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Ningaloo Collaboration Cluster: Biodiversity and ecology of the Ningaloo Reef lagoon

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1. OVERVIEW

Surveys were undertaken of key invertebrate and plant groups in lagoonal areas throughout the Ningaloo Marine Park. Work in this study has focused on identifying and quantifying soft corals, sponges, echinoderms (urchins and sea cucumbers) and seagrasses; this information was linked to the underlying habitat structure in the Ningaloo Reef lagoons. These groups have been poorly studied within the Marine Park to date, even though they play a critical role in the ecology of the Ningaloo Reef ecosystem. Other taxonomic groups have been studied by researchers involved in the C-Reefs (Census of Marine Life) project coordinated by the Australian Institute of Marine Science, as well as other studies addressing species of commercial importance through WAMSI.

In addition to the biodiversity work, we provided validation support for the development of high resolution habitat maps generated from hyperspectral aerial remote sensing (Kobryn et al., 2011). This involved extensive sampling of benthic habitats in the lagoon environments within the Marine Park by SCUBA divers.

Many of the major taxonomic groups have received little or no attention at Ningaloo; by conducting surveys of selected particularly poorly-studied groups (soft corals, sponges, urchins and sea cucumbers and seagrasses) we hope to obtain information that will improve our understanding of how the complex Ningaloo Reef ecosystem operates. This is expected to provide significant benefits for managers seeking to optimise the effective management of the Marine Park. All of the groups targeted in this study are known to play critical roles in coral reef ecosystems elsewhere and therefore improved understanding of these groups locally is important.

The clear waters of Ningaloo make it an ideal location to use aerial photography, with seabed imagery obtainable to a depth of 20 m. Hyperspectral imagery is a relatively new technique that may allow habitat characterisation using additional light wavelengths to those commonly used in photography. Field validation is required to test the accuracy and effectiveness of the models used to develop these habitat maps. Modelled habitat information was validated by extensive field surveys. *In situ* sampling of the habitat classifications derived from the hyperspectral data was used to help refine the models, while reflectance information, collected from a diverse range of marine plants, benthic animals and substrates, was used to build up a reflectance library for interpreting the hyperspectral imagery.

Ningaloo Marine Park runs for approximately 300 km along the coast of North West Cape in Western Australia and sampling was conducted at various locations throughout the length of the Ningaloo reef system. As a fringing reef, Ningaloo coral reefs have developed out from the shoreline, varying from an extensive structure with offshore reef crest, back reef and lagoon to small fragmented reefs that extend only a small distance from the shore. Sampling design included a stratified approach, encompassing back reef, lagoon and nearshore reef zones, where these were present. Emphasis was also placed on sampling sandy areas and seagrass meadows where these occurred.

The biodiversity surveys of sponges, soft corals and seagrasses, conducted principally in the Tantabiddi region in the north of the Marine Park and the Gnaraloo region in the south, have shown that there are clear differences in the lagoon systems in different parts of the Marine

Park. Other groups have been surveyed by scientists in the AIMS-led C-Reefs programme and WAMSI. The northern section of the Marine Park (north of Point Cloates) is more strongly tropical than the southern section, which has many temperate species present. There are also several locations within the Ningaloo Reef system that are quite unique and don't necessarily match the surrounding lagoon environment. Examples of these locations include Coral Bay, Bateman Bay and the Point Cloates region. Several new species of sponges and soft corals were collected from various locations and await further taxonomic work.

Subsequent studies examined the benthic habitat structure and key macroinvertebrate groups throughout the Ningaloo Marine Park, particularly in relation to the nature of the underlying reef structure. The presence or absence of a distinct lagoon environment determines the overall composition of benthic substrate types within each region, which in turn determines habitat structure and density of key macroinvertebrates. Key macroinvertebrate groups were examined at 97 sites throughout the Marine Park, using a combination of nested quadrat and transect designs. Sampling was conducted inside and outside 12 sanctuary zones, thus permitting a perspective on the role of sanctuary zones in the Marine Park. Conditions within the sheltered lagoonal areas in the Ningaloo Marine Park permit the development of extensive coral and algal-dominated communities, whereas regions without a protected lagoon were more exposed to ocean swell and therefore showed greatly reduced biological diversity. The Coral Bay data revealed a difference in macroinvertebrate composition between management zones, with urchins in near-shore areas driving the observed differences (more urchins were present in the recreation zone). The South Ningaloo region data produced the greatest dissimilarity in macroinvertebrate composition between management zones, although in this instance there were more urchins in the sanctuary zone; *Drupella* and other invertebrates also contributed significantly. These results show there is no clear pattern in macroinvertebrate abundance and density resulting from zonation at this stage.

Our validation work has enabled the development of detailed (3.5 m resolution) habitat maps for the entire Ningaloo Marine Park and highlighted several areas requiring further research, to improve the usefulness of the habitat maps in a biological sense (see Kobryn et al. (2011) for details of the marine habitat mapping) .

There are clear differences between the northern and southern lagoon systems at Ningaloo Reef in terms of the reef structure and the marine flora and fauna that dominate the different regions, as highlighted by differences in distribution of sponges, soft corals and seagrasses. This has important implications for the distribution and abundance of many animals, including some of commercial importance. These observations will be important in the management of the Ningaloo Marine Park; the northern and southern sections of the Marine Park may need to be managed differently. The habitat maps are already being used by DEC in their management of the Marine Park.

Surveying biological groups over the whole Marine Park is difficult and time consuming; further sampling in more locations and at different times of year are required to build on the findings of our study. There are clear seasonal differences in primary productivity in the lagoons, which likely drive significant community-wide changes throughout the year. These seasonal variations will also affect the validity of the habitat maps, which were based on imagery collected at only one time of year. Seasonal sampling will improve the reliability of the habitat maps and also give a better understanding of how the Ningaloo system operates.

Additional work is required to further identify some of the sponge and soft coral samples collected as part of this study. Resource limitations meant that large areas of the Ningaloo Reef system could not be sampled adequately, resulting in gaps in our knowledge. These include the reef crest and fore reef areas and stretches of the Ningaloo Marine Park between Cape Farquhar and Point Anderson and between Bateman Bay and Yardie Creek.

1.1 Benefits and management implications

In-water validation work has provided verification of the habitat maps produced from hyperspectral imagery, producing the first high-resolution maps for the Ningaloo Marine Park (see Kobryn et al., 2011). These maps and the associated bathymetry and biological data will provide an excellent baseline for managers to work with and plan around.

Biodiversity work on sponges and soft corals in the lagoon ecosystems, combined with deep-water collections carried out by AIMS provide an excellent start for a holistic, shore-to-shelf edge view of the distribution of these organisms. Collections of sponges, soft corals and seagrasses from around the Ningaloo Marine Park have confirmed some expected patterns of distribution, but also raised the possibility of new range extensions. These studies have reinforced the idea of Point Cloates as a biogeographical barrier where the Leeuwin and Ningaloo Currents are disrupted, as suggested by previous oceanographic research (Woo et al., 2006).

Quantitative studies of benthic macroinvertebrates have highlighted patterns of distribution of several key groups of organisms. Urchins appear to be a key indicator of assemblage structures in different types of benthic ecosystems; i.e., differences in the structure of many benthic macroinvertebrate communities appear to be explained by differences in urchin populations. Urchins may therefore have potential as surrogates for ecosystem characterisation in the region.

1.2 Further Developments

The validation work has highlighted potential gaps in the information provided by remote sensing, identifying areas for further research; in particular, seasonal blooms of organisms and associated ecological phenomena are a key feature of the Ningaloo biological calendar, however the remote sensing was conducted over only a few weeks. This means that key processes may go undetected and unremarked in the resulting habitat maps. Further research is needed to establish the significance of seasonal blooms and events; these include phytoplankton blooms, mass spawning event and aggregations of fish and other organisms.

Several regions within the Ningaloo Marine Park could not be sampled due to funding constraints. Additional research is required to fill these gaps in our knowledge. Some of this work will be accomplished by PhD candidate Mark Langdon, researching the distribution and ecology of urchins at Ningaloo Reef. Further research on seagrass distribution will be carried out on an opportunistic basis.

Additional work on the biodiversity of benthic organisms at Ningaloo will be carried out as funding permits. The Ningaloo Collaboration Cluster has provided a research impetus that will continue driving biodiversity and ecological studies in the region for years to come.

1.3 Acknowledgements

We thank Kimberley Marrs Ekamper for her help in the field and with some of the preliminary analysis. We are grateful to Jane Fromont and Oliver Gomez from the WA Museum for participating in the sponge and soft coral work. Thanks also to our many field assistants who have cheerfully helped collect these new data on innumerable field trips.

1.4 Planned Publications

Final report provided to the Cluster; summaries of the report and information on further scientific publications will be available via the Cluster and related databases.

van Keulen, M., Langdon, M.W., Fromont, J., Schlacher, M. (2011) Habitats and biodiversity of Ningaloo Reef lagoon. Presentation to be made at the Australian Marine Sciences Association Annual Conference, Fremantle, July 2011.

van Keulen, M. The seagrasses of Ningaloo Reef. Proposed for *Journal of the Royal Society of Western Australia*.

van Keulen, M., Langdon, M.W. and Fromont, J. Patterns in biodiversity of lagoonal habitats, Ningaloo Reef. Proposed for *Biological Conservation*.

1.5 Communications:

1.5.1 List publications

van Keulen, M., Loneragan, N., Skilleter, G., Langdon, M., Marrs, K., Pinnel, N., Kobryn, H. T. and Beckley, L. E. (2008) Habitats and Biodiversity of Ningaloo Reef Lagoon, Western Australia. In: *Proceedings of the 11th International Coral Reef Symposium.* pp. 1397-1400. Ft. Lauderdale, Florida.

Presentations

Kobryn, H.T., Pinnel, N., van Keulen, M., Beckley, L.E., Harvey, M.M., Hausknecht, P. and Heyward, A. (2007) Through the looking glass! Revealing the habitats and biodiversity of Ningaloo Reef using hyperspectral imagery. 83rd Australian Coral Reef Society Annual Conference, Fremantle.

Kobryn, H.T., Pinnel, N., Beckley, L.E., Harvey, M.M., van Keulen, M., Heege, T. and Hausknecht, P. (2007) Habitats and biodiversity of Ningaloo Reef. Mapping the habitat

components and bathymetry with hyperspectral remote sensing. 83rd Australian Coral Reef Society Annual Conference, Fremantle.

Kobryn, H.T., Pinnel, N., van Keulen, M. and Beckley, L.E. (2008) Mapping habitats and biodiversity of Ningaloo Reef lagoon using hyperspectral remote sensing data. Ningaloo Research Symposium, Perth.

Langdon, M.W. (2010) The trophic ecology of the grazing sea urchin Echinometra mathaei within Ningaloo Marine Park: Comparing the effects of different closure regimes on urchin distribution and trophodynamics. WAMSI Student Research Day, Perth.

Pinnel, N., Kobryn, H.T., Heege, T., Harvey, M.M., Beckley, L.E., van Keulen, M., Collins, L. and Hausknecht, P. (2007) Spectral discrimination of marine habitats at Ningaloo Reef, Western Australia. 83rd Australian Coral Reef Society Annual Conference, Fremantle.

van Keulen, M. (2007) Ningaloo Cluster Project 1: Habitat Mapping and Biodiversity. *Ningaloo Research Programme Symposium*, Murdoch University, Perth

van Keulen, M. (2009) Biodiversity studies in the Ningaloo Reef lagoon. Ningaloo Research Symposium, Exmouth.

van Keulen, M. (2010) Habitats and biodiversity of Ningaloo Reef lagoon. WAMSI/AMSA(WA) Marine Science Show and Tell, Perth.

van Keulen, M. and Shortland-Jones, H. (2006) A preliminary evaluation of seagrasses in Bateman Bay, Ningaloo Reef, Western Australia. International Seagrass Biology Workshop, Zanzibar, Tanzania.

1.5.2 Student Projects

Mark Langdon – PhD – The trophic ecology of the grazing sea urchin Echinometra mathaei: a study of the effects of closure regimes within Ningaloo Marine Park, Western Australia. Murdoch University (supervisors Dr Mike van Keulen, Murdoch and Dr Eric Paling, SKM); start date 2008, expected completion 2012.

Janja Ceh – PhD – The role of microbial communities in reef-building corals of Ningaloo Reef, Western Australia. Murdoch University (supervisors Dr Mike van Keulen, Murdoch and Dr David Bourne, AIMS); start date 2008, submitted May, 2011.

1.6 Data Accessibility (Data Summary)

1.6.1 Meta data description

WA-AODN MEST: http://waodn.ivec.org/geonetwork/srv/en/metadata.show?uuid=2feb5e4e-27aa-4433-97af-84c525616d94

1.6.2 Who is the custodian of the data

Dr Mike van Keulen.

1.6.3 Raw data and data products description

None.

2. DATA CHAPTERS

2.1 Summary

Surveys were undertaken of key invertebrate and plant groups in lagoon areas throughout the Ningaloo Marine Park, focussing on identifying and quantifying soft corals, sponges, echinoderms (urchins and sea cucumbers) and seagrasses; this information was linked to the underlying habitat structure in the Ningaloo Reef lagoons, used in a parallel habitat mapping project based on hyperspectral aerial photography. The biodiversity surveys conducted throughout the Ningaloo Reef system have shown that there are clear differences in the lagoon systems in different parts of the Marine Park, with clear biogeographic separation of sponges, soft corals and seagrasses. This has important implications for the distribution and abundance of many animals, including some of commercial importance. The northern section of the Marine Park (north of Point Cloates) is more strongly tropical than the southern section, which has many temperate species present. There are also several locations within the Ningaloo Reef system that are quite unique and don't necessarily match the surrounding lagoon environment. Examples include Coral Bay, Bateman Bay and the Point Cloates region. These observations will be important in the management of the Ningaloo Marine Park; the northern and southern sections of the Marine Park may need to be managed differently. Surveying biological groups over the whole Marine Park is difficult and time consuming; further sampling in more locations and at different times of year are required to build on the findings of our study. There are clear seasonal differences in primary productivity in the lagoons, which likely drive significant community-wide changes throughout the year. These seasonal variations will also affect the validity of the habitat maps, which were based on imagery collected at only one time of year. Seasonal sampling will improve the reliability of the habitat maps and also give a better understanding of how the Ningaloo system operates.

2.2 Introduction

2.2.1 Background on NMP – history, management, previous studies.

The Ningaloo Marine Park (NMP), gazetted in 1987 and extended in 2005, encompasses the Ningaloo Reef fringing reef communities that run along the western coast of Cape Range Peninsula, from Red Bluff to Northwest Cape and around to Bundegi in Exmouth Gulf. The reef straddles the Tropic of Capricorn and the interaction of northerly-flowing coastal currents and the southward-flowing Leeuwin Current produces a unique overlap of tropical and temperate biological organisms. Many organisms occur at the northern or southern limits of their range within Ningaloo Reef. The region's remoteness and limited shoreline development has meant relatively low disturbance to the reef system overall; however intensive recreational fishing and shell collecting have impacted some areas severely. Commercial turtle and lobster fishing in the early-mid twentieth century severely depleted stocks of target species along the reef. Nevertheless, a lack of coastal development and inputs from the adjacent watershed has meant the coral reef as a whole is in remarkably good natural condition.

The same isolation that has protected Ningaloo Reef from many potential human impacts has also resulted in relatively little scientific research. Distance from the institutional infrastructure of Perth and lack of local logistical support has been a major impediment to carrying out baseline studies of the reef systems and regular monitoring of natural and human disturbances. The gazetting of the NMP has resulted in an increased need for relevant information to satisfy management performance criteria. The increasing impact of global climate change on coral reef systems around the world has put pressure on both management and scientific interests to document the Ningaloo Reef system and understand its role as a relatively high latitude coral reef.

With the exception of an outbreak of the corallivorous snail *Drupella* in the 1980s (Turner, 1994a, b), Ningaloo Reef has been spared major, wide-spread disturbances such as invasive or pest species and climate change impacts such as warm water bleaching. Localised deoxygenation events related to synchronised coral spawning have been reported for the Coral Bay region, resulting in mass fish kills on occasion (Simpson et al., 1993); however these events are restricted to relatively small areas. Rapid recovery of corals from a cold water bleaching event in 2006 highlighted the resilience of Ningaloo Reef to disturbance (van Schoubroek and Long, 2007). As a relatively pristine, well-managed coral reef Ningaloo is starting to be recognised as an important focus for study.

Minor stochastic natural events (e.g. cyclones and minor tsunamis) appear to have a relatively minor impact on the reef as a whole, although its isolation and relatively recent recorded history mean that little is known about the effect of major episodic (1 in 100+ years) natural events on the coral reef community. Evidence exists that large tsunami events have impacted on the area in the past (Scheffers et al., 2008) and would be expected to have a significant implications for coral communities.

The limited amount of research done at Ningaloo Reef to date means there is a need for a comprehensive, integrated biodiversity survey and inventory of the NMP. This would effectively generate a biodiversity snapshot of the NMP, which can then be used as a baseline against which to judge human impacts and management performance, and as a guide for strategic research funding. Many major taxonomic groups have received very little attention to date; this study will provide an opportunity to find out more about these groups.

Ningaloo Reef

Ningaloo Reef extends north-south for some 300 km along the western shore of Cape Range Peninsula, from Red Bluff in the south to Northwest Cape in the north; the reef also extends into Exmouth Gulf to Bundegi, some 10 km north of Exmouth. Point Cloates, approximately half-way up Cape Range Peninsula protrudes into the Indian Ocean, disrupting the currents flowing along the continental shelf. The prevailing Leeuwin Current flows south from the tropics during autumn and early winter, supplying tropical larvae and spores. From spring through summer the northward flowing Ningaloo Current, driven by wind forcing, pushes the Leeuwin Current offshore in the southern portion of Ningaloo Reef, supplying temperate larvae and spores. Ningaloo Reef is therefore a zone of biogeographical overlap, with both tropical and temperate plants and animals represented. Point Cloates provides a point of discontinuity, where the inshore Ningaloo Current is forced into an eddy, in turn forcing the Leeuwin Current further offshore. The portion of Ningaloo Reef north of Point Cloates remains exposed largely to tropical waters, while the portion south is alternately exposed to tropical and temperate waters. While taxonomic sampling to date has been limited, it is expected that this may lead to a distinct separation of tropical and temperate flora and fauna in northern and southern parts of the reef system. Any study of marine communities at Ningaloo Reef therefore needs to consider this oceanographic discontinuity in planning sampling strategies.

The Ningaloo Cluster programme

In April 2006 the entire Ningaloo Reef was photographed by an airborne hyperspectral imaging instrument (HyMap). The imagery was intended to provide better understanding of human impacts on the region, but also permitted modelling of bathymetry and marine substrates and habitats at an unprecedented spatial resolution. Key to analysing the remotely sensed hyperspectral imagery was collection of a spectral library, to assist in interpreting the hyperspectral data set; and ground-truthing of a variety of habitats throughout the reef system, to validate the imagery. This information would be used to develop a marine habitat classification model at very high resolution (3.5 m pixel size) to a water depth of 20 m.

Built around this unique data set, a range of projects was established to:

- examine biodiversity and ecology of the lagoon areas of Ningaloo Reef;
- map human usage of the Ningaloo region;
- undertake a social and economic assessment of tourism at Ningaloo; and
- estimate socioeconomic values of human use at Ningaloo in a Management Strategy Evaluation model.

This report presents the biodiversity and ecology results of Project 1: Habitats and Biodiversity of Ningaloo Reef lagoon.

2.2.2 Aims

Verification of classification

Field sampling of spectral signatures of a range of living and non-living components in the marine environment was required to develop a library of information that could be used to process the remotely sensed data. Ground-truthing of identifiable features was carried out to validate the habitat maps as they were being modelled. The large size of the project meant that sampling was required across a range of habitats at different locations throughout the Ningaloo Reef.

Qualitative measures of biodiversity

To permit a snap-shot view of the biodiversity of Ningaloo Reef, it was intended that a broad-scale taxonomic survey be undertaken of key lagoon habitats throughout the Ningaloo Marine Park. Of the major taxonomic groups, most have had little or no work done at Ningaloo, despite the fact that they are critical components of coral reef community structure. The groups of particular concern are the macroalgae, Cyanobacteria, seagrasses, the Cnidaria other than hard corals, sponges, ascidians, bryozoans, crustaceans and the various worms. The fishes and hard corals of Ningaloo have been surveyed a number of times and would be likely to provide an excellent summary of the species present in the Ningaloo Marine Park. CSIRO and AIMS researchers were to collate datasets produced by previous surveys and sampling, identify gaps and analyse the data for species distribution and community structure. While the original intention was that this project was to collect information about the distribution and abundance of the less well-known groups, the C-Reefs programme (co-ordinated by AIMS) announced that it would have a sampling node at Ningaloo Reef during the planning stages of the Cluster programme. Linked with the Census of Marine Life programme, C-Reefs has resources and taxonomic expertise not available to this project and it was decided to focus on a limited set of taxonomic groups not extensively covered by C-Reefs. The aim of the biodiversity component of this project was therefore limited to addressing the seagrasses, sponges, Cnidaria other than hard corals, echinoids and holothurians. Specialist staff from the WA Museum were sub-contracted to work on the sponges and soft corals.

Quantitative measures of biodiversity

In addition to spectral and taxonomic sampling, this component presents an ideal opportunity to elucidate some of the processes linking and driving biodiversity patterns in the region. By designing the sampling programme to encompass linked taxonomic and functional groups at key locations it is possible to address important questions about community structure, offshore/inshore linkages across the Ningaloo Reef and aspects of benthic/pelagic coupling. The composition of benthic communities and relative abundance measures for key organism groups were assessed.

The biodiversity studies of this component provide comprehensive information on habitats, biodiversity and land forms for assessing future changes in the system (either natural or human induced), evaluating alternative development and management scenarios and providing information for the review of the marine zoning in the Park.

2.3 Methods

2.3.1 Study area

The Ningaloo Reef fringes the western shore of Northwest Cape, Western Australia, in the Eastern Indian Ocean (Figure 1); it is Australia’s longest fringing coral reef and one of the longest in the world. The Ningaloo Reef is protected by the Ningaloo Marine Park and extends south from Northwest Cape to Gnaraloo (21°40’S to 23°34’S and 113°45’E) for approximately 290 km (Westera et al., 2003). The west-facing reef system is influenced by both the Leeuwin Current, which transports warm, nutrient-poor water southward and the Ningaloo Current, which begins as the Capes Current in the south of Western Australia and transports cold, nutrient-rich water northward during the summer (Woo et al., 2006).

The reef crest lies between ~200 m and 7 km from the shore at its outermost points, enclosing large lagoonal areas (Cassata and Collins, 2008). Lagoonal areas have an average width of 2.5 km and average depth of 2-4 m (CALM, 2005). They are a feature of the reef system from Jurabi Point to Cape Farquhar and include intermittent patch reefs and nearshore platform reefs. North of Jurabi Point, the reef becomes discontinuous and eventually disappears. The southern end of the reef is more fragmented and closer to shore, becoming a nearshore reef from Gnaraloo Bay to Red Bluff (CALM, 2005).

2.3.2 Site selection

To obtain a comprehensive picture of the ecology and biodiversity of Ningaloo Reef, site selection included a latitudinal component and addressed the following major habitats:

- Intertidal
- Lagoonal/back reef
- Seagrass beds
- Sand

The site selection process and fieldwork incorporated as much prior information as was available, including existing low resolution Conservation and Land Management (now Department of Environment and Conservation) habitat maps and preliminary hyperspectral survey data. As the hyperspectral data was refined, the habitat mapping and biodiversity components increasingly supported each other. Fieldwork was carried out and data obtained through a series of staged intensive field expeditions.

Two major geographical regions were initially sampled: Coral Bay and Yardie Creek-Osprey Bay; the geographic range was subsequently expanded to include Red Bluff-Gnaraloo in the south and Lighthouse Bay-Bundegi in the north, to give better spatial coverage of the entire Ningaloo Reef system. A variety of locations within each of these regions was examined to incorporate as much diversity of habitat as possible, based on aerial photographs.

Key habitat types were identified using information from hyperspectral remote sensing and were used to develop a stratified sampling approach. Study areas were also selected to encompass differences caused by current flows along the Ningaloo Reef. The Coral Bay region in the south and Yardie Creek/Osprey Bay in the north were selected as representative of the northern and southern geographic regions of the reef; the geographic range was subsequently expanded to include Red Bluff-Gnaraloo in the extreme south of the Ningaloo Reef and Lighthouse Bay-Bundegi in the extreme north.

Habitat surveys were conducted within 12 sanctuary zones and adjacent recreation zones within Ningaloo Marine Park. In lagoonal areas, sampling was undertaken at nearshore, lagoon and back reef locations with additional nearshore surveys completed in areas north of Jurabi Point and south of Cape Farquhar (Figure 2).

The nature of the Ningaloo Reef system facilitates shore-based access, using small boats to reach lagoon sites. Lagoon, back-reef and inner reef flat habitats were sampled at each location; however not all habitats were present in all locations sampled. For example, the reef structures at Red Bluff and Lighthouse Bay were considerably constrained and consisted solely of narrow inner reef flats.

2.3.3 Sampling

Verification of classification

Preliminary data analysis identified areas of major discrepancies with the existing marine habitat maps from DEC. Sampling for spectral signatures to ground-truth the remotely sensed data was conducted at a number of key sites across the Ningaloo Marine Park to maximise the coverage of the diverse reef habitats and major public access points to the reef. By conducting a quantitative survey of organism distribution and making collections of key groups, the ground-truthing team was able to simultaneously measure spectral signatures for a wide range of community structures and obtain confirmation of community structure.

Field validation exercises for hyperspectral mapping projects in temperate regions have successfully employed weighted ropes to delineate nested quadrats on reef platforms and seagrass meadows (McDonald, 2007). The use of heavy ropes in coral reef habitats is problematic however, due to the high rugosity and fragile nature of coral reefs. A new, non-invasive approach was therefore designed using weighted floats attached to small ropes (~1 m long) to mark the corners of each quadrat, creating a nested 9 m x 9 m “mega-quadrat”, divided into smaller 3 m x 3 m quadrats (the size of the mega-quadrat was predetermined to allow for GPS positional error of mapped pixels, which are approximately 3 m x 3 m) (Figure 3).

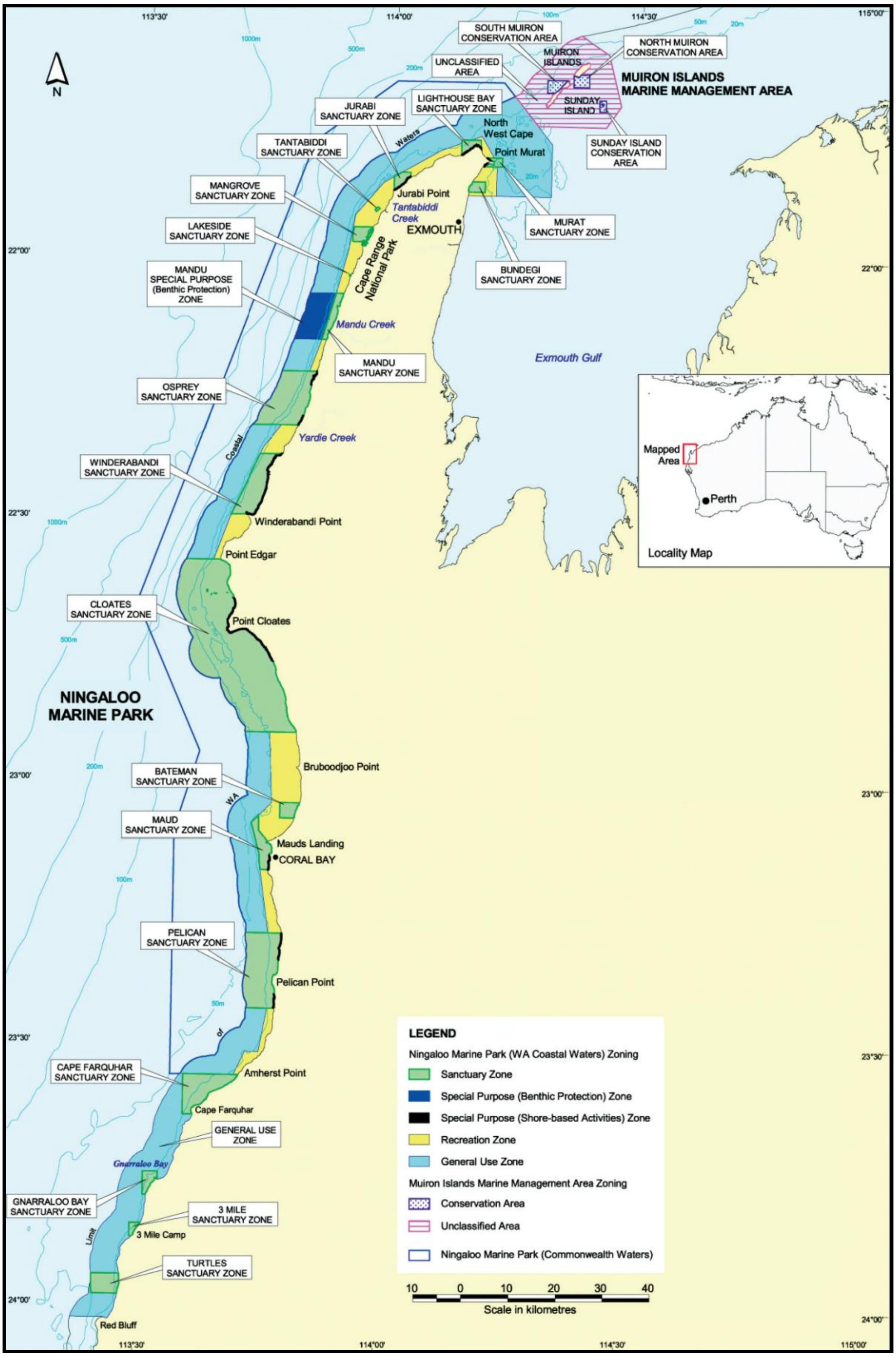

Figure 1 Map of Ningaloo Marine Park & Muiron Islands (including DEC zoning scheme) (CALM, 2005).

Figure 2 Sampling sites overview – NW Cape to Red Bluff (locations indicated by ◘).

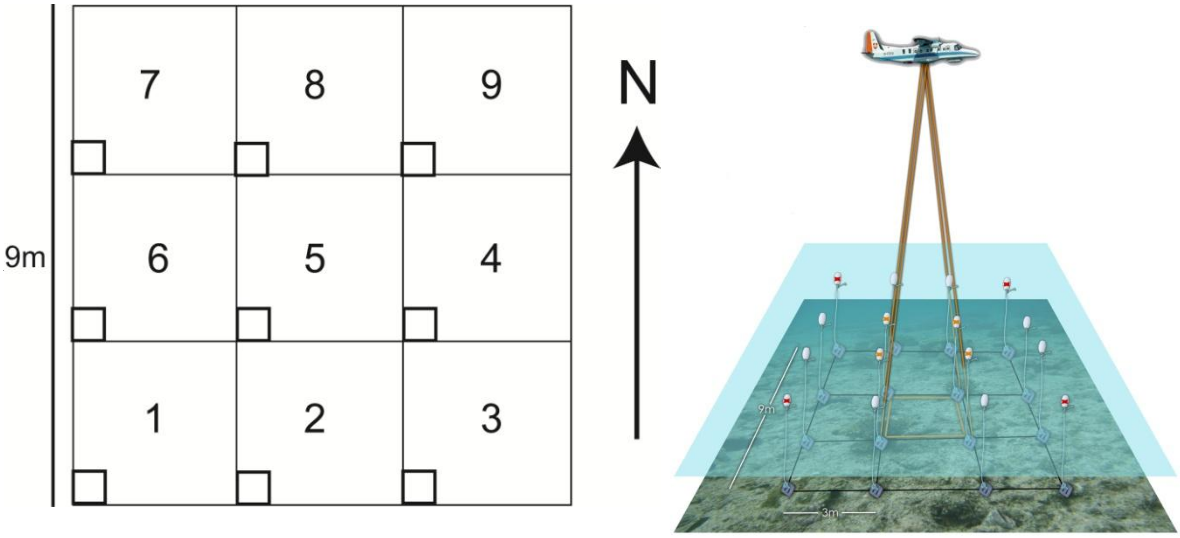

Figure 3 Layout of nested quadrat design (left) indicating orientation, order of sampling and location of sub-quadrats and photo-quadrats. GPS points were taken in the centre of sub-quadrats 1, 3, 5, 7 and 9. The graphic on the right indicates the relationship between the nested quadrat and the remote sensed imagery (3.5 m pixel size).

Initial validation sites (nearshore, lagoon and back reef locations) were chosen at Coral Bay in March 2008 to trial sampling methods. After successful trials, further validation sampling was conducted between Tantabiddi and Yardie Creek in April and October 2008 and at Gnaraloo in December 2008. At each selected site, two divers using SCUBA set out a mega-quadrat comprised of 16 colour-coded weighted floats that correspond to the corners of each nested quadrat. The central 3m x 3m quadrat was then used to provide a GPS reference point for validation. To minimise bias, the same two observers were used for all mega-quadrat sampling; one diver recorded substrate cover while the other recorded macroinvertebrates.

In each quadrat urchins (predominantly *Echinometra mathaei*), holothurians, tridacnid clams, the corallivorous snail, *Drupella cornus* and other macroinvertebrates were counted. Visual identification and estimates of substrate % cover were recorded using substrate categories, adapted from the Australian Institute of Marine Science benthic life form categories used in their long-term benthic monitoring programme (English et al., 1994, Abdo et al., 2004) (Table 1). On occasions where substrate types were difficult to identify in the field (for example, various macroalga), photographs were taken for later identification.

This method enabled visual percent cover estimates to be obtained at a scale that not only was compatible with ground-truthing of the substrate classifications for the hyperspectral habitat maps, but also provided finer-scale biodiversity data for floral/faunal surveys at the same time. Additional boat-based field validations were undertaken by targeting pre-determined areas of interest from the unvalidated hyperspectral images. GPS waypoints and tracks were recorded to mark outlines of different features and transition zones between features (e.g. limestone pavement, sediment patches, lagoonal coral patch reefs (bommies), macroalgae and seagrass beds). A total of 2,932 waypoints (including the 52 mega-quadrats), were recorded for the mapping validation exercise (Table 2).

Further details of the verification of classification process are reported separately (Kobryn, 2010).

Habitat Surveys

Fine-scale habitat surveys were also conducted in 2009 (to complement validation data) in nearshore, lagoon and back reef locations in the Coral Bay region (Figure 4) and from Tantabiddi to Yardie Creek (Figure 5). Further nearshore sampling was later conducted from Jurabi Point to Bundegi, in the north of the park (Figure 5) and from Point Farquhar to Red Bluff in the South (Figure 6).

Five haphazardly selected 50 m transects were completed at each site, with visual estimates of percent cover and macroinvertebrate counts recorded for ten 50 cm x 50 cm quadrats along each transect. To ensure that sampling was conducted over reasonably homogeneous substrates at each site, transects were swum to suit the individual site characteristics (i.e. when sites were not compatible with swimming straight 50 m line transects, 10 quadrats were haphazardly placed every 5 m within the sampling area).

Table 2-1 Benthic life form categories used for substrate cover identification in the field (modified from English et al., 1994, Abdo et al., 2004).

Substrate Category	Code
Sand	S
Sand and Microalgae	SA
Rubble	R
Limestone pavement	LP
Recently dead coral	DC
Intact Dead Coral	IDC
Branching IDC	B-IDC
Digitate IDC	D-IDC
Massive IDC	M-IDC
Tabulate IDC	T-IDC
Turf Algae	TA
Coralline Algae	CA
Macroalgae	MA
Sargassum	SR
Dictyota	DY
Halimeda spp.	HA
Padina	PA
Ulva	UL
Seagrass	SG
Sponge	Sp
Branching Acropora	ACB
Branching Acropora Blue Tip	ACBT
Digitate Acropora	ACD
Tabulate Acropora	ACT
Bottlebrush Acropora	ACX
Sub-massive Acropora	ACS
Encrusting Acropora	ACE
Massive coral	CM
Sub-massive coral	CS
Foliaceous non-Acropora	CF
Mushroom coral	CMR
Branching non-Acropora	CB
Digitate non-Acropora	CD
Encrusting non-Acropora	CE
Soft Coral	SC

Table 2-2 Sampling effort for mapping validations at Ningaloo Marine Park, 2008.

Month 2008	Region sampled	Number of 3m quadrats	Number of GPS points
March	Coral Bay	81	22
April	Yardie	72	124
June- July	Coral Bay	0	1,389
October	Mandu	225	171
December	Gnaraloo	90	1,226
Totals		**468**	**2,932**

Qualitative measures of biodiversity

Of the major taxonomic groups, most have had little or no work done at Ningaloo; groups of particular concern that will be targeted are the seagrasses, Cnidaria other than hard corals (i.e. soft corals) and the sponges. These groups have had very little work done on them despite the fact that they are critical components of coral reef community structure. The fishes, hard corals and molluscs of Ningaloo have been surveyed a number of times and information on the species present in the Ningaloo Marine Park is already available. CSIRO and AIMS researchers have collated data produced by previous surveys and sampling, and analysed the data for species distribution and community structure.

Seagrasses were sampled opportunistically while conducting validation field work and quantitative macro-invertebrate sampling. Information collected in this study was combined with existing data obtained in previous studies.

Dr Jane Fromont and Oliver Gomez from the Western Australian Museum were sub-contracted to collect and identify soft corals and sponges; soft coral material was subsequently sent to Dr Monica Schlacher at the Queensland Museum for further taxonomic analysis. Sampling for these groups was conducted in line with standard procedures established by the WA Museum; full details of the sponge and soft coral sampling programme are provided in an appendix to this report (Appendix 1. Fromont and Gomez, 2010).

With the establishment of the C-Reefs programme run through AIMS, aspects of invertebrate and macroalgal biodiversity sampling proposed for this study have become redundant; in particular, the macroalgae were examined by Rainbo Dixon, under the supervision of Dr John Huisman (Murdoch University/WA Herbarium). Additional sampling of the soft corals and sponges was also carried out through C-Reefs; sampling in the Ningaloo Cluster programme supplemented sampling undertaken at Tantabiddi and Ningaloo Station during C-Reefs expeditions.

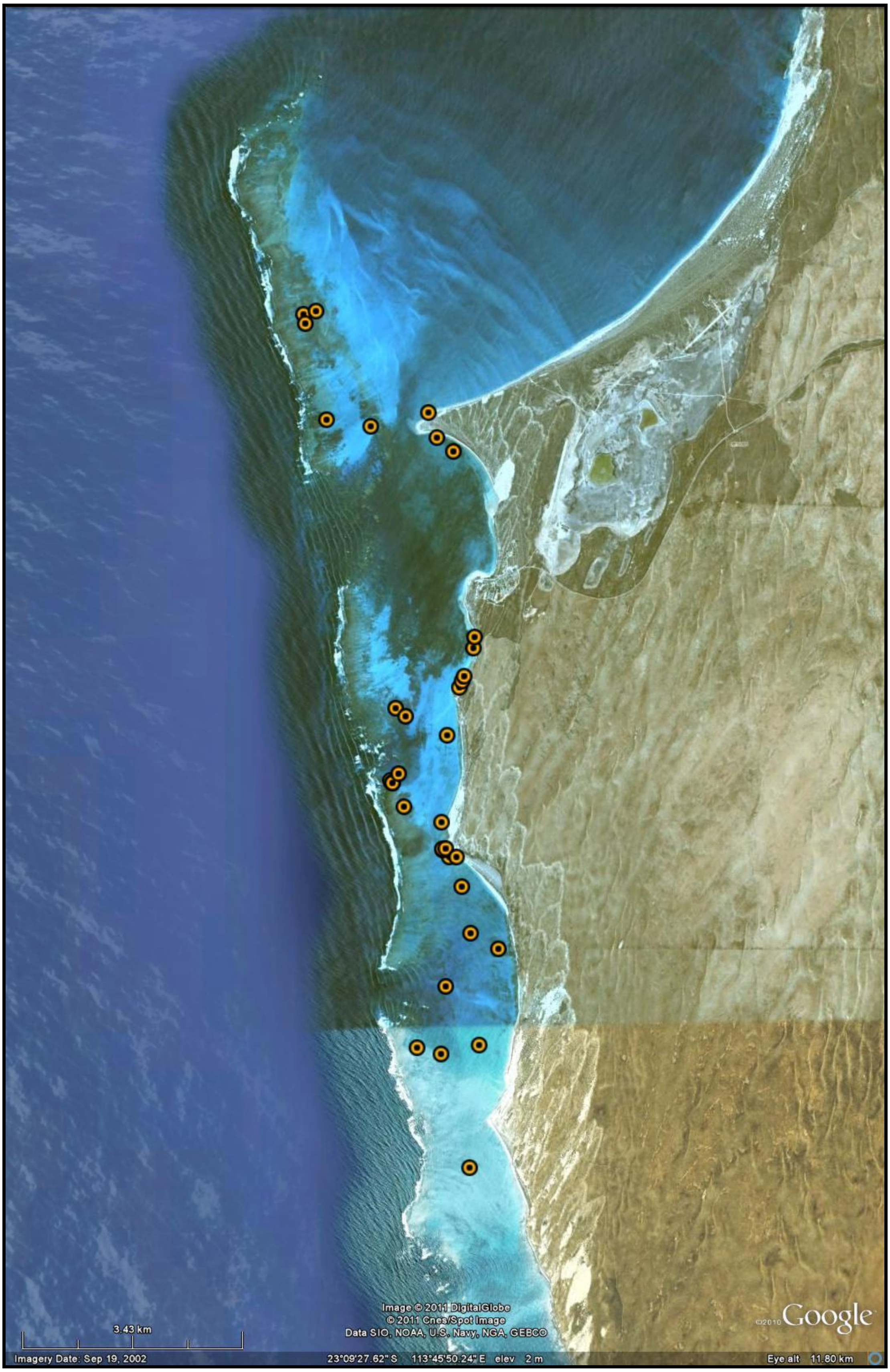

Figure 4 Sampling sites – Coral Bay Region (locations indicated by ◘).

Figure 5 Sampling sites – NW Cape to Yardie Creek (locations indicated by ◘).

Figure 6 Sampling sites – Cape Farquhar to Red Bluff (locations indicated by ◘).

Quantitative measures of biodiversity

The composition of benthic communities and relative abundance measures for key organism groups were obtained using photo transects and supplementary techniques; in particular, nested quadrat sampling and analysis permitted quantitative studies of macroalgae, seagrasses and related fauna to be carried out. These field results were used to verify and refine the classifications generated from the hyperspectral data as well as provide a basis for comparison of similar habitats at different sites.

Protocols for the benthic biodiversity sampling programme were finalized following discussion with project partners and extensive testing. Sampling strategies included monitoring benthic habitat types along transects, nested quadrats to match up with the pixel size obtained by remote sensing, and transects to quantify numbers of key invertebrate species (echinoids, holothurians, tridacnid clams, and the corallivorous snail, *Drupella*).

Sampling for macro-invertebrates was conducted using five 50 m transects at each site, with 0.25 m^2 quadrats sampled every 5 m along each transect. A visual estimate was made of substrate cover, using the AIMS long-term monitoring categories (Abdo et al., 2004). Counts were also made of echinoids, holothurians, tridacnid clams, and the corallivorous snail, *Drupella*, within each quadrat. The GPS location of all transects was recorded.

2.3.4 Data analysis

Benthic life form categories (Table 1) that were rarely recorded throughout sampling were further condensed into broader categories during data collation (Table 3). All algae were grouped into turf, coralline or macroalgae (Total MA) and hard corals were condensed from 14 to 8 categories. Intact dead corals were also grouped together (Total IDC). Habitat characteristics data were collated and expressed as mean percent substrate cover (± 1 SE) for each location.

Mapping Validations

Validation data collected in this study was an integral component of the development of the Ningaloo Marine Park maps. However, the analytical techniques used for refining and classifying the hyperspectral images to produce these maps were not an element of this study and are reported elsewhere (see Kobryn et al., 2010). Unvalidated hyperspectral images were provided as a guide for targeting validation sites and the resultant classified baseline habitat maps produced broad-scale habitat descriptions that provide a framework for use in this study and other related biodiversity studies in the region (van Keulen et al., 2008).

Habitat data analyses

Data from the 2008 validation surveys and the 2009 habitat surveys were tested for homogeneity of variance by using one-way Analysis of Variance (ANOVA) on data collected using both sampling methods at the same sites (n=5). No significant difference was found ($p > 0.05$) so data was pooled for further analyses.

Multivariate analyses

The data was analysed to examine spatial trends in the macroinvertebrate composition of benthic habitats between regions and between habitats within regions (nearshore, lagoon and back reef) where lagoonal areas were surveyed. Multivariate analyses were conducted using the PRIMER v6 statistical package (Clarke and Warwick, 2001). The tests were based on a Bray-Curtis rank similarity matrix, calculated using log(x+1) transformed data (Clarke and Warwick, 2001). Non-metric multidimensional scaling (nMDS) was used for initial interpretation of spatial patterns and one-way Analysis of Similarity (ANOSIM) was used to determine the significance of any spatial differences in habitat composition (Clarke and Warwick, 2001). A Similarity Percentage routine (SIMPER) (Clarke and Warwick, 2001) was then used to examine the contribution of individual macroinvertebrate categories to any observed similarities in composition (within regions and locations) or differences in composition between regions and locations.

Table 2-3 Condensed substrate categories and descriptive definitions (adapted from Abdo et al., 2004).

Substrate Category	Definition
Sand	Fine silt to calcareous sand <0.5 cm diameter.
Sand + Microalgae	Sand mostly covered in fine microalgae.
Rubble	Unconsolidated dead hard coral fragments.
Limestone pavement	Consolidated limestone substrate, can be bare or colonised by turf or other algae < 5cm.
Total IDC	Intact dead coral skeleton that has maintained form. Usually colonised by turf algae.
Turf Algae	Encrusting algae <5cm with no apparent structural features.
Coralline Algae	Crustose, calcareous red algae.
Total MA	All macroalgae > 5cm (e.g. *Sargassum, Padina).*
Seagrass	All seagrasses (e.g. *Posidonia, Halophila).*
Sponge	All sponges. No further ID.
Branching corals	Arborescent corals where branches are generally narrower than they are wide. Includes branching Acropora and non-Acropora.
Digitate corals	Short digit like branches arising from an encrusting base (e.g. *Acropora humilis*).
Tabulate *Acropora*	Table like horizontal plate corals originating from a small base (e.g. *A. spicifera, A. hyacinthus*).
Encrusting corals	Low lying colonies encrusting the substrate.
Sub-massive corals	Irregular shaped colony. Can be rounded, bulbous or with column like structures (e.g. *Pocillopora*).
Massive corals	Usually solid and hemispherical in shape (e.g. *Porites*).
Foliaceous corals	Leaf like or floral morphology (e.g. *Echinopora*).
Mushroom corals	Solitary mushroom like coral.
Soft Corals	All soft corals. No further ID.

2.4 Results

Verification of classification

Verification data was incorporated into the habitat mapping project (see Kobryn, 2010) and the details will not be reported here.

Qualitative measures of biodiversity

Site Characteristics
Ningaloo Marine Park covers almost 300km of coastline (Westera et al., 2003), so survey results have been grouped into appropriate regions, from Bundegi in the north to Red Bluff in the south. In lagoonal areas, habitat descriptions have been additionally separated into nearshore, lagoon and back reef locations (Table 4). Habitat characteristics are expressed as mean percent substrate cover (± 1 SE) for each location. Macroinvertebrate results are shown as mean number of individuals per square metre (± 1 SE).

Table 2-4 Ningaloo Marine Park Major regions and sub-regions, North to South (* indicates regions with lagoonal areas).

Major Region	Sub-regions
NW Cape	Bundegi
	North of Jurabi Point
*Tantabiddi to Yardie Creek	Tantabiddi
	Mangrove Bay
	Mandu
	Osprey
*Point Maud to Point Anderson	Coral Bay North (Maud Sanctuary)
	Coral Bay South
South Ningaloo	Cape Farquhar
	Gnaraloo Bay
	3 Mile
	Red Bluff

(a) NW Cape Region
Habitat surveys in this region were limited to nearshore areas because North of Jurabi Point; the fringing reef becomes discontinuous and eventually disappears, with no distinct lagoon or back reef areas (CALM, 2005). Eight sites were surveyed at Bundegi, Lighthouse and Jurabi (four in sanctuary zones and four in adjacent recreational zones) within the region (Figure 5).

Bundegi
Bundegi Sanctuary lies on the eastern side of NW Cape, in Exmouth Gulf. Nearshore habitats south of Bundegi beach were sampled and are typically sandy to muddy intertidal areas,

framed by narrow beaches and intermittent mangrove stands. Sand is by far the dominant substrate (87 %), interspersed with patches of sand covered limestone pavement (4.5 %) with isolated outcrops of turf (4.35 %) and macro algae (4.15 %) (Figure 7).

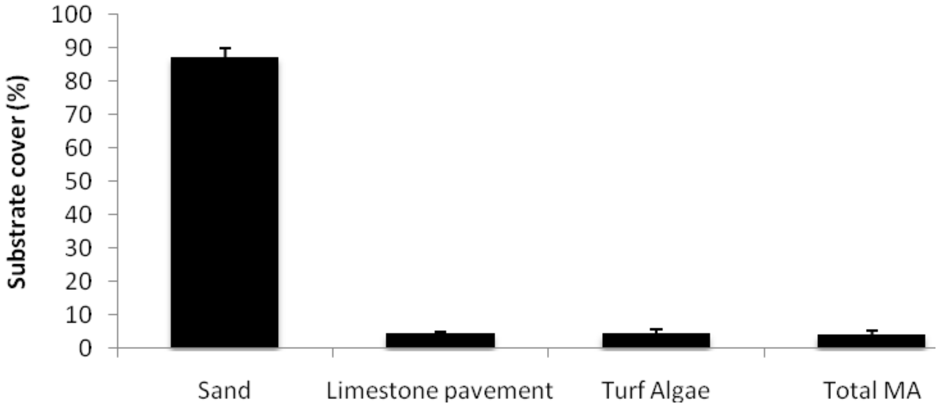

Figure 5 cover of benthic habitats at Bundegi, using broad sampling categories.

North of Jurabi Point

Nearshore areas at Graveyards, Baudin, Trisel, and Hunters were predominantly subtidal and intertidal reef platforms extending from the water's edge, framed by rocky shores with intermittent small sandy beaches. Reef platforms varied in width from around 10 m up to 50 m from the shore. Lighthouse Bay, north of Hunters also had extensive subtidal and intertidal reef platforms that extended up to 60-70 m offshore with the shoreline consisting of a long (~5km) sandy beach with extensive fore dunes. Average depths of nearshore platforms at high tide were 1.5 m.

Reef platforms consisted of bare limestone pavement (32.33 %) with sandy patches (21.33 %) and the underlying pavement was covered in a mosaic of turf algae (20.8 %), macro algae (18.39 %) and coralline algae (6.06 %). Seagrass (4.97 %) had also colonised a small number of sandy patches (Figure 8).

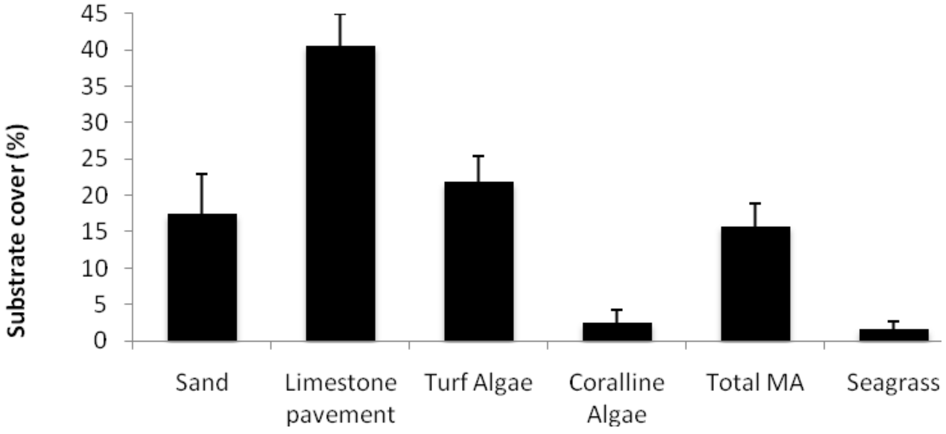

Figure 6 Percent cover of benthic habitats north of Jurabi, using broad sampling categories.

(b) Tantabiddi to Yardie Creek Region
The fringing reef lies offshore from Tantabiddi to Yardie Creek (0.3 – 4.1 km offshore, average lagoon width is about 2.5 km), enclosing large lagoonal areas. Habitat surveys in this region were therefore stratified into nearshore, lagoon and back reef areas within each sub-region (Table 4). A total of 43 sites were surveyed at Tantabiddi, Mangrove Bay, Mandu and Osprey Sanctuary zones and their adjacent recreation zones (Figure 5).

Regional Overview: Tantabiddi to Yardie Creek
Nearshore areas consisted of limestone substrates (10.22 %) predominantly covered by a layer of sand (25.94 %), or in some locations finer silty sand or mud, supporting patches of microalgae (10.05 %) and macroalgae (35.32 %). Intertidal or subtidal reef platforms were not well defined and did not support dense mosaics of turf and macroalgae but rather consisted of sand-covered pavement supporting small patches of turf (2.54 %) and stands of algae such as *Padina, Hincksia* and *Hydroclathrus.* Rubble (4.25 %) and small intermittent patch reefs of sub-massive (3.38 %) and branching corals (2.32 %) were also evident at nearshore sampling sites (Figure 9).

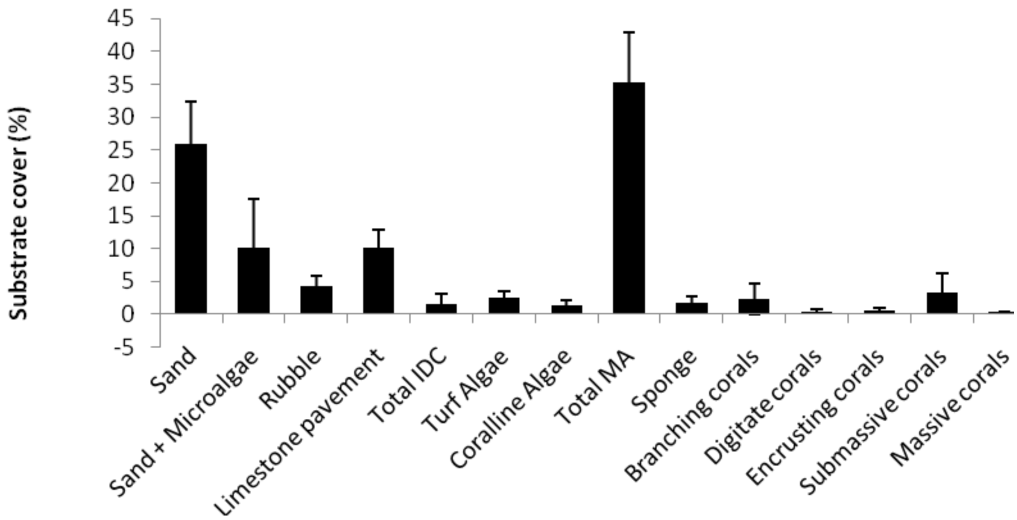

Figure 7 Regional overview of percent cover of substrate types in the nearshore habitats in the Tantabiddi to Yardie Creek region.

Lagoonal areas surveyed were mostly sand-covered pavement (40.03 % sand, 8.03 % bare limestone pavement) with patches of turf (2.91 %) and macroalgae (15.99 %); e.g., *Padina*. Lagoonal patch reefs consisted of dead coral (11.24 %) and a variety of hard corals such as branching (3.04 %) and sub-massive corals (2.34 %). Soft corals (2.6 %) and cryptic sponges (<1 %) were also present in isolated colonies (Figure 10).

Back reef areas (Figure 11) were found to be more diverse, with much less sand (15.27 %) and higher coverage of hard corals than nearshore and lagoonal areas. Tabulate *Acropora* (11.96 %) was the most common hard coral, followed by digitate (5.62 %) and branching corals (3.38 %). Other hard corals (encrusting, sub-massive, foliaceous and massive) accounted for almost 8 % of substrate cover. Limestone pavement (11.35 %), rubble (10.93 %) and dead corals (9.40

%) were also widespread and were usually colonised by turf (9.00 %) and macroalgae (9.37 %). Further descriptions of habitat characteristics (percent substrate cover) for this region have been summarised for nearshore, lagoon and back reef areas within each of the sub-regions (Table 5).

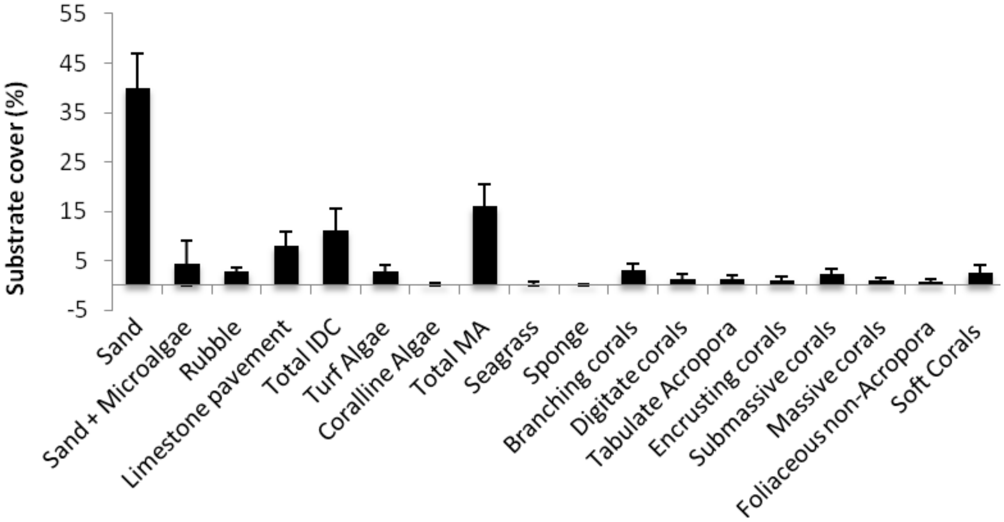

Figure 8 Regional overview of percent cover of substrate types in the lagoonal habitats in the Tantabiddi to Yardie Creek region.

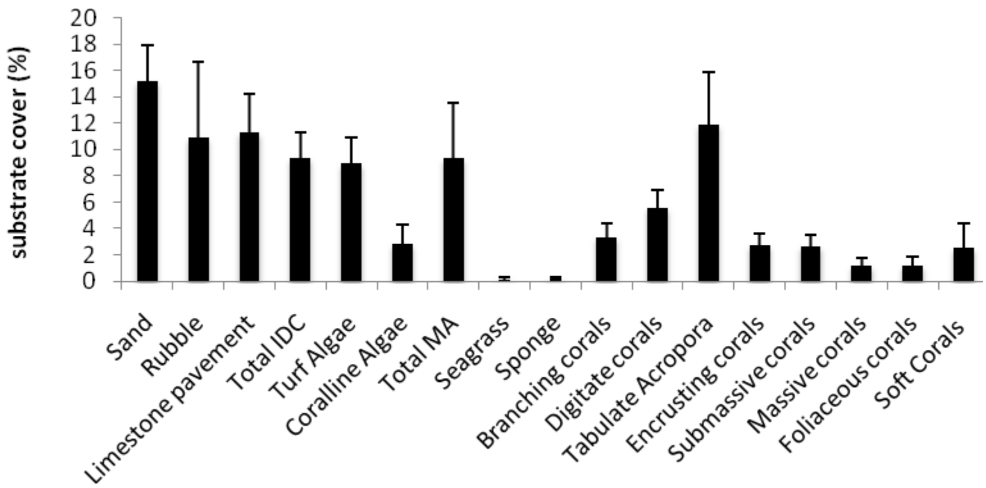

Figure 9 Regional overview of percent cover of substrate types in the back reef habitats in the Tantabiddi to Yardie Creek region.

Table 2-5 Regional summary of benthic substrates: Tantabiddi to Yardie.

a) Tantabiddi	***nearshore***	*****	***lagoon***		***back reef***	*****
Substrate Category	**%**	**± 1 SE**	**%**	**± 1 SE**	**%**	**± 1 SE**
Sand	45.00	45.00	30.95	25.95	19.17	19.17
Rubble	2.75	2.75	9.29	4.29	5.42	5.42
Limestone pavement	12.75	12.75	7.14	2.14	12.50	12.50
Total IDC	0.25	0.25	5.12	4.89	14.17	14.17
Turf Algae			2.50	2.50	17.71	17.71
Coralline Algae					0.63	0.63
Total MA	39.00	39.00	12.26	7.26	3.75	3.75
Sponge	0.25	0.25	0.24	0.24	1.67	1.67
Branching corals			10.00	10.00	8.96	8.96
Digitate corals					4.38	4.38
Tabulate Acropora			2.50	2.50		
Encrusting corals			5.00	5.00	8.13	8.13
Sub-massive corals			7.50	7.50	3.13	3.13
Massive corals			2.50	2.50	0.42	0.42
Foliaceous corals			5.00	5.00		

**Note: Large SEs for nearshore and back reef are because only 1 site sampled for each*

b) Mangrove Bay	***nearshore***		***lagoon***		***back reef***	
Substrate Category	**%**	**± 1 SE**	**%**	**± 1 SE**	**%**	**± 1 SE**
Sand	48.19	1.84	42.51	15.04	18.15	5.19
Rubble	5.68	2.45	2.23	1.30	21.30	11.23
Limestone pavement	3.20	0.86	5.79	2.96	4.54	4.43
Total IDC	0.70	0.38	11.63	5.87	9.44	4.77
Turf Algae	1.42	0.61	5.22	3.26	10.09	3.58
Coralline Algae	0.35	0.19	0.33	0.33	5.93	2.66
Total MA	33.19	4.91	15.06	3.18	12.41	8.12
Seagrass					0.28	0.28
Sponge	6.32	5.25	0.54	0.19		
Branching corals			5.12	5.12	1.02	0.54
Digitate corals			1.50	1.55	1.57	0.95
Tabulate Acropora			0.61	0.61	6.67	6.67
Encrusting corals	0.54	0.54	1.46	1.46	0.37	0.19
Sub-massive corals			4.17	3.00	2.04	1.80
Massive corals	0.41	0.41	1.06	1.06	1.11	1.42
Foliaceous corals					0.74	0.64
Soft Corals			2.78	2.78	4.35	3.80

Cont…

c) Mandu	***nearshore***		***lagoon***		***back reef***	
Substrate Category	**%**	**± 1 SE**	**%**	**± 1 SE**	**%**	**± 1 SE**
Sand	24.47	9.80	42.29	15.46	11.18	5.06
Sand + Microalgae	2.00	2.00				
Rubble	5.52	3.41	3.76	1.60	2.23	1.72
Limestone pavement	10.76	3.17	22.29	8.28	19.65	4.74
Total IDC	3.11	3.11	2.04	1.51	9.86	2.19
Turf Algae	1.91	1.20	3.49	1.35	5.58	2.42
Coralline Algae	1.56	1.30	0.25	0.25	0.23	0.16
Total MA	41.86	14.33	12.20	5.53	12.41	8.09
Sponge	1.05	0.85	0.22	0.22		
Branching corals	5.11	5.11	1.99	1.99	2.89	0.73
Digitate corals	0.67	0.67	2.80	2.80	7.72	0.84
Tabulate Acropora			4.30	4.30	13.55	4.21
Encrusting corals	0.78	0.78	1.41	0.96	3.98	1.80
Sub-massive corals	1.11	1.11	1.83	1.83	3.78	2.61
Massive corals	0.11	0.11	0.78	0.66	2.10	0.72
Foliaceous corals					2.83	1.80
Soft Corals			0.35	0.24	1.99	1.99

d) Osprey	***nearshore***		***lagoon***		***back reef***	
Substrate Category	**%**	**± 1 SE**	**%**	**± 1 SE**	**%**	**± 1 SE**
Sand	7.22	5.64	40.38	10.21	12.29	2.41
Sand + Microalgae	33.52	24.92	7.78	7.78		
Rubble	1.67	1.67	1.54	0.70	0.74	0.14
Limestone pavement	13.15	8.53	4.91	3.72	16.31	1.53
Total IDC	0.19	0.19	14.75	7.21	7.25	1.14
Turf Algae	5.19	2.89	2.20	1.70	7.34	0.42
Coralline Algae	2.22	1.47	0.37	0.35	0.17	0.17
Total MA	24.63	15.93	17.96	7.57	2.13	0.55
Seagrass			0.61	0.61		
Sponge					0.30	0.30
Branching corals			1.49	0.89	6.75	2.83
Digitate corals	0.37	0.37	1.29	1.15	12.03	0.65
Tabulate Acropora			0.48	0.45	24.94	4.50
Encrusting corals	0.74	0.74	0.30	0.30	4.61	1.29
Sub-massive corals	10.56	10.56	1.04	0.77	2.79	1.94
Massive corals	0.56	0.56	0.91	0.66	0.80	0.41
Foliaceous corals			0.35	0.32	1.07	1.07
Soft Corals			3.64	2.46	0.48	0.48

(c) Coral Bay Region

The Coral Bay region is bounded by the fringing reef and runs from Point Anderson in the south to Bateman Bay in the north, enclosing areas that support a diverse mosaic of large patch reefs and shallow (< 4 m) sandy lagoonal areas. The fringing reef flat lies offshore as close as 400 m (south of Maud Sanctuary), is 2 km offshore at Yalobia passage, near Point Anderson and extends to 6 km offshore at the northern boundary of Maud sanctuary, near Cardabia passage. Habitat surveys in this region were therefore stratified into nearshore, lagoon and back reef areas. A total of 29 sites were surveyed at Maud sanctuary zone and the adjacent recreation zone south to Point Anderson (Figure 4).

Nearshore substrates sampled were predominantly limestone pavement (17.12 %), interspersed with sand (15.88 %) and rubble (11 %). Hard coral gardens were also common with diverse mosaics of digitate *Acropora* (10.02 %), tabulate *Acropora* (9.37 %) and foliaceous corals such as *Echinopora* (6.73 %). Massive *Porites* (4.50 %) and sub-massive corals (4.15 %) were also present. Some nearshore coral gardens (around Coral Bay town site and boat ramp) were intermixed with areas of intact dead coral (6.01 %) covered with turf (6.01 %). Expanses of macroalgae (4.52 %), dominated by *Sargassum*, were also evident in some nearshore sites south of Maud sanctuary (Figure 12).

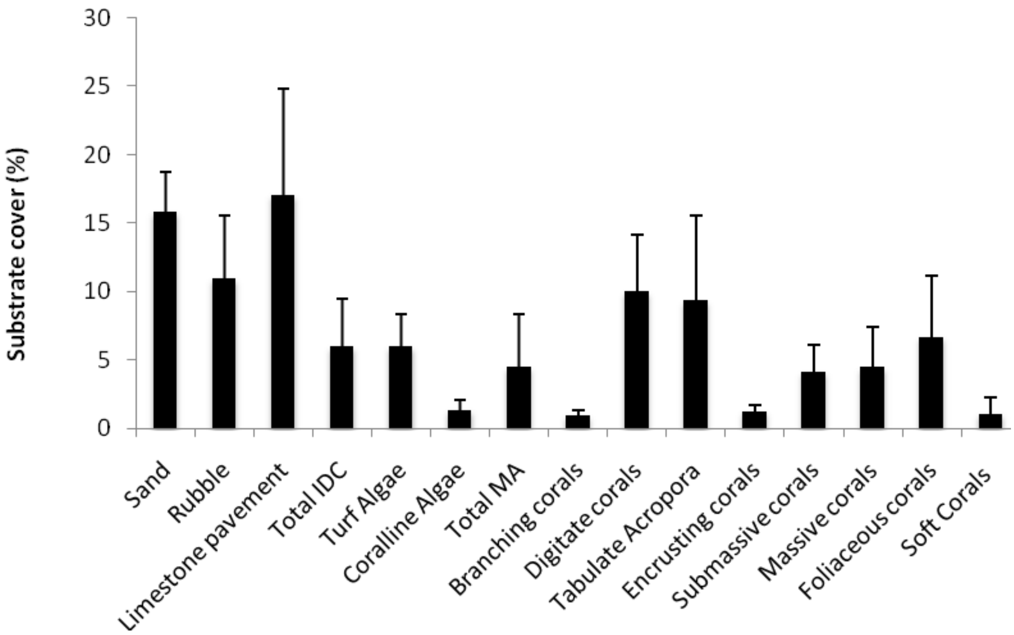

Figure 10 Regional overview of percent cover of substrate types in the nearshore habitats in the Coral Bay region.

Lagoonal areas surveyed were mostly sandy substrates (30.28 %) with some rubble (7.61 %) and exposed limestone pavement ridges (3.17 %). Lagoonal ridges and patch reefs consisted of macroalgae (12.00 %), intact dead coral (10.94 %), turf algae (7.33 %) and a diverse variety of hard corals such as digitate *Acropora* (5.61 %), branching *Acropora,* massive, sub-massive, and foliaceous corals (around 4 % each). Coralline algae and encrusting corals (<3 %) were also noted (Figure 13).

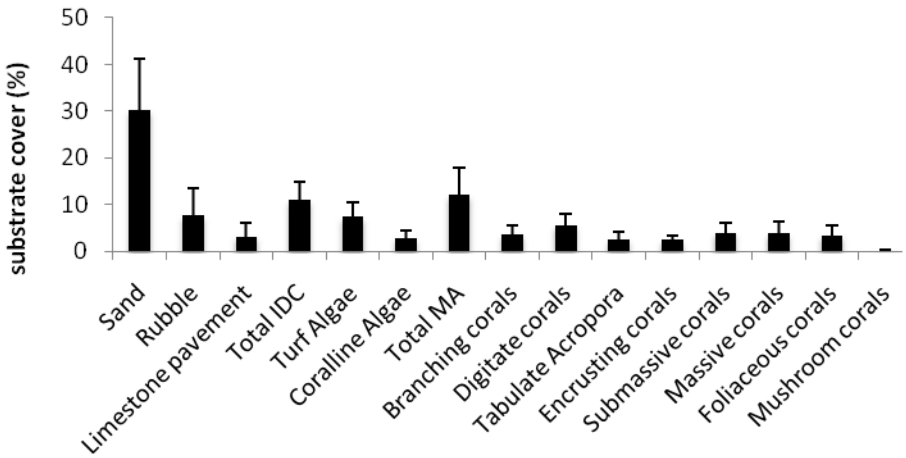

Figure 11 Regional overview of percent cover of substrate types in the lagoonal habitats in the Coral Bay region.

Back reef areas were found to be more diverse than lagoonal areas, with sandy patches (18.91 %), rubble (13.22 %) and a higher coverage of intact dead coral (20.56 %), usually colonised by and macroalgae (6.21 %) and turf (1.2 %). Tabulate *Acropora* (14.29 %) was the most common hard coral, followed by branching corals (10.84 %) and digitate *Acropora* (7.98 %). Other hard corals (encrusting, sub-massive, foliaceous, mushroom and massive) accounted for less than 5 % of substrate cover (Figure 14).

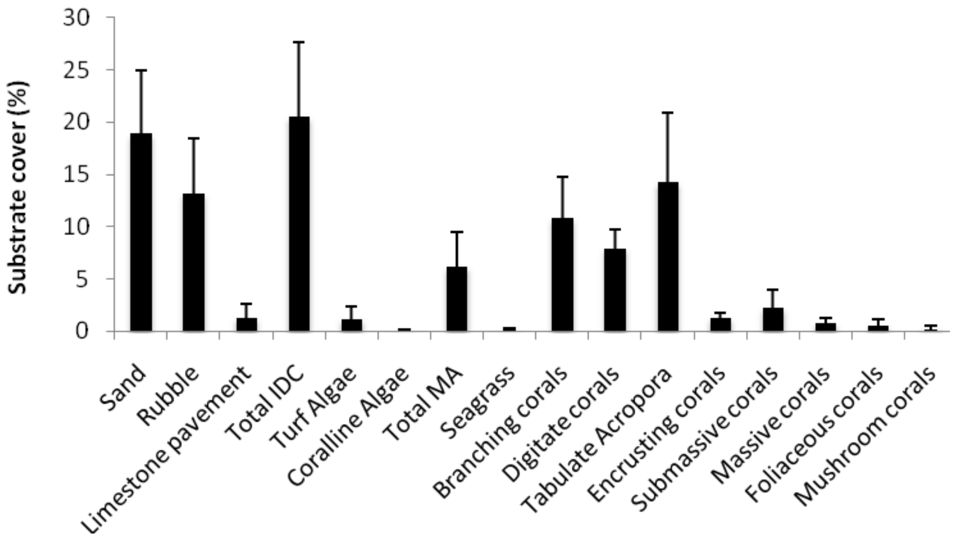

Figure 12 Regional overview of percent cover of substrate types in the back reef habitats in the Coral Bay region.

(d) South Ningaloo Region

The southern end of Ningaloo reef is patchy and closer to shore. South from Cape Farquhar the fragmented fringing reef becomes a nearshore reef through to Gnaraloo Bay, 3 Mile sanctuary and Red Bluff, which is the southernmost point of Ningaloo Marine Park. Sampling was therefore conducted at nearshore reef platform and patch reef sites. A total of 17 sites were surveyed at Cape Farquhar, Gnaraloo Bay, 3 Mile and Turtles sanctuary zones and their adjacent recreation zones (Figure 6). Sampling at Cape Farquhar and Turtles / Red Bluff was limited to intertidal and subtidal limestone reef platforms whereas Gnaraloo Bay and 3 Mile sampling sites consisted of both nearshore reef platform and patch reef sites.

Cape Farquhar

Nearshore areas sampled at Cape Farquhar were predominantly narrow (3-5 m) subtidal and intertidal reef platforms extending out at an angle from a sandy shoreline for 30-50 m and surrounded on all sides by shallow (<2 m) sandy substrate. The platforms were parallel to each other and around 10 m apart. Reef platforms consisted of bare limestone pavement (65 %) with sandy patches (7.5 %) and some areas of pavement were colonised by turf algae (14.58 %) and macroalgae (3.61 %). Soft corals (5.56 %) had also colonised the seaward edges of some platforms (Figure 15).

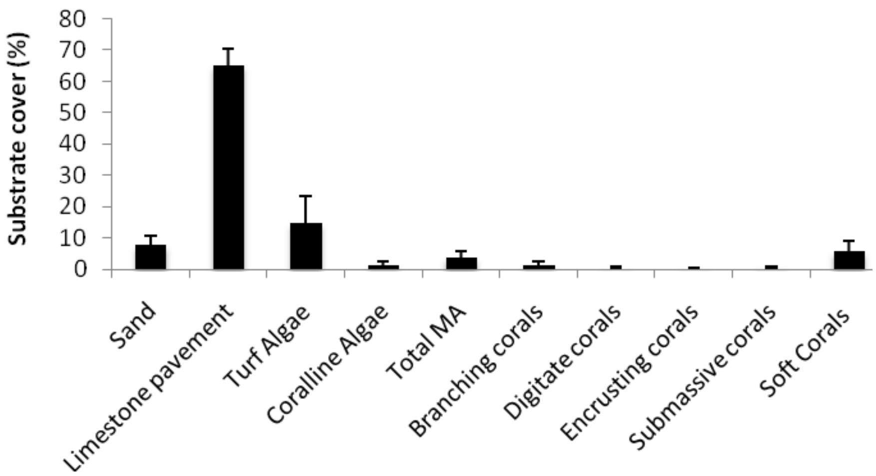

Figure 13 Regional overview of percent cover of substrate types in the nearshore habitats in the Cape Farquhar region.

Gnaraloo Bay

Sites surveyed at Gnaraloo Bay were intertidal/subtidal platforms and shallow (<2 m) nearshore patch reefs in calm sandy areas. The bay comprises a diverse variety of benthic habitats, including macroalgae, hard and soft corals, sponges and seagrass. Branching coral (24.31 %) was the most common hard coral, followed by digitate *Acropora* (9.51 %) and tabulate *Acropora* (6.32 %). Other hard corals (encrusting, sub-massive, foliaceous and massive) accounted for around 8 % of substrate cover. Intact dead corals (11.81 %) and limestone pavement (6.04 %) were also common and were typically colonised by turf (3.78 %) and macroalgae (8.01 %). Soft corals (6.18 %) and seagrass (2.36 %) were also recorded in the bay area (Figure 16).

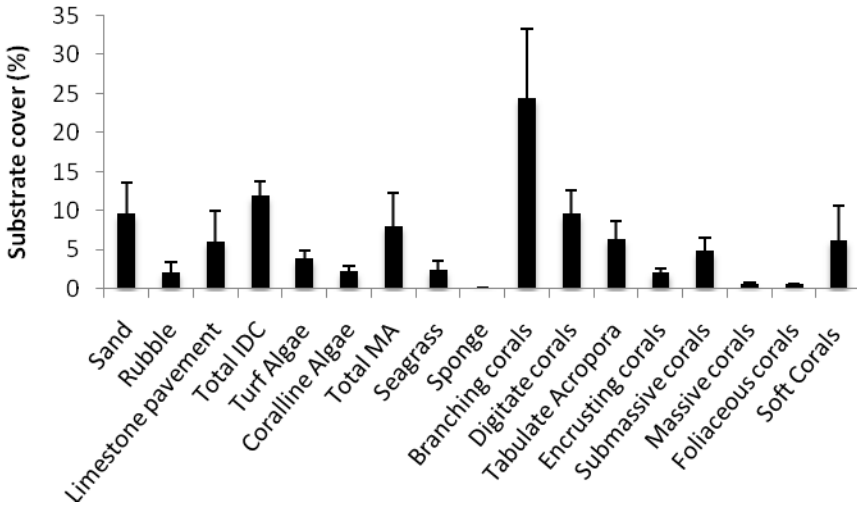

Figure 14 Regional overview of percent cover of substrate types in the nearshore habitats in the Gnaraloo Bay region.

3 Mile and Red bluff

Nearshore sites sampled at 3 Mile and Turtles sanctuaries and adjacent recreation zones were predominantly subtidal and intertidal reef platforms, framed by rocky shores. Intermittent nearshore patch reefs and shallow coral gardens were widespread at 3 Mile but were not evident at Red Bluff, where the subtidal platforms dropped off into deep water.

At 3 Mile, limestone pavement (39.33 %) was the dominant substrate on subtidal and intertidal reef platforms, with mixed patches of turf (14.33 %), macroalgae (5.33 %) and coralline algae (3.00 %). Tabulate *Acropora* (9.67 %), digitate *Acropora* (7.67 %), and branching corals (6.33 %) accounted for almost 25 % of habitat in nearshore patch reefs and shallow coral gardens. Other corals (intact dead corals, sub-massive, foliaceous and soft corals) accounted for around 8 % of substrate cover at 3 mile (Figure 17). At Red Bluff, nearshore limestone pavement (38.78 %) platforms, covered in dense mats of turf (43.73 %) and macroalgae (17.50 %) were the dominant characteristic of the region (Figure 18).

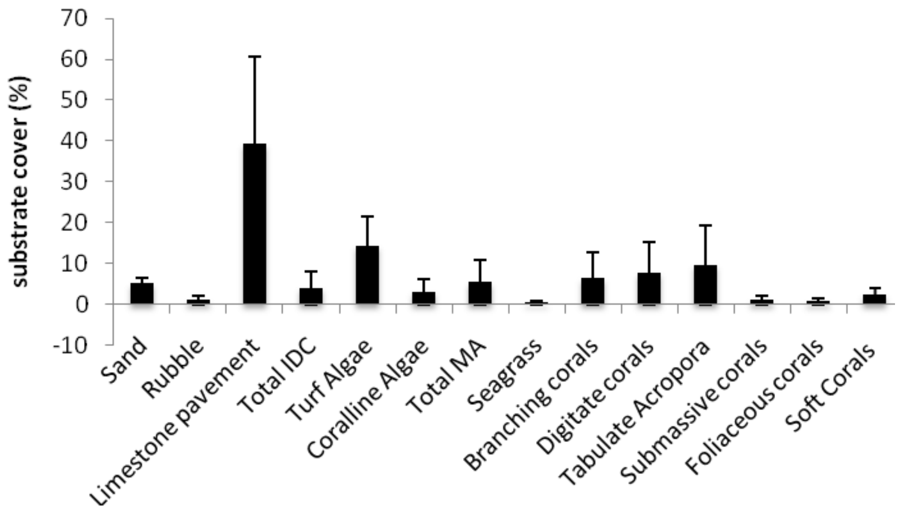

Figure 15 Regional overview of percent cover of substrate types in the nearshore habitats in the 3 Mile region.

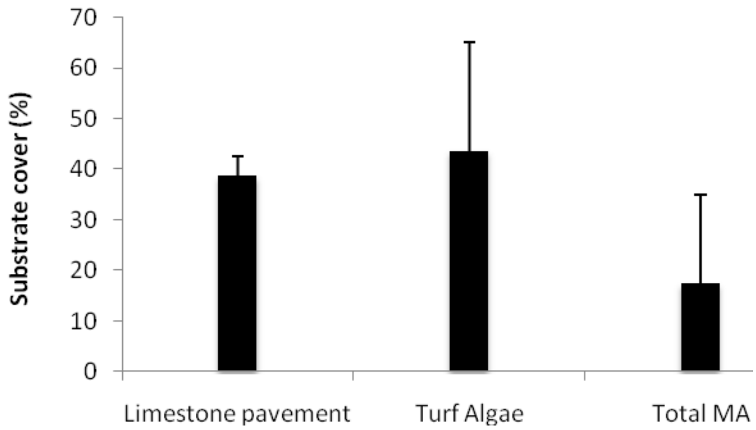

Figure 16 Regional overview of percent cover of substrate types in the nearshore habitats in the Red Bluff region.

Descriptive biodiversity

Seagrasses

The presence of seagrasses was recorded opportunistically during field work for validation and sampling for macro-invertebrates. Material was collected growing *in situ* and also from drift washed up on the shore. Nine species of seagrass have been found in various locations throughout the Ningaloo Reef (Table 6). There are some clear temperate/tropical separations; however several species are found throughout the Ningaloo Reef region.

Table 2-6 Seagrass species of Ningaloo Reef.

Species	Biogeographical affinity	Range limit
Posidonia australis	Temperate	N to Coral Bay (drift)
Posidonia coriacea	Temperate	N to Bateman Bay
Amphibolis antarctica	Temperate	N to Bateman Bay
Cymodocea serrulata	Tropical	S to Coral Bay
Thalassia hemprichii	Tropical	Rare, S to Tantabiddi (drift)
Syringodium isoetifolium	Tropical/Cross-zone	Throughout
Halodule uninervis	Tropical/Cross-zone	Throughout
Halophila spinulosa	Cross-zone	Rare, S to Bateman Bay
Halophila ovalis	Cross-zone	Throughout

The large meadow-forming temperate species *Posidonia australis*, *P. coriacea* and *Amphibolis antarctica* are found at their northern limit in Bateman Bay. *P. coriacea* forms sizeable clumps in water 5 m or more deep; it is tolerant of rough water and is likely found in deeper channels. It is frequently found washed up in drift and will often accumulate in windrows on the water surface during periods of continuous wind. *A. antarctica* can be found growing in large circular clumps in Bateman Bay, particularly near Bruboodjoo Point. It also grows in rocky areas, such as the Lagoon. *P. australis* was not found growing *in situ*; it is possible that the material found was washed up from meadows growing further south.

Cymodocea serrulata and *Thalassia hemprichii* were only found rarely; both are considered tropical and *C. serrulata* was found only as far south as Coral Bay, while *T. hemprichii* was only found in the drift near Tantabiddi.

The other species, while largely tropical, are more commonly found and have broader distributions throughout Ningaloo. *Halophila ovalis* is the most commonly found seagrass at Ningaloo, frequently found growing in sandy patches between coral heads. *Halophila spinulosa* is less common, although unconfirmed reports suggest it forms extensive beds near Point Cloates. It tends to prefer deeper water; a single specimen was collected at 8 m depth near the Porites in Bateman Bay. *Halodule uninervis*, primarily a tropical species, is very common and often found growing together with *Halophila ovalis* in sandy areas. *Syringodium isoetifolium*, also considered tropical, is generally found growing with *Halophila ovalis* and sometimes *Halodule uninervis*, although it will also grow in isolation.

Sponges and soft corals

Twenty-three stations were sampled for sponges and soft corals by Dr Jane Fromont and Oliver Gomez of the WA Museum; 13 stations in the Gnaraloo region and ten in the Tantabiddi region. Thirty-six species of sponges were collected and nine species of soft corals. There was little overlap of species from the two sampling locations, showing clear biogeographical separation between northern and southern populations. Only five sponges and one soft coral were found to occur in both regions of Ningaloo. Most species were rarely encountered, with 27 sponges and six soft corals having five or less individuals recorded from all stations.

Further collections were made from the Point Cloates region, as part of the C-Reefs project; extensive collections have also been made of deep water sponges in the waters offshore of Ningaloo Reef. Further funding is required to match the lagoon specimens from Gnaraloo and Tantabiddi with those from Point Cloates and the deep water samples.

A full description of the results is presented in Appendix 1 (Fromont and Gomez, 2010).

Quantitative measures of biodiversity

Macroinvertebrate surveys

Macroinvertebrate counts were conducted at all sites (97 sites, see Figures 4-6) for individual urchins (predominantly *Echinometra mathaei*), holothurians, tridacnid clams, the corallivorous snail, *Drupella cornus* and soft corals. Other macroinvertebrates, such as sea stars, trochus, large bivalves, sponges and octopus were grouped together as “other”. Macroinvertebrate results are given as mean number of individuals per square metre (± 1 SE).

(a) NW Cape Region

Bundegi

Nearshore habitats south of Bundegi beach were sampled and no macroinvertebrates were observed at any of the sites.

North of Jurabi Point

Nearshore areas at Graveyards, Baudin, Trisel, and Hunters were predominantly inhabited by urchins (5.37 m^{-2}) and clams (0.91 m^{-2}). Low densities (<0.2 m^{-2}) of holothurians, soft corals and sponges were also noted (Figure 19).

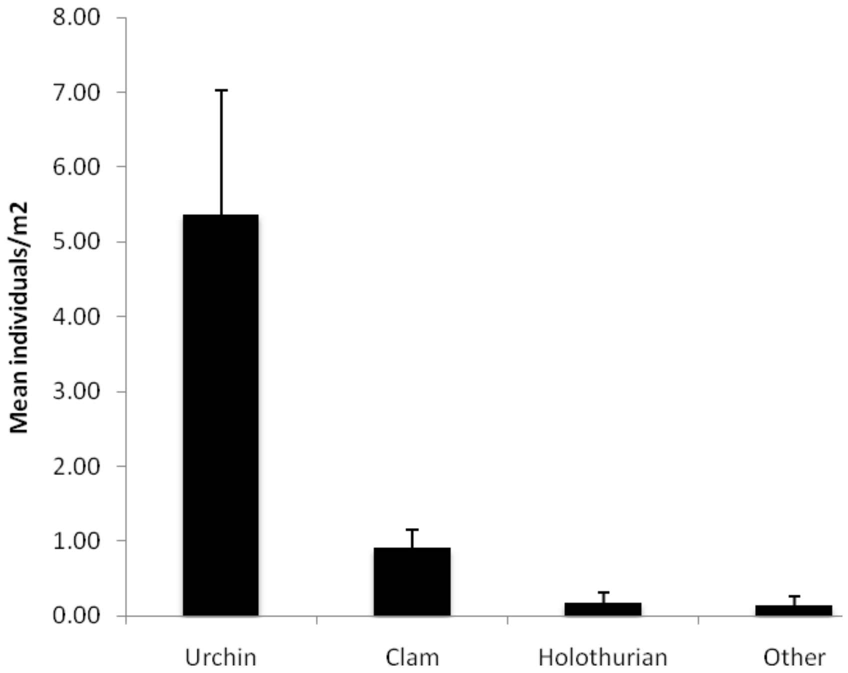

Figure 17 Densities of key macroinvertebrate groups in the nearshore habitat north of Jurabi Point.

(b) Tantabiddi to Yardie Creek Region

Habitats in this region are home to a diverse number of macroinvertebrates (0.48 m^{-2}) including sponges, polychaetes, scallops, trochus, sea stars, octopus and assorted snails. Urchins (0.42 m^{-2}), *Drupella*, (0.22 m^{-2}), holothurians (0.19 m^{-2}) and soft corals (0.19 m^{-2}) were also characteristic of the region (Figure 20).

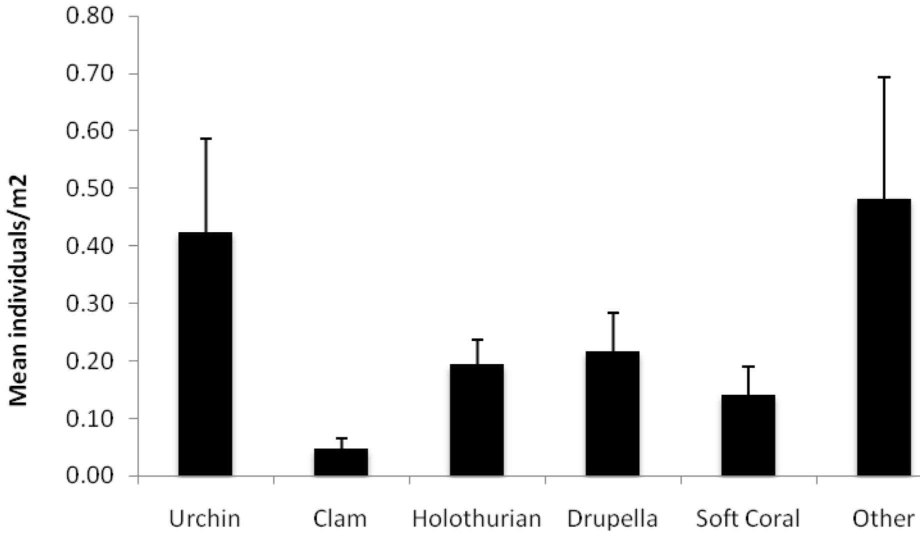

Figure 18 Densities of key macroinvertebrate groups in all habitats in the Tantabiddi to Yardie Creek region.

Nearshore areas sampled had very low densities (<0.22 m^{-2}) of urchins, clams, holothurians and *Drupella*. However, high densities (~9 m^{-2}) of polychaetes recorded at one nearshore site were responsible for a higher mean count (~1.0 m^{-2}) of “other” invertebrates (Figure 21).

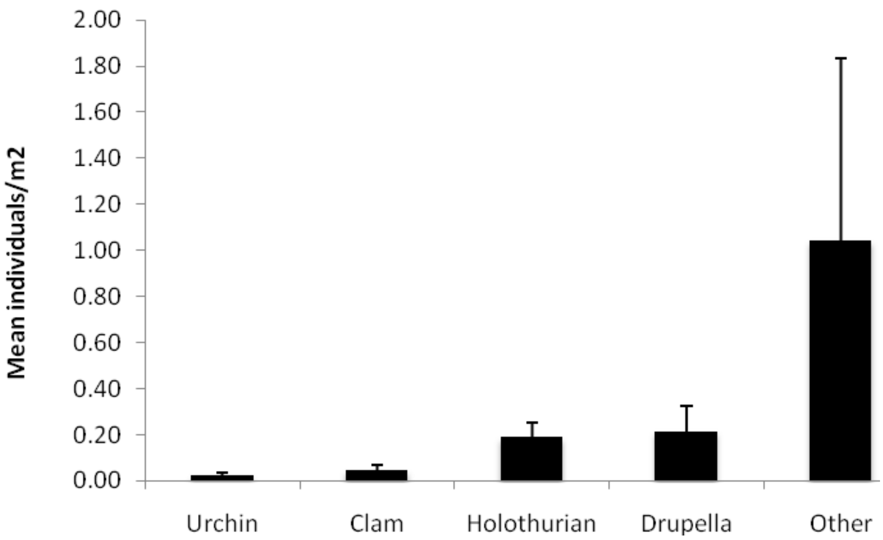

Figure 19 Densities of key macroinvertebrate groups in the nearshore habitat in the Tantabiddi to Yardie Creek region.

Lagoonal areas surveyed had higher densities of urchins (0.61 m^{-2}) on patch reefs and low densities of holothurians and soft corals (~0.2 m^{-2}) in sandy lagoons. Other macroinvertebrates (~0.4 m^{-2}) included sponges, trochus, sea stars and assorted snails (Figure 22).

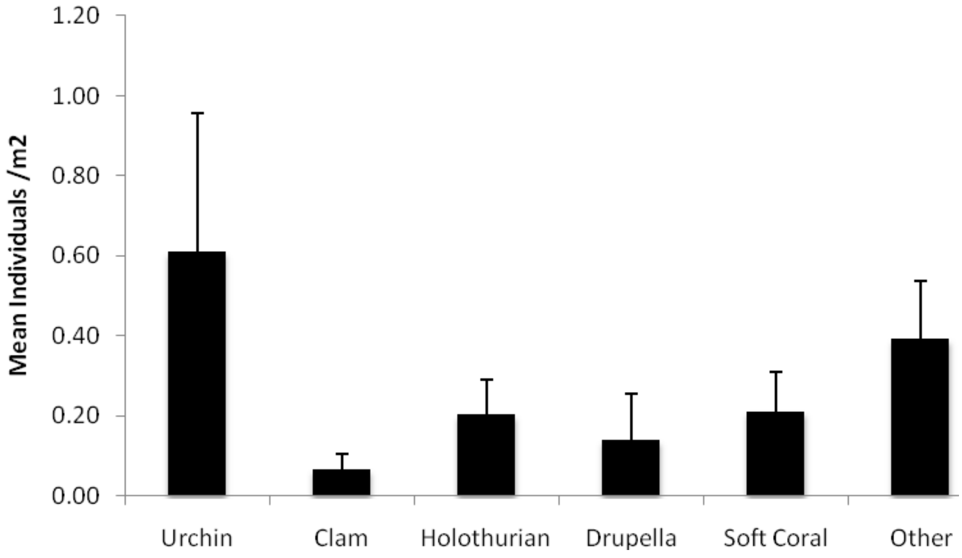

Figure 20 Densities of key macroinvertebrate groups in the lagoonal habitat in the Tantabiddi to Yardie Creek region.

Back reef sites sampled were found to have a diverse mix of invertebrates, with urchins (0.49 m^{-2}) and *Drupella* (0.33 m^{-2}) present in back reef coral gardens. Holothurians (0.18 m^{-2}), and soft corals (0.16 m^{-2}) were also evident in small numbers in shallow sandy patches. Other macroinvertebrates (0.14 m^{-2}) included trochus, sea stars, anemones and octopus (Figure 23).

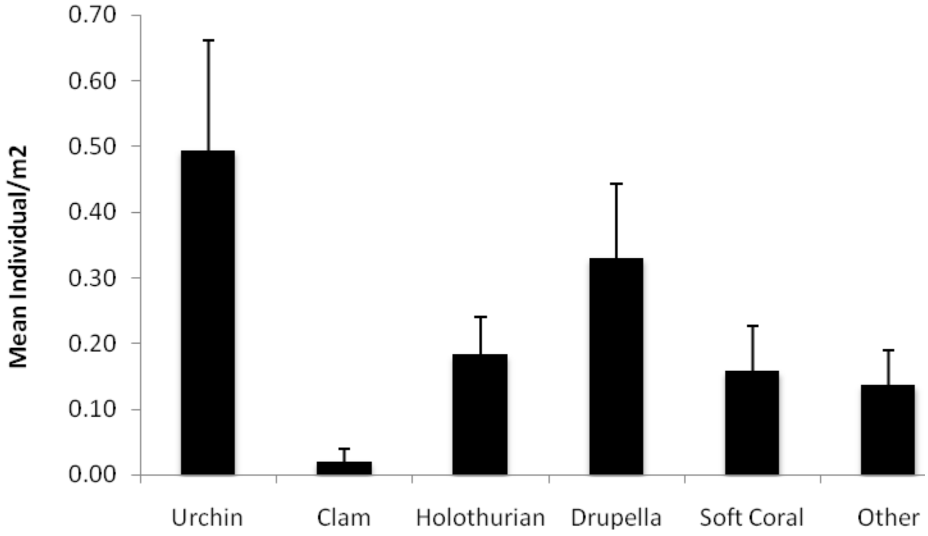

Figure 21 Densities of key macroinvertebrate groups in the back reef habitat in the Tantabiddi to Yardie Creek region.

(c) Coral Bay Region

Habitats surveyed in this region are a diverse mosaic of large patch reefs and shallow (< 4m) sandy lagoonal areas and nearshore limestone platforms. They support a range of invertebrate communities, including urchins (1.33 m^{-2}), *Drupella* (0.52 m^{-2}) clams (0.30 m^{-2}), holothurians (0.15 m^{-2}) and a variety of other invertebrates (0.47 m^{-2}) such as sea stars, trochus, bivalves, and snails (Figure 24). The Coral Bay region can be divided into two sub-regions; North (Maud Sanctuary zone) and South (Recreation Zone).

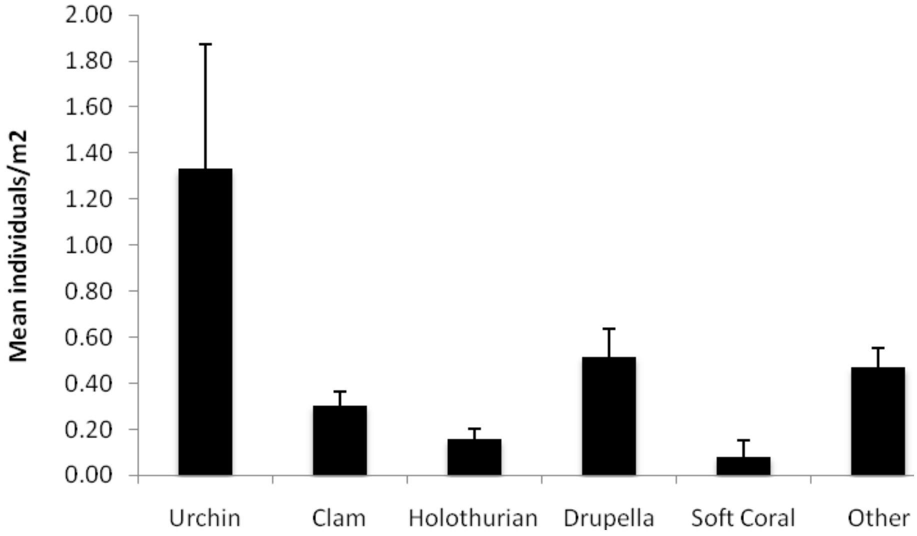

Figure 22 Densities of key macroinvertebrate groups in all habitats in the Coral Bay region.

Nearshore sites surveyed in Maud Sanctuary zone (Figure 25) were typically inhabited by *Tridacnid* clams (0.37 m^{-2}), soft corals (0.33 m^{-2}), urchins (0.27 m^{-2}) and *Drupella* (0.27 m^{-2}). In contrast, nearshore sites in the southern recreation zone (Figure 26) were typically populated by higher densities of urchins (4.06 m^{-2}) on limestone ridges and platforms and a small number of holothurians (0.49 m^{-2}) in sandy nearshore patches.

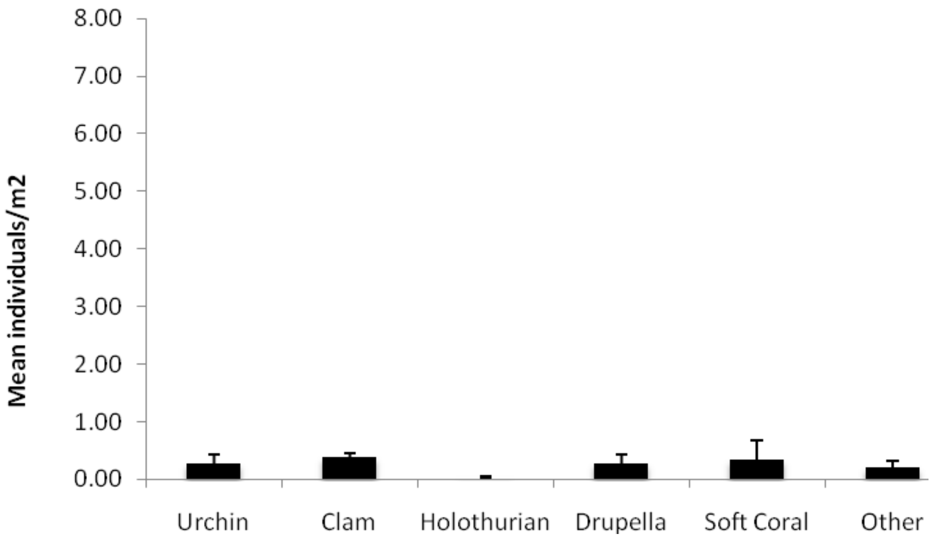

Figure 23 Densities of key macroinvertebrate groups in the nearshore habitat in the Coral Bay region (Maud Sanctuary zone).

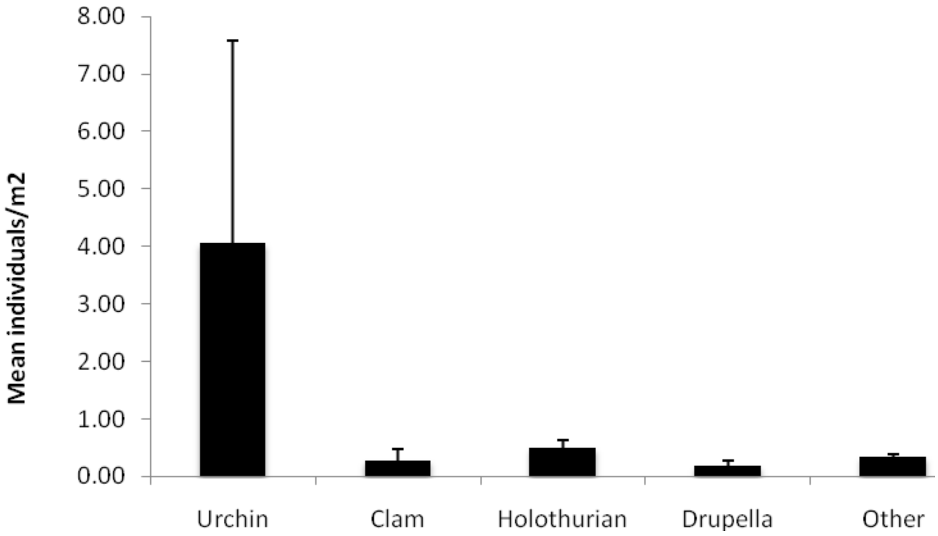

Figure 24 Densities of key macroinvertebrate groups in the nearshore habitat in the Coral Bay region (southern recreational zone).

Lagoonal areas surveyed in Maud Sanctuary zone had much greater densities of the corallivorous snail, *Drupella cornus* (1.49 m^{-2}), when compared to densities in the southern recreation zone (0.08 m^{-2}). However urchin densities in Maud Sanctuary zone were around 40 % of densities recorded at sites in the southern recreation zone (0.85 m^{-2} compared to 2.13 m^{-2}) and clams, holothurians and other invertebrate densities recorded in Maud sanctuary zone (Figure 27) were noted to be around half of those recorded in the southern recreation zone (Figure 28).

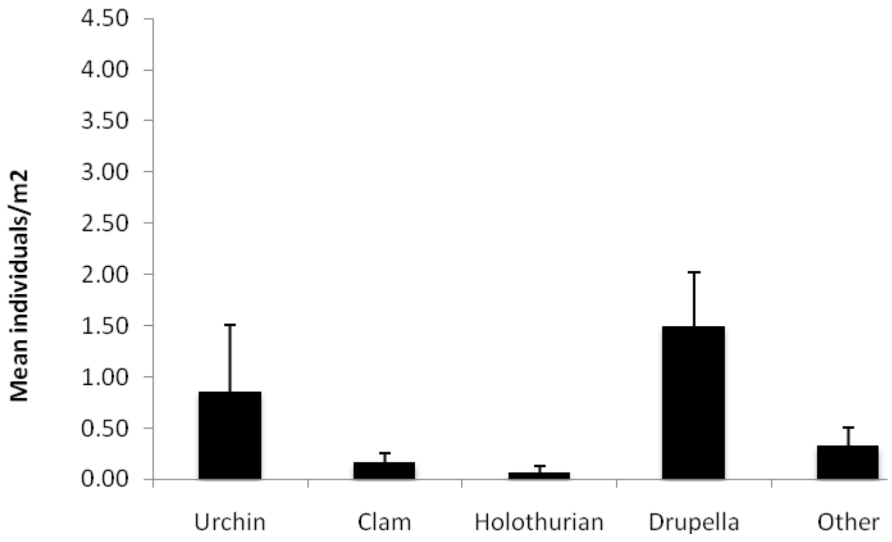

Figure 25 Densities of key macroinvertebrate groups in the lagoonal habitat in the Coral Bay region (Maud Sanctuary zone).

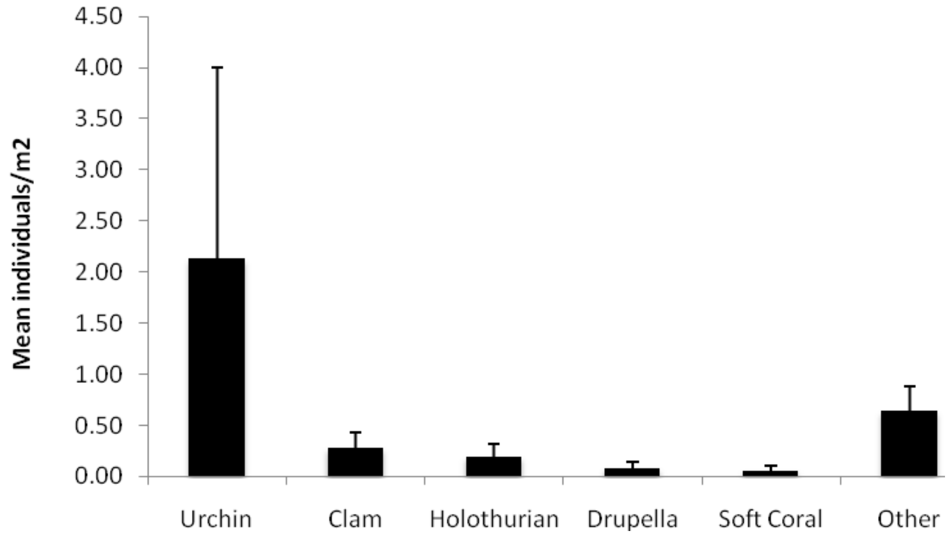

Figure 26 Densities of key macroinvertebrate groups in the nearshore habitat in the Coral Bay region (southern recreational zone).

Back reef habitat types were found to be fairly consistent between Maud Sanctuary zone and the southern recreation zone. Urchins (0.86 m^{-2}) and *Drupella* (0.64 m^{-2}) were typically found inhabiting back reef patch reefs as well as clams (0.34 m^{-2}) and other invertebrates (0.63 m^{-2}) such as sea stars, trochus, bivalves, and snails. A small number of holothurians (0.15 m^{-2}) were also typically found in sheltered sandy areas (Figure 29).

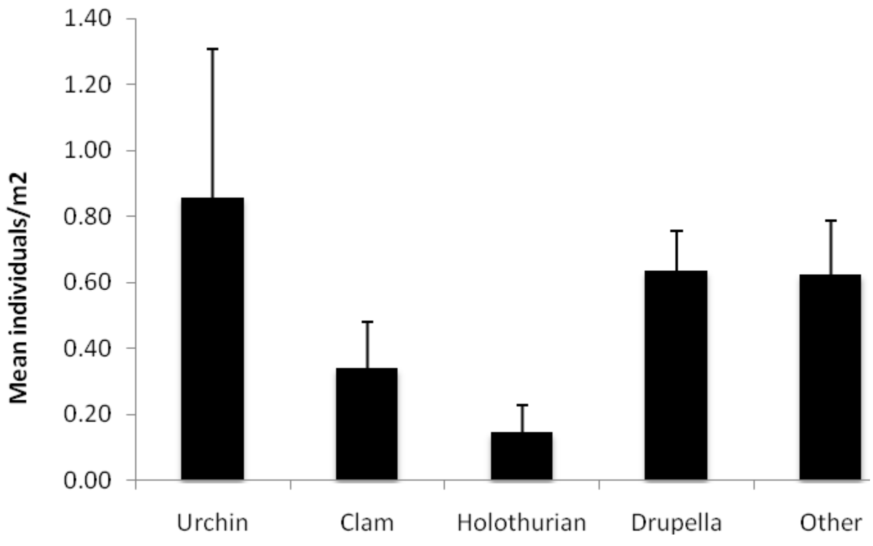

Figure 27 Densities of key macroinvertebrate groups in the back reef habitat in the Coral Bay region.

(d) South Ningaloo Region

Cape Farquhar

Nearshore habitats sampled at Cape Farquhar (Figure 30) were mainly limestone platforms surrounded by shallow sandy substrates. The platforms were typically colonised by urchins (1.36 m^{-2}), holothurians (0.43 m^{-2}), clams (0.2 m^{-2}) and soft corals (0.19 m^{-2}).

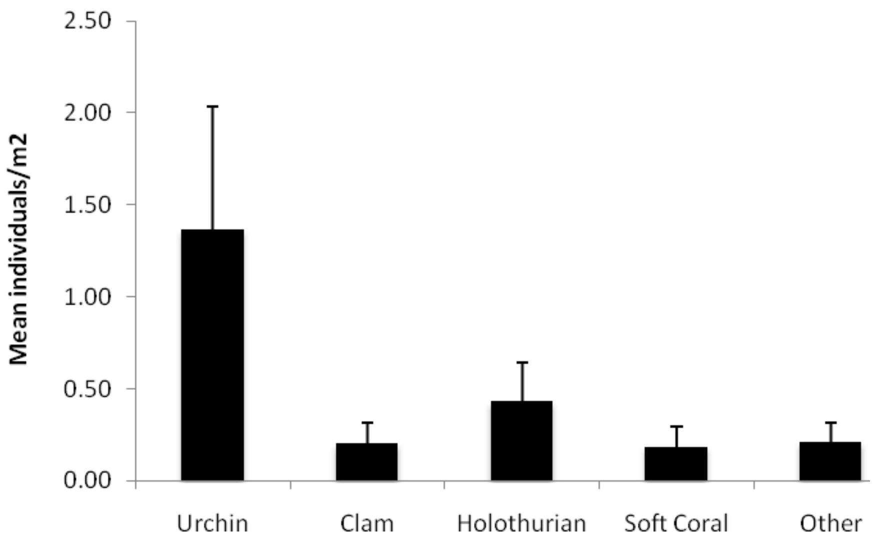

Figure 28 Densities of key macroinvertebrate groups in the nearshore habitat in the Cape Farquhar region.

Gnaraloo Bay

Sites surveyed at Gnaraloo Bay were limestone platforms and shallow (<2m) nearshore patch reefs in calm sandy areas. These sites were inhabited by a diverse macroinvertebrate community including urchins (0.54 m^{-2}), soft corals (0.31 m^{-2}), *Drupella* (0.29 m^{-2}) clams (0.22

m^{-2}) and a variety of other invertebrates (0.56 m^{-2}) such as sea stars, trochus, anemones, and assorted snails (Figure 31).

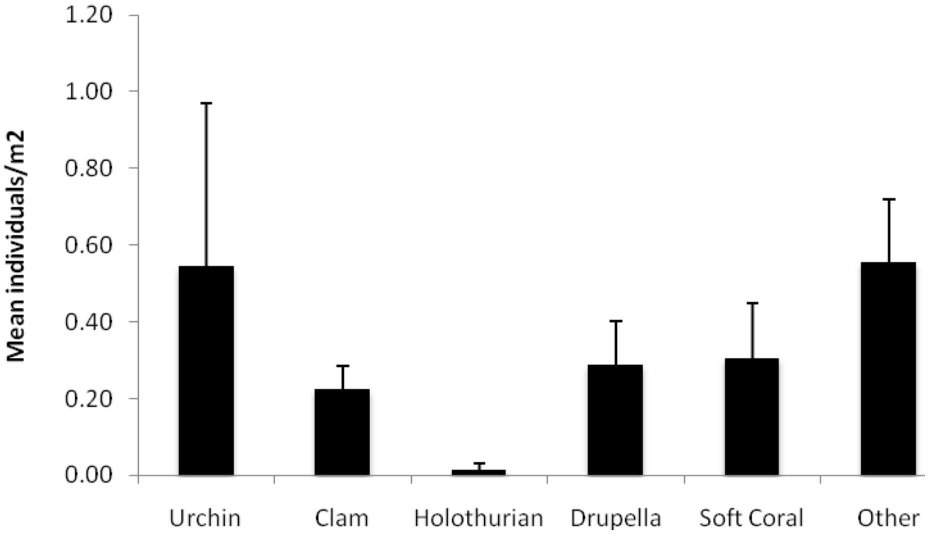

Figure 29 Densities of key macroinvertebrate groups in the nearshore habitat in the Gnaraloo region.

3 Mile

Nearshore sites sampled at 3 Mile Sanctuary and the neighbouring recreation zone were mostly nearshore subtidal and intertidal reef platforms, patch reefs and shallow coral gardens. Sites were predominantly urchin habitats (3.55m^{-2}) and reasonably high densities of *Drupella* (2.24 m^{-2}) were also present in coral gardens. Lower densities of soft corals (0.53 m^{-2}), Tridacnid clams (0.51 m^{-2}) and holothurians (0.40 m^{-2}) were also evident (Figure 32).

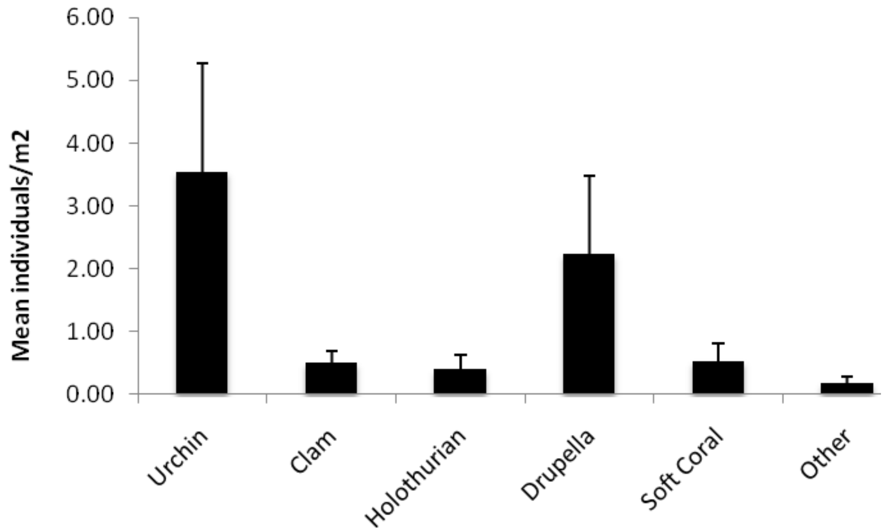

Figure 30 Densities of key macroinvertebrate groups in the nearshore habitat in the 3 Mile region.

Red Bluff

Sites surveyed at Turtles Sanctuary and the neighbouring recreation zone at Red Bluff were characterised by subtidal and intertidal reef platforms nearshore. At Red Bluff, the subtidal platforms dropped off into deep water. All nearshore platforms were predominantly urchin habitat, with very high densities (12.36 m^{-2}) of *Echinometra mathaei* present. Tridacnid clams (1.10 m^{-2}) were also present in high densities on shallow limestone platforms (Figure 33).

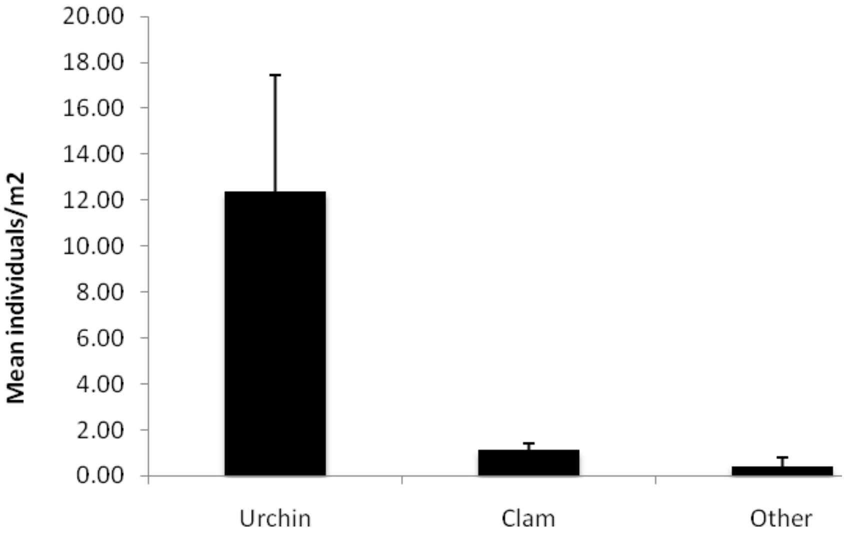

Figure 31 Densities of key macroinvertebrate groups in the nearshore habitat in the Red Bluff region.

Multivariate analyses - Macroinvertebrates

Further analyses were conducted to examine spatial trends in the macroinvertebrate community composition of benthic habitats between regions, between management zones (Sanctuary v Recreation) and between locations within regions (near-shore, lagoon and back reef) where lagoonal areas were surveyed. Multivariate analyses were conducted using the PRIMER v6 statistical package (Clarke and Warwick, 2001). Relevant results are presented below.

a) Comparisons between regions

NW Cape v Tantabiddi - Yardie Creek (nearshore)

Initial interpretation of spatial patterns using a non-metric multidimensional scaling (nMDS) plot indicated differences in macroinvertebrate composition of benthic habitats between regions (Figure 34). One-way analysis of similarity (ANOSIM) using region as a group factor confirmed a significant dissimilarity in invertebrate community structure exists between regions (average dissimilarity = 92.31, $R = 0.456$, $p = 0.001$), where R is based on the difference of mean ranks between groups and within groups ($R= 0$ indicates no differences between groups, $R=1$ indicates no similarities between groups). Further similarity percentage analysis (SIMPER) indicated that urchins were the key species contributing to the regional dissimilarities in composition (55.38 %) with an average 80 times greater abundance at NW Cape. Clams (17.63 %) and other invertebrates (12.70 %) also contributed to dissimilarities in community composition (Table 7).

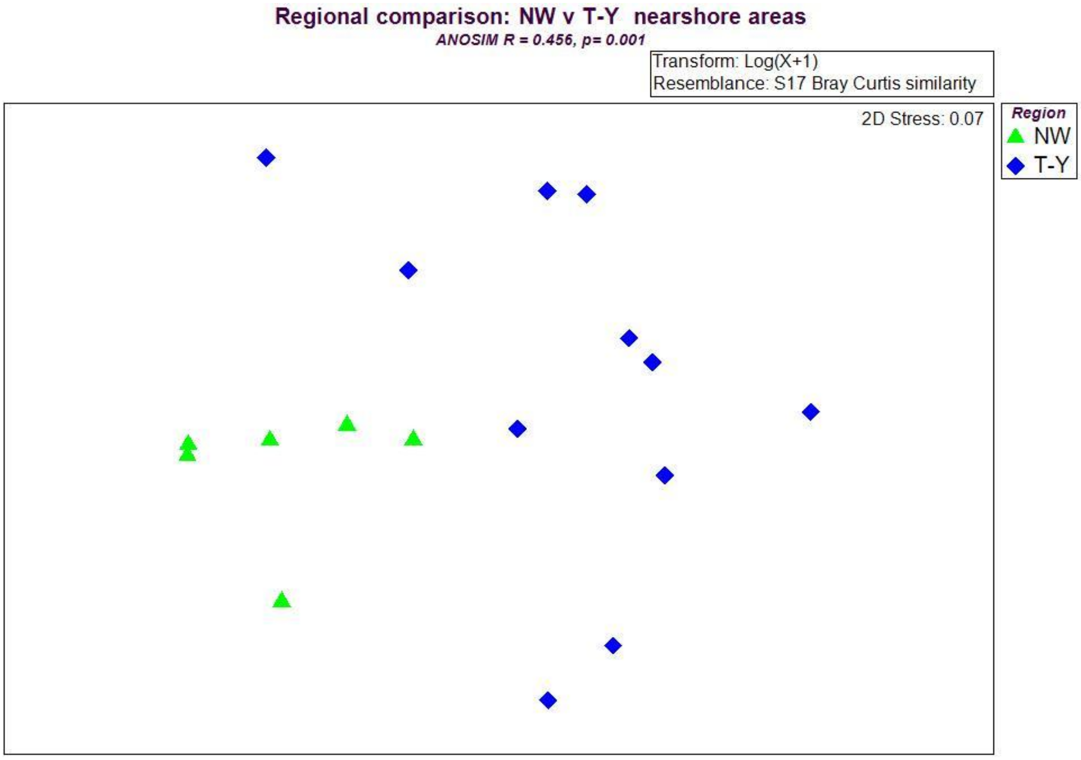

Figure 32 nMDS plot indicating differences in macroinvertebrate composition of nearshore benthic habitats between regions (North West Cape (NW) vs. Tantabiddi to Yardie Creek (T-Y)).

Table 2-7 Regional SIMPER results output – North West Cape (NW) vs. Tantabiddi to Yardie Creek (T-Y).

Region	**NW**	**T-Y**	Average dissimilarity = 92.31			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
URCHIN	1.66	0.02	51.12	3.84	55.38	55.38
CLAM	0.60	0.04	16.27	2.10	17.63	73.01
OTHER	0.10	0.39	11.72	0.72	12.70	85.71
HOLOTHURIAN	0.13	0.16	7.18	0.91	7.77	93.49

South Ningaloo v Tantabiddi - Yardie Creek (nearshore)

Initial analysis of spatial patterns using an nMDS plot indicated differences in macroinvertebrate composition of benthic habitats between regions (Figure 35). One-way ANOSIM using "region" as a group factor confirmed a significant dissimilarity in invertebrate community structure exists between regions (average dissimilarity = 82.53, R = 0.338, p = 0.001). Further SIMPER analysis indicated that urchins were the key species contributing to the regional dissimilarities in composition (36.74 %) with average abundances 50 x more at South Ningaloo. Other invertebrates (17.51 %), *Drupella* (15.14 %), clams and holothurians (~11 % each) also contributed to dissimilarities in community composition (Table 8).

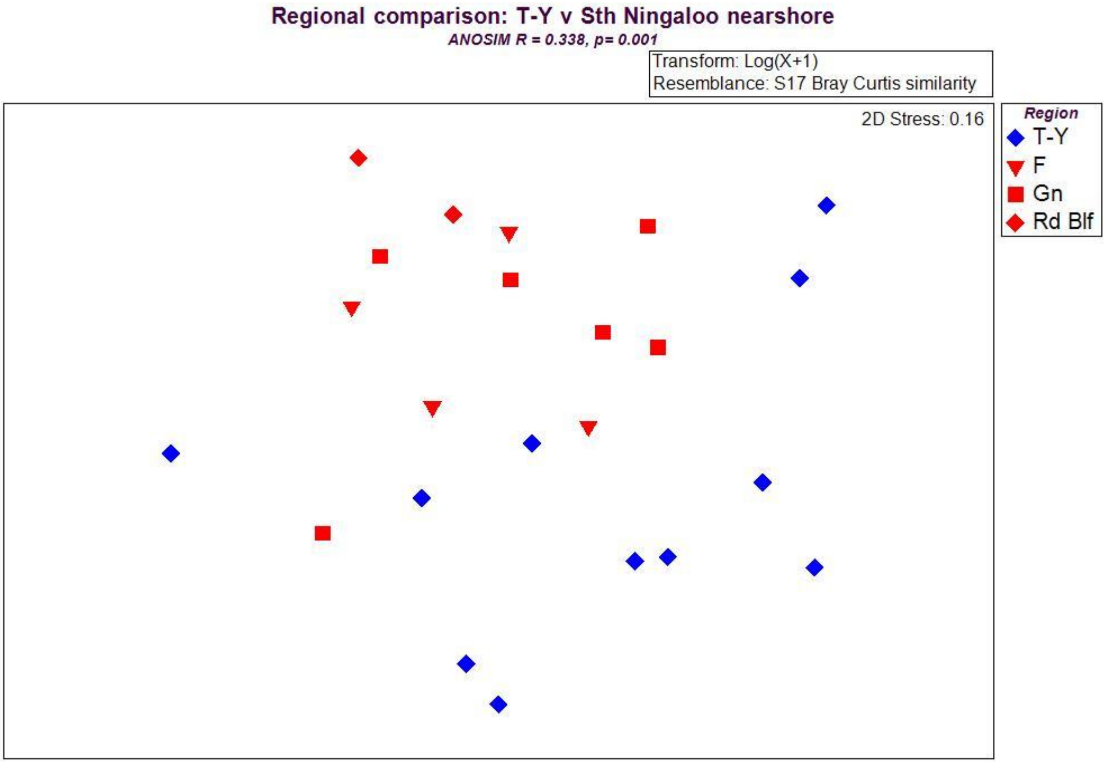

Figure 33 nMDS plot indicating differences in macroinvertebrate composition of nearshore benthic habitats between regions (Tantabiddi to Yardie Creek (T-Y) and South Ningaloo (S)).

Table 2-8 Regional SIMPER results output – South Ningaloo (red symbols) vs. Tantabiddi to Yardie Creek (T-Y).

Region	**T-Y**	**S Ningaloo**	Average dissimilarity = 82.53			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
URCHIN	0.02	1.05	30.32	1.43	36.74	36.74
OTHER	0.39	0.24	14.45	0.90	17.51	54.25
DRUPELLA	0.16	0.33	12.50	0.80	15.14	69.39
CLAM	0.04	0.33	9.51	1.48	11.53	80.92
HOLOTHURIAN	0.16	0.19	9.14	0.89	11.08	92.00

b) Comparisons within regions and sub-regions (Sanctuary vs. Recreation zones)

Initial interpretation of spatial patterns using nMDS plots and ANOSIM (with a group factor of “zoning”) indicated no significant differences in the macroinvertebrate community composition of benthic habitats between management zones for Lighthouse, Jurabi, Tantabiddi, Mangrove Bay, Mandu, Osprey, Turtles or Cape Farquhar Sanctuary zones and their neighbouring recreation zones. However, analyses of zoning data from Coral Bay and South Ningaloo indicated some differences between management zones.

Coral Bay

Although no significant differences in the macroinvertebrate community composition in back reef or lagoonal benthic habitats were evident between Maud Sanctuary and adjacent recreation zones, nearshore habitats differed in community composition. Preliminary analysis of spatial patterns using an nMDS plot indicated differences in macroinvertebrate composition of benthic habitats between zones (Figure 36). One-way ANOSIM using “zoning” as a group factor confirmed a considerable (90 % confidence interval) dissimilarity in invertebrate community structure exists between nearshore management zones (average dissimilarity = 79.29, R = 0.444, p = 0.057). Further SIMPER analysis indicated that urchins (37.22 %) were the key species contributing to the dissimilarities in composition between zones with holothurians (18.51 %) also contributing to dissimilarities in community composition (Table 9).

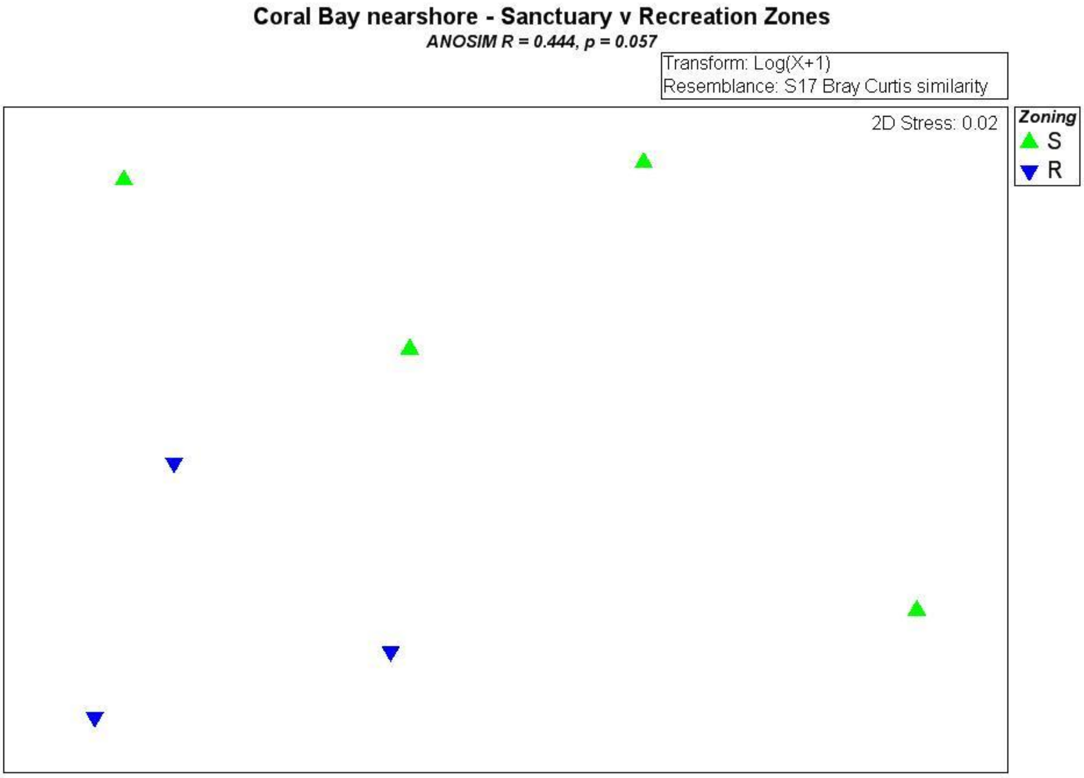

Figure 34 nMDS plot indicating differences in macroinvertebrate composition of nearshore benthic habitats between sanctuary (S) and recreation (R) zones in the Coral Bay region.

Table 2-9 Management zoning SIMPER results output – Coral Bay (Maud Sanctuary).

Region	**Sanctuary**	**Rec**	Average dissimilarity = 79.29			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
URCHIN	0.03	1.11	29.51	1.64	37.22	37.22
HOLOTHURIAN	0.03	0.39	14.68	1.64	18.51	55.73
DRUPELLA	0.3	0.16	9.94	1.05	12.54	68.27
OTHER	0.06	0.29	8.53	1.77	10.76	79.03
SOFT CORAL	0.27	0	8.34	0.53	10.51	89.54

South Ningaloo

Data analysis of spatial trends using an nMDS plot indicated differences in macroinvertebrate composition of benthic habitats between Gnaraloo Sanctuary and the adjacent recreation zone (Figure 37). One-way ANOSIM using “zoning” as a group factor confirmed that a significant dissimilarity in invertebrate community structure exists between nearshore management zones (average dissimilarity = 81.11, R = 0.67, p = 0.036). Further SIMPER analysis indicated that urchins (32.65 %) were the key species contributing to the dissimilarities in composition between zones with *Drupella* (20.25 %) and other invertebrates (19.01 %) also contributing to dissimilarities in community composition (Table 10).

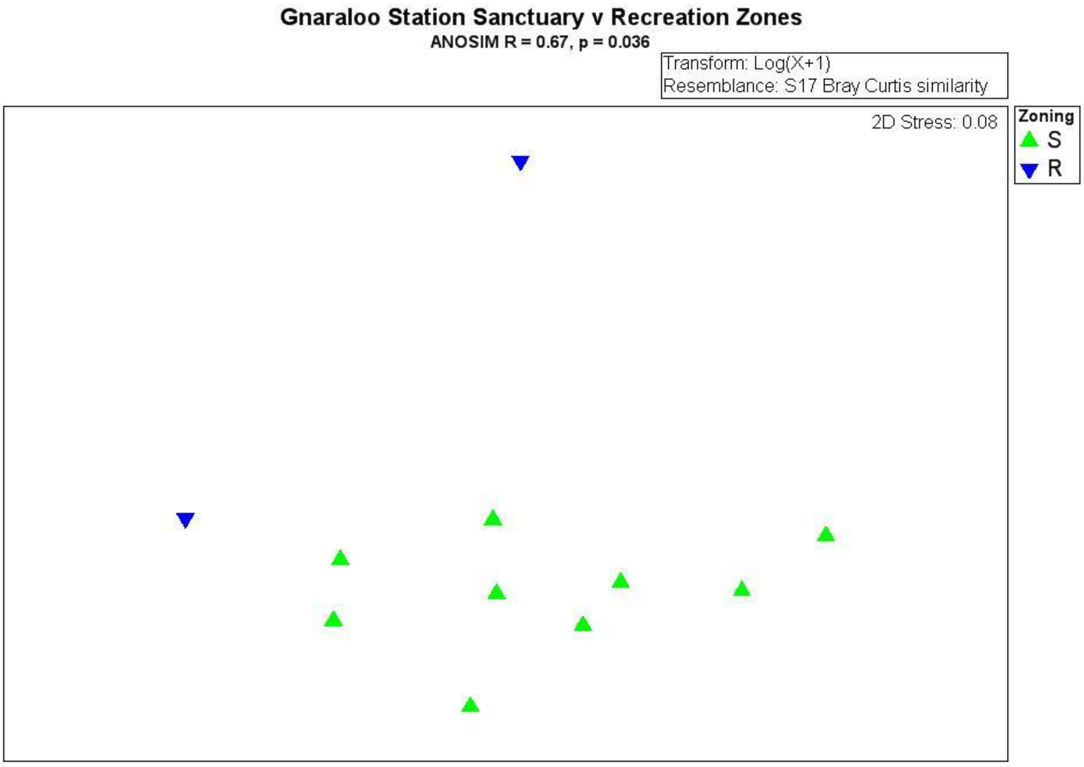

Figure 35 nMDS plot indicating differences in macroinvertebrate composition of nearshore benthic habitats between sanctuary (S) and recreation (R) zones in the Gnaraloo region.

Table 2-10 Management zoning SIMPER results output – Ningaloo south (Gnaraloo Sanctuary).

Region	**Sanctuary**	**Rec**	Average dissimilarity = 81.11			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
URCHIN	1.05	0.45	26.49	1.38	32.65	32.65
DRUPELLA	0	0.53	16.43	1.17	20.25	52.91
OTHER	0.02	0.41	15.42	1.24	19.01	71.92
SOFT CORAL	0	0.33	9.45	1.11	11.64	83.56
CLAM	0.3	0.24	8.88	1.62	10.94	94.5

2.5 Discussion

The Biodiversity and Habitat Mapping project of the Ningaloo Cluster programme has generated significant information about the distribution of habitat types throughout the shallow lagoonal habitats of Ningaloo Marine Park. Surveys were conducted from Red Bluff at the southern-most boundary of the Marine Park to Bundegi in Exmouth Gulf, at the northern limit of the Marine Park. Due to funding constraints the central (Point Cloates) region could not be sampled within this study; however additional sampling will be carried out opportunistically as part of field studies undertaken by PhD candidate Mark Langdon and other studies.

Verification of classification

Verification data was incorporated into the habitat mapping project (see Kobryn, 2010) and will not be discussed further here.

Qualitative measures of biodiversity

Site characteristics
Because of the extent and diversity of the Ningaloo Marine Park habitat it was decided to group survey activities into four major regions: North West Cape, Tantabiddi to Yardie Creek, Point Maud to Point Anderson and South Ningaloo. Within each major region, two to four sub-regions were sampled, with specific habitat types (nearshore, lagoon and back reef) sampled depending on their presence or absence. Of these, Tantabiddi to Yardie Creek and Point Maud to Point Anderson have lagoonal habitats; North West Cape and South Ningaloo only have nearshore habitats.

The presence or absence of a distinct lagoon environment clearly determines the overall composition of benthic substrate types; the regions without a protected lagoon were overall more exposed to ocean swell and therefore showed greatly reduced biological diversity. Nearshore habitats in these areas were dominated by bare sand and sand-covered limestone pavement; exceptions were small nearshore lagoon areas, as at 3 Mile, in the South Ningaloo region. The more benign conditions within the lagoonal areas in the two central regions within the Ningaloo Marine Park permit the development of extensive coral- and algal-dominated communities.

Seagrasses
Sampling at several locations along Ningaloo Reef provided evidence of biogeographic differences in species assemblages, with Point Cloates as a biogeographic barrier. *Posidonia coriacea* and *Amphibolis antarctica* both grow in large patches in Bateman Bay but do not occur further north than Point Cloates. *Posidonia australis* was also collected from the drift south of Coral Bay; however without having been observed growing *in situ* it is possible that this material was washed north from Shark Bay. To date this species has only been recorded to Shark Bay. Further sampling in locations immediately south of Coral Bay would be required to confirm the presence of this species at Ningaloo.

With the exception of *Thalassia hemprichii* and *Cymodocea serrulata*, many of the tropical seagrasses are distributed throughout the Ningaloo Marine Park and have broad distributions along the central west coast of WA. *Halophila ovalis* occurs to Cape Leeuwin, *Syringodium isoetifolium* is found to Perth, *Halophila spinulosa* and *Halodule uninervis* are found to Dongara. Further sampling is required in the northern Bateman Bay / Point Cloates region to confirm range limits of several species.

Sponges and Soft Corals
Sampling at sites in the south (Gnaraloo region) and north (Tantabiddi region) of the Ningaloo Marine Park produced a total of 36 species of sponges and 9 soft corals. There was little overlap of species from the two sampling locations, showing clear biogeographical separation between northern and southern populations. Only three sponges and one soft coral were found to occur in both regions of Ningaloo. Most species were rarely encountered, with 27 sponges and six soft corals having five or less individuals recorded from all stations; however destructive sampling of coral thickets was not carried out and additional cryptic species of sponges might be expected to be found in a more thorough survey.

Additional sampling of sponges and soft corals has been conducted in the Point Cloates region as part of the C-Reefs series of expeditions. Collections of deep-water sponges and soft corals were made as part of AIMS-led deep-water surveys outside the fringing reef. It has not been possible to further work up the samples or integrate the results of the C-Reefs and offshore sampling programmes with the present Wealth from Oceans Cluster programme due to funding constraints; it is hoped that future funding will permit this work to be carried out and thereby provide a holistic view of sponge and soft coral distribution in the entire Ningaloo region.

Quantitative measures of biodiversity

Sampling of a range of locations across most of the Ningaloo Marine Park has confirmed differences in habitat structure and biogeography and density of key macroinvertebrate species. As described above, gross structural differences in habitats produce markedly different levels of substrate diversity at different locations within the Ningaloo Marine Park, with concomitant differences in abundance and diversity of associated organisms. The exposed habitats of North West Cape and Red Bluff resulted in dominance by urchins with little else present. The more diverse habitats in central Ningaloo locations permit the presence of a variety of other macroinvertebrates.

These differences were confirmed using multivariate analysis of macroinvertebrate composition. Comparison of macroinvertebrate composition of the exposed North West Cape region with the lagoon-dominated Tantabiddi-Yardie Creek region confirmed significant differences in invertebrate community structure. This difference was driven largely by differences in urchin populations, which had a markedly higher abundance around North West Cape than in the Tantabiddi-Yardie Creek region. This may be a reflection of the cryptic nature of the dominant urchin species (*Echinometra mathaei*), which lives within shallow burrows in limestone reef habitats and can therefore tolerate more exposed wave conditions. Similar results were obtained when comparing macroinvertebrate populations in Tantabiddi-Yardie Creek with those from the South Ningaloo region. Again, the more exposed environment characteristic of the unprotected nearshore reefs in the South Ningaloo region was reflected in a significantly greater density of urchins than in the lagoon-dominated Tantabiddi-Yardie Creek region.

An important driver of the recent suite of studies conducted at Ningaloo Reef has been the need to obtain appropriate data to support management of the Marine Park. To help examine the effectiveness of sanctuary zones in the protection of reef ecosystems, comparisons of macroinvertebrate communities were made inside and outside sanctuary zones at most locations sampled. While no differences were observed in macroinvertebrate community composition in most sanctuary zones sampled, or for lagoonal and back reef environments, some differences were observed in nearshore environments within the Coral Bay and South Ningaloo regions. Multivariate analysis of the Coral Bay data revealed a difference in macroinvertebrate composition, with urchins driving the observed differences (more urchins were present in the recreation zone). When examining the South Ningaloo region nearshore data urchins again produced the greatest dissimilarity, although in this instance there were more urchins in the sanctuary zone; *Drupella* and other invertebrates also contributed significantly. These results show there is no clear pattern in macroinvertebrate abundance and density resulting from zonation at this stage. Although urchins have been associated with overgrazing in coral reef ecosystems elsewhere (McClanahan, 1994), they appear not to have a dominant grazing role at Ningaloo Reef. The dominant urchin, *Echinometra mathaei*, is primarily cryptic and is a relatively insignificant grazer in comparison to herbivorous fish (Webster, 2008).

Summary

The studies undertaken on seagrasses, sponges and soft corals show clear latitudinal differences in distribution, with little overlap of species. This reinforces the concept of a biogeographical discontinuity in the Point Cloates region, resulting in a partial separation of tropical and temperate species. Unfortunately funding constraints precluded sampling in the Point Cloates region as part of this project; PhD candidate Mark Langdon will be undertaking further sampling in this region as part of his studies. Further funding is also required to complete the work on sponges and soft corals; in particular, further work is required on identification of specimens and analysis of affinities between shallow- and deep-water species.

Species distributions are complicated by physical oceanographic impacts, seasonal variability and fine-scale habitat requirements. Fine-scale variability in distribution of species therefore places limitations on the effectiveness of remotely-sensed broad scale habitat mapping. This was reinforced by a study examining the use of habitat maps for biodiversity; habitat maps were not a suitable surrogate for either habitat or macroinvertebrate assemblages (McCarthy, 2009). This implies that either a more detailed approach is required to elucidate biodiversity and habitat patterns, or such patterns are too weak to be useful at this scale.

This study supports the broad-scale biogeographical separation of Ningaloo Reef into northern and southern regions with tropical and temperate affinities, respectively. This supports observations of oceanographic patterns suggesting tropical waters are diverted offshore during summer at Point Cloates by northerly currents (Woo, 2006).

Management implications

The cryptic nature and high diversity of the targeted groups makes it difficult to quantify them and obtain accurate estimates of their diversity. Fine-scale variability of habitats and highly specific habitat preferences by many species makes it difficult to generate any clear patterns from remotely-sensed habitat mapping without extensive ground-truthing. Numerous important taxonomic groups have been omitted from this study to date. Some of these have significant implications for remotely-sensed habitat maps; in particular, seasonal blooms of microphytobenthos occur across broad areas of the Ningaloo lagoons, significantly discolouring the typically white calcareous sands. These blooms can persist for extended periods, up to several months, contributing significantly to lagoonal primary production. The role of microbial organisms in association with corals and coral reef communities is an area receiving considerable scientific attention and may have implications for the resistance of coral reef ecosystems to long-term climatic impacts (Rosenberg et al., 2007). Only minimal work has been carried out to date on the diversity and function of bacteria in the coral reef communities of Ningaloo Reef; the first studies to date are currently underway by PhD candidate Janja Ceh. The role of microbial interactions with coral reef organisms at Ningaloo Reef clearly requires significantly more attention.

While it is difficult to produce meaningful fine-scale habitat maps of the Ningaloo Reef system, several conclusions can be drawn from this study. Firstly, there is a clear biogeographic divide between the tropically-influenced northern section of Ningaloo and the more temperately-influenced south. Secondly, this means that the lagoonal environment of Ningaloo Reef cannot be treated as a single undifferentiated ecosystem; there are clear differences in important benthic lagoonal communities, such as the presence of significant seagrass communities in Bateman Bay. Thirdly, seasonal variability may be significant, both in species presence/absence and in ecological impacts. The annual patterns of mass coral spawning and migration of megafauna such as the seasonal arrival of whale sharks at Ningaloo are well known; however the ecological role of less obvious organisms, such as macroalgae and microphytobenthos are poorly understood and require further consideration.

We are fortunate to have Ningaloo Reef in Western Australia; a relatively undamaged coral reef not subject to heavy human pressure and with the prospect of strong environmental management, unlike most other reefs around the world. Ningaloo Reef provides us with the opportunity to understand some of the processes that take place in coral reef ecosystems under relatively natural conditions. This is important, as it may allow us to identify ways in which all coral reefs, not just Ningaloo Reef, can resist the inexorable pressures of global climate change.

2.6 Acknowledgements

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APPENDIX A – SPONGES AND SOFT CORALS OF NINGALOO LAGOON: GNARALOO AND TANTABIDDI REGIONS.

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SUMMARY

Quantitative surveys documenting the diversity and abundance of sponges and soft corals at Gnaraloo and Tantabiddi regions, Ningaloo Marine Park, were conducted in September and November 2009. Five lagoon habitats (intertidal reefs, coral patch reefs, shallow back reefs, subtidal pavements and macroalgal dominated habitats) were surveyed by recording numbers of sponge individuals and soft coral colonies on replicate transects, providing baseline data on sponge and soft coral species present and their abundance. In total 36 sponge and 9 soft coral species were recorded from these regions. The majority of the sponge species found (33) were unique to one of the regions, 11 species were only recorded from Gnaraloo and 22 only from Tantabiddi. Only 3 sponge species were common to both regions. The majority of the soft coral species (8) were also unique to one of the regions with 5 species only recorded from Gnaraloo and 3 only from Tantabiddi. Only 1 soft coral species was common to both regions. These results suggest a clear difference in the composition of the sponge and soft coral assemblages between Gnaraloo and Tantabiddi lagoons.

Many of the species were infrequently recorded (rare) species. Twenty seven of the sponge and 6 of the soft coral species were rare, having five or fewer individuals recorded from all stations in the study.

The species have been identified to lowest taxonomic units (OTUs) until time and funding are available to match the sponges collected in this project to those collected from shallow waters off Ningaloo Station (CReefs project), and the deeper water fauna collected during a WAMSI node 3 project. It will also be essential to examine the historic Indian Ocean literature to determine full species identifications. This is the first documentation of the sponge and soft coral faunas occurring in the shallow waters of Ningaloo Marine Park.

A.1 Introduction

The distribution and abundance of sponge and soft coral species in the shallow lagoonal waters of Ningaloo Marine Park have never been studied. This project, funded by the Ningaloo Cluster, aimed to record the distribution and abundance of these taxa from the southern park region of Gnaraloo and the northern region around Tantabiddi. The central section of the park was examined in a parallel study funded by CReefs in May 2009 based out of Ningaloo Station.

The sponges of the marine park in depths of 18 to 144 metres were examined during a WAMSI project in collaboration with the Australian Institute of Marine Science (AIMS) and the Western Australian Museum (WAM). The sponge and soft coral faunas in depths of greater than 100 metres were collected in a 2005 sampling program in collaboration with CSIRO and

WAM. This current study collecting shallow water species, allows for a cross shelf assessment of the sponges of Ningaloo Marine Park from the intertidal to 800 metres depth.

The aims of this study were twofold, firstly to determine the sponge and soft coral species present and their abundance at each of the regions studied. Secondly assemblages were compared between the habitats and regions surveyed to determine if species composition differed significantly between regions or between different habitats.

This report documents the field design and collecting methods for the project. Sponge specimens will be compared with the deeper water studies and the CReefs project in the future should funds become available. A paper on the distribution and abundance of the shallow water sponge and soft coral species as a result of this study is proposed.

A.2 Methods

A.2.1 Field sampling methods.

A total of 23 stations were surveyed (13 in the Gnaraloo region and 10 in the Tantabiddi area).

Stations were chosen to represent dominant lagoonal habitat types: intertidal reefs, coral patch reefs, shallow back reefs, subtidal pavements and macroalgal dominated habitats.

Subtidal station surveys were carried out on SCUBA or snorkel, and intertidal station surveys were carried out by reef walking at low tide. Transect lines (5 x 1 m, n=3, total area 15 m^2) were laid over the dominant habitat and all sponge individuals and soft coral colonies were counted. Where possible images of each species were taken *in situ.*

A.2.2 Specimen collection.

A voucher specimen of each sponge and soft coral species was collected: voucher specimens were also collected if there were morphological or colour differences from previous vouchers. Specimens were separated immediately *in situ* to avoid contamination by mucous exudation from other specimens. After collection, records were made of natural colour, changes in coloration on exposure to air, mucous exudation, and gross morphology for each specimen collected. Specimens were labeled, photographed, and preserved individually in 75 % ethanol.

Preliminary sponge and soft coral identifications were undertaken at the end of each survey day by preparing bleach preparations of all specimens collected. These were examined with a Leitz DME compound microscope with a calibrated eyepiece graticule. Details and sizes of spicule and skeletal characters (for sponges) and sclerites (for soft corals) were recorded for comparison with other specimens.

A.3 Results.

General patterns.

Sponges

Thirty-six species of sponges were collected from the 23 stations examined (Table 1, 3). The greatest number of species at any station (10) was found at Tantabiddi (TN) station 3, followed by 8 species at TN station 2 and 6 at TN station 5. These were all shallow pavement habitats. Seven stations at Gnaraloo and 1 station at Tantabiddi had no sponges recorded, and 5 of these were coral patch reefs among sand. The three remaining stations that lacked sponges were not coral dominated and were scoured, one was subtidal in the surge zone at Gnaraloo (GN stn 3) and two were intertidal (GN 11 & 13). The remaining stations examined had between 1 and 5 sponge species present.

Twenty seven of the sponge species were rare, having five or fewer individuals recorded from all stations in the study. A few sponge species were common. Clathrinida sp. J6 had 35 individuals at GN stn 9, the deepest limestone pavement habitat sampled in the study. *Spirastrella* NR3 was common at TN stns 3, 5 and 7 with 20, 13 and 20 individuals present in 15 m^2 respectively. These stations were shallow pavement habitats. The massive ochre cup sponge, *Rhabdastrella globostellata*, was found at both Gnaraloo and Tantabiddi with highest numbers at TN stns 1 and 8 (12 and 11 individuals respectively). Both stations were coral patch reef habitats. Other species with fewer numbers, but more than 5 individuals were: *Haliclona cymaeformis, Iotrochota* cf. *coccinea* and *Aka* sp TB1.

This study found a large number of the species were only found in 1 of the regions. Eleven species were recorded only at Gnaraloo and 22 only at Tantabiddi. Therefore a total of 33 species were unique to one of the areas examined and only 3 species were widespread and common to both areas.

Of the 36 species of sponges collected only 7 species could be fully identified with the basic laboratory techniques used (Table 1), and a further 8 species were assigned to a known species but require comparison with type material (signified as cf. in Table 1). The remaining 21 species were only able to be assigned to a genus and given a species number. These are most likely poorly known species described in old taxonomic literature or are new to science. The 36 species recorded were assigned to 29 genera and 22 families of the Demospongiae and 2 belonged to the Class Calcarea (Table 1).

Soft Corals

Nine species of soft corals were collected from the 23 stations examined (Table 2, 3). Soft coral species were poorly represented at all stations with 1 or 2 species occurring at 15 stations and no soft corals reported at the remaining 8 stations. Unlike sponges, soft corals were usually found on coral patch reefs, and occasionally on some of the shallow limestone pavement habitats. Four of the 13 stations at Gnaraloo and 4 of the 10 stations at Tantabiddi lacked soft coral species.

Six of the soft coral species were rare, having five or fewer individuals recorded from all stations in the study. The remaining three species were more common. *Klyxum* 5328 had 33, 16 and 10 colonies in 15 m^2 at GN stn 6, 8 and 13 respectively. The former 2 stations were coral patch reef and the latter intertidal pavement. *Sinularia* 5331 had 11 colonies at GN stn 7, a shoreline pavement habitat, and *Sinularia* 5333 had 23 and 30 colonies respectively at TB stn 4 and 8, both coral patch reefs.

The majority of the soft coral species (8) were also unique to one of the regions with 5 species only recorded from Gnaraloo and 3 only from Tantabiddi with 1 species, *Sinularia* 5333, found at both locations.

Of the 9 species of soft corals collected only 1 species could be fully identified and the remaining 8 species require detailed taxonomic research beyond the scope of this study. The 9 soft coral species were assigned to 6 genera from 3 families (Table 2).

A.4 Discussion.

This study has found relatively low species diversity of sponges and soft corals in shallow water habitats in Gnaraloo and Tantabiddi lagoons. Some cryptic species in coral patch reef habitats may not have been seen and consequently not collected, as destructive sampling of coral thickets was not undertaken. Small sponges and soft corals can occur in coral thickets and can be missed if damage to corals is minimized which was the method adopted here.

Diversity of sponges was higher than soft corals with 36 species of sponges collected compared to 9 species of soft corals. A significant finding for both sponges and soft corals was that very few species were found at both Gnaraloo and Tantabiddi (3 species of sponges and 1 soft coral species). Two explanations are possible: 1) that species did occur at both sites but because they were rare they were not detected with the sampling regime used or 2) different assemblages occurred in the two locations. It would be of value to examine current regimes within these lagoons to determine if they entrain recruits, thereby restricting gene flow to inside the lagoons. It would also be useful to compare these results with other phyla to see if different species assemblages occur in other taxa in these lagoons. In addition, comparison of the species found in this study with those in Ningaloo lagoon would determine if some species were found in this third lagoon, or it also contained unique species assemblages.

In Gnaraloo Bay large numbers of individuals of Clathrinida sp J6 were found on deep limestone pavement (12.6 metres depth). This species is common in Jurien Bay southwards suggesting it is a temperate species. It was not found at the more northward Tantabiddi stations. In contrast, the tropical Indo-Pacific species, *Neopetrosia exigua,* was found north of Cape Faraquar (Gnaraloo region) but not to the north in Tantibiddi. Possibly Gnaraloo has some overlap of faunas with sponges of a tropical and more temperate origin occurring in this region. In the Tantabiddi lagoon some tropical Indo-Pacific species were common, e.g. *Haliclona cymaeformis,* the small ramose branching sponge that occurs in symbiosis with a macroalgae. Three dark coloured sponges were abundant on shallow limestone pavements around Tantabiddi: the dark purple encrusting *Iotrochota* cf. *coccinea,* the dark brown burrowing sponge *Aka* sp TB1, and the dark brown bioeroding sponge *Spirastrella* NR3. The dark colouration of these species may offer some protection against predators or high light, and their cryptic habit would prevent damage during high turbulence.

In general most sponge and soft coral species were rare and only a few were common. At some stations soft corals dominated the benthic cover and this was particularly evident at TB stn 8 (Turquoise Bay). Many colonies were also found in patches among coral thickets at TB stn 4 (Mangrove Bay back reef). *Sinularia* 5333 was the predominant species at both these stations forming extensive monospecific stands in Turquoise Bay. Sponges did not dominate benthic cover to the same extent as some species of soft corals, although *Rhabdastrella globostellata*, a massive cup sponge, was common on some coral patch reefs, for example TB stns 1 and 8, Tantabiddi lagoon mooring and Turquoise Bay respectively. Soft coral species were found mainly on coral patch reef and abundance of colonies was highest in this habitat, while sponges occurred mainly in pavement habitats within the lagoons.

A.5 Acknowledgements

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Table A-1 summary of sponge species found.

		No. of stations			**No. of individuals**		
Class Demospongiae:		**Gnaraloo**	**Tantabiddi**	**Total station**	**Gnaraloo**	**Tantabiddi**	**Total individuals**
Family	**Species**	**GN1-13**	**TB1-10**	**sightings**			
Ancorinidae	*Rhabdastrella globostellata*	2	3	5	6	29	35
Tetillidae	*Cinachyra cf isis*	0	1	1	0	6	6
Chondrillidae	*Chondrilla australiensis* Carter, 1873	0	2	2	0	2	2
Clionaidae	*Cliona cf orientalis* Thiele, 1900	0	1	1	0	3	3
	Hemiasterella sp	1	0	1	1	0	1
	Spirastrella NR3	0	4	4	0	56	56
	Spirastrella TB1	0	1	0	0	1	2
	Terpios cf symbioticus	1	0	1	2	0	2
Axinellidae	*Cymbastela* sp.	1	1	2	1	1	2
Halichondriidae	*Topsentia cf halichondriodes*	0	1	1	0	1	1
	?*Amorphinopsis* sp 1	1	0	1	1	0	1
	Amorphinopsis cf excavans	0	1	1	0	1	1
	Hymeniacidon TB1	0	1	1	0	1	1
Coelosphaeridae	*Coelocarteria singaporense*	0	1	1	0	1	1
Crellidae	*Crella (Yvesia) cf. spinulata* (Hentschel, 1911)	1	0	1	1	0	1
Chondropsidae	*Chondropsis* sp G1	1	0	1	4	0	4
Myxillidae	*Iotrochota cf. coccinea* (Carter, 1886)	0	4	4	0	19	19
Microcionidae	*Clathria (Thalysias) reinwardti* Vosamer, 1880	0	3	3	0	3	3
Tedaniidae	*Tedania* TB1	0	1	1	0	2	2
Mycalidae	*Mycale* TB1	0	1	1	0	2	2
Rhabderemiidae	*Rhabderemia* TB1	0	1	1	0	1	1
Chalinidae	*Haliclona cymaeformis* (Esper, 1794)	0	4	4	0	22	22
	Haliclona (Reniera) TB1	0	2	2	0	7	7
	Haliclona (Haliclona) TB1	0	2	2	0	5	5
Niphatidae	*Amphimedon cf paraviridis* Fromont, 1993	1	1	2	2	1	3
Petrosiidae	*Neopetrosia exigua* (Kirkpatrick, 1900)	1	0	1	7	0	7

Phloeodictyidae	*Aka* TB1	0	3	3	0	33	33
Spongiidae	*Spongia (Spongia)* TB1	0	2	2	0	4	4
	Coscinoderma	2	0	2	3	0	3
Irciniidae	*Ircinia* cf.	0	1	1	0	1	1
	Sarcotragus spNW1	1	0	1	1	0	1
Dysideidae	*Lamellodysidea herbacea* (Keller, 1889)	1	0	1	2	0	2
Aplysinidae	*Aplysina* TB1	0	1	1	0	5	5
	?*Aplysina* TB2	0	2	2	0	2	2
Class Calcarea:	Clathrinida sp J6	1	0	1	35	0	35
	Calcarea spNR3 pink encrusting	1	0	1	1	0	1
	Total number of species				36		

Table A-2 Summary of soft coral species found.

		No. of stations			**No. of individuals**		
		Gnaraloo	**Tantabiddi**	**total station**	**Gnaraloo**	**Tantabiddi**	**Total individuals**
Family	**Species**	**GN1-13**	**TB1-10**	**sightings**			
Alcyoniidae	*Klyxum* 5328	4	0	4	64	0	64
	Cladiella 5330	1	0	1	1	0	1
	Lobophytum 5335	0	1	1	0	5	5
	Lobophytum 5336	0	1	1	0	5	5
	Sinularia 5331	1	0	1	11	0	11
	Sinularia 5332	3	0	3	8	0	8
	Sinularia 5333	2	3	5	3	56	59
Nephtheidae	*Chromonephthea exosis* Oefwegen, 2005	1	0	1	1	0	1
Briareidae	*Briareum* 5334	0	1	1	0	1	1
	Total number of species			9			

APPENDIX B – THE ROLE OF SEA URCHINS IN NINGALOO REEF: KEY POINTS TO DATE.

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The presence or absence of a distinct lagoon environment determines the overall composition of benthic substrate types within each region, which in turn determines habitat structure and density of key macroinvertebrates.

- Conditions within the sheltered lagoonal areas in the Ningaloo Marine Park permit the development of extensive coral and algal-dominated communities, whereas regions without a protected lagoon were more exposed to ocean swell and therefore showed greatly reduced biological diversity.
- The Coral Bay data revealed a difference in macroinvertebrate composition between management zones, with urchins driving the observed differences (more urchins were present in the recreation zone).
- The South Ningaloo region data produced the greatest dissimilarity in macroinvertebrate composition between management zones, although in this instance there were more urchins in the sanctuary zone; *Drupella* and other invertebrates also contributed significantly.
- These results show there is no clear pattern in macroinvertebrate abundance and density resulting from zonation at this stage.

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