape files showing the start/end point for each tow and tracks respectively. Still images from the samples acquired will be attached using the hyperlink technique.
- Sediment Grabs – ArcGIS point shape file created showing locations of each grab. Attributes include date, time and operational code for each grab.

Analysis data from each of the surveys can be attached via relational joins from their associated tables in the Access database. Alternatively, new layers with attributes that include the analysis data can be created.

Data can be exported from ArcMap™ to create Google Earth™ kml/kmz files. These files allow access to the data for non-GIS users. Additionally, a web-based system for viewing the data is being created to provide more access for non-GIS users.

Multivariate statistical analysis and GIS modeling may establish trends between physical and biotic values and identify factors that are reliable 'surrogates' of specific habitats. These relationships will be extrapolated to the broader area to aid in the production of broadscale habitat maps of the NMP. As the Project matures through 2008-9 and more comprehensive and detailed data is obtained, additional ecological modeling of the datasets is planned, with the objective of delivering a predictive spatial model, with spatially defined probabilities or uncertainties, for the presence and absence of key habitat types throughout the NMP.

INTRODUCTION

The primary criteria identified for establishing MPAs are that they contain a comprehensive, adequate and representative (CAR) sample of marine biodiversity (Jordan et al. 2005). Comprehensive is the extent to which the full range of ecosystems and habitats are included in MPAs; adequate with regard to the degree to which the size, boundaries and location of MPAs are adequate to maintain biodiversity and ecological patterns and processes, especially in relation to the ability to manage impacting activities; and representative with regard to the extent to which MPAs reflect the range of biological diversity of communities within ecosystems and habitats (Jordan et al. 2005). Representativeness here means the intention of planners to include samples of each habitat, seascape or community type, depending on the scale of the MPA area and the issues being addressed (Stevens and Connolly 2004). When considering representation in design planning, it is the biological distributions that are the central interest (Stevens and Connolly 2004). The effectiveness of marine reserves depends on their goals, but many are envisaged to play an ecosystem role on a scale larger that the reserve boundaries (Palumbi 2003). Marine reserves, regardless of their size, and with very few exceptions, lead to increases in density, biomass, individual size, and diversity in all functional groups (Halpern 2003).

Seabed habitat mapping is increasingly being used to identify the distribution and structure of marine ecosystems and as surrogate measures of biodiversity for MPA planning (Jordan et al. 2005). The representative protection of marine biota in Australia would ideally be based upon extensive knowledge of the distribution of biota and ecosystem components (Post 2006). Identifying and protecting all habitats is an essential objective for a network of reserves (Roberts et al. 2003). Optimal placement of MPAs requires identification of the range of habitats used by species of concern, determination of their demographic rates in these habitats and comparisons of species abundances over a broad range of habitats (Eggleston and Dahlgren 2001). Such information, however, is not always readily available. Habitat heterogeneity, acting as a proxy for maximizing the number of species protected, can be used in its place to guide the selection of individual reserve units (Roberts et al. 2003). For example, as the number of habitats increases at a site, the site becomes more heterogeneous and so does its value as a reserve (Roberts et al. 2003).

Choosing the most suitable mapping method, out of the many techniques available depends on the objective(s) of each project, particularly with respect to the scale and distribution of the sea floor features of interest and the required resolution of the resulting maps (Diaz et al. 2004). The application of acoustic technologies to sea floor mapping has enabled effective collection of data on sea floor substrata and has led many mapping studies to equate benthic habitat with bottom sediment or substratum type (Ball et al. 2006). This approach to mapping emphasises the concept of benthic habitat as a ‘dwelling place’ or ‘preferred substratum’ for biota, from species to entire communities, with the biota representing a form of cover overlying the physical bottom features (Ball et al. 2006). This approach can be limiting, however many such studies also include biological sampling or observations (e.g. underwater video) to verify and identify presumed connections between physical characteristics and distribution of biota (Ball et al. 2006).

Ningaloo Marine Park

Ningaloo Marine Park is situated on the northern extremity of the Dirk Hartog Shelf of Western Australia and extends 260 km west of Cape Range peninsula from Point Murat near North West Cape south to Red Bluff, beyond Coral Bay (21°50'S to 23°35'S) encompassing most of Ningaloo Reef (Carrigy and Fairbridge 1954; LeProvost Dames and Moore 2000) (Fig.1). The submarine shelf is gently sloping underlain by Pleistocene limestone with a veneer of marine sediments and interrupting this shelf, a fringing barrier reef system (Carrigy and Fairbridge 1954). One of the major features of Ningaloo Marine Park is the bathymetry which sees a very rapid drop-off in bottom depth in the northern part of the Marine Park in front of Cape Range (LeProvost Dames and Moore 2000). This results in a narrow shelf with its landward edge unusually close to the shore, i.e. between Point Cloates and Jurabi Point, depths of 100 m occur within 6 km of the shore and 500 m within 15 km, which brings oceanic species like whales and pelagic fish relatively close to shore (LeProvost Dames and Moore 2000), due to upwellings and nutrient rich waters. In the south of Ningaloo Marine Park the shelf broadens to greater than 30 km near Gnaraloo and Red Bluff (LeProvost Dames and Moore 2000).

Ningaloo Marine Park includes areas under Commonwealth (2,326 km^2) and State (2,240 km2) jurisdiction (Fig. 1) and covers a total area of 4,566 km^2 from the shoreline to the continental slope. The State jurisdiction extends 5.5 km seaward of the outer edge of the reef crest and comprises the narrow terrestrial strip from Amherst Point to Winderabandi Point, the fringing reef, and back reef lagoon adjacent to the land and 5.5 km seaward of the reef crest.

Ningaloo Reef forms a discontinuous barrier enclosing a shallow, narrow lagoon (2 to 4 m depth) varying in width from 200 m to more than 7 km (MPRA CALM CCPAC 2005). It is a unique fringing reef, the largest in Australia and among the longest fringing corals reefs in the world (MPRA CALM CCPAC 2005). Ningaloo Reef is often described as one of the most biologically diverse shallow water marine ecosystems in the world. Although even in the shallow waters knowledge of diversity is not uniform across all phyla. However, little is known about the benthic habitats and communities in the deeper waters (>20 m) beyond the fringing reef which makes up the majority of the marine park's 4,566 km^2. Roberts et al. (2002) identified the North West Cape and the Ningaloo region as one of the 18 richest multi-taxon centres of endemism. Many coral reef taxa have restricted ranges, and are clustered into centres of endemism, making them vulnerable to extinction (Roberts et al. 2002). The paucity of knowledge about seabed biodiversity in the intermediate and deeper waters of the Ningaloo Marine Park has been recognised since its inception in 1987.

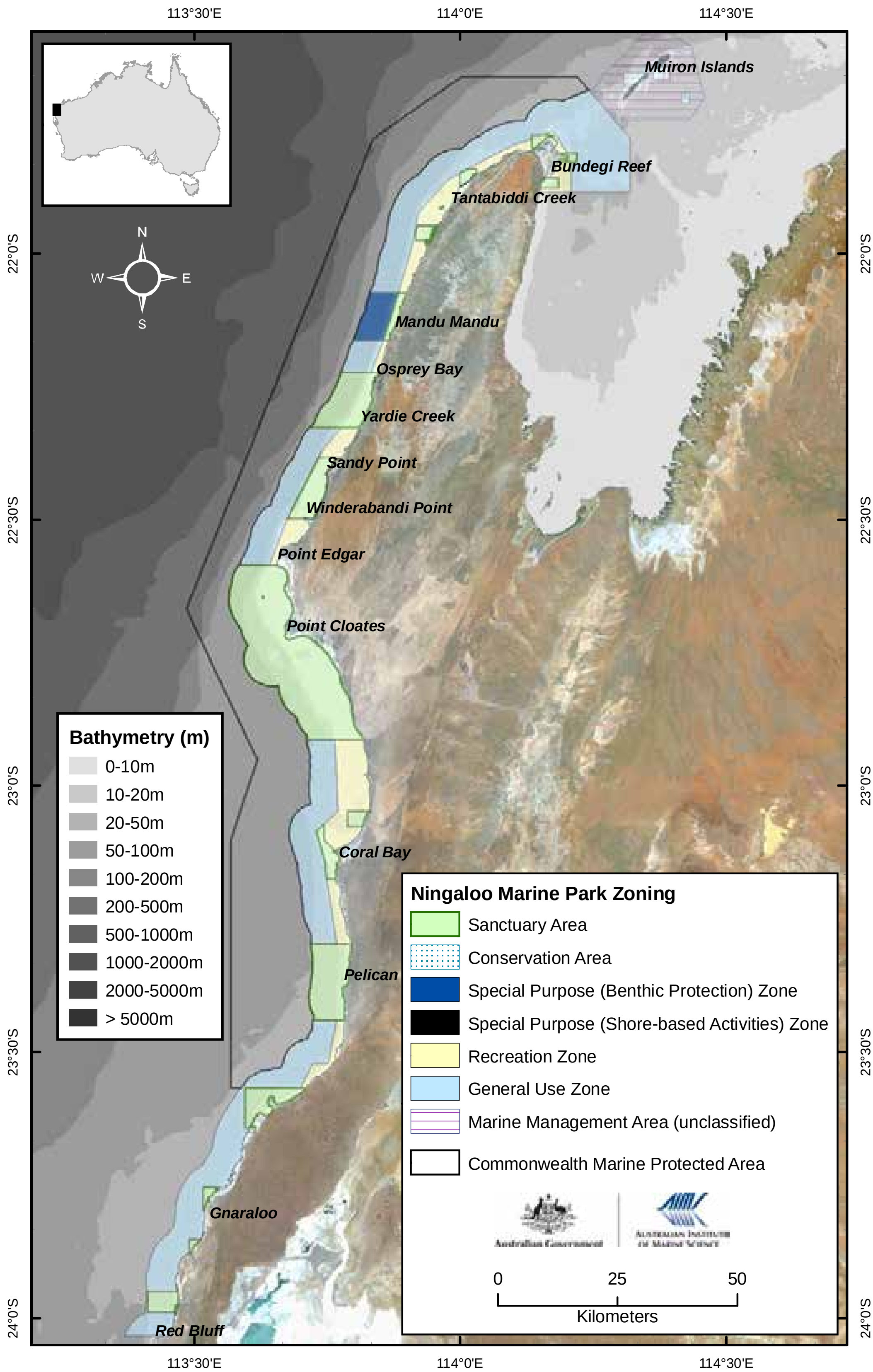

Figure 1. Map of Ningaloo Marine Park and Muiron Island Marine Management Area: zoning and deepwater bathymetry (compiled by Felicity McAllister, AIMS).

Dominant Benthic Communities

Due to the logistical constraints sampling benthos in deeper waters of Ningaloo Marine Park (20-110 m), few studies have investigated the key species/functional groups that make up the major benthic communities and the geomorphology/surficial sediments underpinning these communities on the scale of this investigation, especially in the southern part of the Shelf (Carrigy and Fairbridge 1954; Wilson 1972; Western Australian Museum 1988; Rees et al. 2004). Previous studies suggest that the substrate of the deeper waters of the northern Ningaloo Marine Park consist, in general, of a varying veneer of sand overlying limestone with a predominant sessile flora and fauna of algae and sponges with a diverse mobile crustacean and mollusc fauna (LeProvost Dames and Moore 2000). The Western Australian Museum (1988) reported that the bottom fauna in waters >40 m is dominated by sponges, however the sponge assemblages have never been systematically examined.

Biodiversity analyses of Australian tropical fauna, at smaller intra-regional spatial scales, indicate that sponges frequently form spatially heterogeneous assemblages with patchy distributions in deeper waters (Wörheide et al. 2005). These assemblages often contain high numbers of species not found in adjacent communities (i.e. apparent endemics), sometimes with as little as 15% similarity in species composition (Wörheide et al. 2005). Studies of cross-shelf distributions have shown certain environmental variables to be linked to community heterogeneity, most notably light, depth, substrate quality and nature such as coralline vs. non-coralline, hard vs. soft substrata, local reef geomorphology indicative of the presence or absence of specialised niches, water quality and flow regimes, food particle size availability, and larval recruitment and survival (Wörheide et al. 2005).

It is imperative to describe existing natural patterns of species distribution and abundance in Ningaloo Marine Park so that changes to biodiversity can be quantified and managed effectively in the future.

Project Aims

The aims of the project are:

- To develop an improved bathymetry for Ningaloo marine Park through collation of available data and acquisition of new soundings using acoustics
- Undertake a broadscale characterisation of the biodiversity of the deepwater benthic habitats and associated fish communities of Ningaloo Marine Park based on historical information and information to be provided through deepwater broadscale habitat mapping as part of this study.
- Characterise the surficial sediments and seabed geomorphology of the deeper waters of the Ningaloo Marine Park.

Survey Approach

This research is using singlebeam and multibeam acoustics, traditional sedimentological and geomorphological sampling techniques, macro-benthos sampling and the creation of bio-inventories, Baited Remote Underwater Stereo-Video sampling targeting the diversity and abundance of demersal finfish and towed video, Remote Operated Vehicle (ROV) and digital stills for habitat characterisation and classification. The Australian Institute of Marine Science (AIMS) is leading the project, which is a multi-institutional collaboration, supported through co-investment with WAMSI. Field work has continued annually since 2006 and should be finalised in 2009. At the end of 2007 a large proportion of the data collection has been completed, with data synthesis and analysis progressing well.

The focus of the biodiversity survey effort is the benthos in depths between 20 and 110 m throughout Western Australian waters of the NMP. Different methods with varying degrees of resolution were used. All the surveys in 2006 and 2007 were conducted on the AIMS research vessels *RV* Cape Ferguson and the general approach during 2007 was to extend the spatial coverage of the sampling begun in 2006, with the ultimate aim of providing some level of characterisation for the whole of the offshore component of Ningaloo Marine Park (NMP). This report summarises both field work and analytical results completed during 2007.

GENERAL DISCUSSION

The singlebeam and multibeam acoustics surveys achieved during the 2006/2007 have provided detail of the seafloor most of the Ningaloo Marine Park. Different habitats, based on bathymetry and geomorphology could be distinguished within this area. Sediment generation, transport and deposition patterns were evident, ridge systems were identified, and patches of previously unknown rubble mounds were discovered. A considerable amount of spatial detail was gained. The acoustics combined with sedimentological and geomorphological data enabled us to categorise different habitats according to depth, topography, substrate stability, hardness and roughness, grain size and suitability to support significant biota, from the back of the reef slope (beyond the fringing reef) out to the edge of the continental shelf plateau. The significance of the acoustic data collected in 2006/2007 has prompted the survey team to try and include the whole of the Ningaloo Marine Park in the next acoustic survey in 2008, and to improve the resolution of the data to allow for easier and to provide more accurate interpretations of the data. Additional opportunities to include further mulitbeam surveys will be explored as part of the 2008 effort.

Significant findings from this study include discovery of diverse sponge and soft coral communities in the deeper waters of the continental shelf (50-110 m in the north and also 30-60m in the south) with potentially high and unique biodiversity values, several large ridge systems parallel to the coastline supporting a vast array of species with diverse piscatorial associations, and several patches of previously unknown and unidentified rubble mounds. Nonetheless there were very extensive areas throughout the NMP of low macroscopic species diversity, possibly due to sediment transport and deposition of sand. Few hard corals were evident beyond 40-50 m during the survey and even in shallower depths were sometimes a less significant component of the benthic communities at the southern extreme of the Park. While large sand and rhodolith habitats were evident, the biological diversity associated with these areas is likely to be interstitial and habitat utilisation by mobile species may also be transitory. Consequently, while these habitats types are very important components of the deeper waters of NMP, this study will markedly under sample their biodiversity values and there contribution to ecosystem integrity requires study. Even though there have been very few surveys previously in this region, from the few surveys conducted north of the Ningaloo Marine Park, Hooper et al. (2002) identified the northwest shelf of Australia as a sponge biodiversity ‘hotspot’. Our results support this conclusion.

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CHAPTER 1
Analysis of Ningaloo Singlebeam and Multibeam Sonar Data

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Introduction

This document summarises analysis of acoustic data collected in Ningaloo Marine Park organised by the Australian Institute of Marine Science (AIMS). In late April to mid May 2006 and May 2007 the AIMS vessel RV Cape Ferguson collected singlebeam echosounder data using a Centre for Marine Science Technology (CMST), Curtain University of Technology Simrad EQ60 sonar (38 and 200 kHz) running dedicated survey lines, along most of the western side of Ningaloo reef out to the 100 or 200 m depth contour (Figure 1a & b) shows the wide scale sampling regions). Multibeam data was collected at several locations by Fugro Survey Pty. Ltd. using a Reson 8101 sonar (240 kHz operating frequency) mounted on the RV Cape Ferguson in April 2006 (Figure 1a) for sampling area). The sonar data sets are part of an AIMS project to describe the seafloor biological community structure, geological attributes and general biological productivity of waters to the west of Ningaloo reef. The sonar data sets were collected in conjunction with extensive biological and physical sampling techniques plus underwater video and still footage (Figure 1(c) for sampling). An AUV was deployed off the RV Cape Ferguson on multiple occasions for obtaining multibeam sonar and still imagery of the seabed. In August 2007 AIMS agreed for the CMST to process acoustic data collected in Ningaloo Marine Park in 2006 and 2007 to:

- provide bathymetry data from all singlebeam sonar data collected in 2006 and 2007.
- use sonar backscatter to segment the seabed using singlebeam and multibeam data (collected by Fugro Survey Pty. Ltd.) for selected regions.

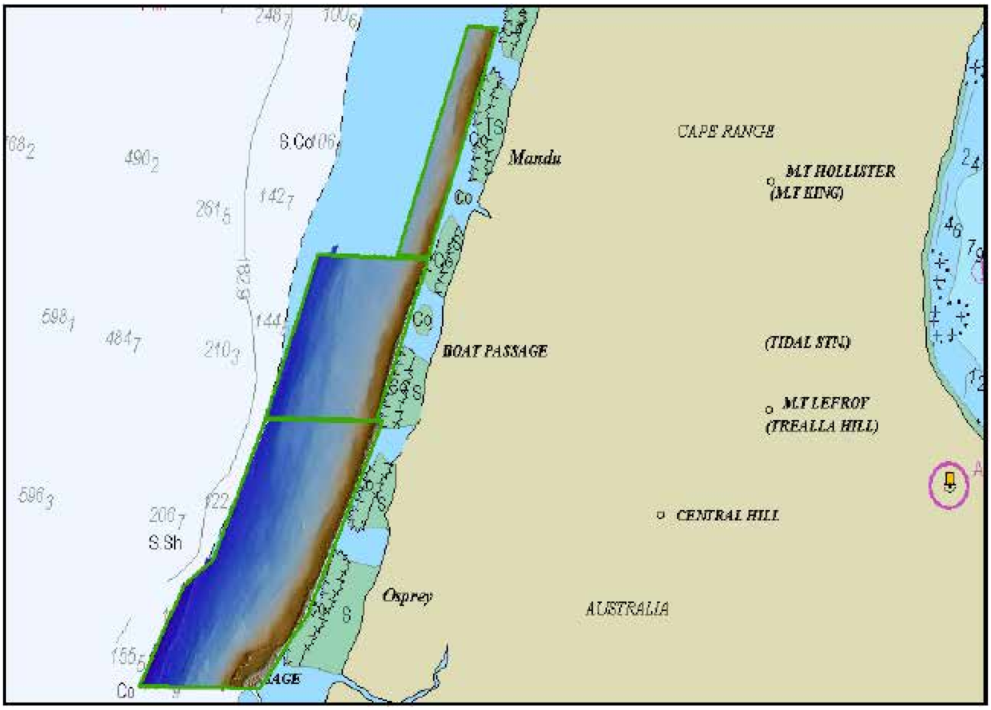
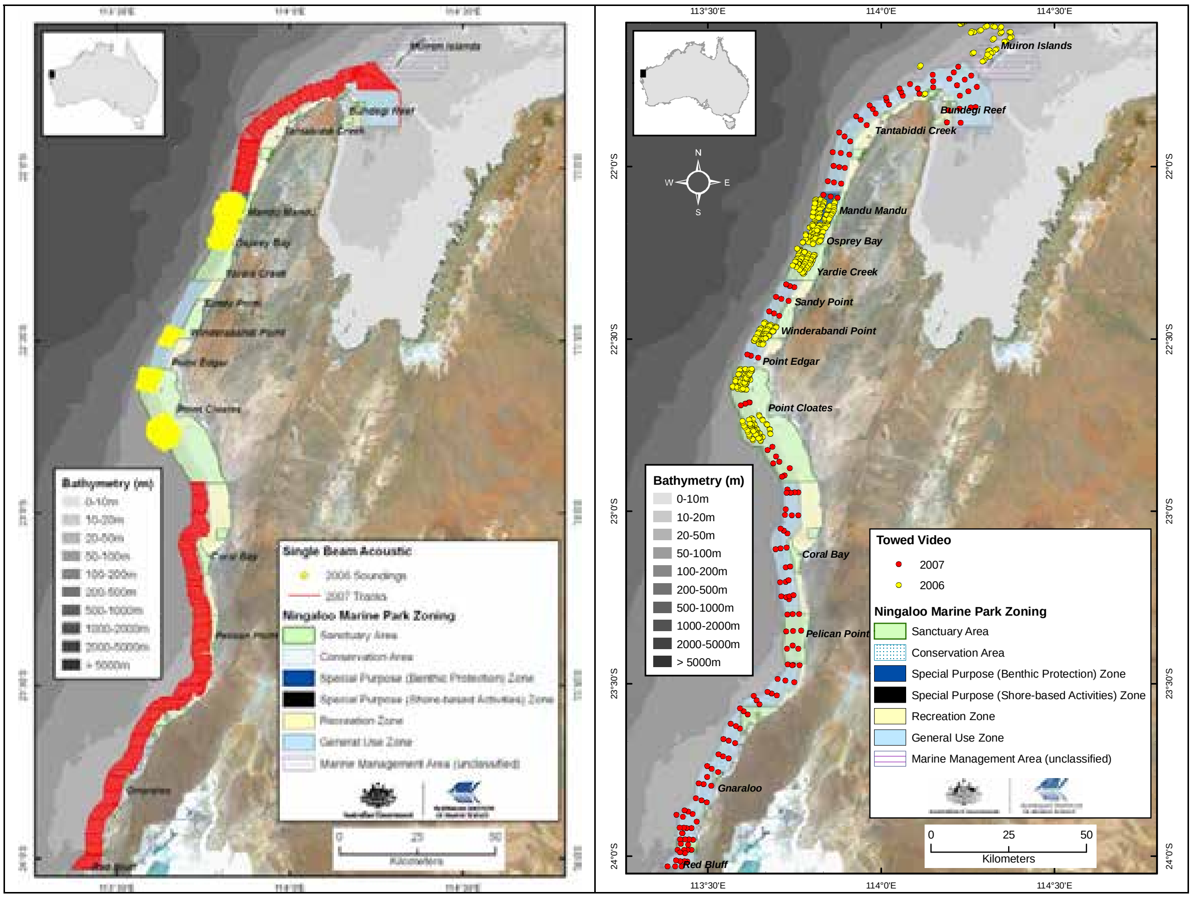


Figure 1(a). Map of Ningaloo Marine Park with multibeam swath.



b) **c)**

Figure 1(b & c). Maps of Ningaloo Marine Park together with b) singlebeam tracks; c) towed video transect locations.

Methods

Marine survey specialists FUGRO were contracted in 2006 to conduct a habitat mapping hydro acoustic survey covering three distinct areas of Ningaloo Marine Park in close proximity to each other; Osprey, Boat Passage and Mandu (Fig. 1a). The Multibeam survey was limited to three regions (Fig. 1a) due to cost constraints and the need for a preliminary assessment of the results from this particular survey technique. The survey was carried out onboard the AIMS Research Vessel RV Cape Ferguson.

From 2006-2008 AIMS in collaboration with CMST, Curtain University of Technology, singlebeam-surveyed the whole of Ningaloo Marine Park using a Simrad EQ60 Singlebeam echo-sounder providing cross and along shelf profiles. Detailed soundings with dates, times and coordinates (latitude and longitude) were recorded. Sounding transects were approximately 500 metres apart running east/west extending from the shallowest parts of the back reef (approximately 10-30 metres depth) seaward to the outer limit of the Ningaloo Marine Park boundary. CMST, Curtain University of Technology have processed the singlebeam and multibeam data from 2006/2007.

Singlebeam

The RoxAnn technique has been adopted and used for processing singlebeam data. The RoxAnn system uses echo-integration methodology to derive values for the tail of the first return echo (E1) and the whole of the second return echo (E2) as shown in Figure 2. While E2 is primarily a function of the gross reflectivity of the sediment and therefore hardness, E1 is influenced by the small to meso-scale backscatter from the seabed and is used to describe the roughness of the bottom. In general terms E1 and E2 are related dominantly to acoustic roughness and hardness respectively, although each measure contains components of both physical attributes of the seabed.

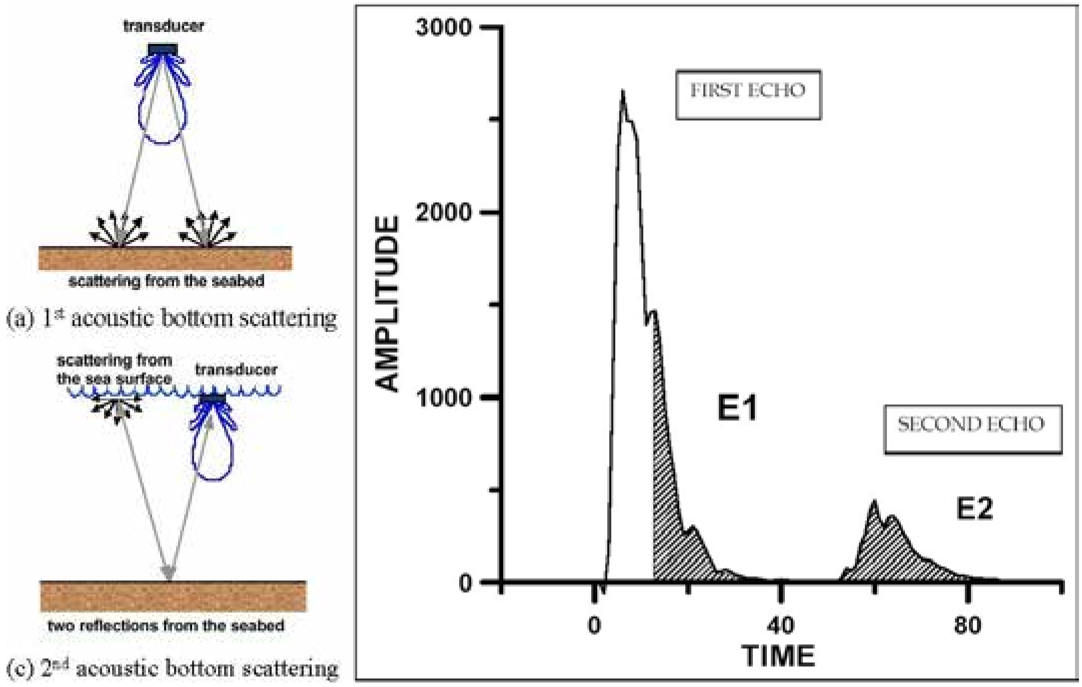


Figure 2. Scattering geometry and parts of interest of 1st and 2nd bottom returns.

Echoview™ software commercially developed by SonarData has been used for quality control and data processing. The CMST has a commercial Echoview™ license. Following procedures described in Siwabessy et al. (2004; 2000) the two RoxAnn parameters (E1 and E2) were derived from the Echoview™ software.

Interpolation is required to produce images of E1 and E2 to fill unsampled area from the along-track singlebeam data. Of the commonly used interpolation techniques, Krigging was found to give the most satisfactory results and was adopted here.

Multibeam

Figure 3 depicts the main processes involved to produce bathymetry and backscatter strength from the multibeam data and is self-explanatory. Multibeam bathymetry is derived from the sonar travel time while backscatter is one or more measures of the seafloor "reflectivity" and like the E1 and E2 parameters described above reveals information on the seafloor type. The CMST has developed a processing toolbox for multibeam bathymetry and backscatter analysis which is described in Gavrilov et al. (2005a; 2005b) with the angular dependence type 2 (AD type 2) known as 'angle cubes' summarised in Parnum et al. (2007; 2006). The CMST has developed novel techniques to remove or account for the differences in backscatter which arise due to the differing angle of ensonification by multibeam sonars. These are briefly described below.

Angular dependence type 1 (sliding window)

The multibeam backscatter data and the angle of incidence are used to derive the backscatter angular dependence averaged in 1° bins from spatially corrected locations over a predefined number of pings that constitute a spatial window of certain length along the swath line. The angular dependence derived within the window is attributed to its spatial centre. A 50% overlap between neighbouring spatial windows has been used in order to reduce boundary effects. These angular dependence values are then removed from the backscatter data. The resulting backscatter values are restored to the absolute level by scaling to the absolute backscatter levels calculated at 30-31° in the average angular dependence.

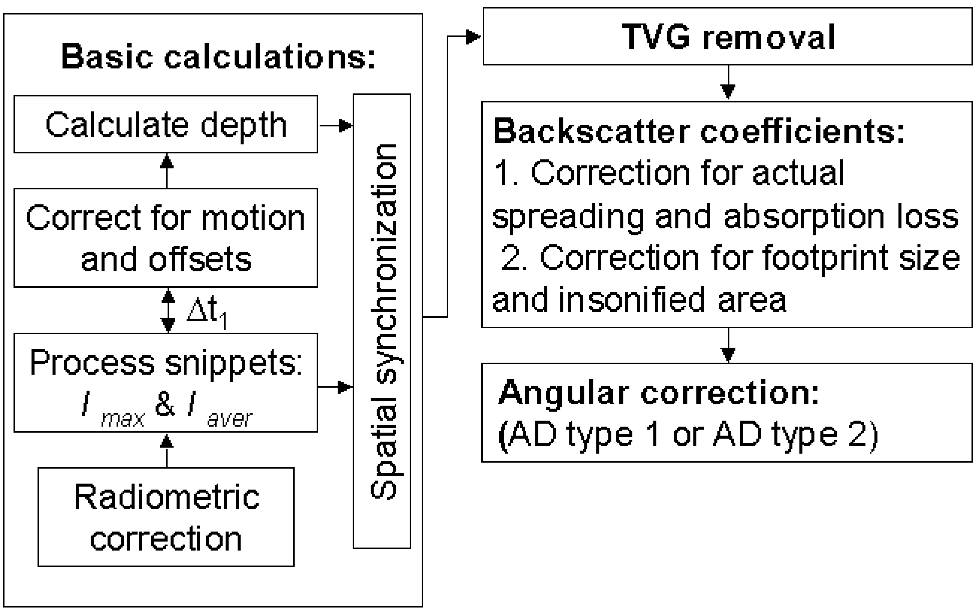


Figure 3. Flowchart of the multibeam main process.

Angular dependence type 2 (angle cube)

An 'angle cube' can be thought as analogous to a hyperspectral cube. To create an angle cube, all the multibeam backscatter data from a survey area are gridded in 3 dimensions: X, Y and incident angle using 1° bins and spatially corrected pings. Data in each angle layer are then interpolated, using a Krigging interpolation technique, into each node of the grid, producing a solid cube. Both the mean and STD of backscatter strength versus incident angle have been shown to be important statistical descriptors. Therefore, an angle cube was generated for both of these properties, referred to here as the mean cube and STD cube. The actual backscatter data in the sparse gridded array were normalised by removing the mean values and normalising by the STD at each angle and at each X and Y location on the seafloor. This procedure reproduces the underlying local variations, but is independent of incident angle. The resulting backscatter values are restored to the absolute level at each point by multiplying by reference STD values and then adding reference mean levels. Reference STD values and reference mean levels are the average value at the oblique angles greater than 20°.

Classification

A cluster analysis (CA) was adopted here and applied to acoustic data (RoxAnn E1 and E2 parameters for the singlebeam and backscatter strength for the multibeam). A supervised clustering technique with Bayesian distance was used. A training set comprising distinct seabed habitat based on video footages and results of video analysis conducted by AIMS was set up. The mean of E1 and E2 for the singlebeam and the mean of backscatter strength for the multibeam, and their covariance matrices were estimated from the training set. The results from the training set then became the seeds of the initial centroids. Using these seeds of the initial centroids, the supervised clustering technique was eventually performed on remaining data.

Results

In 2006, singlebeam data were collected in Mandu, Osprey and Cloates (Cloates Reference, Cloates North and Cloates Zone) areas (see Figure 1b) whereas multibeam data were obtained in Mandu, Boat Passage and Osprey areas (see Figure 1a). In 2007, single beam data were obtained in consecutive areas between Red Bluff and Coral Bay and between Mandu and Bundegi Reef (see Figure 1b).

The bathymetry produced from the singlebeam and the multibeam acoustic data was tide corrected to the lowest astronomical tide (LAT) using respectively the predicted tides provided by AIMS taken from the Department of Planning and Infrastructure (DPI), and those used by Fugro Pty. Ltd.

Quality control was carried out using the Echoview™ software for the single beam data. Pings of missing data as shown in Figure 4 and pings with spike noise were marked as bad and excluded from further computations. Much of the bad data was believed due to the Simrad sonar having hard disk problems.

Spike noise as shown in Figure 5(a) were found in almost all multibeam data. This was identified and acknowledged in Fugro (2006). The CMST multibeam process toolbox (SAJI) was used to remove artefacts and noise from the multibeam data. This was a major exercise.

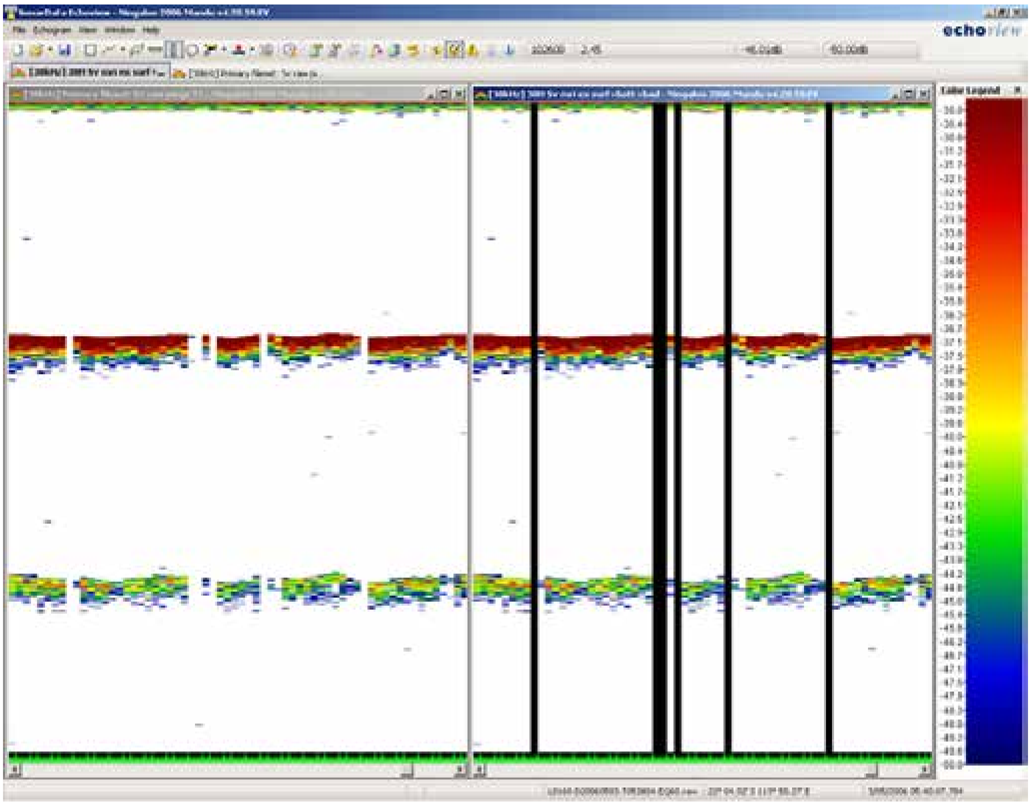


Figure 4. Representative example of single beam data with pings of missing data detected and marked as bad using the Echoview software.

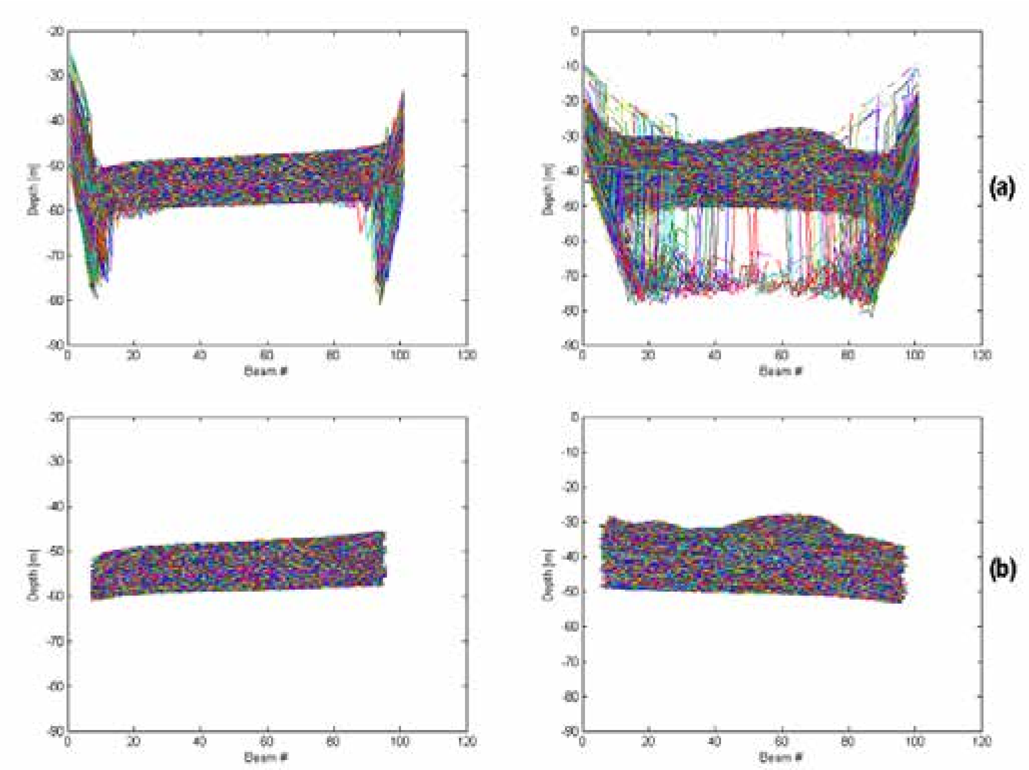


Figure 5. Representative examples of spike noise in multibeam data.
a) Before and b) After removal.

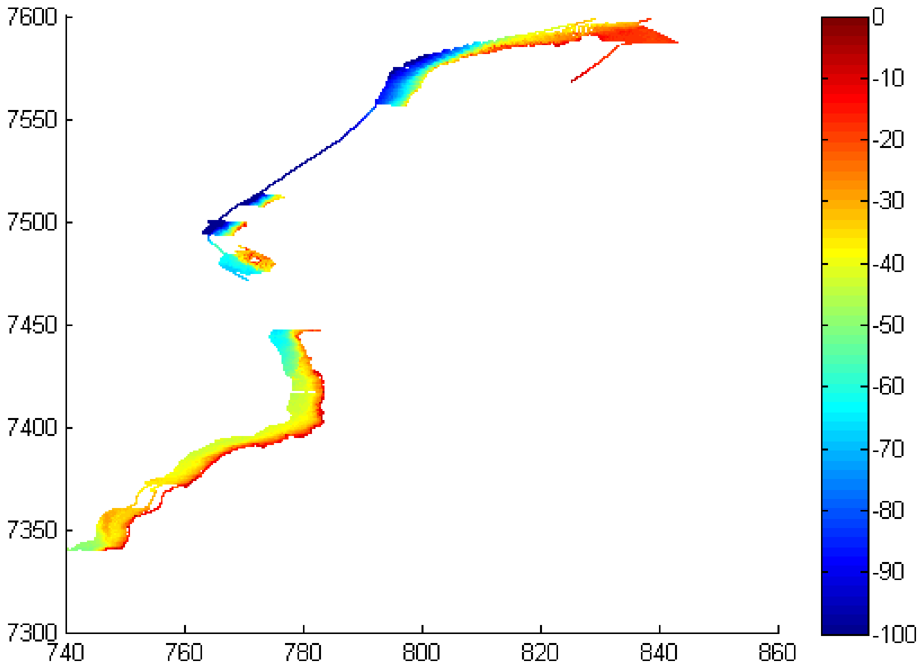


Figure 6. Bathymetry along single beam track.

The final singlebeam bathymetry was extracted from all "good" singlebeam pings from all areas except those which overlapped with the multibeam (Figure 6). The final multibeam bathymetry in all areas (Mandu, Boat Passage and Osprey) was gridded in 5 m bins (Figure 7) which was considered the optimum bin size for the data quality. The large number of bad pings in the multibeam data led to significant gaps between swath lines when higher resolution bins were used. Interpolation techniques could be used to fill these gaps but the data quality would then be similar to starting with a larger bin size anyway.

Due to a limited analytical budget only one set of multibeam backscatter data could be produced using the AD type 2 technique (Figure 8), this for the Mandu area. The remaining areas, Boat Passage and Osprey, were processed using the AD type 1 analytical technique (Figures 9 and 10). For the singlebeam data images of the RoxAnn parameters interpolated in 50 m nodes were derived only for Mandu, Cloates Zone and Red Bluff areas (Figures 11, 12 and 13).

Multibeam backscatter data gridded within the singlebeam footprint size along the track was compared with the RoxAnn parameters E1 and E2 at 38 and 200 kHz (Figure 14). A significant correlation between multibeam backscatter and singlebeam E1 was observed but no correlation with multibeam backscatter and singlebeam E2 values was found. Multibeam backscatter and E1 values are derived from the first bottom return and therefore possess similar physical mechanism; hence a strong correlation would be expected. E2 values however are different because they are derived from the second bottom return and as such have different physical scattering mechanisms. The correlation between the multibeam backscatter values at 240 kHz and E1 values at 200 kHz was higher than those at 38 kHz. E1 and E2 values at 38 and 200 kHz were interpolated in 25 m nodes within the multibeam swath area and compared with the multibeam backscatter (Figure 15).

Seabed classification derived from the multibeam backscatter strength was carried out for Mandu, Boat Passage areas, and from the singlebeam RoaxAnn parameter for Mandu, Cloates Zone and Red Bluff areas. Results of the video footage analysis conducted by AIMS, video footages, E1 [and multibeam backscatter] images were used to determine seabed classes and hence to set up training data sets.

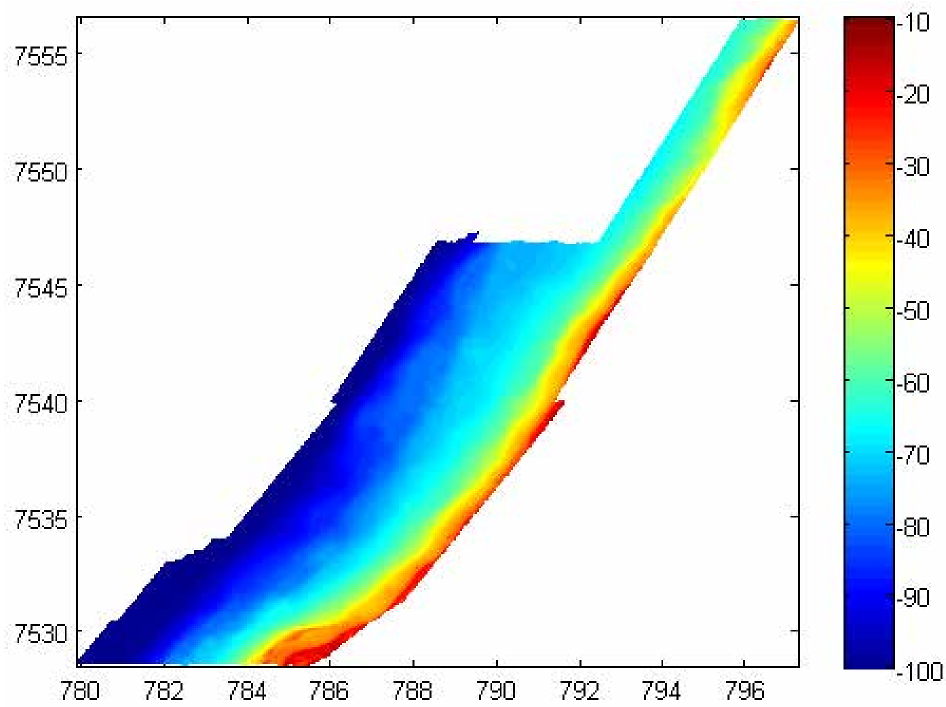


Figure 7. Multibeam swath bathymetry in 5m bins.

Three seabed classes were observed, these being "rhodolith" or calcareous nodules, sand and "mixed" in the Mandu and Boat Passage areas (Figures 8, 9, 11) and "algae", sand and "mixed" in the Red Bluff area (Figure 13). In Cloates Zone however, four classes were found (Figure 12) namely "rhodolith", "algae", sand and "mixed". Class descriptions are presented in Table 1. Table 2 provides a description of class index assigned to processed data files. The derived classes were compared with the ground truthed video data (video classes) in each area to produce a confusion matrix which was used to assess the overall classification accuracy of that area. Table 3 summaries the overall classification accuracy together with the user's classification accuracy, i.e., the probability that a classified pixel actually represents that information class on the ground.

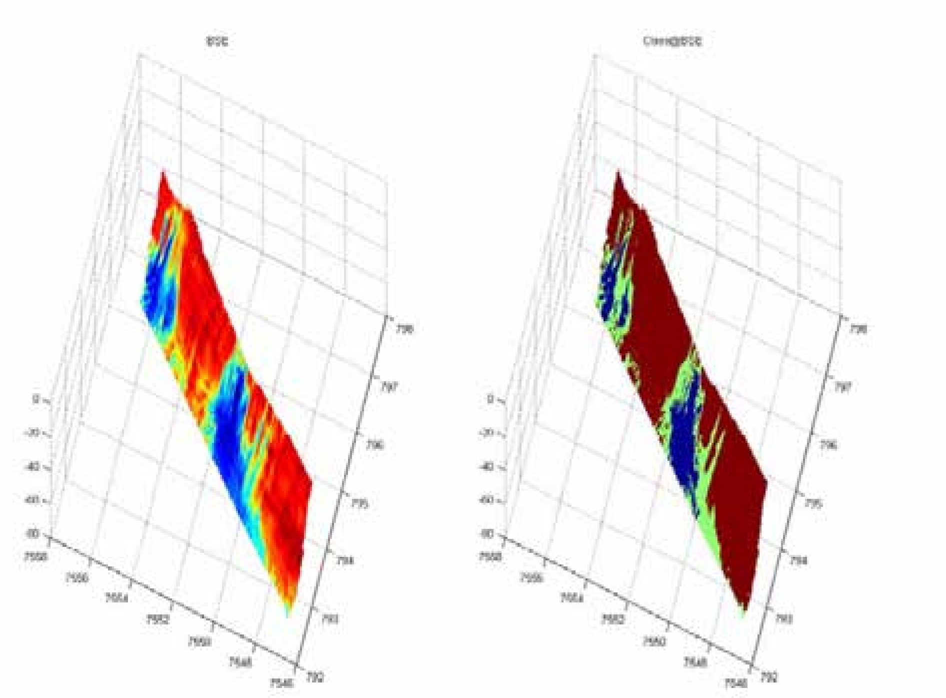


Figure 8. Backscatter strength image derived using AD type 2 a) and class image b) draped over the bathymetry in 5m bins in Mandu area.

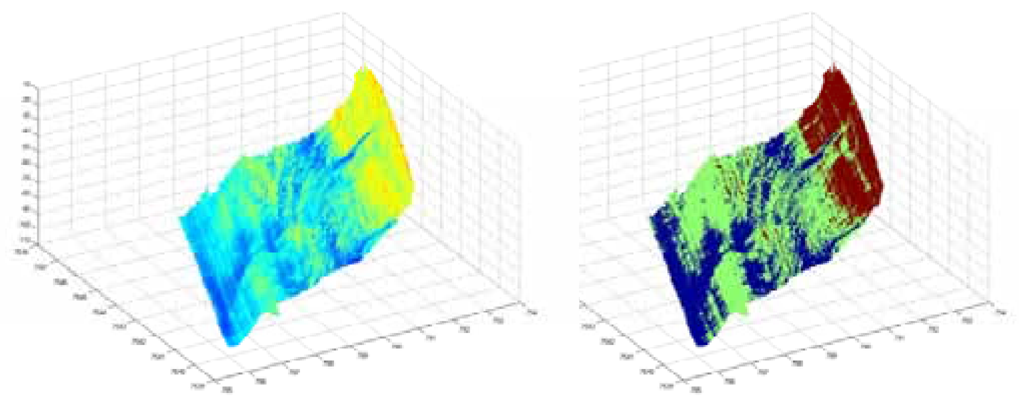


Figure 9. Backscatter strength image derived using AD type 1 a) and class image b) draped over the bathymetry in 5m bins in Boat Passage area.

Table 1. Class description.

Class	Description
"rhodolith"	All hard seabeds such as rhodolith, rubble, coralline, hard rock/reef  
"algae"	Macro algae, soft coral, vegetation or sponge on rhodolith or rock/reef  
sand	Relatively flat sand 
mixed	Sand (dominant) mixed with sparse "rhodolith" or sparse "algae". Sand waves/dunes or sand with large ripples.  

Table 2. Description of class index assigned on processed data file.

Area	Index assigned on data file			
	1	2	3	4
Mandu	sand	mixed	“rhodolith”	n/a
Boat Passage	sand	mixed	“rhodolith”	n/a
Cloates Zone	sand	mixed	“algae”	“rhodolith”
Red Bluff	sand	mixed	“algae”	n/a

Table 3. Summary of classification accuracy derived from confusion matrices.

Area	System	Classification accuracy (%)				
		Overall	User’s			
			rhodolith	algae	mixed	Sand
Mandu	SB 38kHz	73.00	68.42		81.82	57.14
	SB 200kHz	88.00	92.86		92.00	66.67
	MBS 240kHz	90.00	92.86		80.00	100.00
Boat Passage	MBS 240 kHz	90.00	100.00		82.76	93.33
Cloates Zone	SB 38 kHz	72.00	62.50	60	87.50	100.00
	SB 200 kHz	78.00	75.00	65.38	100.00	100.00
Red Bluff	SB 38 kHz	76.00		78.57	61.11	100.00
	SB 200 kHz	83.00		80.00	78.57	100.00

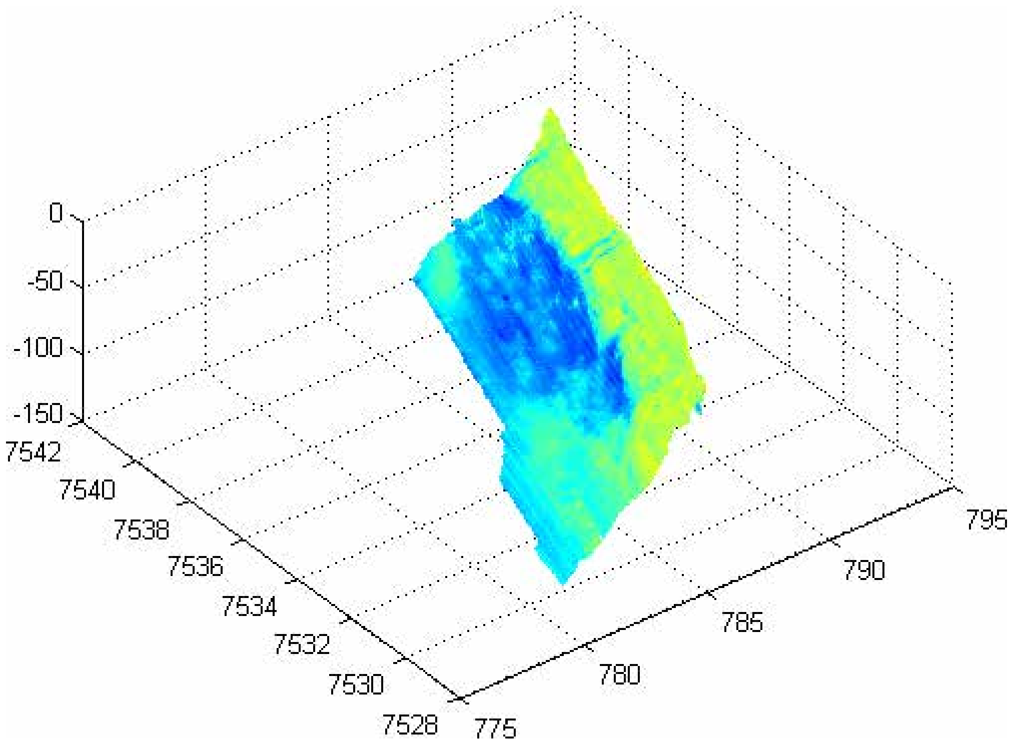


Figure 10. Backscatter strength image derived using AD type 1 draped over bathymetry in 5m bins in Osprey area.

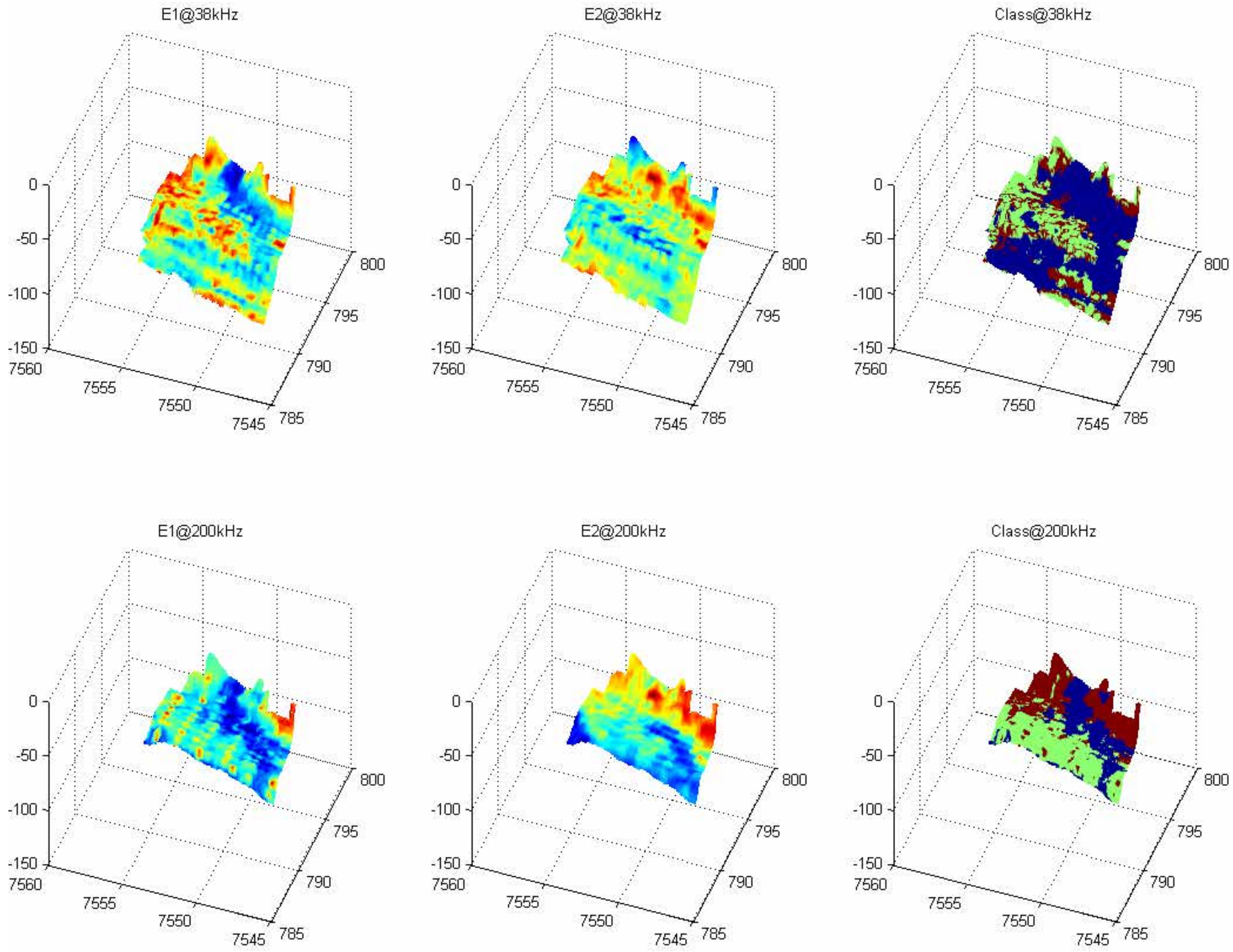


Figure 11. RoxAnn parameters E1 and E2 images interpolated in 50m nodes and class images at 38 and 200 kHz in Mandu area.

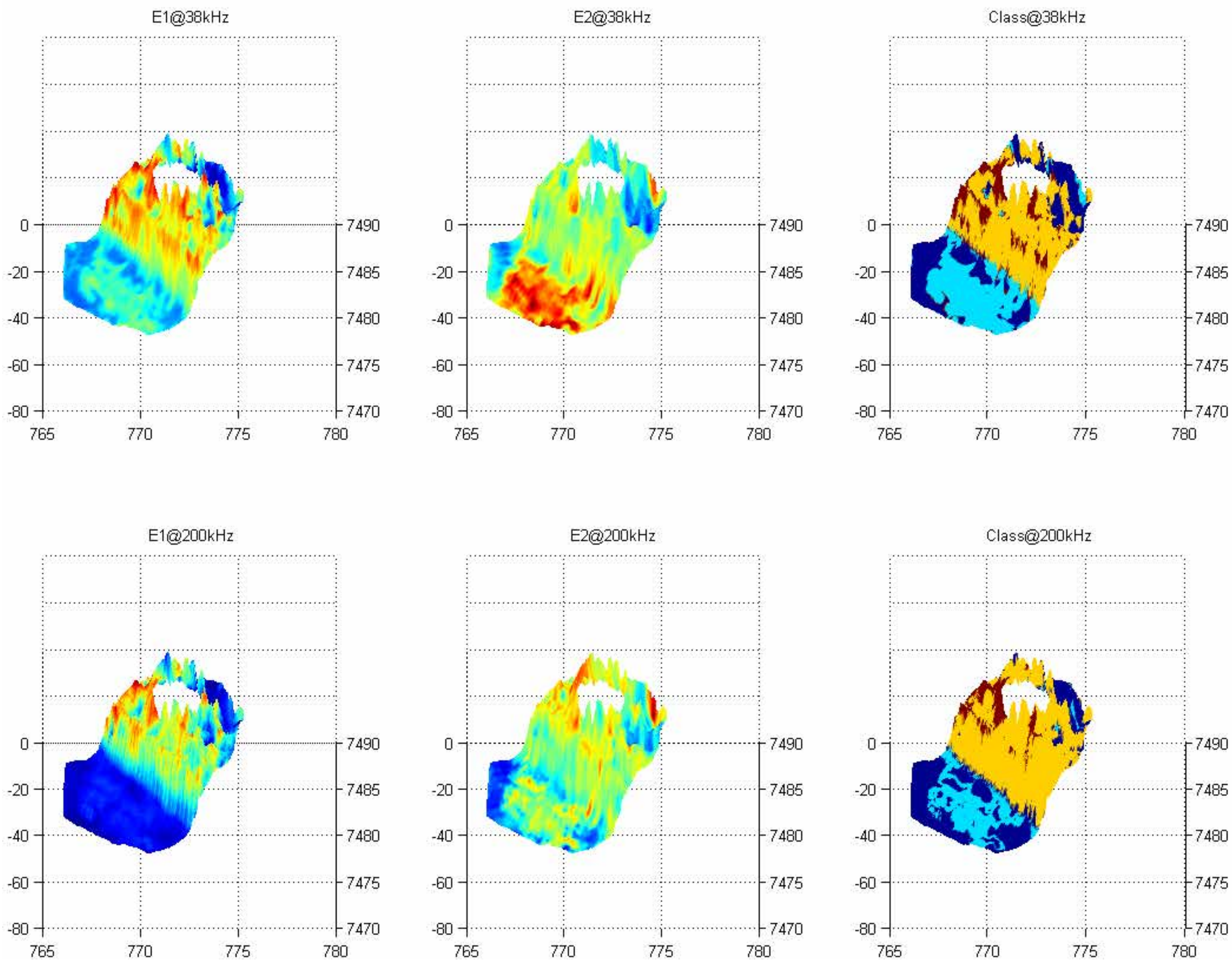


Figure 12. RoxAnn parameters E1 and E2 images interpolated in 50m nodes and class images at 38 and 200 kHz in Cloates Zone area.

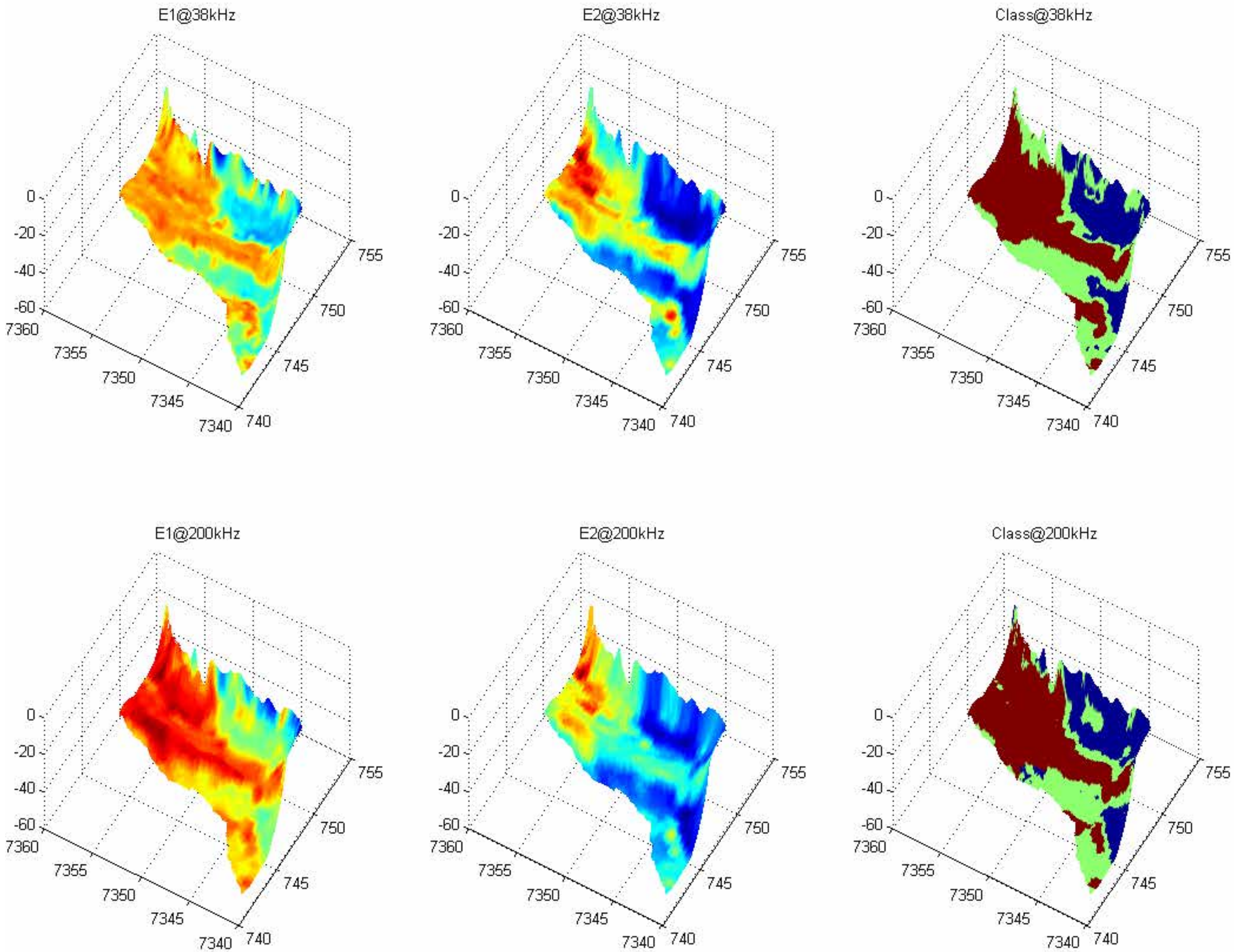


Figure 13. RoxAnn parameters E1 and E2 images interpolated in 50m nodes and class images at 38 and 200 kHz in Red Bluff area.

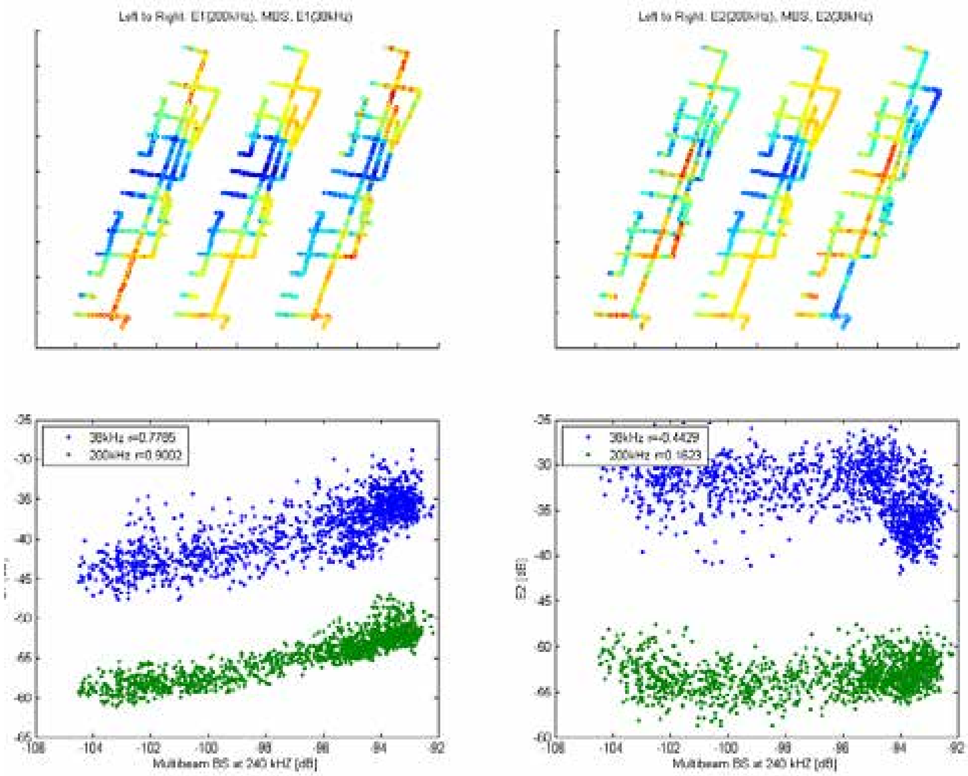


Figure 14. Comparison between E1, E2 values and multibeam backscatter within the singlebeam footprint size along the singlebeam track in Mandu area.

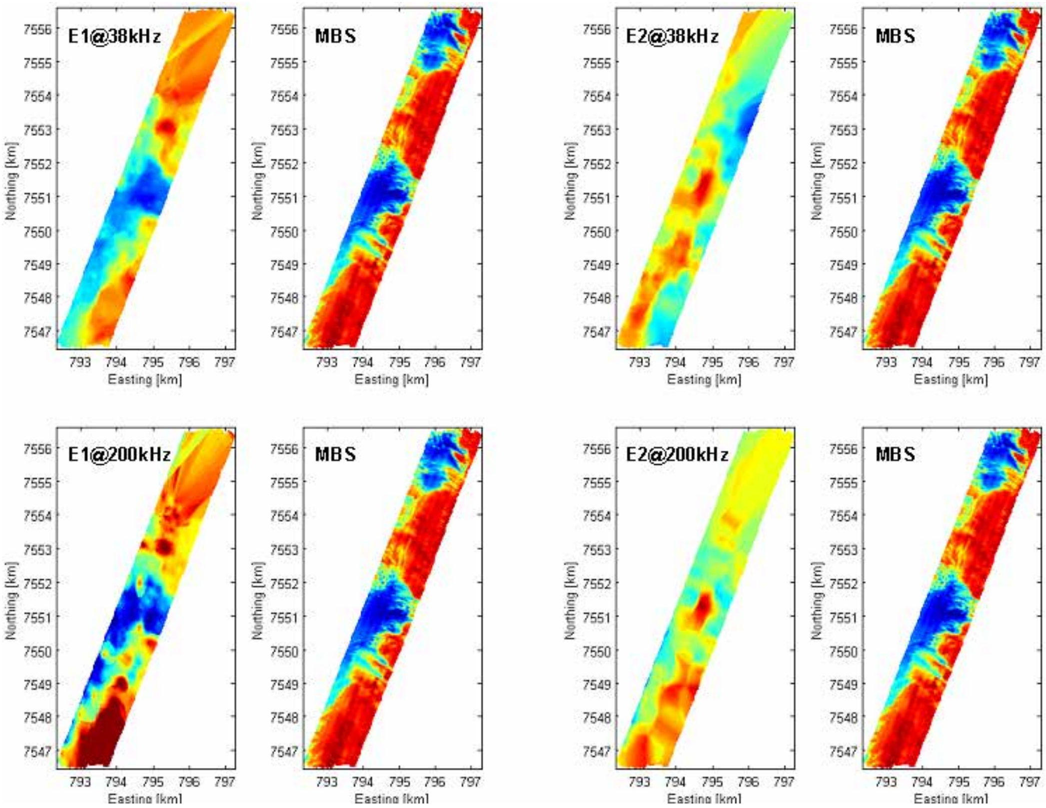


Figure 15. Comparison between multibeam backscatter and E1, E2 values within the multibeam swath area in Mandu area.

Deliverables

All processed data (bathymetry and backscatter) together with class indices for some areas, are stored in a Microsoft Office Access database format in a file called:

“Proc_Ningaloo_Sonar_Data.mdb”

and in ASCII formats (see Table 4). The file “Proc_Ningaloo_Sonar_Data.mdb” comprises seven table objects. Of the seven table objects, four are data tables i.e.
“Multibeam_5m”,
“Multibeam_x_Singlebeam_@Mandu_25m”,
“Singlebeam_50m” and
“Singlebeam_bathy_ping”

and 3 are information tables i.e.
“Geodetic information”,
“Location information” and
“Tide information” (see Figure 16).

All information tables provide repeating, supportive information (see Figure 17) to each data table
“Multibeam_5m” stores processed, gridded multibeam data in 5m bins. It includes: Easting
Northing
Depth
Backscatter strength
Seabed Classes
AD type.

“Multibeam_x_Singlebeam_@Mandu_25m” stores processed, gridded multibeam data in 25 m bins together with Krigging interpolated single beam data in 25 m nodes at the Mandu area. It comprises
Easting
Northing
Depth (from multibeam)
E1 and E2 parameters at 38 and 200 kHz
Backscatter strength
Seabed Classes based on 38 kHz, 200 kHz and Backscatter data.

“Singlebeam_50m” keeps Krigging interpolated single beam data in some areas. It consists of
Easting
Northing
Depth,
E1 and E2 parameters at 38 and 200 kHz
Seabed Classes based on 38 and 200 kHz data.

"Singlebeam_bathy_ping" keeps single beam-derived bathymetry data. It includes
Date
Longitude
Latitude
Easting
Northing
Depth.

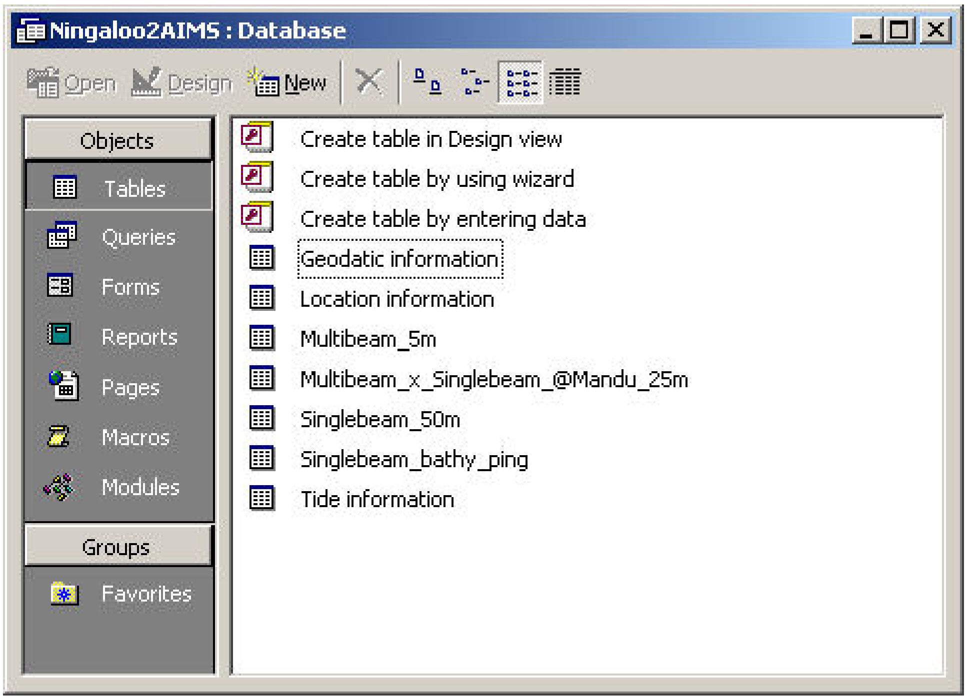


Figure 16. List of table objects (data and information) in "Proc_Ningaloo_Sonar_Data.mdb"

The relationship between information tables and each data table is shown in Figures 18 to 21. These relationships form query objects in "Proc_Ningaloo_Sonar_Data.mdb" as shown in Figure 22. To extract data, the "Location" (see Figure 17(b)) is simply entered in a query object of interest. For instance, the query shown in Figure 18 extracts Easting, Northing and Depth from the table "Multibeam_5m" for Osprey and produces an ASCII file "Multibeam_5m_Osprey(Easting,Northing,Depth).csv" listed in Table 4;

The query shown in Figure 19 pulls out Easting, Northing and E1_38kHz from the table "Multibeam_x_Singlebeam_@Mandu_25m" for Mandu and makes an ASCII file "Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,E1_38kHz).csv" listed in Table 4;

The query shown in Figure 20 takes out Easting, Northing and Class_200kHz from the table "Singlebeam_50m" for Red Bluff and results in an ASCII file "Singlebeam_50m_RedBluff(Easting,Northing,Class_200kHz).csv" listed in Table 4;

The query shown in Figure 21 extracts Date, Longitude, Latitude, Depth from the table "Singlebeam_bathy_ping" for Cloates Zone and gives an ASCII file "Singlebeam_bathy_ping_CloatesZone(Date,Longitude,Latitude,Depth).csv" listed in Table 4.

Note that information written within brackets in every filename of the ASCII formatted file tells the data structure of that particular file.

Conclusions and Recommendations

It has been demonstrated here that singlebeam and multibeam sonars are useful in seafloor mapping. The multibeam system offers better resolution, coverage accuracy and thus better seafloor classification than the singlebeam system can provide. Nonetheless, the singlebeam system offers the distinct advantage in that it is simpler and cheaper to mobilise and relatively straightforward to analyse. Since the singlebeam system only provides along track data, an interpolation technique is required to fill gaps of unsampled areas. Of many interpolation methods, Krigging was found to give the most satisfactory results. The correlation between multibeam backscatter strength and E1 values at 200 kHz was higher than that at 38 kHz. This was believed due to the similar operating frequencies of the sonars, 200 kHz for the singlebeam and 240 kHz for the multibeam. The classification accuracy increased with the operating frequency. It varied between 72% and 90%, with the singlebeam at 38 kHz giving the lowest accuracy of 72% and the multibeam the highest of 90%. It should be noted that the viable operational depth decreases as the operating frequency of the acoustic system increases, thus deeper areas require low frequency sonars.

The multibeam system was by all means the best remote sensing tool for seabed habitat mapping. The singlebeam system however provided a better general picture in a broader scale in a short time frame. Since interpolation was required for the singlebeam system, line separation or transect planning was critical. This will dictate classification results and accuracies as to wide a line separation renders interpolation between lines largely useless. A small degree of interpolation artefacts was been observed in one or two areas. This suggested that the line separation adopted in the last two surveys in the region in 2006 and 2007 fell just in the viable upper limit. We thus recommend that the line separation be reduced or at least be kept to that previously used. An increase in the line separation will increase interpolation artefacts and is therefore not recommended.

Geodatic information : Table

Geodetic_ID	Zone	Datum	Projection
1	49	WGS84	UTM
2	49	GDA94	UTM

Record: 1 of 2

a) Geodetic information

Location information : Table

Location_ID	Location	Survey	Comments
1	Mandu	Ningaloo 2006	
2	Boat Passage	Ningaloo 2006	
3	Osprey	Ningaloo 2006	
4	Cloates Reference	Ningaloo 2006	
5	Cloates North	Ningaloo 2006	
6	Cloates Zone	Ningaloo 2006	
7	Red Bluff	Ningaloo 2007	
8	All 2007	Ningaloo 2007	Only for the bathymetry
(AutoNumber)			

Record: 8 of 8

b) Location information

Tide information : Table

Tide_ID	Tide station	Filename	Original filename	Type	Information
1	Uncorrected	n/a	n/a	n/a	Data were not tide corrected
2	Exmouth	Exmouth 02-05-2007 - 15-02-2007.csv	EXM2007.PRE	Prediction	Exmouth: Datum is 12.796m below tidal benchmark DMH 052. AHD is 1.40m on that sca
3	Tantabiddi	Tantabiddi 02-05-2007 - 15-02-2007.csv	TAN2007.PRE	Prediction	Tantabiddi: Datum is 3.453m below tidal benchmark PWD B950.The benchmark is 3.153
4	Coral Bay	Coral Bay 02-05-2007 - 15-02-2007.csv	CRL2007.PRE	Prediction	Coral bay: Datum is 2.265m below tidal benchmark PWD BM B924. The benchmark is 1.
5	Carnarvon	Carnarvon 02-05-2007 - 15-02-2007.csv	CAR2007.PRE	Prediction	Carnarvon: Datum is 3.739m below tidal benchmark A876. AHD is 0.81m on that scale (
6	Unknown	Ningaloo 10-04-2006 - 17-04-2006.csv	ningalootides_date_depth.csv	Unknown	Adopted from FUGRO

Record: 1 of 6

c) Tide information

Figure 17. Repeating, supportive information provided in the information tables in "Proc_Ningaloo_Sonar_Data.mdb"

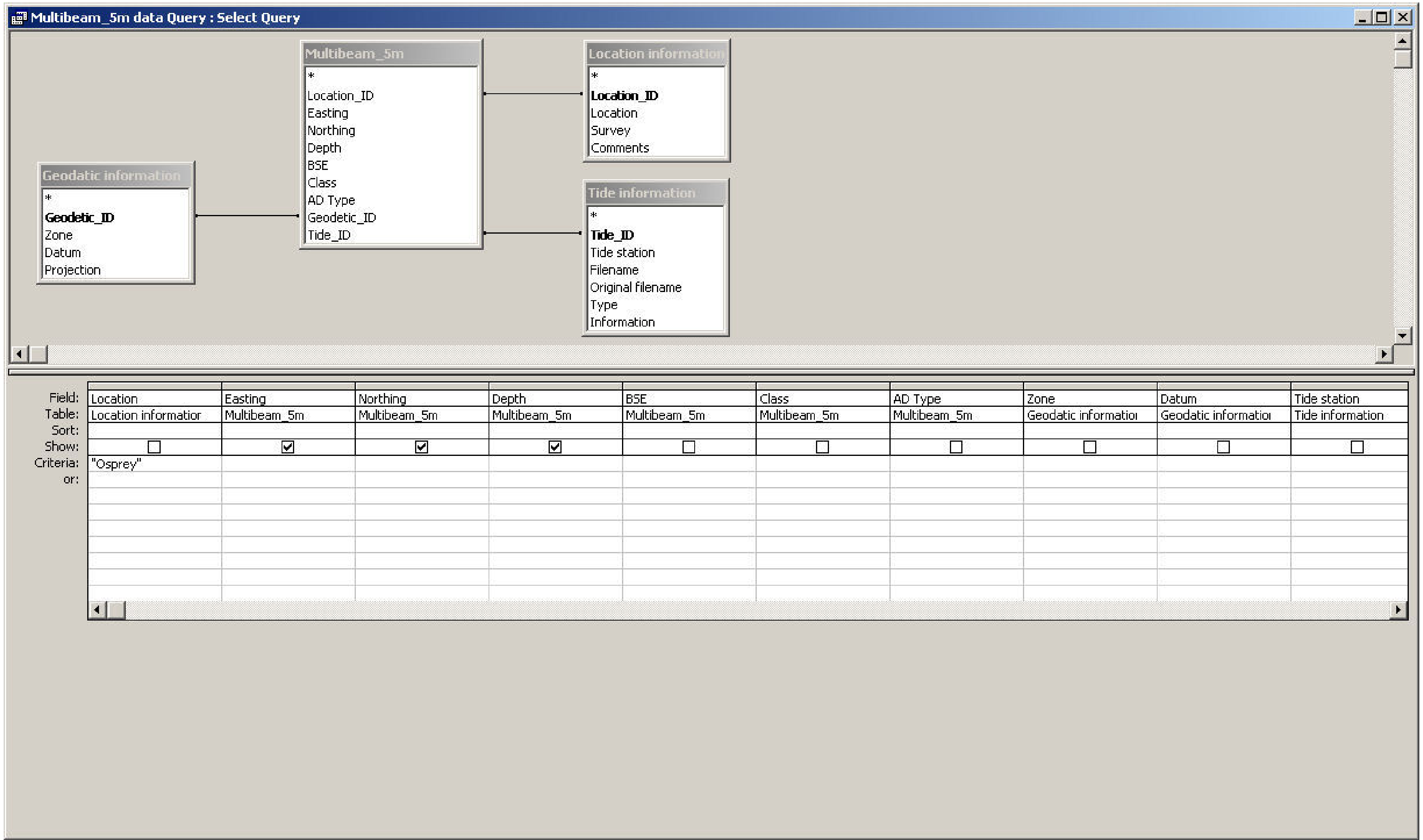


Figure 18. The relationship between “Multibeam_5m” data table and information tables (called “Multibeam_5m data Query”).

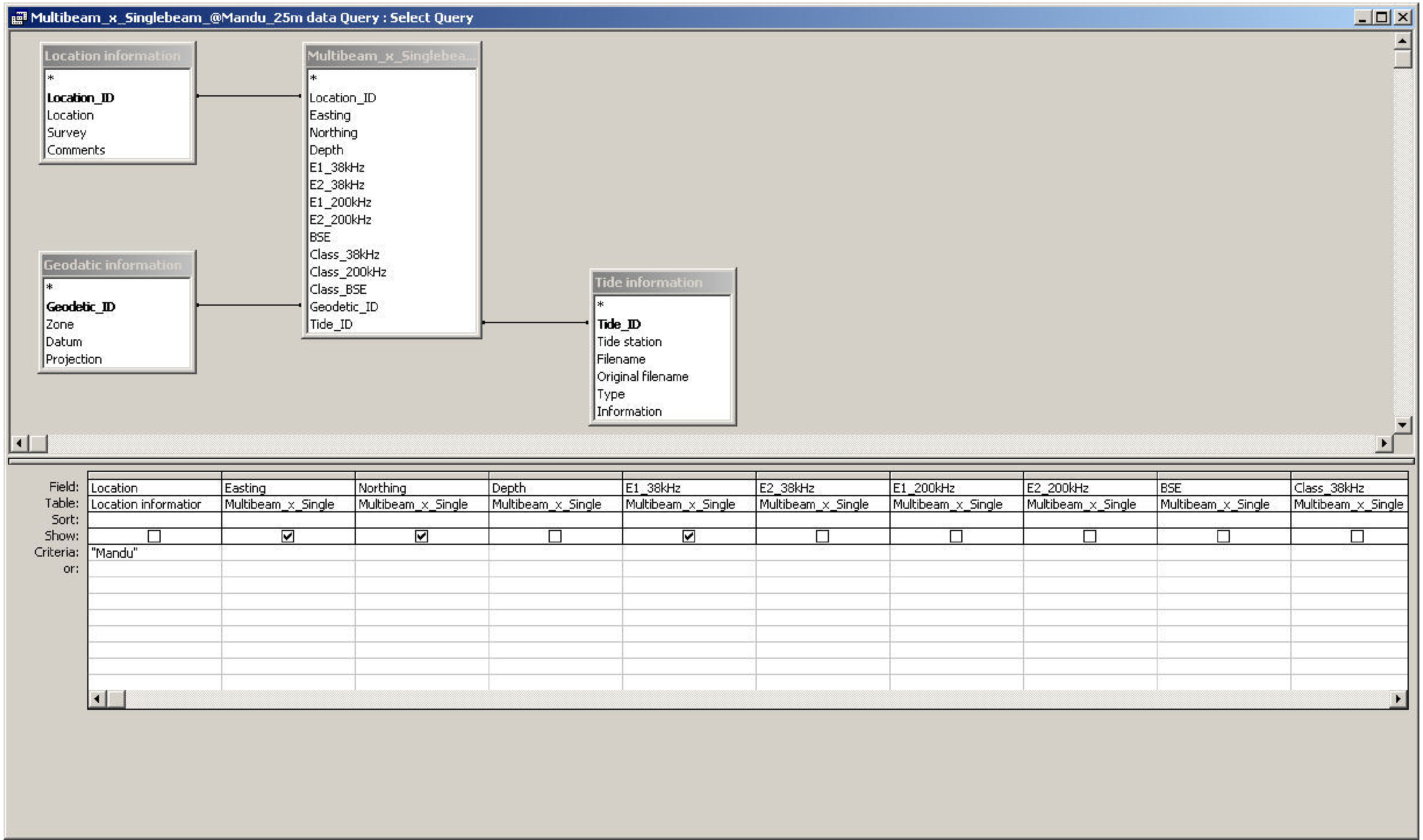


Figure 19. The relationship between "Multibeam_x_Singlebeam_@Mandu_25m" data table and information tables (called "Multibeam_x_Singlebeam_@Mandu_25m data Query").

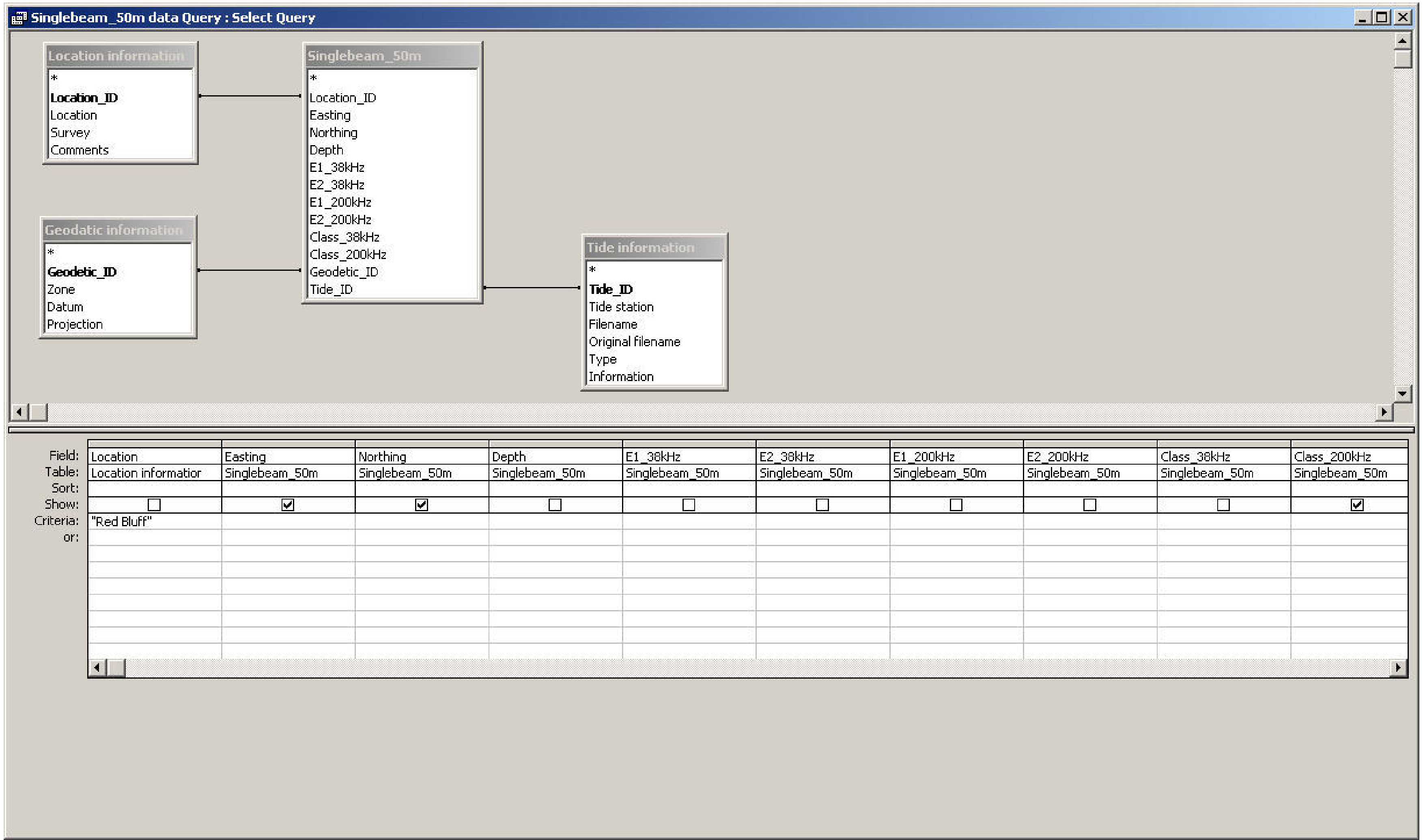


Figure 20. The relationship between “Singlebeam_50m” data table and information tables (called “Singlebeam_50m data Query”).

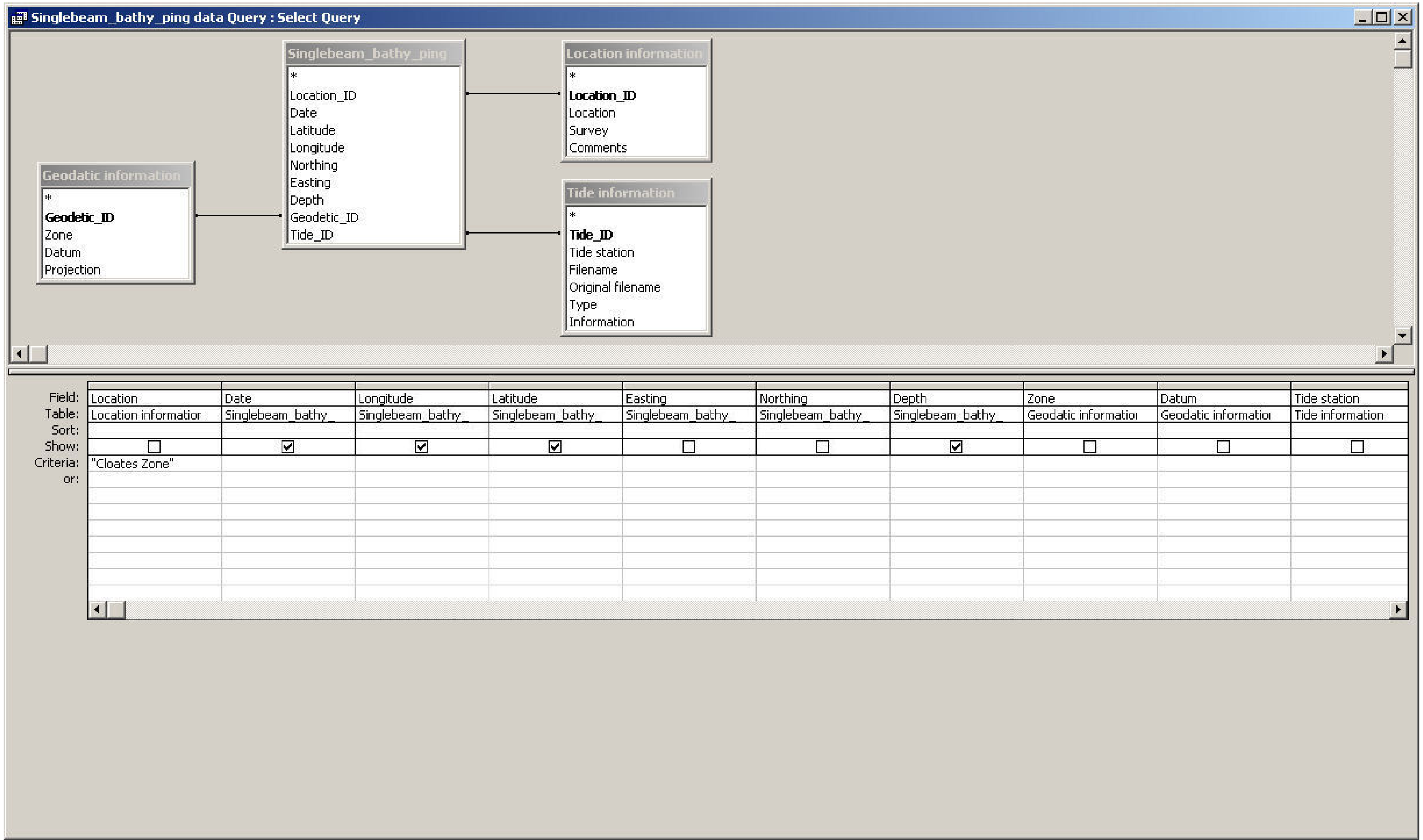


Figure 21. The relationship between "Singlebeam_bathy_ping" data table and information tables (called "Singlebeam_bathy_ping data Query").

Table 4. Description of the content of all processed data in ASCII format. Information within brackets in every filename tells the data structure of that file.

Filename	Description of content
Multibeam_5m_BoatPassage(Easting,Northing,BSE).csv	Multibeam backscatter in 5m bins in Boat Passage area with AD type 1
Multibeam_5m_BoatPassage(Easting,Northing,Class).csv[2)]	Multibeam seabed classes in 5m bins in Boat Passage area
Multibeam_5m_BoatPassage(Easting,Northing,Depth).csv	Multibeam bathymetry in 5m bins in Boat Passage area
Multibeam_5m_Mandu(Easting,Northing,BSE).csv	Multibeam backscatter in 5m bins in Mandu area with AD type 2
Multibeam_5m_Mandu(Easting,Northing,Class).csv[1)]	Multibeam seabed classes in 5m bins in Mandu area
Multibeam_5m_Mandu(Easting,Northing,Depth).csv	Multibeam bathymetry in 5m bins in Mandu area
Multibeam_5m_Osprey(Easting,Northing,BSE).csv	Multibeam backscatter in 5m bins in Osprey area with AD type 1
Multibeam_5m_Osprey(Easting,Northing,Depth).csv	Multibeam bathymetry in 5m bins in Osprey area
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,BSE).csv	Multibeam backscatter in 25m bins in Mandu area with AD type 1
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,Class_200kHz).csv[1)]	200 kHz single beam classes in 25m krigged nodes in Mandu
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,Class_38kHz).csv[1)]	38 kHz single beam classes in 25m krigged nodes in Mandu
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,Class_BSE).csv[1)]	Multibeam seabed classes in 25m bins in Mandu area
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,Depth).csv	Multibeam bathymetry in 25m bins in Mandu area
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,E1_200kHz).csv	200 kHz E1 parameters in 25m krigged nodes in Mandu
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,E1_38kHz).csv	38 kHz E1 parameters in 25m krigged nodes in Mandu
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,E2_200kHz).csv	200 kHz E2 parameters in 25m krigged nodes in Mandu
Multibeam_x_Singlebeam_@Mandu_25m(Easting,Northing,E2_38kHz).csv	38 kHz E2 parameters in 25m krigged nodes in Mandu
Singlebeam_50m_CloatesZone(Easting,Northing,Class_200kHz).csv[3)]	200 kHz single beam classes in 50m krigged nodes in Cloates Zone
Singlebeam_50m_CloatesZone(Easting,Northing,Class_38kHz).csv[3)]	38 kHz single beam classes in 50m krigged nodes in Cloates Zone
Singlebeam_50m_CloatesZone(Easting,Northing,Depth).csv	Single beam bathymetry in 50m krigged nodes in Cloates Zone
Singlebeam_50m_CloatesZone(Easting,Northing,E1_200kHz).csv	200 kHz E1 parameters in 50m krigged nodes in Cloates Zone
Singlebeam_50m_CloatesZone(Easting,Northing,E1_38kHz).csv	38 kHz E1 parameters in 50m krigged nodes in Cloates Zone
Singlebeam_50m_CloatesZone(Easting,Northing,E2_200kHz).csv	200 kHz E2 parameters in 50m krigged nodes in Cloates Zone
Singlebeam_50m_CloatesZone(Easting,Northing,E2_38kHz).csv	38 kHz E2 parameters in 50m krigged nodes in Cloates Zone
Singlebeam_50m_Mandu(Easting,Northing,Class_200kHz).csv[1)]	200 kHz single beam classes in 50m krigged nodes in Mandu

Table 4. *Continued*.

Filename	Description of content
Singlebeam_50m_Mandu(Easting,Northing,Class_38kHz).csv[1)]	38 kHz single beam classes in 50m krigged nodes in Mandu
Singlebeam_50m_Mandu(Easting,Northing,Depth).csv	Single beam bathymetry in 50m krigged nodes in Mandu
Singlebeam_50m_Mandu(Easting,Northing,E1_200kHz).csv	200 kHz E1 parameters in 50m krigged nodes in Mandu
Singlebeam_50m_Mandu(Easting,Northing,E1_38kHz).csv	38 kHz E1 parameters in 50m krigged nodes in Mandu
Singlebeam_50m_Mandu(Easting,Northing,E2_200kHz).csv	200 kHz E2 parameters in 50m krigged nodes in Mandu
Singlebeam_50m_Mandu(Easting,Northing,E2_38kHz).csv	38 kHz E2 parameters in 50m krigged nodes in Mandu
Singlebeam_50m_RedBluff(Easting,Northing,Class_200kHz).csv[4)]	200 kHz single beam classes in 50m krigged nodes in Red Bluff
Singlebeam_50m_RedBluff(Easting,Northing,Class_38kHz).csv[4)]	38 kHz single beam classes in 50m krigged nodes in Red Bluff
Singlebeam_50m_RedBluff(Easting,Northing,Depth).csv	Single beam bathymetry in 50m krigged nodes in Red Bluff
Singlebeam_50m_RedBluff(Easting,Northing,E1_200kHz).csv	200 kHz E1 parameters in 50m krigged nodes in Red Bluff
Singlebeam_50m_RedBluff(Easting,Northing,E1_38kHz).csv	38 kHz E1 parameters in 50m krigged nodes in Red Bluff
Singlebeam_50m_RedBluff(Easting,Northing,E2_200kHz).csv	200 kHz E2 parameters in 50m krigged nodes in Red Bluff
Singlebeam_50m_RedBluff(Easting,Northing,E2_38kHz).csv	38 kHz E2 parameters in 50m krigged nodes in Red Bluff
Singlebeam_bathy_ping_All2007(Date,Easting,Northing,Depth).csv	Single beam bathymetry for all 2007 data in Easting and Northing
Singlebeam_bathy_ping_All2007(Date,Longitude,Latitude,Depth).csv	Single beam bathymetry for all 2007 data in Longitude and Latitude
Singlebeam_bathy_ping_CloatesNorth(Date,Easting,Northing,Depth).csv	Single beam bathymetry in Cloates North in Easting and Northing
Singlebeam_bathy_ping_CloatesNorth(Date,Longitude,Latitude,Depth).csv	Single beam bathymetry in Cloates North in Longitude and Latitude
Singlebeam_bathy_ping_CloatesReference(Date,Easting,Northing,Depth).csv	Single beam bathymetry in Cloates Reference in Easting and Northing
Singlebeam_bathy_ping_CloatesReference(Date,Longitude,Latitude,Depth).csv	Single beam bathymetry in Cloates Reference in Longitude and Latitude
Singlebeam_bathy_ping_CloatesZone(Date,Easting,Northing,Depth).csv	Single beam bathymetry in Cloates Zone in Easting and Northing
Singlebeam_bathy_ping_CloatesZone(Date,Longitude,Latitude,Depth).csv	Single beam bathymetry in Cloates Zone in Longitude and Latitude

Description of index assigned on the processed data file:

[1)]1=sand; 2=mixed; 3="rhodolith"

[2)]1=sand; 2=mixed; 3="rhodolith"

[3)]1=sand; 2=mixed; 3="algae"; 4="rhodolith"

[4)]1=sand; 2=mixed; 3="algae"

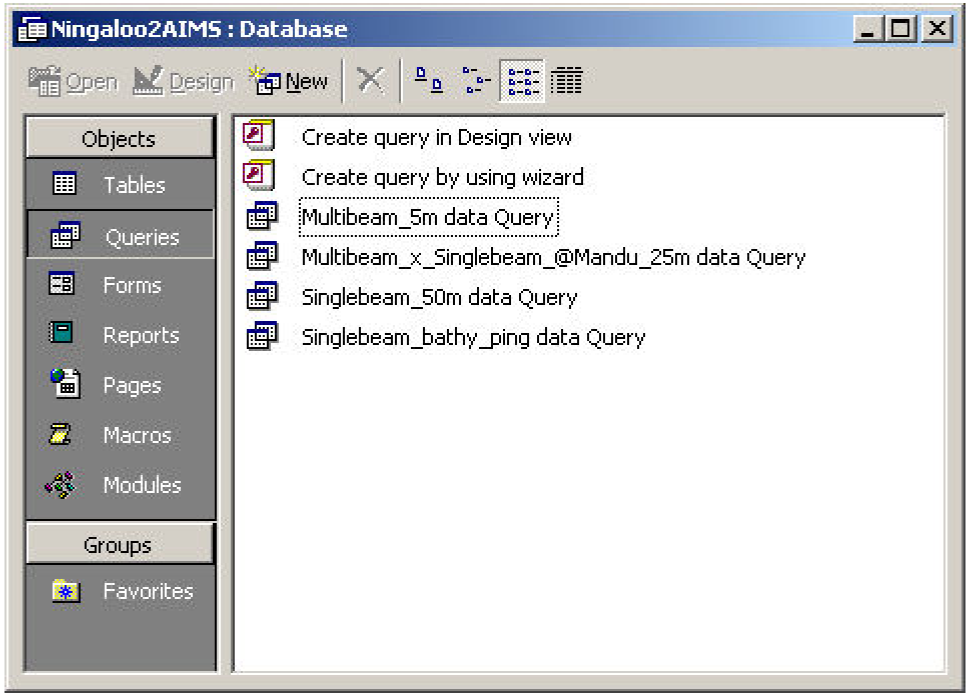


Figure 22. List of query objects in "Proc_Ningaloo_Sonar_Data.mdb".

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CHAPTER 2
Offshore Geomorphology, Surficial Sediments and Habitat Linkages – Characterisation of Geomorphology and Surface Sediments

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Research Activity

Long Term Goal

Geological and sedimentological data are to be consolidated into a Geographic Information System (GIS) to aid in the production of geomorphic, sedimentary facies and benthic habitat maps of the continental shelf of the Ningaloo Marine Park (NMP). Habitat maps will provide stakeholders, managers, regulators and policy makers with crucial georeferenced information that will aid in the conservation, preservation and sustainable use of the NMP environment and its values. This research will establish a baseline understanding of the geomorphology and sediment distribution in the deeper offshore waters of the NMP between 20 and 110m. The interrelationship between sedimentary characteristics and seabed geomorphology, and its influence on the spatial distribution of benthic habitats and communities will be determined. The project will focus on mapping the seafloor with acoustics (multibeam, single beam and sidescan sonar) and collecting georeferenced video data, sediment grabs and dredged rock samples to verify acoustic interpretations. The characterisations determined at this scale will improve our understanding of benthic habitat variability across the NMP.

Introduction

The representative protection of marine environments relies on an understanding of the ecosystem components that define benthic communities (Post et al. 2006). The characterisation and conservation of benthic habitats and communities based on physical abiotic factors is central in the selection and ongoing monitoring management of Marine Protected Areas (MPA's). Geophysical factors including geomorphology, sediment composition (texture, mineralogy and constituents), mobility of the substrate, bathymetry, the hardness and roughness texture of the seabed and water depth, can be significant in describing the distribution of benthic biota, habitat types and fish distributions over broad geographic regions (Williams and Bax 2001, Roff et al. 2003; Beaman et al. 2005, Post et al. 2006). A number of studies in a range of settings around the Australian margin (see review by Post 2006), have shown that physical surrogates can be used for the determination of biological distributions. Seabed geomorphology determines the long-term stability of the substrate which represents a major control on biological diversity (Freeman and Rogers 2003). Grab sampling and geomorphic investigations can be used as ground-truthing for acoustic surveys to characterise the nature of the seabed over the broadscale in terms of surficial sediment distribution, benthic habitats and their patchiness, and infer ecological information in a particular environment (Bale and Kenny 2005).

The main goal of this study is to improve the understanding of the character of the geomorphology and surficial deposits of the Ningaloo continental shelf and determine their influence on the distribution of offshore benthic habitats and communities. This study forms WAMSI Project 3.4 to characterise the geomorphology and surficial sediments of the Ningaloo Reef. There are strong collaborative linkages to WAMSI Project 3.1.1 Habitat mapping and biodiversity assessment of the offshore component of the NMP.

Main Aims:

- Map and characterise:
  - bathymetry and seabed texture
  - geomorphology (shelf zones and features)
  - sedimentary bedform environments
  - surficial sediments (physical and biological components)
  - benthic community assemblages
- Determine influence of geomorphology and sediments on habitat and community distribution:
  - Which geophysical factors (e.g. seabed geology, geomorphology, sediment composition, mobility of substrate, bathymetry, hardness and roughness of seabed and water depth) show significant relationships with benthos?
  - Can these be used as 'surrogates' for biodiversity?
- These relationships may be used to inform our understanding of benthic habitat variability across the whole Marine Park, and will aid in development of benthic habitat maps which are central to the ongoing conservation and monitoring of biodiversity at Ningaloo.

Background

Regional geology

The NMP lies across the boundary of the Northern and Southern Carnarvon Basins with the majority located in the Exmouth Sub-Basin of the Northern Carnarvon Basin (Fig. 1). This large Palaeozoic-Recent mainly offshore basin on the Northwest Shelf, is Australia's premier hydrocarbon province where the majority of deepwater wells have been drilled (greater than 500m depth). The Tertiary Cape Range Anticline is one of the dominant features of the terrestrial landscape of the Exmouth Sub-Basin and the Muiron Islands, to the north-east, are recognised as extensions of the anticline. Cape Range, Ningaloo Reef and Exmouth Gulf, are underlain by thick sedimentary sequences ranging from Palaeozoic to Holocene in age (van de Graaff et al. 1980; Hocking et al. 1983, Collins et al. 2006). Emergent, tectonically warped Pleistocene terraces overlying mid-late Tertiary units are present on the western side of Cape Range (Wyrwoll et al. 1993). The youngest terrace, the Tantabiddi, is of Last Interglacial (LI) age (ca. 125 ka; Stirling et al. 1998) and lacks deformation, attesting to the tectonic stability of the region since that time. The Tantabiddi precedes the present day Ningaloo Reef and represents a far larger reef system (Collins et al. 2003) with outcrops along the modern shoreline and underlying the coastal plain (Fig. 2). The continental slope and shelf comprise the Northern Carnarvon Ramp (formally the Dirk Hartog Shelf) to the west of the Cape Range peninsula, Rowley Shelf to the north-east and Exmouth Gulf to the east.

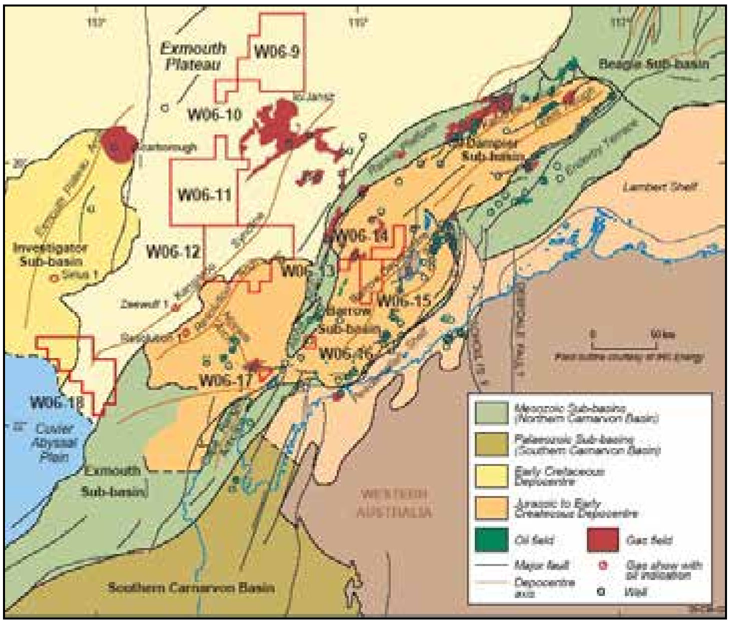

Figure 1. Structural elements of the Carnarvon Basin. From (Offshore Acreage Release 2006)

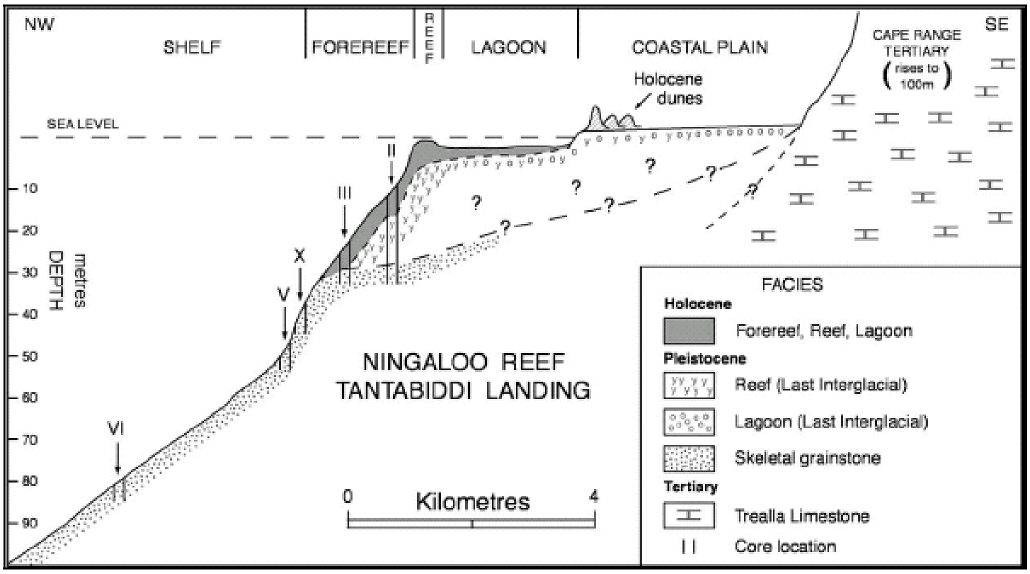

Figure 2. Idealised northwest-southeast cross section of northern Ningaloo Reef based on the cored transect and seismic data at Tantabiddi (Collins et al. 2003).

Continental Shelf geomorphology and sedimentology of WA

The western continental margin of Australia provides a significant regional context to study carbonate sediment facies transitions from cool to warm-water (Collins et al. 1997). This gradational setting spans from the cool-water setting in the south (Collins 1988) to the Ningaloo fringing reef in the north. The Rottnest Shelf to the south is open, wave-dominated and characterised by cool-water carbonate sedimentation. Carbonate grains are those of temperate assemblage with bryozoans and coralline algae being the dominant biotic constituents. Linear topographic ridges of Pleistocene limestone partition the shelf into varying physical energy, biota and sediment supply. The Houtman Abrolhos coral reefs comprise three shelf-edge carbonate platforms which together form the discontinuously rimmed Abrolhos Shelf. This shelf lies in the biotic transition zone between the northern tropical and southern temperate environments and this is reflected in the carbonate facies, with cool-water carbonate shelf to the south and increasing coral development in the north (Collins 1997). The Carnarvon Ramp stretching from Shark Bay to Ningaloo Reef is gently inclined throughout and in places there is no declivity to mark the shelf edge. This a currently a `starved` tropical ramp (James et al. 1999) where although bottom temperatures are tropical the biota is largely subtropical with an absence of modern carbonate production on the mid-outer ramp. Biodegraded sediments and clasts do however represent carbonate production in the recent past implying that as sea-level rose carbonate production became unfavourable. The North West Shelf to the north of Ningaloo is an ocean-facing carbonate ramp that lies in a warm-water setting and is one of the largest such systems in the carbonate realm. (James et al. 2004, Dix et al. 2005). Sediments have diverse particle types and ages and are largely explainable in the context of modern and late Quaternary oceanography where the shallow water sediments were stranded by rapid rise in sea-level changing the character of the sediments from photozoan (warm-water carbonate deposits) to heterozoan (cooler-water carbonate deposits).

Methodology

Bathymetry and acoustic surveys

Data collection

Historical Royal Australian Navy (RAN) sounding data was digitised and interpolated to create 3D bathymetry of the northern Ningaloo and aid in the planning of sites during field surveys. Acoustic data has also been collected onboard the *RV Cape Ferguson* and *Solander* using two different technologies: Single beam data was collected by AIMS during April to mid May 2006 and May 2007 using a CMST Simrad EQ60 (38 and 200 kHz) and Multibeam data was collected by Fugro Survey Pty. Ltd. during April 2006 using a Reson 8101 sonar (240 Hz operating frequency). For a detailed account of bathymetric and acoustic data collection and processing see Chapter 1.

The data does not currently cover the entire NMP (Figs. 3a and 3b); its extension is limited from Red Bluff in the south to Point Murat in the north. There are two large gaps: the first one is situated in an area 7 km north of Point Maud and 10 km south of Point Cloates and the second one is placed between 15 km South of Point Edgar and the southern limit of Osprey SZ.

Detailed characterisation of geomorphic features and sedimentary bedforms come from the Multibeam data which covers Osprey and Mandu SZ and the Boat Passage area, with a total extension of around 32 km. Osprey and Boat Passage areas having a complete coverage of between 10 and 120 m of depth, in Mandu SZ it reaches only 70 m due to time and safety constraints during the survey. Geophysical information on the Ningaloo Reef shelf also comes from the characterisation of the single beam data, which extends around 205 km.

Acoustic data processing

The Centre for Marine Science and Technology (CMST) is processing the acoustic data to provide bathymetry from all single beam sonar data collected in 2006/2007, and use sonar backscatter to segment the seabed using both single beam and multibeam data. A seabed habitat classification has been produced from the backscatter data, using sediment and towed-video as ground-truthing to confirm benthic classes. This will aid in the production of broadscale habitat maps of the offshore component of the NMP. The reader is forwarded to Chapter 1 for additional information on processing methods and preliminary results for habitat classification.

CMST have supplied the acoustic datasets to the Department of Applied Geology at Curtin University in ASCII format allowing easy integration into the ESRI ArcGIS platform. Coordinates are referenced to the Geocentric Datum of Australia 1994 (GDA94). The dataset has been interpolated in ArcGIS 9.2 environment. 3D models have been created using ArcScene 9.2, Global Mapper 9 and Surfer 8 mapping software for the visualization and characterisation of seabed topography and sedimentary bedforms.

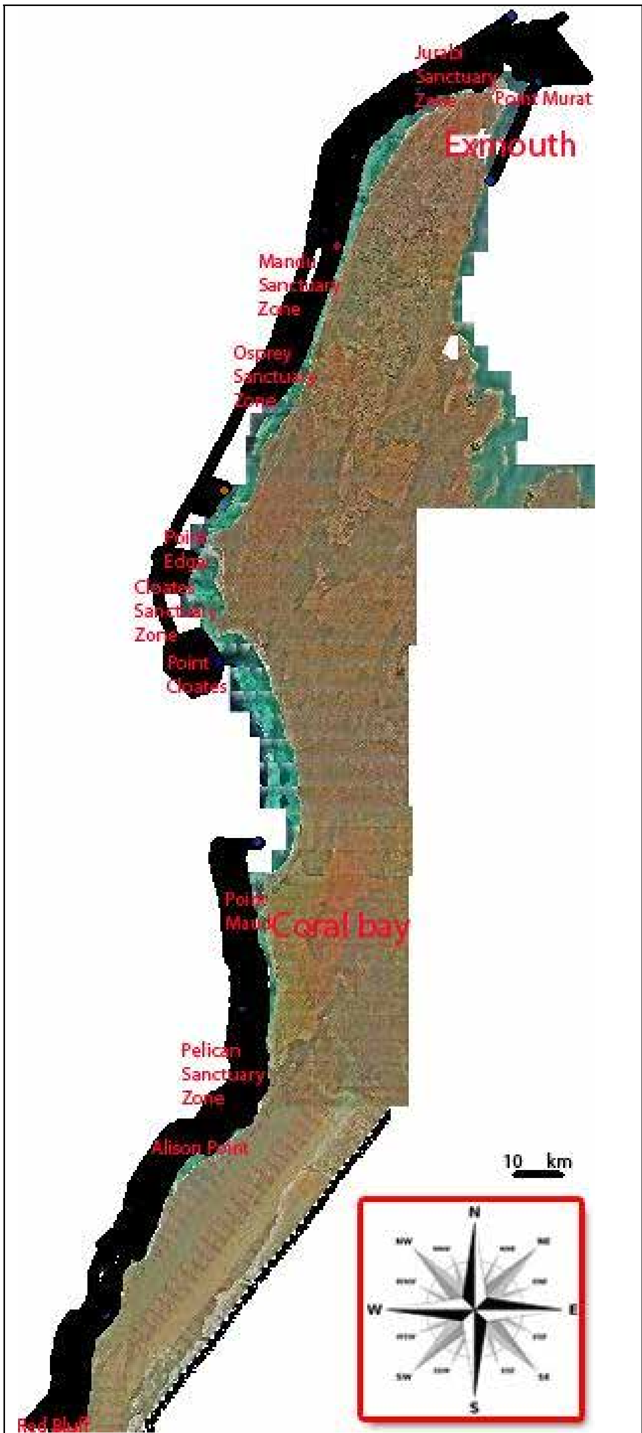

Figure 3a: Single beam and Multibeam complete tracks

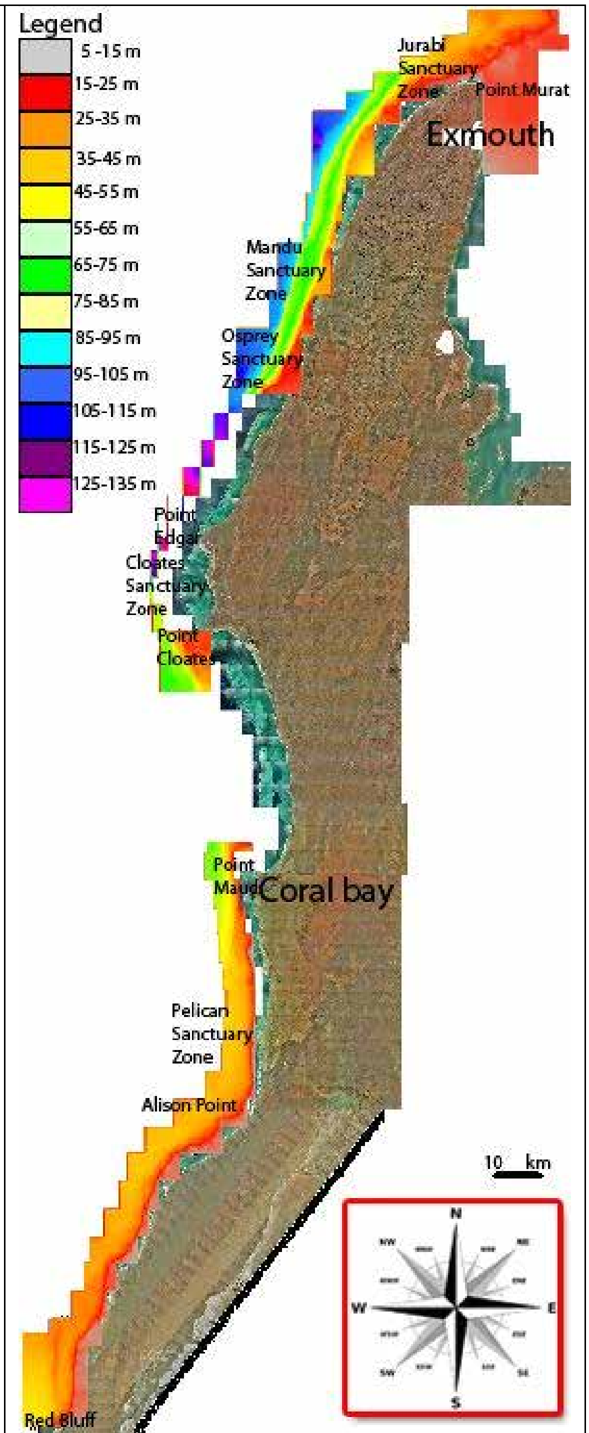

Figure 3b. Global data visualisation

Both bathymetry and backscatter data from the acoustic surveys will show detailed distribution of geomorphic features and sedimentary bedforms, such as sand ripples, sand waves, megaripples and sand ridges with the potential to identify reef structures, such as drowned reefs and paleo-channels. Bathymetrical data is the main subject of this chapter, although some backscatter has been analysed to identify broadscale geomorphic and sedimentary characteristics. Further GIS analysis of the acoustic data will include characterisation and mapping of all geomorphic and sedimentary features on the continental shelf using both bathymetric and textural data. The combination of topography and textural surfaces provide an excellent reference dataset for research and management of the Ningaloo environment.

Surficial sediments

Sample design and collection

A total of 290 successful sediment samples have been collected using a Van-Veen grab sampler (Figs. 4, 5) for surface and subsurface material to a depth of ~10cm. Rhodolith samples were also collected from both grab and benthic sled sampling (Fig. 6). A widely spaced systematic grid of samples was used in order to characterise each region and these were stratified by depth contours across the shelf. Positions were fixed using a Differential Global Positioning System (DGPS) and imported directly into ArcGIS for live onboard spatial analysis. Grabs were dropped at or close to benthic video stations to obtain habitat linkages to surficial sediment facies, and infer biological activity and sediment transport pathways from sedimentary bedforms. The sediment/substrate data will provide ground-truthing and add value to the acoustic backscatter data.

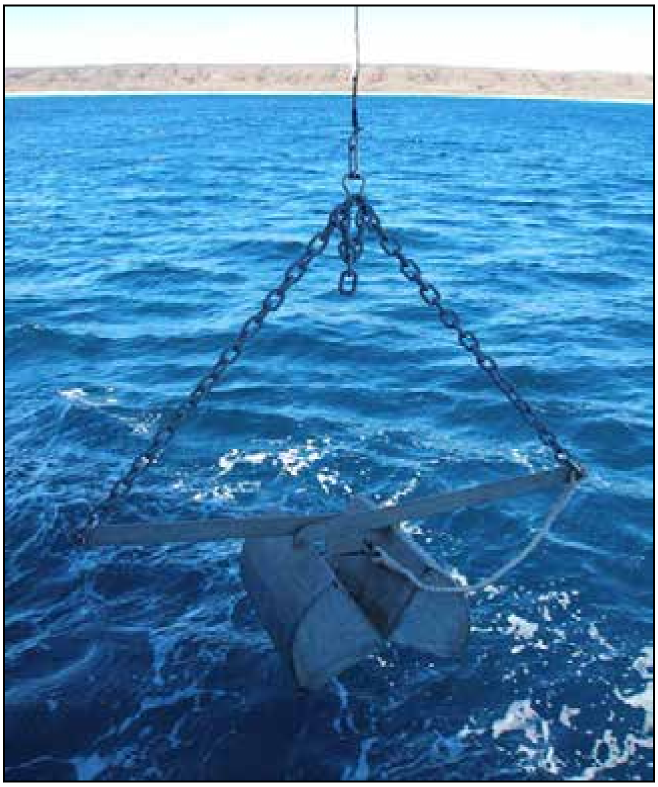

Figure 4. Van-Veen grab sampler for collecting surface and subsurface material to a depth of ~10 cm from Ningaloo Marine Park.

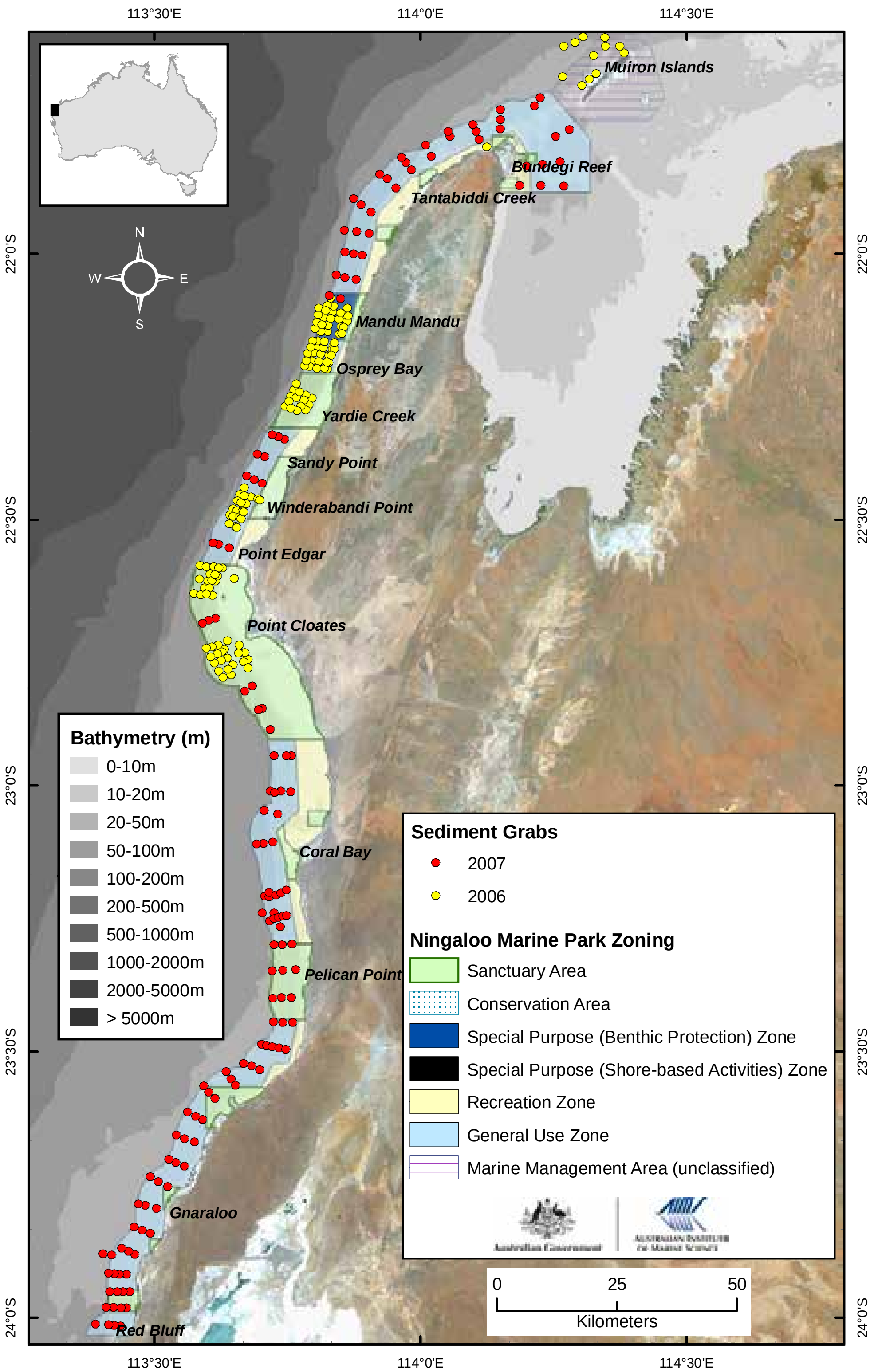

Figure 5. Offshore sediment grab sampling locations in the Ningaloo Marine Park.

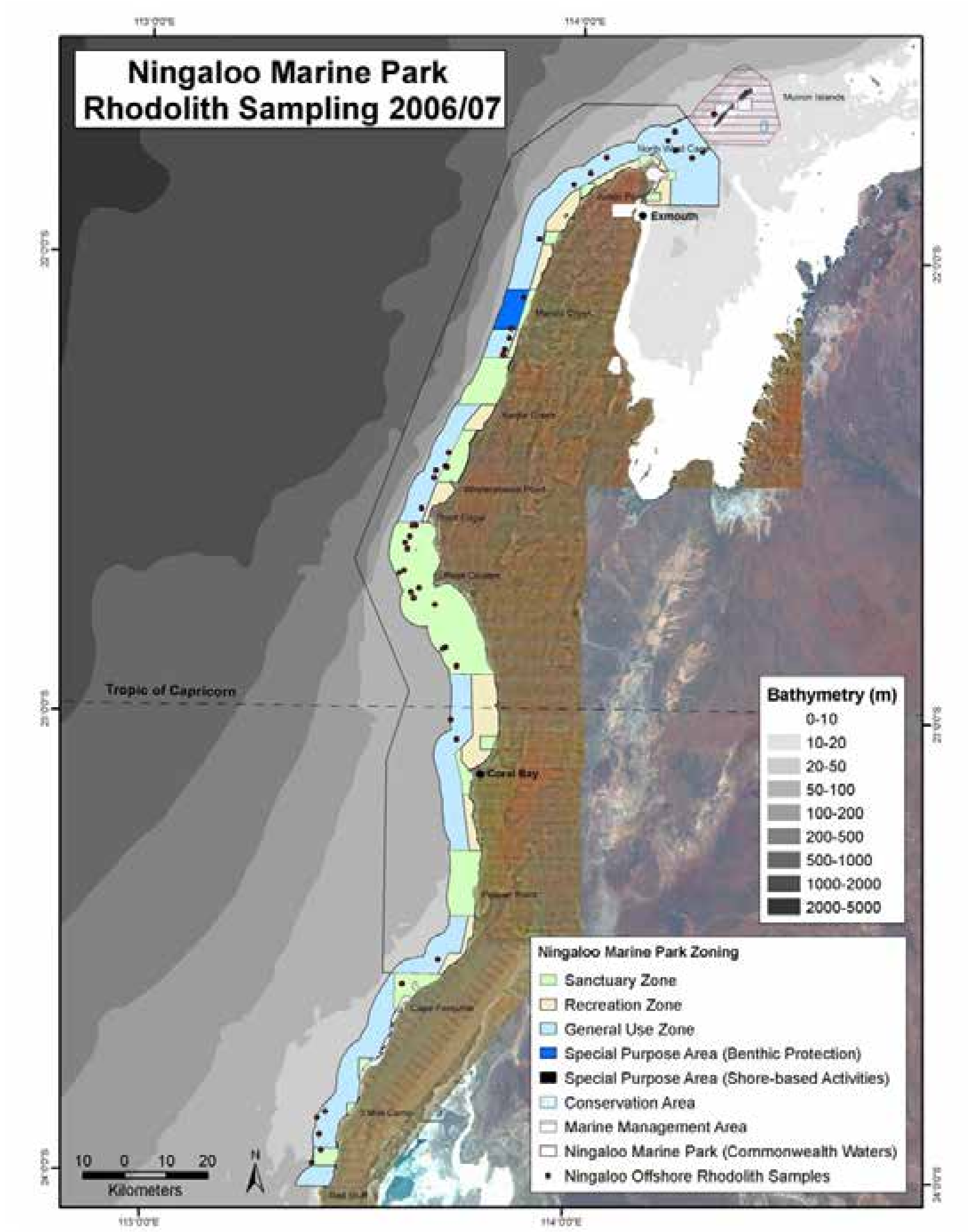

Figure 6. Offshore rhodolith sampling locations in the Ningaloo Marine Park.

Laboratory Analysis

In the laboratory sediments were initially washed to remove salts and then dried and split by the cone and quartering method, to provide representative samples of the bulk. Sediment fractions were separated for; granulometry, grain component analysis, taxonomy of main biological constituents, and X-ray diffraction (XRD) for the determination of ratios of carbonate mineralogy.

Granulometry - Granulometric grain size analysis has been completed on all offshore samples. Dried samples were sieved using a mechanical sieve shaker with -1 to 4 Phi (Ø) sieve units at 0.5Ø intervals based on the Udden-Wentworth grain size scale (Table 1 in Appendix 1.2). Wet sieving was necessary for samples with a silt and clay fraction exceeding 10% using a 4Ø sieve. GRADISTAT software (Blott and Pye 2001) was used in the calculation of grain size statistics, textural parameters and descriptive terminology, allowing both tabular and graphical output into Microsoft Excel and input into ArcGIS. The physical description of the textural group from which the sample belongs to, and the sediment name (such as "fine gravelly coarse sand") is based on the classification by Folk (1954). Table 2 in Appendix 1.2 outlines the calculation of grain size statistics. Detailed grain size analysis is an essential tool for classifying sedimentary environments and will provide important clues to the sediment provenance, transport history and depositional conditions on the Ningaloo continental shelf.

Grain Components - Biological components have been examined on selected cross-shelf sediment samples using both binocular microscope for loose grains, and transmitted-light polarizing petrographic microscope for grain mounted thin-sections. Quantitative component analysis is being undertaken on representative cross-shelf sediment samples (~150) to examine the contribution of different marine organisms to the shelf sediments. Grain mounted thin-sections will be examined with a transmitted light-polarizing petrographic microscope, using standard techniques. To provide an estimate of the frequency of components, all thin sections will be subjected to point-counting analysis using a grid of 300 points. Grains and components will be identified using standard classifications and photographs of each main compositional group present in the slides will used as a reference to maintain identification consistency. A broad visual compositional estimate of the gravel fraction will be made.

Taxonomy - Taxonomy of the main species of foraminifera, bryozoans, molluscs and coralline algae will be identified in representative samples. Quantitative analysis of the foraminifera is being determined by point counting for both modern and relict specimens.

Mineral XRD and Scanning Electron Microscopy (SEM) - XRD will determine mineral composition and ratios of carbonate mineralogy on cross-shelf samples, in particular for mud sized grains on the outer shelf that cannot be identified from thin-section analysis. SEM analysis will aid in the identification of components that contribute to mud sized grains.

Coral Dating - Limestone substrate samples and a coral sample at ~72 m from offshore ridges were dredged and recovered using a benthic sled. The coral sample is being dated using U-series Thermal Ionization Mass Spectrometry (TIMS) method, providing an insight into the geological and sea-level history of the continental shelf in this region.

Towed video analysis

Underwater towed video was captured near or at grab stations. The AIMS AVTAS technique has been used to analyse the video data following the methods used by Abdo et al. (2003). Further analysis will add to this dataset to include descriptions of all environmental variables for each video transect: 1) substrate (e.g. sand, gravels, limestone rock); 2) bedforms including physical (e.g. sand ripples, lineations) and biogenic structures (e.g. burrow mounds, resting/feeding traces); 3) benthos (e.g. hard coral, soft coral, cup sponge; 4) relief; and 5) mobility of substrate. Counts will be made for each biological and physical variable then standardised into the percent occurrence from each transect. The reader is forwarded to Chapter 3 for additional information on video methods used.

Multivariate statistical analysis

Multivariate statistics will measure the similarity and trends of all environmental variables in determining habitat variability (Clarke and Warwick 2001). Multivariate statistical analysis of sedimentary data, will determine different sediment facies and foraminifera assemblages across the study area, which will then be mapped in ArcGIS. Analysis of all datasets including sedimentary, geomorphic, biological and textural variables will be undertaken using multivariate software packages such as PRIMER (Clarke 1993, Clarke and Warwick 2001) to establish trends and similarities across the study area. Relationships identified between these physical and biotic values may identify factors that are reliable indicators or 'surrogates' of specific habitats. Physical factors including geomorphology, sediment composition, mobility of substrate, bathymetry, the hardness and roughness of the seabed and water depth will be significant in describing the distribution of benthic biota and classifying habitat types over the region. The relationships determined at this scale will improve our understanding of habitat variability and be used to aid in the production of offshore habitat maps for the NMP.

Initial Results

Shelf geomorphology

In the northern section of Ningaloo reef, between Point Cloates and North West Cape, the shelf runs parallel to the coastline (see Figs. 7 and 8a-f). At Tantabiddi the shelf is wide, gently sloping and there is no distinct change in slope gradient to indicate a shelf break. At Mandu SZ the shelf is narrow (about 10 km wide) and gentle with a marked change in gradient at the shelf break, dropping steeply to depths of 1000 m within only 20 km offshore. Here geomorphic zonation is distinct across the shelf (see Figs. 9 and 10). There are similar profiles at Osprey and Winderbandi SZ, although there is also evidence of backstepping reefs just offshore of the modern Ningaloo reef. South of Point Cloates, the coastline veers eastward and there is a marked transition in bathymetry with a gentler and wider shelf to the south. There is a more complex history of constructional and pre-existing antecedent topography at Cloates SZ down to 60 m (Fig. 8f), where Tertiary limestone surfaces, paleo-stillstand escarpments and shorelines, and stepwise fossil reefs have created a complex environment with numerous ridges and pinnacles. Further offshore of the ridges, the shelf has a very gentle slope with depths of 60 m at 6 km offshore, up to around 75 m at 13 km offshore, where it then steepens and drops off at around 110 m on the slope edge. The NMP incorporates depths of up to around 110 m in the north and thus the majority of the continental shelf, and only up to 50-60 m in the south with only the inner-mid continental shelf represented. Fig. 9 illustrates the main geomorphic zones across an example x-section of the shelf at Mandu SZ.

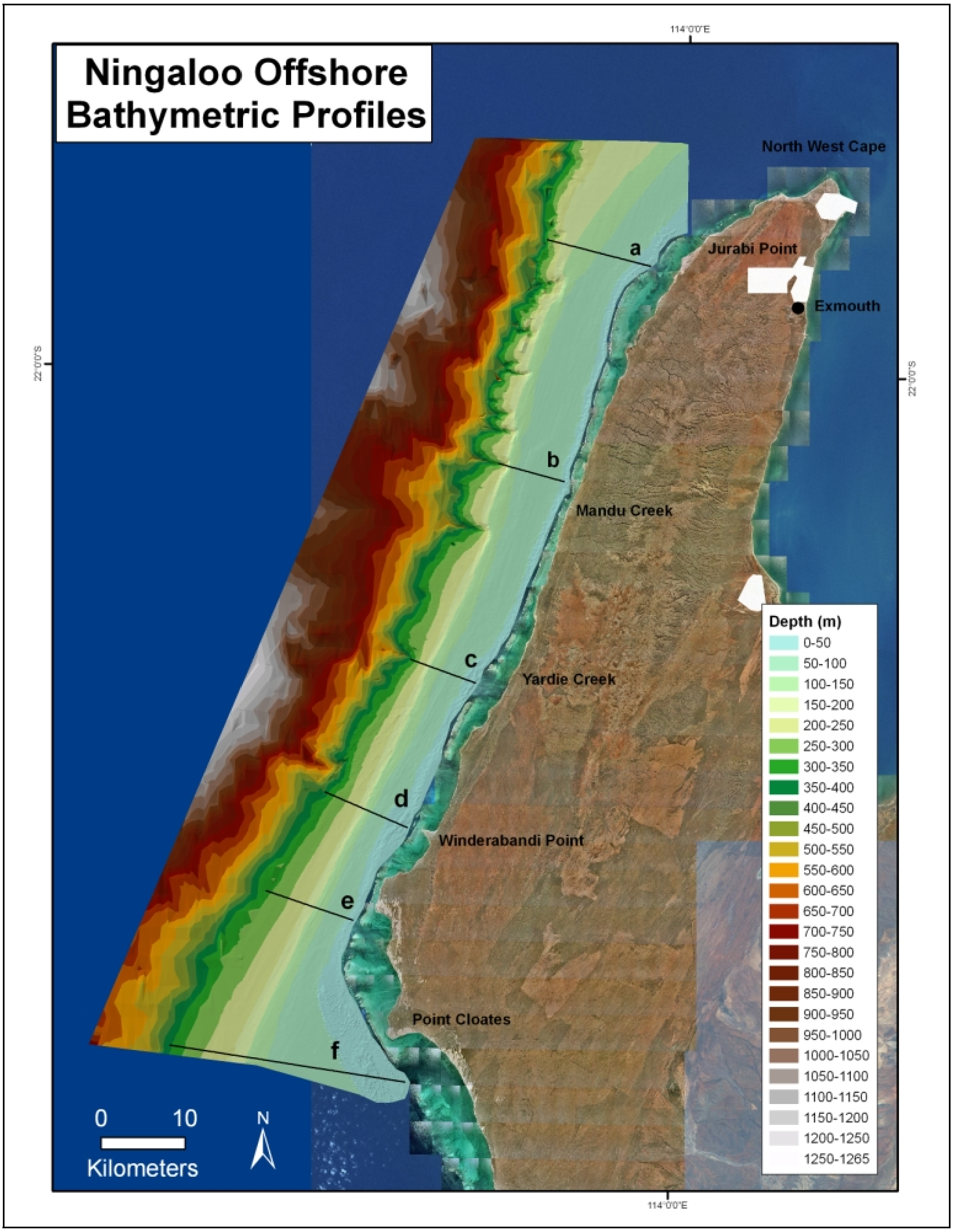

Figure 7. Locations of bathymetric profiles for the northern Ningaloo overlaid on RAN bathymetric model (created in ArcGIS™).

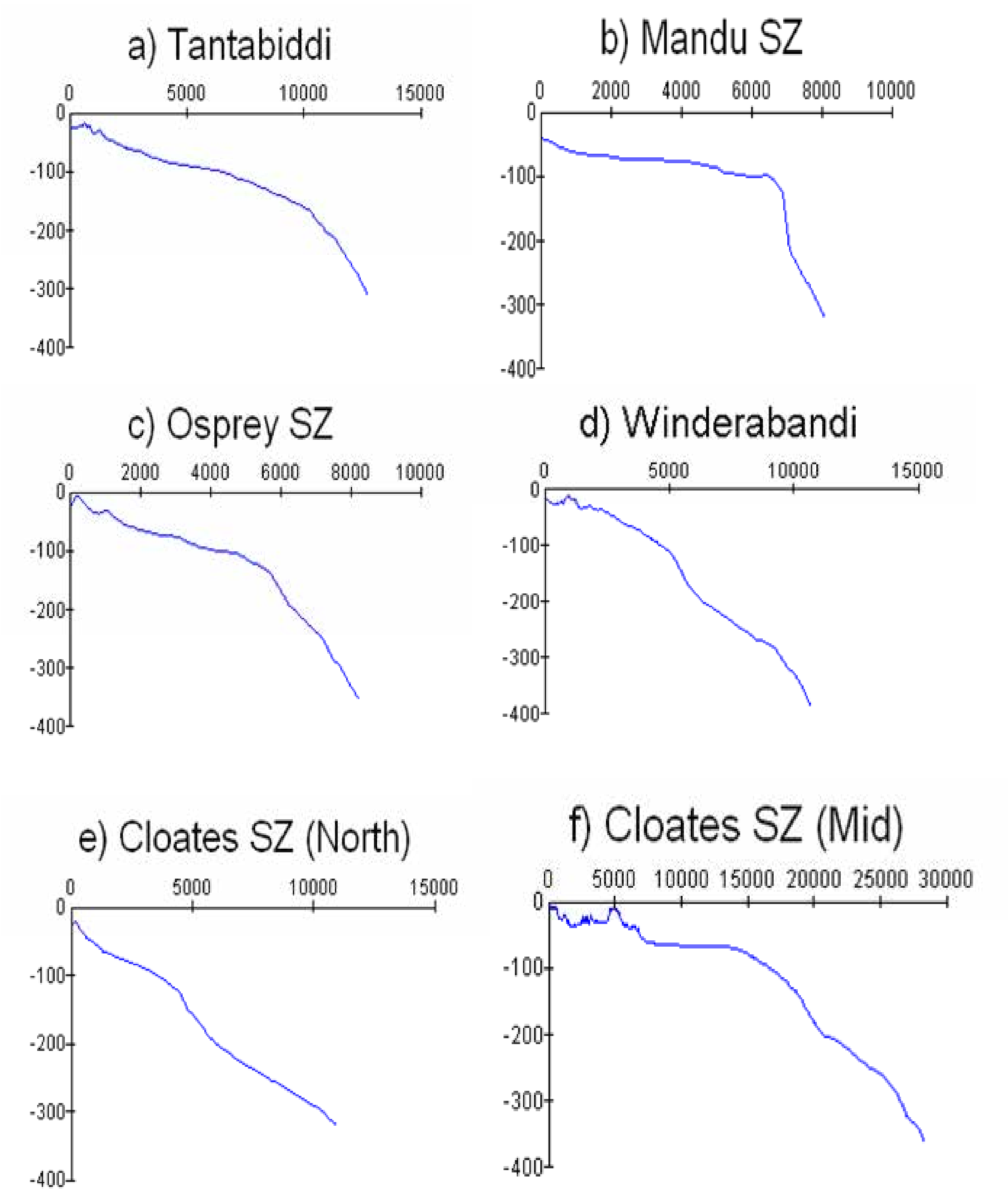

Figure 8 a-f. Bathymetric profiles across the continental shelf of northern Ningaloo (profiles from RAN TIN model in ArcGIS™, see Fig.7).

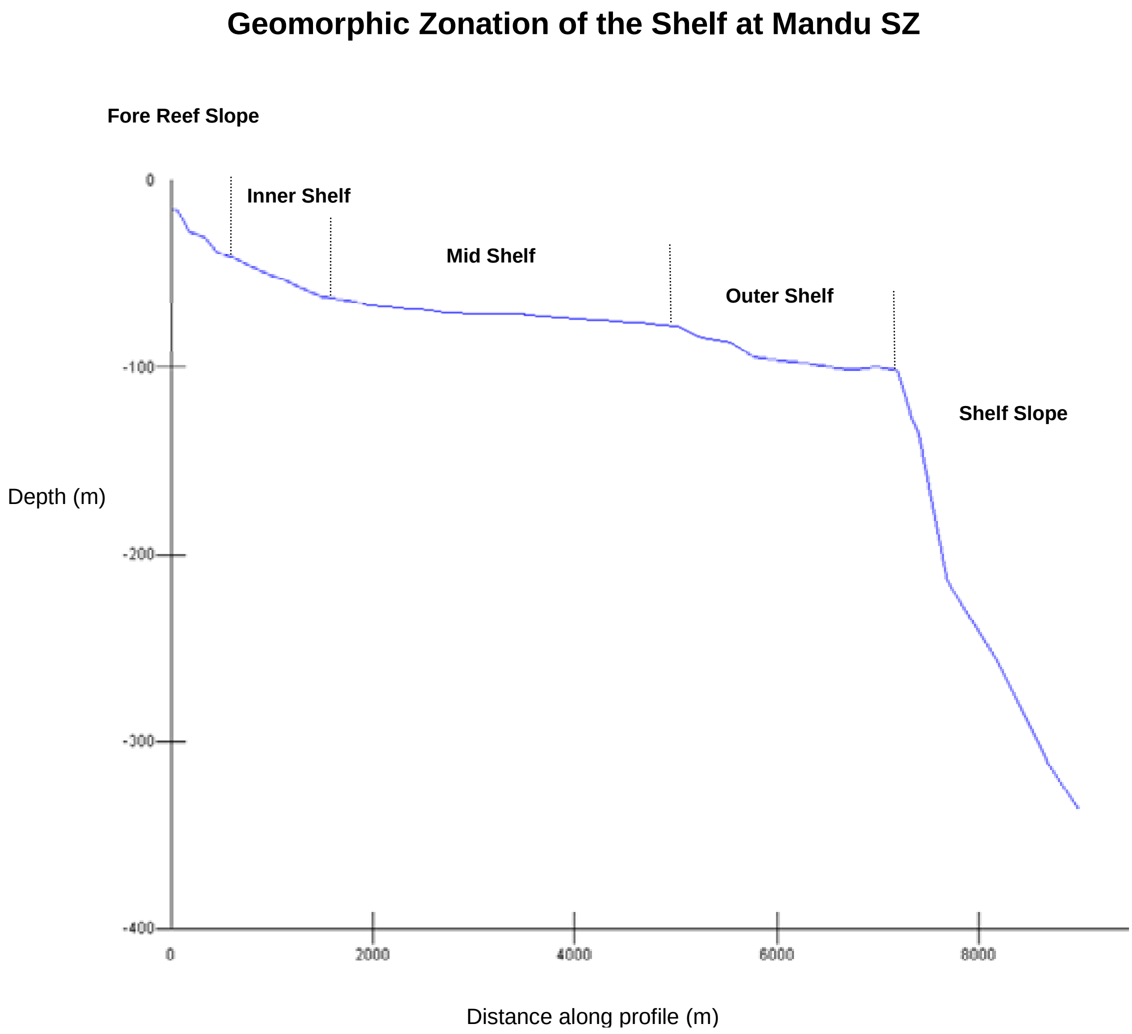

Figure 9. Typical shelf profile and geomorphic zonation for the northern Ningaloo at Mandu SZ.

Geomorphic zonation, features and associated habitats

Analysis of acoustics combined with sedimentological, geomorphic and video data has enabled characterisation of the shelf depth, geomorphology, substrate stability, hardness and roughness, grain size and suitability to support significant biota, from the reef slope to the edge of the continental shelf. The shelf in the northern Ningaloo is narrow and preliminary results have defined a clear zonation of habitats across the continental shelf. The multibeam data between the Osprey to Mandu region illustrates this distinct geomorphic zonation (Fig. 10) including: a seaward fore reef slope with base at ~30-40 m depth; an inner shelf zone between 40-60 m; a wide, flat middle shelf sand plain in ~60-75 m, interrupted by low relief ridge systems; outer shelf sand dune and ridge systems at ~75-125 m; and a shelf break ridge and deep-sea canyon heads at ~125 m. A number of large geomorphic features have been identified from the acoustic data that are important for habitat development. These include, but are not limited to: reef slope spur and grooves and drowned reefs; inner shelf pinnacle and ridge systems; inner shelf relict reef platform; inner-mid shelf submarine fans; extensive mid-outer shelf dune fields; mid-outer shelf ridge systems; and continental slope canyons.

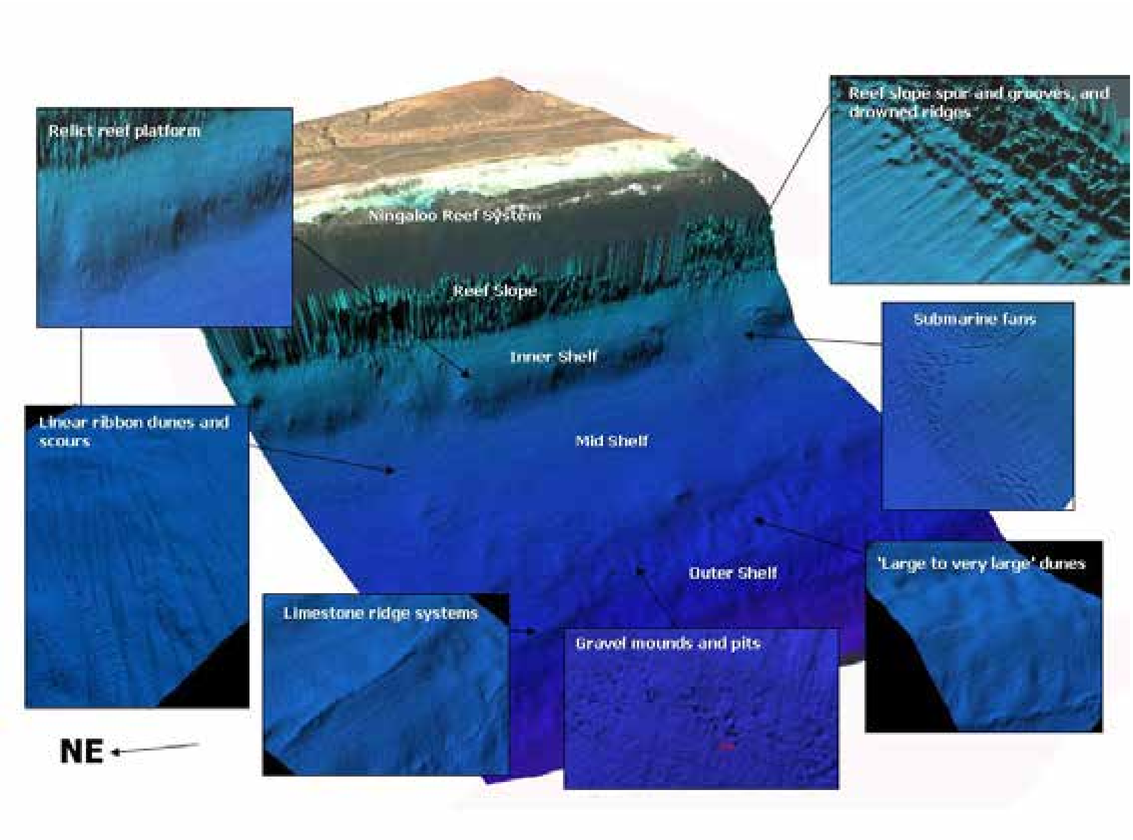

Figure 10. Summary 3D geomorphic zonation in the Mandu region

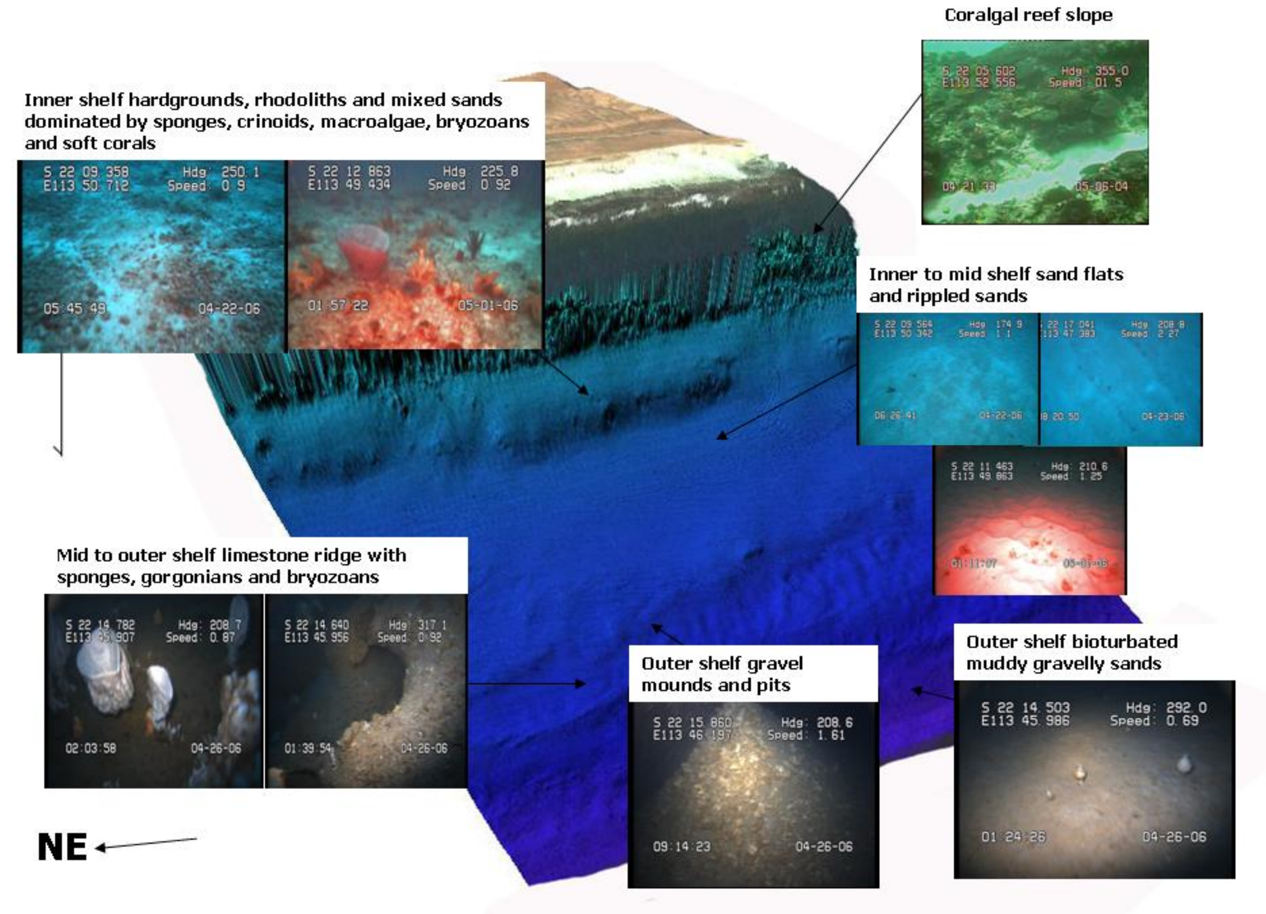

Figure 11. Summary of habitat zonation in the Mandu region.

Sedimentary bedform distribution is closely linked with geomorphic provinces and features on the shelf. There is a strong association with geomorphology, sedimentology and habitats, with communities taking advantage of availability of Pleistocene and early Holocene limestone substrates and gravelly sediments (Fig. 11). In the southern part of the Marine Park where the shelf widens and shallows, the zonation is less obvious with communities being opportunistic and substrate dependent.

Fore reef slope to inner shelf - Multiple spur and grooves and drowned reefs (coral and coralline algae dominated community)

Multiple spur and groove systems and pinnacles are present just seaward of the Ningaloo reef crest (Figs. 12, 13). This habitat extends to around 35-45 m and is composed of hard corals including large encrusting *Montipora* and large tabular, small digitate and corymbose *Acropora* (Fig. 14).

Encrusting red coralline algae are common encrusting the underlying limestone substrate. Spur and grooves are common on the slope with communities growing on large spurs with gravelly sands in the grooves (Fig. 14). The benthic community also consists of sponges (mainly cups), soft corals, turf algae, macroalgae, *Halimeda,* and bryozoans (including *Adeona* sp.). Corals rapidly disappear at the transition zone to the base of the reef slope to inner shelf at ~30-40 m, to a mixed deeper-water benthic community dominated by sponges, soft corals, crinoids and bryozoans. Deeper coral communities to around 45 m have been observed at Cloates SZ.

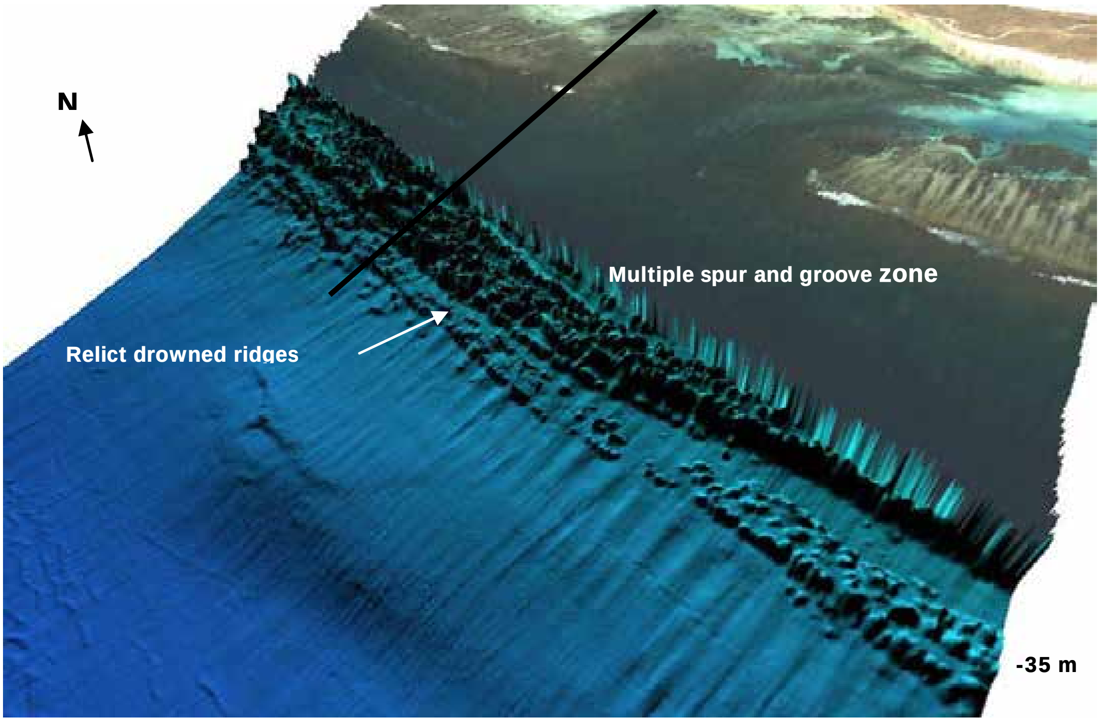

Figure 12. Fore reef slope spur and groove and drowned reefs.

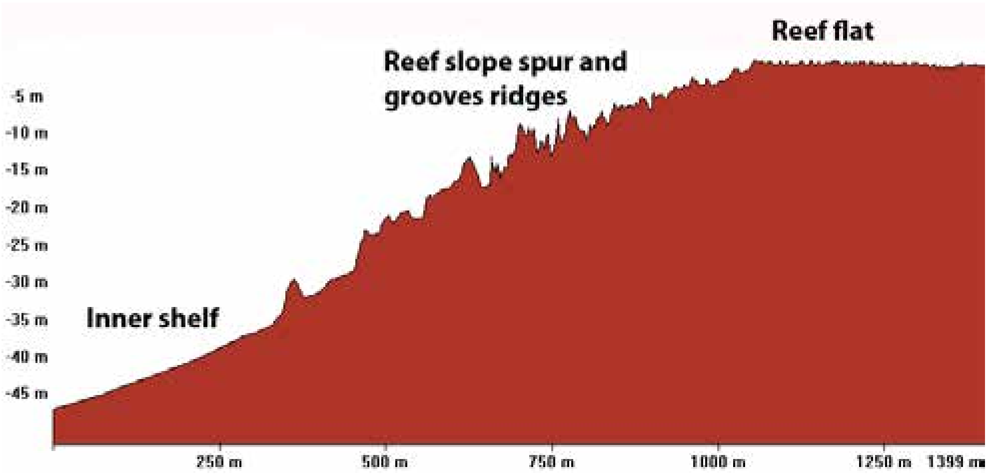

Figure 13. Profile of fore reef slope, profile line on Fig. 11.

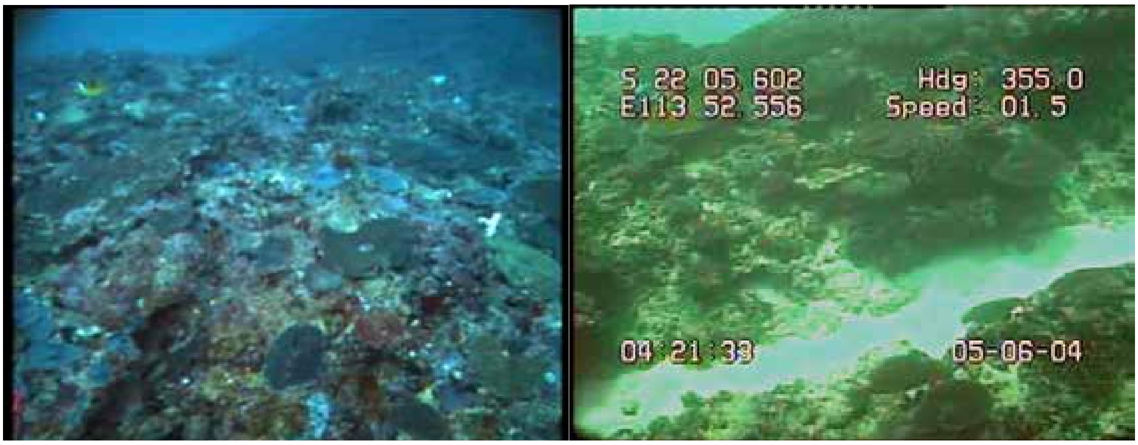

Figure 14. Coral and red coralline algae growth on bedrock and on spurs, with gravelly sand within the grooves.

Inner shelf - Relict reef platform (rhodolith and hardgrounds with mixed filter-feeding communities)

At the transition between the base of the reef slope and the inner shelf, rhodolith gravel beds, hardgrounds and mixed gravelly sands are the dominant substrate observed in depths of around ~35-60 m (Figs. 15, 16). The topography is generally flat and regular and the platform morphology is parallel to the modern reef line suggesting a relict reef system. Rhodoliths supply the hard substrate for a diverse mixed community of crinoids, sponges, turf algae, *Halimeda*, soft corals, gorgonians, sea whips, ascidians, sea pens and sea stars (Fig. 17).

The density of gravel is influenced by local oceanographic processes including flushing of lagoonal waters and sediments through reef passes, reducing the density of rhodolith gravel.

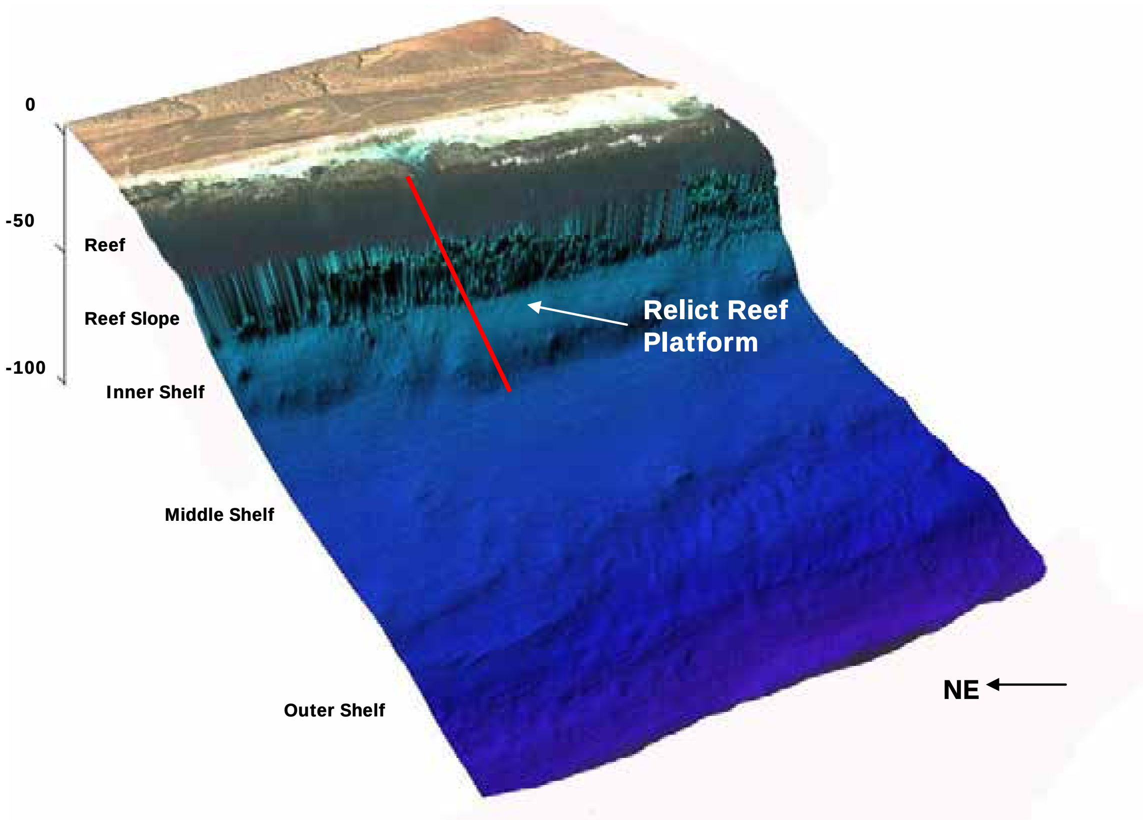

Figure 15. Inner shelf relict reef platform at Mandu SZ.

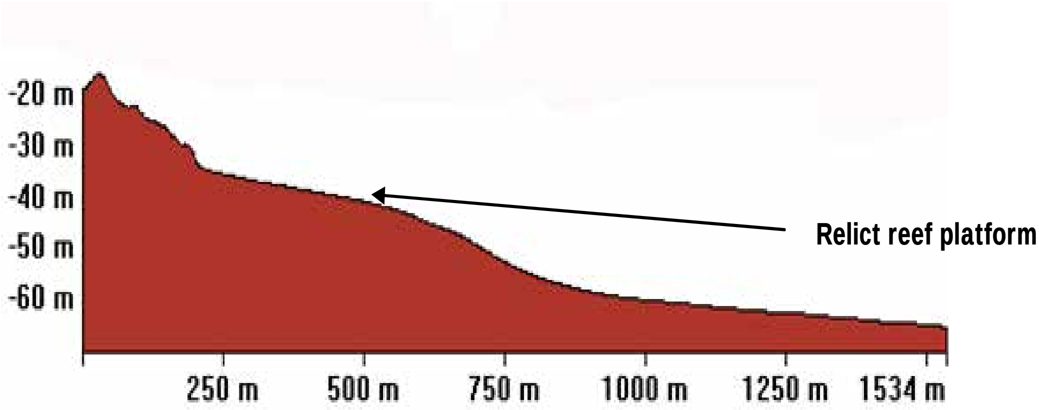

Figure 16. Profile of relict reef system, profile line on Fig. 15

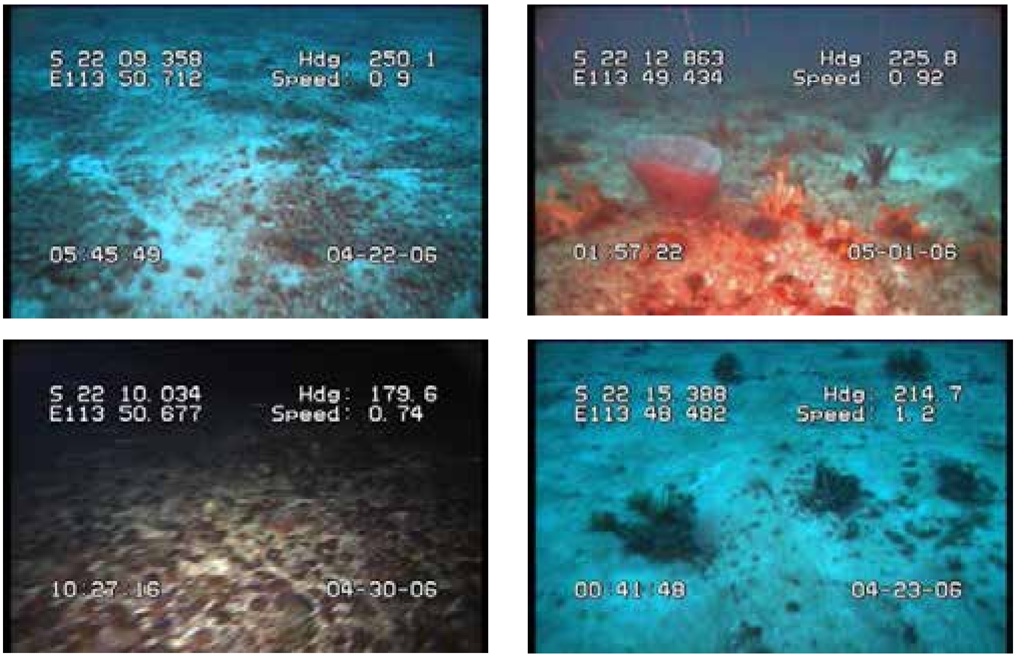

Figure 17. Community dominated by crinoids, sponges, bryozoans, turf algae, macroalgae, *Halimeda,* soft corals, gorgonians and sea whips to ~65m.

Inner shelf - Mixed coarse gravelly burrowed sand (bioturbators and mixed filter-feeding communities)

Rhodolith beds grade into course gravelly sands on the outer edge of the inner shelf (Fig. 18). Bioturbation is present with diverse infauna reworking the sediments to build mounds and burrows. Feeding and resting traces from fish, echinoids and asteroids are common. In more gravelly substrates this habitat also supports mixed, filter-feeding invertebrate communities of sponges, crinoids, soft corals and bryozoans.

Figure 18. Biogenic sedimentary structures on gravelly sand.

Inner to mid shelf - Submarine fans

Submarine fans adjacent to reef passes, are clearly seen on the mulitbeam bathymetry (Figs. 19, 20, 21).

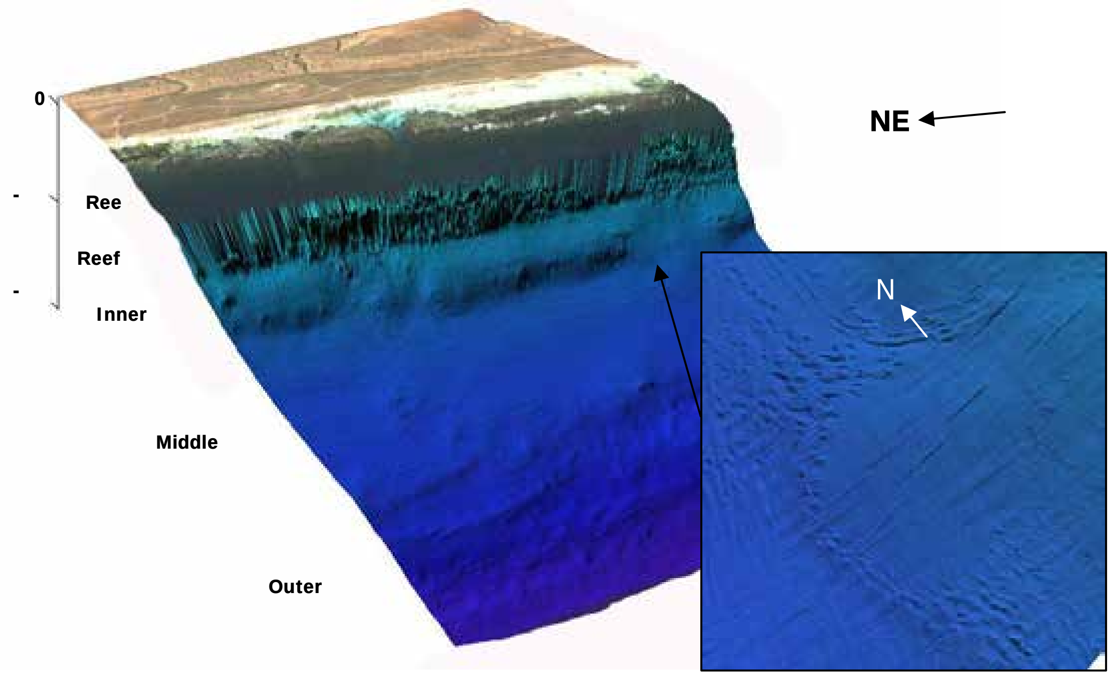

Figure 19. Multibeam bathymetry image of submarine fans and associated complex dunes

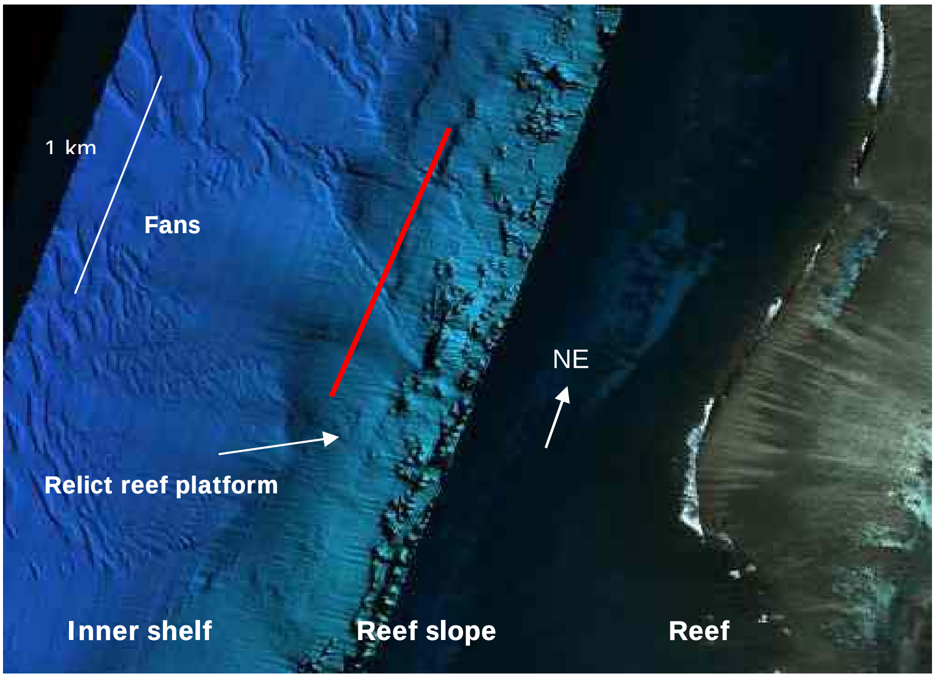

Figure 20. Close up of submarine fans and associated dunes at Mandu.

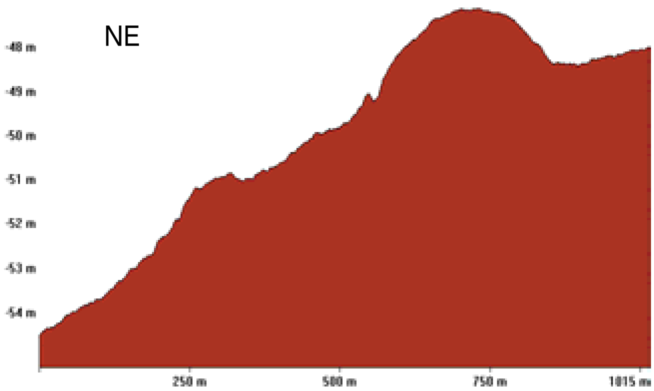

Figure 21. Profile of submarine fan system at Mandu, profile line on Fig. 20.

The multibeam bathymetry profile (Fig. 21) illustrates the bathymetric highs of the fans. The multibeam backscatter image also indicates that the fans are texturally different to the surrounding substrate (Fig. 22). The sediments within these fans are finer and well sorted compared to adjacent areas and correlate with low backscatter values (see also Fig. 51). These features have formed as a result of flushing of lagoonal sediments through reef passes offshore onto the shelf, where they are currently mixing with relict mid-shelf sands. The fans are associated with complex 2D and 3D medium –very large dunes (Ashley 1990) formed by the interaction of lagoon flushing, tidal and wave dominated currents (Fig. 23). The sediments forming these bedforms further offshore on the mid shelf, have been subsequently entrained northward as a result of the dominant SW currents, forming linear sand ribbons dunes (see below).

Figure 22. Multibeam backscatter image of the submarine fans adjacent to reef passes. (Low backscatter values = light shades).

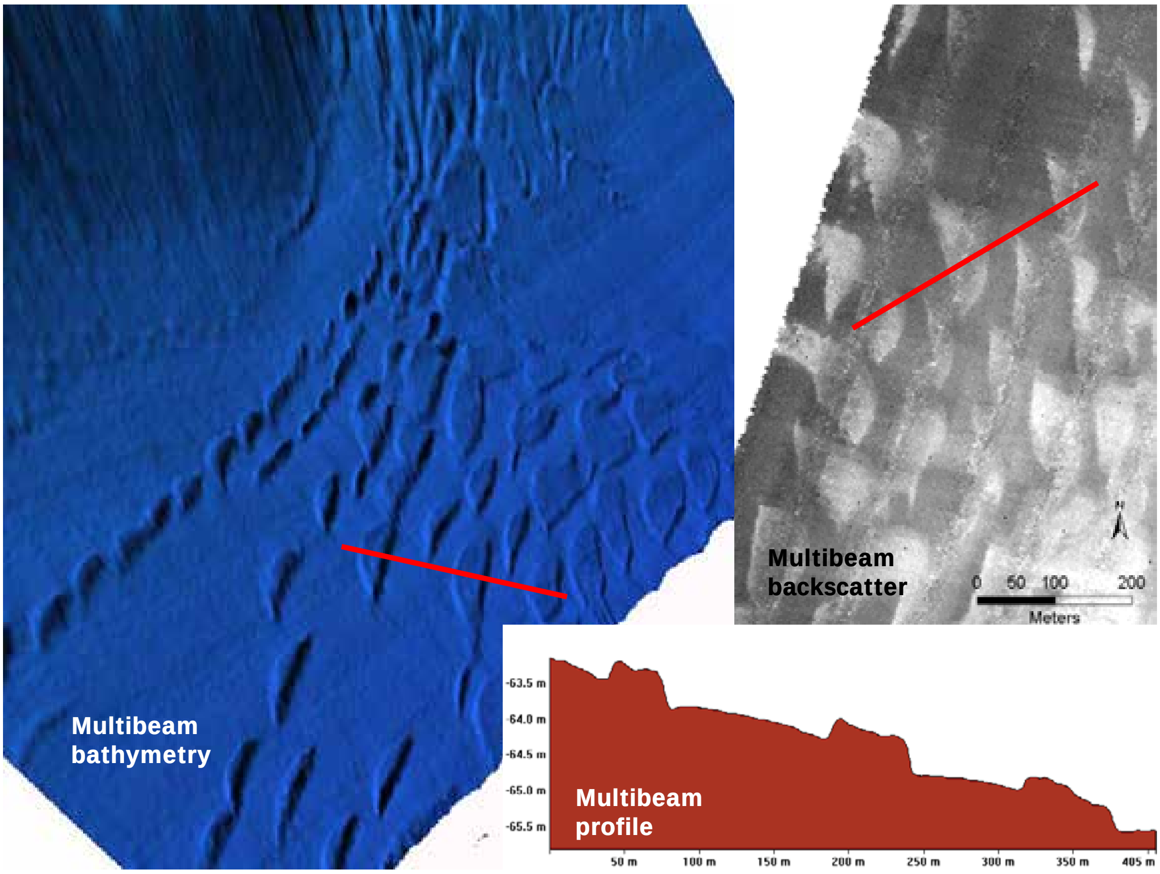

Figure 23. Complex 2D and 3D bedforms associated with the edges of submarine fans.

Inner shelf - Straight crested rippled sand adjacent to reef passes

Straight crested ripples with little epibenthos have been observed on the towed videos adjacent to reef passes (Fig. 24). Video sites correlate with submarine fans and indicate strong currents flushing from the lagoon through reef passes, along with potential swell wave and tidal influences. Sediment thickness is variable overlying limestone pavement. Rubble and rhodolith are sometimes present in the troughs of the ripples, supporting sparse communities of sponges, macroalgae, soft corals, crinoids and bryozoans.

Figure 24. Straight crested sand ripples.

Inner to mid shelf - Rippled and bioturbated sand

The inner-mid shelf sand habitats are characterised by mounds and burrows, straight crested and interference ripples (Fig. 25) with little epibenthos. Inner-mid shelf sand communities of sponges, crinoids, soft corals, sea pens, sea whips, bryozoans, and hydroids are patchy with higher abundance related to exposed surfaces and rhodolith rubble in the troughs.

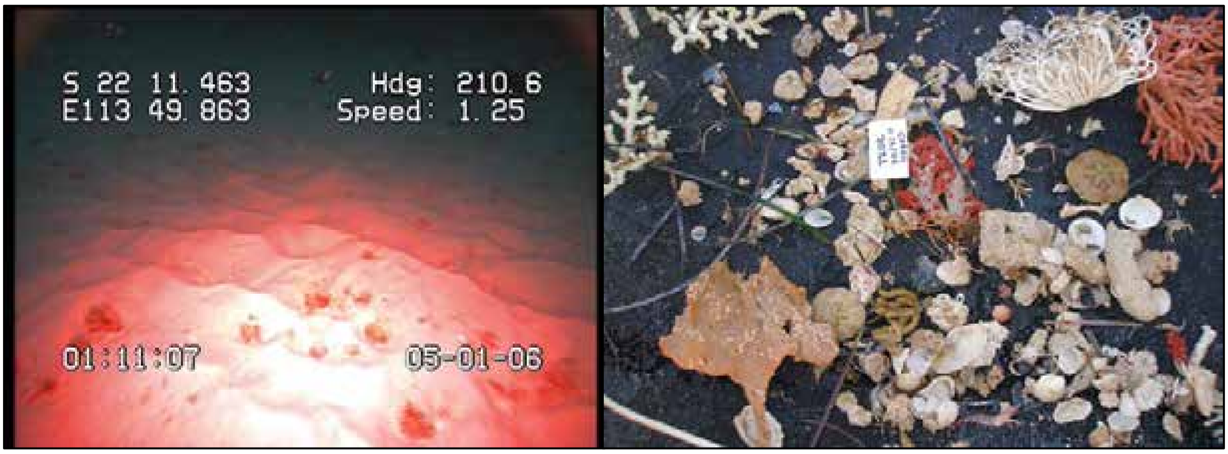

Figure 25. Interference sand ripples with little epibenthos and invertebrates recovered in sled.

Mid shelf - Linear sand ribbon dunes and scours

Linear ribbon dunes with a NE-SW crest orientation occur on the mid shelf. The texture of the backscatter and sediment grab data indicates alternation between gravelly sediments and bedrock (darker) and more finer (lighter) sands (Figs. 26, 27, 28). Their crests range from a few hundred metres up to around 2 km length, and they cover the entire mid shelf in particular in the Boat passage area. Many linear dunes merge to form Y-shaped compound dunes. These bedforms suggest strong currents in a NE-SW orientation but on there own do not indicate current direction. Direction of the currents has been determined by crag and tail geomorphic features in the region of these dunes, which confirm a strong NE current direction due to build up of sediment on their NE lee sides.

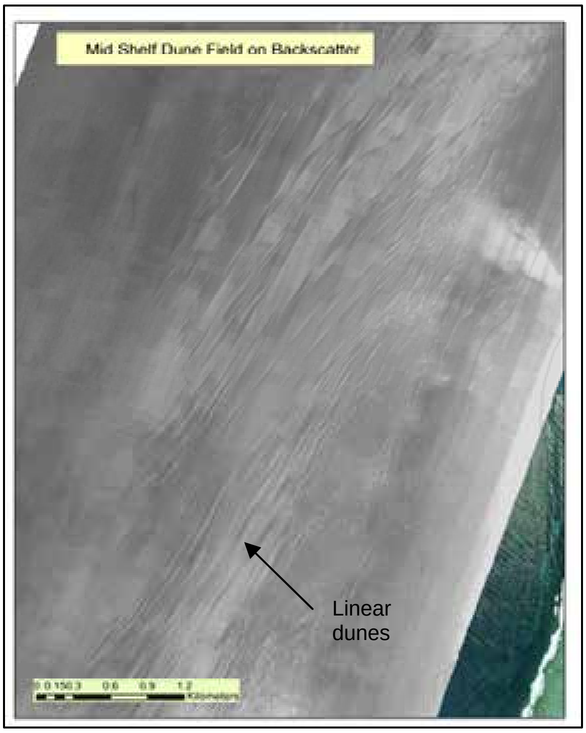

Figure 26. Backscatter image of mid shelf linear dunes, illustrating the alternation between finer sands (low backscatter values = light shades) and gravelly sand and bedrock (high backscatter values = dark shades).

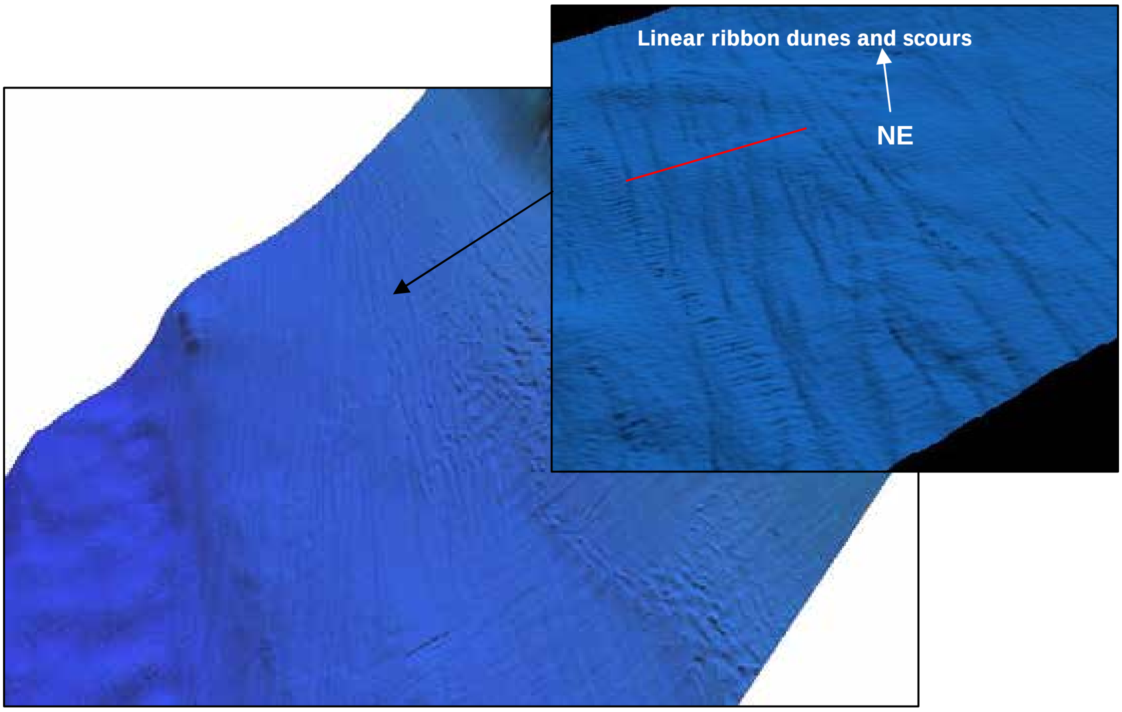

Figure 27. Multibeam image of linear ribbon dunes and scours.

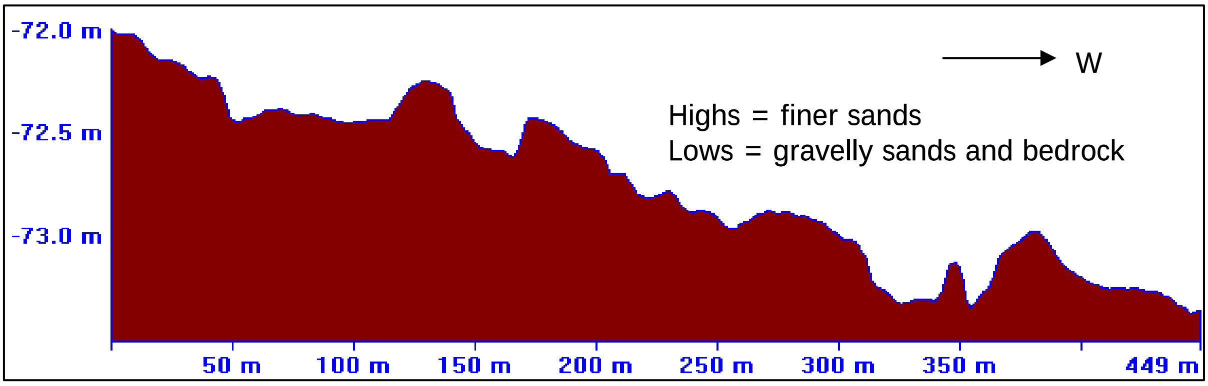

Figure 28. Profile of linear dunes and scours, profile line on Fig. 27.

Mid to outer shelf - 'Large to very large' dune systems

3D bathymetric models have aided in the classification of bedforms from profile analysis. It has been possible to quantify bedform height and wavelengths and to evaluate their asymmetry. Sediment transport direction has been obtained indicating orientation of the majority of currents towards the NE. Ashley's (1990) classification (Table 1) has been adopted and on this basis it has been possible to distinguish two types of sand dunes: 'large' and 'very large' (Figs. 29, 30).

Table 1. Sand dune classification by Ashley (1990).

Subaqueous Dune									
First order descriptors (necessary)									
Size:	Spacing	small	0.6-5 m;	medium	5-10 m;	large	10-100 m;	very large	>100 m
	Height		0.075-0.4 m;		0.4-0.75 m;		0.75-5 m;		>5 m
Shape:	2-Dimensional								
	3-Dimensional								

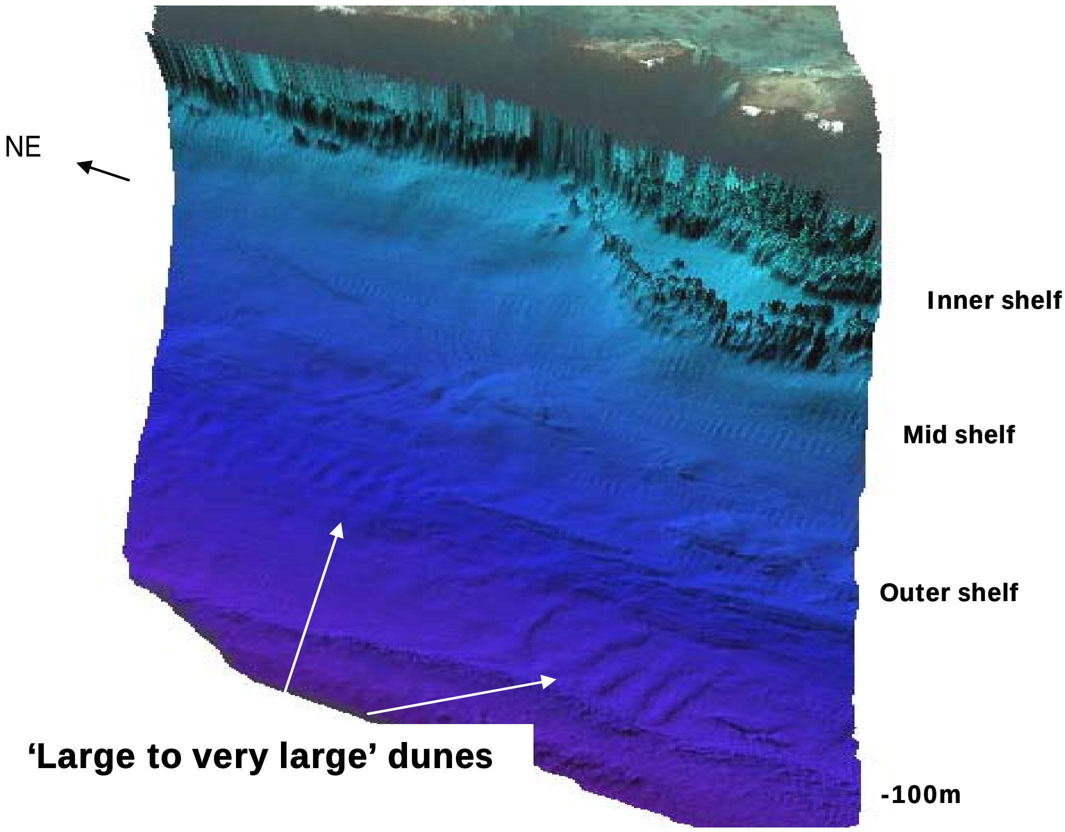

Figure 29. 'Large to very large' dunes in the Osprey region.

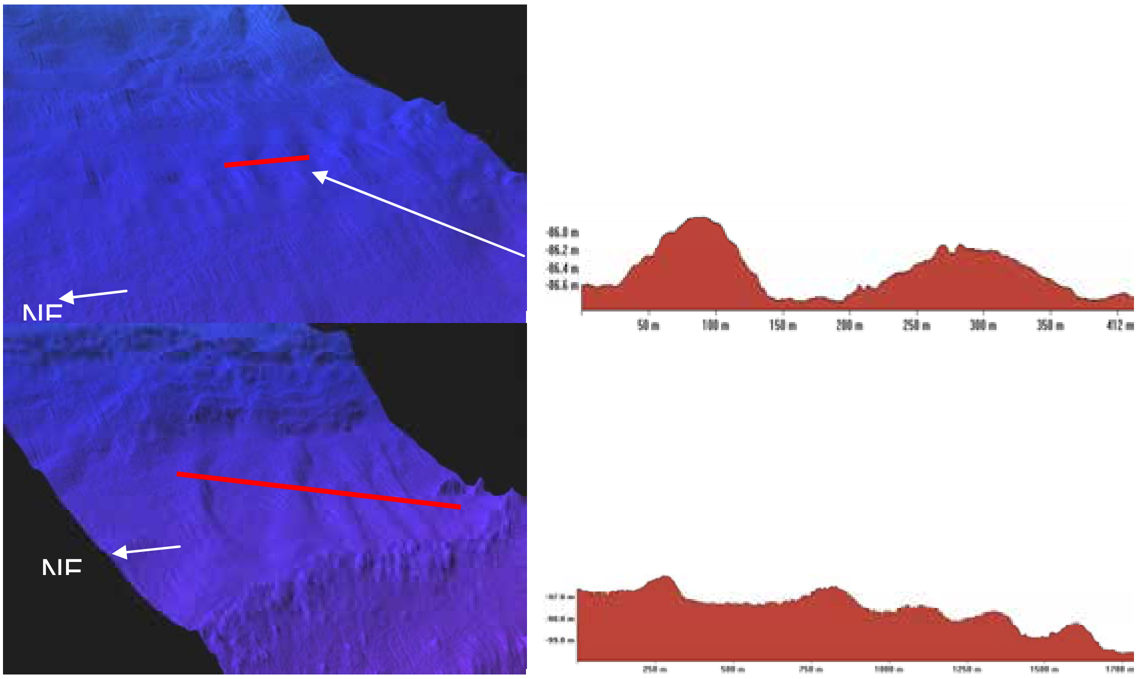

Figure 30. Symmetrical and slightly asymmetrical 'Very large' dunes on the outer shelf.

In the Osprey to Mandu region 'large' dunes have wavelengths ranging from 10-100 m and heights from 5 cm to 1.8 m. They represent most of the bedforms in the area covered by the multibeam. Their morphologies fall into the following classes: 2D trochoidal, 3D trochoidal, 3D barchan and 3D barchan/trochoidal (Fig. 30). The majority of large dunes are asymmetrical with a prevailing transport direction to the ENE and NE. A number of these bedforms are superimposed on 'very large' bedforms. 'Very large' mainly asymmetrical dunes can be found on the mid-outer shelf, indicating bottom currents towards the NE. Wavelengths of 'very large' bedforms are between 105-480 m and wave height from 20 cm - 1.9 m. Both asymmetrical and symmetrical forms have been observed (Fig. 31) and their main morphologies include: 2D trochoidal, 3D barchan/ trochoidal, 3D barchan and 3D trochoidal. Some show 'large' bedforms on their stoss side.

The variability of bedform morphology is connected to the interaction of different currents on the bottom. The currents are derived from wave dominated processes (SW swell), storm activity, tidal currents closer inshore and potentially the oceanic Leeuwin Current which hugs the edge of the shelf at Ningaloo. Barchan type dunes identified migrate towards the major current direction (here the SW) and commonly form on shelves with only a veneer of coarse sediment overlying hard substrate.

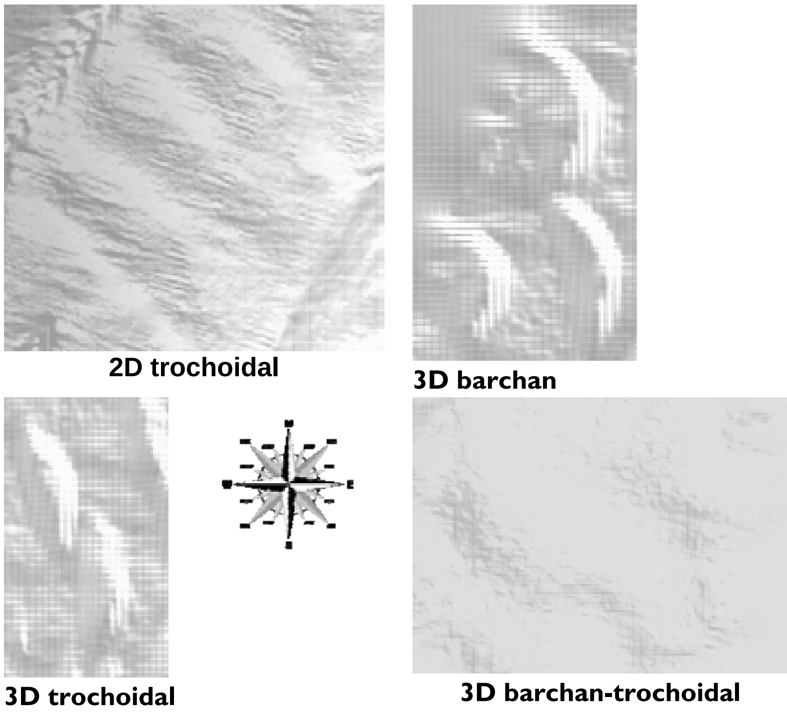

Figure 31. Bedform morphologies

Outer shelf - Gravel mound fields

Large gravelly sand mounds have been identified at around the 85-95m contour on the outer shelf. These features were initially identified from the towed video and with further investigation were clearly present on the multibeam backscatter and bathymetry (Figs. 32, 33). The backscatter indicates an area of 400 m x 200 m with over 30 mounds; many of them are 15-20 m in basal diameter. Three mound fields of similar dimensions are present in the Osprey to Mandu region and a further investigation into these features is underway. Currently their origin is unknown but there is the potential that these may be linked to freshwater seeps, karst and/or paleo-channels.

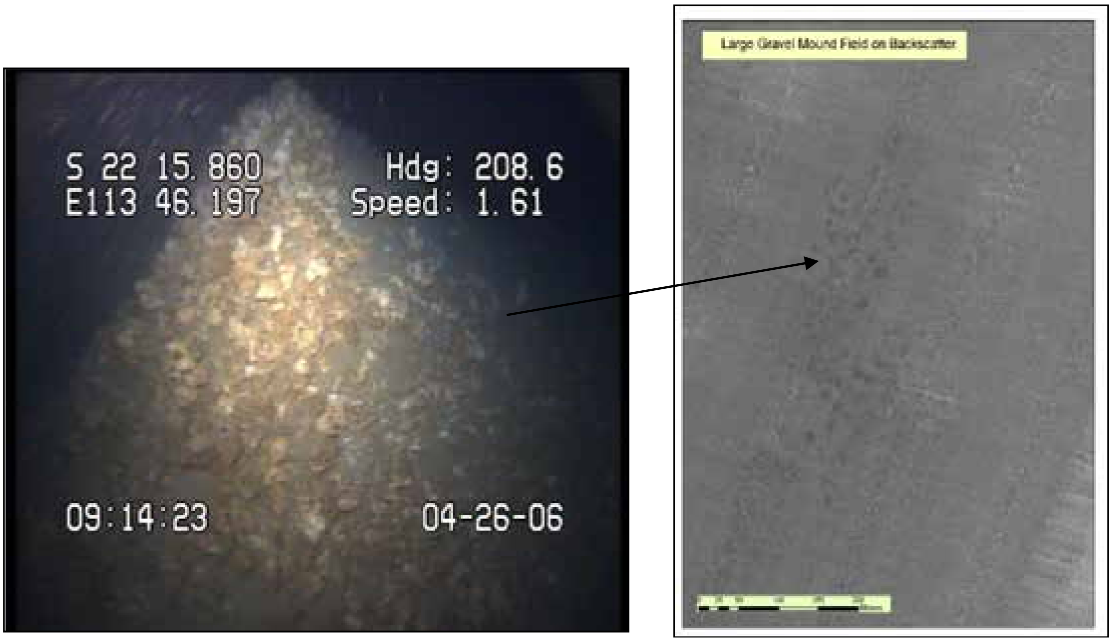

Figure 32. Video still image of large gravel mounds and gravel mound field identified from multibeam backscatter imagery.

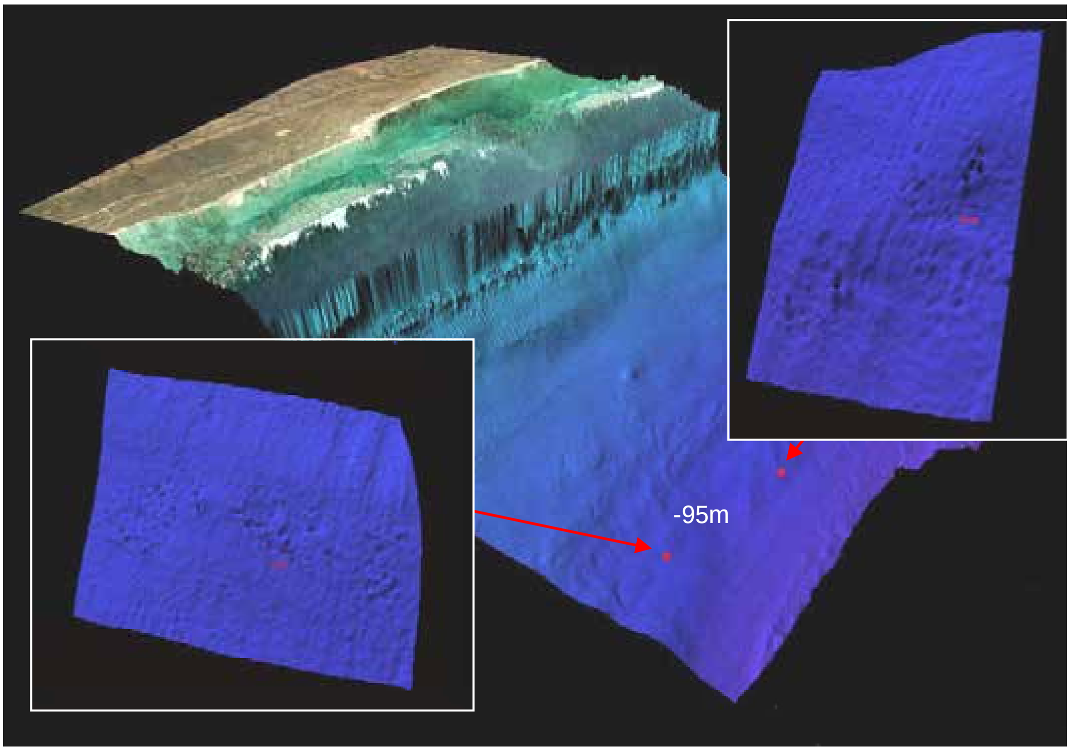

Figure 33. Two areas of gravel mound fields identified on the multibeam bathymetry.

Outer shelf - Gravelly muddy sand with burrows and mounds

Bioturbation is the dominant sedimentary process occurring on the outer shelf. This region is below wave base and as a result the sediment is highly burrowed by infauna (Fig. 34). Bryozoans, sponges, gorgonians and molluscs are the dominant benthos with higher abundance related to exposed surfaces. Strong localised currents were present in some of the videos and may relate to areas of 'large to very large' bedform development.

Figure 34. Burrows and mounds in gravelly muddy sands.

Inner to outer shelf - Extensive ridge and pinnacle systems (coral reefs and prolific sponge, gorgonian and bryozoan 'gardens')

A number of low-high relief ridges and pinnacles on a very irregular bottom have been recognised at various depths during preliminary bathymetric data observations. These ridges are typically sites of important habitats for invertebrates that affix to hard substrates. Examples of ridge and pinnacle systems identified throughout the Marine Park are outlined below:

Osprey Sanctuary Zone - Boat Passage (Figs. 35, 36): These areas form part of the multibeam coverage, consequently a detailed analysis has been possible. Prominent and extensive systems occur on the outer shelf at around 65-125m in the northern Ningaloo Reef (Fig. 35). A number of ridges exist between 65 and 110 m of depth (ridges identified at 65, 69, 75, 81, 83, 88, 90, 100, 102 and 110 m), mainly oriented NNE-SSW (parallel to the coastline). Their length range from hundreds of meters to a kilometre and their width varies between meters and tens of meters. They have created an uneven bottom with a variation of several metres relief.

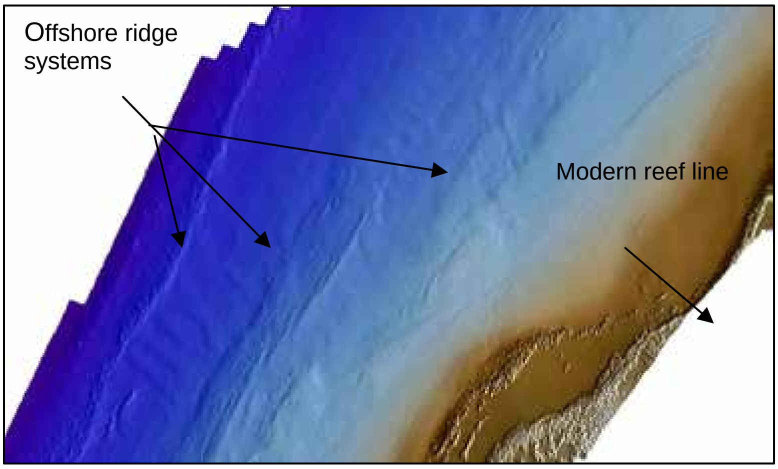

Figure 35. Osprey SZ showing ridge systems on the mid and outer shelf.

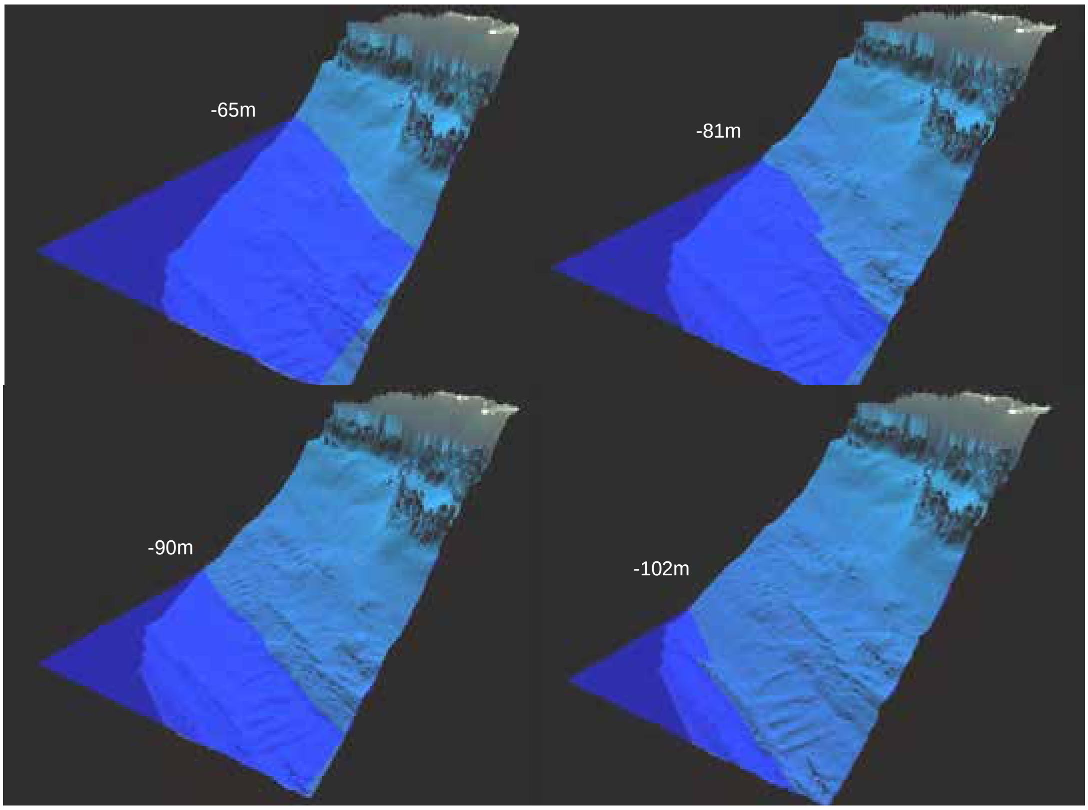

Figure 36. 3D Multibeam bathymetry image of Osprey SZ showing ridge systems (and paleo sea-levels) at various depths on the mid and outer shelf.

Red Bluff (Fig. 37): It has been observed as a slightly sinuous ridge developed along a N-S direction. The ridge is around 7.5 km long and its average width ranges from 300 m at its southern extreme to 1100 m at its northern extreme. Its distance from the coast is approximately 4.2 km at the southern end to approximately 6.6 km at the northern end. The ridge has developed around depths of 28 m. The surrounding bottom depth is 35 m on the landward side and 40 m on the ocean side.

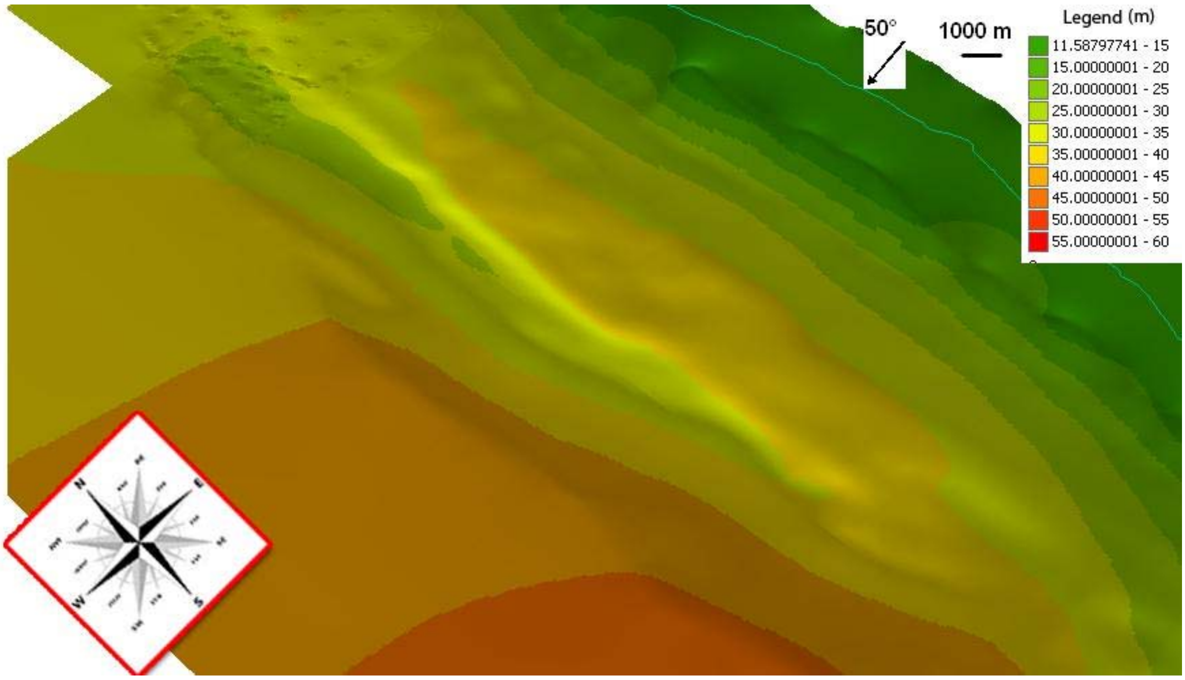

Figure 37. Red bluff area ridge extracted by single beam data.

Pelican Sanctuary Zone (Fig. 38): It has been identified as a ridge extended in a NNE-SSW direction and sited between approximately 12 km south of Point Maud to the major part of Pelican SZ for a total length of approximately 11 km and a width of 700 m. The ridge is developed at depths of 32 m in the northern sector but it deepens to 40 m in the southern part, it creates a relief of ~12 m on its ocean side and only a depth of a few metres or so on its landward facing side. It is approximately 5.2 km away from the coast and shows a bifurcation in the middle of its extension. The secondary branch has a length of 2 km and it is developed toward the land approximately 4.5 km from the coastline; its orientation is parallel to the main ridge at an average depth of 35 m.

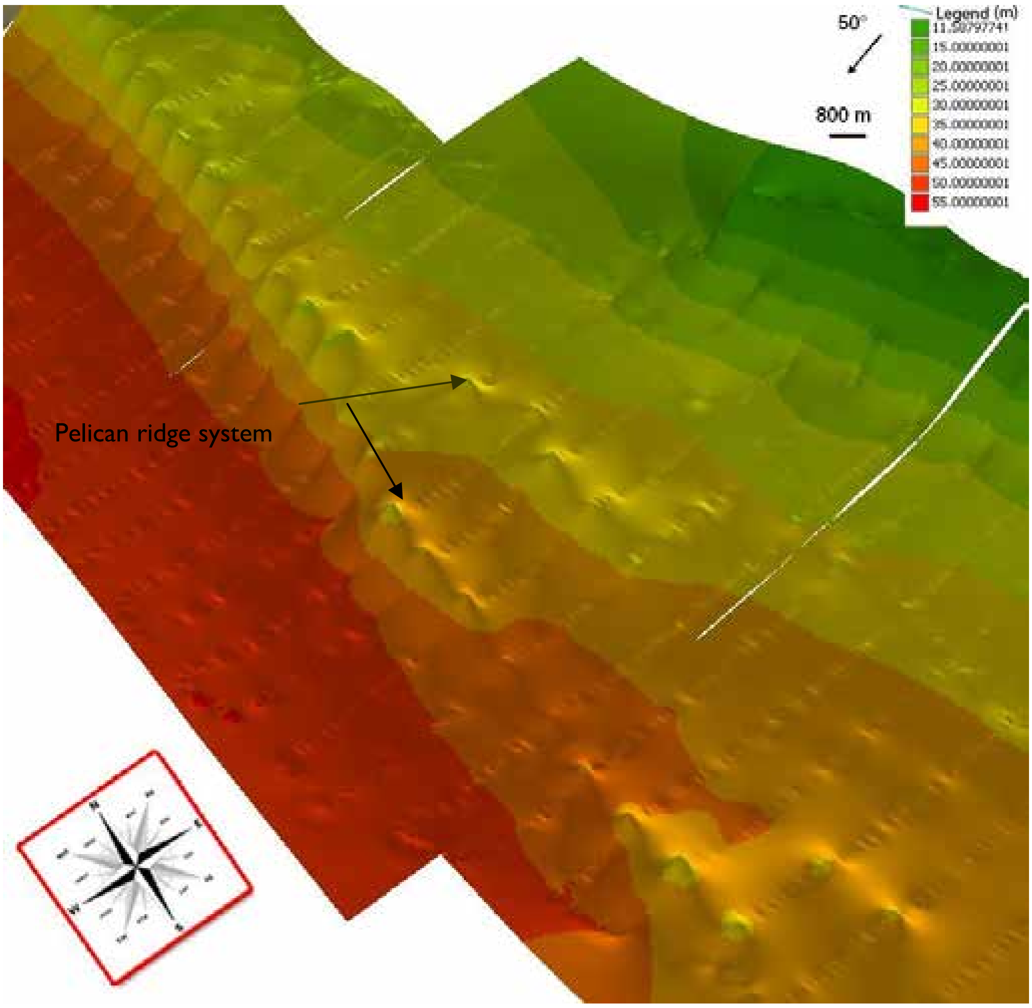

Figure 38. Pelican SZ ridge extracted by single beam data (the evident lines represent tracks).

Cloates Sanctuary Zone (Figs. 39, 40): This is the most irregular area of the shelf characterized by the presence of ridges located 3.5 km south of Point Cloates and by pinnacles that cover the bottom surroundings down to around 40 m depth. At 40 linear ridges slope to depths of 60 m. The main ridge (known as Black Rock) is oriented NW-SE through a total length of 3.5 km and a width of 2.1 km. The pinnacles are distributed at a depth of ~30 m across the bottom, and they have a variation in height of 0.5 to 15 m; their radius is in the order of hundreds of meters. Figures 39 and 40 represent a bathymetric TIN model and x-section created using hydrographic RAN sounding data. The area of Black Rock is included and illustrates the complex structures of the Cloates area. Two prominent ridges have been identified in 40-60 m seaward of Black Rock. These ridges have a relief of up to ~15-20 m and produce a difference of 20 m depth within only one kilometre. Cloates represents a complex history of constructional and pre-existing antecedent topography, where Tertiary limestone surfaces, paleo-stillstand escarpments and shorelines, and stepwise fossil reefs are present.

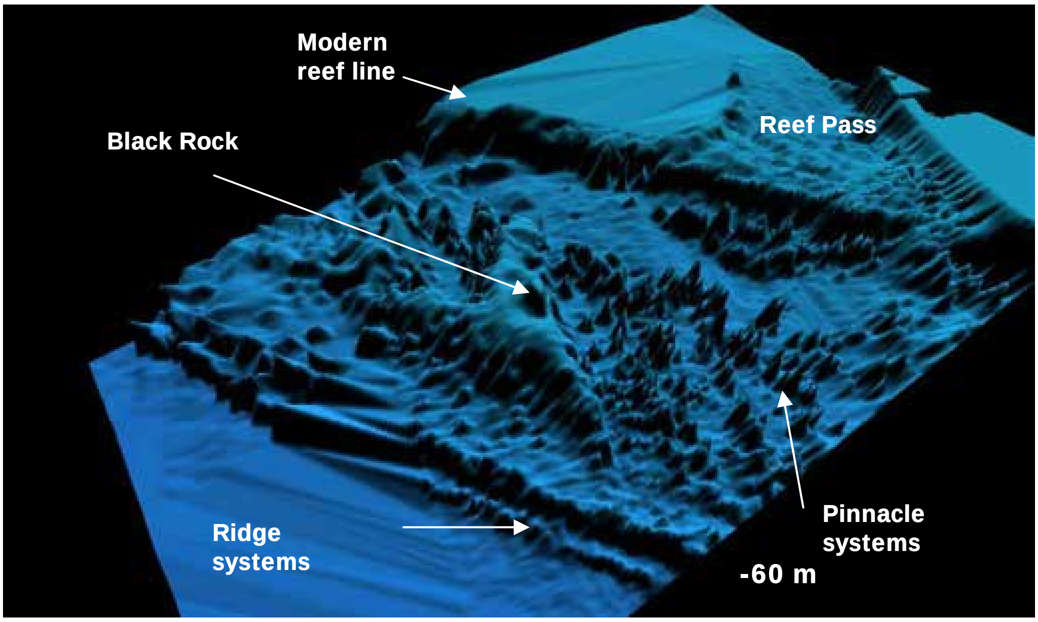

Figure 39. Cloates SZ ridge and pinnacles extracted from hydrographic RAN sounding data.

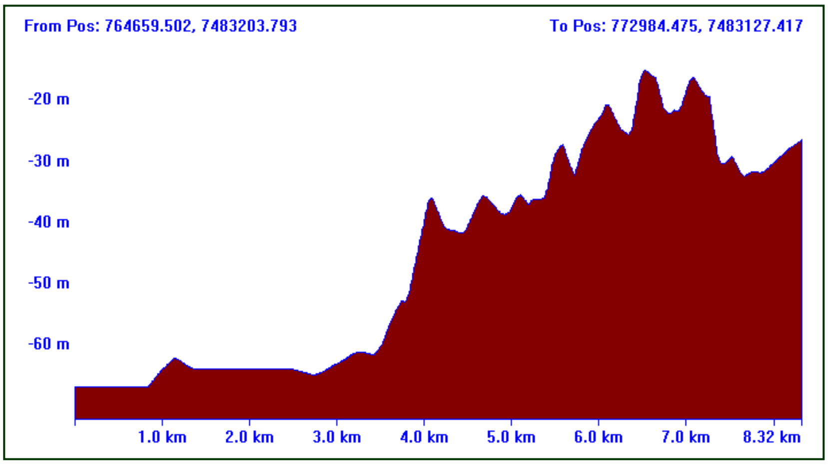

Figure 40. Profile illustrating back-stepping ridges and pinnacles at Cloates SZ.

Initial observation of these large ridge features using the towed video data, indicates that many have 'spur and groove' morphologies running perpendicular to the reef line, and attest to the high wave energy environment of this section of the reef. Separating these high relief ridges or `spurs` are coarse sandy areas `grooves` with large, straight-crested sand ripples and mega ripples with little epibenthos (Fig. 41). Many of these ripples have gravel lags and seagrass debris in the troughs. Seagrass beds are present in the lagoon adjacent. At Cloates SZ corals persist to greater depths (40-50m) than those observed in the northern Ningaloo Reef. These features support a diverse coral, algal and sponge community.

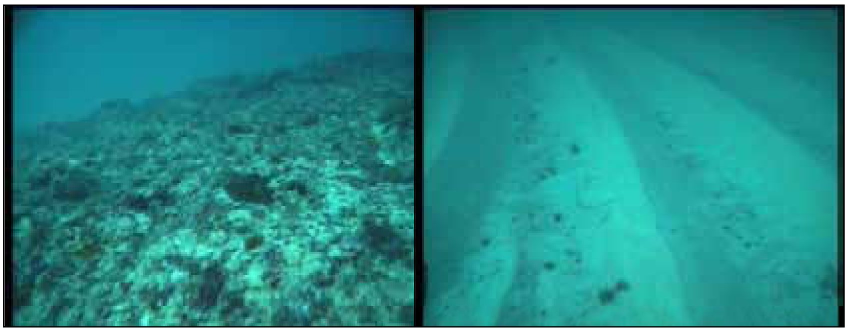

Figure 41. Ridges and straight crested sand ripples with gravel lags

Jurabi Sanctuary Zone - Vlamingh Head (Fig. 42): in these areas ridge and pinnacles are present, but much more isolated from each other in regards of those noted in the Cloates SZ. The ridge is long, around 5.6 km, and its width ranges from around 600 m to 200 m from the northern extreme to the southern; its depth is variable between 16 and 20 m from north to south and creates a difference in depth of 10-15 m relief on its seaward side. The ridge is oriented ENE-WSW and ~40 pinnacles are present landward along the same orientation. Their radius range from tens to hundreds of meters and their tops reach the same depths as the ridge but have lower relief compared to the surrounding seabed. Both features are parallel to the coastline.

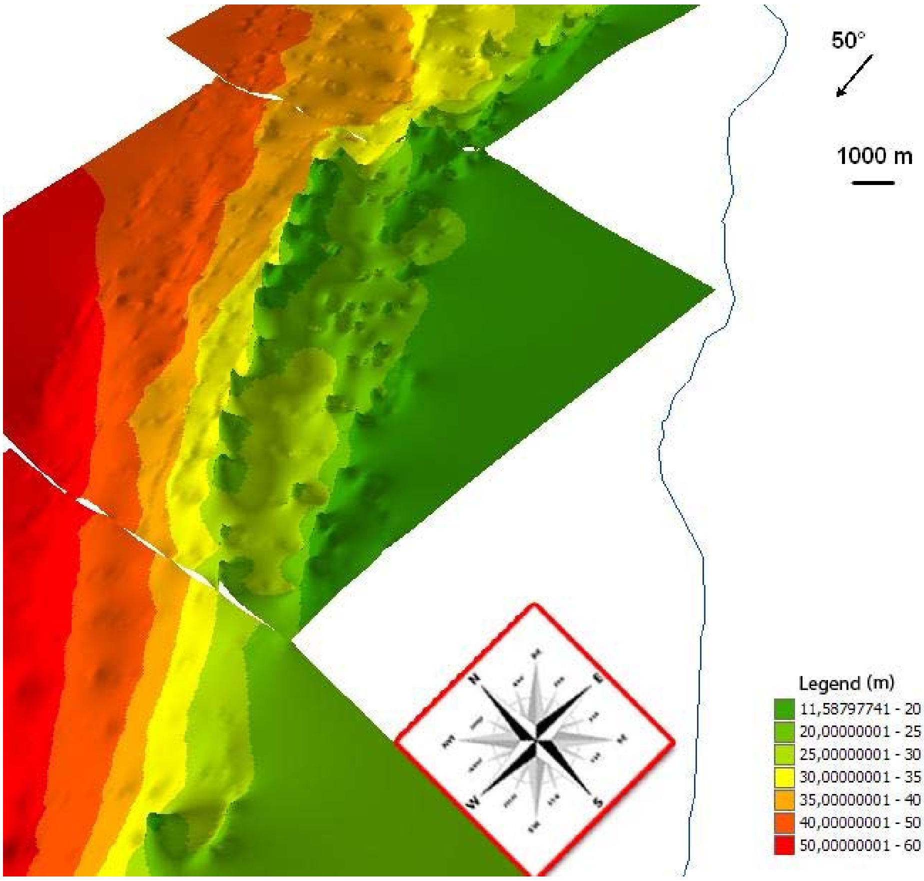

Figure 42. Jurabi SZ ridge and pinnacles extracted by single beam data.

Lighthouse Sanctuary Zone (Fig. 43): A sub-conical pinnacle structure has been identified in the area 4.2 km from the coastline. Its top is in 17 m depth with surrounding depths of 35 m seaward and 25 m landward. The diameter of the minor axis is approximately 1.7 km long and the major axis is approximately 2.2 km. On the landward side of this structure are a couple of depressions with maximum depths of ~30 m.

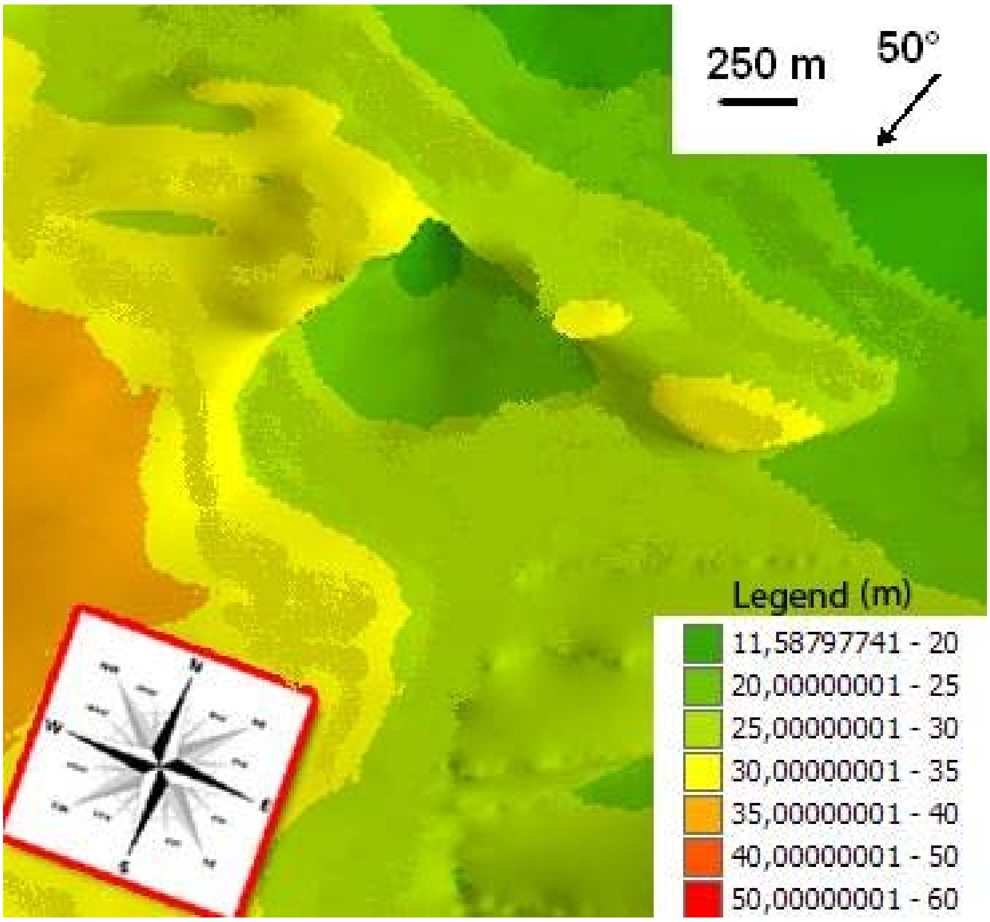

Figure 43. Lighthouse SZ conical pinnacle and near depressions extracted by single beam data.

Ridge Formation - The ridge structures may be erosional or constructional features. During glacial lowstand periods the present continental shelf was completely exposed down to the current shelf edge at ~ -125m. Karstification of pre-existing Tertiary and Pleistocene limestone surfaces took place and now influences modern shelf topography. Paleo-shorelines formed by erosion of substrates during sea-level stillstands, as sea-levels rose over the last 20 ka (ka = thousand years). Constructional growth may have taken place during reef building episodes as water temperatures increased and sea-level rose.

a) Drowned backstepping reefs

A limestone sample recovered from the benthic sled at 72 m contained well preserved corals (Fig. 44). Corals are being dated to provide an insight into the geological and sea-level history of the continental shelf in this region. The ridges run parallel to the modern reef line and may have formed as a series of constructional back-stepping reefs as sea-level rose during the Pleistocene.

Figure 44. Dredged rock samples from 72m water depth with close up of sample containing well preserved coral samples.

b) Last Glacial paleo-shoreline (~125m)

A ridge at 125 m is identified as the Last Glacial lowstand shoreline, ca. 20 ka. This can be identified clearly on the TIN bathymetric model and x-shelf profiles (Fig. 45).

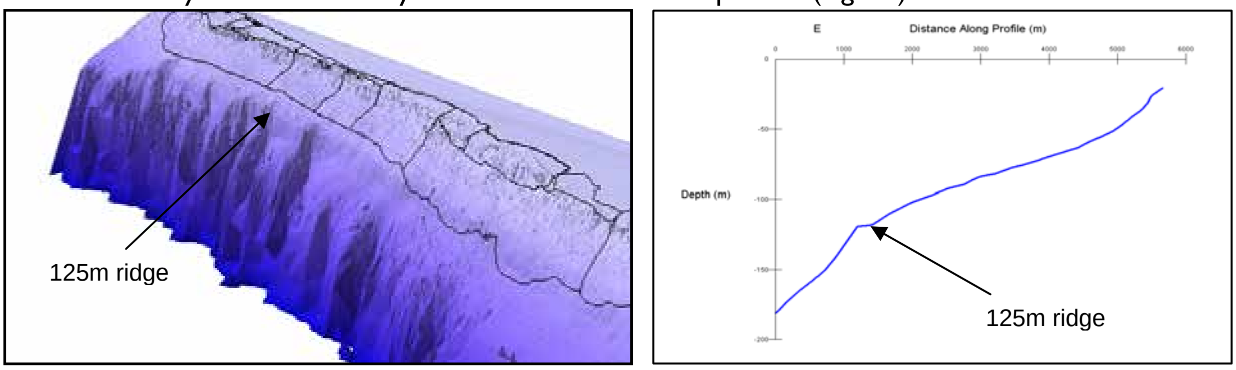

Figure 45. Profile at Mandu SZ (north) showing well defined ridge at 125m identified as the last Glacial shoreline at 20ka.

These ridges are typically sites of prolific growth with invertebrates growing affixed to the substrate, illustrating the importance of hard substrates to production. Exposed limestone substrates are colonised with high cover of exotic sponge, gorgonian and bryozoan 'gardens', *some of which are likely to be new species*. Diversity is high adjacent to continental slope canyons which bring nutrient rich, cold-water upwellings to the surface, ideal conditions for cool-water carbonate production. (Figs. 46, 47).

Figure 46. Limestone outcrops with prolific sponge growth.

Figure 47. Gorgonians, sponges and bryozoans (*Adeona* sp.).

Continental slope canyons and canyon heads

Large continental slope canyon systems lie just off the continental shelf break in the northern Ningaloo Reef (Fig. 48). Here the shelf is very narrow and the slope is only 10 km offshore. Diversity is particularly high in areas adjacent to the canyons, which are thought to bring cold-water upwellings and nutrients to the shelf edge. Additional surveys may be able to identify connectivity to x-shelf paleo-channels and passes in the reef system, maintained by erosion during periods of lower sea-level.

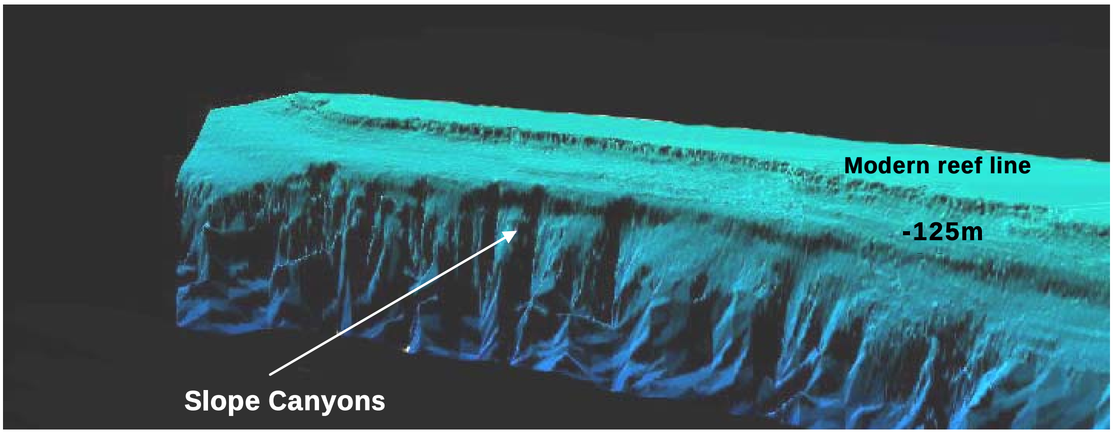

Figure 48. 3D bathymetric model of the northern Ningaloo Reef showing large canyons just off the Ningaloo shelf.

Sediment Characteristics

Grain Size Characteristics and Distribution

The textural analysis of the sediments has identified sub-parallel belts across the shelf which correlates well with the changes in the multibeam backscatter signatures and geomorphic features for the northern Ningaloo shelf. Figures 49 and 50 illustrate the interpolated grain size statistics for all offshore sites.

Sediments on the Ningaloo shelf generally contain a high proportion of gravelly sands. The relative abundance of gravel, sand and mud in the northern Ningaloo area is typical for carbonate shelf settings, with gravels dominating the inner shelf, sands in the middle shelf, with an increase in carbonate muds on the outer shelf (Fig. 51). The inner shelf is characterised by gravels and gravelly, rhodolith-rich sands which are interspersed by well sorted sands in submarine fans, adjacent to reef passes. Similar grain size distribution is reflected on the mid-shelf dune field, where well-sorted lagoon flushed sands have been deposited as submarine fans identified on multibeam backscatter (Fig. 52) and entrained northwards in the dominant SW current. Preliminary investigations into the biological constituents are confirming lagoon assemblages. Sands further away from submarine fans are coarser and moderately sorted, and have a higher density of relict Pleistocene grains. Outer shelf sediments are generally poorly sorted, gravelly muddy sands and the mud component (up to 19.4%) reflects an increase in the contribution of planktonic foraminifera at this depth. The gravel content is high where limestone ridges outcrop on the mid-outer shelf. Gravels are dominant in the Cloates area, on the inner shelf in the northern Ningaloo and the area between North West Cape and the Muiron Islands. Finer sandy sediments are dominant adjacent to reef passes, on the mid-shelf and in particular in areas where the shelf widens near Tantabiddi and on the shelf south of Point Cloates, where the shelf widens and shallows dramatically. South of Point Cloates rhodolith gravels and sands are common. The southern part of the Marine Park is dominated by sands. At Red Bluff a ridge system offshore influences the increase in more gravelly sediments.

This x-shelf sedimentary zonation is present at Mid Cloates SZ but the topographic complexity of ridge and pinnacle systems illustrates the relationship between geomorphology and grain size distribution. The inner shelf contains well-sorted medium to fine sands with finer sands adjacent to reef passes, reflected in the muddy sublittoral seagrass sands in the lagoon adjacent which have been deposited offshore. Coarse gravels and gravelly sands are found close to ridges and pinnacle systems with medium grained sand flats in-between. There is an increase in mud content offshore but shallower depths of the widening shelf in this area has resulted in lower percentages (up to 2%) compared to the sediments further north (up to 19.4%).

South of Point Cloates rhodolith gravels and sands are common. The southern part of the Marine Park is dominated by sands. At Red Bluff a ridge system offshore influences the increase in more gravelly sediments.

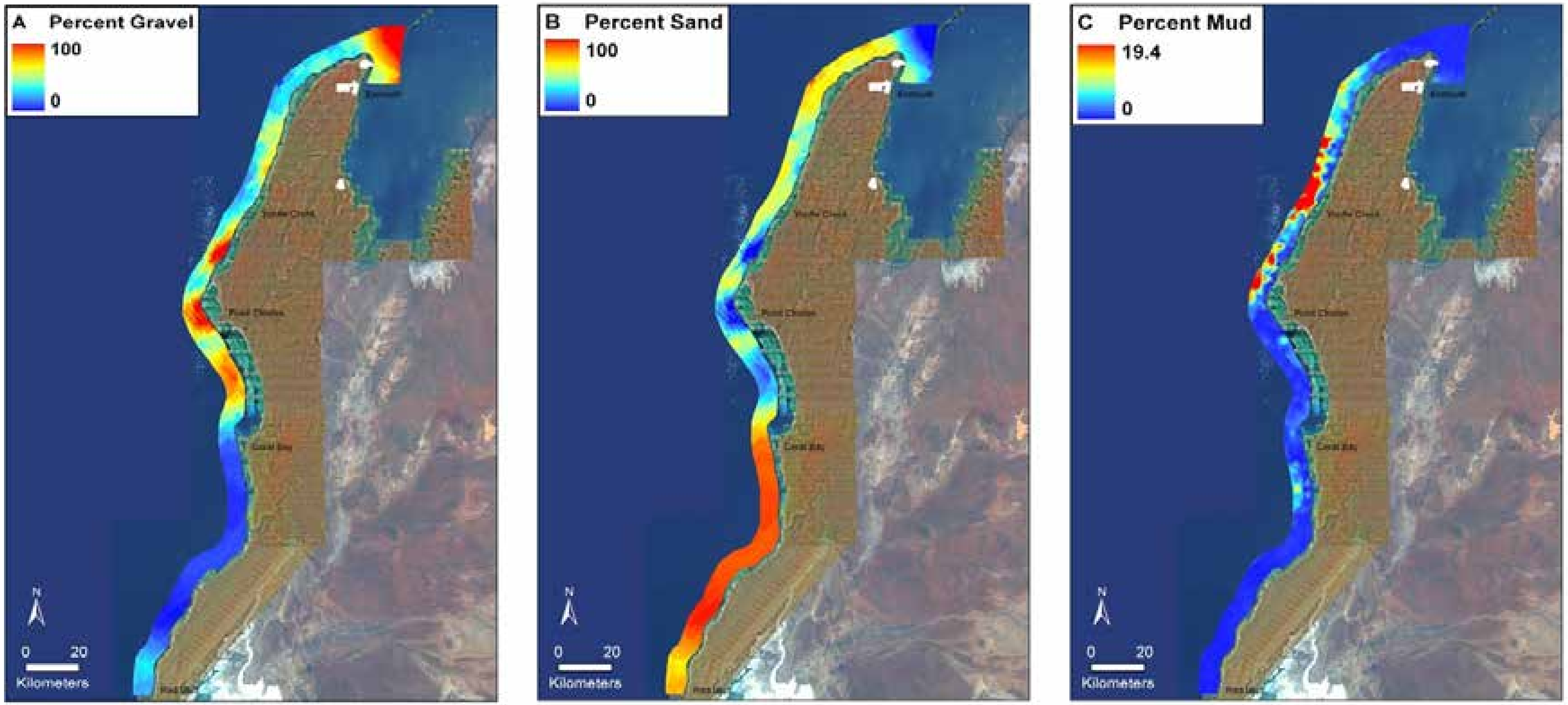

Figure 49. Preliminary Interpolated distribution maps for percentage of gravel, sand and mud for sediments of Ningaloo Reef (Kriging interpolation method used in ArcGIS v. 9).

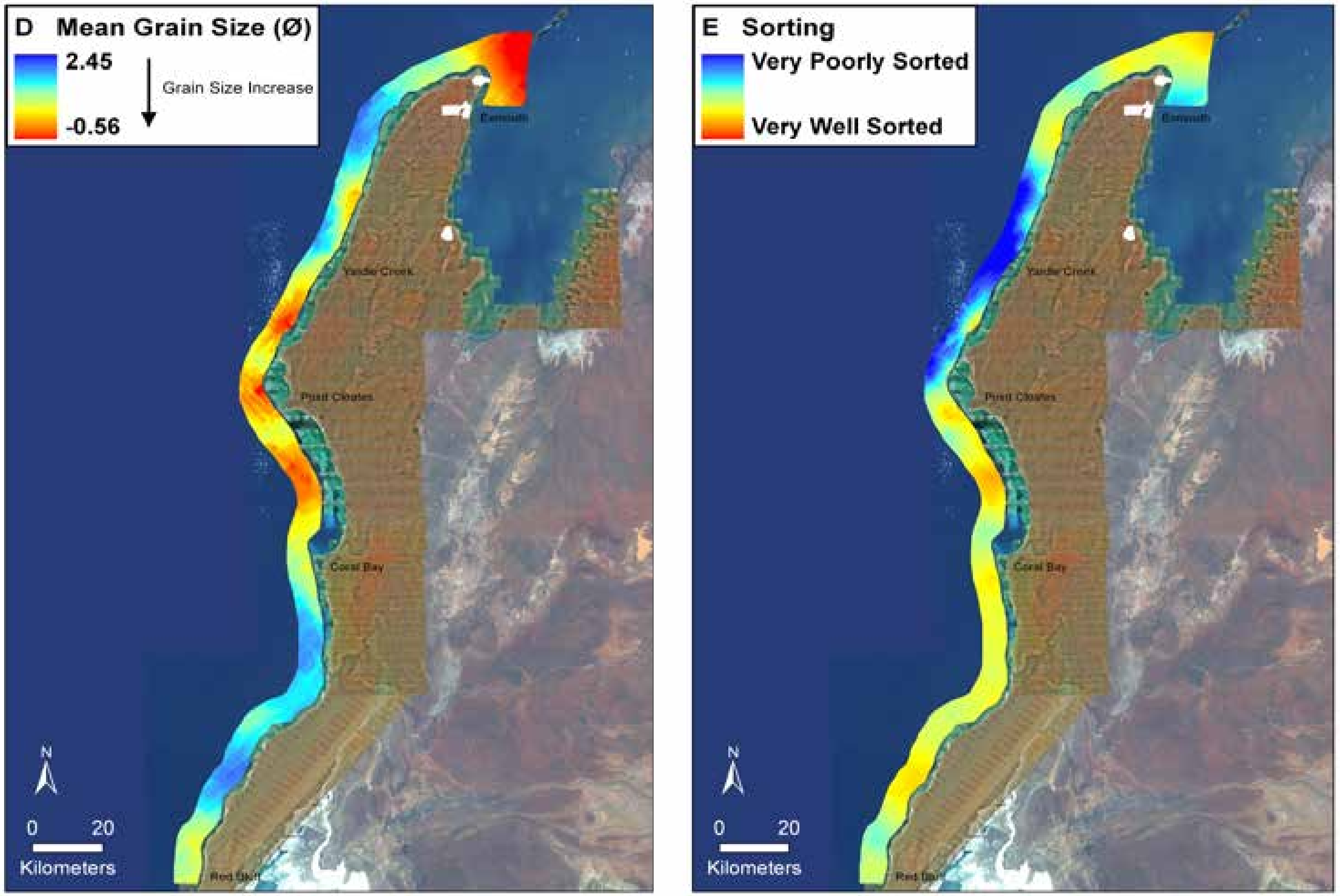

Figure 50. Preliminary Interpolated distribution maps for mean grain size and sorting for sediments of Ningaloo Reef (Kriging interpolation method used in ArcGIS v.9).

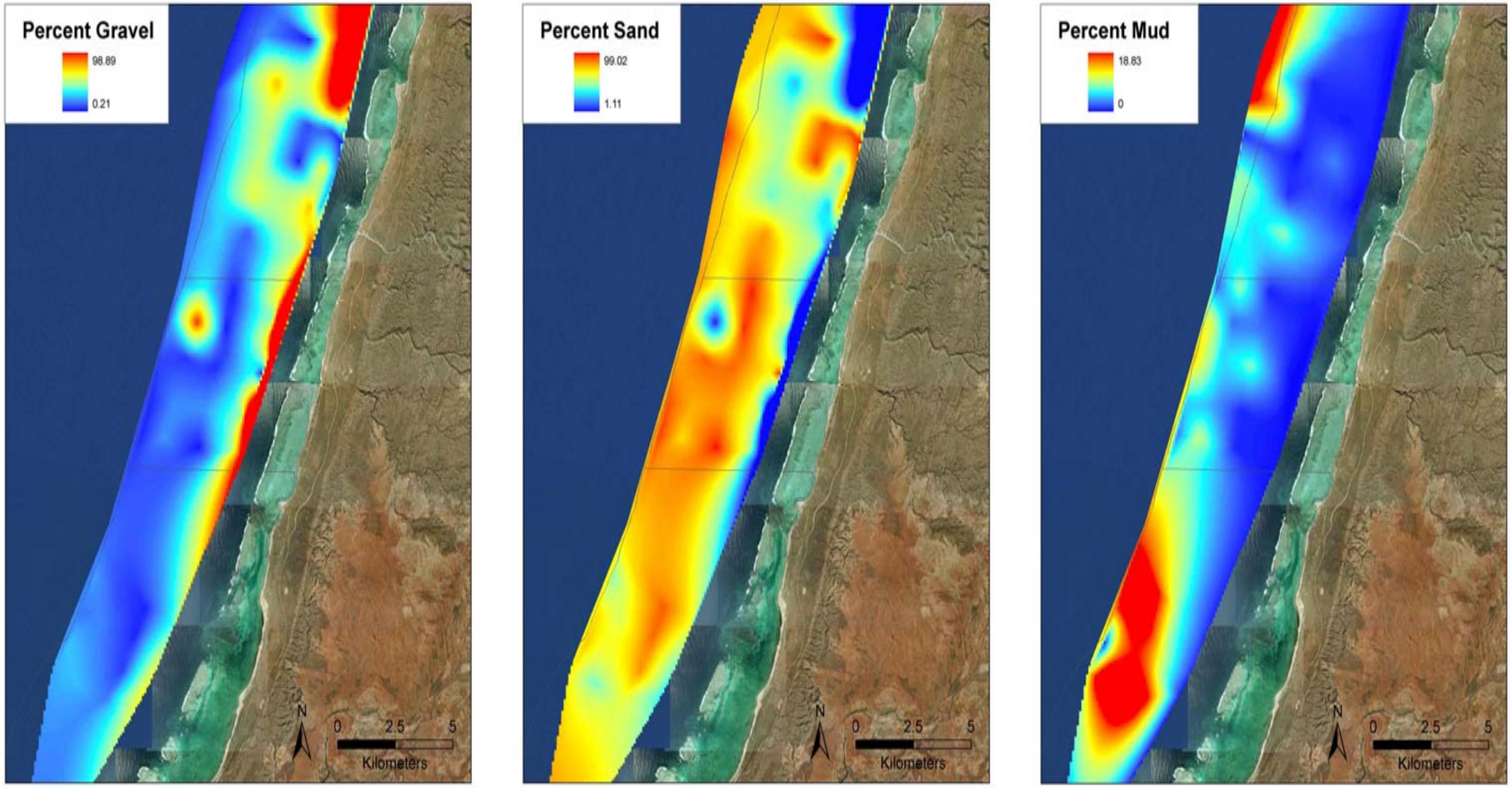

Figure 51. Preliminary Interpolated distribution maps of sediment grain size (between Mandu and Osprey SZ) illustrating the zonation of gravel, sand and mud across the shelf.

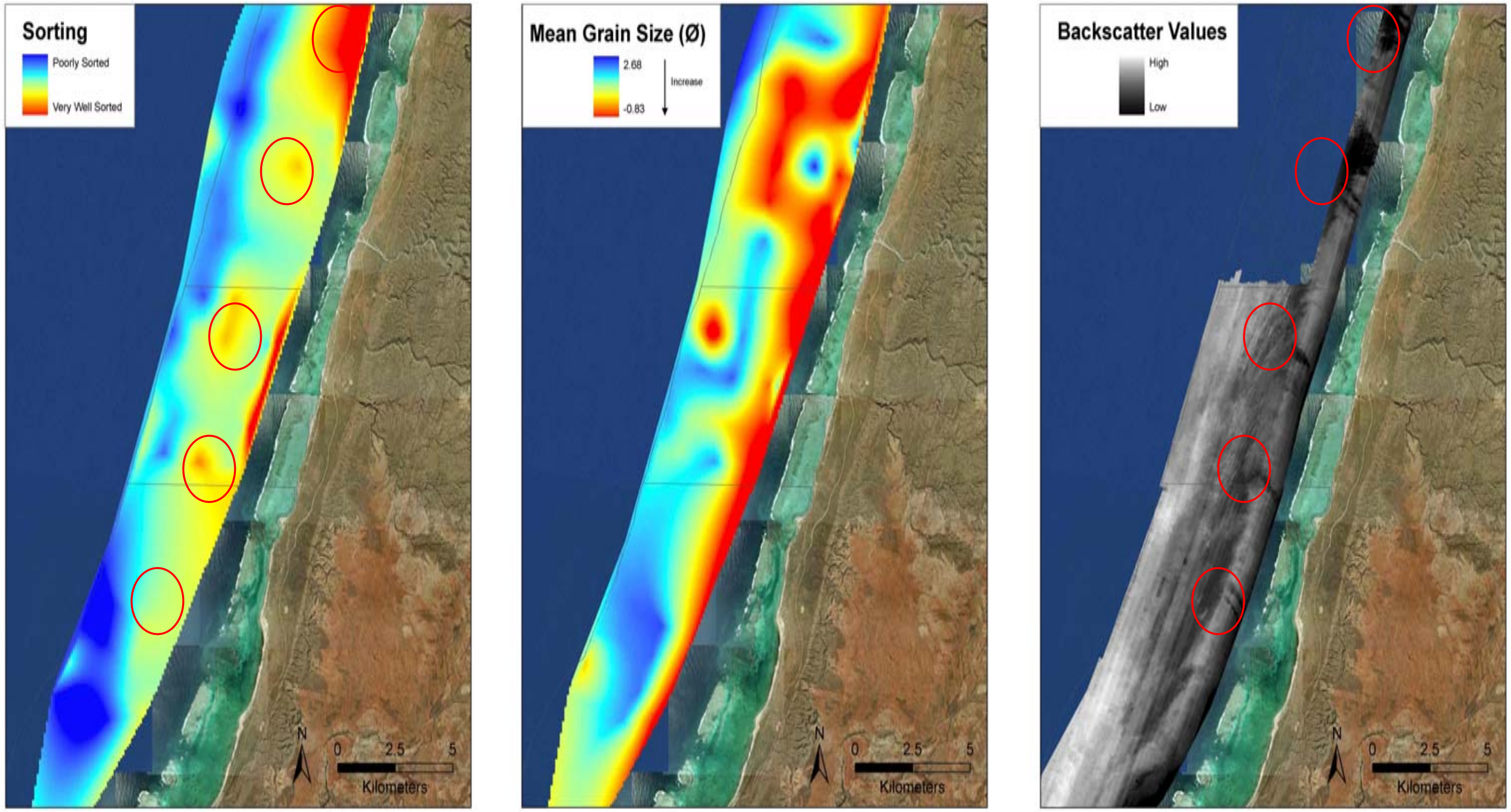

Figure 52.
Preliminary interpolated distribution maps of mean grain size and sorting (between Mandu and Osprey SZ) illustrating their relationship to submarine fans identified in the multibeam backscatter. Very well sorted fine-medium sands correlate with low backscatter values in the fans.

Sediment Textural Classification

There are six sediment types based on textural classification (relative proportions of sand:gravel:mud) for the Ningaloo shelf (Fig. 53, Appendix 1.3). There is a dominance of gravelly sands throughout the Marine Park. These sediments can be further classified into sixteen sediment classes when the grain size of the sand fraction is taken into account (Table 2). Appendix 1.4 classifies each grab sample using this scheme.

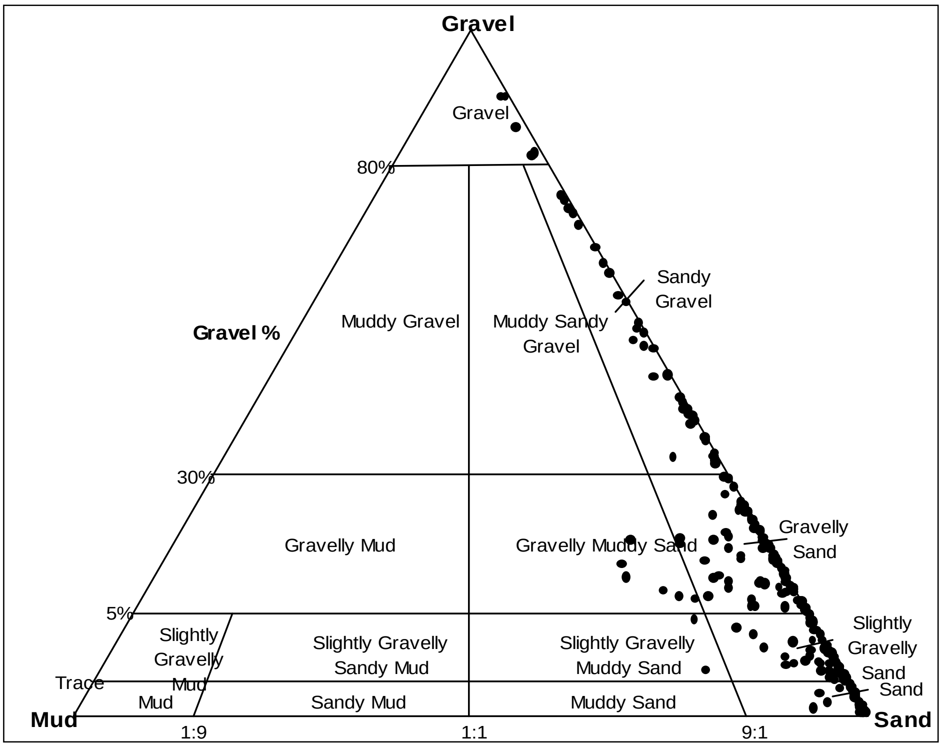

Figure 53. Ternary diagram showing the percentages of gravel:sand:mud for all sediment samples (After Folk et al. 1970).

Table 2. Sediment name classes based on grain size analysis classification by Folk (1954).

Gravel	Sandy Gravel
Gravelly Coarse Sand	Slightly Gravelly Coarse Sand
Gravelly Fine Sand	Slightly Gravelly Medium Sand
Gravelly Medium Sand	Slightly Gravelly Fine Sand
Gravelly Muddy Coarse Sand	Slightly Gravelly Muddy Very Fine Sand
Gravelly Muddy Very Fine Sand	Slightly Gravelly Very Fine Sand
Gravelly Very Coarse Sand	Slightly Very Gravelly Very Coarse Sand
Gravelly Very Fine Sand	Very Coarse Rhodolite Gravel

Sediment Grain Components

The importance of calcium carbonate secreting organisms to the surficial sediments is evident. Grains are almost wholly biogenic in origin consisting of older relict and reworked grains mixed with modern skeletal fragments. Depth consistent sediment facies can be recognised in the northern Ningaloo Reef, on the basis of component composition. Inner shelf sediments are dominated by hardground/rhodolith/coralline algal gravelly sands, modern skeletal rippled sands transported in submarine fans adjacent to reef passes, modern skeletal gravelly shelf sands dominated by a mixture of coralgal, mulluscan, foraminiferal and bryozoan components and seagrass/sublittoral fine sands. Grains composing whole skeletons or fragments, and gravel sized clasts are heavily encrusted by coralline algae. Mid shelf sediment is dominated by foraminiferal dominated relict skeletal sands, with initial observations indicating modern counterparts in shallower water depths, suggesting deposition during lower sea-levels in the Pleistocene. Subphotic sediments on the outer shelf and upper slope are a mixture of modern cool-water, poorly sorted, bryozoan/molluscan dominated gravelly muddy sands with small benthic and planktonic forminifera, sponge spicules and brachiopods. Relict grains again are common (Fig. 54).

Illustrated percentages of the dominant components making up the sediments in an example x-shelf section, is shown in Fig. 55. Sediments have assumed the character of the benthos and become a proxy for habitats. Red coralline algae are dominant across the shelf in particular on the inner-mid shelf zones. Molluscs and benthic foraminfera numbers are high throughout the shelf and bryozoan and echinoids are high in areas of exposed substrates and ridges across the shelf. There is an increase in planktic foraminifera on the mid-outer shelf in depths greater than 75m, reflected in the increase in mud content on the outer shelf. There is only a small contribution of quartz to the sediments at Ningaloo. Corals form a major part of the sediments inside the lagoon but only a minor contribution in sediments on the inner shelf (<5%). Additional quantitative component analysis will classify different sediment assemblages and facies types.

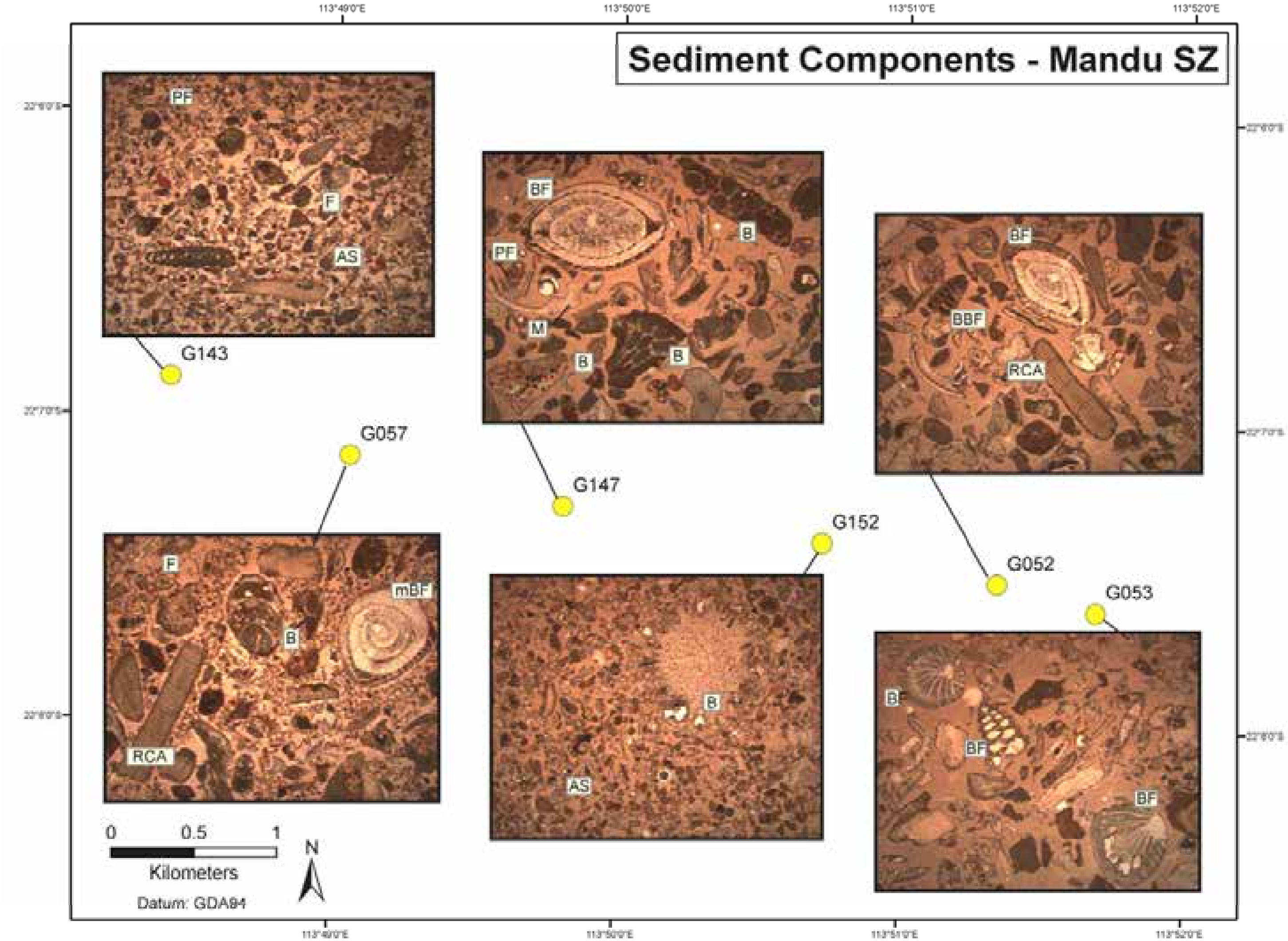

Figure 54. Map illustrating the typical grain components identified in selected cross-shelf sample transect from Mandu SZ, BF = benthic foraminifera, PF = planktic foraminifera, BBF = biserial benthic foraminifera, mBF = miliolid benthic foraminifera, F = foraminifera, RCA = red coralline algae, M = mollusc, AS = angular skeletal grains.

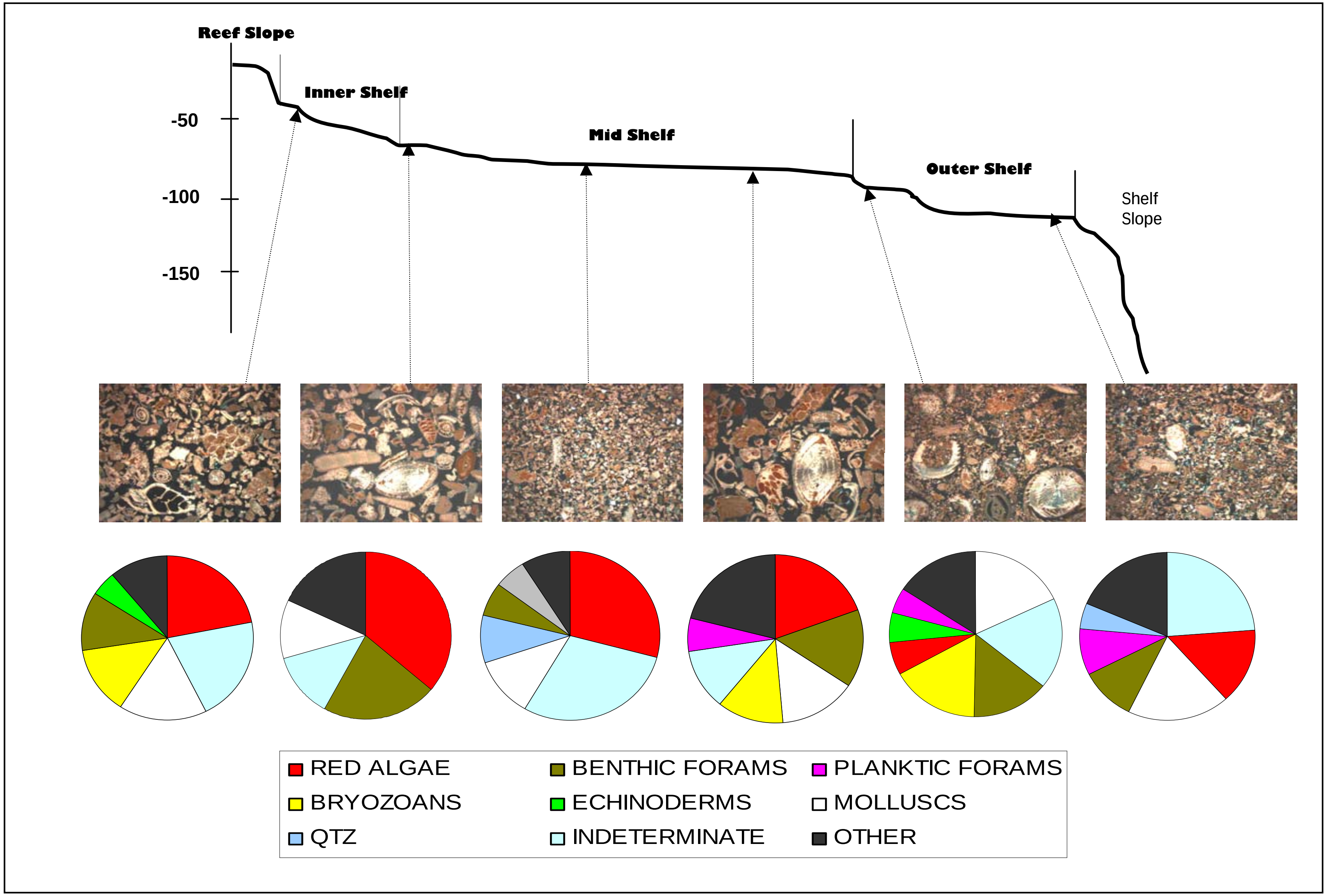

Figure 55. Profile of the shelf at Mandu SZ illustrating percentages of the dominant components.

Summary

In the northern section of Ningaloo reef, between Point Cloates and North West Cape, the shelf runs parallel to the coastline. At Tantabiddi the shelf is wide, gently sloping and there is no distinct change in slope gradient to indicate a shelf break. At Mandu SZ the shelf is narrow (about 10 km wide) and gentle with a marked change in gradient at the shelf break, dropping steeply to depths of 1000 m within only 20km offshore. Here geomorphic zonation is distinct across the shelf including: a seaward fore reef slope with base at ~30-40 m depth; an inner shelf zone between 40-60 m; a wide, flat middle shelf sand plain in ~60-75 m, interrupted by low relief ridge systems; an outer shelf sand plain and ridge systems at ~75-125 m; and a shelf break ridge and deep-sea canyon heads at ~125 m. There is a more complex history of constructional and pre-existing antecedent topography at Cloates SZ down to 60 m, where Tertiary limestone surfaces, paleo-stillstand escarpments and shorelines, and stepwise fossil reefs have created a complex environment with numerous ridges and pinnacles. South of Point Cloates, the coastline veers eastward and there is a marked transition in bathymetry with a gentler and wider shelf to the south. The NMP incorporates depths of up to around 110 m in the north and thus the majority of the continental shelf, and only up to 50-60 m in the south with only the inner-mid continental shelf represented. A number of large geomorphic features have been identified from the acoustic data that are important for habitat development. These include, but are not limited to: reef slope spur and grooves and drowned reefs; inner shelf pinnacle and ridge systems; inner shelf relict reef platform; inner-mid shelf submarine fans; extensive mid-outer shelf dune fields; mid-outer shelf ridge systems; and continental slope canyons.

Acoustics combined with sedimentological and geomorphological data enabled the characterisation of different habitats according to depth, topography, substrate stability, hardness and roughness, grain size and suitability to support significant biota, from the base of the fore reef slope (beyond the fringing reef) to the edge of the continental shelf. The continental shelf within the northern NMP is narrow and preliminary results show a clear zonation of habitats across the shelf. There is a strong association between geomorphology and benthic habitats with communities taking advantage of the availability of Pleistocene substrates. The hardbottom is mainly composed of a fossilised limestone reef surface, karstified in places due to glacial lowstand subaerial exposure. In the shallow fore-reef slope, there is a thin veneer of Holocene (<10 ka, ka=1000yr) coralgal growth on multiple backstepping spur and groove systems. Modern growth is largely determined by the antecedent Last Interglacial (LI, ca. 125 ka) topography. Between 30-40 m depth, even where hard substrates are still available, hard corals rapidly disappear, gradually replaced by a mixed, deep-water sessile filter feeding community. This transition, between the base of the fore reef slope and the inner shelf relict reef platform, is characterised by reef and rhodolith gravel that supply the hard substrate for a diverse community dominated by crinoids, sponges, gorgonians, sea whips, soft corals, turf algae, macroalgae and Halimeda, with minor ascidians and sea pens. On the inner-mid shelf, submarine fans formed from the offshore flushing of lagoon sediments through reef passes, complicate this pattern locally. Rippled sands, with no epibenthos, are commonly associated with these features. On the open mid-outer shelf, sediment veneers over limestone pavement and large dunes are interrupted by low-high relief ridge and pinnacle systems. Extensive linear ribbons, 'large-very

large' asymmetrical and barchan type dunes indicate currents towards the NE and NNE. Communities of sponges, crinoids, bryozoans, soft corals, sea pens and hydroids are patchy in these regions with higher abundance associated to exposed substrates. In areas of lower energy, bioturbation is evident from echinoderm feeding traces, polychaetes and burrowing fish and a diverse infauna have reworked the sediments to build mounds and burrows. Fields of large gravelly mounds occur in depths of ~95 m with basal diameters of up to 20 m. A number of ridges have been identified at various depths with prominent and extensive systems on the mid-outer shelf (~70-125 m). Their lengths range from hundreds of metres to tens of kms with widths up to tens of metres, creating an uneven bottom with up to several metres relief. These features may represent drowned backstepping reefs and/or paleo-shorelines. The Last Glacial (~20 ka) shoreline has been identified at the 125 m depth contour. Ridges are colonised by high cover of exotic sponge, gorgonian and bryozoan "gardens", some of which are likely to be new species. Diversity is particularly high in areas adjacent to the continental slope canyons which bring nutrient rich, cold-water upwelling to the shelf edge; ideal conditions for cool-water carbonate production. A more complex history exists at Cloates SZ, where paleo-stillstand escarpments and shorelines, and very high-relief stepwise fossil reefs and pinnacles, support a diverse coralgal and sponge community. South of Point Cloates there is a marked transition in bathymetry with a gentler and wider shelf to the south. Rhodolith and sandy habitats are common in the southern part of the Marine Park. An offshore sinuous ridge system at Red Bluff, at the southern end of Marine Park, again provides the hard substrate for a diverse sponge, soft coral and bryozoan community.

Ningaloo Reef lies in a latitudinal transition zone of carbonate-producing communities where both photozoan-reef (warm-water/low nutrient) and heterozoan-carbonate ramp (cool-water/elevated nutrient) producers are found. Global shallow-water carbonate production is being affected by impacts as a result of climate change conditions. The study of this unique, near-pristine system will likely provide one of the best analogues for predicting the response of shallow-water carbonates under environmental change. The carbonate-depositional environment provides a complete range of modern shallow cool-warm water carbonate sedimentary facies across the shelf, with communities dominated by corals (inside the reef), red coralline algae, bryozoans, Halimeda, benthic forams, molluscs and planktic forams. Sediments are almost wholly biogenic in origin consisting of older relict and reworked grains mixed with modern skeletal fragments. The sediments have assumed the character of the benthos and have become a proxy for habitats that produced them. Depth consistent sediment facies can be recognised across the shelf and latitudinally, based on component composition and grain size characteristics. Inner shelf sediments are dominated by; hardground/rhodolith/coralline algal gravelly sands; modern skeletal rippled sands transported in submarine fans adjacent to reef passes; modern skeletal gravelly shelf sands dominated by a mixture of coralgal, mulluscan, foraminiferal and bryozoan components; and modern seagrass/sublittoral fine sands in areas adjacent to lagoonal seagrass meadows. Grains composing whole skeletons or fragments, and gravel sized clasts are heavily encrusted by coralline algae. Middle shelf sediment is dominated by foraminiferal dominated relict skeletal sands, with initial observations indicating modern counterparts in shallower water depths suggesting deposition during lower sea-level in the Pleistocene. Subphotic sediments on the outer shelf and upper slope are a mixture of modern cool-water, poorly sorted, bryozoan/molluscan dominated gravelly muddy sands with small benthic and planktonic forminifera, sponge spicules and brachiopods. Relict grains again are common.

The importance of hard substrates to carbonate production is evident (see Fig. 56 for summary of processes).

A - Importance of hard substrate to carbonate production. Typically site of prolific growth with inverts growing affixed to substrate

B - Sediments generated by growth of invertebrates

C - Rippled sands form with no epibenthos. Seafloor becomes covered and factory buried in own detritus and sediments assume character of benthos. This effect can be blurred by episodic storms.

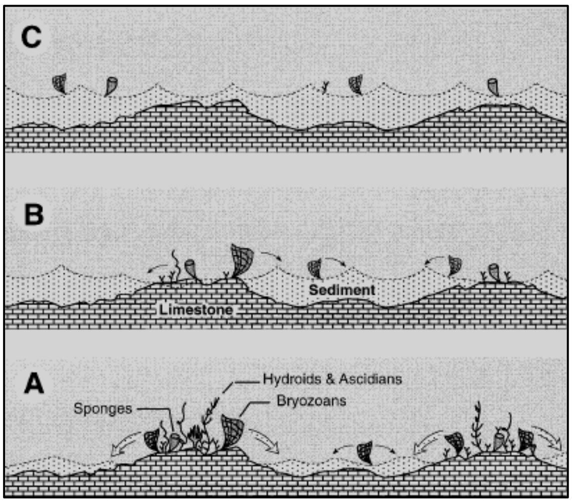

Figure 56. Process of carbonate production on the shelf (modified from James et al. 2001).

Multivariate statistical analysis and GIS modelling of all datasets may establish trends between physical and biotic values and identify factors that are reliable 'surrogates' of specific habitats. These relationships will be extrapolated to the broader area to aid in the production of broadscale habitat maps of the NMP.

Future Analysis

The fieldwork has now been completed for the research. There will be at least 4 months of additional data analysis for the various datasets. A number of scientific papers for the offshore component will form part of the PhD thesis of Emily Twiggs, due for completion at the end of 2008. At least 2 papers will be initially submitted to scientific journals and other papers will follow soon after. This will include the following topics:

- Carbonate sedimentology of the Ningaloo continental shelf and reef system.
- Influence of geomorphology and sedimentology on the distribution of benthic habitats of the continental shelf.
- Using geophysical surrogates to map the offshore biodiversity of Ningaloo Marine Park.

There will be further collaborations with the various groups involved in the project during 2008, culminating in additional scientific papers, reports, GIS products and maps for geomorphology, sediments and habitats of Ningaloo Reef.

Ackowlegdements

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CHAPTER 3
Benthic Communities

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Introduction

Characterising the range of benthic communities in the deeper waters of Ningaloo Marine Park is being carried out through direct observation and collections, using towed video imaging and a custom-made benthic sled. Towed video has become increasingly popular with research and resource management agencies requiring quantitative estimates of percent cover of sessile benthic organisms. Video transects capture a continuous series of archivable images along a know length of benthic habitat (Davidson 1997).

Macro benthos cover, diversity, and population density estimates will vary depending on the methodology used for data collection (Houk and Van Woesik 2005). For benthic video surveys, relative abundance estimates and the statistical power to detect change will vary according to: 1) the number of data points analyzed in each paused (video) frame, 2) the number of frames analysed in each transect, 3) the number of replicate transects used, and 4) the length of transect (Houk and Van Woesik 2005). These criteria will vary with respect to the question being addressed i.e. it may be useful to analyse a large number of points on any one frame for estimates of coral cover, but problematic using the same high number of points to examine the number of colonies because of the increased likelihood of autocorrelation (counting the same colonies more than once) (Carleton and Done 1995). Rapid ecological assessments are less concerned about the statistical power of detecting a change than long-term monitoring programs (Andrew and Mapstone 1987).

At Ningaloo, the 2006 benthic surveys which applied a relatively intensive and stratified design to the areas of the Marine Park north of Point Cloates, identified several routinely occurring substrate types extending across the shelf from the foot of the fore-reef. Sand areas, along with rubble and rodolith fields were extensive components, with smaller areas of low or high relief rock and reef which tended to support diverse and in places quite abundant filter feeding communities. In consultation with DEC the decision was made to focus, during 2007, on a more spatially extensive sampling approach that would provide braod-brush coverage and data on examples of typical habitats along the full length of the Ningaloo Marine Park.

Methods

Towed video

Field methods

Visual imagery of the benthos, in depths from 15 to 130 m, was captured using a 1/3 inch single CCD colour video camera mounted on a Para-vane styled towing frame and controlled by a winch with 320 m of electromechanical cable (Figs. 1 and 2). Two 12 Volt, HID underwater lights illuminated the field of view. The video signal was recorded on a shipboard miniDV tape recorder. In addition to the visual imagery the miniDV tape recorder received Geographical Positioning System (GPS) data (latitude and longitude, ground speed, true heading, date and time), which was recorded on the audio track. A computer based application running Visual Basic™ script (TowVid) developed by AIMS (Speare et al. 2004), allows for real-time touch-screen classification of substrata, benthos and individual organisms interfaced with a GPS to facilitate real-time geo-referencing of all data points. C-Map™ vector charts and Maxsea™ electronic navigation software were used to record the ship's track and water depth. Data points were recorded at 8-second intervals or on demand when a new substrate, benthos or organism was recorded on TowVid. An average speed of 1.5 knots was achieved over the towed video surveys equating to resolution of 6 m.

Towed video sampling effort was concentrated around Mandu, Osprey, Yardie, Winderabandi and Point Cloates in 2006 (Figs. 3 and 4). In 2007, to ensure representative sampling effort throughout the marine park, sampling was stratified at 5 km intervals from Point Murat to Red Bluff conducting 3-4 transects from the back of the reef, parallel to the coast, out to the seaward marine park boundary at different depth contours (Fig. 4). Towed video will allow us to visualise the range of benthic communities, ground truth areas with significant bathymetric and textural properties and provide detailed information on the variability in diversity, abundance and biomass of all the different communities within the marine park.

Video imagery from a total of 365 towed video transects approximately 500 metres long was collected in the 2006/2007 surveys (Figs. 3 and 4). Further video transects will be conducted in 2008 in areas of special interest, where sampling is considered limited and where ground-truthing for comparison with acoustic mapping data is still required. Previous studies with this video sampling method indicate that a single long transect gave equivalent results in species richness, assemblages and abundance to the more conventional technique of using multiple replicate transects (Stevens & Connolly 2004).

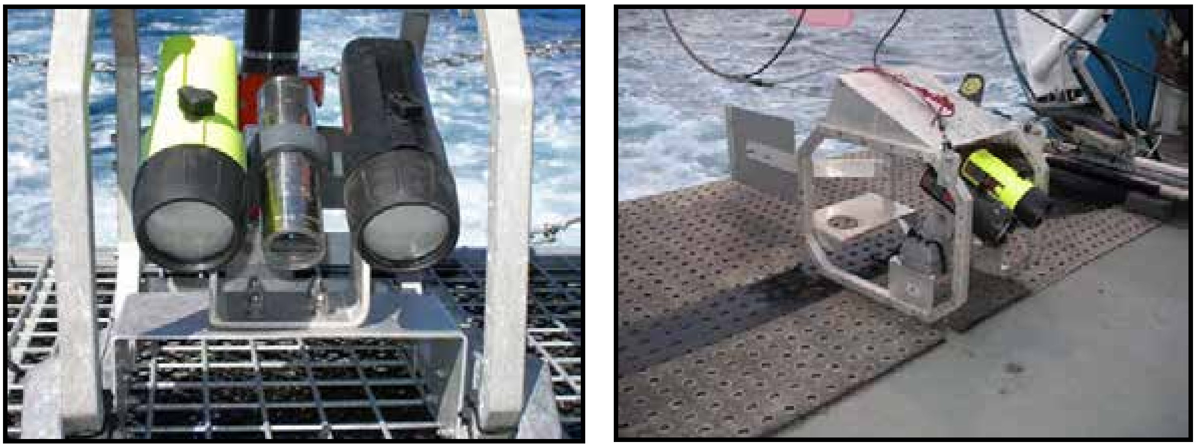

Figure 1. Towed video vane with video camera and lights.

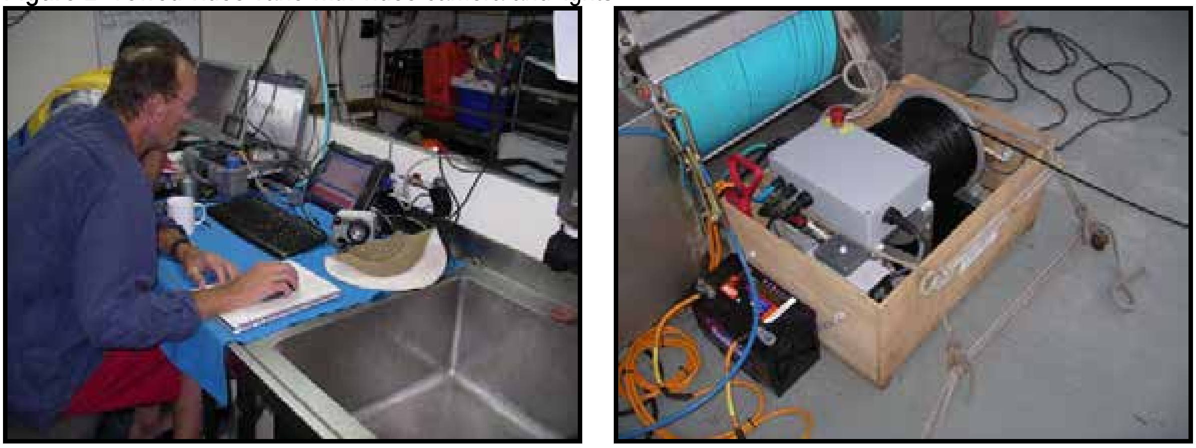

Figure 2. a) Operating real-time AIMS TowVid software. b) Towed video winch and electromechanical winch and cable.

Quantitative data extraction

While the real-time habitat classification from towed video provides maps of major bio-habitat transitions and an indication of within and between transects spatial variations, some more quantitative measures of species abundance are desirable for site characterisation and comparison. One approach to quantitative analysis is to derive compositional data along each video tow, based on the percent of observations per tow allocated to specific classification strategies. In this way a particular video transect can be represented as consisting of a certain percentage of, for example, medium, high or low sponge garden. This type of analysis will be applied to all towed video transects in the final analysis, but we also plan to derive more quantitative measures of absolute abundance or cover by post-processing the video records using a point-intercept method. Post-processing of the towed video transects, using a modified version of AIMS AVTAS software program (Coleman unpublished 2007), and the habitat classifications in Table 2 has commenced. Approximately 30 transects, from varying habitats, have been analysed using custom made software written in JAVA™. An Oracle Lite™ database is used to store the data and Microsoft Access™ to automatically calculate percentage cover. A Sony DVCAM DSR-20P™ digital videocassette recorder and GeoStamp (GPS to Audio Encoder) are used to process video imagery from each transect. The length (time) of each transect and amount of frames to be analysed for each transect is calculated and input into the software. For the purposes of this broadscale survey two hundred frames from each transect are being analysed. The software automatically stops the tape at each frame and using five data points on a digital monitor the habitat and geomorphology/bedform is classified from the entire frame and the substrate, benthos and individual organisms classified from under each point. Short video snippets, representing each of the 365 towed video transects have been extracted, described and geo-referenced for input into ArcGIS™. These provide visual record of the different habitats throughout the park and a means for interpretation and explanation for planners, policy makers and managers. The complete visual record for each transect will be archived and delivered to WAMSI in the 2009 reports, but can be accessed henceforth by request if required.

Data from the real-time TowVid software (Speare et al. 2004) and classifications in Table 1 have been extracted and form broad-scale maps of macro-benthos and underlying substrates (Figs. 5-10).

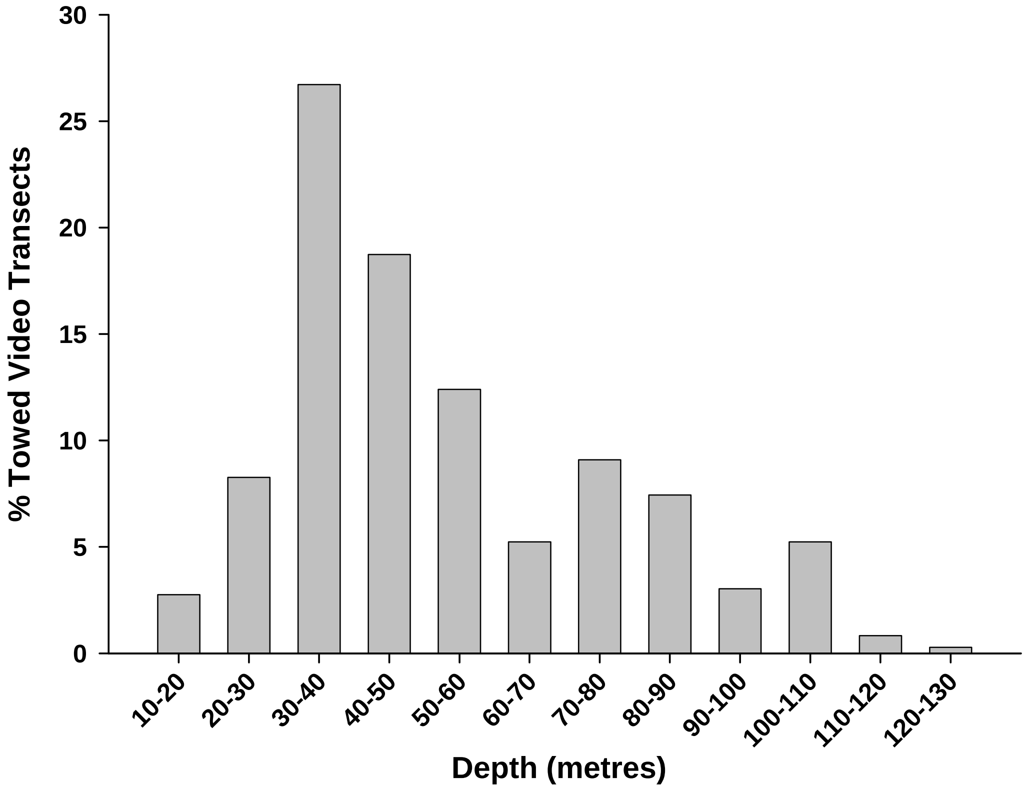

Figure 3. Towed video sampling effort 2006/2007 at different depths in Ningaloo Marine Park.

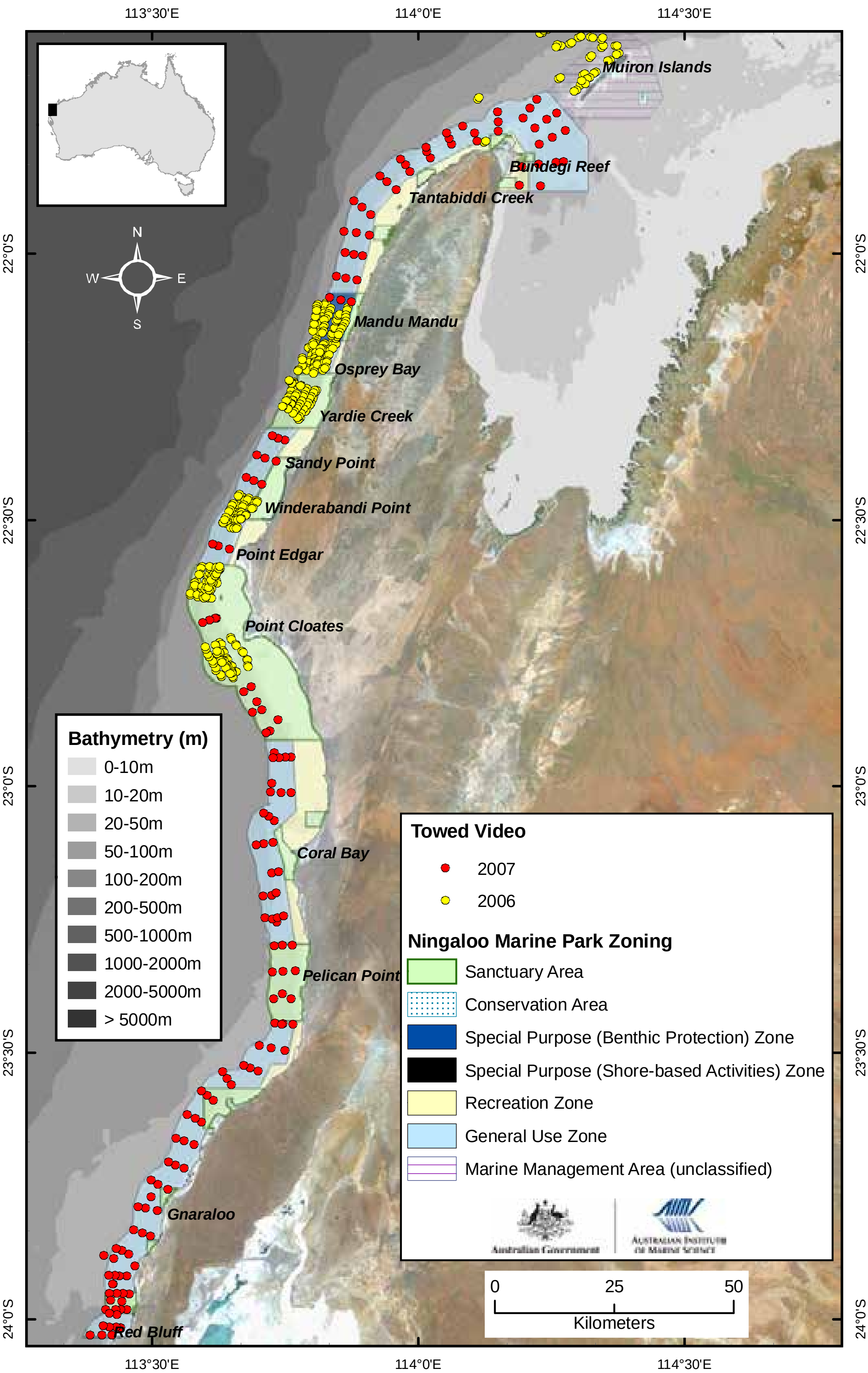

Figure 4. Towed video transect locations 2006/2007 surveys.

Table 1. Real-time habitat classification system for towed video TowVid analysis.

Habitat (Descriptor = Dense, Medium, Sparse)	Substrate	Organism/Items of Interest
Filter Feeders (Sponge Dominant)	Rhodoliths	Sea Star
Filter Feeders (Soft Coral Dominant)	Rhodoliths/Sand	Holothurian
Filter Feeders (Gorgonian Dominant)	Rubble	Urchin
Filter Feeders (Whip Dominant)	Rubble/Sand	Schooling Fish
Filter Feeders (General)	Bedrock	Rubble Mounds
Hard Coral Reef	Bedrock/Sand	Sand Holes
Hard/Soft Coral + Macroalgae + Sponge	Sand Burrows	
Macroalgae dominated + Sponge + Hard/Soft	Sand Mounds	
Seagrass	Sand Mega Ripples	
Macroalgae	Sand Ripples	
	Sand Flat	

Table 2. Post-processing habitat classification system for towed video analysis.

Habitat	Geomorphology/ Bedform	Substrate	Benthos	Organism
(Frame analysis)	*(Frame analysis)*	*(Point analysis)*	*(Point analysis)*	*(Point/ Frame analysis)*
Filter Feeders (Sponge Dominant)	Unrippled sand flat	Rhodoliths	Sponge	Holothurian
Filter Feeders (Soft Coral Dominant)	Unrippled sand flat with biogenic traces	Coarse Sand	Soft Coral	Urchin
Filter Feeders (Gorgonian Dominant)	Sand ripples < 0.6m	Fine Sand	Soft Coral Whip	Sea Star
Filter Feeders (Whip Dominant)	Sand mega ripples >0.6m	Mud	Soft Coral Gorgonian	Other
Filter Feeders (General)	Irregular sand ripples (hummocky)	Rubble 2-64 mm	Hard Coral	Uncolonised
Hard Coral Reef	Rubble field	Rubble >64 mm	Sea Pen	Undefined
Hard/Soft Coral Dominant + macroalgae + sponge	Rhodolith field on sand	Bedrock	Bryozoan	
Macroalgae Dominant + sponge + hard/soft coral	Rhodolith field on hard ground	Undefined	Crinoid	
Seagrass	Mounds/burrows		Hydroid	
Macoralgae Dominant	Low outcrop/reef <1m		Ascidian	
Rhodolith Dominant	High outcrop/reef >1m		Macroalgae	
Uncolonised	Undefined		Coralline Algae	
Undefined			Halimeda	
			Turf Algae	
			Seagrass	
			Uncolonised	
			Undefined	

Preliminary Results

The towed video sampling has revealed a diverse but spatially patchy arrangement of soft and hard seabed and associated sessile benthos. At broad scales of several to tens of kilometres along the length of the park, the video work has identified a limited range of major habitats with different substrates and associated benthos extending from the foot of the reef slope across the shelf. Sand is the most common substrate throughout the deeper waters of the park and, while likely to support significant infauna and various mobile fauna, tends to have little or no macroscopic biohabitat associated with it. Rubble fields can also be extensive, particularly around the base of the main reef front and between relic submerged outcrops in the 30-60m depth ranges. Often these rubble fields consist of high densities of crustose coralline algal rhodoliths 2-8cm in diameter. Rhodoliths are colourful, unattached, branching crustose benthic marine algae (coralline red algae) that create biogenic habitat for diverse communities. Rhodolith beds in some parts of the deeper waters of Ningaloo Marine Park seem to form a transition habitat between the deeper seaward edge of the fringing reef and barren sandy habitats. Many rhodolith beds provide a stable and three-dimensional habitat onto which a variety of species can settle, including other algae, clams, scallops and some corals.

The most common biohabitats with significant epibenthos, although less extensive that sand and rubble areas, are the sponge dominated filter feeding communities located in all depths between 30-110m, but most routinely encountered on underlying hard reef and rock adjacent to the fore reef in depths of 30-50m or mid- to outershelf low relief ridges in the 60-110m depth range.. Initial observations and collections suggest changes in overall species diversity and abundance with depth and latitude, although some species of sponge, bryozoan and soft corals appear to be ubiquitous throughout the length of the Marine Park. It is expected that factors influencing the distribution of dominant species will become more evident with further spatial analysis in conjunction with species identification.. All these filter feeding communities are generally associated with stable hard substrates, although in places the organisms were growing up through a veneer of fine sand, indicating a dynamic seabed current environment. Hard bottom hard coral communities interspersed with sponges, soft corals and macroalgae dominate the shallow water (20-40 m) seaward of the fringing reef and are typically structurally complex. Many of these communities have significant proportions of bryozoans species interspersed throughout and occasionally seem to be dominated by bryozoan. There are limited areas supporting seagrass and macroalgae dominated communities, generally in the shallower waters adjacent to the forereef.

The widespread colonised and uncolonised sand habitats were encountered in various forms, including dunes, ripples, waves, mounds and burrows, with and without bioturbation and sand flats. It seems evident that the stability of the sand habitat and depth overlaying hard substrate (limestone) influences it's suitability for macro benthic organisms to settle and proliferate. Some communities may be quite dynamic depending on changes in the volume and movement of sediments. Also evident from the video transects is that sand dominated habitats associated with shallow waters (20-50 m) are significantly more unstable and disturbed than in deeper waters (50-130 m).

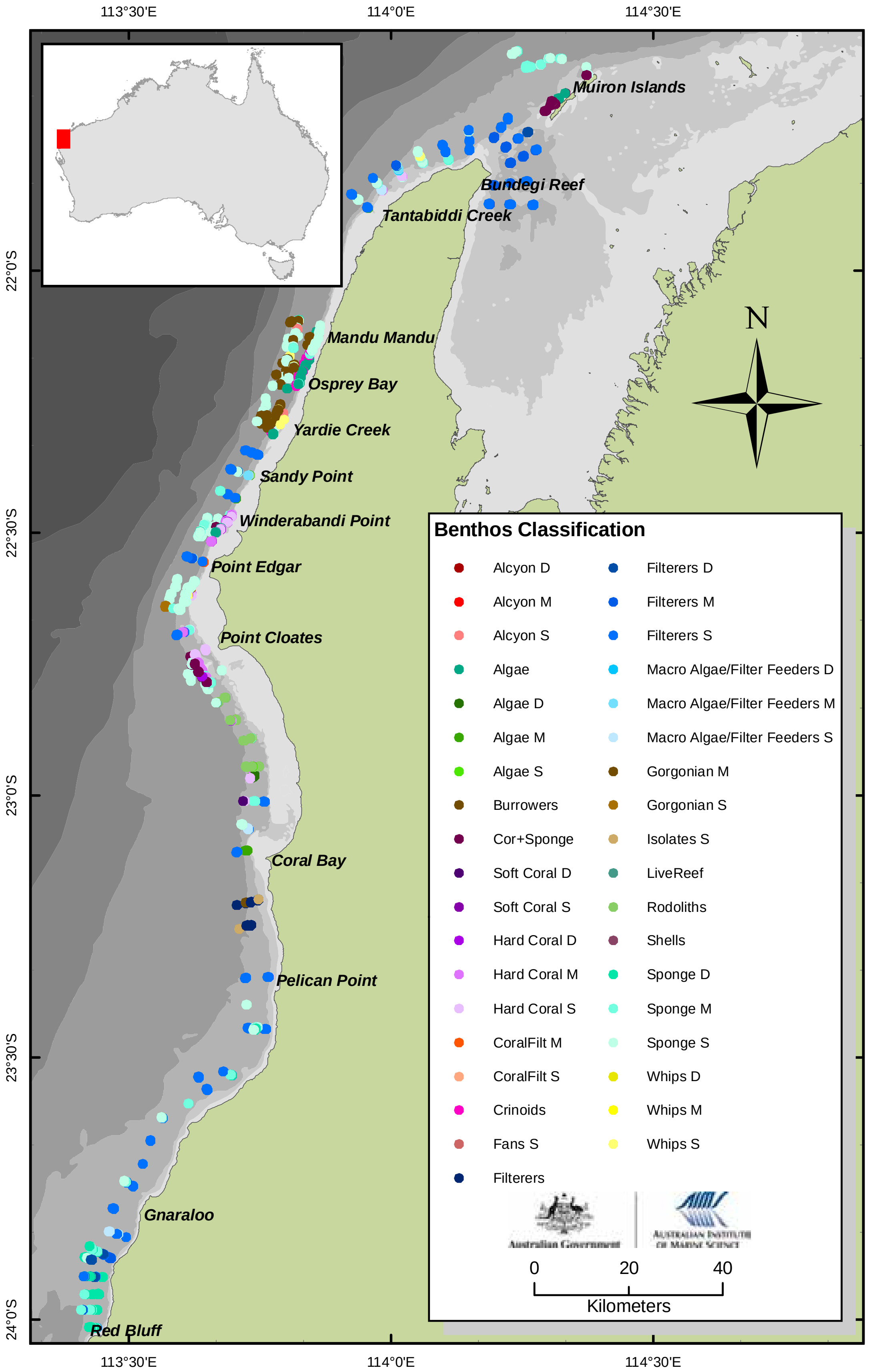

Figure 5. Real-time (TowVid software) towed video broad-scale classifications for Ningaloo Marine Park.

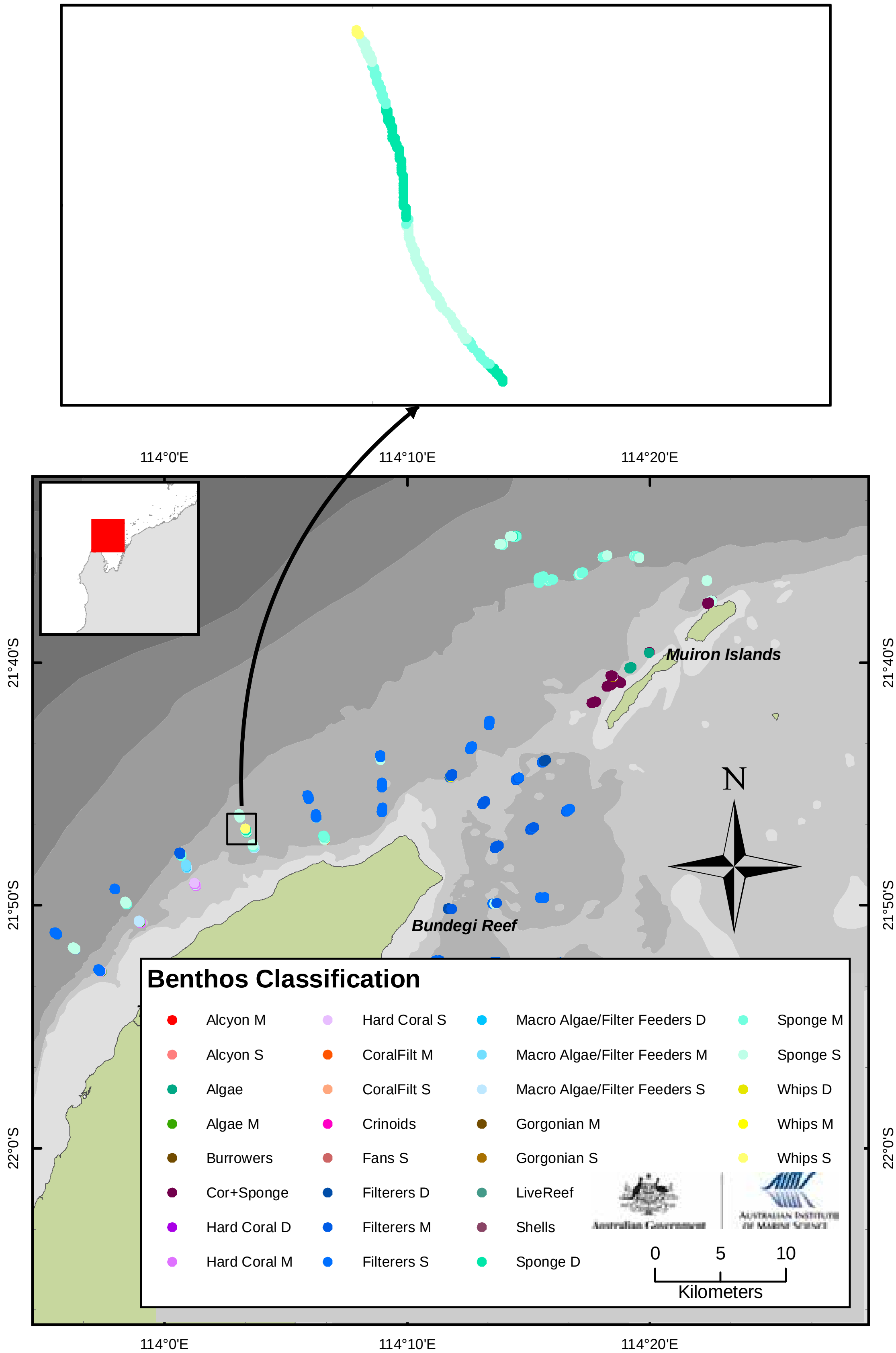

Figure 6. Real-time (TowVid software) towed video broad-scale classifications for Bundegi to Tantabiddi Ningaloo Marine Park.

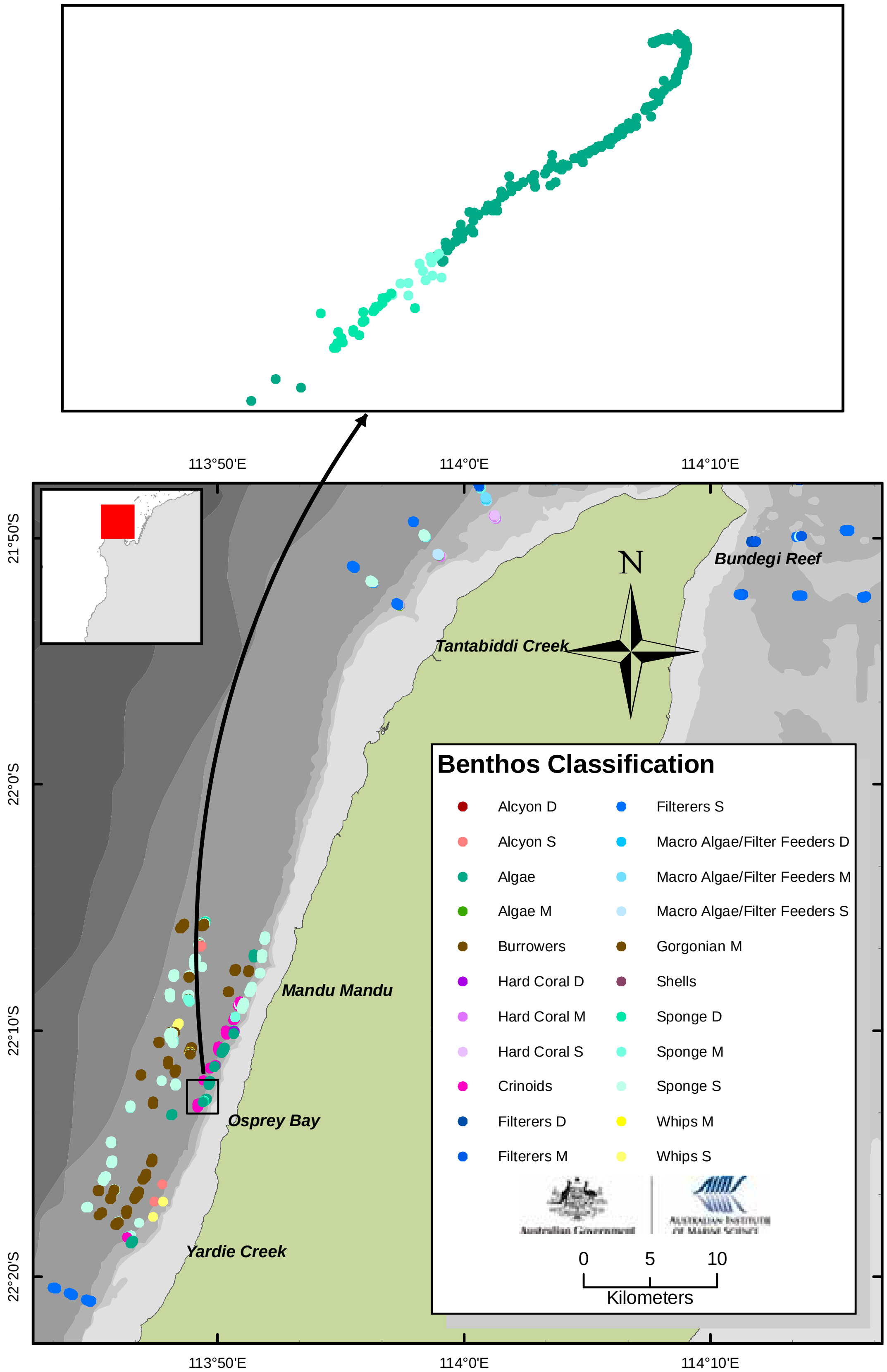

Figure 7. Real-time (TowVid software) towed video broad-scale habitat classifications for Bundegi to Yardie Ningaloo Marine Park.

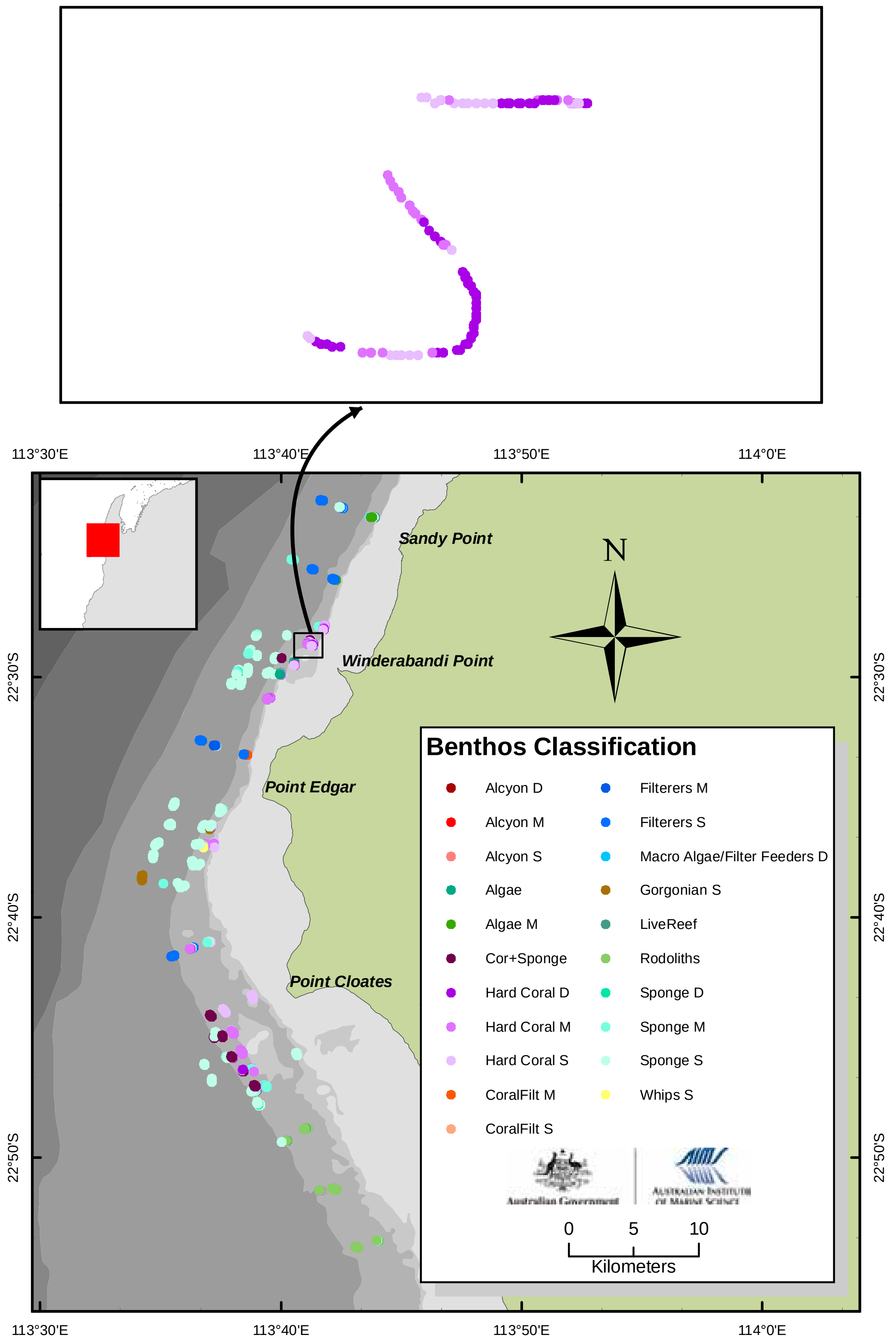

Figure 8. Real-time (TowVid software) towed video broad-scale habitat classifications for Sandy Point to Cloates Ningaloo Marine Park.

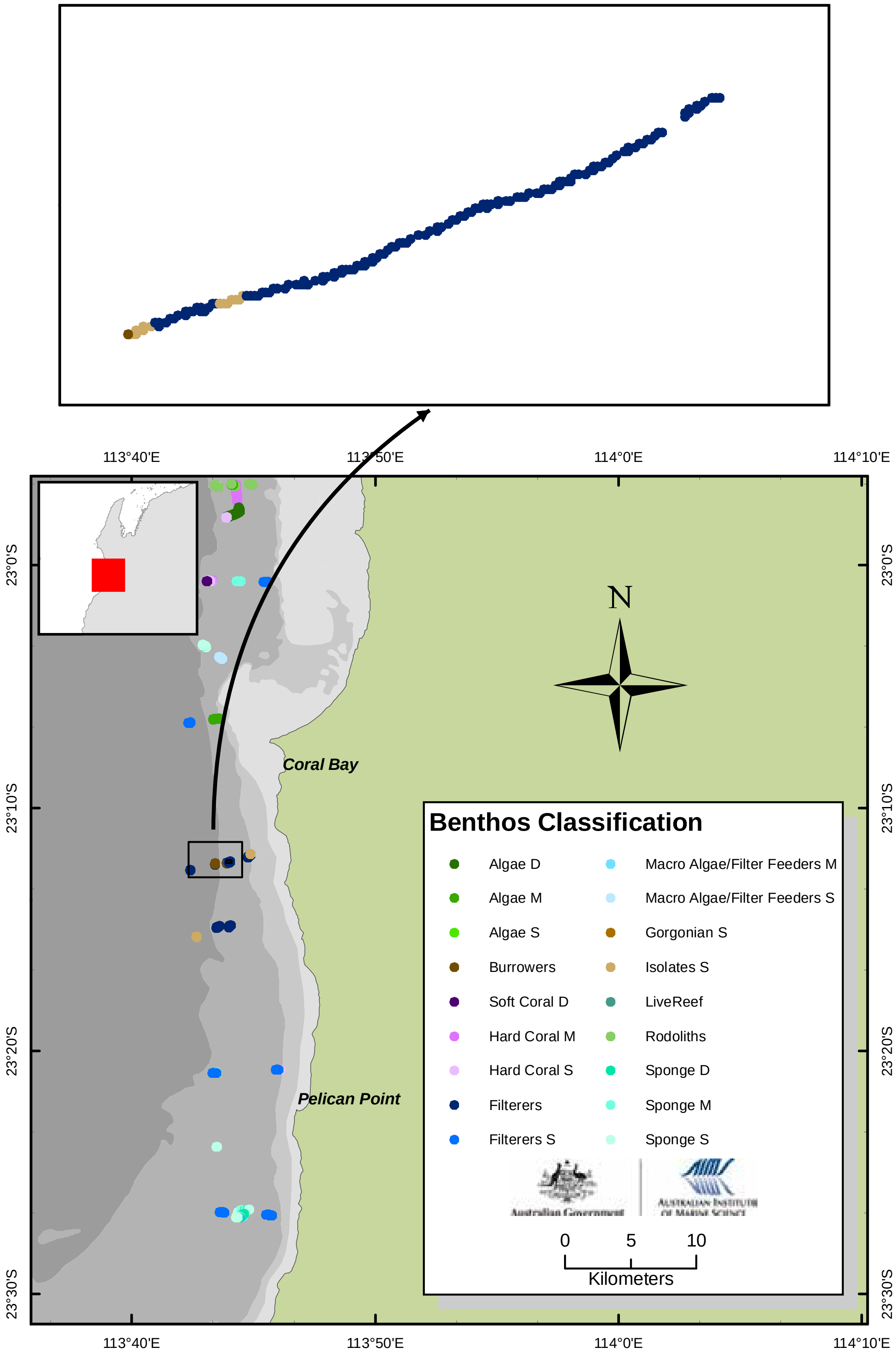

Figure 9. Real-time (TowVid software) towed video broad-scale classifications for Coral Bay and Pelican Point Ningaloo Marine Park.

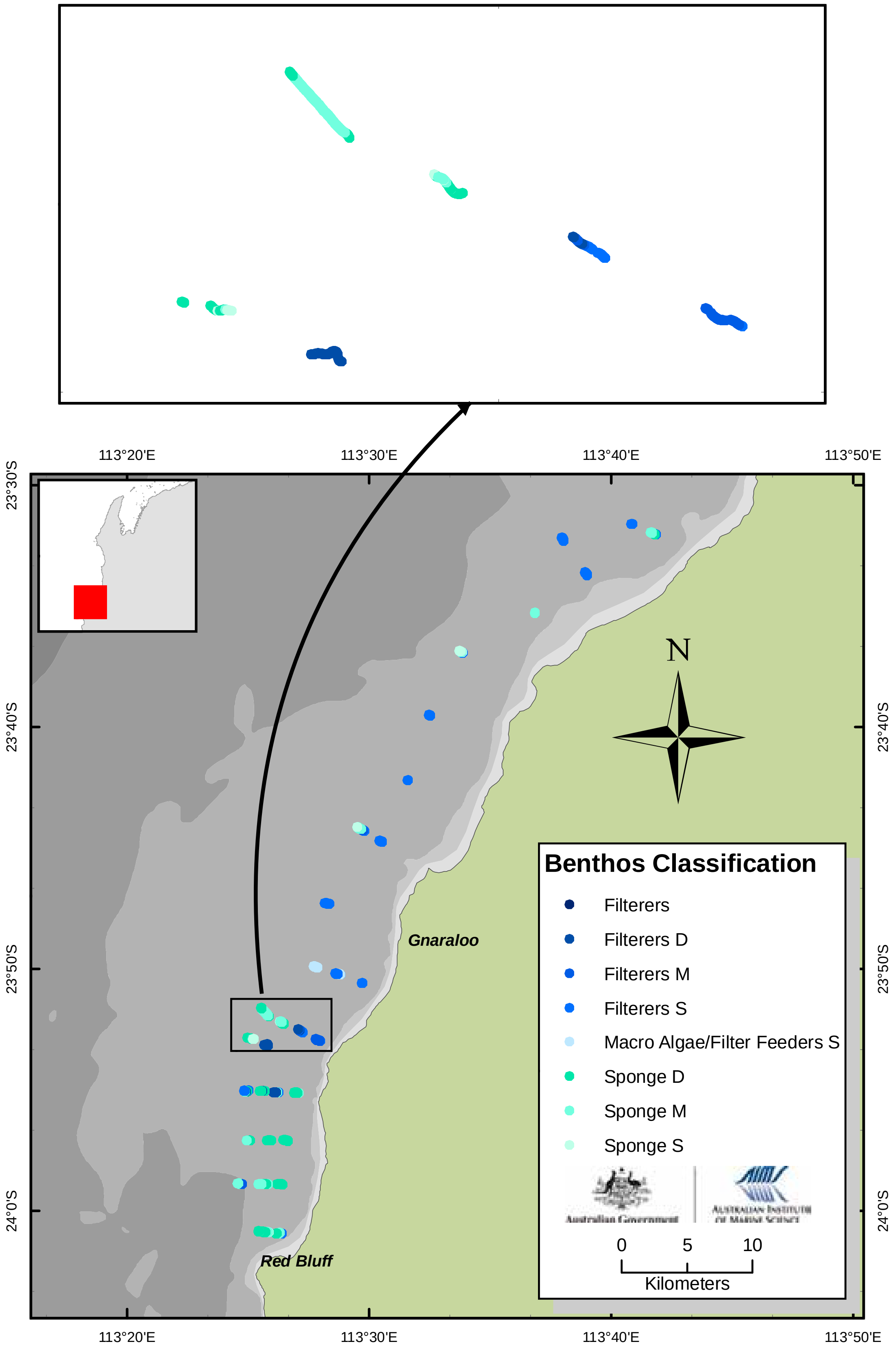

Figure 10. Real-time (TowVid software) towed video broad-scale classifications for Gnaraloo and Red Bluff Ningaloo Marine Park.

Benthic sled

A key deliverable in the overall project is the establishment of a baseline biodiversity inventory for the deeper waters of Ningaloo Marine Park. This will be a key focus of the collaboration between AIMS and the WA Museum. During each research cruise, video and acoustic surveys facilitated targeting of benthic communities with benthic sled, so species and functional groups could be collected preserved and identified (Western Australian Museum). The sled sampling also provided additional information on species distribution, abundance, biomass and size composition. The original sled design, based on that used by AIMS and CSIRO on the GBR, was not always sampling well, due to the large size and abundance of some of the benthos collected in the 2006 field work, notably sponges and gorgonians. A new sled was designed and built for the 2007 field work.

The new steel benthic sled is based on the design of a commercial fishing Tri-gear Trawl Beam, slightly modified for our purposes (Fig.11a, b). Traditionally a Tri-gear Trawl Beam is used to locate, track and sample scallops and deep water prawns in depths less than 1000 metres. The dimensions of the sled used at Ningaloo are 1.5 m wide x 1 m high. The net and cod end (Figs. 12 and 13) are made of 48 ply 17/8" Amican™. The top and bottom net panels are 60 meshes wide and 75 meshes long with a 2 point 1 bar taper, used to bring the net down to 100 meshes around. A 50 mesh sock was used to give the net extra length to allow the codend to be hauled aboard without taking the weight of the sled. The codend is 1 7/8" 3 mm black braided net. The codend is 55 meshes long. A 45 mesh shirt is sewn on 5 meshes down from the start of the codend so that before tying the codend and skirt, the codend protrudes 5 meshes through the end of the skirt. A 10 mm drawstring cord is used for both codend and skirt. The codend is tied first and pushed up into the skirt before the skirt is tied. The lazyline is attached to a dogear 25 meshes wide and 40 meshes long. The dogear is attached to the start of the codend just before the skirt. The head/foot lines are 150 cm long, made from 6 mm stainless steel wire and wrapped. A stainless steel thimble is swaged at each end. The net is hung at ½ i.e. 2 meshes hung on a 1 7/8" hanging. It was hung at ½ to close off the meshes a little to give the net more length and to prevent the loss of smaller specimens (S. Davis, pers.comm. to J. Colquhoun).

In order to trial the new sled and provide semi-quantitative samples of a manageable size for taxonomic processing, twelve benthic sled samples were collected over 4 days in different habitats with varying degrees of benthos (i.e. dense, medium, and sparse) (Figs. 14 and 15). The sled was lowered to the bottom by a winch with steel cable and dragged along the bottom. Distance fished was estimated by the winch operator, recording the GPS position when the sled touches the bottom and when it leaves the bottom. GPS positions provide the distance travelled in metres of all the samples conducted. To ensure more accurate fishing times for the sled in the future a depth sensor or in situ camera, time synchronised to the ships GPS, will be attached to provide a downloadable profile of fishing time and distance.

Trials indicated the new sleds' sampling was an improvement on 2006 and all the macro benthos shown on towed video was being sampled. Trials also indicated that the most representative and manageable sled sample distance, out of several tested, was 50 metres in all the habitats sampled. Replicated fifty metre long sled samples will be adopted as the preferred standard for future samples to be carried out in early 2008. The improved benthic sled design and fishing time/distance measurement capabilities to be fitted before 2008 will allow us to quantify more accurately the abundance and biomass of phyla that make up the benthic communities in different areas of the marine park. An improved processing protocol for each sample has been established, with the assistance of the West Australian Museum, and will be further developed and documented in preparation for 2008.

a

b

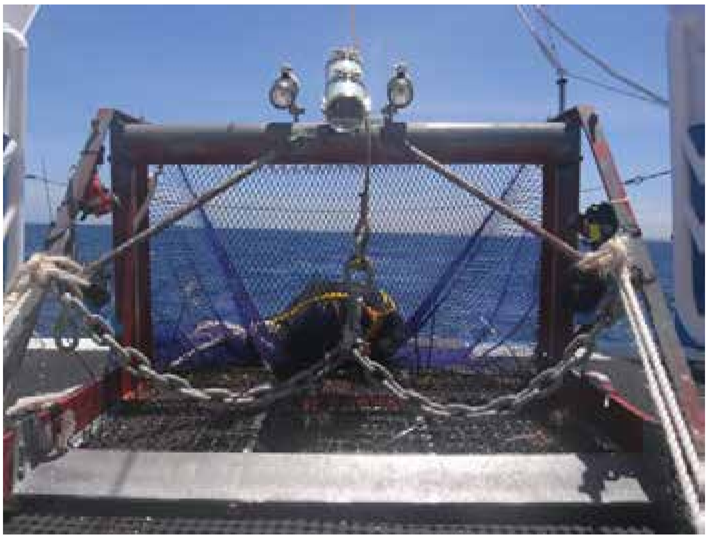

Figure 11 a & b: New benthic sled used to sample taxa from targeted benthic communities in 2007. Trial of attached camera gear fitted to the top cross-bar is shown.

Figure 12. New benthic sled net and cod end.

Figure 13. Benthic sled sampling locations in Ningaloo Marine Park 2006/2007.

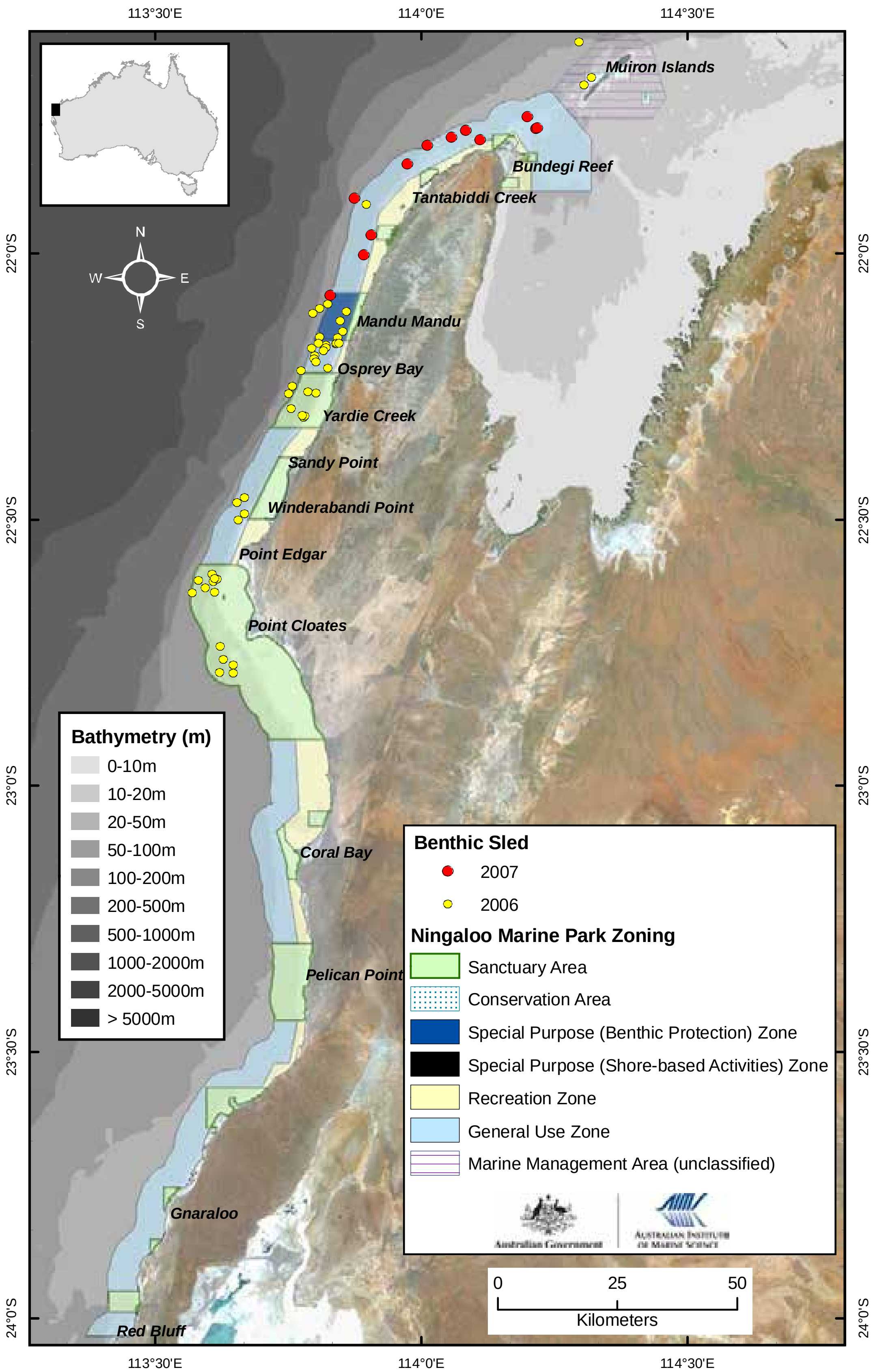

Figure 14. Benthic sled sample locations 2006/2007 surveys.

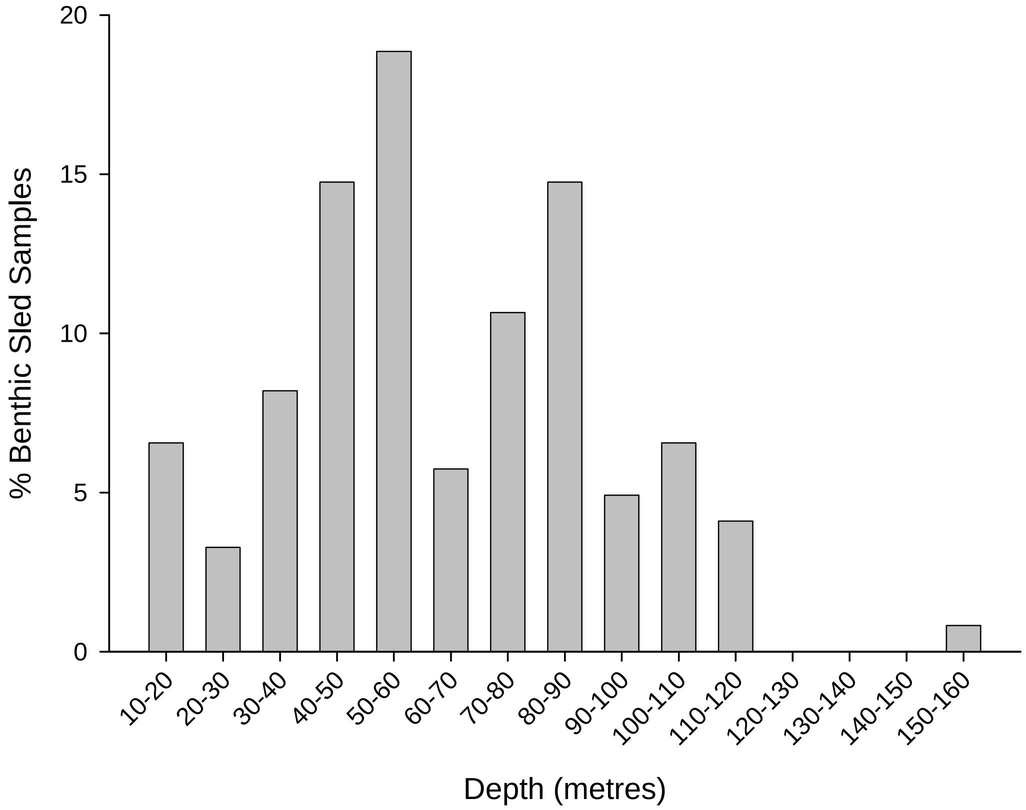

Figure 15. Benthic Sled sampling effort 2006/2007 at different depths in Ningaloo Marine Park.

Overall weight of each sample was calculated by weighing the empty and full cod end with a 200 kg capacity digital scale attached to the end of a crane. A standard fixed lifting point was made at the end of the cod end. Weighing both empty and full codends allowed for the total biomass of each sample to be calculated in varying conditions on board the vessel. The whole sample was then emptied onto the sorting tray (Fig. 16). Each phyla represented was separated (Fig. 17). The dominant taxa from the main habitats were selected for priority identification i.e. Porifera (sponges), Alcyonaria (gorgonians, whip corals). As sponges were typically dominant in terms of biomass in all significant catches, overall sponge weight in each sample was recorded. Individual sponge weights in each sample were measured. The weight of other dominant sessile phyla was recorded (i.e. bryozoans, soft corals etc). The weights of the dominant mobile phyla were weighed. Trials indicated that both a higher capacity scale >200 kg and lower capacity scales <100 g were required to efficiently collect biomass measurements from all the phyla collected in each sample. Voucher specimens of all taxa were labelled, photographed and preserved for identification at the Western Australian Museum.

The 2006/2007 specimen collections form the basis for primary species inventories at Ningaloo Marine Park however, a significant proportion of taxonomy remains to be done by the West Australian Museum. The 2008 field work will focus on acquiring benthic samples from as many different habitats as possible that have been identified to date in the surveys. Priority will be given to sampling northern, middle and southern areas. Replicate sled samples will be stratified in different habitats depending on their size and variability. Sled tows will be standardised to 50 metres fishing distance (e.g. from the time the sled is on the bottom sampling to the time it leaves the bottom).

Figure 16. Benthic samples emptied into sorting tray.

Figure 17. Benthic samples of sponges being sorted, photographed and weighed.

In situ still-photo Imaging methods and preliminary analysis

An additional sampling protocol, using a high resolution digital still camera, was developed during 2007. The objective was to capture images that would lend themselves to more quantitative analysis of the benthic communities and better resolve the identification of biota into taxonomic groups.

To achieve this, an underwater camera, fitted with 24mm wide angle lens and slave strobe was attached directly to the rear end of the towed video frame, facing onwards at the seabed. An onboard interval timer was set to take an image every 5 seconds. The exposure settings on the camera were set manually and adjusted through trial and error to compensate for the speed of the tow body (1-2 knots). Exposures of 1/1000 of a second and F3.6-5.0 provided adequate images in the majority of cases. Focus was also set manually, typically at 0.7m and this provided sharp images for most photos. Using this method a photo was obtained every 4-6m along a typical tow.

Further refinement of camera settings is possible, but by and large the still camera delivered valuable additional images of the benthos and these images, which represent a fomr of photo-quadrat, will provide a useful additional resource, particularly for quantitative analysis of organism abundance. It became clear from comparison of the still and video images that the forward looking video camera perspective tends to bias impressions toward greater abundance of macro-benthos, particularly the more three-dimensional forms such as sponges. This observation reinforces the view that multiple simultaneous sampling approaches, including various forms of imaging and the sled collecting are required to get the best assessment of the biohabitats.

The towed high resolution stills lend themselves to point-interpret analysis of seabed cover for quantification of key taxa. In some cases identification to species will be possible, which is a significant improvement on what can be achieved suing video images. The 2007 experimentation supports the addition of these imaging methods to all future towed video transects where possible. The trial systems were rated to 60m depth. Prior to the 2008 surveys new pressure housings will be fabricated for the cameras, to enable their use at all survey depths, which extend beyond 100m (see Figs. 18-20).

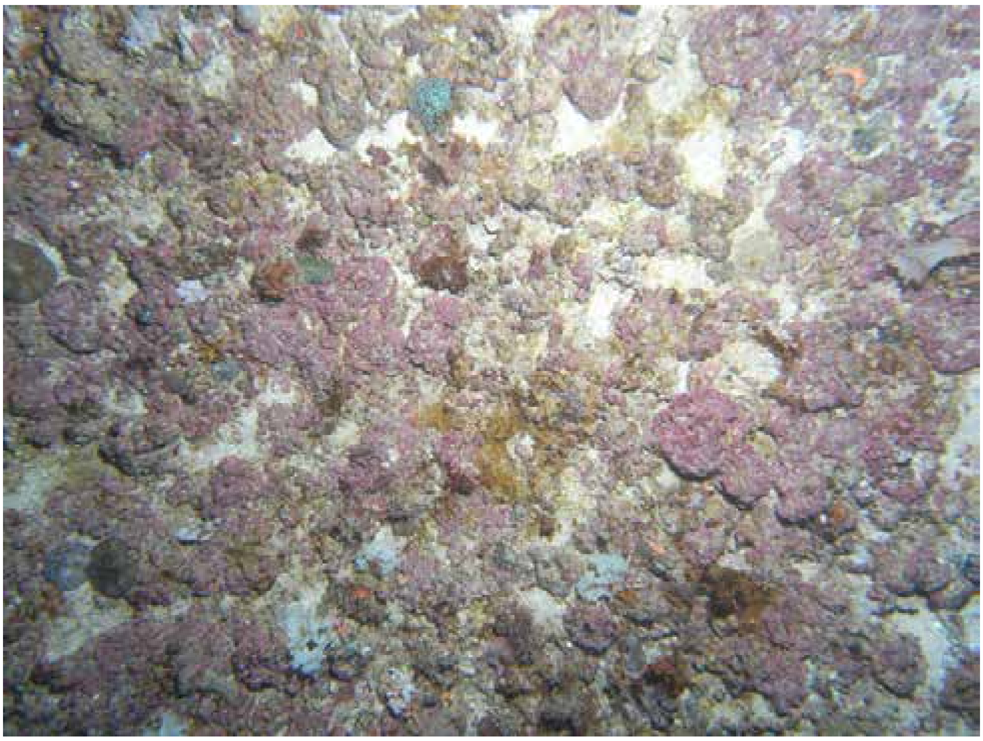

Figure 18. Mandu Mandu 35m – rhodolith rubble zone. Example of towed still photo-quadrat.

Figure 19. Jurabi 49-55m –sponge community. Example of towed still photo-quadrat

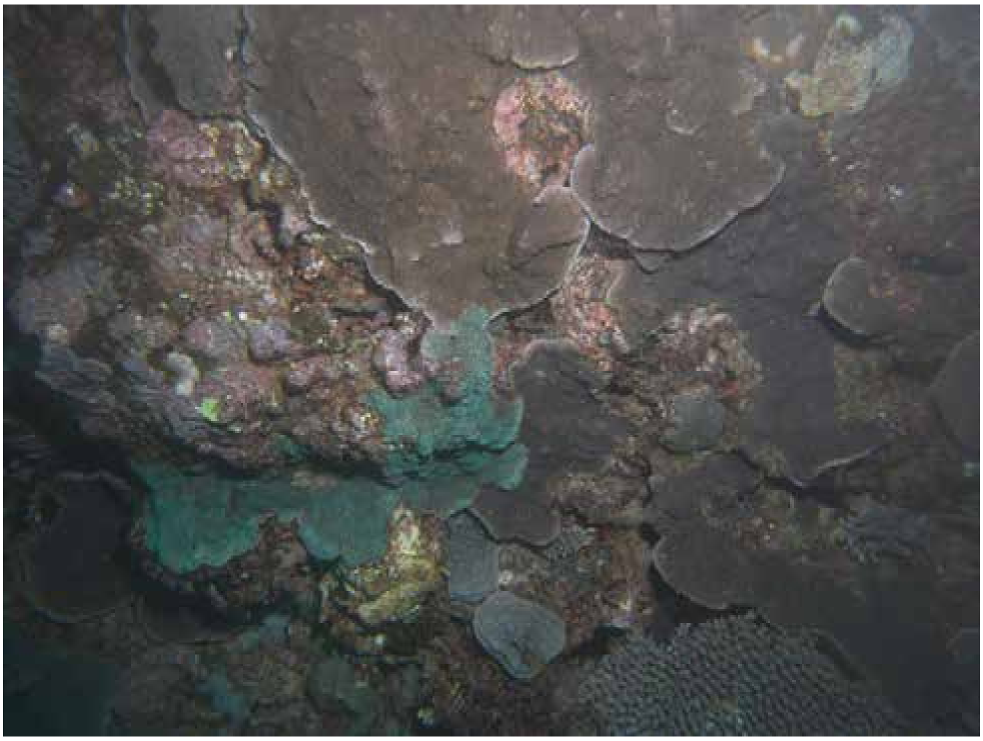

Figure 20. Tantabiddi 25-30m – coral dominated fore-reef. Example of towed-still photo quadrat

LBV Seabotix Remote Operated Vehicle (ROV) – Dual Video Camera Operation

The AIMS LBV Seabotix Remote Operated Vehicle is a small observation class ROV. It is portable and has capabilities of capturing high quality video footage, equivalent to that produced in shallow waters by divers, down to 300 m (Fig. 21a). The ROV has dual video camera operation and is remotely operated from a console (Fig. 21b). The ROV was used in four different locations and communities of the marine park to gather more detailed video data of different benthic communities, previously identified from towed video. Two locations were in the northern section of the park, North West Cape and Point Murat and two in the southern part, Red Bluff and Warroora (Fig. 22). Four 50 m ROV video transects originating from a centre weight at four different bearings (90°, 180°, 270°, 360°) were conducted at each location. Each transect will be analysed using AVTAS software to investigate in more detail the diversity and composition of different communities in the marine park. Due to its stability and manoeuvrability the ROV was also used to gather '*in situ*' video footage of individual sponges, soft corals, gorgonians and other benthic species making up each community. The data will assist the WA Museum with the taxonomy of different species. Video footage from all transects and '*in situ*' footage will be included in the final reporting deliverables and linked to an ArcGIS™ framework.

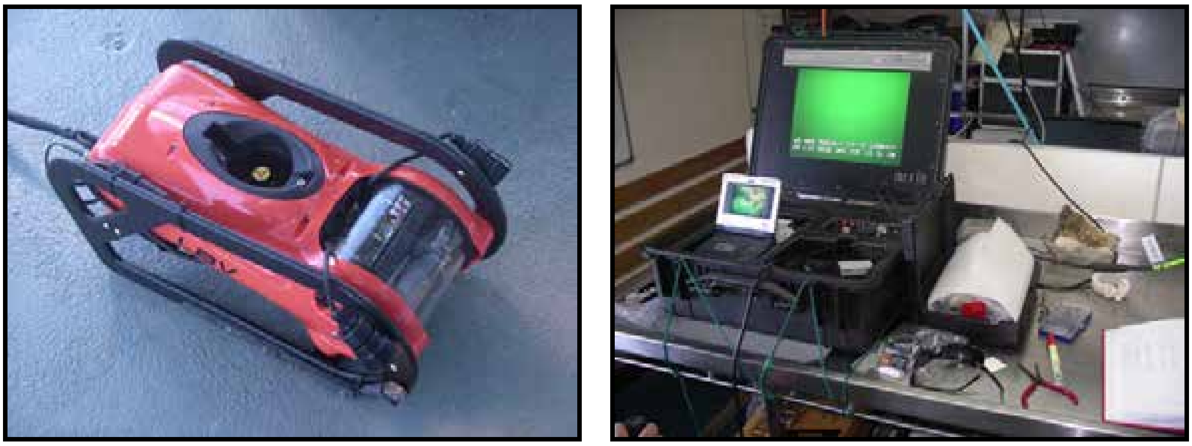

Figure 21. a) LBV ROV Seabotix remote operated vehicle. b) ROV operating console.

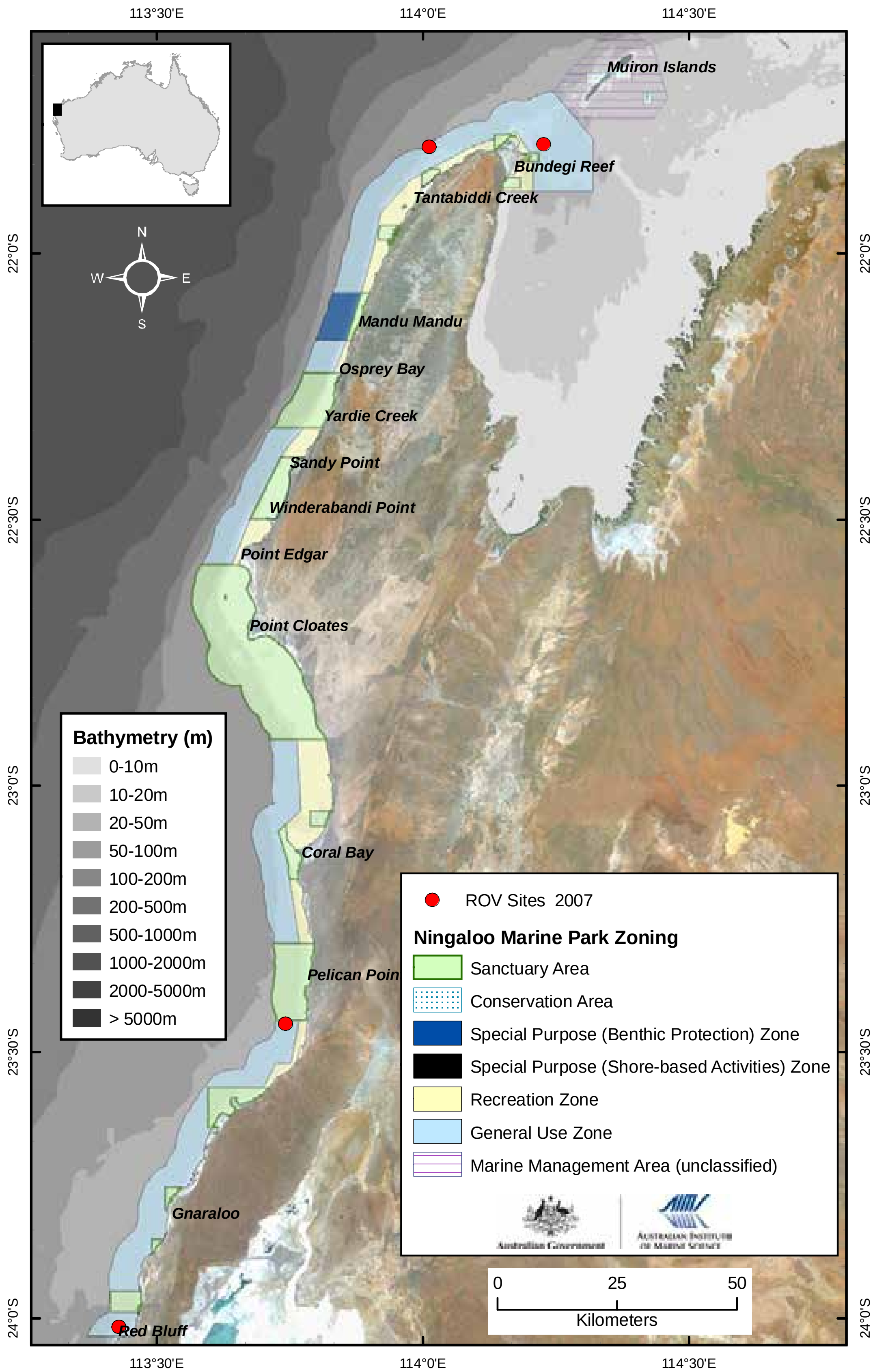

Figure 22. Remote Operated Vehicle (ROV) deployments 2007.

Future work

This report provides an interim update at the mid-point of a four year study. The project is on track to meet its objectives. A variety of sampling methods for acoustic mapping, benthic sampling and seabed imaging have been refined significantly during 2007 and the focus in 2008 will be application of these standardised approaches to provide an adequate and representative sample of the deeper waters of the marine park.

Priority in 2008 will be to conclude sampling related to habitat characterisation, bathymetry and biodiversity inventory. All of these data will then be used to plan a final survey of the associated fish communities in 2009.

In 2008 the 500m - spaced single beam acoustic mapping, which shall provide the core for developing an improved bathymetry of the entire offshore marine park, will continue and aims to cover 90-100% of the waters between 30-100m depth. Discrete replicated sled tows will be used to provide the WA Museum with representative samples of the dominant macrobenthos, while at the same time the biomass measurements should yield additional information on the abundance of key species and their spatial patchiness. Further habitat characterisation is planned with additional towed video augmented henceforth with simultaneous high resolution stills.

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CHAPTER 4
Identification of Demosponges from the Ningaloo Deepwater Survey – 2007 Expedition

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Summary

This report presents the preliminary results from the collections sampled in deeper water off Ningaloo reef, Western Australia in 2007. The research is part of a collaborative study with the Australian Institute of Marine Science (AIMS) and the Western Australian Marine Science Institute (WAMSI).

The WA Museum was requested to identify the dominant filter feeders collected in the study. Specimens of other taxa collected are held in the Museum and some of this material has been identified. The collection was dominated by sponges.

Specimens were collected with an epibenthic sled at depths between 18 to 102m. The WA Museum established a set of protocols firstly for sampling the biota in a quantitative manner, and secondly detailed methods to be used in the field for preservation of specimens of each species collected. All species of all phyla were collected.

Thirty-six sponge species were identified from the 12 stations sampled in 2007. These species were determined as dominant because they comprised a significant proportion of the total weight of biota collected from each station. Some specimens with high recorded weights could not be found but will be identified and included in the final report. Forty-five stations were sampled in 2006 and 39 species were identified as dominant from these stations. Of these 75 species in total, only six were found to be common to both collecting years.

Within the 2007 sampling the majority of the dominant sponges were found at only one station (22 species), 11 species were found at two stations, one species was at 3 stations, and one species was found at seven of the 12 stations sampled. This interesting finding suggests that each station that has sponge habitat is dominated by a different sponge assemblage. Alternatively the species occurring at each station maybe the same, but the dominant species, determined by weight, differ across stations.

Four sponge species identification sheets have been included as an attachment to this report to demonstrate the taxonomic tools that are being developed as part of this study. Identification sheets are being compiled for all sponge species found in this study.

This report also documents the work that will be undertaken on the Ningaloo deepwater fauna, and the outcomes that will result as a consequence of this project.

Background

The AIMS vessel 'R.V. Cape Ferguson' conducted a first survey of the deeper water habitats off Ningaloo Reef in May 2006, a second survey in February 2007, and a final survey in February 2008. This report documents the dominant sponges that were found in 2007.

Sampling stations were determined by reference to an acoustic generated map and video footage that indicated different habitat types in the area. Collection of organisms within these areas would indicate whether the fauna or bottom type differed in accordance with the acoustic maps.

The primary aims of this aspect of the study were to address the following management questions:

- What is the distribution of the major benthic communities in the deeper (non lagoonal) waters of the Ningaloo Marine Park?
- What are the major species/functional groups in the major benthic communities?
- What is the abundance/biomass/size composition of the major species?
- What are the causes of these distributions?
- What is the significance of the biodiversity of the deeper waters globally?
- Are the deep water sanctuary zones appropriately situated (conservation and representativeness)?
- What species/functional groups and sites should be used to measure temporal changes in these communities in the long-term?

Procedures

The 2007 expedition aboard the RV Cape Ferguson mobilised from Exmouth and consisted of a 14 day cruise, with 5 days set aside specifically for biological collecting for biodiversity studies. Biological specimens were collected from each of the different habitats encountered using an epibenthic sled.

Sampling using the sled was quantitative with tows standardised as much as possible to 50 metre lengths on the substrate. These tows focussed on collecting a representative subset of biota from the different habitats. It was difficult to sample highly consolidated outcropping reef, which occurred in some areas.

Mark Salotti participated in this cruise and used sampling procedures and collection and preservation protocols that had been developed by the WA Museum. Preservation of specimens was in 75% ethanol or material was frozen. Sampling techniques and preservation methods are outlined in section 3 of this report.

All phyla collected were weighed, the number of individuals determined and preserved. The priority taxa were the filter feeders, specifically the Porifera.

Specimens are to be accessioned into the WA Museum collections.

Methods

Tow methods

- Three replicate sled tows per habitat.
- Sled tow lengths standardized from time tow touches bottom for 50 metres.
- Lat/long and depth recorded at start and end of tow.

Weights (as surrogates for biomass/dominance)

- Cod-end weighed empty and full so overall catch-weight determined (standard fixed-lifting point made at end of cod-end)
- Total sponges weighed.
- Sponges separated into morphospecies and weighed separately for each station.
- Dominant morphospecies (≤10) determined by weight, or volume judged by eye. Where weight was <100g, it was recorded as such, no scales were available that could record weights <100g.
- Weight of other sessile organisms in sled recorded (if dominated by another phyla, eg cnidaria, rhodoliths, bryozoa etc).
- Cnidarians; antipatherians; ascidians, echinoderms, molluscs, crustaceans, fishes, worms, hydroids, bryozoans and algae were separated from each other and weighed if their weight exceeded 100g.

Voucher specimens

- A voucher specimen representative of size and shape of each morphospecies selected, remaining specimens discarded.
- Voucher specimens labelled with field number and name and photographed with scale bar and label. Details recorded in field notebook.
- Sub-samples taken from some sponge voucher specimens for a PhD study on trophic relationships (Alex Wyatt, UWA), labels duplicated and samples frozen.
- Voucher specimens preserved in 75% ethanol (large specimens frozen).

Protocols for specimen preservation

SPONGES:

- Small and medium-sized specimens placed in freezer bag with label and preserved in 75% ethanol.
- Large specimens frozen.

ECHINODERMS:

- Echinoderms were divided into classes: asteroids, crinoids, echinoids, ophiuroids, holothurians.
- Asteroids and crinoids: where there were multiple specimens of each morphospecies, some were preserved in 75% ethanol and some were fixed in 10% formalin.
- Ophiuroids: were frozen flat.
- Echinoids: where there were multiple specimens of each morphospecies present, most were preserved in 75% ethanol, and some were fixed in 10% formalin or frozen.

MOLLUSCS:

- Molluscs were divided into classes: bivalves, cephalopods and gastropods – the latter divided into nudibranchs/opisthobranchs and prosobranchs.
- Bivalves and prosobranchs were relaxed in an isotonic, aqueous solution of Magnesium Chloride and labelled.
- Nudibranchs/opisthobranchs and cephalopods were relaxed in the refrigerator and photographed with scale-bar and label.
- All molluscs were frozen.
- Dead-taken molluscs were also collected.

OTHER GROUPS

- Crustacea were divided into orders: amphipods, decapods, isopods and stomatopods (when time permitted), labelled and frozen.
- Fish, algae and seajellies labeled and frozen.
- All other groups labelled and preserved in 75% ethanol.

Results and Discussion

At many of the sled stations sponges were found to be the dominant filter feeding group present (Appendix 2). Of the 12 stations examined 4 stations were dominated by sponges (51, 52, 55, 62), 6 stations had a significant component of sponge (53, 54, 56, 57, 59, 60), and 2 had one or no sponges (58, 61, Appendix 2).

Appendix 2 documents the dominant sponge species found at each station sampled. Dominance was determined by sponge biomass contribution to overall weight of the haul. Weight of sponge per sled station varied from 0 (1 station) to 114 kg at station 55. These weights can be used as surrogates for biomass, and be related to the substratum type (when this information becomes available) and depth characteristics of each station. Individual species weights determined the dominant species at each station and varied between 0.1 to 34.2 kgs. Thirty-six sponge species were identified. All of these species belonged to the Class Demospongiae and were collected from depths between 18-114 metres. Additional species were collected but have not yet been identified. Note that for 3 stations (51, 52 and 56) some of the dominant sponge specimens have not yet been found, so this number may increase slightly with further work.

When the results of the 2007 survey were compared with the 2006 survey, a number of interesting points emerged. In the 2006 survey we reported 39 dominant species from 45 stations sampled compared to 36 dominant species found at the 12 stations sampled in 2007. Although the sampling methods were different and are therefore not directly comparable, only 6 species were found in both years: *Cinachrya* cf. *isis*, *Pseudoceratina* sp. Ng.1, *Monanchora* sp. Ng.1, *Clathria (Thalysias) cactiformis, Haliclona (Haliclona)* sp. Ng.1, and *Axinella* sp.Ng.1, suggesting that the dominant species differed between the areas sampled and the sampling years.

Within the 2007 sampling the majority of the dominant sponges were found at only one station (22 species), while 11 species were found at two of the stations sampled. *Echinodictyum clathrioides* and *Iotrochota acerata* were more common, being found at 3 stations, and *Sigmaxinella* sp.SS1 was the most common sponge found in 2007, occurring at 7 of the 12 stations sampled. This interesting finding suggests that each station that has sponge habitat is dominated by a different sponge assemblage. Alternatively the species occurring at each station maybe the same, but the dominant ones, which are determined by weight, differ across stations. All specimens, including non-dominant ones, would need to be examined to see if the assemblages at each station are the same but species dominance changes. We will examine this result further for the final report.

Many of the sponge species of WA are poorly known and described so determination of distributions of these species is problematic (see Appendix 2 for the proportion of the 36 dominant species without known species names at this time). Of the 14 known species found in 2007, six have distributions restricted to Western Australia, four are Indian Ocean species, two are more widespread within Australia, and two are Indo-Pacific. The 14 species restricted to Western Australian demonstrate how localised sponge species distributions can be. With further work these species may be found to be Western Australian endemics. This is the first report of eleven of these species from the Ningaloo region, and this result is a consequence of the lack of any prior work on sponges at these depths in this region.

Four sponge species identification sheets have been included as an attachment (Appendix 3) to this report to show the taxonomic tools that are being developed as part of this study. Identification sheets are being compiled for all sponge species found in this study.

Very few cnidarians dominated the filter feeding communities with weight of these taxa being low. At station 53 an ascidian comprised a significant component of the biomass, at station 54 a bryozoan was a significant component, and at station 60 a coral species was dominant by biomass.

Information on Porifera (sponges) and Cnidaria (with the exception of hard corals) in the region is restricted to previous AIMS surveys 2001, 2002 to the north, some collections in Exmouth Gulf as a consequence of a FRDC trawling study by Fisheries WA and the WA Museum, and work undertaken by the Southern Surveyor in deeper water (>100 metres) to the west of this study by CSIRO in 2005. No work has been undertaken on these taxa in shallow waters on Ningaloo Reef apart from the Scleractinia.

Two CSIRO expeditions on the "Diamantina" had a few collecting stations northward of the area examined in this expedition. One station on the 6/63 cruise and three stations on the 1/64 cruise were greater than 200 metres depth. These stations were reported to consist of fine mud or soft ooze. CSIRO may hold information about the fauna collected from these sites.

Extensive trawl surveys were conducted by CSIRO in the early 1980s on the North West Shelf between the Montebello Islands and Cape Leveque between 30-200m depth but very few stations were sampled between 200-600 metres. The WA Museum holds a large collection of the by-catch of these surveys, ie. cnidaria, sponges, echinoderms and some crustaceans. CSIRO targeted fishes and prawns. Parts of these collections have been identified and some published e.g. azooxanthellate corals, but much of the other taxa collected have not had additional taxonomic work done on them.

The specimens that have resulted from the 2006 and 2007 fieldwork are the first comprehensive collections ever to have been collected from Ningaloo deeper waters. Prior to this a few studies had collected a few specimens, outlined above, but not with the targeted geographical and habitat related collecting that these latest surveys have achieved. The most comparable study is the one undertaken by CSIRO 'Voyage of Discovery' in 2005 which collected at depths greater than 100 metres in the Ningaloo region, and this latest work will be compared to the species collected during the CSIRO survey.

Some of the mollusc material from the 2006 and 2007 expeditions has been identified; however this phylum and the Echinodermata were not prioritised as groups to be identified in this project until 2007. It has now been recognised that identification of the abundant or major mollusc and echinoderm species found in the region would assist with interpretation of the results, particularly those relating to interpretation of the biogeography of the region. Consequently mollusc and echinoderm identifications will begin in 2008 and be included in the final report.

Fishes are being studied separately by UWA. A few fish species were collected in 2006 and are being identified by staff of the WA Museum. These will be incorporated into a future checklist of species of the region.

Work to be undertaken

The seven primary aims of this research will be addressed in full in the final report. At that point we will have identified the major benthic assemblages in the deeper waters of Ningaloo. The differences in diversity of sponge species occurring at each of the stations examined in 2007 suggests that these stations have dominant species that are frequently unique to the station, but this will be examined in greater detail in the next year.

To give species names to the sponge taxa currently with a species number code would require a taxonomic revision of each family. This is an enormous task that is beyond the scope of this project. However comparison of the specimens collected in 2006 and 2007 to those collected in 2008 will address the core questions of this component of the project, with anticipated results listed below.

The species collected during this project can also be compared to other expeditions (eg CSIRO Voyage of Discovery) and will provide a Western Australian distribution for those species that were found in both studies. This will provide excellent distribution knowledge of these taxa, and will assist with determining the uniqueness of the Ningaloo deeper water fauna. This work will be achieved for the final report.

Assessing better known phyla, such as echinoderms and molluscs will assist with answering questions about biogeographic affinities of the Ningaloo deepwater fauna. These phyla will be examined and reported on in the final report from all three survey years. Any dominant Cnidaria and Crustaceans will also be identified for the final report.

Anticipated Results

- Determination of habitats with characterisation of the dominant taxa for each habitat by biomass or abundance.
- Identification of dominant biota ranked by weight or abundance.
- Comparison of deeper water habitats by dominant sessile phyla eg Porifera, Cnidaria etc.
- Comparison of habitats by dominant sessile species.
- Comparison of habitats by dominant mobile species.
- Distribution in park of dominant species.
- Images of dominant species with associated identification.
- Determine if all habitats are represented in marine reserves.
- Comparison with AIMS Vincent-Enfield collections.
- Comparison of species results with deepwater (100+metres) survey results from CSIRO 'Voyage of Discovery' offshore from this study.

CHAPTER 5
The distribution and biodiversity of demersal fishes of the northern Ningaloo Marine Park

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Introduction

This research aims to characterize the structure and distribution of fish assemblages across Ningaloo continental shelf habitats from 90+m water depths at the shelf break to inside the coral reef lagoon. It will provide detailed finescale information about the diversity, spatial distribution and habitat affiliation of demersal fin fishes across a range of depths and habitats within the northern section of the Ningaloo Marine Park (Fig. 1). Although this report primarily pertains to the: WAMSI Node 3, Project 1, Subproject 3.1.1: Deepwater Communities at Ningaloo Marine Park including demersal fish assemblages; data from WAMSI Node 3 Project 2 Subproject 3.2.2: Ecosystem Effects of Fishing for inshore coral reef fishes is also presented. We have combined these data to provide a complete cross-shelf consideration of fish assemblages associated with different depths and habitats, and the families and species responsible for these differences.

Methods

Sampling design

The survey investigated the diversity, relative abundances and size of demersal fish and elasmobranchs at four cross-shelf areas between 22 April and 30 June 2006. The field survey was planned around the outcomes of habitat groundtruthing undertaken by AIMS, Curtin and FUGRO during 2006. Habitat groundtruthing consisted of georeferenced towed video, acoustics, aerial imagery and benthic sleds and provided information on the distribution of benthic habitats on the seafloor between 0 and 100 m depths. The mapping of seafloor habitats, allowed us to stratifying our fish sampling by habitat at five offshore locations and four inshore areas. Offshore areas included Mandu, Osprey and Cloates Sanctuary Zones, and Osprey and Cloates reference areas (Fig.1) and inshore areas included Mandu and Osprey sanctuary zones and Osprey and Mandu references areas. For the purposes of this analysis Cloates Sanctuary zone data were omitted from the offshore dataset to balance the inshore/offshore sampling. Fish assemblages were randomly sampled from within 16 discrete habitats at four cross-shelf areas in the northern Ningaloo Reef (offshore and inshore areas combined) (Fig.2). Fish sampling was undertaken using one consistent sampling technique: stereo baited remote underwater video (Stereo-BRUVS) and we obtained up to six random stereo BRUV replicates at any area x habitat combination.

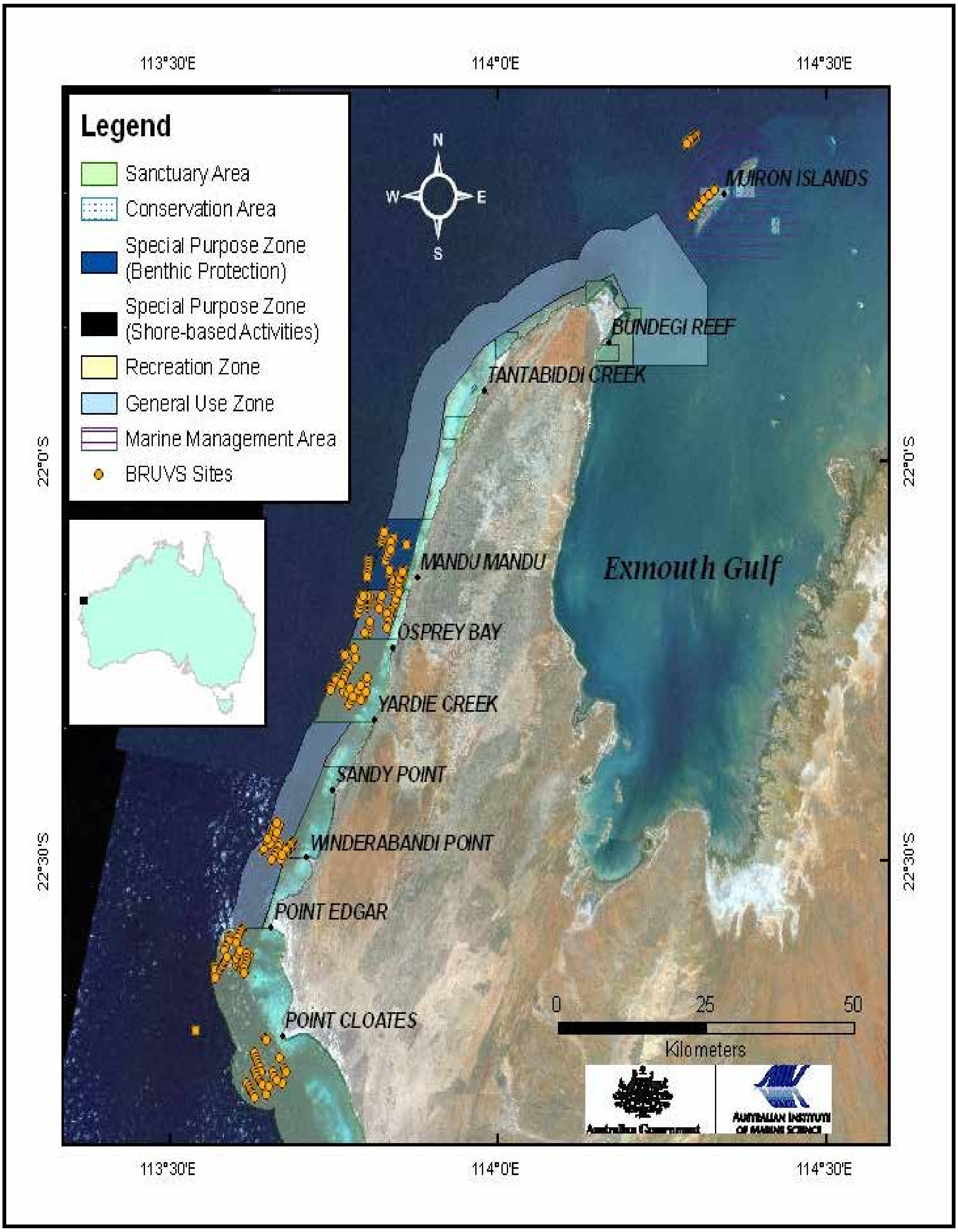


Figure 1. Stereo-BRUVs sampling locations in the northern Ningaloo Marine Park (compiled by Felicity McAllister, AIMS).

Area / Habitat	1. Algal pavement 1-2	2. Branching coral 2-4	3. Tabulate acropora 1-2	4. Reef flat 0-1	5. Channel/bommies 4-7	6. Reef Pass 7-10	7. Reef slope 10-30	8. Reef base 30-50	9. Rodolith 30-50	10. Rodolith 50-70	11. Sponge 50-70	12. Sand 50-70	13. Sand 70-90	14. Sponge 70-90	15. Sponge 90+	16. Sand 90+
1	6	5		6	6	5	7	13	4	6	3	3	4	14	14	4
2	6	6	6	5	5	7	4	1	6	4		2	2	9	4	2
3	6	5	6	6		6	6	2	5	3		1	13	2	1	6
4	11		6		10	6	3	2	5	3		2	3	3	3	10

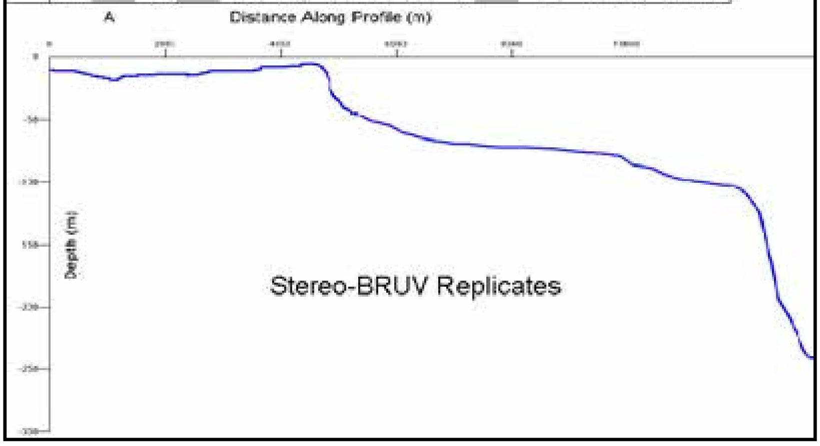


Figure 2. Depth/habitat factor groups and corresponding stereo-BRUVS replicates undertaken.

Data collection

The stereo-BRUVS used Sony HC15 digital camcorders within waterproof housings (see Harvey and Shortis 1996, 1998; Harvey et al. 2002 for stereo-video design and measurement procedures). Bait arms made of 20 mm plastic conduit with a standard rock lobster bait canister fastened to one end were attached to the stereo-video frame and detached after deployment (Watson et al. 2005). We used ~ 800 gms of crushed *Sardinops sagax* placed in the bait bag for each deployment. The stereo-BRUVS were retrieved after recording for one hour at each station. At deep sites where available light was extremely low on the seafloor, the stereo-BRUVS were set to record on night shot. Stereo-BRUVS rather than single cameras were used due to their ability to capture a baseline of the relative abundance of fishes and their length frequency. Single video BRUVS can only provide a measure of absence or presence of a species as data cannot be standardized for area sampled. Stereo-BRUVs facilitate measurement of distance (Harvey et al. 2004) allowing a consistent area to be defined and used spatially and temporally. This report presents an analysis of demersal fish presence/absence data with preliminary information on size frequency from stereo-BRUVS measurements.

Image analysis

Interrogation of each tape was conducted using a custom interface BRUVS1.5.mdb©, Australian Institute of Marine Science 2006) to manage data from field operations, tape reading, capture the timing of events, capture reference images of the seafloor and fish in the field of view. The following data were recorded for each species; the time of first sighting, time of first feeding at the bait, the maximum number seen together at any one time on the whole tape (*MaxN)*, time at which *MaxN* occurred, and any intraspecific and interspecific behaviour. The use of *MaxN* as an estimator of relative abundance has been reviewed in detail by Cappo et al. (2003, 2004). Estimates of *MaxN* are considered conservative, particularly in areas where fish occur in high densities. Fish lengths and distances were measured using a stereo photo-comparator. All imagery was converted from digital video to AVIs (audio video interleaved files) and compressed with DivX to allow this. To measure fish lengths and distances we used PhotoMeasure (www.seagis.com.au).

Statistical analysis

Two outlying stereo-BRUVS drops where no species were recorded were omitted from this analysis. Records of schooling fish species that appeared in high numbers (100s - 1000s) on individual stereo-BRUV samples but were seen rarely on other samples were also omitted.

Assemblage data

A two way non-parametric multivariate analysis of variance (PERMANOVA, Anderson 2001, Anderson and Robinson 2003, Anderson 2005, Anderson and Gorley 2007) was used to detect differences in fish assemblages between habitats and depth zones. The statistical analyses consisted of two factors: depth (ten levels, fixed) and habitat (11 levels, fixed). Because not all habitats were present in all depth zones, there needs to be further thought given to whether habitat should be classified as a random factor nested within depth. Because the use of MaxN for analysing stereo-BRUVS video tapes results in conservative estimates of the relative abundance of fish (Cappo et al. 2003), a Modified Gower Logbase 10 dissimilarity measure was used when we analyse the relative abundance data matrix (Anderson et al. 2006). The Modified Gower Log10 places less emphasis on compositional change of the assemblage and more on changes in relative abundance (Anderson et al. 2006). For each term in the analysis, 4999 permutations of the raw data units were computed to obtain *P*- values. Where significant main effects or interactions were detected, pair-wise comparisons were undertaken to investigate where the differences were occurring. To visually compare the assemblages between different depths and habitats, plots of the principal coordinates were constructed from a constrained Canonical Analysis of Principal Coordinates (CAP) (Anderson and Robinson 2003, Anderson and Willis 2003).

Results

A total of 340 stereo BRUV samples were collected, recording 410 species from 63 families. We sampled ~24000 individual fish from which ~12000 fish fork lengths were derived, describing fish assemblages associated with 16 habitat/depth combinations. Species relative abundance and family relative abundance were found to be significantly different between different habitats and depths and habitat*depth factors (Table 1). From 410 species, 68 were found to dominate assemblage structure and differences between habitat/depth categories (Fig.3a). Of the 63 families censused during this survey, 24 families explain a majority of the differences between habitat/depth groups (r CAP 1 and/or CAP 2 > 0.25) (Fig.3b, 4a, 5a).

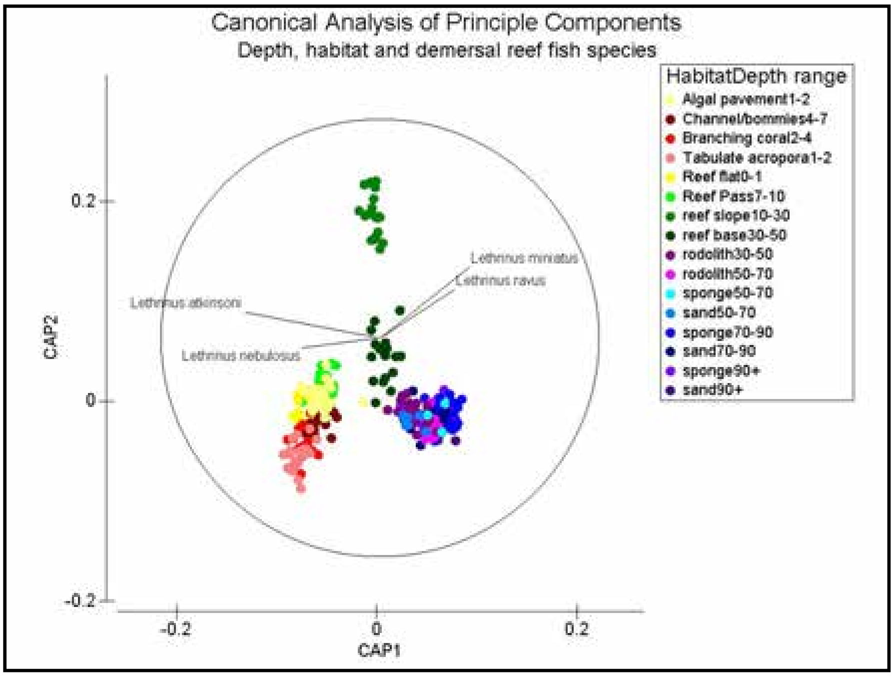
Table 1. Multivariate PERMANOVA results displaying the significance of interactions between species relative abundance (Modified Gower logbase10); and family relative abundance (Modified Gower logbase10); to habitat, depth and habitat/depth terms, using 4999 permutations.

PERMANOVA table of results

	df	SS	MS	Pseudo-F	
Species					
Source	df	SS	MS	Pseudo-F	
Habitat	4	6.1675	1.5419	4.5922	0.0002*
Depth	3	3.8825	1.2942	3.8544	0.0002*
HaxDe**	2	1.1742	0.5871	1.7486	0.0002*
Res	288	96.699	0.33576		
Total	303	131.86			
Family					
Habitat	4	9.006	2.2515	8.2225	0.0002*
Depth	3	2.7365	0.91218	3.3313	0.0002*
HaxDe**	2	1.1167	0.55837	2.0392	0.001*
Res	288	78.86	0.27382		
Total	303	124.83			

* Significant interaction
** Term has one or more empty cells

a)



b)

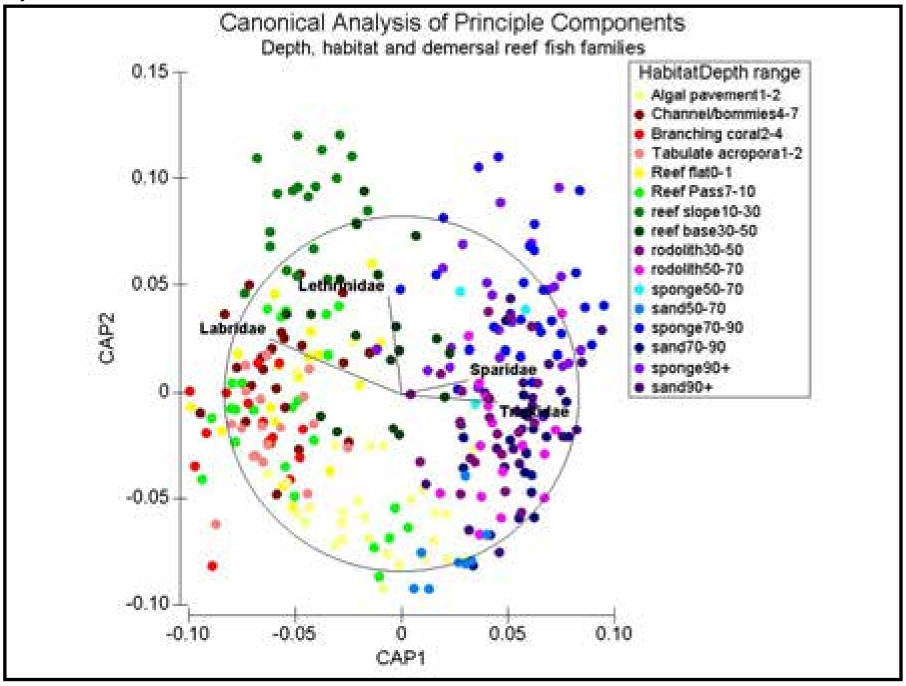
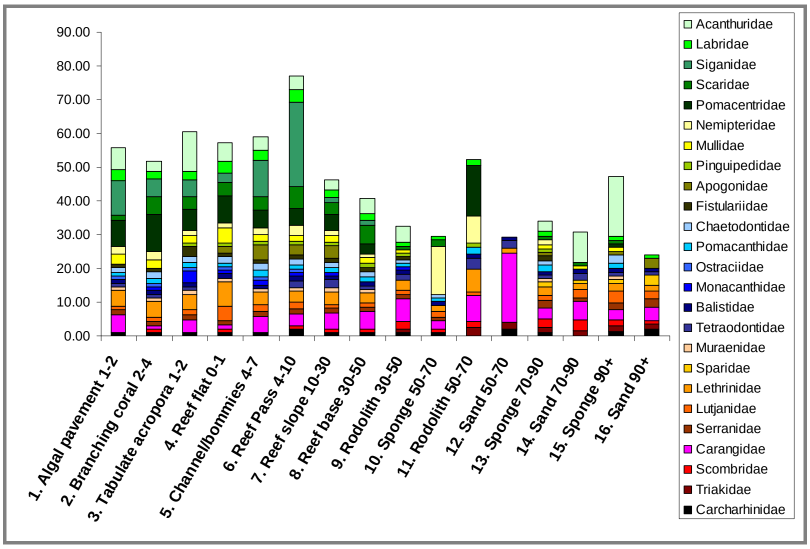


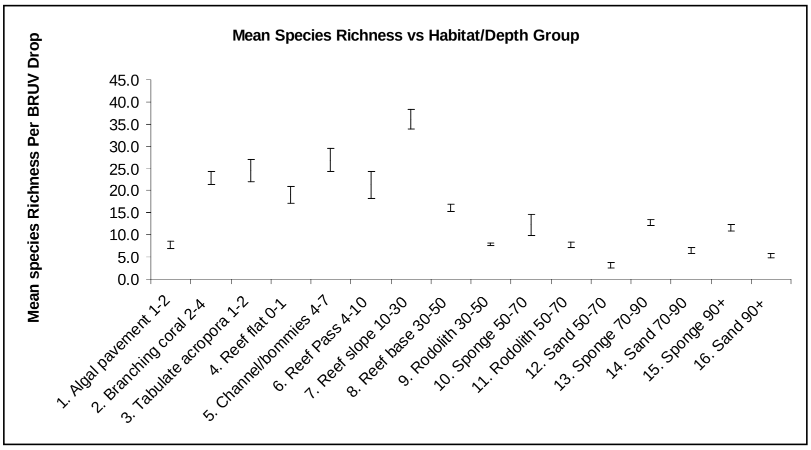
Figure 3. a). Showing assemblage structure of 410 sp in relation to 16 habitat/depth zones. 68 species explain majority of differences in fish assemblages (rCAP 1 or 2 >0.25). b). showing abundance of 63 families in relation to 16 depth/habitat zones.
25 families explain majority of differences in fish assemblages (rCAP 1 or 2 >0.25).

Species richness was highest within reef slope and inshore coral reef habitats in general in direct contrast to body size of individuals which increased with depth (Fig.4b, c). Significant habitat partitioning between species from the same family was common to major fish guilds including targeted families Lethrinids, Lutjanids, Serranids and Carangids. In one example, *Lethrinus nebulosus* adults demonstrate a generalist habitat strategy and are found across all 16 habitat/depth categories, whilst *L.atkinsoni* and *L. miniatus* were found only within coral lagoon and reef slope habitats and offshore habitats respectively. Within species habitat partitioning between size classes occurs in all three species with juveniles found in high abundances within nearshore branching coral, algal reef and offshore rhodolith habitats respectively (Fig.6a, b, c). Following this, depth range extensions for many species that are generally thought to be closely linked to shallow phototrophic habitats were recorded. Chaetodonts; including *Chaetodon auriga*, *Chaetodon assarius* and *Heniochus acuminatus,* Labrids; including *Bodianus axillaris, B. perditio, B. bilunulatus, Labroides dimidiatus* and *Choerodon jordani,* Acanthurids; such as *Naso tuberosus, N. hexacanthus, Acanthurus mata, A. blochi, A. grammoptilus* and Balistidae including *Sufflamen chrysopterus, S fraenatum, S frenatus* and *Abalistes stellatus* were all found in depths beyond 80m (Fig.7).

a)



b)



c)

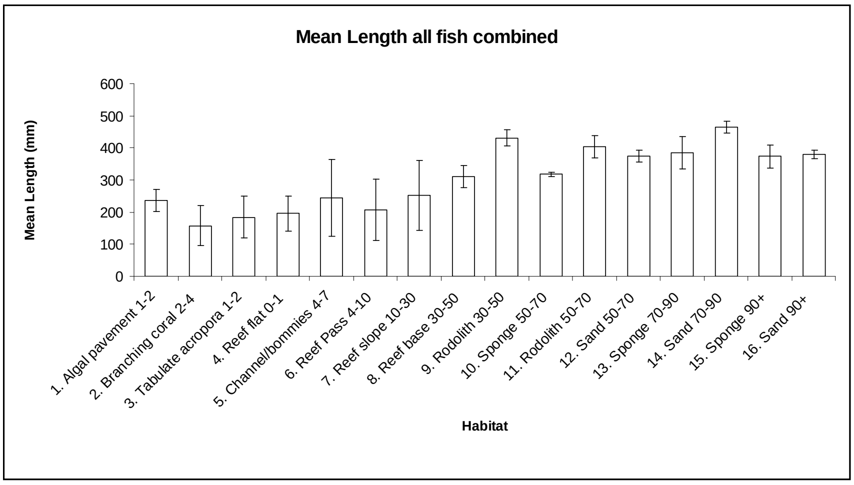


Figure 4. a) Abundance of 25 families that explain a majority of the differences between habitat/depth groups (r CAP 1 and/or CAP 2 > 0.25) Caesonidae excluded, Carcharhinidae included. b) Species richness changed significantly with depth/habitat groups. c) Mean length of fish increased with increasing distance from shore.

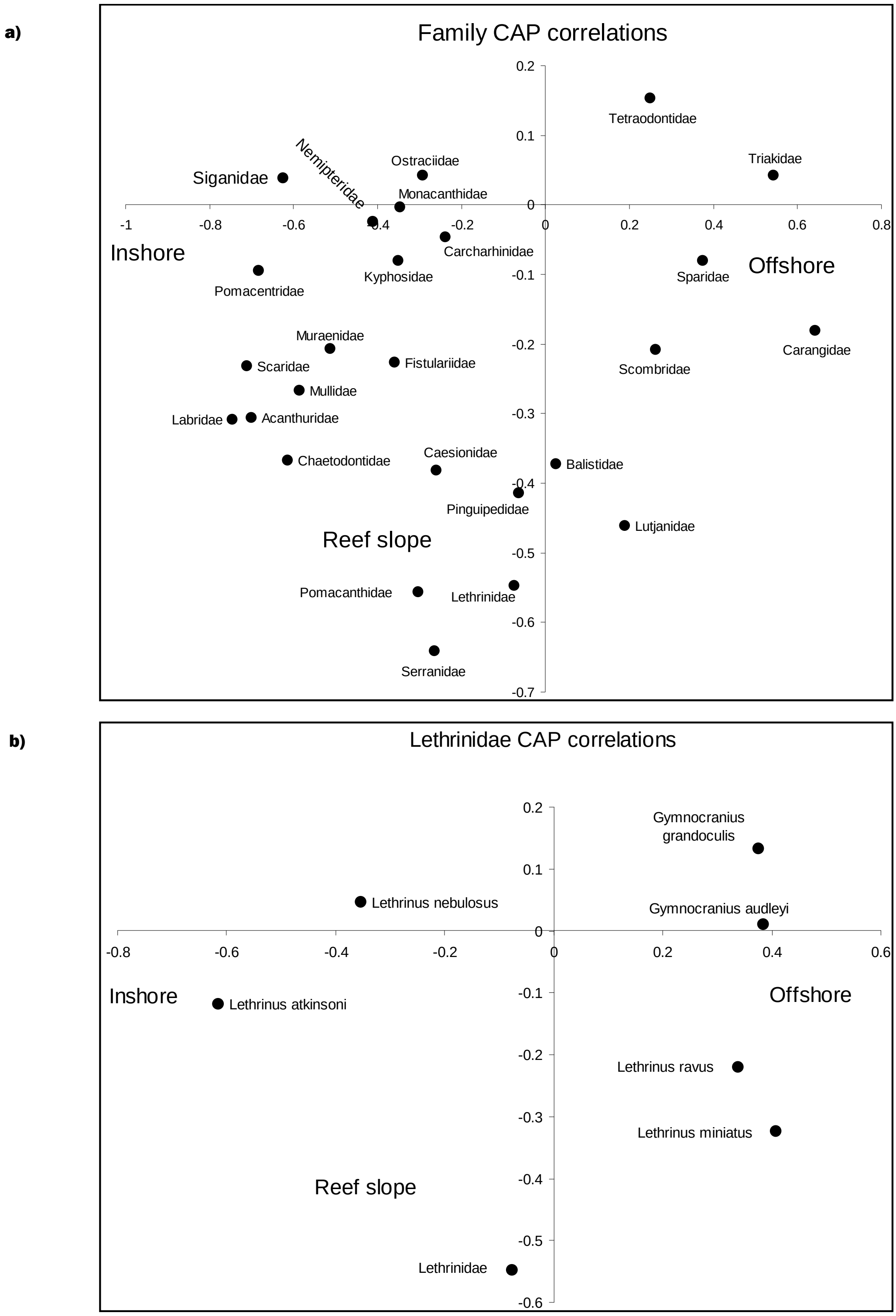


Figure 5. a) Correlation with conanical axis for the 25 families that explain a majority of differences between habitat/depth zones (rCAP 1 or 2 >0.25). b) 6 species of Lethrinids that contribute significant differences between habitat/depth zones (rCAP 1 or 2 >0.25).

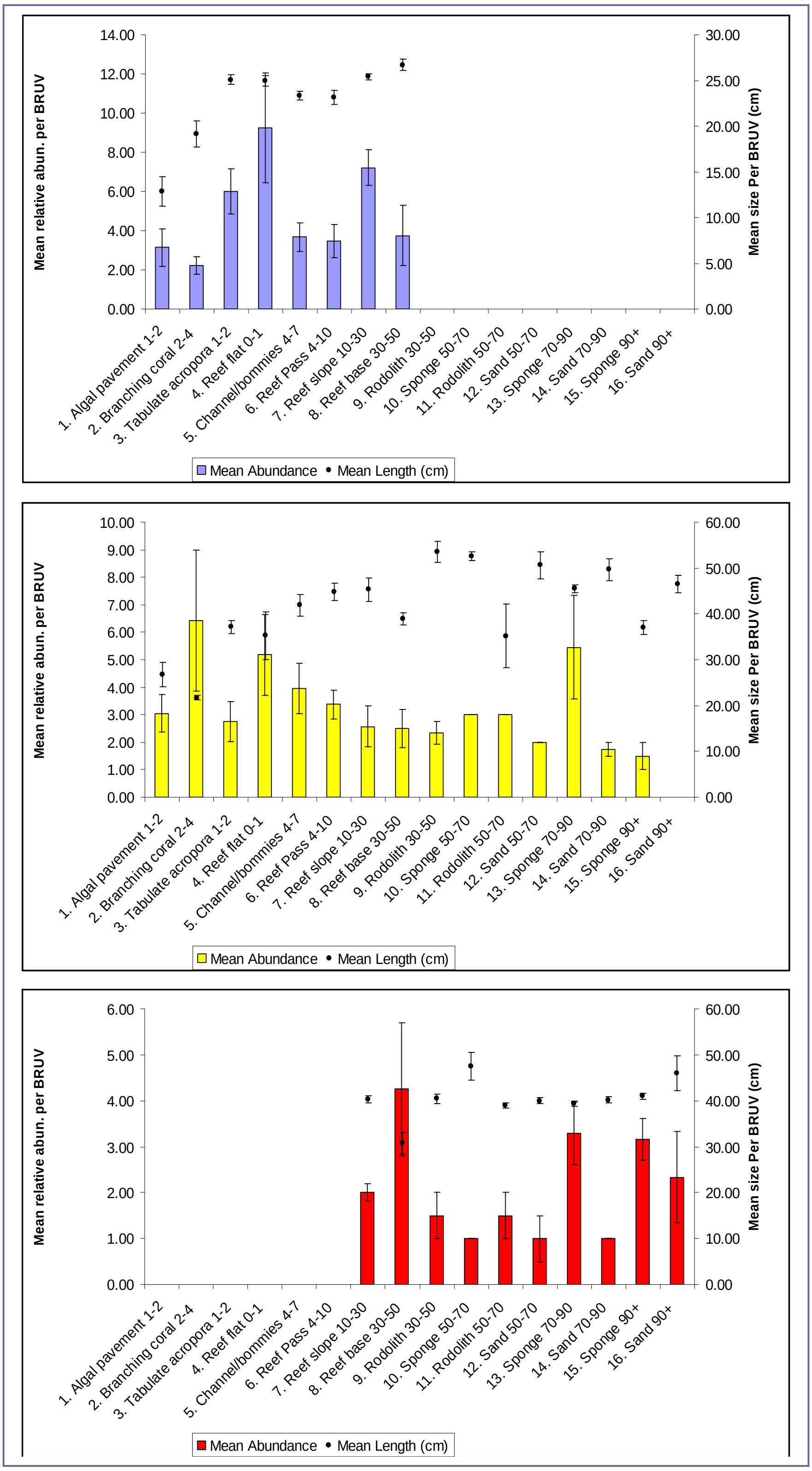
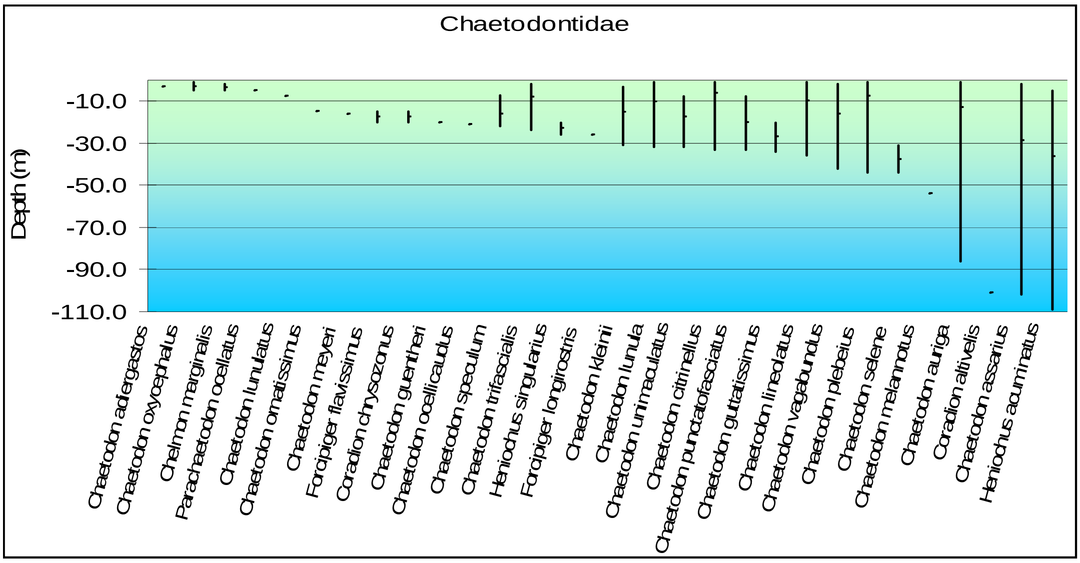
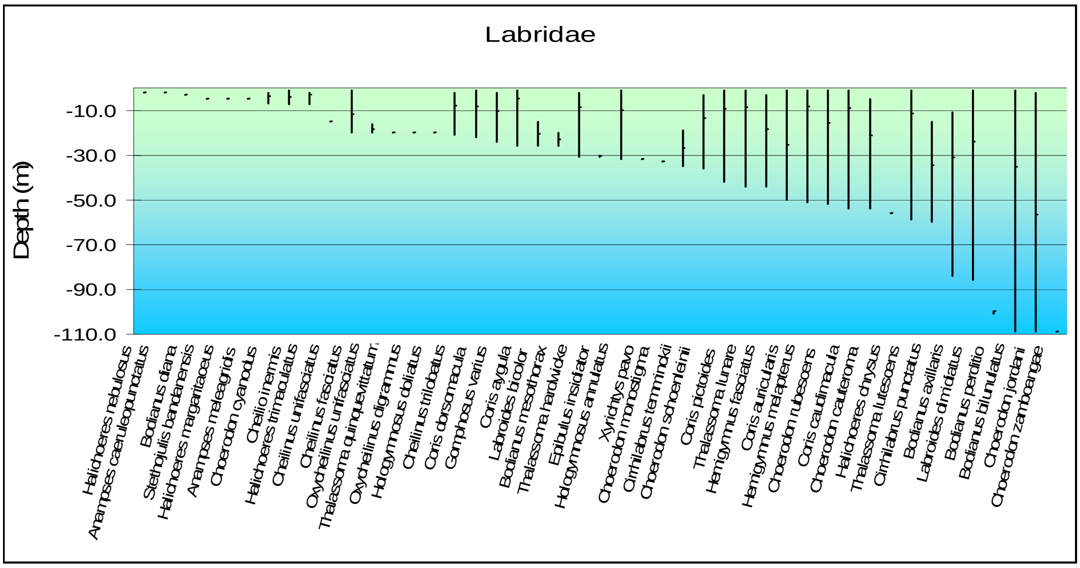


Figure 6. Size class and abundance distribution of a) *Lethrinus atkinsoni*, b) *L. nebulosus* and c) *L. miniatus*.

a)


Chaetodontidae
Depth (m)
-10.0
-30.0
-50.0
-70.0
-90.0
-110.0
Chaetodon adergastos
Chaetodon oxycephalus
Chelmon marginalis
Parachaetodon ocellatus
Chaetodon lunulatus
Chaetodon ornatissimus
Chaetodon meyeri
Forcipiger flavissimus
Coradion chrysozonus
Chaetodon guentheri
Chaetodon ocellicaudus
Chaetodon speculum
Chaetodon trifascialis
Heniochus singularius
Forcipiger longirostris
Chaetodon kleinii
Chaetodon lunula
Chaetodon unimaculatus
Chaetodon citrinellus
Chaetodon punctatofasciatus
Chaetodon guttatissimus
Chaetodon lineolatus
Chaetodon vagabundus
Chaetodon plebeius
Chaetodon selene
Chaetodon melannotus
Chaetodon auriga
Coradion altivelis
Chaetodon assarius
Heniochus acuminatus

b)


Labridae
Depth (m)
-10.0
-30.0
-50.0
-70.0
-90.0
-110.0
Halichoeres nebulosus
Anampses caeruleopunctatus
Bodianus diana
Stethojulis bandanensis
Halichoeres margaritaceus
Anampses meleagrides
Choerodon cyanodus
Cheilio inermis
Halichoeres trimaculatus
Cheilinus unifasciatus
Cheilinus fasciatus
Oxycheilinus unifasciatus
Thalassoma quinquevittatum
Oxycheilinus digrammus
Hologymnosus doliatus
Cheilinus trilobatus
Coris dorsomacula
Gomphosus varius
Coris aygula
Labroides bicolor
Bodianus mesothorax
Thalassoma hardwicke
Epibulus insidiator
Hologymnosus annulatus
Xyrichtys pavo
Choerodon monostigma
Cirrhilabrus temminckii
Choerodon schoenleinii
Coris pictoides
Thalassoma lunare
Hemigymnus fasciatus
Coris auricularis
Hemigymnus melapterus
Choerodon rubescens
Coris caudimacula
Choerodon cauteroma
Halichoeres chrysus
Thalassoma lutescens
Cirrhilabrus punctatus
Bodianus axillaris
Labroides dimidiatus
Bodianus perditio
Bodianus bilunulatus
Choerodon jordani
Choerodon zamboangae

c)

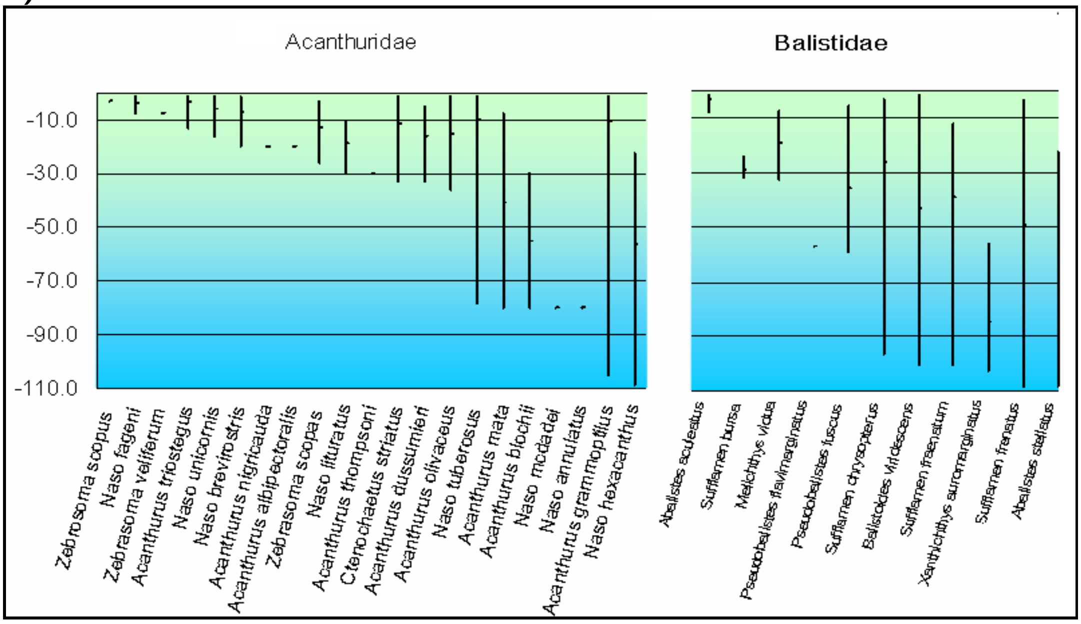


Figure 7. (a), (b), (c) examples of depth ranges and extensions in demersal reef fish families.

Discussion

We have found distinctive fish assemblages and fish size frequency partitioning strongly correlated with different habitat/depth categories. Although the diversity of species decreases with increasing water depth, the average length of fish increases across the Ningaloo Reef shelf. Fish assemblages associated with deepwater habitats have biomass concentrated in upper trophic levels, while inshore and reef slope sites have high diversity with an abundance of rare species and low average body size. A number of families contribute significantly to this trend with large bodied individuals dominating offshore habitats including Lethrinids, Lutjanids, Carangids and Serranids.

Within these families different species exhibit significant ontogenetic habitat shifts, for example small spangled emperor (*Lethrinus nebulosus)* less than 15cm in fork length were restricted to shallow branching acropora and inshore algal reefs, while larger individuals were associated with deeper water habitats found across the shelf. *L. atkinsoni* and *L. miniatus* display similar size frequency distributions. Ontogenetic habitat shifts were characteristic of many other recreationally targeted species including red emperor (*Lutjanus sebae*), red throat emperor (*Lethrinus miniatus*), goldband snapper (*Pristipomoides multidens*) and rankin cod (*Epinephelus multinotatus*).

Depth range extensions for many non-target species have also been found, with a number of butterfly fish (*Chaetodontidae*), parrot fish (*Scaridae*) and wrasse (*Labridae*) found in water up to 100m deep, away from the shallow phototrophic coral and algae habitats they are usually associated with. This data demonstrates greater species habitat versatility than was previously thought for many of these species, important in the context of potential responses to shallow water impacts.

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CHAPTER 6
GIS Data Management

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Summary

The ESRI™ suite of Geographical Information System (GIS) software ArcGIS™ is employed at AIMS as the preferred spatial data management system. AIMS utilises the add-on component Arc Spatial Data Engine (ArcSDE™) to provide a multi-user database environment incorporating the ORACLE™ database management system (DBMS). The ArcGIS software also interfaces directly with Microsoft Access™ Database (Access) format. The data collected as part of this study will be stored in the first instance in Access allowing a structured and relational storage system with the added advantage of ready spatial representation. This format is also widely used and is portable, allowing easy packaging of the data and associated maps etc for individual stakeholders. This will also assure secure access to the data until such time as this is no longer required. In the future, the data can be readily integrated into an enterprise database system such as the AIMS ORACLE/ArcSDE environment, which will allow extra functionality such as dynamic publication of data and maps to the Web (Figure 1).

Base spatial datasets have been provided primarily through the Western Australian Department of Environment and Conservation (DEC). These include high resolution aerial mosaics, marine and shoreline habitat information, coastal outlines and marine fauna observations. Multibeam surveys conducted by FUGRO have been included as both point and raster (gridded) GIS datasets. The GIS layers for the data collected in April – May 2006 are described below:

- Demersal Fish Assemblages Surveys using BRUVS – ArcGIS point shape file created with attributes including date, time and operational code for each camera deployment. Video samples from each deployment have also been added as an attribute to utilize the hyperlink functionality of ArcMap (the mapping component of ArcGIS). This allows the user to "click" on the location and launch the associated files application.
- Towed Video Surveys – ArcGIS point shape file created showing start and end points for each tow as well as an ArcGIS line shape file created showing the track. Attributes for each include date, time and operational codes for each tow. As for the BRUVS data, video files will be linked via an attribute and thus viewable from the ArcMap environment.
- Benthic Sled – ArcGIS point and line shape files showing the start/end point for each tow and tracks respectively. Still images from the samples acquired will be attached using the hyperlink technique.

- Sediment Grabs – ArcGIS point shape file created showing locations of each grab. Attributes include date, time and operational code for each grab.

Analysis data from each of the surveys can be attached via relational joins from their associated tables in the Access database. Alternatively, new layers with attributes that include the analysis data can be created.

Data can be exported from ArcMap™ to create Google Earth™ kml/kmz files. These files allow access to the data for non-GIS users. Additionally, a web-based system for viewing the data is being created to provide more access for non-GIS users.

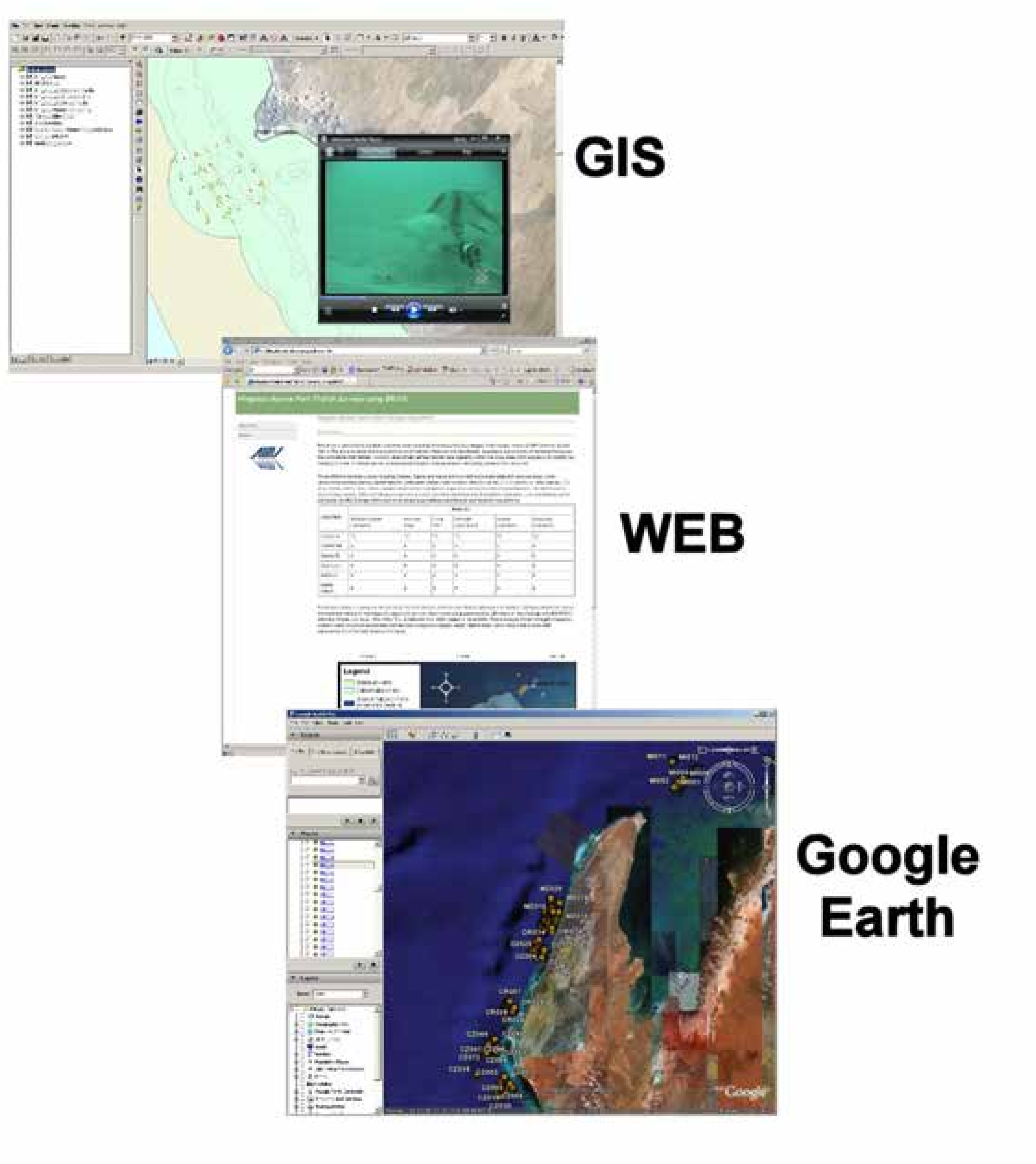

Figure 1. Different visual formats some of the data will take in the final GIS database.

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APPENDICES

Appendix 1: Sediment Data

Appendix 1.1: Sediment grab survey data

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4010	Grab	Max Rees	22/04/06	16:27	G002	Osprey Ref	-22.1727	113.8353	60.8
CF4010	Grab	Max Rees	22/04/06	18:10	G003	Osprey Ref	-22.1748	113.8038	80.2
CF4010	Grab	Max Rees	25/04/06	9:57	G011	Osprey SZ	-22.2713	113.7955	58.4
CF4010	Grab	Max Rees	25/04/06	10:11	G012	Osprey SZ	-22.2842	113.7893	57.4
CF4010	Grab	Max Rees	25/04/06	10:22	G013	Osprey SZ	-22.2935	113.7836	56.2
CF4010	Grab	Max Rees	25/05/06	16:12	G014	Osprey SZ	-22.2655	113.784	75.2
CF4010	Grab	Max Rees	25/04/06	16:25	G015	Osprey SZ	-22.2747	113.7797	77.2
CF4010	Grab	Max Rees	25/04/06	16:39	G016	Osprey SZ	-22.286	113.7742	74.2
CF4010	Grab	Max Rees	25/04/06	16:53	G017	Osprey SZ	-22.2946	113.7677	76.7
CF4010	Grab	Max Rees	26/04/06	13:09	G018	Osprey SZ	-22.2563	113.7619	100.3
CF4010	Grab	Max Rees	26/04/06	13:35	G019	Osprey SZ	-22.2679	113.7561	103.5
CF4010	Grab	Max Rees	26/04/06	14:45	G020	Seaward Osprey SZ	-22.2444	113.7658	102
CF4010	Grab	Max Rees	27/04/06	11:20	G022	Osprey SZ	-22.2698	113.7658	92.6
CF4010	Grab	Max Rees	27/04/06	11:43	G023	Osprey SZ	-22.2599	113.7722	91.6
CF4010	Grab	Max Rees	27/04/06	14:04	G024	Osprey SZ	-22.2869	113.7446	102.2
CF4010	Grab	Max Rees	27/04/06	14:18	G025	Osprey SZ	-22.2774	113.7516	102.5
CF4010	Grab	Max Rees	27/04/06	14:38	G026	Osprey SZ	-22.2901	113.755	90.1
CF4010	Grab	Max Rees	28/04/06	12:03	G027	Osprey Ref	-22.1638	113.8063	86.5
CF4010	Grab	Max Rees	28/04/06	12:20	G028	Osprey Ref	-22.1862	113.7994	85.5
CF4010	Grab	Max Rees	28/04/06	14:27	G029	Osprey Ref	-22.2014	113.7948	82.6
CF4010	Grab	Max Rees	28/04/06	14:44	G030	Osprey Ref	-22.2121	113.7902	82.8
CF4010	Grab	Max Rees	28/04/06	16:33	G031	Osprey Ref	-22.1906	113.8273	60.1
CF4010	Grab	Max Rees	28/04/07	16:47	G032	Osprey Ref	-22.1786	113.8334	57.3
CF4010	Grab	Max Rees	28/04/07	16:55	G033	Osprey Ref	-22.1794	113.8378	42.9
CF4010	Grab	Max Rees	29/04/06	10:52	G034	Seaward Osprey Ref	-22.1631	113.7964	102.5
CF4010	Grab	Max Rees	29/04/06	11:23	G035	Osprey Ref	-22.187	113.7876	101.4
CF4010	Grab	Max Rees	29/04/06	15:49	G036	Osprey Ref	-22.1888	113.8118	71.9
CF4010	Grab	Max Rees	29/04/06	16:01	G037	Osprey Ref	-22.2026	113.8077	70.2
CF4010	Grab	Max Rees	29/04/06	16:11	G038	Osprey Ref	-22.2146	113.8051	71.2
CF4010	Grab	Max Rees	30/04/06	11:33	G039	Osprey Ref	-22.211	113.781	103.3

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4010	Grab	Max Rees	30/04/06	12:13	G040	Osprey Ref	-22.1748	113.7929	100.1
CF4010	Grab	Max Rees	30/04/06	12:42	G041	Osprey Ref	-22.2009	113.7845	102.2
CF4010	Grab	Max Rees	1/5/2006	10:58	G042	Osprey Ref	-22.2164	113.8245	44.6
CF4010	Grab	Max Rees	1/5/2006	11:06	G043	Osprey Ref	-22.2155	113.8185	62.2
CF4010	Grab	Max Rees	1/5/2006	11:20	G044	Osprey Ref	-22.2042	113.8273	45.5
CF4010	Grab	Max Rees	1/5/2006	11:32	G045	Osprey Ref	-22.1908	113.8311	45.9
CF4010	Grab	Max Rees	1/5/2006	15:55	G046	Osprey Ref	-22.2038	113.8229	65.1
CF4010	Grab	Max Rees	1/5/2006	16:23	G047	Osprey Ref	-22.1764	113.8159	73.5
CF4010	Grab	Max Rees	1/5/2006	16:38	G048	Osprey Ref	-22.1646	113.819	74.1
CF4010	Grab	Max Rees	2/5/2006	12:27	G050	Osprey Ref	-22.1671	113.8379	60.9
CF4010	Grab	Max Rees	2/5/2006	13:56	G051	Mandu SZ	-22.1133	113.859	59.7
CF4010	Grab	Max Rees	2/5/2006	14:08	G052	Mandu SZ	-22.1253	113.8556	58.2
CF4010	Grab	Max Rees	2/5/2006	15:37	G053	Mandu SZ	-22.1268	113.8614	46.4
CF4010	Grab	Max Rees	2/5/2006	15:49	G054	Mandu SZ	-22.1372	113.8507	58
CF4010	Grab	Max Rees	2/5/2006	15:59	G055	Mandu SZ	-22.1376	113.8552	47.9
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CF4010	Grab	Max Rees	3/5/2006	12:13	G057	Mandu SZ	-22.1188	113.8176	86.2
CF4011	Grab	Andrew Heyward	6/5/2006	11:48	G058	Mandu SZ	-22.1168	113.8635	45.1
CF4011	Grab	Andrew Heyward	7/5/2006	11:49	G060	Cloates SZ (Mid)	-22.7622	113.6752	38.8
CF4011	Grab	Andrew Heyward	7/5/2006	12:01	G061	Cloates SZ (Mid)	-22.7498	113.6696	27
CF4011	Grab	Andrew Heyward	7/5/2006	12:14	G062	Cloates SZ (Mid)	-22.7357	113.6588	28.4
CF4011	Grab	Andrew Heyward	7/5/2006	4:53	G065	Cloates SZ (Mid)	-22.7724	113.6465	37.5
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CF4011	Grab	Andrew Heyward	8/5/2006	9:03	G070	Cloates SZ (Mid)	-22.7484	113.6253	37
CF4011	Grab	Andrew Heyward	8/5/2006	14:28	G071	Cloates SZ (Mid)	-22.7917	113.6434	63.1
CF4011	Grab	Andrew Heyward	8/5/2006	14:45	G072	Cloates SZ (Mid)	-22.7811	113.6373	60.1
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CF4011	Grab	Andrew Heyward	9/5/2006	9:07	G075	Cloates SZ (Mid)	-22.7522	113.6172	60.7
CF4011	Grab	Andrew Heyward	9/5/2006	9:20	G076	Cloates SZ (Mid)	-22.7646	113.6243	60.7
CF4011	Grab	Andrew Heyward	9/5/2006	10:42	G078	Cloates SZ (Mid)	-22.7843	113.6196	65.7
CF4011	Grab	Andrew Heyward	9/5/2006	10:58	G079	Cloates SZ (Mid)	-22.7697	113.6122	66.5
CF4011	Grab	Andrew Heyward	9/5/2006	11:15	G080	Cloates SZ (Mid)	-22.7574	113.6048	66
CF4011	Grab	Andrew Heyward	9/5/2006	13:05	G081	Cloates SZ (Mid)	-22.7965	113.6278	65

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4011	Grab	Andrew Heyward	10/5/2006	9:44	G083	Cloates SZ (North)	-22.586	113.5845	130
CF4011	Grab	Andrew Heyward	10/5/2006	12:23	G086	Cloates SZ (North)	-22.6118	113.5833	102.6
CF4011	Grab	Andrew Heyward	10/5/2006	16:20	G088	Cloates SZ (North)	-22.588	113.5962	99
CF4011	Grab	Andrew Heyward	11/5/2006	9:51	G089	Cloates SZ (North)	-22.6144	113.6003	72
CF4011	Grab	Andrew Heyward	11/5/2006	10:07	G090	Cloates SZ (North)	-22.602	113.604	77.7
CF4011	Grab	Andrew Heyward	11/5/2006	10:19	G091	Cloates SZ (North)	-22.588	113.6104	76
CF4011	Grab	Andrew Heyward	11/5/2006	13:19	G092	Cloates SZ (North)	-22.6382	113.5729	94.1
CF4011	Grab	Andrew Heyward	11/5/2006	13:34	G093	Cloates SZ (North)	-22.6405	113.5857	74.6
CF4011	Grab	Andrew Heyward	11/5/2006	13:47	G094	Cloates SZ (North)	-22.6274	113.5932	73
CF4011	Grab	Andrew Heyward	12/5/2006	14:28	G095	Cloates SZ (North)	-22.6152	113.6139	36.5
CF4011	Grab	Andrew Heyward	12/5/2006	14:51	G096	Cloates SZ (North)	-22.614	113.607	57.4
CF4011	Grab	Andrew Heyward	12/5/2006	15:05	G097	Cloates SZ (North)	-22.6282	113.6029	52.8
CF4011	Grab	Andrew Heyward	12/5/2006	16:48	G099	Cloates SZ (North)	-22.6417	113.6081	36
CF4011	Grab	Andrew Heyward	12/5/2006	16:58	G100	Cloates SZ (North)	-22.64	113.5971	56
CF4011	Grab	Andrew Heyward	13/05/06	7:54	G101	Cloates SZ (North)	-22.5905	113.6275	35
CF4011	Grab	Andrew Heyward	13/05/06	8:28	G102	Cloates SZ (North)	-22.5904	113.6196	55
CF4011	Grab	Andrew Heyward	13/05/06	8:39	G103	Cloates SZ (North)	-22.6061	113.6175	37.8
CF4011	Grab	Andrew Heyward	13/05/06	8:46	G104	Cloates SZ (North)	-22.6037	113.6132	55.7
CF4011	Grab	Andrew Heyward	13/05/06	13:22	G107	Cloates SZ (Mid)	-22.7268	113.6365	34.7
CF4011	Grab	Andrew Heyward	13/05/06	13:56	G109	Cloates SZ (Mid)	-22.75	113.6577	35
CF4011	Grab	Andrew Heyward	13/05/06	14:11	G110	Cloates SZ (Mid)	-22.7673	113.6673	33
CF4011	Grab	Andrew Heyward	13/05/06	14:27	G111	Cloates SZ (Mid)	-22.7792	113.6749	28.9
CF4011	Grab	Andrew Heyward	13/05/06	15:38	G112	Cloates SZ (Mid)	-22.7413	113.5964	64.4
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CF4011	Grab	Andrew Heyward	14/05/06	11:21	G114	Cloates Ref	-22.4524	113.6592	104
CF4011	Grab	Andrew Heyward	14/05/06	11:37	G115	Cloates Ref	-22.4642	113.6548	103
CF4011	Grab	Andrew Heyward	14/05/06	13:50	G116	Cloates Ref	-22.4792	113.6473	102
CF4011	Grab	Andrew Heyward	14/05/06	14:02	G117	Cloates Ref	-22.4915	113.6407	98.4
CF4011	Grab	Andrew Heyward	15/05/06	10:25	G118	Cloates Ref	-22.5115	113.6512	56
CF4011	Grab	Andrew Heyward	15/05/06	10:39	G119	Cloates Ref	-22.5071	113.6398	80
CF4011	Grab	Andrew Heyward	15/05/06	12:06	G120	Cloates Ref	-22.4703	113.6719	58.4
CF4011	Grab	Andrew Heyward	15/05/06	12:18	G121	Cloates Ref	-22.4672	113.6622	80
CF4011	Grab	Andrew Heyward	15/05/06	14:09	G122	Cloates Ref	-22.4824	113.6542	75.7
CF4011	Grab	Andrew Heyward	15/05/06	15:02	G123	Cloates Ref	-22.4929	113.6465	82
CF4011	Grab	Andrew Heyward	15/05/06	15:16	G124	Cloates Ref	-22.4946	113.6582	58

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4011	Grab	Andrew Heyward	15/05/06	15:28	G125	Cloates Ref	-22.4843	113.6645	53
CF4011	Grab	Andrew Heyward	15/05/06	15:46	G126	Cloates Ref	-22.4575	113.6805	62
CF4011	Grab	Andrew Heyward	15/05/06	15:58	G127	Cloates Ref	-22.4548	113.668	82
CF4011	Grab	Andrew Heyward	15/05/06	16:23	G128	Cloates Ref	-22.4615	113.696	39
CF4011	Grab	Andrew Heyward	16/05/06	9:41	G129	Cloates Ref	-22.4603	113.6938	43
CF4011	Grab	Andrew Heyward	16/05/06	9:56	G130	Cloates Ref	-22.4625	113.6972	29.1
CF4011	Grab	Andrew Heyward	16/05/06	11:56	G131	Cloates Ref	-22.4979	113.662	39.7
CF4011	Grab	Andrew Heyward	16/05/06	12:14	G132	Cloates Ref	-22.5146	113.6537	41
CF4011	Grab	Andrew Heyward	16/05/06	12:20	G133	Cloates Ref	-22.4857	113.6673	45
CF4011	Grab	Andrew Heyward	17/05/06	7:30	G134	Norwegian Bay	-22.6104	113.6486	7
CF4011	Grab	Andrew Heyward	17/05/06	13:16	G135	Mandu SZ	-22.1461	113.8246	72
CF4011	Grab	Andrew Heyward	17/05/06	13:27	G136	Mandu SZ	-22.1344	113.8263	73.6
CF4011	Grab	Andrew Heyward	17/05/06	14:02	G137	Mandu SZ	-22.1088	113.8337	75
CF4011	Grab	Andrew Heyward	17/05/06	14:12	G138	Mandu SZ	-22.0984	113.8361	73.8
CF4011	Grab	Andrew Heyward	17/05/06	14:25	G139	Mandu SZ	-22.0968	113.824	80.7
CF4011	Grab	Andrew Heyward	17/05/06	17:37	G140	Mandu SZ	-22.1457	113.8122	82.7
CF4011	Grab	Andrew Heyward	17/05/06	17:46	G141	Seaward Mandu SZ	-22.1404	113.8008	101
CF4011	Grab	Andrew Heyward	17/05/06	19:31	G142	Seaward Mandu SZ	-22.1285	113.805	100.4
CF4011	Grab	Andrew Heyward	17/05/06	20:13	G143	Seaward Mandu SZ	-22.1146	113.807	100.4
CF4011	Grab	Andrew Heyward	17/05/06	20:52	G144	Seaward Mandu SZ	-22.102	113.8087	98
CF4011	Grab	Andrew Heyward	18/05/06	10:05	G145	Mandu SZ	-22.1059	113.8208	98
CF4011	Grab	Andrew Heyward	18/05/06	10:25	G146	Mandu SZ	-22.1334	113.8136	80
CF4011	Grab	Andrew Heyward	18/05/06	11:27	G147	Mandu SZ	-22.1214	113.8301	75
CF4011	Grab	Andrew Heyward	18/05/06	13:29	G149	Mandu SZ	-22.1503	113.8467	56
CF4011	Grab	Andrew Heyward	18/05/06	13:38	G150	Mandu SZ	-22.1496	113.8513	40
CF4011	Grab	Andrew Heyward	18/05/06	14:01	G152	Mandu SZ	-22.1232	113.8453	70
CF4011	Grab	Andrew Heyward	18/05/06	14:16	G153	Mandu SZ	-22.1112	113.8487	70
CF4011	Grab	Andrew Heyward	18/05/06	14:35	G154	Mandu SZ	-22.1022	113.8618	58.7
CF4011	Grab	Andrew Heyward	19/05/06	7:50	G156	Lighthouse SZ	-22.7988	114.1243	13
CF4011	Grab	Andrew Heyward	19/05/06	14:57	G157	Muiron Islands	-21.6664	114.2667	32
CF4011	Grab	Andrew Heyward	19/05/06	16:03	G158	Muiron Islands	-21.6274	114.3246	26.6
CF4011	Grab	Andrew Heyward	19/05/06	16:35	G159	Muiron Islands	-21.6098	114.3475	27.5
CF4011	Grab	Andrew Heyward	19/05/06	17:07	G160	Muiron Islands	-21.6099	114.3737	30
CF4011	Grab	Andrew Heyward	20/05/06	7:14	G161	Muiron Islands	-21.6219	114.3817	21.4
CF4011	Grab	Andrew Heyward	20/05/06	8:15	G162	Muiron Islands	-21.6611	114.3297	21

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4011	Grab	Andrew Heyward	20/05/06	9:15	G163	Muiron Islands	-21.6716	114.3164	19
CF4011	Grab	Andrew Heyward	20/05/06	9:35	G164	Muiron Islands	-21.6831	114.303	19.6
CF4011	Grab	Andrew Heyward	20/05/06	14:00	G165	Muiron Islands	-21.6095	114.2692	57
CF4011	Grab	Andrew Heyward	20/05/06	14:25	G166	Muiron Islands	-21.6025	114.2903	53
CF4011	Grab	Andrew Heyward	20/05/06	14:49	G167	Muiron Islands	-21.5918	114.3051	62
CF4011	Grab	Andrew Heyward	20/05/06	15:45	G169	Muiron Islands	-21.5932	114.3456	63
CF4313	Grab	Max Rees	19/04/07	9:17	G170	Coral Bay	-23.1615	113.7018	60
CF4313	Grab	Max Rees	19/04/07	10:12	G171	Coral Bay	-23.1615	113.7239	50.6
CF4313	Grab	Max Rees	19/04/07	10:45	G172	Coral Bay	-23.1593	113.7360	32
CF4313	Grab	Max Rees	19/04/07	11:41	G173	Coral Bay	-23.2076	113.7063	56.7
CF4313	Grab	Max Rees	19/04/07	11:55	G174	Coral Bay	-23.2088	113.7150	57
CF4313	Grab	Max Rees	19/04/07	14:11	G175	Coral Bay	-23.2006	113.7150	52.5
CF4313	Grab	Max Rees	19/04/07	14:24	G176	Coral Bay	-23.2055	113.7273	50.5
CF4313	Grab	Max Rees	19/04/07	14:49	G177	Coral Bay	-23.2023	113.7367	38
CF4313	Grab	Max Rees	19/04/07	15:16	G178	Coral Bay	-23.1963	113.7472	31
CF4313	Grab	Max Rees	19/04/07	16:25	G179	Coral Bay	-23.2541	113.7153	52
CF4313	Grab	Max Rees	19/04/07	16:38	G180	Coral Bay	-23.2497	113.7243	43.6
CF4313	Grab	Max Rees	19/04/07	17:06	G181	Coral Bay	-23.2474	113.7326	43.4
CF4313	Grab	Max Rees	19/04/07	17:34	G182	Coral Bay	-23.2452	113.7403	40
CF4313	Grab	Max Rees	19/04/07	17:43	G183	Coral Bay	-23.2434	113.7472	32.8
CF4313	Grab	Max Rees	20/04/07	6:48	G184	Carter Hill	-22.8216	113.6696	52
CF4313	Grab	Max Rees	20/04/07	7:19	G185	Carter Hill	-22.8178	113.6776	40
CF4313	Grab	Max Rees	20/04/07	7:43	G186	Carter Hill	-22.8125	113.6830	35
CF4313	Grab	Max Rees	20/04/07	8:43	G187	Carter Hill	-22.8541	113.7015	34
CF4313	Grab	Max Rees	20/04/07	9:05	G188	Carter Hill	-22.8573	113.6952	48
CF4313	Grab	Max Rees	20/04/07	9:30	G188b	Carter Hill	-22.8593	113.6860	53
CF4313	Grab	Max Rees	20/04/07	10:35	G189	Carter Hill	-22.8913	113.7338	32
CF4313	Grab	Max Rees	20/04/07	10:40	G190	Carter Hill	-22.8938	113.7282	36.2
CF4313	Grab	Max Rees	20/04/07	11:02	G191	Carter Hill	-22.8949	113.7171	48.5
CF4313	Grab	Max Rees	20/04/07	11:30	G192	Carter Hill	-22.8983	113.7108	57
CF4313	Grab	Max Rees	20/04/07	13:03	G193	Stanley Pool	-22.9438	113.7570	33
CF4313	Grab	Max Rees	21/04/07	7:36	G194	Warrola	-23.4859	113.7002	40
CF4313	Grab	Max Rees	21/04/07	7:46	G195	Warrola	-23.4884	113.7105	42
CF4313	Grab	Max Rees	21/04/07	7:35	G196	Warrola	-23.4906	113.7209	41
CF4313	Grab	Max Rees	21/04/07	8:08	G197	Warrola	-23.4932	113.7338	37

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4313	Grab	Max Rees	21/04/07	8:17	G198	Warrola	-23.4954	113.7465	28.9
CF4313	Grab	Max Rees	21/04/07	9:55	G199	Warrola	-23.4434	113.7229	45.5
CF4313	Grab	Max Rees	21/04/07	10:09	G200	Warrola	-23.4451	113.7400	40
CF4313	Grab	Max Rees	21/04/07	10:23	G201	Warrola	-23.4454	113.7589	33.8
CF4313	Grab	Max Rees	21/04/07	12:56	G202	Warrola	-23.5217	113.6668	45
CF4313	Grab	Max Rees	21/04/07	13:13	G203	Warrola	-23.5271	113.6815	42
CF4313	Grab	Max Rees	21/04/07	13:24	G204	Warrola	-23.5337	113.6971	34
CF4313	Grab	Max Rees	21/04/07	14:23	G205	Warrola	-23.5375	113.6338	46
CF4313	Grab	Max Rees	21/04/07	14:48	G206	Warrola	-23.5517	113.6432	44
CF4313	Grab	Max Rees	21/04/07	15:13	G207	Warrola	-23.5634	113.6511	29.7
CF4313	Grab	Max Rees	21/04/07	16:16	G208	Warrola	-23.5872	113.6133	36
CF4313	Grab	Max Rees	21/04/07	16:48	G209	Warrola	-23.5762	113.6007	44
CF4313	Grab	Max Rees	21/04/07	17:13	G210	Warrola	-23.5647	113.5921	47
CF4313	Grab	Max Rees	22/04/07	6:54	G211	Farquhar	-23.6278	113.5894	31.1
CF4313	Grab	Max Rees	22/04/07	7:20	G212	Farquhar	-23.6215	113.5766	41
CF4313	Grab	Max Rees	22/04/07	7:40	G213	Farquhar	-23.6138	113.5620	44
CF4313	Grab	Max Rees	22/04/07	8:36	G214	Farquhar	-23.6695	113.5741	32
CF4313	Grab	Max Rees	22/04/07	8:59	G215	Farquhar	-23.6639	113.5558	43
CF4313	Grab	Max Rees	22/04/07	9:21	G216	Farquhar	-23.6567	113.5407	42
CF4313	Grab	Max Rees	22/04/07	10:11	G217	Farquhar	-23.7148	113.5551	36
CF4313	Grab	Max Rees	22/04/07	10:31	G218	Farquhar	-23.7084	113.5396	39
CF4313	Grab	Max Rees	22/04/07	10:50	G219	Farquhar	-23.7018	113.5262	41
CF4313	Grab	Max Rees	22/04/07	11:40	G220	Gnarraloo	-23.7540	113.5246	36
CF4313	Grab	Max Rees	22/04/07	12:00	G221	Gnarraloo	-23.7440	113.5069	40
CF4313	Grab	Max Rees	22/04/07	12:20	G222	Gnarraloo	-23.7346	113.4917	41
CF4313	Grab	Max Rees	22/04/07	13:25	G223	Gnarraloo	-23.7941	113.5036	34
CF4313	Grab	Max Rees	22/04/07	13:46	G224	Gnarraloo	-23.7891	113.4825	34
CF4313	Grab	Max Rees	22/04/07	14:08	G225	Gnarraloo	-23.7866	113.4697	39
CF4313	Grab	Max Rees	22/04/07	14:59	G226	Gnarraloo	-23.8410	113.4918	35
CF4313	Grab	Max Rees	22/04/07	15:16	G227	Gnarraloo	-23.8351	113.4763	36
CF4313	Grab	Max Rees	22/04/07	15:52	G228	Gnarraloo	-23.8300	113.4613	35
CF4313	Grab	Max Rees	23/04/07	11:24	G229	Red Bluff	-24.0154	113.4351	35
CF4313	Grab	Max Rees	23/04/07	11:52	G230	Red Bluff	-24.0139	113.4231	45
CF4313	Grab	Max Rees	23/04/07	12:12	G231	Red Bluff	-24.0134	113.4133	50
CF4313	Grab	Max Rees	23/04/07	12:30	G232	Red Bluff	-24.0121	113.3883	53

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4313	Grab	Max Rees	23/04/07	13:44	G233	Red Bluff	-23.9816	113.4465	38
CF4313	Grab	Max Rees	23/04/07	14:00	G234	Red Bluff	-23.9813	113.4365	39
CF4313	Grab	Max Rees	23/04/07	14:30	G235	Red Bluff	-23.9802	113.4221	41
CF4313	Grab	Max Rees	23/04/07	14:47	G236	Red Bluff	-23.9808	113.4088	50
CF4313	Grab	Max Rees	23/04/07	15:37	G237	Red Bluff	-23.9508	113.4525	35
CF4313	Grab	Max Rees	23/04/07	16:01	G238	Red Bluff	-23.9509	113.4403	38
CF4313	Grab	Max Rees	23/04/07	16:18	G239	Red Bluff	-23.9515	113.4291	34
CF4313	Grab	Max Rees	23/04/07	16:42	G240	Red Bluff	-23.9512	113.4150	43
CF4313	Grab	Max Rees	24/04/07	7:14	G241	Red Bluff	-23.9188	113.4466	36.9
CF4313	Grab	Max Rees	24/04/07	7:30	G242	Red Bluff	-23.9182	113.4327	35.9
CF4313	Grab	Max Rees	24/04/07	7:42	G243	Red Bluff	-23.9176	113.4241	33
CF4313	Grab	Max Rees	24/04/07	8:55	G244	Red Bluff	-23.9165	113.4131	40
CF4313	Grab	Max Rees	24/04/07	9:13	G245	Gnarraloo	-23.8812	113.4619	34
CF4313	Grab	Max Rees	24/04/07	9:30	G246	Gnarraloo	-23.8750	113.4501	35
CF4313	Grab	Max Rees	24/04/07	9:40	G247	Gnarraloo	-23.8689	113.4380	33
CF4313	Grab	Max Rees	24/04/07	9:57	G248	Gnarraloo	-23.8596	113.4248	37
CF4313	Grab	Max Rees	24/04/07	10:03	G249	Gnarraloo	-23.8647	113.4301	36
CF4313	Grab	Max Rees	24/04/07	10:32	G250	Gnarraloo	-23.8794	113.4028	42
CF4313	Grab	Max Rees	24/04/07	11:07	G251	Gnarraloo	-23.8818	113.4194	34
CF4313	Grab	Max Rees	25/04/07	11:30	G252	Coral Bay	-23.1058	113.7215	40.2
CF4313	Grab	Max Rees	25/04/07	11:35	G253	Coral Bay	-23.1081	113.7046	63
CF4313	Grab	Max Rees	25/04/07	12:07	G254	Coral Bay	-23.1099	113.6913	67
CF4313	Grab	Max Rees	25/04/07	12:50	G255	Pelican Point	-23.2981	113.7574	31.8
CF4313	Grab	Max Rees	25/04/07	14:08	G256	Pelican Point	-23.2986	113.7394	46.5
CF4313	Grab	Max Rees	25/04/07	14:28	G257	Pelican Point	-23.2987	113.7236	48
CF4313	Grab	Max Rees	25/04/07	15:26	G258	Pelican Point	-23.3458	113.7645	34
CF4313	Grab	Max Rees	25/04/07	15:47	G259	Pelican Point	-23.3472	113.7403	44
CF4313	Grab	Max Rees	25/04/07	16:05	G260	Pelican Point	-23.3482	113.7209	46.7
CF4313	Grab	Max Rees	25/04/07	16:58	G261	Pelican Point	-23.3985	113.7562	36
CF4313	Grab	Max Rees	25/04/07	17:18	G262	Pelican Point	-23.3986	113.7385	45.5
CF4313	Grab	Max Rees	25/04/07	17:35	G263	Pelican Point	-23.3991	113.7222	44.4
CF4313	Grab	Max Rees	27/04/07	13:30	G264	Coral Bay	-23.0110	113.7561	55.2
CF4313	Grab	Max Rees	27/04/07	13:54	G265	Coral Bay	-23.0104	113.7373	42
CF4313	Grab	Max Rees	27/04/07	14:19	G266	Coral Bay	-23.0103	113.7168	34
CF4313	Grab	Max Rees	27/04/07	15:10	G267	Coral Bay	-23.0119	113.7257	34.2

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4313	Grab	Max Rees	27/04/07	15:27	G268	Coral Bay	-23.0535	113.7313	41.4
CF4313	Grab	Max Rees	27/04/07	15:45	G269	Coral Bay	-23.0467	113.7048	59
CF4313	Grab	Max Rees	27/04/07	16:32	G270	Coral Bay	-22.9437	113.7235	40
CF4313	Grab	Max Rees	27/04/07	16:44	G271	Coral Bay	-22.9453	113.7387	38
CF4313	Grab	Max Rees	27/04/07	16:54	G272	Coral Bay	-22.9440	113.7474	36
CF4313	Grab	Max Rees	28/04/07	7:33	G273	Point Cloates	-22.6846	113.6140	38
CF4313	Grab	Max Rees	28/04/07	7:53	G274	Point Cloates	-22.6885	113.6016	32
CF4313	Grab	Max Rees	28/04/07	8:08	G275	Point Cloates	-22.6943	113.5899	56
CF4313	Grab	Max Rees	28/04/07	9:41	G276	Norwegian Bay	-22.5529	113.6400	46
CF4313	Grab	Max Rees	28/04/07	10:02	G277	Norwegian Bay	-22.5464	113.6194	82
CF4313	Grab	Max Rees	28/04/07	10:27	G278	Norwegian Bay	-22.5432	113.6092	115
CF4313	Grab	Max Rees	28/04/07	11:56	G279	Sandy Point	-22.4312	113.7016	48
CF4313	Grab	Max Rees	28/04/07	12:17	G280	Sandy Point	-22.4240	113.6867	79
CF4313	Grab	Max Rees	28/04/07	12:49	G281	Sandy Point	-22.4172	113.6729	127
CF4313	Grab	Max Rees	28/04/07	14:28	G282	Sandy Point	-22.3885	113.7276	42
CF4313	Grab	Max Rees	28/04/07	14:51	G283	Sandy Point	-22.3816	113.7063	83
CF4313	Grab	Max Rees	28/04/07	15:20	G284	Sandy Point	-22.3764	113.6930	123
CF4313	Grab	Max Rees	28/04/07	16:31	G285	Sandy Point	-22.3482	113.7437	53
CF4313	Grab	Max Rees	28/04/07	16:48	G286	Sandy Point	-22.3436	113.7319	72
CF4313	Grab	Max Rees	28/04/07	17:13	G287	Sandy Point	-22.3400	113.7205	96
CF4313	Grab	Max Rees	29/04/07	7:53	G288	Tantabiddi	-21.8760	113.9536	36
CF4313	Grab	Max Rees	29/04/07	8:20	G289	Tantabiddi	-21.8584	113.9372	74
CF4313	Grab	Max Rees	29/04/07	8:43	G290	Tantabiddi	-21.8504	113.9228	91
CF4313	Grab	Max Rees	29/04/07	9:41	G291	Tantabiddi	-21.8419	113.9820	35
CF4313	Grab	Max Rees	29/04/07	10:07	G292	Tantabiddi	-21.8283	113.9716	65
CF4313	Grab	Max Rees	29/04/07	10:26	G293	Tantabiddi	-21.8189	113.9632	77
CF4313	Grab	Max Rees	29/04/07	11:19	G294	Vlamingh Head	-21.8166	114.0200	26
CF4313	Grab	Max Rees	29/04/07	11:39	G295	Vlamingh Head	-21.8039	114.0143	41
CF4313	Grab	Max Rees	29/04/07	12:00	G296	Vlamingh Head	-21.7959	114.0098	48
CF4313	Grab	Max Rees	29/04/07	12:59	G297	Vlamingh Head	-21.7900	114.0593	34
CF4313	Grab	Max Rees	29/04/07	13:13	G298	Vlamingh Head	-21.7791	114.0544	38
CF4313	Grab	Max Rees	29/04/07	13:32	G299	Vlamingh Head	-21.7692	114.0511	44
CF4313	Grab	Max Rees	29/04/07	14:21	G300	Vlamingh Head	-21.7844	114.1093	31
CF4313	Grab	Max Rees	29/04/07	14:39	G301	Vlamingh Head	-21.7697	114.1039	33
CF4313	Grab	Max Rees	29/04/07	14:56	G302	Vlamingh Head	-21.7566	114.0981	36

SURVEY	SAMPLING	CRUISE LEADER	DATE	TIME	GRAB ID	LOCATION	LATITUDE	LONGITUDE	DEPTH
CF4313	Grab	Max Rees	29/04/07	16:00	G303	Vlamingh Head	-21.7652	114.1497	28
CF4313	Grab	Max Rees	29/04/07	16:16	G304	Vlamingh Head	-21.7476	114.1495	23
CF4313	Grab	Max Rees	29/04/07	16:39	G305	Vlamingh Head	-21.7284	114.1490	38
CF4313	Grab	Max Rees	29/04/07	17:47	G306	Point Murat	-21.7421	114.1983	20.7
CF4313	Grab	Max Rees	29/04/07	18:10	G307	Point Murat	-21.7223	114.2135	24
CF4313	Grab	Max Rees	29/04/07	18:31	G308	Point Murat	-21.7060	114.2241	32
CF4313	Grab	Max Rees	29/04/07	19:30	G309	Point Murat	-21.7616	114.2214	20
CF4313	Grab	Max Rees	29/04/07	19:54	G310	Point Murat	-21.7449	114.2441	19
CF4313	Grab	Max Rees	29/04/07	20:14	G311	Point Murat	-21.7329	114.2624	21
CF4313	Grab	Max Rees	29/04/07	21:16	G312	Point Murat	-21.7914	114.2311	20
CF4313	Grab	Max Rees	29/04/07	21:38	G313	Point Murat	-21.7790	114.2542	21
CF4313	Grab	Max Rees	29/04/07	22:00	G314	Point Murat	-21.7667	114.2791	22
CF4313	Grab	Max Rees	29/04/07	22:26	G315	Point Murat	-21.8351	114.1982	20
CF4313	Grab	Max Rees	29/04/07	23:48	G316	Point Murat	-21.8314	114.2292	22
CF4313	Grab	Max Rees	30/04/07	0:13	G317	Point Murat	-21.8267	114.2617	21
CF4313	Grab	Max Rees	30/04/07	0:46	G318	Point Murat	-21.8730	114.2689	20
CF4313	Grab	Max Rees	30/04/07	1:15	G319	Point Murat	-21.8710	114.2250	21
CF4313	Grab	Max Rees	30/04/07	1:37	G320	Point Murat	-21.8709	114.1858	19
CF4314	Grab	Max Rees	4/5/2007	9:03	G321	Tantabiddi	-21.9212	113.9060	61
CF4314	Grab	Max Rees	4/5/2007	9:42	G322	Tantabiddi	-21.9079	113.8876	86
CF4314	Grab	Max Rees	4/5/2007	10:19	G323	Tantabiddi	-21.8962	113.8739	101
CF4314	Grab	Max Rees	4/5/2007	13:27	G324	Tantabiddi	-21.9618	113.9032	46
CF4314	Grab	Max Rees	4/5/2007	13:55	G325	Tantabiddi	-21.9585	113.8789	75
CF4314	Grab	Max Rees	4/5/2007	14:25	G326	Tantabiddi	-21.9555	113.8559	89
CF4314	Grab	Max Rees	5/5/2007	8:16	G327	T-Bone	-22.0901	113.8696	41.2
CF4314	Grab	Max Rees	5/5/2007	8:46	G328	T-Bone	-22.0844	113.8493	69
CF4314	Grab	Max Rees	5/5/2007	9:09	G329	T-Bone	-22.0786	113.8283	90
CF4314	Grab	Max Rees	5/5/2007	10:32	G330	T-Bone	-22.0477	113.8781	67
CF4314	Grab	Max Rees	5/5/2007	11:01	G331	T-Bone	-22.0446	113.8575	76
CF4314	Grab	Max Rees	5/5/2007	11:31	G332	T-Bone	-22.0398	113.8404	88
CF4314	Grab	Max Rees	5/5/2007	12:46	G333	T-Bone	-22.0023	113.8898	55
CF4314	Grab	Max Rees	5/5/2007	13:10	G334	T-Bone	-21.9997	113.8736	70
CF4314	Grab	Max Rees	5/5/2007	13:34	G335	T-Bone	-21.9965	113.8571	82

Appendix 1.2: Grain Size Statistics

Table 1. Grain Size scale for sediments from Udden (1914) and Wentworth (1922)

Grain Size		Descriptive term	
phi	mm		
		Gravel	
-1	2		Sand
		Very coarse	Sand
0	1		Sand
	microns	Coarse	Sand
1	00		Sand
		Medium	Sand
2	250		Sand
		Fine	Sand
3	125		Sand
		Very fine	Sand
4	63		Sand
		Mud	

Table 2. Statistical formulae used in the calculation of grain size parameters. (Blott and Pye 2001). f is the frequency in percent; m is the mid-point of each class interval in metric (m_m) or phi (m) units; P_x and $_x$ are grain diameters, in metric or phi units respectively, at the cumulative percentile value of x.

(a) Arithmetic Method of Moments

Mean	Standard Deviation	Skewness	Kurtosis
$\bar{x}_a = \frac{\Sigma f m_m}{100}$	$\sigma_a = \sqrt{\frac{\Sigma f (m_m - \bar{x}_a)^2}{100}}$	$Sk_a = \frac{\Sigma f (m_m - \bar{x}_a)^3}{100 \sigma_a{}^3}$	$K_a = \frac{\Sigma f (m_m - \bar{x}_a)^4}{100 \sigma_a{}^4}$

(b) Geometric Method of Moments

Mean	Standard Deviation	Skewness	Kurtosis
$\bar{x}_g = \exp \frac{\Sigma f \ln m_m}{100}$	$\sigma_g = \exp \sqrt{\frac{\Sigma f (\ln m_m - \ln \bar{x}_g)^2}{100}}$	$Sk_g = \frac{\Sigma f (\ln m_m - \ln \bar{x}_g)^3}{100 \ln \sigma_g{}^3}$	$K_g = \frac{\Sigma f (\ln m_m - \ln \bar{x}_g)^4}{100 \ln \sigma_g{}^4}$

Sorting (σ_g)		Skewness (Sk_g)		Kurtosis (K_g)	
Very well sorted	< 1.27	Very fine skewed	< $^{-}$1.30	Very platykurtic	< 1.70
Well sorted	1.27 – 1.41	Fine skewed	$^{-}$1.30 – $^{-}$0.43	Platykurtic	1.70 – 2.55
Moderately well sorted	1.41 – 1.62	Symmetrical	$^{-}$0.43 – $^{+}$0.43	Mesokurtic	2.55 – 3.70
Moderately sorted	1.62 – 2.00	Coarse skewed	$^{+}$0.43 – $^{+}$1.30	Leptokurtic	3.70 – 7.40
Poorly sorted	2.00 – 4.00	Very coarse skewed	> $^{+}$1.30	Very leptokurtic	> 7.40
Very poorly sorted	4.00 – 16.00				
Extremely poorly sorted	> 16.00				

(c) Logarithmic Method of Moments

Mean	Standard Deviation	Skewness	Kurtosis
$\bar{x}_\phi = \frac{\Sigma f m_\phi}{100}$	$\sigma_\phi = \sqrt{\frac{\Sigma f(m_\phi - \bar{x}_\phi)^2}{100}}$	$Sk_\phi = \frac{\Sigma f(m_\phi - \bar{x}_\phi)^3}{100\sigma_\phi^{\ 3}}$	$K_\phi = \frac{\Sigma f(m_\phi - \bar{x}_\phi)^4}{100\sigma_\phi^{\ 4}}$

Sorting (σ)		Skewness (Sk)		Kurtosis (K)	
Very well sorted	< 0.35	Very fine skewed	> $^{+}$1.30	Very platykurtic	< 1.70
Well sorted	0.35 – 0.50	Fine skewed	$^{+}$0.43 – $^{+}$1.30	Platykurtic	1.70 – 2.55
Moderately well sorted	0.50 – 0.70	Symmetrical	$^{-}$0.43 – $^{+}$0.43	Mesokurtic	2.55 – 3.70
Moderately sorted	0.70 – 1.00	Coarse skewed	$^{-}$0.43 – $^{-}$1.30	Leptokurtic	3.70 – 7.40
Poorly sorted	1.00 – 2.00	Very coarse skewed	< $^{-}$1.30	Very leptokurtic	> 7.40
Very poorly sorted	2.00 – 4.00				
Extremely poorly sorted	> 4.00				

(d) Logarithmic (Original) Folk and Ward (1957) Graphical Measures

Mean	Standard Deviation	Skewness	Kurtosis
$M_Z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$	$\sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$	$Sk_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$	$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$

Sorting (σ_I)		Skewness (Sk_I)		Kurtosis (K_G)	
Very well sorted	< 0.35	Very fine skewed	$^{+}$0.3 to $^{+}$1.0	Very platykurtic	< 0.67
Well sorted	0.35 – 0.50	Fine skewed	$^{+}$0.1 to $^{+}$0.3	Platykurtic	0.67 – 0.90
Moderately well sorted	0.50 – 0.70	Symmetrical	$^{+}$0.1 to $^{-}$0.1	Mesokurtic	0.90 – 1.11
Moderately sorted	0.70 – 1.00	Coarse skewed	$^{-}$0.1 to $^{-}$0.3	Leptokurtic	1.11 – 1.50
Poorly sorted	1.00 – 2.00	Very coarse skewed	$^{-}$0.3 to $^{-}$1.0	Very leptokurtic	1.50 – 3.00
Very poorly sorted	2.00 – 4.00			Extremely leptokurtic	> 3.00
Extremely poorly sorted	> 4.00				

(e) Geometric Folk and Ward (1957) Graphical Measures

Mean	Standard Deviation
$M_G = \exp\frac{\ln P_{16} + \ln P_{50} + \ln P_{84}}{3}$	$\sigma_G = \exp\left(\frac{\ln P_{16} - \ln P_{84}}{4} + \frac{\ln P_5 - \ln P_{95}}{6.6}\right)$

Skewness	Kurtosis
$Sk_G = \frac{\ln P_{16} + \ln P_{84} - 2(\ln P_{50})}{2(\ln P_{84} - \ln P_{16})} + \frac{\ln P_5 + \ln P_{95} - 2(\ln P_{50})}{2(\ln P_{25} - \ln P_5)}$	$K_G = \frac{\ln P_5 - \ln P_{95}}{2.44(\ln P_{25} - \ln P_{75})}$

Sorting (σ_G)		Skewness (Sk_G)		Kurtosis (K_G)	
Very well sorted	< 1.27	Very fine skewed	$^{-}$0.3 to $^{-}$1.0	Very platykurtic	< 0.67
Well sorted	1.27 – 1.41	Fine skewed	$^{-}$0.1 to $^{-}$0.3	Platykurtic	0.67 – 0.90
Moderately well sorted	1.41 – 1.62	Symmetrical	$^{-}$0.1 to $^{+}$0.1	Mesokurtic	0.90 – 1.11
Moderately sorted	1.62 – 2.00	Coarse skewed	$^{+}$0.1 to $^{+}$0.3	Leptokurtic	1.11 – 1.50
Poorly sorted	2.00 – 4.00	Very coarse skewed	$^{+}$0.3 to $^{+}$1.0	Very leptokurtic	1.50 – 3.00
Very poorly sorted	4.00 – 16.00			Extremely leptokurtic	> 3.00
Extremely poorly sorted	> 16.00				

Appendix 1.3. Grain size percentage values for gravel, sand and mud.

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G002	22	24.3	26.3	20.5	5.8	0.8	0.2
G003	52.4	20.1	12.6	7.7	3.6	2.2	1.4
G011	20.4	25.3	25.2	23.5	4.2	1	0.4
G012	32.1	26.2	20.9	12.3	4.9	3	0.5
G013	36.1	29.9	22.4	9.3	1.4	0.8	0.1
G014	1.6	2.8	7.5	15.1	44.4	24.7	3.9
G015	1.5	4.7	8.3	16.7	39.5	24.6	4.7
G016	3.4	4.7	9.6	19.7	30.3	26.1	6.2
G017	7.9	7.2	10.5	16	22.7	23	12.7
G018	11.4	9.1	13.7	15.3	12.2	18.8	19.4
G019	7.8	9	17.2	19	16.7	21.8	8.5
G020	7.4	7	13.4	17.7	18.6	25.8	10.1
G022	9	6.7	12.1	14.8	18.4	24.3	14.7
G023	4.4	5.6	11.2	15.5	23.9	27.1	12.2
G024	11.5	13.4	24.1	22.5	7.9	14.3	6.4
G025	14	14.3	20.4	33.4	15.6	2.1	0.1
G026	13.7	15.2	17.4	13.5	8	13.2	19.1
G027	18.2	12.4	12.2	15.4	19.3	17.6	4.8
G028	3	4.4	8.5	17.6	40.9	22.6	3
G029	10.1	10	18.5	20.2	23.5	15.3	2.4
G030	10.7	11.9	18.3	17.5	16.8	19.2	5.6
G031	18.7	22.1	26.1	23.6	8.6	0.9	0.1
G032	33.9	13.2	14.9	18.1	17.3	2.6	0.1
G034	9.5	10.1	19.2	26.3	19.8	13.8	1.2
G035	3.9	5.8	11.2	23.7	31	17	7.5
G036	2	3.2	5.7	22.1	40.1	22.4	4.4
G037	10.5	10.6	20.6	41.2	14.1	2.8	0.3
G038	0.5	0.3	1.4	40	49.6	7.9	0.3
G039	1.7	6.8	20.9	31.5	28.4	9	1.6

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G040	11.2	8.3	12.5	20	21.9	19.2	7
G041	1.7	4.5	10.9	23.2	39.6	17.3	2.7
G042	64.9	17.7	11.4	4	1.2	0.6	0.1
G043	24.9	25.2	26.7	14.9	7.1	0.9	0.2
G045	1.8	5.9	12.3	39.5	40	0.6	0
G046	24.9	23	25	19.6	6.8	0.6	0.2
G047	0.6	1	4.8	33.8	46.3	12	1.4
G048	1.2	1.9	7.2	36.4	47.1	6	0.2
G050	36	25.4	17.8	15.5	4.4	0.8	0.2
G051	4.3	18.6	27	28.3	18.8	2.6	0.3
G052	33.4	15.5	26.9	17.8	5	1.1	0.3
G053	8.7	27.5	35.8	19.4	6.9	1.5	0.2
G054	40.2	22.6	20.5	13.1	2.9	0.5	0.2
G055	13	6.2	23.8	48	8.8	0.3	0
G056	9.5	11.5	15.1	14	16.8	27.1	6
G057	16.6	15.7	20.5	17.4	17.1	12	0.7
G058	0.6	1.2	4.3	23.6	61.9	8.2	0.1
G060	63.4	2.9	13.6	18.4	1.3	0.3	0.1
G061	0	0.1	0.8	28.1	69	1.9	0
G062	0.1	0.3	1.2	7.4	55.6	35	0.3
G065	3.5	14.3	42.7	37.9	1.5	0	0
G066	22.1	24.1	49	4.8	0	0	0
G068	23.8	21.9	39.7	14.3	0.4	0	0
G071	2.3	5.4	28.6	54.3	9	0.4	0
G072	0.1	0.5	3.6	40.6	52.6	2.6	0.1
G074	0.1	0.4	1.3	14.3	76.1	7.8	0.1
G075	9.9	21.1	31.9	30.8	5.6	0.5	0.1
G076	0.2	0.3	4.5	54.1	38.6	2.2	0.1
G078	38.5	15.4	18.5	17.5	6.8	2.6	0.6
G079	23.4	30.6	21.8	15.8	5.8	2.3	0.3
G080	0.3	1.2	6.1	21.8	54.8	15.7	0.2

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G081	18	12.6	15	25	20.3	8.8	0.3
G083	18.3	15.6	26.1	15.9	3.1	5.5	15.6
G086	8.7	10.2	29.1	25.7	10	15.3	0.9
G088	10.4	17.9	34	25.6	3.3	6	2.9
G089	10.5	11.4	19.5	23.6	14.4	17.8	2.6
G090	3.1	4.2	17.5	51.3	17	5.8	1.1
G091	1.6	3.9	13.3	56.9	20.7	3.2	0.6
G092	18.8	23.1	35.3	12.3	2	5.3	3.3
G093	25.3	25.5	31.8	15.4	1	0.8	0.3
G094	8.7	37.9	34.5	14	4.2	0.7	0
G096	2.3	6.8	31.8	51.7	6.5	0.8	0.2
G097	41	4.4	5.3	31.1	11.1	6.6	0.4
G100	46.5	10.2	7.6	15.9	6.7	11.7	1.5
G101	0.3	0.6	10.8	85.3	2.7	0.3	0
G102	9.8	3.3	13.3	55.9	15.9	1.7	0.2
G103	42.1	8	9.8	27.5	10.8	1.6	0.2
G104	13.8	23.8	62	0.4	0	0	0
G107	75.4	13.8	5.9	1.9	1.3	1.4	0.3
G109	58.5	17.8	16.3	6	1.2	0.1	0
G110	0	0.1	0.4	2.6	56.6	39.8	0.4
G111	0.3	0.3	0.6	1.4	36.8	57.5	3
G112	0.1	0.2	0.9	63.1	34.4	1.3	0
G113	22.4	21.3	30	13.5	8.5	4.2	0.2
G114	33.2	23.8	21.5	10	2.8	4.8	3.9
G115	14.7	20.3	28.7	20.4	7.3	5.3	3.3
G116	19.7	9.7	24.7	29.9	8.4	4.2	3.3
G117	14.4	14.9	24	22.1	6.6	11.2	6.8
G118	24.7	19	32.9	20.9	2.4	0.1	0.1
G119	18.5	12.8	17.7	19.5	8.8	14.9	7.8
G120	54.2	14.5	8.8	11.8	7.8	2.4	0.5
G121	5.7	9.9	21	39.1	17.7	4.7	1.9

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G122	10	14.2	33.3	36.6	5.1	0.7	0.1
G123	14.5	20	33.9	26.8	3.7	0.8	0.4
G124	86.6	7.1	2.5	1.2	0.8	1.1	0.7
G125	59.6	22.3	11.7	4.1	1.3	0.7	0.4
G126	17.7	29	25.1	20	7.1	0.9	0.2
G127	2.7	6.8	17.2	35.6	23.4	8.6	5.8
G129	82.8	9.4	2.1	0.9	1.6	2.8	0.5
G131	91.1	5.7	1.7	0.7	0.4	0.3	0.2
G132	1.1	4.4	19.5	55.7	19	0.3	0
G134	1.1	0.8	2.4	9.3	36.1	49.2	1.1
G135	6	5.4	9.7	15.2	31.1	28	4.6
G136	32.8	17.5	23.2	19.3	5.6	1.3	0.4
G137	29.8	23.2	19.9	18.9	6	1.9	0.4
G138	41	20.4	21.1	14.3	2.2	0.7	0.3
G139	23	15.7	19	18.6	7.2	13	3.5
G140	15.3	10.8	14.3	19.7	20.8	16.1	3
G141	7.2	6.2	15.5	26	23.7	16.8	4.6
G142	6	9.2	15.1	26.8	21.6	16.3	5.1
G143	2.5	3.7	10	24.4	50.2	8.8	0.3
G144	1.1	2.5	7.3	16.8	28.7	29.8	13.7
G145	17.4	13.4	18.4	19.9	9.6	13.3	8.1
G146	16.7	18.9	23.2	17.4	7.8	12.3	3.8
G147	28.1	28.3	25.1	14.5	3.4	0.5	0.1
G149	26.7	24.6	24.7	15.4	4.4	3	1.3
G150	51.3	15.8	14.9	10.7	4.1	2.4	0.8
G152	1.1	1.4	3	12.3	55.9	24.5	1.8
G153	4.6	32.8	27.1	23.4	9.9	2	0.2
G154	71.1	14.1	8.5	4.2	1.1	0.7	0.3
G170	0.3	0.9	44.8	41.9	11.5	0.6	0.0
G171	0.8	10.2	84.7	4.1	0.2	0.0	0.0
G172	0.9	23.8	69.2	4.6	1.4	0.1	0.0

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G173	0.9	1.4	4.4	16.8	69.3	7.0	0.2
G174	2.1	2.1	3.4	6.2	40.0	44.2	2.0
G175	0.4	1.8	6.2	28.2	59.8	3.7	0.0
G176	15.4	27.0	56.2	1.2	0.2	0.0	0.0
G177	5.1	61.1	28.5	3.8	1.4	0.1	0.0
G178	3.7	2.1	30.4	52.2	11.3	0.3	0.1
G179	0.5	1.1	3.0	5.2	85.1	4.9	0.3
G181	3.7	9.5	39.1	39.4	7.6	0.3	0.3
G182	6.9	15.6	54.7	21.2	1.4	0.2	0.0
G183	0.3	6.4	56.3	34.5	2.3	0.1	0.0
G184	9.1	38.3	39.2	12.2	1.1	0.1	0.0
G186	29.6	54.1	15.7	0.6	0.0	0.0	0.0
G187	82.3	3.2	2.9	4.0	3.7	3.1	0.8
G188	9.6	27.2	50.7	12.1	0.3	0.0	0.0
G191	0.4	0.7	3.6	30.0	63.2	2.0	0.0
G193	9.3	21.3	49.0	19.7	0.5	0.1	0.0
G194	0.5	0.7	3.2	29.1	58.3	7.8	0.3
G195	0.5	1.9	17.3	58.4	20.2	1.6	0.1
G196	0.1	0.5	9.5	48.9	35.3	5.5	0.2
G197	0.4	0.4	2.0	19.0	74.1	4.1	0.0
G198	16.9	41.0	38.8	1.0	1.9	0.4	0.0
G199	3.0	7.5	27.5	43.3	15.1	3.3	0.2
G200	10.6	10.2	17.7	34.8	25.0	1.6	0.1
G201	0.0	0.1	1.5	18.7	68.1	11.4	0.2
G202	0.1	0.4	4.4	31.7	55.9	7.3	0.2
G203	0.2	0.9	4.2	34.9	52.9	6.7	0.2
G204	4.8	0.9	7.1	28.8	53.1	5.1	0.1
G205	12.0	24.2	30.1	28.1	4.8	0.8	0.1
G206	11.2	16.3	33.9	29.1	8.5	1.0	0.0
G207	0.1	0.9	10.8	40.3	46.4	1.5	0.0
G208	2.2	0.5	14.4	64.0	18.7	0.2	0.0

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G209	1.1	4.3	21.1	65.3	7.9	0.3	0.0
G210	1.6	6.2	27.0	57.2	7.4	0.5	0.0
G211	4.3	10.6	29.9	33.6	21.2	0.4	0.0
G212	1.9	4.5	19.5	60.5	12.6	1.0	0.0
G213	6.1	11.5	26.7	46.9	8.5	0.2	0.0
G214	1.5	1.5	14.7	37.6	42.1	2.6	0.0
G215	0.1	0.2	1.3	13.3	73.2	11.7	0.2
G216	0.3	0.6	2.7	18.0	71.0	7.3	0.1
G217	0.0	0.1	0.7	9.4	68.0	21.4	0.3
G218	0.1	0.4	2.9	34.1	55.5	7.0	0.1
G219	0.5	0.5	17.5	58.8	22.1	0.5	0.0
G220	0.0	0.1	2.4	39.0	54.3	4.0	0.1
G221	0.1	0.4	8.9	55.6	33.8	1.1	0.0
G222	1.1	4.1	32.3	40.2	21.8	0.5	0.0
G223	0.0	0.1	1.3	20.4	73.7	4.3	0.1
G224	0.0	0.3	8.0	43.5	47.0	1.1	0.0
G225	0.2	1.4	18.7	43.2	35.7	0.8	0.0
G226	0.0	0.6	11.3	46.8	40.1	1.2	0.0
G227	5.8	22.1	51.5	17.9	2.6	0.1	0.0
G228	1.3	1.4	21.2	49.0	27.0	0.1	0.0
G229	4.4	25.6	52.3	16.1	1.5	0.1	0.0
G230	23.4	27.8	24.8	14.9	8.3	0.9	0.1
G231	0.2	0.7	9.2	59.3	29.9	0.7	0.0
G232	12.4	13.8	17.8	40.3	15.2	0.4	0.0
G233	0.1	3.0	81.3	13.8	1.6	0.1	0.0
G234	5.2	8.7	38.9	31.8	14.2	1.2	0.0
G235	0.0	0.2	1.4	19.8	77.1	1.4	0.0
G236	0.5	0.7	6.9	55.0	35.9	1.0	0.0
G237	0.0	0.1	3.8	19.5	67.7	8.9	0.0
G238	14.8	48.8	19.5	7.0	9.7	0.1	0.0
G239	50.9	10.3	11.4	12.0	14.3	1.0	0.1

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G240	0.0	0.1	1.1	14.3	79.8	4.6	0.0
G241	9.8	55.4	29.0	4.2	1.4	0.1	0.0
G242	0.7	3.3	9.8	38.1	47.7	0.3	0.0
G243	23.5	16.4	12.4	39.8	7.9	0.0	0.1
G244	4.3	1.5	10.2	59.6	23.7	0.7	0.0
G245	5.4	13.4	66.2	14.1	0.8	0.0	0.0
G246	16.7	15.4	24.0	24.3	19.6	0.0	0.0
G247	14.3	6.0	12.9	32.4	33.5	0.9	0.0
G250	0.3	0.8	3.5	32.8	61.5	1.0	0.1
G251	39.1	11.7	14.2	15.7	18.7	0.5	0.0
G252	2.5	23.6	43.3	29.7	0.8	0.1	0.0
G253	1.6	2.2	3.4	6.2	58.0	27.1	1.5
G254	1.3	4.7	17.3	47.7	27.3	1.7	0.1
G255	6.3	16.8	42.4	28.3	6.0	0.2	0.0
G256	0.9	3.5	31.2	52.6	9.6	2.1	0.1
G257	0.1	0.3	2.2	5.4	23.4	64.4	4.2
G258	0.3	0.8	9.4	62.3	27.1	0.0	0.0
G259	0.1	1.0	13.7	59.8	22.6	2.7	0.1
G260	2.5	2.2	2.2	5.4	39.2	46.9	1.7
G261	0.1	0.3	3.5	18.8	70.2	7.0	0.1
G262	0.9	4.8	27.5	52.1	13.1	1.6	0.0
G263	1.0	2.1	14.5	61.1	19.9	1.3	0.0
G264	0.4	0.7	3.1	15.2	65.1	14.5	1.0
G265	0.1	0.4	3.9	50.1	44.9	0.6	0.0
G266	67.3	17.9	10.1	2.9	1.4	0.4	0.0
G267	20.1	7.1	56.3	14.0	2.4	0.1	0.0
G268	23.8	9.0	15.4	17.5	25.3	8.1	0.9
G269	15.3	24.7	31.4	23.5	4.5	0.4	0.1
G270	91.2	2.2	2.5	2.5	0.9	0.4	0.4
G272	2.8	10.3	73.6	12.9	0.4	0.0	0.0
G273	2.0	14.2	54.4	26.2	3.0	0.2	0.0

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G274	55.2	22.6	10.4	9.6	2.0	0.1	0.0
G275	46.7	19.4	19.3	13.1	1.4	0.1	0.0
G276	42.9	10.6	17.5	17.5	9.6	1.8	0.1
G277	17.3	20.5	32.3	21.5	4.2	4.2	0.1
G279	36.5	12.4	39.0	8.5	3.5	0.2	0.0
G280	6.1	8.7	19.6	36.7	24.4	2.7	1.8
G281	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G283	10.9	11.4	26.2	32.8	8.8	7.4	2.6
G284	18.6	16.0	28.8	21.6	13.2	1.7	0.1
G285	6.2	10.7	11.1	26.8	40.1	5.0	0.2
G286	6.9	14.2	28.9	39.5	9.0	1.4	0.1
G288	0.9	3.0	6.5	29.7	51.6	7.7	0.6
G289	0.5	1.3	3.6	23.6	63.2	6.7	1.1
G290	0.2	7.0	14.8	44.0	25.0	6.3	2.8
G291	24.2	11.1	14.7	19.5	27.5	2.8	0.1
G292	7.1	17.7	26.5	30.7	16.8	0.9	0.4
G293	1.0	3.5	7.0	24.2	56.7	7.0	0.5
G294	73.9	14.4	7.6	2.2	0.7	0.9	0.4
G296	19.8	5.4	8.4	48.1	17.9	0.4	0.0
G298	1.2	1.0	3.3	44.6	49.1	0.9	0.0
G299	0.6	0.3	3.1	56.3	38.8	0.9	0.1
G300	14.4	15.5	38.2	28.9	2.5	0.2	0.1
G301	0.3	0.4	0.9	21.9	73.4	3.1	0.1
G302	0.9	1.1	14.9	71.0	11.6	0.6	0.0
G303	0.6	5.0	39.1	41.0	13.7	0.5	0.0
G304	0.4	0.8	3.0	64.8	30.9	0.1	0.0
G305	17.3	12.9	41.3	26.4	1.8	0.3	0.0
G307	76.2	13.7	8.1	1.2	0.4	0.2	0.2
G308	29.4	35.4	26.2	7.4	1.3	0.3	0.1
G313	53.6	20.3	19.6	5.8	0.5	0.1	0.1
G314	73.1	15.8	7.6	2.3	0.9	0.3	0.1

GRAB ID	GRAVEL (%)	V COARSE SAND (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	V FINE SAND (%)	MUD (%)
G315	39.9	13.5	19.0	22.2	5.2	0.2	0.0
G316	2.0	11.0	56.0	30.5	0.5	0.0	0.0
G317	21.2	30.7	38.9	8.3	0.8	0.1	0.0
G318	32.7	12.4	15.5	24.1	13.7	1.2	0.4
G319	14.8	17.1	24.3	30.3	11.8	1.5	0.3
G320	8.4	9.4	15.0	24.3	35.6	6.0	1.3
G321	0.6	2.7	15.1	62.6	17.5	1.4	0.1
G322	0.9	3.8	3.6	37.9	43.7	8.3	1.9
G323	6.2	3.8	8.1	28.6	38.9	10.0	4.3
G324	100.0	0.0	0.0	0.0	0.0	0.0	0.0
G325	1.2	0.6	2.4	10.2	50.1	32.0	3.5
G326	1.3	1.6	3.7	15.6	55.4	20.7	1.7
G328	0.9	2.0	5.6	27.6	42.7	20.0	1.2
G330	4.1	7.6	24.2	49.9	13.1	1.1	0.0
G331	7.8	5.1	7.7	13.4	27.9	35.3	2.8
G333	2.8	5.1	20.6	55.5	14.4	1.5	0.0
G334	0.0	0.2	0.5	4.0	48.5	46.3	0.5

Appendix 1.4. Grain size statistics for grab samples.

GRAB	SEDIMENT NAME	MODE	MEAN	SORTING	SKEWNESS	KURTOSIS
G002	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G003	Sandy Gravel	Unimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Leptokurtic
G011	Gravelly Very Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G012	Sandy Gravel	Bimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G013	Sandy Gravel	Bimodal	Very Coarse Sand	Moderately Sorted	Fine Skewed	Platykurtic
G014	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Poorly Sorted	Very Coarse Skewed	Leptokurtic
G015	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Poorly Sorted	Very Coarse Skewed	Leptokurtic
G016	Slightly Gravelly Fine Sand	Trimodal	Fine Sand	Poorly Sorted	Coarse Skewed	Leptokurtic
G017	Gravelly Muddy Very Fine Sand	Trimodal	Fine Sand	Very Poorly Sorted	Coarse Skewed	Leptokurtic
G018	Gravelly Muddy Very Fine Sand	Trimodal	Fine Sand	Very Poorly Sorted	Fine Skewed	Mesokurtic
G019	Gravelly Very Fine Sand	Polymodal	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
G020	Gravelly Muddy Very Fine Sand	Polymodal	Fine Sand	Poorly Sorted	Symmetrical	Leptokurtic
G022	Gravelly Muddy Very Fine Sand	Polymodal	Fine Sand	Very Poorly Sorted	Coarse Skewed	Leptokurtic
G023	Slightly Gravelly Muddy Very Fine Sand	Bimodal	Fine Sand	Poorly Sorted	Coarse Skewed	Leptokurtic
G024	Gravelly Coarse Sand	Trimodal	Medium Sand	Poorly Sorted	Fine Skewed	Mesokurtic
G025	Gravelly Medium Sand	Trimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G026	Gravelly Muddy Coarse Sand	Trimodal	Medium Sand	Very Poorly Sorted	Very Fine Skewed	Platykurtic
G027	Gravelly Fine Sand	Trimodal	Medium Sand	Poorly Sorted	Coarse Skewed	Very Platykurtic
G028	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Poorly Sorted	Very Coarse Skewed	Leptokurtic
G029	Gravelly Fine Sand	Polymodal	Medium Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G030	Gravelly Very Fine Sand	Polymodal	Medium Sand	Poorly Sorted	Symmetrical	Platykurtic
G031	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G032	Sandy Gravel	Polymodal	Coarse Sand	Poorly Sorted	Fine Skewed	Very Platykurtic
G033	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G034	Gravelly Medium Sand	Bimodal	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
G035	Slightly Gravelly Fine Sand	Bimodal	Fine Sand	Poorly Sorted	Symmetrical	Leptokurtic
G036	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Poorly Sorted	Coarse Skewed	Leptokurtic
G037	Gravelly Medium Sand	Bimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Mesokurtic
G038	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Fine Skewed	Mesokurtic
G039	Slightly Gravelly Medium Sand	Unimodal	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
G040	Gravelly Fine Sand	Trimodal	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
G041	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Poorly Sorted	Coarse Skewed	Leptokurtic
G042	Sandy Gravel	Unimodal	Very Coarse Sand	Moderately Sorted	Very Fine Skewed	Leptokurtic

GRAB	SEDIMENT NAME	MODE	MEAN	SORTING	SKEWNESS	KURTOSIS
G043	Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G044	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G045	Slightly Gravelly Fine Sand	Unimodal	Medium Sand	Moderately Sorted	Very Coarse Skewed	Leptokurtic
G046	Gravelly Coarse Sand	Polymodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G047	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
G048	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G050	Sandy Gravel	Trimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G051	Slightly Gravelly Medium Sand	Bimodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G052	Sandy Gravel	Bimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G053	Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
G054	Sandy Gravel	Bimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G055	Gravelly Medium Sand	Bimodal	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
G056	Gravelly Very Fine Sand	Trimodal	Medium Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G057	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G058	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G060	Sandy Gravel	Bimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
G061	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Very Well Sorted	Coarse Skewed	Leptokurtic
G062	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G065	Slightly Gravelly Coarse Sand	Unimodal	Coarse Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
G066	Gravelly Coarse Sand	Bimodal	Very Coarse Sand	Moderately Sorted	Coarse Skewed	Platykurtic
G068	Gravelly Coarse Sand	Bimodal	Very Coarse Sand	Moderately Sorted	Coarse Skewed	Platykurtic
G069	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G070	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G071	Slightly Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
G072	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G074	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Well Sorted	Fine Skewed	Very Leptokurtic
G075	Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G076	Slightly Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G078	Sandy Gravel	Bimodal	Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G079	Gravelly Very Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G080	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Very Coarse Skewed	Mesokurtic
G081	Gravelly Medium Sand	Trimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G083	Gravelly Muddy Coarse Sand	Trimodal	Medium Sand	Very Poorly Sorted	Very Fine Skewed	Leptokurtic
G086	Gravelly Coarse Sand	Trimodal	Medium Sand	Poorly Sorted	Fine Skewed	Mesokurtic
G088	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Symmetrical	Leptokurtic

GRAB	SEDIMENT NAME	MODE	MEAN	SORTING	SKEWNESS	KURTOSIS
G089	Gravelly Medium Sand	Polymodal	Medium Sand	Poorly Sorted	Symmetrical	Platykurtic
G090	Slightly Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Symmetrical	Very Leptokurtic
G091	Slightly Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G092	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Leptokurtic
G093	Gravelly Coarse Sand	Bimodal	Very Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G094	Gravelly Very Coarse Sand	Bimodal	Coarse Sand	Moderately Sorted	Fine Skewed	Leptokurtic
G095	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G096	Slightly Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G097	Sandy Gravel	Bimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Very Platykurtic
G099	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G100	Sandy Gravel	Trimodal	Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G101	Slightly Gravelly Medium Sand	Unimodal	Medium Sand	Well Sorted	Symmetrical	Mesokurtic
G102	Gravelly Medium Sand	Bimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Very Leptokurtic
G103	Sandy Gravel	Bimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Very Platykurtic
G104	Gravelly Coarse Sand	Bimodal	Very Coarse Sand	Moderately Well Sorted	Very Coarse Skewed	Mesokurtic
G107	Sandy Gravel	Unimodal	Very Fine Gravel	Moderately Well Sorted	Very Fine Skewed	Extremely Leptokurtic
G109	Sandy Gravel	Unimodal	Very Coarse Sand	Moderately Sorted	Very Fine Skewed	Mesokurtic
G110	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Well Sorted	Symmetrical	Mesokurtic
G111	Slightly Gravelly Very Fine Sand	Unimodal	Very Fine Sand	Well Sorted	Symmetrical	Mesokurtic
G112	Slightly Gravelly Medium Sand	Bimodal	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Very Platykurtic
G113	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G114	Sandy Gravel	Unimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Mesokurtic
G115	Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Mesokurtic
G116	Gravelly Medium Sand	Bimodal	Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
G117	Gravelly Coarse Sand	Trimodal	Medium Sand	Very Poorly Sorted	Fine Skewed	Leptokurtic
G118	Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G119	Gravelly Medium Sand	Trimodal	Medium Sand	Very Poorly Sorted	Fine Skewed	Platykurtic
G120	Sandy Gravel	Unimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G121	Gravelly Medium Sand	Bimodal	Medium Sand	Poorly Sorted	Coarse Skewed	Leptokurtic
G122	Gravelly Medium Sand	Bimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Mesokurtic
G123	Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G124	Gravel	Unimodal	Very Fine Gravel	Well Sorted	Very Fine Skewed	Very Leptokurtic
G125	Sandy Gravel	Unimodal	Very Coarse Sand	Moderately Sorted	Very Fine Skewed	Leptokurtic
G126	Gravelly Very Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G127	Slightly Gravelly Medium Sand	Bimodal	Medium Sand	Poorly Sorted	Symmetrical	Leptokurtic

GRAB	SEDIMENT NAME	MODE	MEAN	SORTING	SKEWNESS	KURTOSIS
G128	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G129	Gravel	Unimodal	Very Fine Gravel	Moderately Well Sorted	Very Fine Skewed	Extremely Leptokurtic
G130	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G131	Gravel	Unimodal	Very Fine Gravel	Very Well Sorted	Fine Skewed	Very Leptokurtic
G132	Slightly Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G133	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G134	Slightly Gravelly Very Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Very Coarse Skewed	Leptokurtic
G135	Gravelly Fine Sand	Trimodal	Fine Sand	Poorly Sorted	Very Coarse Skewed	Leptokurtic
G136	Sandy Gravel	Bimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G137	Gravelly Very Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G138	Sandy Gravel	Bimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G139	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G140	Gravelly Fine Sand	Trimodal	Medium Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G141	Gravelly Medium Sand	Bimodal	Medium Sand	Poorly Sorted	Coarse Skewed	Mesokurtic
G142	Gravelly Medium Sand	Bimodal	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
G143	Slightly Gravelly Fine Sand	Unimodal	Medium Sand	Poorly Sorted	Very Coarse Skewed	Leptokurtic
G144	Slightly Gravelly Muddy Very Fine Sand	Unimodal	Fine Sand	Poorly Sorted	Symmetrical	Very Leptokurtic
G145	Gravelly Medium Sand	Trimodal	Medium Sand	Very Poorly Sorted	Fine Skewed	Mesokurtic
G146	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G147	Gravelly Very Coarse Sand	Bimodal	Very Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G149	Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G150	Sandy Gravel	Bimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Mesokurtic
G152	Slightly Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G153	Slightly Very Gravelly Very Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G154	Sandy Gravel	Unimodal	Very Coarse Sand	Moderately Sorted	Very Fine Skewed	Very Leptokurtic
G164	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G170	Slightly Very Fine Gravelly Coarse Sand	Trimodal	Coarse Sand	Moderately Well Sorted	Coarse Skewed	Platykurtic
G171	Slightly Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Well Sorted	Symmetrical	Mesokurtic
G172	Slightly Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Well Sorted	Symmetrical	Very Leptokurtic
G173	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G174	Slightly Very Fine Gravelly Very Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Very Coarse Skewed	Very Leptokurtic
G175	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Very Coarse Skewed	Very Leptokurtic
G176	Very Fine Gravelly Coarse Sand	Bimodal	Very Coarse Sand	Moderately Sorted	Coarse Skewed	Platykurtic
G177	Very Fine Gravelly Very Coarse Sand	Unimodal	Very Coarse Sand	Moderately Well Sorted	Fine Skewed	Leptokurtic
G178	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Mesokurtic

GRAB	SEDIMENT NAME	MODE	MEAN	SORTING	SKEWNESS	KURTOSIS
G179	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Well Sorted	Symmetrical	Leptokurtic
G181	Slightly Very Fine Gravelly Medium Sand	Bimodal	Coarse Sand	Moderately Sorted	Symmetrical	Leptokurtic
G182	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G183	Slightly Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G184	Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Moderately Sorted	Symmetrical	Mesokurtic
G186	Very Fine Gravelly Very Coarse Sand	Unimodal	Very Coarse Sand	Moderately Well Sorted	Symmetrical	Platykurtic
G187	Very Fine Gravel	Unimodal	Very Fine Gravel	Moderately Sorted	Very Fine Skewed	Extremely Leptokurtic
G188	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
G190	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G191	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G193	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
G194	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G195	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
G196	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Symmetrical	Leptokurtic
G197	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Well Sorted	Coarse Skewed	Very Leptokurtic
G198	Very Fine Gravelly Very Coarse Sand	Bimodal	Very Coarse Sand	Moderately Well Sorted	Very Fine Skewed	Platykurtic
G199	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Symmetrical	Leptokurtic
G200	Very Fine Gravelly Medium Sand	Trimodal	Medium Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
G201	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G202	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G203	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G204	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Very Coarse Skewed	Very Leptokurtic
G205	Very Fine Gravelly Coarse Sand	Polymodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G206	Very Fine Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Mesokurtic
G207	Slightly Very Fine Gravelly Fine Sand	Unimodal	Medium Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G208	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G209	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G210	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
G211	Slightly Very Fine Gravelly Medium Sand	Trimodal	Medium Sand	Poorly Sorted	Coarse Skewed	Mesokurtic
G212	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G213	Very Fine Gravelly Medium Sand	Bimodal	Coarse Sand	Moderately Sorted	Very Coarse Skewed	Mesokurtic
G214	Slightly Very Fine Gravelly Fine Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
G215	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G216	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G217	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic

GRAB	SEDIMENT NAME	MODE	MEAN	SORTING	SKEWNESS	KURTOSIS
G218	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G219	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G220	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G221	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G222	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
G223	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Well Sorted	Symmetrical	Mesokurtic
G224	Slightly Very Fine Gravelly Fine Sand	Unimodal	Medium Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
G225	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Symmetrical	Platykurtic
G226	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
G227	Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Moderately Sorted	Symmetrical	Leptokurtic
G228	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
G229	Slightly Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Moderately Sorted	Symmetrical	Mesokurtic
G230	Very Fine Gravelly Very Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
G231	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G232	Very Fine Gravelly Medium Sand	Trimodal	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic
G233	Slightly Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Well Sorted	Symmetrical	Very Leptokurtic
G234	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Symmetrical	Leptokurtic
G235	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Very Well Sorted	Coarse Skewed	Very Leptokurtic
G236	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G237	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Very Coarse Skewed	Leptokurtic
G238	Very Fine Gravelly Very Coarse Sand	Trimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Leptokurtic
G239	Sandy Very Fine Gravel	Bimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G240	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Well Sorted	Coarse Skewed	Mesokurtic
G241	Very Fine Gravelly Very Coarse Sand	Unimodal	Very Coarse Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G242	Slightly Very Fine Gravelly Fine Sand	Unimodal	Medium Sand	Moderately Well Sorted	Very Coarse Skewed	Leptokurtic
G243	Very Fine Gravelly Medium Sand	Trimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Very Platykurtic
G244	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Very Leptokurtic
G245	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G246	Very Fine Gravelly Medium Sand	Trimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G247	Very Fine Gravelly Fine Sand	Bimodal	Medium Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
G250	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G251	Sandy Very Fine Gravel	Trimodal	Coarse Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
G252	Slightly Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Moderately Sorted	Coarse Skewed	Platykurtic
G253	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Very Coarse Skewed	Very Leptokurtic
G254	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic

GRAB	SEDIMENT NAME	MODE	MEAN	SORTING	SKEWNESS	KURTOSIS
G255	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
G256	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
G257	Slightly Very Fine Gravelly Very Fine Sand	Unimodal	Very Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G258	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G259	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G260	Slightly Very Fine Gravelly Very Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Very Coarse Skewed	Very Leptokurtic
G261	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G262	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
G263	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G264	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G265	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Well Sorted	Coarse Skewed	Mesokurtic
G266	Sandy Very Fine Gravel	Unimodal	Very Coarse Sand	Moderately Well Sorted	Very Fine Skewed	Leptokurtic
G267	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Moderately Sorted	Very Coarse Skewed	Leptokurtic
G268	Very Fine Gravelly Fine Sand	Trimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Very Platykurtic
G269	Very Fine Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G270	Very Fine Gravel	Unimodal	Very Fine Gravel	Well Sorted	Very Fine Skewed	Extremely Leptokurtic
G272	Slightly Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G273	Slightly Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Moderately Sorted	Symmetrical	Leptokurtic
G274	Sandy Very Fine Gravel	Unimodal	Very Coarse Sand	Moderately Sorted	Very Fine Skewed	Leptokurtic
G275	Sandy Very Fine Gravel	Trimodal	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G276	Sandy Very Fine Gravel	Trimodal	Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
G277	Very Fine Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
G279	Sandy Very Fine Gravel	Bimodal	Very Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G280	Very Fine Gravelly Medium Sand	Trimodal	Medium Sand	Poorly Sorted	Very Coarse Skewed	Leptokurtic
G283	Very Fine Gravelly Medium Sand	Trimodal	Coarse Sand	Poorly Sorted	Symmetrical	Leptokurtic
G284	Very Fine Gravelly Coarse Sand	Trimodal	Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
G285	Very Fine Gravelly Fine Sand	Trimodal	Medium Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
G286	Very Fine Gravelly Medium Sand	Bimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Mesokurtic
G288	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G289	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G290	Slightly Very Fine Gravelly Medium Sand	Bimodal	Medium Sand	Poorly Sorted	Symmetrical	Leptokurtic
G291	Very Fine Gravelly Fine Sand	Polymodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Very Platykurtic
G292	Very Fine Gravelly Medium Sand	Trimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G293	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G294	Sandy Very Fine Gravel	Unimodal	Very Coarse Sand	Moderately Well Sorted	Very Fine Skewed	Very Leptokurtic

GRAB	SEDIMENT NAME	MODE	MEAN	SORTING	SKEWNESS	KURTOSIS
G296	Very Fine Gravelly Medium Sand	Bimodal	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic
G298	Slightly Very Fine Gravelly Fine Sand	Unimodal	Medium Sand	Well Sorted	Coarse Skewed	Leptokurtic
G299	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Well Sorted	Symmetrical	Leptokurtic
G300	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic
G301	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Well Sorted	Symmetrical	Mesokurtic
G302	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
G303	Slightly Very Fine Gravelly Medium Sand	Bimodal	Medium Sand	Moderately Sorted	Symmetrical	Platykurtic
G304	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Well Sorted	Symmetrical	Leptokurtic
G305	Very Fine Gravelly Coarse Sand	Bimodal	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
G307	Sandy Very Fine Gravel	Unimodal	Very Coarse Sand	Moderately Well Sorted	Very Fine Skewed	Very Leptokurtic
G308	Very Fine Gravelly Very Coarse Sand	Bimodal	Very Coarse Sand	Moderately Sorted	Fine Skewed	Platykurtic
G313	Sandy Very Fine Gravel	Bimodal	Very Coarse Sand	Moderately Sorted	Very Fine Skewed	Platykurtic
G314	Sandy Very Fine Gravel	Unimodal	Very Coarse Sand	Moderately Well Sorted	Very Fine Skewed	Very Leptokurtic
G315	Sandy Very Fine Gravel	Trimodal	Very Coarse Sand	Poorly Sorted	Fine Skewed	Very Platykurtic
G316	Slightly Very Fine Gravelly Coarse Sand	Unimodal	Coarse Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
G317	Very Fine Gravelly Coarse Sand	Bimodal	Very Coarse Sand	Moderately Sorted	Symmetrical	Platykurtic
G318	Sandy Very Fine Gravel	Polymodal	Coarse Sand	Poorly Sorted	Symmetrical	Very Platykurtic
G319	Very Fine Gravelly Medium Sand	Trimodal	Coarse Sand	Poorly Sorted	Coarse Skewed	Platykurtic
G320	Very Fine Gravelly Fine Sand	Trimodal	Medium Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
G321	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
G322	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Symmetrical	Very Leptokurtic
G323	Very Fine Gravelly Fine Sand	Bimodal	Medium Sand	Poorly Sorted	Coarse Skewed	Very Leptokurtic
G324	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G325	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G326	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G327	Very Coarse Rhodolith Gravel	Unimodal	V Coarse Gravel	No sediment	No sediment	No sediment
G328	Slightly Very Fine Gravelly Fine Sand	Unimodal	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
G330	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G331	Very Fine Gravelly Very Fine Sand	Bimodal	Fine Sand	Poorly Sorted	Very Coarse Skewed	Leptokurtic
G333	Slightly Very Fine Gravelly Medium Sand	Unimodal	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic
G334	Well Sorted Fine Sand	Unimodal	Fine Sand	Well Sorted	Coarse Skewed	Mesokurtic

Appendix 2: Dominant Porifera (Demosponges) found in 2007

							May-07											
FIELD NO.	FAMILY	GENUS	SUBGENUS	SPECIES	AUTHORITY	BIOGIOGRAPHY	D051	D052	D053	D054	D055	D056	D057	D058	D059	D060	D061	D062
1	Plakinidae	Plakinastrella		sp.SS1							4.2							
9	Tetillidae	Cinachyra		cf. isis	Lendenfeld, 1907	NW Australia							0.4					
15	Ancorinidae	Asteropus		cf. simplex	(Carter, 1879)	Fremantle, Indian Ocean, 0-126m					5.5							
14	Ancorinidae	Ecionemia		sp.SS1							34.2							
3,10	Geodiidae	Erylus		sp.SS1							10.8		0.7					
2,23,5,8,8,3,4	Desmacellidae	Sigmaxinella		sp.SS1				0.5	0.1	0.9			0.1	0.1	1.8	1.3		
30	Chondropsidae	Chondropsis		sp.Ng1					0.1									
3,2	Petrosiidae	Petrosia	(Petrosia)	sp.SS2				15.4			26.1							
2	Pseudoceratinidae	Pseudoceratina		sp.Ng1											3.1			
6	Crambeidae	Monanchora		sp.Ng1														0.7
8	Crellidae	Crella	(Yvesia)	spinulata	(Hentschel, 1911)	WA, NT, Qld, 6-55m, Indian Ocean										0.5		
9	Hymedesmiidae	Phorbas		sp.Ng1												0.2		
12,13	Microcionidae	Clathria	(Axociella)	patula	Hooper, 1996	Carnarvon & Houtman Abrolhos, pavement, 39-85m		0.6,0.1										
34,24	Microcionidae	Clathria	(Thalysias)	abietina	(Lamarck, 1814)	N & NW coasts to Exmouth Gulf, coral, pavement 0-86m, IO			0.1							0.1		
19	Microcionidae	Clathria	(Thalysias)	cactiformis	(Lamarck, 1814)	S, E, & WA coasts to Pt. Hedland, East Africa 10-100m, IO										0.1		
13,26	Microcionidae	Clathria	(Thalysias)	lendenfeldi	Ridley & Dendy, 1886	Indo Pacific, 0-108m				0.7						0.1		
29	Microcionidae	Clathria	(Thalysias)	reinwardti	Vosmaer, 1880	Indo-West Pacific, 0-10m				0.1								
15,12	Microcionidae	Clathria	(Thalysias)	spinifera	(Lindgren, 1897)	Pt. Hedland & Indonesia, 45-84m		0.5										0.3
1,4	Chalinidae	Haliclona	(Haliclona)	sp.Ng1								0.9						1.0
10	Chalinidae	Haliclona	(Haliclona)	sp.Ng2								3.0						
4,5	Axinellidae	Axinella		sp.Ng3						7.5								1.9
27,9	Axinellidae	Axinella		sp.Ng4					0.1	0.5								
25,20	Axinellidae	Reniochalina		sp.1					0.3							0.1		
7,26,7	Raspailidae	Echinodictyum		clathrioides	Hentschel, 1911	SW to mid NW coast, 2-85m		1.1				0.1				0.1		
36	Raspailidae	Ceratopsion		cf. montebelloensis	Hooper 1991	W. Australia, 6m			0.1									
28,7	Raspailidae	Raspailia	(Clathriodendron)	sp.Ng1					0.8	2.4								
20	Raspailidae	Raspailia	(Raspaxilla)	sp.Ng1					0.1									
5	Mycalidae	Mycale	(Grapelia)	parasitica	(Carter, 1885)	S. Australia & Victoria									1.0			
26,39,6,3	Iotrochotidae	Iotrochota		acerata	Dendy, 1896	Victoria & W. Australia			0.1,0.1	1.3						0.1		
27	Iotrochotidae	Iotrochota		sp.2												0.1		
27	Theonellidae	Theonella		sp.Ng1								1.5						
7,6	Theonellidae	Theonella		levior	Lendenfeld, 1907	NW Australia, 130m									0.7	0.3		
7	Spongiidae	Spongia	(Heterofibria)	sp.Ng1							2.9							
2	Thorectidae	Thorecta		sp.Ng1								1.0						
22	Thorectidae	Hyrtios		sp.Ng1					0.1									
6	Irciniidae	Sarcotragus		sp.Ng2											0.9			
						No. of Demosponge Collected	3	15	21	21	15	17	3	1	18	24	0	26
						Dominant sponge weight (kg)	0.0[a]	18.2[b]	2.0	13.4	72.9	6.5[b]	1.2	0.1	7.5	3.0[b]	0.0	4.0[c]
						Total Sponge Wt (Kg)	3.1	47.4	3.0	19.8	114.0	13.7	1.6	0.1	9.8	4.5	0.0	56.1
						Depth (Start) (m)	18.9	19.4	37.9	28.9	102.0	40.2	89.7	52.5	56.8	19.8	36.6	45.0
						Depth (End) (m)	18.7	19.2	38.6	28.5	99.5	40.5	88.7	51.0	50.7	19.9	36.4	44.0
						Habitat												

[a] All dominant sponges missing.

[b] Could only find 2 of 5 dominant sponges

[c] Could only find 3 of 5 dominant sponges

Appendix 3. Examples of sponge species identification sheets.

FIELD No:

SS1005/143-009-010

SS1005/144-050a

CF4314-D055-014

CAAB TAXON CODE: 10009000

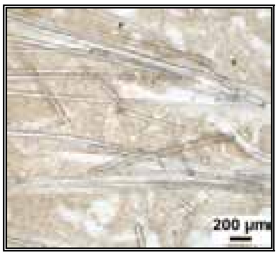
REG. No: WAM Z35067-69

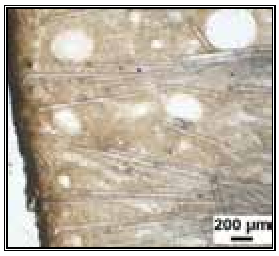
ORDER: Astrophorida

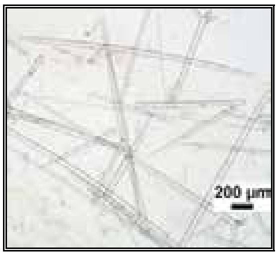
FAMILY: Ancorinidae

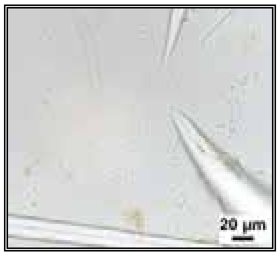
GENUS: *Ecionemia*

SPECIES: sp. SS1









AUTHORITY:

GROWTH FORM: Smooth erect mounds to thick pillars or erect lobes and branches. Dimensions: **WAM Z35067** - 18.5cm (H) x 9.5cm (W) x 5cm (T) (specimen sub sectioned), **WAM Z35068** – 15cm (H) x 18cm (W) x 9.5cm (T) & **WAM Z35069** – 6.5cm (H) x 6cm (W) x 6cm (T).

COLOUR: Brown surface and interior, occasionally lighter beige interior in ethanol.

OSCULES: Occasionally visible apically clustered in surface depression.

TEXTURE: Firm, compressible to stoney consistency.

SURFACE ORNAMENTATION: Smooth surface with cortical region ~3mm thick, choanosome more disorganised.

ECTOSOMAL SKELETON: Microrhabds in dermal layer, triaenes with cladome immediately beneath sponge surface and radial to interior. Small oxeas at right angles to surface in surface layer.

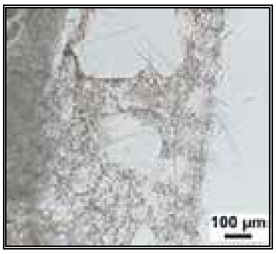
CHOANOSOMAL SKELETON: Plagiotriaenes and long oxeas form radial skeleton with abundant microrhabds between.

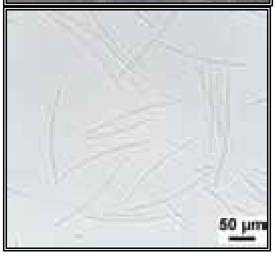
MEGASCLERES: Plagiotriaenes length: 2385µm and width: 56µm, oxeas length: 2226µm and width: 53µm and small oxeas length: 87µm and width: 9µm.

MICROSCLERES: Oxyasters 13µm and microrhabds 7µm.

REMARKS: This genus *Ecionemia* does not have oxyasters, but they are present here. Will need to look closely at genus allocation. Doesn't fit elsewhere e.g. *Psammastra* because of lack of conulose surface, maybe new genus. Specimen field name: "Golden Nugget sponge".

SPECIMENS: **WAM Z35067** (SS1005/143-009 (Lot 123-8)), **WAM Z35068** (SS1005/143-010 (Lot 120-21)) and **WAM Z35069** (SS1005/144-050a (Lot 120-11)). Specimens SS1005/143-011-012 (Lot 120-19 & 6) donated to other institutions. CF4314-D055-014 (LotN124-22).





FIELD No:
SS1005/164-031
CF4314-D052-003
CF4314-D055-002

CAAB TAXON CODE:

REG. No: WAM Z35083

ORDER: Haplosclerida

FAMILY: Petrosiidae

GENUS: *Petrosia (Petrosia)*

SPECIES: sp. SS2

AUTHORITY:

GROWTH FORM: Massive erect cup or mound. Check image. Dimensions: (**WAM Z35083**) 8.5cm (H) x 11cm (W) x 7.5cm (T).

COLOUR: Light fawn to mid grey-brown in ethanol.

OSCULES: Not seen.

TEXTURE: Solid, firm, slightly compressible.

SURFACE ORNAMENTATION: Longitudinal ridges, vertical flukes. Smooth adherent membrane.

ECTOSOMAL SKELETON: Cross hatching and tangential spicules in surface layer 138µm thick.

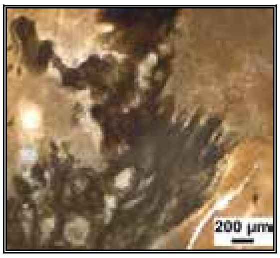
CHOANOSOMAL SKELETON: Round meshed reticulation of spicules 342µm wide. Tracts dense spicules ~ 30 spicules across. Smaller spicules at surface and near spicule tracts. Fibre visible macroscopically.

MEGASCLERES: oxeas 2 size categories; short, thick, slightly curved, length: 208µm and width: 12µm. Short pencil points, length: 180µm and width: 6µm.

MICROSCLERES: None.

REMARKS: Specimen D052-003 (LotN 124-1) stonier texture than specimen D055-002 (LotN124-12). Looks like *Xestospongia testudinaria*. Specimen field name: "Chocolate Mousse sponge" and "Cream Cup sponge".

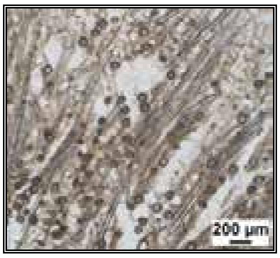
SPECIMENS: **WAM Z35083** (SS1005/164-031 (Lot 121-3)). D052-003 (LotN 124-1) and D055-002 (LotN124-12).

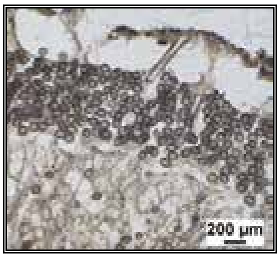


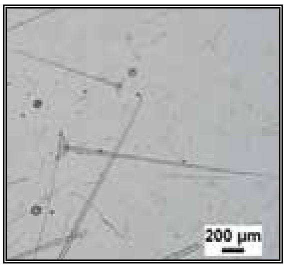
FIELD No:
CF4314-D059-002
CAAB TAXON CODE:
REG. No:
AUTHORITY:

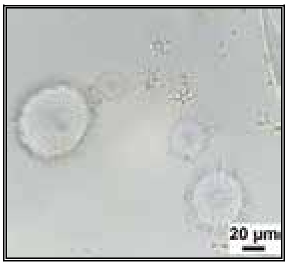
ORDER: Verongida
FAMILY: Pseudoceratidae
GENUS: *Pseudoceratina*
SPECIES: sp. Ng1

GROWTH FORM: Massive collagenous sponge, open texture 'holey' interior with crustaceans and other fauna.
COLOUR: Medium brown in ethanol.
OSCULES: Small on apex of knobs over surface ~1mm wide.
TEXTURE: Firm, barely compressible.
SURFACE ORNAMENTATION: Irregular 'knobbly' surface. Smooth where not encrusted by sediment or other organisms.
ECTOSOMAL SKELETON: Collagenous with occasional widely spaced fibres.
CHOANOSOMAL SKELETON: Reticulate? Thick widely spaced fibres ~1mm thick.
MEGASCLERES: None.
MICROSCLERES: None.
REMARKS: No oxidation reaction on collection? Specimen field name: "Organ sponge".
SPECIMENS: CF4314-D059-002 (LotN 129-2).









FIELD No:

CF4314-D055-003
CF4314-D057-010
SS1005/144-046a & 030

CAAB TAXON CODE:

10012000

REG. No: WAM Z35038-39

ORDER: Astrophorida

FAMILY: Geodiidae

GENUS: *Erylus*

SPECIES: sp. SS1

AUTHORITY:

GROWTH FORM: Compact small mound, almost ball-shaped approximately 3.5cm (H) x 4cm (W) x 4.5cm (T) (**WAM Z35039**). Also shallow cup shape 14cm (H) x 22cm (W) x 3.5cm (T) (WAM **Z35038**).

COLOUR: Light fawn in ethanol.

OSCULES: Tiny 'pinprick' size ostia over upper surface. Oscules not visible.

TEXTURE: Firm incompressible.

SURFACE ORNAMENTATION: Partially covered by a thin encrusting sponge (<1mm), otherwise smooth with tiny pores over surface, like pinpricks.

ECTOSOMAL SKELETON: Pronounced cortex approximately 1mm, hispid basally. Cortex of oval aspidasters 740µm thick. Oxyspherasters and oxyasters also in cortex.

CHOANOSOMAL SKELETON: Radial, slightly spongy. Tracts of megascleres running to surface 125µm wide stopping beneath cortex. Triaene cladomes beneath aspidasters. Asters throughout mesohyl.

MEGASCLERES: Very long oxeas with tapering points 1644-**2014**-2585µm, dichotriaenes, long tapering 1367-**2125**-3354µm, orthotriaenes less common than above, short, thin and tapering 2193-**3589**-4846µm.

MICROSCLERES: Sterrasters oval 63-**86**-100µm (width), oxyasters large slightly microspined 21-**26**-30µm (width). Oxysphaerasters small, 23-**28**-35µm (width), microrhabds small not centrotylote 7-**9**-11µm (width).

REMARKS: Thin encrusting sponge has long thin oxeas approximately 190x5µm and asters of *Erylus* throughout, possibly a *Haliclona (Reniera) sp.* See Adams and Hooper 2001, not any species described from Australia, need to check wider literature. Specimen SS1005/144-046b (Lot 121-20) not kept but to be donated to another institution. Specimen field name: "Elephant's Foot sponge" and "Party Cone sponge"

SPECIMENS: WAM Z35038 (SS1005/144-046a (Lot 121-19)), **WAM Z35039** (SS1005/144-030 (Lot 123-4)). Specimen SS1005/144-046b (Lot 121-20) not kept but to be donated to another institution. CF4314-D055-003 (LotN128-1) and D057-010 (LotN124-10).

Appendix 4. List of Figures and Tables