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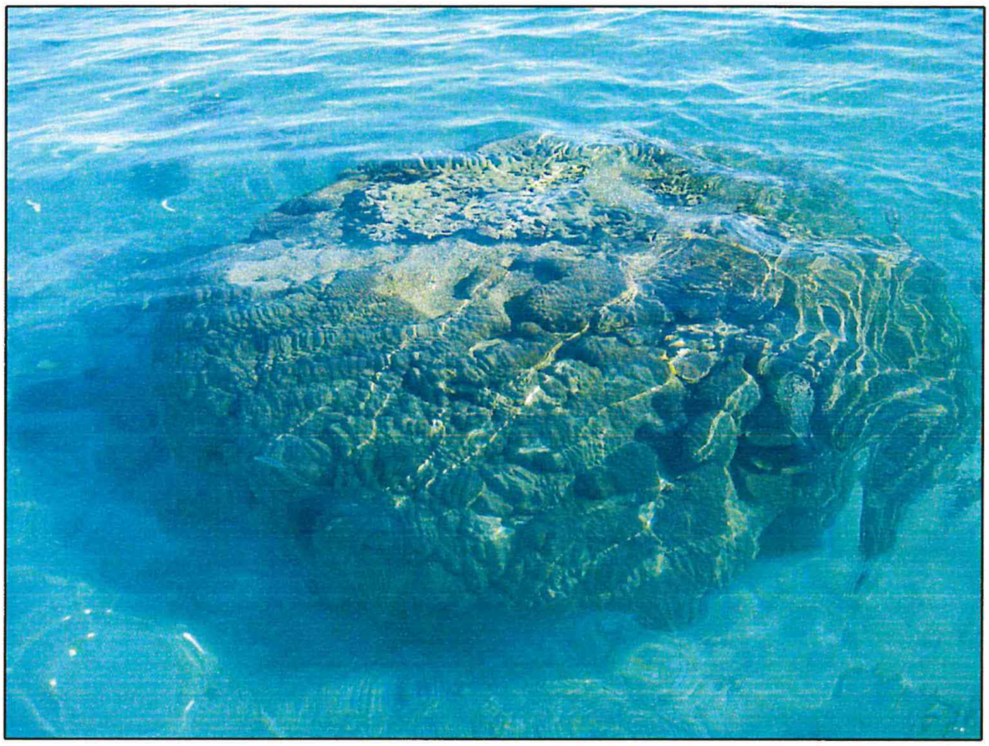
WAMSI Node 3 Project 3.4 Characterisation of Geomorphology and Surface Sediments



Ningaloo Marine Park Inshore Geomorphology, Surficial Sediments and Habitat Linkages - Progress Report July 2007

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CONTENTS

PROJECT DETAILS

WAMSI project reference no: WAMSI Node 3 Project 3.4

Project title: Characterisation of Geomorphology and Surface Sediments

Node leader: Chris Simpson

Project leader: A/Prof Lindsay B Collins

Project duration: 3 Years, end September 2009

Due date for current milestone report: July 2007

PROJECT OBJECTIVES

The aims of the project are:

- To characterise the coastal and seabed geomorphology of the reef system, including the deeper reserve areas offshore of the fringing reef;
- To characterise the surficial sediments of the shallow (lagoonal) waters and continental shelf;
- To characterise the morphology and growth history of the reef system, and identify growth characteristics relevant to maintenance of marine biodiversity and climate change impacts.

EXECUTIVE SUMMARY

The Ningaloo Reef, situated on the central west coast, is Australia's largest fringing coral reef extending southward from 22°S for approximately 290 km, and the only extensive reef in the world fringing the west coast of a continent. The Ningaloo Reef is one of the last relatively pristine major coral reef systems in the world. Its remote location has so far prevented over-development of the area, providing an ideal case study to advance baseline understanding of near pristine reef geomorphology, sediment distribution and habitats and establish the current condition of the reef for the evaluation and monitoring of future change. The location and geomorphology of the reef environments has a critical relationship with the oceanography within and surrounding the Marine Park and the complex intertidal and subtidal geomorphology plays a significant role in the variety of marine habitat types and correspondingly high species diversity.

The characterisation and conservation of benthic habitats and communities based on physical factors is central in the ongoing monitoring and management of the Ningaloo Marine Park (NMP). Physical factors including geomorphology, sediment composition, mobility of the substrate, bathymetry, the texture of the seabed and water depth, can be significant in describing the distribution of benthic biota and coral reef habitat types over this broad geographic region.

This research presents an interdisciplinary study through the use of a Geographic Information System (GIS) and remote sensing techniques, traditional sedimentological sampling, benthic video and still photography. In July and November 2006 students from Curtin University of Technology (CUT) and the University of Western Australia (UWA), initiated surveys in the northern part of the NMP to characterise finescale fish and coral communities, and map the geomorphology and sediment distribution, aiding in the development of broadscale coral reef habitat maps of the inshore component of the Ningaloo Reef. This research meets needs originally identified in the *Ningaloo Marine Park Management Plan 2005*. Subsequently the Western Australian Marine Science Institution (WAMSI) has outlined the key research priorities needed for geomorphic, sedimentary and habitat investigations. Initially this includes an understanding of their spatial distribution and characterisation.

The main goal of this study is to improve the understanding of the character of the geomorphology and surficial deposits of the Ningaloo Reef system. This report covers the inshore parts of Objective 1 and 2 in WAMSI Node 3 Project 3.4. The project will focus on mapping the reef system with remote sensing imagery (aerial photography and hyperspectral imagery) and collecting ground-truthing data including georeferenced video transects, sediment grabs, rock samples and shallow cores. The relationships determined at this scale may be used to inform our understanding of benthic habitat variability across the whole Marine Park. Known relationships will be extrapolated to the broader area to aid in the production of broadscale habitat maps of the Ningaloo Marine Park (NMP).

In this context the first two of four finescale surveys of habitats, sediments, geomorphology and reef fish assemblages, a collaborative effort with a UWA PhD student under WAMSI Project 3.2, were completed in July and November 2006. Using diver operated benthic video, specific lagoon habitats were surveyed and broadscale sediment grabs were collected. Further surveys will take place in July and November of 2007.

The underlying geologic framework and geomorphology provide the primary control on benthic habitats and communities within the shallow waters of NMP. Initial results have characterised specific lagoon habitats across the main geomorphic zones of the reef including; outer reef flat coralline algae/coral community, middle/inner reef flattabular *Acropora* community, inner reef flat patchy staghorn, massive and submassive coral community, lagoonal sand flats with sparse corals and algae community, Coral "bommies" and algal patch reef community in lagoonal and inter-reef gutters, macroalgal community on lagoon pavement shoreward of reef passes, mixed coral, algae, rubble/sand communities in reef passes and a diverse coral community in lagoonal channels. Additional investigations will further quantify these habitats and communities and provide detailed information on the coral communities. Further information collected on habitat validation and sediment distribution will aid in the production of broadscale GIS habitat maps based on a hierarchical coral reef classification scheme of the NMP.

RESEARCH ACTIVITY

1. LONG TERM GOAL

Geological and sedimentological data are to be consolidated into a Geographic Information System (GIS) to aid in the production of geomorphic, surficial sedimentary facies and benthic habitat maps of the reef system of the 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 shallow inshore waters of the NMP. The interrelationship between sedimentary characteristics and geomorphology, and there influence on the spatial distribution of benthic habitats and communities will be determined. The project will focus on mapping the coral reef with remote sensing (aerial photography and hyperspectral imagery) and collecting georeferenced video data and sediment grabs to verify interpretations. The characterisations determined at this scale will improve our understanding of benthic habitat variability across the NMP.

2. INTRODUCTION

The Ningaloo Reef, situated on the central west coast, is Australia's largest fringing coral reef extending southward from 22°S for approximately 290 km, and the only extensive reef in the world fringing the west coast of a continent. The Ningaloo Reef is one of the last relatively pristine major coral reef systems in the world. Its remote location has so far prevented over-development of the area, providing an ideal case study to advance baseline understanding of near pristine reef geomorphology, sediment distribution and habitats and establish the current condition of the reef for the evaluation and monitoring of future change. The location and geomorphology of the reef environments has a critical relationship with the oceanography within and surrounding the Marine Park and the complex intertidal and subtidal geomorphology plays a significant role in the variety of marine habitat types and correspondingly high species diversity.

The characterisation and conservation of benthic habitats and communities based on physical factors is central in the ongoing monitoring and management of the NMP.

Physical factors including geomorphology, sediment composition (texture, mineralogy and constituents), mobility of the substrate, bathymetry, the texture of the seabed and water depth, can be significant in describing the distribution of benthic biota and habitat types over broad geographic regions (Roff et al., 2003; Beaman et al., 2005).

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 remote sensing surveys to characterise the nature of the reef system 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). Grab samples also provide direct information for comparison with biological data such as benthos and fish distributions.

The main goal of the inshore component of WAMSI Project 3.4 is to improve the understanding of the character of the geomorphology and surficial deposits of the Ningaloo Reef system. There are strong collaborative linkages with WAMSI Node 3 Project 3.2 Ecosystem effects of fishing, with shared fieldwork and datasets. Project 3.4 will focus on mapping the reef with remote sensing and collecting georeferenced video data and sediment grabs. The relationships determined at this scale may be used to inform our understanding of benthic habitat variability across the whole Marine Park. Known relationships will be extrapolated to the broader area to aid in the production of broadscale inshore geomorphic, sedimentary and habitat maps of the NMP.

3. BACKGROUND

3.1. Quaternary Geology and Evolution

Fringing reef growth would appear to be intimately linked to sea-level, growing to or maintaining a crest at the surface, with sea-level fluctuations and corresponding climate change being the principal factors that determine the growth and geomorphology of coral reefs. The sea surface determines the absolute accommodation space for a given reef and the ability of the reef to keep-up or catch-up to the sea-level surface, or give-up in the case of drowned reefs (Kennedy & Woodroffe, 2002). Seismic profiling and a coring and dating program at Ningaloo Reef, along a transect through a reef pass, has provided the first details of the morphology and growth history of the Ningaloo Reef, evaluation of its relationship with the underlying fossil reef, and determined the role of this foundation in controlling Holocene reef development (Figure 1, Collins et al., 2003). Two periods of reef development in the northern part of the reef have been identified: Holocene and Last Interglacial. Holocene reef development is limited to depths of less than 30 m and reaches a maximum thickness of circa 10-15 m below the reef crest. U/Th dates from the Last Interglacial section, give ages toward the end of the last sea-level highstand (120-115 ka) where sea level was 2-3 m higher than present levels. Last Interglacial reef growth was more extensive of the two, as a result of the stronger Leeuwin Current at this time, thought to have suppressed upwelling during highstand periods, and provided an antecedent foundation for Holocene reef development. A continuing study as part of the objectives for WAMSI Node 3.4, on the Quaternary evolution of the Ningaloo Reef to map, date, document and interpret the growth histories of the reef system, will identify the importance of reef growth characteristics and morphology for the maintenance of reef biodiversity and provide an understanding of reef conditions and natural variability over evolutionary timescales.

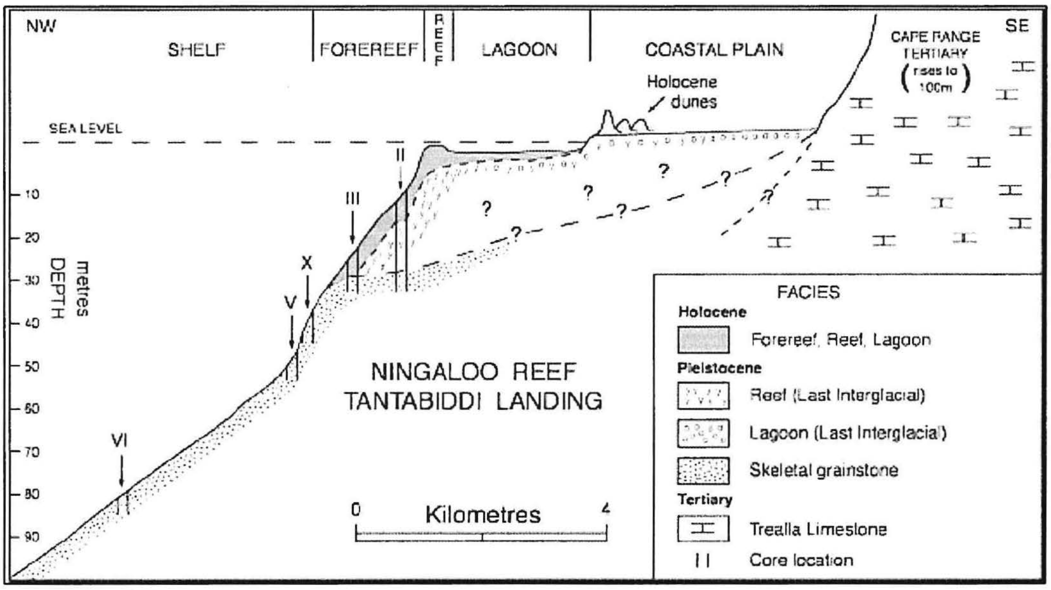


Figure 1: Idealised northwest-southeast cross section of northern Ningaloo Reef based on the cored transect and seismic data at Tantabiddi (Collins et al. 2003).

3.2. Reef and Seabed Geomorphology

Many coral reefs exhibit distinctive patterns of geomorphic zonation which have been attributed to the interaction of reef processes and the physical environment (Stoddard, 1969). Typical zones including the fore reef, reef crest, reef flat, back reef and lagoon, are associated with characteristic depths and benthic community structures that have evolved to adapt under the specific conditions present. These spatial patterns occur at spatial scales from ten to hundreds of metres.

The Ningaloo Reef forms a discontinuous barrier, running adjacent to the foreshore, enclosing a lagoon with an average width of 2.5 km. The reef complex consists of a narrow reef crest with well developed spur and groove morphology on the outer reef slopes, which is backed by a reef flat that has robust coral communities, coral veneers and deep grooves floored by sandy sediment. The shallow (0-4 m depth) lagoon has occasional patch reefs, rock pavements with sparse corals and unconsolidated sandy substrates with scattered coral communities. The lagoon shore is sandy and has rock pavements vegetated by macroalgae, with low cliffs and emergent platforms of Last Interglacial reef limestones (Collins et al., 2003). Reef development is interrupted by passes and transverse channels, which are sites for water exchange between the lagoon and the adjacent shelf, incised by channels eroded during sea-level lowstands, as suggested by links to relict and current ephemeral creeks.

The complex intertidal and subtidal geomorphology of the reserves plays a significant role in the variety of marine habitat types and corresponding high species diversity. There is little information however, on the relationships, patterns and influence of geomorphology on the distribution of habitats, communities and substrates within the Marine Park. For example in the offshore waters it is believed that linear drowned reefs influence nutrient flows and the feeding behaviour of whale sharks. Reef structures such as drowned terraces and spur and groove formations in the fore reef zone, and alluvial fan and relict channel structures eroded during low sea-level periods, could potentially be important habitat zones that will be investigated as part of WAMSI Project 3.4.

3.3. Surficial Sediment Facies

The sediments of the NMP are generally characterised by calcareous sands in the shallow lagoon and by calcareous fine sands and silts in the deeper offshore waters (Carrigy & Fairbridge, 1954; James et al., 1999; CALM & MPRA, 2005). Within the lagoonal complex of Ningaloo Reef exist vast expanses of intertidal and subtidal siliciclastic and carbonate sediments. These habitats shelter rich and diverse communities of plants, invertebrates, fish and birds (Alongo et al., 1996). The sediment quality of the reserves is high and generally undisturbed, apart from localised and low level contamination in some relatively high boat use areas (e.g. southern Bills Bay), and is essential to the maintenance of a healthy ecosystem within the NMP (CALM & MPRA, 2005). Characterisation of the mineralogy, biota and size analysis of these sediments will provide baseline conditions to assist in the interpretation of sediment infauna and contaminants at selected areas.

4. METHODOLOGY

This research presents an interdisciplinary study through the use of GIS, aerial remote sensing mapping techniques, traditional sedimentological sampling and ground-truthing methods. The project has strong collaborations with WAMSI Node 3 Project 3.2 and includes shared fieldwork and datasets. Surveys were initiated in four areas of the northern part of the NMP in 2006 to characterize and develop broadscale habitat maps of the shallow inshore component of the Marine Park. The focal point of the 2006 surveys was benthic habitat, geomorphology and sediment characterization, and reef fish assemblages. All the surveys were conducted from a 5.5m shallow draft, aluminium pontoon research boat enabling access to shallow sites <1m in depth and fitted with a davit arm and electric winch (Figure 2).

Figure 2: UWA Research boat used for shallow water surveys.

4.1. Preliminary Analysis

Shallow Water Classification Scheme

Traditionally habitat maps have mixed geomorphology (e.g. spur and groove zone), physiognomy (e.g. coral reef), ecology (e.g. turf algae) and geological history (e.g. relict reef) due to non-systematic approaches (Mumby and Harborne, 1999). A hierarchical classification that incorporates geomorphology, substrates, biota and physical factors, ensures that these classes are not mixed, and thus provides additional flexibility when describing specific habitats. A functional habitat should therefore be a mixture of these different classes and variables. Geomorphological classes are generally easy to label due to the nomenclature used in previous classification schemes (Hopley, 1982; Kulcher, 1986; Holthus & Maragos, 1995) and their visually distinct boundaries. A number of previous classification schemes have included geomorphology, as these are generally relatively simple to distinguish from remotely sensed data (Mumby & Harborne, 1999; Edinger & Risk, 2000; Coyne et al., 2001; Kendall et al, 2001; Cassata & Collins, 2004; NOAA, 2004).

The classification scheme is largely based on a scheme established by NOAA's biogeography program (Coyne et al., 2001; Kendall et al., 2001) (Table 1), and influenced by the existing state-wide classification scheme (Bancroft, 2002) and schemes for other coral reef habitats (Hopley, 1982; Kuchler, 1986; Holthus & Maragus, 1995; Greene et al., 1999). It defines benthic habitats on the basis of five attributes: (1) the major structure or underlying substrate, (2) the dominant structure, (3) the major biological cover found on the substrate, (4) the percentage of major biological cover, and (5) the geomorphic zone indicating the location of the habitat (Figure 3). The hierarchical nature of the scheme allows users to expand or collapse the level of thematic detail as necessary. The scheme has been used as a starting point, but modifications will be made once analysis of remote sensing and field data has been completed, to better reflect the specific habitats types.

Geomorphic Zone Types:	Geomorphological Structure Types:	Biological Cover Types:
Shoreline Intertidal	**Unconsolidated Sediment:**	**Live Coral**
Vertical Wall	Sand	Sparse 10% > 50%
Lagoon	Mud	Patchy 50% > 90%
Back Reef	**Coral Reef and Hardbottom:**	Continuous 90% - 100%
Reef Flat	Spur and Groove	**Seagrass**
Reef Crest	Patch Reefs:	Sparse 10% > 50%
Fore Reef	Individual Patch Reef	Patchy 50% > 90%
Bank/Shelf	Aggregate Patch Reef	Continuous 90% - 100%
Bank/Shelf Escarpment	Aggregate Reef	**Macroalgae**
Channel	Scattered Coral/Rock	Sparse 10% > 50%
Dredged	Pavement	Patchy 50% > 90%
Unknown	Rock/Boulder (Carbonate)	Continuous 90% - 100%
Land	Reef Rubble	**Coralline Algae**
	Pavement with Sand Channels	Sparse 10% > 50%
	Other Delineations:	Patchy 50% > 90%
	Artificial	Continuous 90% - 100%
	Unknown	**Turf Algae**
		Sparse 10% > 50%
		Patchy 50% > 90%
		Continuous 90% - 100%
		Emergent Vegetation
		Uncolonized
		Unknown
		Unclassified

Table 1: Example classification based on NOAA shallow water habitat s (Coyne et al, 2001).

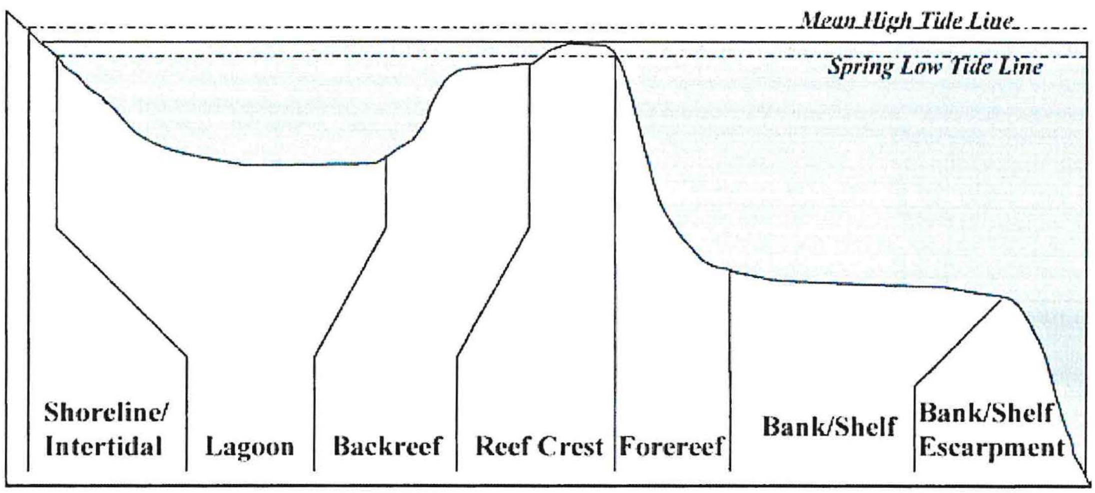


Figure 3: Typical geomorphic zones of fringing reefs (Coyne et al, 2001).

Aerial Photographs - 'Heads-up' Digitising

Aerial photography interpretation of the shallow areas (0-~20 m) will be determined using digital orthorectified images. These images are at a scale of 1:20,000 and 1:25,000, with pixel resolution of 0.4 m and 1.4 m respectively. This dataset will be used as a base layer in the GIS and interpretation will allow geomorphic and habitat boundaries to be identified visually, delineated and labelled manually as polygons directly into ESRI's ArcGIS software, using the NOAA Habitat Digitiser extension (NOAA, 2004). This extension allows users to delineate habitat areas and assign attributes to the habitat polygons based on the preliminary classification scheme. Where there is no clear boundary between habitats, supplementary data will guide the decision, including field data, local knowledge, previous data sets and contextual editing. Digitising will be at a scale of 1:6000 with a Minimum Mapping Unit (MMU) of 100 m. The preliminary maps produced will be further ground-truthed in the field to determine thematic accuracy.

Hyperspectral Imagery

Hyperspectral data was collected in 2006 by Hyvista Corporation as part of the CSIRO Wealth from Oceans Cluster Project. The data is currently being processed by the Remote Sensing and Satellite Research Group (RSSRG) in the Department of Applied Physics and Imaging at Curtin University. A basic classification of ecological bottom types (sand, coral, seagrass and algae) based on spectral evaluations will be one of the main outputs and will aid in the classification of habitats within this study. This data will be combined with the geomorphological classification to create an open-ended hierarchical classification map. These maps will be further ground-truthed and checked in the field for representativeness of the habitats they are describing. Bathymetric maps have also been created from the hyperspectral imagery which will be used to aid in the interpretation of habitats and geomorphology of the reef system (Figure 4 and 5).

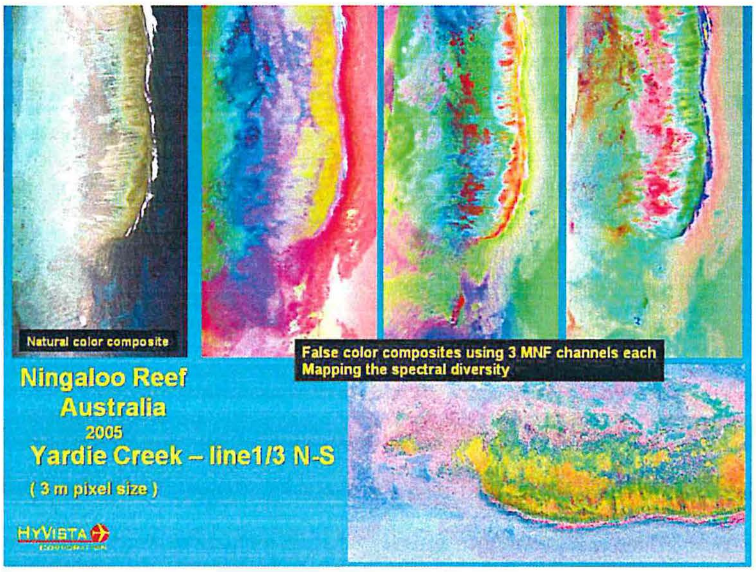


Figure 4: Hymap Imagery of Yardie Creek (HYVISTA Corporation).

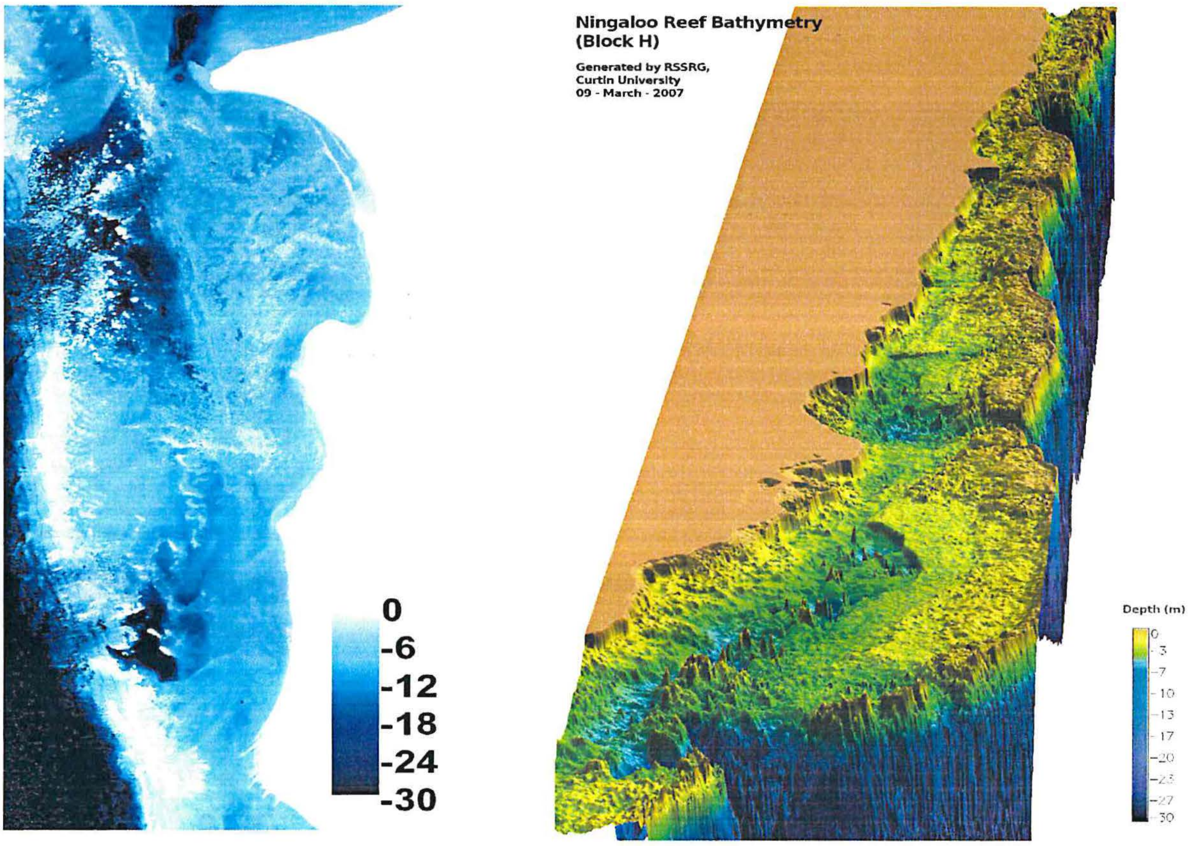


Figure 5: Example of 2D and 3D bathymetry extracted from Hyperspectral Imagery (Images processed by the Remote Sensing and Satellite Research Group (RSSRG), Curtin University).

4.2. Field Data Collection and Analysis

Habitat Validation and Coral Community Structure

Detailed habitat and coral community structure has been undertaken in selected areas in the Northern section of Ningaloo reef, adding to work previously done by Cassata and Collins (2004). Habitat validation to determine the accuracy of the preliminary habitat map, has included random checks of representative habitats and validation during sediment, diving and fish surveys.

For finescale surveys of communities, locations were identified where combinations of the most commonly encountered coral reef lagoon habitats in geomorphic zones across the reef could be found. Four areas were identified including Osprey and Mandu Sanctuary, and Osprey and Mandu Reference areas (Appendix 1). Each contains comparable coral lagoon habitats composed of some or all identified (Table 2).

Benthic Community	Geomorphic Feature
Coralline algae/coral community	Outer reef flat aligned coralgal and rubble zone
Tabular *Acropora* community	Middle/inner reef flat pavement
Patchy staghorn, massive and submassive coral community	Inner reef flat pavement
Sparse corals and algae community	Lagoonal sand flat
Coral "bommies" and algal patch reef community	Lagoonal and inter-reef gutters
Macroalgal community	Lagoon pavement shoreward of reef passes
Coral, algae, rubble/sand communities	Reef passes
Diverse coral community	Lagoonal channel

Table 2: Inshore communities and related geomorphic substrates, identified in the western Ningaloo Reef. Modified from Cassata and Collins (2004).

Preliminary co-ordinates for Scuba Benthic Video were chosen randomly within each habitat type at each of the four locations. A random point generator extension in ArcGIS was used to choose random points within each habitat type for the initial starting co-ordinates of the first transect. The choice of sites was constrained by the need to accommodate 5 x 50 m transects with spaces between. Random numbers between -5 and +5 were assigned to each replicate and used to deviate a predetermined compass bearing along which video was taken. Resulting co-ordinates were projected into WGS84 datum and uploaded to a handheld Garmin ETrex GPS for use in the field.

Scuba divers were deployed from the research boat to swim 5 x 50m transects with the first diver operating the stereo Diver Operated Video (Stereo-DOV) for fish investigations, and the second filming benthic video (Figure 6). Replicates were spaced 10-20 m apart and swam on a predetermined bearing randomly adjusted between 10 degrees of range to ensure habitat remained as uniform as possible across replicate transects. As transects were swam, a biodegradable cotton counter was deployed to precisely measure 50 m, each of which were timed to take between 4 and 5 minutes. Benthic video captured by the second diver will be analysed to quantify biophysical habitat variables. The Australian Institute of Marine science Automated Video Transect Analysis System (AVTAS) will be used for this purpose. This was developed by AIMS to monitor the status of benthic communities in the Great Barrier Reef (Page et al, 2001).

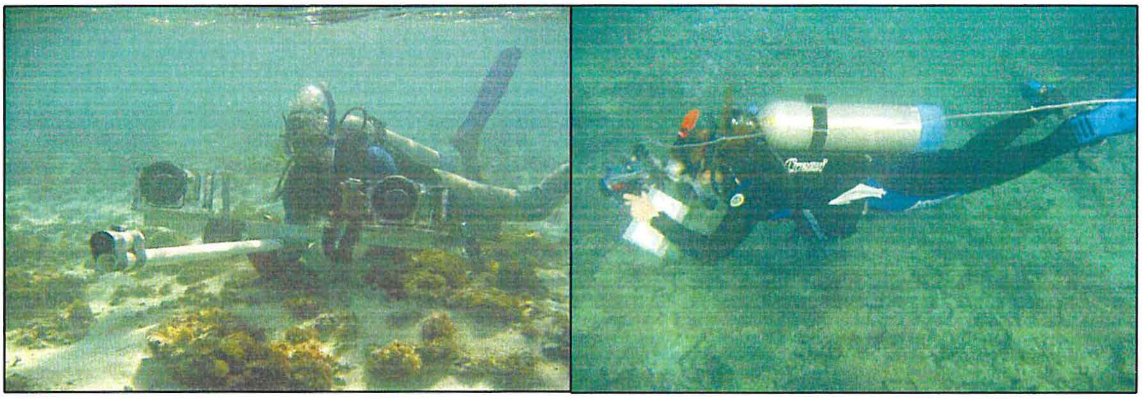


Figure 6: Scuba video transects

Two sets of 120 transects across a range of shallow coral reef lagoon habitats have been collected during 2006 surveys (Table 3 and Appendix 2).

	Reef pass	Porites bommies and sand	Reef flat coralline algae	Reef flat Tabulate acropora	Reef flat Branching acropora	Lagoon channel	Sparse corals and algae	Inshore algae
July 06 Benthic Video replicates	20	10	15	15	15	10	10	20
Nov 06 Benthic Video replicates	20	10	15	15	15	10	10	20

Table 3: Number of habitat transects undertaken in 2006.

Surficial Sediments

A total of 145 sediment samples were collected during snorkelling surveys in 2006 (Figure 7 and Appendix 3). Sampling sites were chosen to include geomorphic provinces of the lagoon from the dune systems to the reef crest and reef passes. Widely spaced systematic grid of samples was used in order to characterise each region and these were stratified in habitats across the reef lagoon and reef flat. (Appendix 1 and 3). Positions were fixed using a Garmin ETrex GPS and imported into ArcGIS for spatial analysis. Video of habitats were taken at each grab site 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 hyperspectral data. Sampling planned for the inshore sediments in 2007 surveys will collect sediments adjacent to offshore samples to provide sediment facies of the entire Ningaloo Reef (see Figure 8).

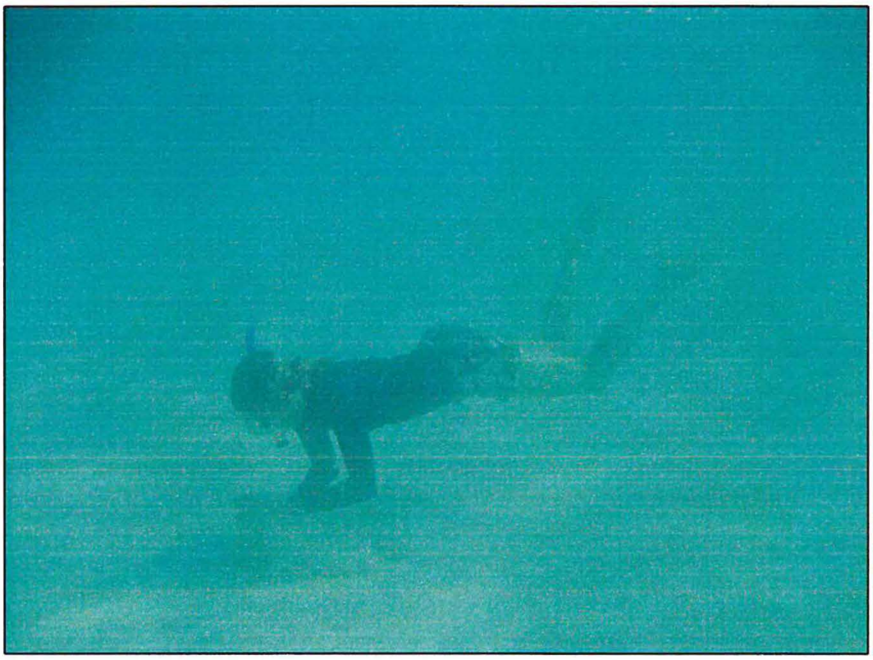


Figure 7: Sediment snorkeling grab samples in lagoonal sand flats

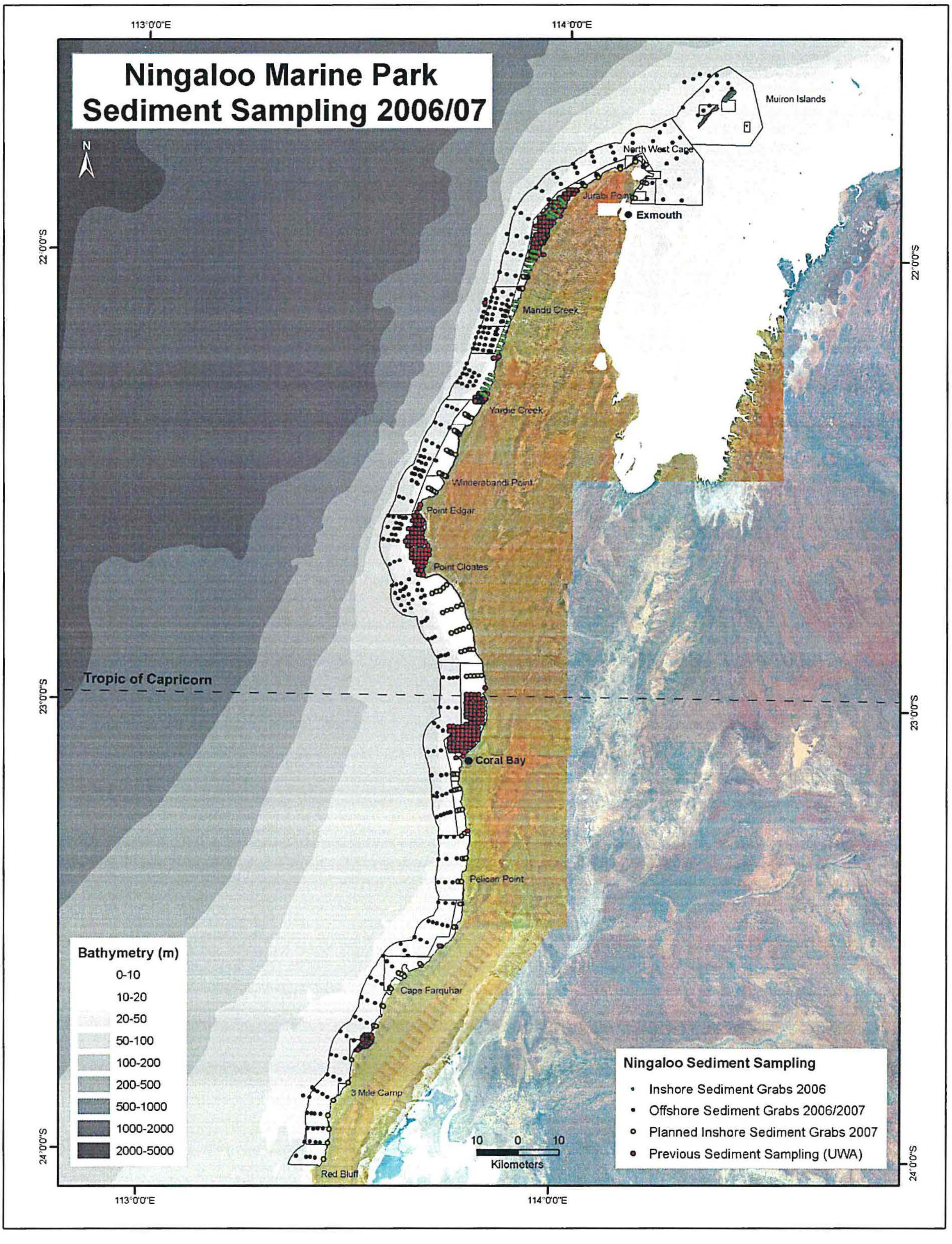


Figure 8: Sediment Grab sampling locations in the northern Ningaloo Marine Park.

4.3. Statistical Data Analysis and Interpretation

Accuracy Assessment

When maps are produced from aerial remote sensing imagery, a coefficient can be used that describes the agreement and accuracy between classes on the map and those observed during ground-truthing observations in the field (Green et al., 2000). The thematic accuracy of the maps will be determined at general and detailed levels within the classification, including both biological and geomorphological structure. User and producer accuracies will be determined for each classification class by using error matrices. The 'user accuracy' is the probability that a pixel classified on the image actually represents that category in the field and the 'producer accuracy' is the probability that any pixel in that category has been correctly classified. The overall accuracy will be determined by using the Tau coefficient, which has been shown to be the most meaningful measure in remote sensing studies (Ma & Redmond, 1995). Misinterpreted polygons will be corrected from the accuracy assessment, increasing the percentage accuracy of the final maps.

Video/Photo Analysis of Sedimentary Bedforms and Geomorphic Features

The AIMS AVTAS technique will be used to analyse the video data following the methods used by Abdo et al. (2003). Counts will be made for each biological and physical variable then standardised into the percent occurrence from each transect.

Sediment Granulometric and Component Analysis

In the laboratory sediments were initially washed in distilled water 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; grain size, component analysis, taxonomy of main biological constituents, and X - ray diffraction (XRD) for the determination of ratios of carbonate mineralogy.

Granulometric grain size analysis of the 2006 survey samples has been completed and analysis for the 2007 samples will be underway on completion of the surveys in July and

November. Dried samples were sieved using a mechanical sieve shaker with -1 – 4 Phi (Ø) sieve units at 0.5 Ø intervals based on the Udden-Wentworth grain size scale (Table 1 in Appendix 4). Wet sieving was necessary for samples with a silt and clay fraction exceeding 10% using a 4 Ø sieve. 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 reef. 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 format. 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 4 outlines the calculation of grain size statistics.

Quantitative component analysis will be undertaken on representative cross shelf sediment samples to examine the contribution of different marine organisms to the reef 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 of the main species of bryozoans, foraminifera, molluscs and coralline algae will be identified in representative samples. X-ray diffraction (XRD) will determine mineral composition on cross shelf samples in particular for mud sizes grains, including ratios of carbonate mineralogy.

Multivariate Classification of Field Data

Once the fieldwork has been completed, the complex data sets will need to be grouped into classes to simplify the data. Multivariate statistics allow the extraction of the natural groupings and hierarchical structure of the data. Similarities between sites of the benthic assemblages, sediments and substrates will be measured using multivariate classification and cluster analysis. The Bray-Curtis similarity coefficient has been shown to be one of the most robust measures of ecological distance and adapted by marine ecologists to objectively determine different assemblages (Bray & Curtis, 1957). Cluster analysis will then be used to identify natural patterns and occurrences in the reef assemblages, to allow classification and labelling of habitats and communities. With this method similarities (or dissimilarities) in pairs of sites can be determined with group average sorting algorithms, that allow different levels of descriptive resolutions to be defined and subsequently, representative habitat types that can be represented clearly on dendogram diagrams. Description of these classes can then be described using software, such as PRIMER with Similarity Percentage Analysis (SIMPER), to identify discriminating features (Clarke, 1993). Multivariate statistics have also been used to examine correlations between sediment component types, particle size, depositional environments and physiographical zones and will be used in this study to define recognisable sediment facies types (Gabrie & Montaggioni, 1982). Relationships identified between these physical and biotic values may identify factors that are reliable indicators or 'surrogates' of specific habitats. The relationships determined at this scale will improve our understanding of habitat variability and be used to aid in the production of inshore habitat maps for the Ningaloo Marine Park (NMP).

5. INITIAL RESULTS

5.1. Geomorphic Controls on Coral Reef Habitats

The underlying geologic framework and geomorphology of the reef provide the primary controls on benthic habitats with the Ningaloo Reef

Outer Reef Flat - Aligned coralgal and rubble zone

The high wave energy creates a distinct aligned coralgal 'spur and groove' morphology, with rubble to sand in longitudinal channels and rocky substrate on spurs. The living community consists of coralline algae (cover ≈ 80%) - encrusting dead corals, rocks and rubble- and hard corals (cover ≈ 20%). Coral are mainly small and compact tabular

Acropora colonies, but also massive and submassive forms on rocky substrate (Figure 9).

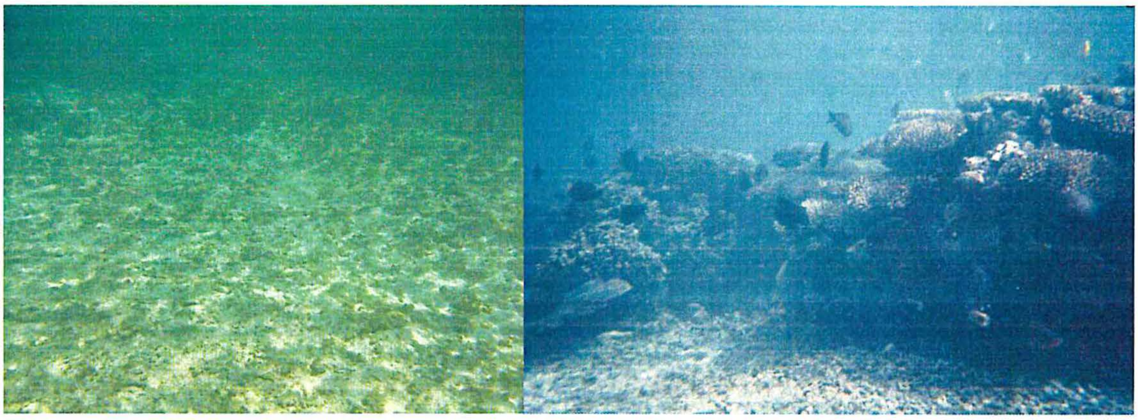
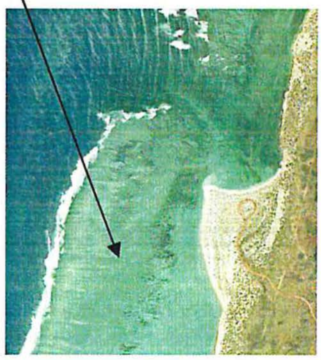


Figure 9: Aligned coralgal community and rubble zone

Middle to inner reef flat - Tabular Acropora community



Here there is extensive growth of tabular *Acropora* on a rocky pavement (50-90% cover). Water depth is about 1m and generally less turbulent than the outer reef flat, allowing more luxuriant growth of the tabulate forms. Although this habitat does not include a wide variety of coral species, it supports a high diversity and abundance of fish and other coral reef fauna (Figure 10).

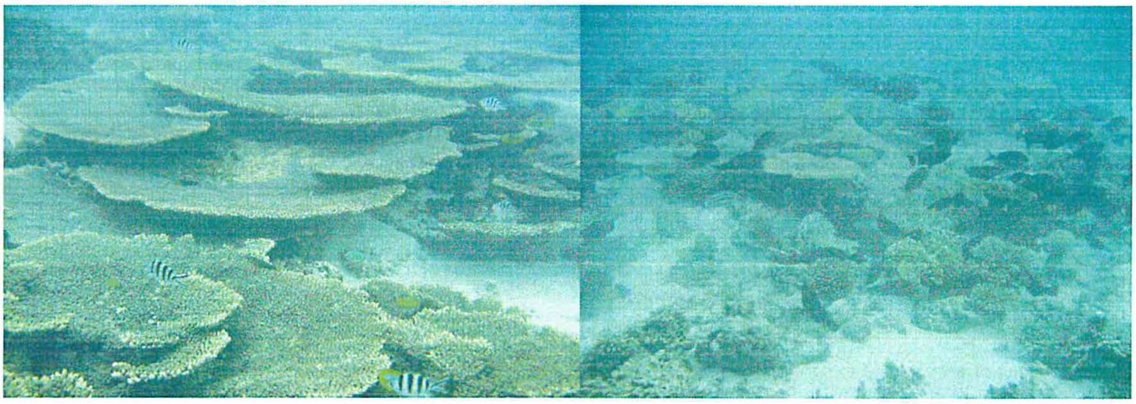
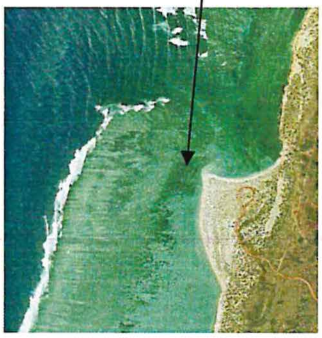


Figure 10: *Tabular Acropora community*

Inner reef flat - Patchy Acropora, massive and sub-massive coral community



This habitat consists of flat sandy floor, ~ 2 meters deep, with large (≥ 1 m across) coral colonies (cover between 20% and 50%), very diverse in morphology, mainly staghorn corals to landward and massive to sub- massive colonies to seaward. Some soft corals occur in this habitat as well usually close to the seaward boundary of the area (Figure 11) .

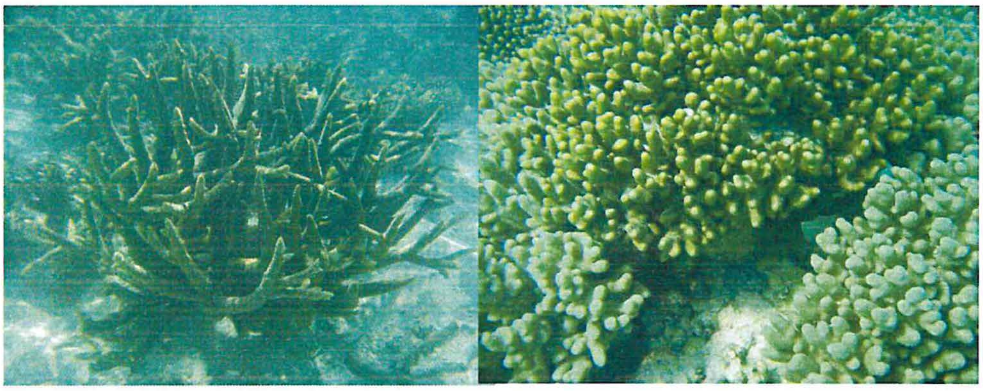
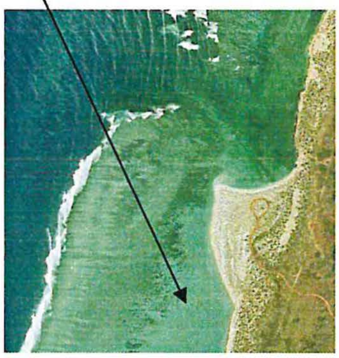


Figure 11: Patchy Acropora, massive and sub-massive coral community

Lagoonal sand flat - Sparse corals and algae community



This habitat is characterised by sheltered areas, with small clumps of low coral growth (*Acropora*, *Porites*) and scattered patches of macroalgae (e.g. *Sargassum*, *Halimeda*, *Caulerpa*) or seagrass (*Halophila*). The substrate is a shallow (1-2 m depth), flat limestone surface, usually covered by a veneer of rippled sand with sea cucumbers and worms (Figure 12).

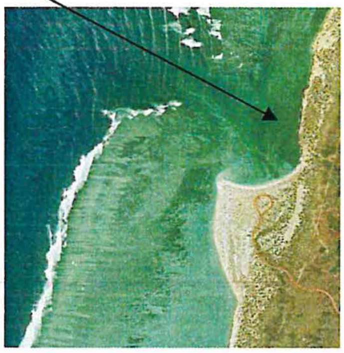
Figure 12: Sparse coral and algae community.

Lagoonal and inter- reef sandy gutters - Coral patch reef community

Sandy depressions are found either as large deep regions within lagoon or as small "holes" and gutters inside reef flat. Deeper (3-15 m depth) than surrounding areas and have steep edges forming a recognisable and distinctive habitat of bare, flat, sandy floor interrupted by clumps of brown and green algae and diverse coral "bommies". *Porites* is the dominant species with flat topped microatoll, truncated colonies, up to 5 m across, with tabular or staghorn *Acropora* often growing on top.

Figure 13: Coral patch reef community

Lagoon pavement - Macroalgal community



Brown algae up to 0.5 meters high (e.g. *Sargassum* spp.) are the dominant group in this habitat, best developed shoreward of the reef passes. These large fleshy macroalgae, together with minor red and green algae, typically colonise a subtidal limestone substratum with a sandy cover up to 10 cm thick. Small patches of hard and soft corals, sponges and ascidians can also be found, associated with the algae (Figure 14).

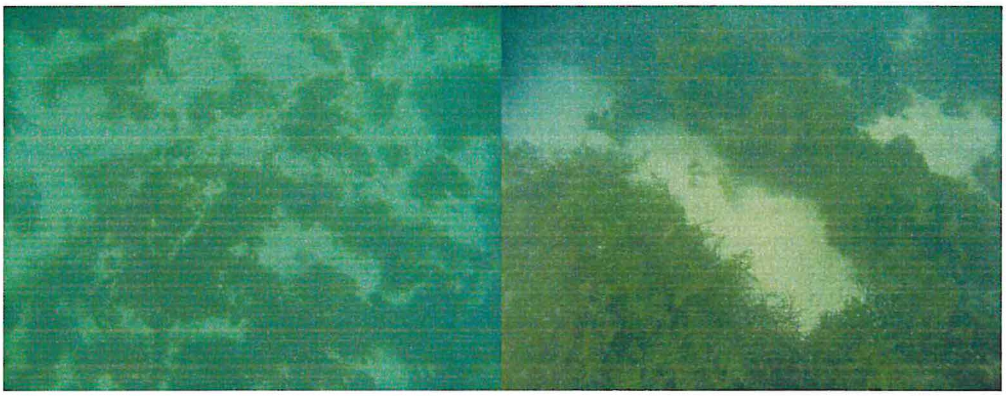
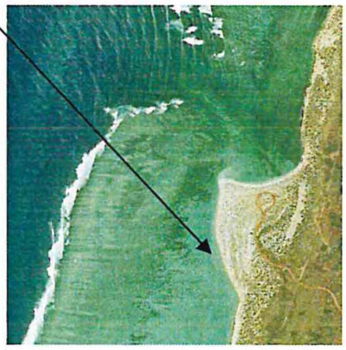


Figure 14: Macroalgae community

Lagoonal sand flat



This habitat comprises nearshore areas and is covered by white carbonate sand, rippled and unburrowed, usually overlying a limestone surface. It is typically bare supporting very little seasonal vegetation and invertebrate fauna (Figure 15).

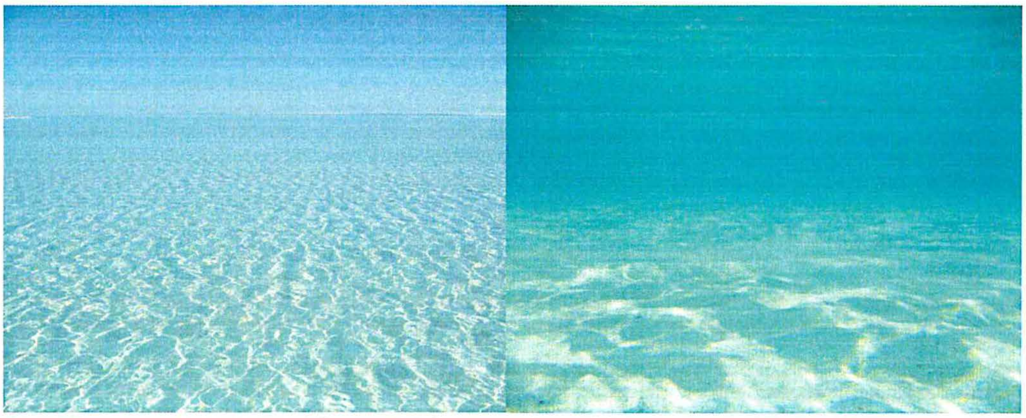


Figure 15: Lagoonal sand flats

Reef Passes - Coral, algae, rubble/sand communities

Reef passes are characterized by a mixture of diverse coral, macro and coralline algae and rubble and sand, influenced by strong tidal currents and lagoonal flushing. Coral communities are high in cover and include a wide variety of morphological forms and species (Figure 16).

Figure 16: Coral, algal, rubble/sand community

6. FUTURE FIELDWORK AND ANALYSIS

Further fieldtrips are planned for July and November 2007. Video transects will be supported by high resolution digital photographs taken with photoquats at 1m intervals along each 50 m transect. This will allow a more detailed characterisation of coral communities to genus level and morphology in each of the main coral reef habitats. Additional sediment grabs will be collected (see Figure 8) to complete all inshore samples for the entire length of the Ningaloo reef, adding to an offshore dataset already collected as part of WAMSI Project 3.4. Additional geomorphic features on the reef and their associated community structures will be investigated further. A coring program planned for late in 2007 and 2008 field season will determine the growth histories of the reef system and identify the importance of reef growth characteristics and morphology for the maintenance of reef biodiversity.

ACKNOWLEDGEMENTS

This research was funded by the WAMSI. The project is being undertaken in collaboration with WAMSI Node 3 Project 3.2 and includes shared field and vessel time. Thanks to all the volunteers who have helped on fieldtrips and to Helen Shortland-Jones for video analysis. Thanks to DEC for the use of research facilities at Ningaloo.

COMMUNICATION ACHIEVEMENTS

Presentations

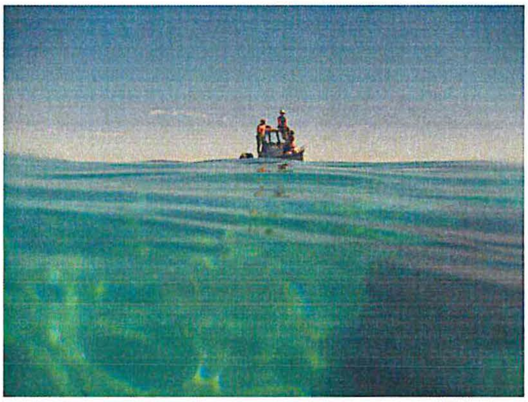
Ningaloo Tourism Futures Workshop June 2007 - Lindsay Collins, invited delegate.
WAMSI SHOW and TELL, March 2007 - Lindsay Collins, invited delegate and presenter.
WAMSI Launch, May 2007 - Lindsay Collins and Emily Twiggs, invited delegates.
WAMSI Symposium, July 2007 - Lindsay Collins and Emily Twiggs, proceedings abstracts.

Media Presentations

Emily WAMSI PhD Scholarship Award 2007 - awarded by the Premier of WA, Hon Alan Carpenter.

OTHER COMMENTS

There will be further collaborative fieldtrips during 2007/2008 associated with WAMSI Node 3 Project 3.2 Ecosystem Effects of Fishing.



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Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 19: 117-143.

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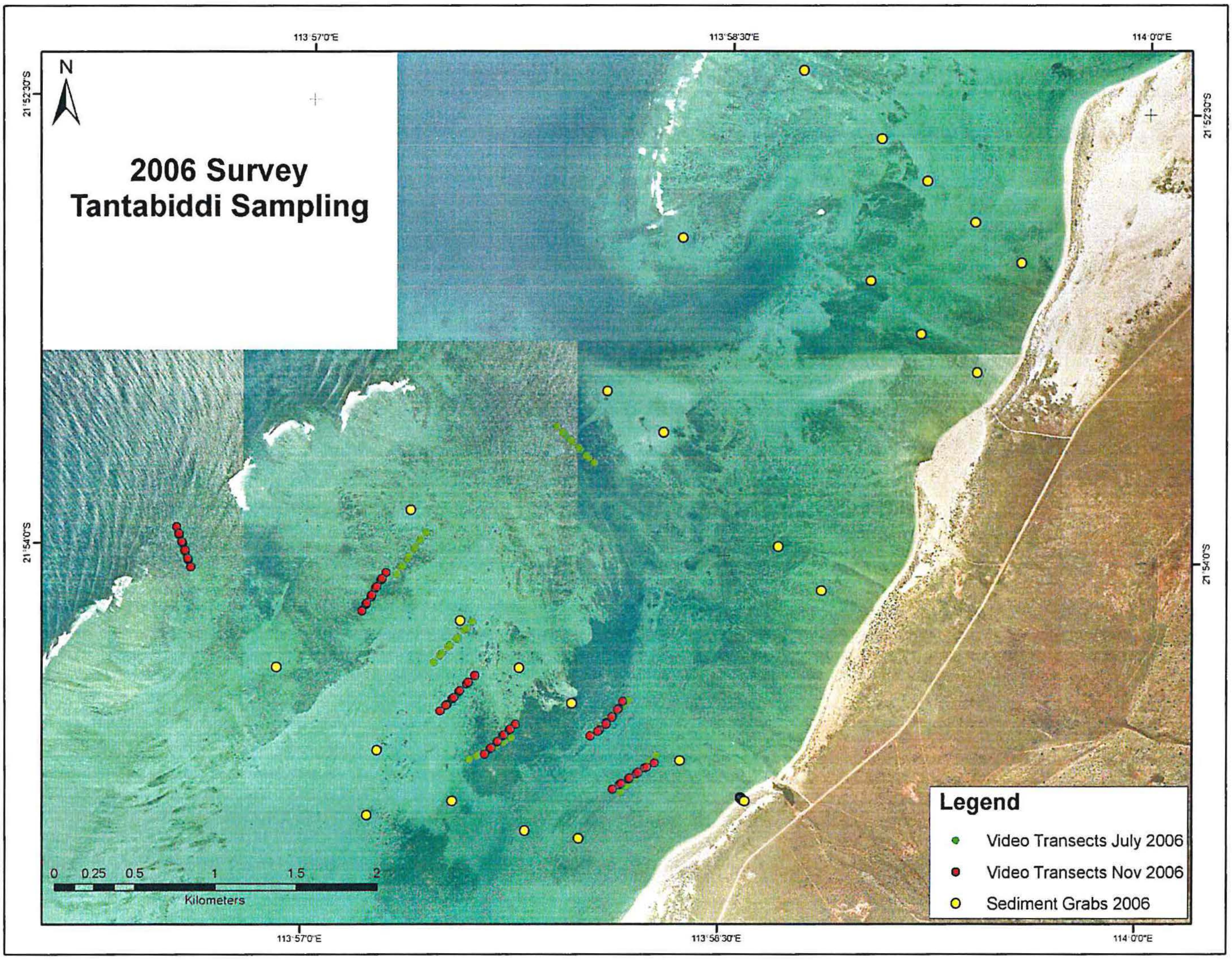
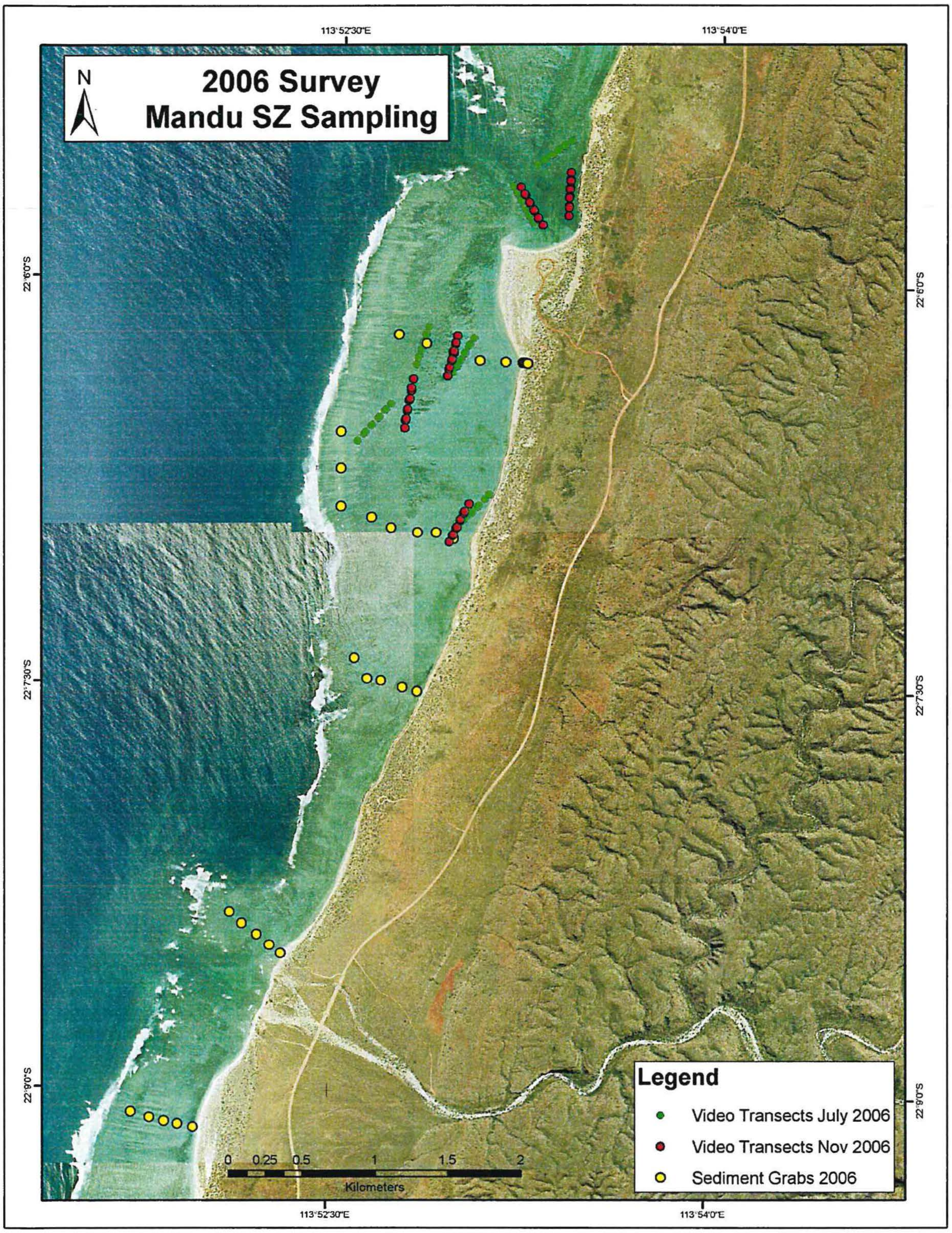
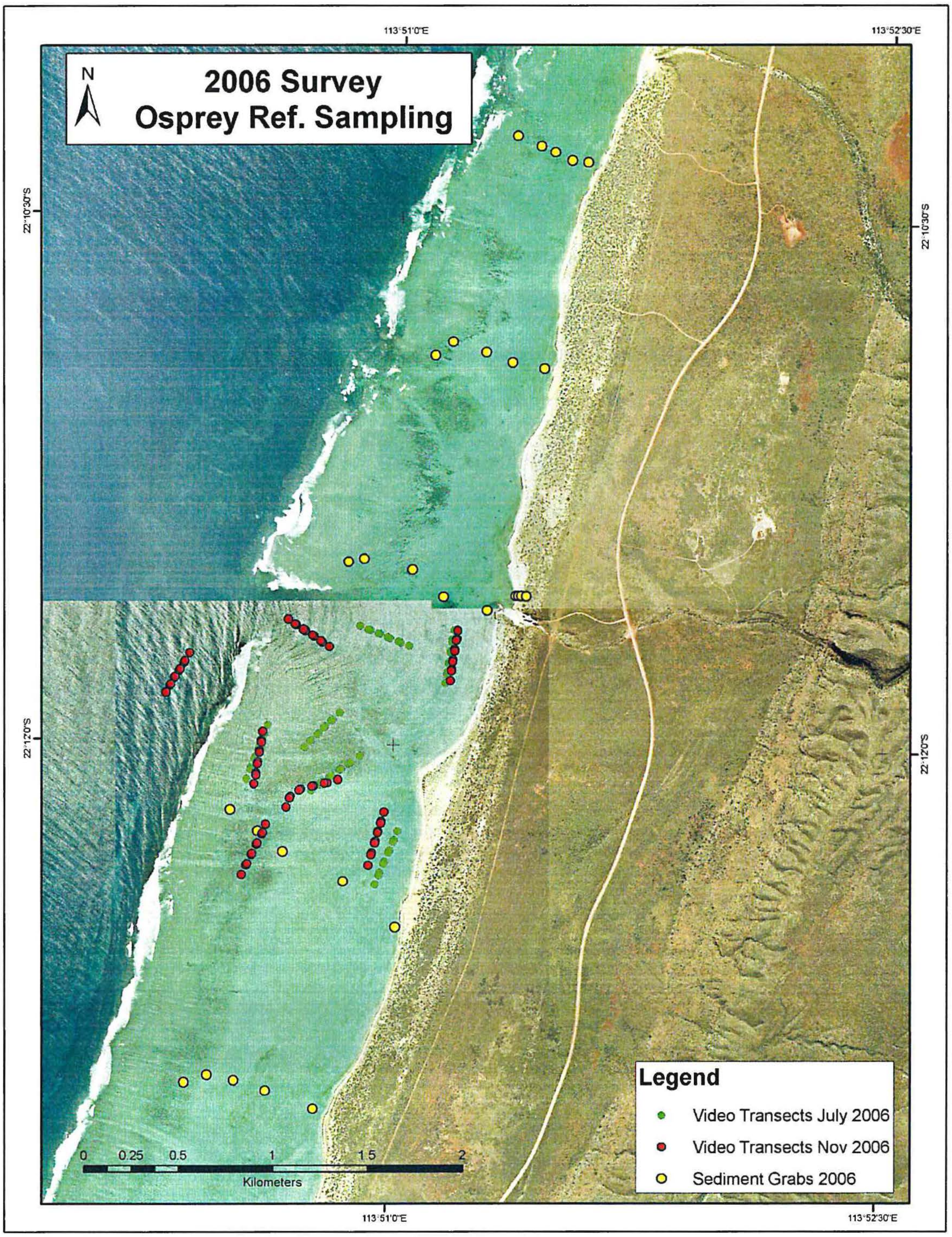
APPENDIX 1: 2006 Inshore Survey Maps

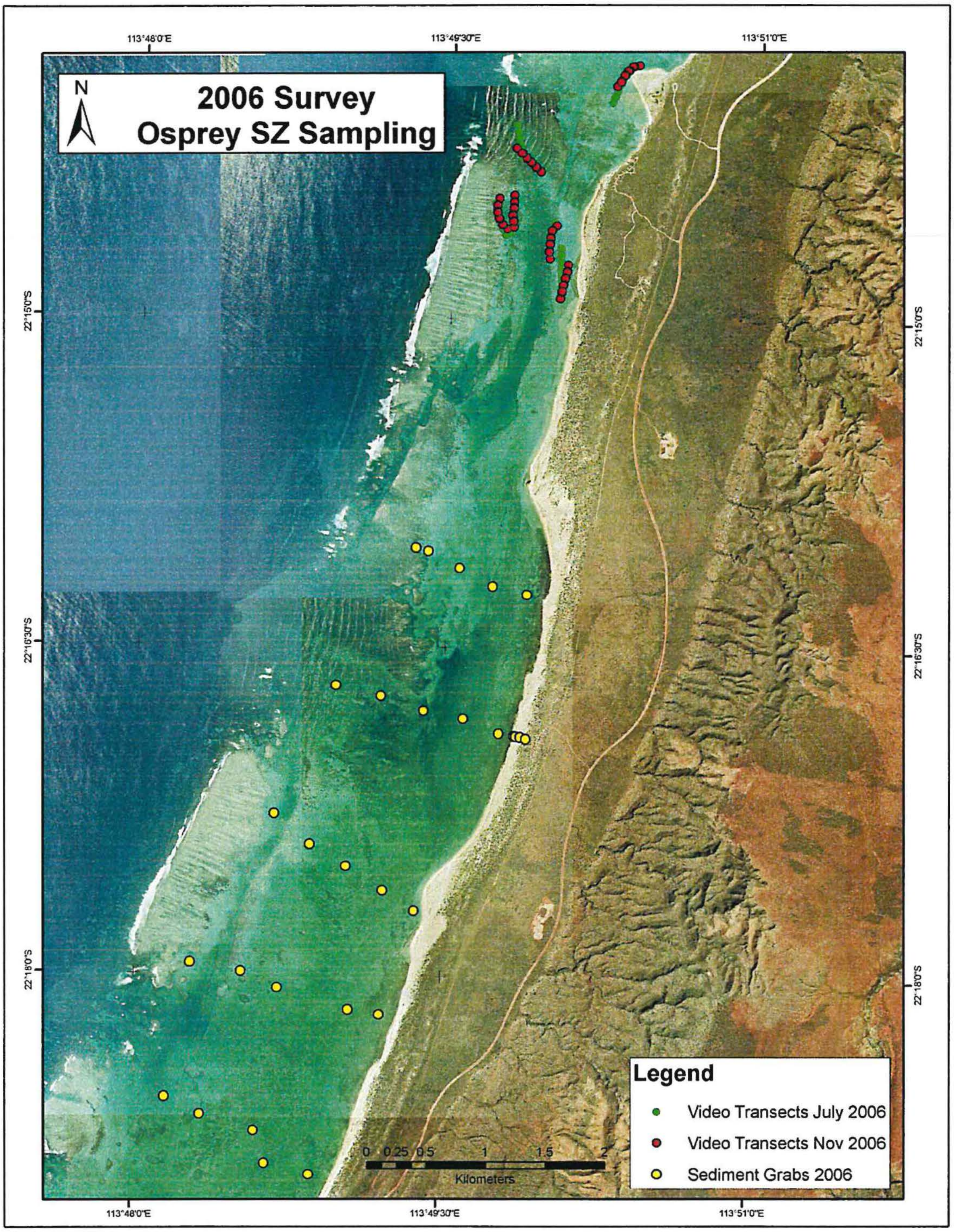
Appendix 1.1: 2006 Survey Maps for Tantabiddi (Mandy Reference), Mandu SZ, Osprey Reference and Osprey SZ.





2006 Survey
Mandu SZ Sampling
N
113°52'30"E
113°54'0"E
22°6'0"S
22°7'30"S
22°9'0"S
Legend
Video Transects July 2006
Video Transects Nov 2006
Sediment Grabs 2006
0 0.25 0.5 1 1.5 2
Kilometers


2006 Survey
Osprey Ref. Sampling
N
113°51'0"E
113°52'30"E
22°10'30"S
22°12'0"S
Legend
Video Transects July 2006
Video Transects Nov 2006
Sediment Grabs 2006
0 0.25 0.5 1 1.5 2
Kilometers


2006 Survey
Osprey SZ Sampling
N
113°48'0"E
113°49'30"E
113°51'0"E
22°15'0"S
22°16'30"S
22°18'0"S
Legend
Video Transects July 2006
Video Transects Nov 2006
Sediment Grabs 2006
0 0.25 0.5 1 1.5 2
Kilometers

APPENDIX 2: Benthic Video Metadata

Appendix 2.1 July 2006, WGS84.

OpCode	Location	Comments	Sampling	Replicate	Depth	Timein	Timeout		Latitude	Longitude
ABMR1	Mandu Reference	Branching acropora	BV	1	3.0	8:30	9:00	start	-21.91060	113.96205
								end	-21.91038	113.96244
ABMR1	Mandu Reference	Branching acropora	BV	2	3.0	8:30	9:00	start	-21.91085	113.96156
								end	-21.91066	113.96195
ABMR1	Mandu Reference	Branching acropora	BV	3	3.0	8:30	9:00	start	-21.91109	113.96108
								end	-21.91091	113.96145
ABMR1	Mandu Reference	Branching acropora	BV	4	3.0	8:30	9:00	start	-21.91136	113.96054
								end	-21.91116	113.96095
ABMR1	Mandu Reference	Branching acropora	BV	5	3.0	8:30	9:00	start	-21.91163	113.95997
								end	-21.91142	113.96041
ABMR2	Mandu Reference	Porites/sand	BV	1	5.0	8:00	8:30	start	-21.90587	113.95810
								end	-21.90626	113.95774
ABMR2	Mandu Reference	Porites/sand	BV	2	5.0	8:00	8:30	start	-21.90540	113.95858
								end	-21.90575	113.95821
ABMR2	Mandu Reference	Porites/sand	BV	3	5.0	8:00	8:30	start	-21.90493	113.95906
								end	-21.90529	113.95870
ABMR2	Mandu Reference	Porites/sand	BV	4	5.0	8:00	8:30	start	-21.90444	113.95954
								end	-21.90484	113.95917
ABMR2	Mandu Reference	Porites/sand	BV	5	5.0	8:00	8:30	start	-21.90397	113.96000
								end	-21.90435	113.95964
ABMR3	Mandu Reference	Reef pass	BV	1	8.0	15:00	15:30	start	-21.89469	113.96675
								end	-21.89498	113.96710
ABMR3	Mandu Reference	Reef pass	BV	2	8.0	15:00	15:30	start	-21.89425	113.96626
								end	-21.89459	113.96664
ABMR3	Mandu Reference	Reef pass	BV	3	8.0	15:00	15:30	start	-21.89383	113.96577
								end	-21.89415	113.96615
ABMR3	Mandu Reference	Reef pass	BV	4	8.0	15:00	15:30	start	-21.89341	113.96530
								end	-21.89373	113.96567
ABMR3	Mandu Reference	Reef pass	BV	5	8.0	15:00	15:30	start	-21.89299	113.96482
								end	-21.89331	113.96519
ABMR4	Mandu Reference	Reef flat rubble	BV	1	4.0	16:00	16:30	start	-21.90100	113.95570
								end	-21.90140	113.95545

ABMR004	Mandu Reference	Reef flat rubble	BV	2	4.0	16:00	16:30	start	-21.90051	113.95605
								end	-21.90090	113.95577
ABMR004	Mandu Reference	Reef flat rubble	BV	3	4.0	16:00	16:30	start	-21.89997	113.95642
								end	-21.90038	113.95613
ABMR004	Mandu Reference	Reef flat rubble	BV	4	4.0	16:00	16:30	start	-21.89950	113.95678
								end	-21.89988	113.95650
ABMR004	Mandu Reference	Reef flat rubble	BV	5	4.0	16:00	16:30	start	-21.89902	113.95713
								end	-21.89940	113.95685
ABMR005	Mandu Reference	Lagoon channel	BV	1	7.0	12:00	12:30	start	-21.90849	113.96911
								end	-21.90821	113.96945
ABMR005	Mandu Reference	Lagoon channel	BV	2	7.0	12:00	12:30	start	-21.90888	113.96866
								end	-21.90860	113.96901
ABMR005	Mandu Reference	Lagoon channel	BV	3	7.0	12:00	12:30	start	-21.90929	113.96818
								end	-21.90899	113.96854
ABMR005	Mandu Reference	Lagoon channel	BV	4	7.0	12:00	12:30	start	-21.90968	113.96775
								end	-21.90938	113.96809
ABMR005	Mandu Reference	Lagoon channel	BV	5	7.0	12:00	12:30	start	-21.91009	113.96731
								end	-21.90978	113.96764
ABMR006	Mandu Reference	Inshore algae	BV	1	2.0	10:30	11:00	start	-21.91297	113.96939
								end	-21.91330	113.96905
ABMR006	Mandu Reference	Inshore algae	BV	2	2.0	10:30	11:00	start	-21.91251	113.96985
								end	-21.91288	113.96949
ABMR006	Mandu Reference	Inshore algae	BV	3	2.0	10:30	11:00	start	-21.91209	113.97031
								end	-21.91243	113.96997
ABMR006	Mandu Reference	Inshore algae	BV	4	2.0	10:30	11:00	start	-21.91164	113.97075
								end	-21.91197	113.97040
ABMR006	Mandu Reference	Inshore algae	BV	5	2.0	10:30	11:00	start	-21.91121	113.97120
								end	-21.91155	113.97083
ABMZ001	Mandu Sanctuary	Inshore algae	BV	1	1.5	13:45	14:15	start	-22.09142	113.88974
								end	-22.09624	113.88765
ABMZ001	Mandu Sanctuary	Inshore algae	BV	2	1.5	13:45	14:15	start	-22.09171	113.88930
								end	-22.09149	113.88964
ABMZ001	Mandu Sanctuary	Inshore algae	BV	3	1.5	13:45	14:15	start	-22.09201	113.88888
								end	-22.09176	113.88921
ABMZ001	Mandu Sanctuary	Inshore algae	BV	4	1.5	13:45	14:15	start	-22.09231	113.88841
								end	-22.09207	113.88878
ABMZ001	Mandu Sanctuary	Inshore algae	BV	5	1.5	13:45	14:15	start	-22.09403	113.88635

								end	-22.09239	113.88830
ABMZ002	Mandu Sanctuary	Reef pass	BV	1	10.0	12:45	13:15	start	-22.09589	113.88743
								end	-22.09117	113.89012
ABMZ002	Mandu Sanctuary	Reef pass	BV	2	10.0	12:45	13:15	start	-22.09543	113.88716
								end	-22.09580	113.88736
ABMZ002	Mandu Sanctuary	Reef pass	BV	3	10.0	12:45	13:15	start	-22.09498	113.88691
								end	-22.09535	113.88712
ABMZ002	Mandu Sanctuary	Reef pass	BV	4	10.0	12:45	13:15	start	-22.09453	113.88663
								end	-22.09489	113.88685
ABMZ002	Mandu Sanctuary	Reef pass	BV	5	10.0	12:45	13:15	start	-22.09267	113.88789
								end	-22.09442	113.88657
ABMZ003	Mandu Sanctuary	Sand/coral	BV	1	1.5	9:00	10:00	start	-22.11462	113.88344
								end	-22.11493	113.88307
ABMZ003	Mandu Sanctuary	Sand/coral	BV	2	1.5	9:00	10:00	start	-22.11424	113.88388
								end	-22.11454	113.88353
ABMZ003	Mandu Sanctuary	Sand/coral	BV	3	1.5	9:00	10:00	start	-22.11383	113.88432
								end	-22.11416	113.88397
ABMZ003	Mandu Sanctuary	Sand/coral	BV	4	1.5	9:00	10:00	start	-22.11341	113.88477
								end	-22.11375	113.88441
ABMZ003	Mandu Sanctuary	Sand/coral	BV	5	1.5	9:00	10:00	start	-22.11303	113.88506
								end	-22.11336	113.88480
ABMZ004	Mandu Sanctuary	Branching acropora	BV	1	2.0	9:35	10:25	start	-22.10382	113.88362
								end	-22.10343	113.88388
ABMZ004	Mandu Sanctuary	Branching acropora	BV	2	2.0	9:35	10:25	start	-22.10430	113.88332
								end	-22.10392	113.88355
ABMZ004	Mandu Sanctuary	Branching acropora	BV	3	2.0	9:35	10:25	start	-22.10477	113.88303
								end	-22.10439	113.88327
ABMZ004	Mandu Sanctuary	Branching acropora	BV	4	2.0	9:35	10:25	start	-22.10513	113.88281
								end	-22.10480	113.88300
ABMZ004	Mandu Sanctuary	Branching acropora	BV	5	2.0	9:35	10:25	start	-22.10557	113.88253
								end	-22.10521	113.88276
ABMZ005	Mandu Sanctuary	Tabulate acropora	BV	1	1.2	10:30	11:00	start	-22.10320	113.88073
								end	-22.10280	113.88088
ABMZ005	Mandu Sanctuary	Tabulate acropora	BV	2	1.2	10:30	11:00	start	-22.10370	113.88057
								end	-22.10329	113.88070
ABMZ005	Mandu Sanctuary	Tabulate acropora	BV	3	1.2	10:30	11:00	start	-22.10415	113.88042
								end	-22.10376	113.88054

ABMZ005	Mandu Sanctuary	Tabulate acropora	BV	4	1.2	10:30	11:00	start	-22.10460	113.88026
								end	-22.10423	113.88040
ABMZ005	Mandu Sanctuary	Tabulate acropora	BV	5	1.2	10:30	11:00	start	-22.10511	113.88009
								end	-22.10470	113.88024
ABMZ006	Mandu Sanctuary	Reef flat rubble	BV	1	1.4	11:30	12:00	start	-22.10944	113.87669
								end	-22.10988	113.87628
ABMZ006	Mandu Sanctuary	Reef flat rubble	BV	2	1.4	11:30	12:00	start	-22.10894	113.87717
								end	-22.10934	113.87677
ABMZ006	Mandu Sanctuary	Reef flat rubble	BV	3	1.4	11:30	12:00	start	-22.10845	113.87762
								end	-22.10885	113.87724
ABMZ006	Mandu Sanctuary	Reef flat rubble	BV	4	1.4	11:30	12:00	start	-22.10798	113.87806
								end	-22.10837	113.87768
ABMZ006	Mandu Sanctuary	Reef flat rubble	BV	5	1.4	11:30	12:00	start	-22.10756	113.87847
								end	-22.10791	113.87812
ABOR001	Osprey Reference	Reef flat rubble	BV	1	2.0	9:00	9:30	start	-22.19960	113.84341
								end	-22.19915	113.84360
ABOR001	Osprey Reference	Reef flat rubble	BV	2	2.0	9:00	9:30	start	-22.20014	113.84318
								end	-22.19970	113.84336
ABOR001	Osprey Reference	Reef flat rubble	BV	3	2.0	9:00	9:30	start	-22.20065	113.84296
								end	-22.20024	113.84313
ABOR001	Osprey Reference	Reef flat rubble	BV	4	2.0	9:00	9:30	start	-22.20116	113.84274
								end	-22.20075	113.84292
ABOR001	Osprey Reference	Reef flat rubble	BV	5	2.0	9:00	9:30	start	-22.20171	113.84253
								end	-22.20127	113.84271
ABOR002	Osprey Reference	Tabulate acropora	BV	1	1.5	11:00	11:30	start	-22.19883	113.84691
								end	-22.19850	113.84727
ABOR002	Osprey Reference	Tabulate acropora	BV	2	1.5	11:00	11:30	start	-22.19916	113.84654
								end	-22.19889	113.84683
ABOR002	Osprey Reference	Tabulate acropora	BV	3	1.5	11:00	11:30	start	-22.19949	113.84621
								end	-22.19922	113.84647
ABOR002	Osprey Reference	Tabulate acropora	BV	4	1.5	11:00	11:30	start	-22.19983	113.84584
								end	-22.19955	113.84614
ABOR002	Osprey Reference	Tabulate acropora	BV	5	1.5	11:00	11:30	start	-22.20015	113.84551
								end	-22.19988	113.84577
ABOR003	Osprey Reference	Branching acropora	BV	1	2.0	12:00	12:30	start	-22.20192	113.84629
								end	-22.20222	113.84588
ABOR003	Osprey Reference	Branching acropora	BV	2	2.0	12:00	12:30	start	-22.20156	113.84679

								end	-22.20183	113.84638
ABOR003	Osprey Reference	Branching acropora	BV	3	2.0	12:00	12:30	start	-22.20122	113.84730
								end	-22.20150	113.84688
ABOR003	Osprey Reference	Branching acropora	BV	4	2.0	12:00	12:30	start	-22.20091	113.84775
								end	-22.20118	113.84737
ABOR003	Osprey Reference	Branching acropora	BV	5	2.0	12:00	12:30	start	-22.20053	113.84831
								end	-22.20086	113.84786
ABOR004	Osprey Reference	Reef pass	BV	1	5.0	10:00	10:30	start	-22.19515	113.85028
								end	-22.19527	113.85070
ABOR004	Osprey Reference	Reef pass	BV	2	5.0	10:00	10:30	start	-22.19493	113.84973
								end	-22.19509	113.85016
ABOR004	Osprey Reference	Reef pass	BV	3	5.0	10:00	10:30	start	-22.19474	113.84923
								end	-22.19489	113.84962
ABOR004	Osprey Reference	Reef pass	BV	4	5.0	10:00	10:30	start	-22.19457	113.84873
								end	-22.19471	113.84914
ABOR004	Osprey Reference	Reef pass	BV	5	5.0	10:00	10:30	start	-22.19436	113.84820
								end	-22.19454	113.84864
ABOR005	Osprey Reference	Inshore algae	BV	1	2.0	14:00	14:30	start	-22.19495	113.85290
								end	-22.19452	113.85298
ABOR005	Osprey Reference	Inshore algae	BV	2	2.0	14:00	14:30	start	-22.19547	113.85282
								end	-22.19506	113.85289
ABOR005	Osprey Reference	Inshore algae	BV	3	2.0	14:00	14:30	start	-22.19603	113.85275
								end	-22.19558	113.85281
ABOR005	Osprey Reference	Inshore algae	BV	4	2.0	14:00	14:30	start	-22.19651	113.85266
								end	-22.19611	113.85274
ABOR005	Osprey Reference	Inshore algae	BV	5	2.0	14:00	14:30	start	-22.19702	113.85259
								end	-22.19662	113.85265
ABOR006	Osprey Reference	Sand/coral	BV	1	1.5	13:00	13:30	start	-22.20449	113.85012
								end	-22.20407	113.85030
ABOR006	Osprey Reference	Sand/coral	BV	2	1.5	13:00	13:30	start	-22.20499	113.84990
								end	-22.20458	113.85008
ABOR006	Osprey Reference	Sand/coral	BV	3	1.5	13:00	13:30	start	-22.20552	113.84966
								end	-22.20509	113.84985
ABOR006	Osprey Reference	Sand/coral	BV	4	1.5	13:00	13:30	start	-22.20605	113.84941
								end	-22.20563	113.84962
ABOR006	Osprey Reference	Sand/coral	BV	5	1.5	13:00	13:30	start	-22.20660	113.84918
								end	-22.20617	113.84937

ABOZ001	Osprey Sanctuary	Tabulate acropora	BV	1	2.0	9:00	9:30	start	-22.24319	113.82916
								end	-22.24358	113.82935
ABOZ001	Osprey Sanctuary	Tabulate acropora	BV	2	2.0	9:00	9:30	start	-22.24271	113.82889
								end	-22.24310	113.82911
ABOZ001	Osprey Sanctuary	Tabulate acropora	BV	3	2.0	9:00	9:30	start	-22.24221	113.82868
								end	-22.24260	113.82884
ABOZ001	Osprey Sanctuary	Tabulate acropora	BV	4	2.0	9:00	9:30	start	-22.24168	113.82857
								end	-22.24213	113.82866
ABOZ001	Osprey Sanctuary	Tabulate acropora	BV	5	2.0	9:00	9:30	start	-22.24116	113.82850
								end	-22.24158	113.82856
ABOZ002	Osprey Sanctuary	Porites/sand	BV	1	5.5	10:00	10:30	start	-22.24125	113.82994
								end	-22.24081	113.82999
ABOZ002	Osprey Sanctuary	Porites/sand	BV	2	5.5	10:00	10:30	start	-22.24176	113.82993
								end	-22.24133	113.82994
ABOZ002	Osprey Sanctuary	Porites/sand	BV	3	5.5	10:00	10:30	start	-22.24231	113.82990
								end	-22.24186	113.82991
ABOZ002	Osprey Sanctuary	Porites/sand	BV	4	5.5	10:00	10:30	start	-22.24271	113.82986
								end	-22.24238	113.82989
ABOZ002	Osprey Sanctuary	Porites/sand	BV	5	5.5	10:00	10:30	start	-22.24325	113.82983
								end	-22.24281	113.82983
ABOZ003	Osprey Sanctuary	Lagoon channel	BV	1	7.0	11:00	11:30	start	-22.24308	113.83316
								end	-22.24260	113.83333
ABOZ003	Osprey Sanctuary	Lagoon channel	BV	2	7.0	11:00	11:30	start	-22.24364	113.83297
								end	-22.24318	113.83311
ABOZ003	Osprey Sanctuary	Lagoon channel	BV	3	7.0	11:00	11:30	start	-22.24420	113.83290
								end	-22.24375	113.83294
ABOZ003	Osprey Sanctuary	Lagoon channel	BV	4	7.0	11:00	11:30	start	-22.24476	113.83283
								end	-22.24430	113.83287
ABOZ003	Osprey Sanctuary	Lagoon channel	BV	5	7.0	11:00	11:30	start	-22.24530	113.83289
								end	-22.24485	113.83285
ABOZ004	Osprey Sanctuary	sand/coral	BV	1	1.5	12:00	12:30	start	-22.24499	113.83387
								end	-22.24453	113.83387
ABOZ004	Osprey Sanctuary	sand/coral	BV	2	1.5	12:00	12:30	start	-22.24552	113.83389
								end	-22.24508	113.83388
ABOZ004	Osprey Sanctuary	sand/coral	BV	3	1.5	12:00	12:30	start	-22.24598	113.83389
								end	-22.24560	113.83390
ABOZ004	Osprey Sanctuary	sand/coral	BV	4	1.5	12:00	12:30	start	-22.24650	113.83391

								end	-22.24608	113.83390
ABOZ004	Osprey Sanctuary	sand/coral	BV	5	1.5	12:00	12:30	start	-22.24707	113.83393
								end	-22.24660	113.83391
ABOZ005	Osprey Sanctuary	Reef pass	BV	1	6.0	8:00	8:30	start	-22.23729	113.83058
								end	-22.23772	113.83065
ABOZ005	Osprey Sanctuary	Reef pass	BV	2	6.0	8:00	8:30	start	-22.23680	113.83047
								end	-22.23720	113.83054
ABOZ005	Osprey Sanctuary	Reef pass	BV	3	6.0	8:00	8:30	start	-22.23633	113.83036
								end	-22.23672	113.83046
ABOZ005	Osprey Sanctuary	Reef pass	BV	4	6.0	8:00	8:30	start	-22.23585	113.83027
								end	-22.23625	113.83035
ABOZ005	Osprey Sanctuary	Reef pass	BV	5	6.0	8:00	8:30	start	-22.23527	113.83015
								end	-22.23575	113.83025
ABOZ6	Osprey Sanctuary	Inshore algae	BV	1	1.5	14:00	14:30	start	-22.23141	113.83870
								end	-22.23097	113.83892
ABOZ6	Osprey Sanctuary	Inshore algae	BV	2	1.5	14:00	14:30	start	-22.23194	113.83848
								end	-22.23150	113.83866
ABOZ6	Osprey Sanctuary	Inshore algae	BV	3	1.5	14:00	14:30	start	-22.23243	113.83825
								end	-22.23203	113.83843
ABOZ6	Osprey Sanctuary	Inshore algae	BV	4	1.5	14:00	14:30	start	-22.23290	113.83806
								end	-22.23253	113.83822
ABOZ6	Osprey Sanctuary	Inshore algae	BV	5	1.5	14:00	14:30	start	-22.23342	113.83783
								end	-22.23298	113.83800

Appendix 2.2: November 2006, WGS84.

OpCode	Location	comments	Gear	Replicate	depth	timein	timeout		lat	lon
BBMR1	Mandu Reference	Branching acropora	BV	1	4.0	8:00	8:40	Start	-21.91104	113.96119
								End	-21.91133	113.96085
BBMR1	Mandu Reference	Branching acropora	BV	2	4.0	8:00	8:40	Start	-21.91065	113.96159
								End	-21.91098	113.96126
BBMR1	Mandu Reference	Branching acropora	BV	3	4.0	8:00	8:40	Start	-21.91029	113.96193
								End	-21.91060	113.96164
BBMR1	Mandu Reference	Branching acropora	BV	4	4.0	8:00	8:40	Start	-21.90996	113.96230
								End	-21.91022	113.96201
BBMR1	Mandu Reference	Branching acropora	BV	5	4.0	8:00	8:40	Start	-21.90962	113.96266
								End	-21.90989	113.96236
BBMR2	Mandu Reference	Porites/sand	BV	1	5.0	22:05	22:40	Start	-21.90867	113.95850
								End	-21.90898	113.95815
BBMR2	Mandu Reference	Porites/sand	BV	2	5.0	22:05	22:40	Start	-21.90828	113.95887
								End	-21.90860	113.95856
BBMR2	Mandu Reference	Porites/sand	BV	3	5.0	22:05	22:40	Start	-21.90788	113.95926
								End	-21.90822	113.95896
BBMR2	Mandu Reference	Porites/sand	BV	4	5.0	22:05	22:40	Start	-21.90744	113.95971
								End	-21.90782	113.95933
BBMR2	Mandu Reference	Porites/sand	BV	5	5.0	22:05	22:40	Start	-21.90696	113.96019
								End	-21.90735	113.95979
BBMR3	Mandu Reference	Reef pass	BV	1	7	12:20	13:00	Start	-21.90079	113.94297
								End	-21.90120	113.94312
BBMR3	Mandu Reference	Reef pass	BV	2	7	12:20	13:00	Start	-21.90032	113.94279
								End	-21.90071	113.94294
BBMR3	Mandu Reference	Reef pass	BV	3	7	12:20	13:00	Start	-21.89986	113.94261
								End	-21.90025	113.94276
BBMR3	Mandu Reference	Reef pass	BV	4	7	12:20	13:00	Start	-21.89942	113.94241
								End	-21.89980	113.94257
BBMR3	Mandu Reference	Reef pass	BV	5	7	12:20	13:00	Start	-21.89898	113.94223
								End	-21.89935	113.94238
BBMR4	Mandu Reference	Reef flat rubble	BV	1	1.5	8:50	9:54	Start	-21.90311	113.95359
								End	-21.90347	113.95337
BBMR4	Mandu Reference	Reef flat rubble	BV	2	1.5	8:50	9:54	Start	-21.90268	113.95388
								End	-21.90303	113.95365
BBMR4	Mandu Reference	Reef flat rubble	BV	3	1.5	8:50	9:54	Start	-21.90220	113.95416
								End	-21.90258	113.95393
BBMR4	Mandu Reference	Reef flat rubble	BV	4	1.5	8:50	9:54	Start	-21.90175	113.95447

								End	-21.90211	113.95423
BBMR4	Mandu Reference	Reef flat rubble	BV	5	1.5	8:50	9:54	Start	-21.90132	113.95477
								End	-21.90166	113.95454
BBMR5	Mandu Reference	Lagoon channel	BV	1	5.0	23:06	23:45	Start	-21.90865	113.96885
								End	-21.90825	113.96908
BBMR5	Mandu Reference	Lagoon channel	BV	2	5.0	23:06	23:45	Start	-21.90908	113.96851
								End	-21.90871	113.96879
BBMR5	Mandu Reference	Lagoon channel	BV	3	5.0	23:06	23:45	Start	-21.90945	113.96814
								End	-21.90914	113.96844
BBMR5	Mandu Reference	Lagoon channel	BV	4	5.0	23:06	23:45	Start	-21.90985	113.96770
								End	-21.90952	113.96808
BBMR5	Mandu Reference	Lagoon channel	BV	5	5.0	23:06	23:45	Start	-21.91019	113.96716
								End	-21.90992	113.96761
BBMR6	Mandu Reference	Inshore algae	BV	1	3.0	13:30	14:10	Start	-21.91290	113.96897
								End	-21.91314	113.96858
BBMR6	Mandu Reference	Inshore algae	BV	2	3.0	13:30	14:10	Start	-21.91257	113.96950
								End	-21.91283	113.96908
BBMR6	Mandu Reference	Inshore algae	BV	3	3.0	13:30	14:10	Start	-21.91226	113.96998
								End	-21.91251	113.96958
BBMR6	Mandu Reference	Inshore algae	BV	4	3.0	13:30	14:10	Start	-21.91193	113.97048
								End	-21.91219	113.97009
BBMR6	Mandu Reference	Inshore algae	BV	5	3.0	13:30	14:10	Start	-21.91164	113.97104
								End	-21.91188	113.97060
BBMZ1	Mandu Sanctuary	Inshore algae	BV	1	1.5	8:00	8:40	Start	-22.09358	113.89005
								End	-22.09315	113.89007
BBMZ1	Mandu Sanctuary	Inshore algae	BV	2	1.5	8:00	8:40	Start	-22.09407	113.89003
								End	-22.09366	113.89005
BBMZ1	Mandu Sanctuary	Inshore algae	BV	3	1.5	8:00	8:40	Start	-22.09460	113.89000
								End	-22.09419	113.89002
BBMZ1	Mandu Sanctuary	Inshore algae	BV	4	1.5	8:00	8:40	Start	-22.09519	113.88998
								End	-22.09470	113.88999
BBMZ1	Mandu Sanctuary	Inshore algae	BV	5	1.5	8:00	8:40	Start	-22.09581	113.88998
								End	-22.09529	113.88999
BBMZ2	Mandu Sanctuary	Reef pass	BV	1	7	22:05	22:40	Start	-22.09601	113.88798
								End	-22.09642	113.88827
BBMZ2	Mandu Sanctuary	Reef pass	BV	2	7	22:05	22:40	Start	-22.09555	113.88770
								End	-22.09596	113.88795
BBMZ2	Mandu Sanctuary	Reef pass	BV	3	7	22:05	22:40	Start	-22.09511	113.88741
								End	-22.09547	113.88764

BBMZ2	Mandu Sanctuary	Reef pass	BV	4	7	22:05	22:40	Start	-22.09459	113.88711
								End	-22.09502	113.88735
BBMZ2	Mandu Sanctuary	Reef pass	BV	5	7	22:05	22:40	Start	-22.09408	113.88679
								End	-22.09449	113.88703
BBMZ3	Mandu Sanctuary	sand/coral	BV	1	1.0	12:20	13:00	Start	-22.11565	113.88266
								End	-22.11602	113.88247
BBMZ3	Mandu Sanctuary	sand/coral	BV	2	1.0	12:20	13:00	Start	-22.11518	113.88289
								End	-22.11558	113.88270
BBMZ3	Mandu Sanctuary	sand/coral	BV	3	1.0	12:20	13:00	Start	-22.11472	113.88316
								End	-22.11512	113.88295
BBMZ3	Mandu Sanctuary	sand/coral	BV	4	1.0	12:20	13:00	Start	-22.11425	113.88341
								End	-22.11464	113.88319
BBMZ3	Mandu Sanctuary	sand/coral	BV	5	1.0	12:20	13:00	Start	-22.11368	113.88372
								End	-22.11414	113.88345
BBMZ4	Mandu Sanctuary	Branching acropora	BV	1	1.0	8:50	9:54	Start	-22.10541	113.88224
								End	-22.10582	113.88215
BBMZ4	Mandu Sanctuary	Branching acropora	BV	2	1.0	8:50	9:54	Start	-22.10486	113.88239
								End	-22.10529	113.88228
BBMZ4	Mandu Sanctuary	Branching acropora	BV	3	1.0	8:50	9:54	Start	-22.10433	113.88252
								End	-22.10476	113.88241
BBMZ4	Mandu Sanctuary	Branching acropora	BV	4	1.0	8:50	9:54	Start	-22.10384	113.88265
								End	-22.10425	113.88254
BBMZ4	Mandu Sanctuary	Branching acropora	BV	5	1.0	8:50	9:54	Start	-22.10333	113.88275
								End	-22.10375	113.88267
BBMZ5	Mandu Sanctuary	Tabulate acropora	BV	1	1.0	23:06	23:45	Start	-22.10860	113.87942
								End	-22.10905	113.87937
BBMZ5	Mandu Sanctuary	Tabulate acropora	BV	2	1.0	23:06	23:45	Start	-22.10799	113.87952
								End	-22.10848	113.87943
BBMZ5	Mandu Sanctuary	Tabulate acropora	BV	3	1.0	23:06	23:45	Start	-22.10734	113.87964
								End	-22.10788	113.87954
BBMZ5	Mandu Sanctuary	Tabulate acropora	BV	4	1.0	23:06	23:45	Start	-22.10672	113.87976
								End	-22.10725	113.87967
BBMZ5	Mandu Sanctuary	Tabulate acropora	BV	5	1.0	23:06	23:45	Start	-22.10603	113.87990
								End	-22.10659	113.87977
BBOR1	Osprey Reference	Reef flat rubble	BV	1	1.5	13:30	14:10	Start	-22.19989	113.84325
								End	-22.19947	113.84332
BBOR1	Osprey Reference	Reef flat rubble	BV	2	1.5	13:30	14:10	Start	-22.20038	113.84317
								End	-22.19997	113.84324
BBOR1	Osprey Reference	Reef flat rubble	BV	3	1.5	13:30	14:10	Start	-22.20091	113.84309

								End	-22.20047	113.84316
BBOR1	Osprey Reference	Reef flat rubble	BV	4	1.5	13:30	14:10	Start	-22.20143	113.84300
								End	-22.20100	113.84307
BBOR1	Osprey Reference	Reef flat rubble	BV	5	1.5	13:30	14:10	Start	-22.20195	113.84291
								End	-22.20153	113.84299
BBOR2	Osprey Reference	Tabulate acropora	BV	1	1.0	8:00	8:40	Start	-22.20582	113.84256
								End	-22.20627	113.84233
BBOR2	Osprey Reference	Tabulate acropora	BV	2	1.0	8:00	8:40	Start	-22.20531	113.84283
								End	-22.20574	113.84261
BBOR2	Osprey Reference	Tabulate acropora	BV	3	1.0	8:00	8:40	Start	-22.20483	113.84309
								End	-22.20525	113.84286
BBOR2	Osprey Reference	Tabulate acropora	BV	4	1.0	8:00	8:40	Start	-22.20433	113.84335
								End	-22.20475	113.84312
BBOR2	Osprey Reference	Tabulate acropora	BV	5	1.0	8:00	8:40	Start	-22.20384	113.84355
								End	-22.20426	113.84339
BBOR3	Osprey Reference	Branching acropora	BV	1	1.5	22:05	22:40	Start	-22.20260	113.84476
								End	-22.20303	113.84459
BBOR3	Osprey Reference	Branching acropora	BV	2	1.5	22:05	22:40	Start	-22.20221	113.84524
								End	-22.20251	113.84482
BBOR3	Osprey Reference	Branching acropora	BV	3	1.5	22:05	22:40	Start	-22.20201	113.84589
								End	-22.20217	113.84533
BBOR3	Osprey Reference	Branching acropora	BV	4	1.5	22:05	22:40	Start	-22.20187	113.84654
								End	-22.20199	113.84598
BBOR3	Osprey Reference	Branching acropora	BV	5	1.5	22:05	22:40	Start	-22.20167	113.84722
								End	-22.20185	113.84667
BBOR4	Osprey Reference	Reef pass	BV	1	4.0	12:20	13:00	Start	-22.19519	113.84631
								End	-22.19540	113.84667
BBOR4	Osprey Reference	Reef pass	BV	2	4.0	12:20	13:00	Start	-22.19493	113.84587
								End	-22.19512	113.84621
BBOR4	Osprey Reference	Reef pass	BV	3	4.0	12:20	13:00	Start	-22.19464	113.84541
								End	-22.19487	113.84580
BBOR4	Osprey Reference	Reef pass	BV	4	4.0	12:20	13:00	Start	-22.19437	113.84495
								End	-22.19459	113.84532
BBOR4	Osprey Reference	Reef pass	BV	5	4.0	12:20	13:00	Start	-22.19412	113.84453
								End	-22.19433	113.84487
BBOR5	Osprey Reference	Inshore algae	BV	1	1.0	8:50	9:54	Start	-22.19494	113.85312
								End	-22.19452	113.85315
BBOR5	Osprey Reference	Inshore algae	BV	2	1.0	8:50	9:54	Start	-22.19542	113.85302
								End	-22.19501	113.85309

BBOR5	Osprey Reference	Inshore algae	BV	3	1.0	8:50	9:54	Start	-22.19592	113.85294
								End	-22.19550	113.85301
BBOR5	Osprey Reference	Inshore algae	BV	4	1.0	8:50	9:54	Start	-22.19638	113.85288
								End	-22.19601	113.85293
BBOR5	Osprey Reference	Inshore algae	BV	5	1.0	8:50	9:54	Start	-22.19691	113.85281
								End	-22.19645	113.85285
BBOR6	Osprey Reference	sand/coral	BV	1	1.0	23:06	23:45	Start	-22.20363	113.84944
								End	-22.20319	113.84958
BBOR6	Osprey Reference	sand/coral	BV	2	1.0	23:06	23:45	Start	-22.20410	113.84930
								End	-22.20371	113.84941
BBOR6	Osprey Reference	sand/coral	BV	3	1.0	23:06	23:45	Start	-22.20457	113.84916
								End	-22.20418	113.84927
BBOR6	Osprey Reference	sand/coral	BV	4	1.0	23:06	23:45	Start	-22.20512	113.84899
								End	-22.20466	113.84913
BBOR6	Osprey Reference	sand/coral	BV	5	1.0	23:06	23:45	Start	-22.20572	113.84881
								End	-22.20522	113.84897
BBOR7	Osprey Reference	Reef front	BV	1	11.0	13:30	14:10	Start	-22.19734	113.83849
								End	-22.19769	113.83829
BBOR7	Osprey Reference	Reef front	BV	2	11.0	13:30	14:10	Start	-22.19698	113.83872
								End	-22.19729	113.83853
BBOR7	Osprey Reference	Reef front	BV	3	11.0	13:30	14:10	Start	-22.19663	113.83896
								End	-22.19694	113.83876
BBOR7	Osprey Reference	Reef front	BV	4	11.0	13:30	14:10	Start	-22.19624	113.83920
								End	-22.19657	113.83900
BBOR7	Osprey Reference	Reef front	BV	5	11.0	13:30	14:10	Start	-22.19580	113.83949
								End	-22.19618	113.83924
BBOZ1	Osprey Sanctuary	Tabulate acropora	BV	1	1.5	8:00	8:40	Start	-22.24286	113.82909
								End	-22.24313	113.82943
BBOZ1	Osprey Sanctuary	Tabulate acropora	BV	2	1.5	8:00	8:40	Start	-22.24242	113.82881
								End	-22.24280	113.82903
BBOZ1	Osprey Sanctuary	Tabulate acropora	BV	3	1.5	8:00	8:40	Start	-22.24192	113.82864
								End	-22.24234	113.82877
BBOZ1	Osprey Sanctuary	Tabulate acropora	BV	4	1.5	8:00	8:40	Start	-22.24139	113.82862
								End	-22.24181	113.82864
BBOZ1	Osprey Sanctuary	Tabulate acropora	BV	5	1.5	8:00	8:40	Start	-22.24082	113.82880
								End	-22.24130	113.82863
BBOZ2	Osprey Sanctuary	Porites/sand	BV	1	5.0	22:05	22:40	Start	-22.24104	113.82997
								End	-22.24057	113.83000
BBOZ2	Osprey Sanctuary	Porites/sand	BV	2	5.0	22:05	22:40	Start	-22.24151	113.82996

								End	-22.24111	113.82997
BBOZ2	Osprey Sanctuary	Porites/sand	BV	3	5.0	22:05	22:40	Start	-22.24203	113.82985
								End	-22.24159	113.82995
BBOZ2	Osprey Sanctuary	Porites/sand	BV	4	5.0	22:05	22:40	Start	-22.24250	113.82991
								End	-22.24212	113.82985
BBOZ2	Osprey Sanctuary	Porites/sand	BV	5	5.0	22:05	22:40	Start	-22.24300	113.82994
								End	-22.24256	113.82990
BBOZ3	Osprey Sanctuary	Lagoon channel	BV	1	6	12:20	13:00	Start	-22.24319	113.83312
								End	-22.24285	113.83345
BBOZ3	Osprey Sanctuary	Lagoon channel	BV	2	6	12:20	13:00	Start	-22.24373	113.83296
								End	-22.24325	113.83306
BBOZ3	Osprey Sanctuary	Lagoon channel	BV	3	6	12:20	13:00	Start	-22.24418	113.83292
								End	-22.24382	113.83295
BBOZ3	Osprey Sanctuary	Lagoon channel	BV	4	6	12:20	13:00	Start	-22.24473	113.83286
								End	-22.24426	113.83290
BBOZ3	Osprey Sanctuary	Lagoon channel	BV	5	6	12:20	13:00	Start	-22.24534	113.83292
								End	-22.24483	113.83287
BBOZ4	Osprey Sanctuary	sand/coral	BV	1	1.5	8:50	9:54	Start	-22.24624	113.83434
								End	-22.24580	113.83443
BBOZ4	Osprey Sanctuary	sand/coral	BV	2	1.5	8:50	9:54	Start	-22.24677	113.83422
								End	-22.24632	113.83432
BBOZ4	Osprey Sanctuary	sand/coral	BV	3	1.5	8:50	9:54	Start	-22.24730	113.83410
								End	-22.24685	113.83420
BBOZ4	Osprey Sanctuary	sand/coral	BV	4	1.5	8:50	9:54	Start	-22.24781	113.83397
								End	-22.24735	113.83406
BBOZ4	Osprey Sanctuary	sand/coral	BV	5	1.5	8:50	9:54	Start	-22.24836	113.83382
								End	-22.24790	113.83393
BBOZ5	Osprey Sanctuary	Reef pass	BV	1	7	23:06	23:45	Start	-22.23844	113.83174
								End	-22.23875	113.83210
BBOZ5	Osprey Sanctuary	Reef pass	BV	2	7	23:06	23:45	Start	-22.23808	113.83133
								End	-22.23838	113.83167
BBOZ5	Osprey Sanctuary	Reef pass	BV	3	7	23:06	23:45	Start	-22.23774	113.83094
								End	-22.23803	113.83127
BBOZ5	Osprey Sanctuary	Reef pass	BV	4	7	23:06	23:45	Start	-22.23740	113.83055
								End	-22.23770	113.83090
BBOZ5	Osprey Sanctuary	Reef pass	BV	5	7	23:06	23:45	Start	-22.23699	113.83009
								End	-22.23736	113.83049
BBOZ6	Osprey Sanctuary	Inshore algae	BV	1	1.5	13:30	14:10	Start	-22.23065	113.83949
								End	-22.23058	113.83995

BBOZ6	Osprey Sanctuary	Inshore algae	BV	2	1.5	13:30	14:10	Start	-22.23096	113.83910
								End	-22.23067	113.83940
BBOZ6	Osprey Sanctuary	Inshore algae	BV	3	1.5	13:30	14:10	Start	-22.23130	113.83879
								End	-22.23101	113.83903
BBOZ6	Osprey Sanctuary	Inshore algae	BV	4	1.5	13:30	14:10	Start	-22.23175	113.83850
								End	-22.23137	113.83874
BBOZ6	Osprey Sanctuary	Inshore algae	BV	5	1.5	13:30	14:10	Start	-22.23217	113.83816
								End	-22.23185	113.83842

APPENDIX 3: Sediment Metadata

Appendix 3.1: Sediment grab survey data, WGS84.

Grab ID	Sampling	Date	Location	Latitude	Longitude
LZ001	Snorkelling Grab	Nov-06	Lakeside	-22.0375	113.9111
LZ002	Snorkelling Grab	Nov-06	Lakeside	-22.0377	113.9075
LZ003	Snorkelling Grab	Nov-06	Lakeside	-22.0375	113.9048
LZ004	Snorkelling Grab	Nov-06	Lakeside	-22.0373	113.9019
LZ005	Snorkelling Grab	Nov-06	Lakeside	-22.037	113.9007
LZ006	Snorkelling Grab	Nov-06	Lakeside	-22.0228	113.9024
LZ007	Snorkelling Grab	Nov-06	Lakeside	-22.0257	113.9079
LZ008	Snorkelling Grab	Nov-06	Lakeside	-22.0266	113.9104
LZ009	Snorkelling Grab	Nov-06	Lakeside	-22.0268	113.9141
LZ010	Snorkelling Grab	Nov-06	Lakeside	-22.0281	113.9171
LZ011	Snorkelling Grab	Nov-06	Lakeside	-22.0152	113.9217
LZ012	Snorkelling Grab	Nov-06	Lakeside	-22.0141	113.9165
LZ013	Snorkelling Grab	Nov-06	Lakeside	-22.0138	113.9124
LZ014	Snorkelling Grab	Nov-06	Lakeside	-22.0131	113.9085
LZ015	Snorkelling Grab	Nov-06	Lakeside	-22.0126	113.9062
LZ016	Snorkelling Grab	Nov-06	Lakeside	-22.001	113.9129
LZ017	Snorkelling Grab	Nov-06	Lakeside	-22.0026	113.9165
LZ018	Snorkelling Grab	Nov-06	Lakeside	-22.0035	113.9199
LZ019	Snorkelling Grab	Nov-06	Lakeside	-22.0045	113.9246
LZ020	Snorkelling Grab	Nov-06	Lakeside	-22.0047	113.926
LZ021	Snorkelling Grab	Nov-06	Lakeside	-21.9945	113.9328
LZ022	Snorkelling Grab	Nov-06	Lakeside	-21.9938	113.9285
LZ023	Snorkelling Grab	Nov-06	Lakeside	-21.9924	113.9241
LZ024	Snorkelling Grab	Nov-06	Lakeside	-21.9911	113.9212
LZ025	Snorkelling Grab	Nov-06	Lakeside	-21.9907	113.9162
LB1	Snorkelling Grab	Nov-06	Lakeside	-22.0043	113.9283
LB2	Snorkelling Grab	Nov-06	Lakeside	-22.0044	113.9284
LB3	Snorkelling Grab	Nov-06	Lakeside	-22.0044	113.9286
LB4	Snorkelling Grab	Nov-06	Lakeside	-22.0045	113.9288
MR001	Snorkelling Grab	Jul-06	Tantabiddi	-21.9149	113.9539
MR002	Snorkelling Grab	Jul-06	Tantabiddi	-21.9159	113.9666
MR003	Snorkelling Grab	Jul-06	Tantabiddi	-21.9155	113.9633
MR004	Snorkelling Grab	Jul-06	Tantabiddi	-21.914	113.959
MR005	Snorkelling Grab	Jul-06	Tantabiddi	-21.9112	113.9544
MR006	Snorkelling Grab	Jul-06	Tantabiddi	-21.9067	113.9483
MR007	Snorkelling Grab	Jul-06	Tantabiddi	-21.8978	113.9562
MR008	Snorkelling Grab	Jul-06	Tantabiddi	-21.9039	113.9593
MR009	Snorkelling Grab	Jul-06	Tantabiddi	-21.9065	113.9628
MR010	Snorkelling Grab	Jul-06	Tantabiddi	-21.9084	113.966
MR011	Snorkelling Grab	Jul-06	Tantabiddi	-21.9115	113.9726
MR012	Snorkelling Grab	Jul-06	Tantabiddi	-21.9019	113.9809
MR013	Snorkelling Grab	Jul-06	Tantabiddi	-21.8995	113.9782
MR014	Snorkelling Grab	Jul-06	Tantabiddi	-21.8932	113.9712
MR015	Snorkelling Grab	Jul-06	Tantabiddi	-21.891	113.9678

MR017	Snorkelling Grab	Jul-06	Tantabiddi	-21.8824	113.9722
MR019	Snorkelling Grab	Jul-06	Tantabiddi	-21.8845	113.9834
MR020	Snorkelling Grab	Jul-06	Tantabiddi	-21.8875	113.9865
MR021	Snorkelling Grab	Jul-06	Tantabiddi	-21.8895	113.9899
MR022	Snorkelling Grab	Jul-06	Tantabiddi	-21.8834	113.9924
MR023	Snorkelling Grab	Jul-06	Tantabiddi	-21.8812	113.9896
MR024	Snorkelling Grab	Jul-06	Tantabiddi	-21.8789	113.9867
MR025	Snorkelling Grab	Jul-06	Tantabiddi	-21.8766	113.9839
MR026	Snorkelling Grab	Jul-06	Tantabiddi	-21.8729	113.9792
TB1	Snorkelling Grab	Nov-06	Tantabiddi	-21.9135	113.9762
TB2	Snorkelling Grab	Nov-06	Tantabiddi	-21.9135	113.9763
TB3	Snorkelling Grab	Nov-06	Tantabiddi	-21.9136	113.9764
TB4	Snorkelling Grab	Nov-06	Tantabiddi	-21.9137	113.9765
MZ001	Snorkelling Grab	Jul-06	Mandu SZ	-22.1158	113.8828
MZ002	Snorkelling Grab	Jul-06	Mandu SZ	-22.1155	113.8816
MZ003	Snorkelling Grab	Jul-06	Mandu SZ	-22.1155	113.8804
MZ004	Snorkelling Grab	Jul-06	Mandu SZ	-22.1152	113.8786
MZ005	Snorkelling Grab	Jul-06	Mandu SZ	-22.1146	113.8773
MZ006	Snorkelling Grab	Jul-06	Mandu SZ	-22.1253	113.8805
MZ006	Snorkelling Grab	Jul-06	Mandu SZ	-22.1253	113.8805
MZ007	Snorkelling Grab	Jul-06	Mandu SZ	-22.1251	113.8795
MZ008	Snorkelling Grab	Jul-06	Mandu SZ	-22.1247	113.8781
MZ009	Snorkelling Grab	Jul-06	Mandu SZ	-22.1246	113.8772
MZ010	Snorkelling Grab	Jul-06	Mandu SZ	-22.1233	113.8763
MZ011	Snorkelling Grab	Jul-06	Mandu SZ	-22.1049	113.886
MZ012	Snorkelling Grab	Jul-06	Mandu SZ	-22.1048	113.8843
MZ013	Snorkelling Grab	Jul-06	Mandu SZ	-22.1043	113.8825
MZ014	Snorkelling Grab	Jul-06	Mandu SZ	-22.1038	113.8807
MZ015	Snorkelling Grab	Jul-06	Mandu SZ	-22.1033	113.8789
MZ016	Snorkelling Grab	Jul-06	Mandu SZ	-22.1416	113.8718
MZ017	Snorkelling Grab	Jul-06	Mandu SZ	-22.1411	113.871
MZ018	Snorkelling Grab	Jul-06	Mandu SZ	-22.1404	113.8702
MZ019	Snorkelling Grab	Jul-06	Mandu SZ	-22.1397	113.8692
MZ020	Snorkelling Grab	Jul-06	Mandu SZ	-22.1391	113.8683
MZ021	Snorkelling Grab	Jul-06	Mandu SZ	-22.1515	113.862
MZ022	Snorkelling Grab	Jul-06	Mandu SZ	-22.1518	113.8633
MZ023	Snorkelling Grab	Jul-06	Mandu SZ	-22.152	113.8642
MZ024	Snorkelling Grab	Jul-06	Mandu SZ	-22.1522	113.8651
MZ025	Snorkelling Grab	Jul-06	Mandu SZ	-22.1524	113.8662
MB1	Snorkelling Grab	Nov-06	Mandu SZ	-22.1049	113.8871
MB2	Snorkelling Grab	Nov-06	Mandu SZ	-22.1049	113.8872
MB3	Snorkelling Grab	Nov-06	Mandu SZ	-22.1049	113.8873
MB4	Snorkelling Grab	Nov-06	Mandu SZ	-22.1049	113.8875
OR001	Snorkelling Grab	Jul-06	Osprey Ref	-22.2173	113.8462
OR002	Snorkelling Grab	Jul-06	Osprey Ref	-22.2165	113.8438
OR003	Snorkelling Grab	Jul-06	Osprey Ref	-22.216	113.8421
OR004	Snorkelling Grab	Jul-06	Osprey Ref	-22.2158	113.8408
OR005	Snorkelling Grab	Jul-06	Osprey Ref	-22.2161	113.8396
OR006	Snorkelling Grab	Jul-06	Osprey Ref	-22.2086	113.8502
OR007	Snorkelling Grab	Jul-06	Osprey Ref	-22.2065	113.8476

OR008	Snorkelling Grab	Jul-06	Osprey Ref	-22.2051	113.8445
OR009	Snorkelling Grab	Jul-06	Osprey Ref	-22.2042	113.8431
OR010	Snorkelling Grab	Jul-06	Osprey Ref	-22.2032	113.8417
OR011	Snorkelling Grab	Jul-06	Osprey Ref	-22.1936	113.8546
OR012	Snorkelling Grab	Jul-06	Osprey Ref	-22.1929	113.8524
OR013	Snorkelling Grab	Jul-06	Osprey Ref	-22.1917	113.8508
OR014	Snorkelling Grab	Jul-06	Osprey Ref	-22.1912	113.8484
OR015	Snorkelling Grab	Jul-06	Osprey Ref	-22.1914	113.8476
OR016	Snorkelling Grab	Jul-06	Osprey Ref	-22.1821	113.8573
OR017	Snorkelling Grab	Jul-06	Osprey Ref	-22.1818	113.8557
OR018	Snorkelling Grab	Jul-06	Osprey Ref	-22.1813	113.8544
OR019	Snorkelling Grab	Jul-06	Osprey Ref	-22.1809	113.8527
OR020	Snorkelling Grab	Jul-06	Osprey Ref	-22.1815	113.8518
OR021	Snorkelling Grab	Jul-06	Osprey Ref	-22.1722	113.8594
OR022	Snorkelling Grab	Jul-06	Osprey Ref	-22.1722	113.8586
OR023	Snorkelling Grab	Jul-06	Osprey Ref	-22.1718	113.8577
OR024	Snorkelling Grab	Jul-06	Osprey Ref	-22.1715	113.857
OR025	Snorkelling Grab	Jul-06	Osprey Ref	-22.171	113.8558
ORB1	Snorkelling Grab	Nov-06	Osprey Ref	-22.1928	113.8561
ORB2	Snorkelling Grab	Nov-06	Osprey Ref	-22.1928	113.8562
ORB3	Snorkelling Grab	Nov-06	Osprey Ref	-22.1928	113.8564
ORB4	Snorkelling Grab	Nov-06	Osprey Ref	-22.1928	113.8566
OZ001	Snorkelling Grab	Jul-06	Osprey SZ	-22.2709	113.8316
OZ002	Snorkelling Grab	Jul-06	Osprey SZ	-22.2703	113.8288
OZ003	Snorkelling Grab	Jul-06	Osprey SZ	-22.2689	113.8261
OZ004	Snorkelling Grab	Jul-06	Osprey SZ	-22.2677	113.8235
OZ005	Snorkelling Grab	Jul-06	Osprey SZ	-22.2674	113.8225
OZ006	Snorkelling Grab	Jul-06	Osprey SZ	-22.2815	113.8295
OZ007	Snorkelling Grab	Jul-06	Osprey SZ	-22.2804	113.8266
OZ008	Snorkelling Grab	Jul-06	Osprey SZ	-22.2798	113.8233
OZ009	Snorkelling Grab	Jul-06	Osprey SZ	-22.2787	113.8198
OZ010	Snorkelling Grab	Jul-06	Osprey SZ	-22.278	113.8161
OZ011	Snorkelling Grab	Jul-06	Osprey SZ	-22.2878	113.8113
OZ012	Snorkelling Grab	Jul-06	Osprey SZ	-22.2901	113.8142
OZ013	Snorkelling Grab	Jul-06	Osprey SZ	-22.2917	113.8172
OZ014	Snorkelling Grab	Jul-06	Osprey SZ	-22.2935	113.8202
OZ015	Snorkelling Grab	Jul-06	Osprey SZ	-22.295	113.8228
OZ016	Snorkelling Grab	Jul-06	Osprey SZ	-22.3029	113.8201
OZ017	Snorkelling Grab	Jul-06	Osprey SZ	-22.3026	113.8175
OZ018	Snorkelling Grab	Jul-06	Osprey SZ	-22.301	113.8118
OZ019	Snorkelling Grab	Jul-06	Osprey SZ	-22.2998	113.8088
OZ020	Snorkelling Grab	Jul-06	Osprey SZ	-22.2991	113.8046
OZ021	Snorkelling Grab	Jul-06	Osprey SZ	-22.3094	113.8027
OZ022	Snorkelling Grab	Jul-06	Osprey SZ	-22.3107	113.8056
OZ023	Snorkelling Grab	Jul-06	Osprey SZ	-22.3119	113.81
OZ024	Snorkelling Grab	Jul-06	Osprey SZ	-22.3144	113.811
OZ025	Snorkelling Grab	Jul-06	Osprey SZ	-22.3152	113.8146
OZB1	Snorkelling Grab	Nov-06	Osprey SZ	-22.2816	113.8307
OZB2	Snorkelling Grab	Nov-06	Osprey SZ	-22.2817	113.8308
OZB3	Snorkelling Grab	Nov-06	Osprey SZ	-22.2817	113.8312

OZB4	Snorkelling Grab	Nov-06	Osprey SZ	-22.2818	113.8317

APPENDIX 4: Grain Size Statistics

Grain Size phi	Grain Size mm	Descriptive term	
		Gravel	
-1	2		
		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		
		Mud	

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

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
$\bar{x}_\phi = \frac{\Sigma f m_\phi}{100}$	$\sigma_\phi = \sqrt{\frac{\Sigma f (m_\phi - \bar{x}_\phi)^2}{100}}$	$Sk_\phi = \frac{\Sigma f (m_\phi - \bar{x}_\phi)^3}{100\sigma_\phi^{\,3}}$	$K_\rho = \frac{\Sigma f (m_\phi - \bar{x}_\phi)^4}{100\sigma_\phi^{\,4}}$

Sorting ($\sigma_□$)		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 –	Platykurtic	1.70 – 2.55
Moderately well sorted	0.50 – 0.70	Symmetrical	$^{+}$1.30	Mesokurtic	2.55 – 3.70
Moderately sorted	0.70 – 1.00	Coarse skewed	$^{-}$0.43 – $^{+}$0.43	Leptokurtic	3.70 – 7.40
Poorly sorted	1.00 – 2.00	Very coarse skewed	$^{-}$0.43 – $^{-}$1.30	Very leptokurtic	> 7.40
Very poorly sorted	2.00 – 4.00		< $^{-}$1.30		
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	$^{-}$0.3 to $^{-}$1.0	Very leptokurtic	1.50 – 3.00
Very poorly sorted	2.00 – 4.00	skewed		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				