NINGALOO MARINE PARK- INITIAL SURVEY OF SEABED BIODIVERSITY IN INTERMEDIATE AND DEEPER WATERS (MARCH 2004)

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TABLE OF CONTENTS

List of Figures and Tables

Executive Summary

- This study was carried out in Ningaloo Marine Park and included both Commonwealth and Western Australian State Waters. It was undertaken for the Department of Environment and Heritage to begin a process of describing deep-water biodiversity in the marine park, addressing a lack of such information seaward of Ningaloo Reef crest. In the addition, the project was to identify any areas of high biodiversity in both Commonwealth and State waters of the park. This information will be used to assist in identifying potential sanctuary zones in the reserve.

- The study consisted of surveys at three sites adjacent to existing State marine sanctuary zones, Mandu Mandu, Point Cloates, and Point Maud. These areas were selected to test the spatial variation of benthic communities along a north-south gradient at the 10-100km scales, (ie. 10km scale within sites and 100km scale between sites). At each survey site, fifteen transects at five depth zones from the seaward edge of Ningaloo Reef were surveyed using a towed video camera system. Simultaneously, BRUVS (Baited Remote Underwater Video Stations) were deployed at various point locations in the study area. BRUVS deployments were opportunistic, weather dependent and varied among sites, three deployments at Mandu Mandu, six at Point Cloates and nine at Point Maud.

- Commonwealth waters surveyed ranged from 60-200m depths. At these depths no areas of reef building stony corals (Scleractinia) were observed. The most significant macrobenthic communities detected consisted of filter feeding organisms. These were dominated by a variety of sponges and octocorals, such as gorgonians. A limited number of sites contained medium to high density communities, so-called sponge “gardens”

- There was no clear trend in abundance or diversity of the filter feeding communities with latitude. Sponge density when estimated against total biomass increased with depth particularly at Point Cloates and Mandu

Mandu. The soft corals (octocorals) became less prevalent as depth increased beyond the 80m zones. Scleractinia (ie. hard corals) were dominant in the shallow zones <40m, which is to be expected. Communities of low-density filter feeders are likely to be widespread throughout Commonwealth waters of the Marine Park as they were observed in most locations although their presence at Point Maud was very low. The distribution of medium to high-density communities is patchier and may relate to presence/absence of consolidated substrate, such as low outcropping ledges or exposed and near-surface pavement areas.

- The North West Shelf has previously been identified as a sponge biodiversity hotspot, (Hooper et al. 2002). The variety of sponge spp. observed in this survey adds further support to this claim. Four different sponge garden habitats appeared to exist in this small bioregion (Dr J.Fromont, pers. comm.). Typical tropical species were absent from the video footage at Ningaloo. Some of the sponge species and filter feeding community types observed in the Commonwealth waters of Ningaloo Marine Park appear to be substantially different to those observed by the WA Museum in waters around the Dampier Archipelago to the north and the Abrolhos Islands to the south. Unfortunately there is little other data for comparison in this region.

- The octocoral communities seen at Ningaloo were often high in biomass but low in species richness. Often recurring in the video were the same species of several families (predominantly Anthothelidae, Subergorgiidae, Plexauridae, Ellisellidae), (Dr P.Alderslade, pers. comm.).

- Although the video sampling has provided an initial insight into the complexity and range of biodiversity in Ningaloo Marine Park, it will be important for both biodiversity and biogeographic considerations, to obtain sample specimens in order to better characterise the uniqueness and extent of seabed biodiversity in this region. Detailed taxonomic analysis is difficult to achieve with non-destructive video techniques without costly solutions.

- A taxonomic census of soft coral and sponge biodiversity, based on specimen collections, has never been undertaken for either State or Commonwealth waters of Ningaloo Marine Park. It may be possible to compare images collected during this study with data based on collections from just north of the Marine Park in similar depths that have been lodged with the Museum of Western Australia as part of work undertaken by AIMS with support from Woodside Energy Ltd. This comparison would reference the only collections from similar depth and latitude with new data. It's possible that clear distinctions could be made pointing to an area of significant and unique regional change in the community composition that lies somewhere between these locations. The video images, while useful for an overview of the general habitat, are not suitable for reliable taxonomy of the sessile biota.

- A deployment of 18 BRUVS at point locations in the Commonwealth waters revealed 454 individuals of 52 species from 25 fish and elasmobranch families.

- Greater fish diversity and a wider mix of functional groups (eg. snappers, damselfishes, parrotfishes) were observed in patches of higher density sponge and octocoral habitats. This is expected, given the greater structural complexity of such habitats, and the possible provision of detrital subsidies for local food chains provided by the sponges, gorgonians and other animals in the patches. A larger, cross-shelf sample from Point Cloates and Mandu, with BRUVS set in the full suite of habitats present, would give a better idea of the relative importance of megabenthos gardens and depth in the distribution of fish communities.

- There is some hotspots of seabed biodiversity in the Commonwealth waters of Ningaloo Marine Park. The use of high-resolution acoustic mapping of bottom hardness, combined with side scan and limited video validation, can provide a cost effective means to survey large areas of the park and determine the extent of potentially unique filter feeding communities discovered in this initial study.

1. Introduction

Ningaloo Marine Park, Western Australia, lies in tropical waters extending from Point Murat in the region of North West Cape southwards beyond Coral Bay to Amherst Point, encompassing the majority of the Ningaloo Reef. The fringing reef, which extends for 260km along the west coast of the Cape Range peninsula, is the largest in Australia and the central feature of the marine park. A recent review of literature on the Ningaloo Marine Park and adjacent regions (Le Provost, 2000) noted the importance of the reef system and concluded that “most of the commercial, educational and recreational resources identified in the park occur permanently (corals, seagrass, mangroves), congregate in (whale sharks, turtles), or migrate through (whales) the nearshore zone, including the area immediately seaward of Ningaloo Reef and shallow (<20m) waters of the Rowley Shelf and Exmouth Gulf”. However the majority of the park’s 4,566km^2, lies beyond this near shore zone. This area consists of major areas of continental shelf within both Commonwealth and State boundaries and extending, particularly in the northern half, to include upper areas of the continental slope. Commonwealth waters of the Park are all in depths greater than approximately 30m, typically exceeding 70-100m north of Pt Cloates, and lying in the range of 40-80m to the south.

The fact that the bulk of Ningaloo Marine Park lies in depths greater than 20m has created a significant impediment to sampling the benthos adequately. Scientific expeditions to the area assessing benthic habitats and biota have tended to be sporadic. These surveys have focused on selected taxa, and to a large degree restricted to standard diving surveys which, due to operational and safety constraints, have an inherent bias to depths of 20m or less. Somewhat surprisingly, even in the shallow waters of the lagoon and fringing reef, biodiversity surveys have been limited in scope. For example, while fishes and scleractinian corals have been well documented, soft corals and sponges have not. The paucity of knowledge about seabed biodiversity in the intermediate and deeper waters of the marine park has been recognized since the park’s inception in 1987 (Western Australian Museum 1988), but neither State nor Commonwealth has mounted dedicated surveys until now.

This report provides data from an initial survey of seabed biodiversity in the intermediate and deeper waters of Ningaloo Marine Park, seawards of the fringing reef crest. The research was undertaken by the Australian Institute of Marine Science (AIMS), in collaboration with department of Conservation and Land Management (CALM), at the request of and with the support of the Commonwealth Department of the Environment and Heritage (DEH). Using non-destructive video methods, the principal aim of the research was to describe the general nature and spatial patterns of macrobenthic communities below normal diving depths (>~30 metres) within Ningaloo Marine Park.

2. Purpose of the Study

The study was undertaken for DEH, to begin a process of describing deep-water biodiversity in the Ningaloo marine park and to address a lack of such information seaward of Ningaloo Reef crest. Another aim of the project was to identify any areas of high biodiversity in both Commonwealth and State waters of the park. This information would be used to assist in identifying potential sanctuary zones to preserve the areas of high biodiversity that are considered to be relatively important within the reserve.

3. Location of the Study

The study consisted of surveys at three sites Mandu Mandu, Point Cloates and Point Maud (see Figure 1). These sites were selected to test the spatial variation of benthic communities along a north-south gradient at a range of spatial scales (ie. within sites ~ 10km, and between sites ~ 100km). At each survey site, five depth zones were surveyed.

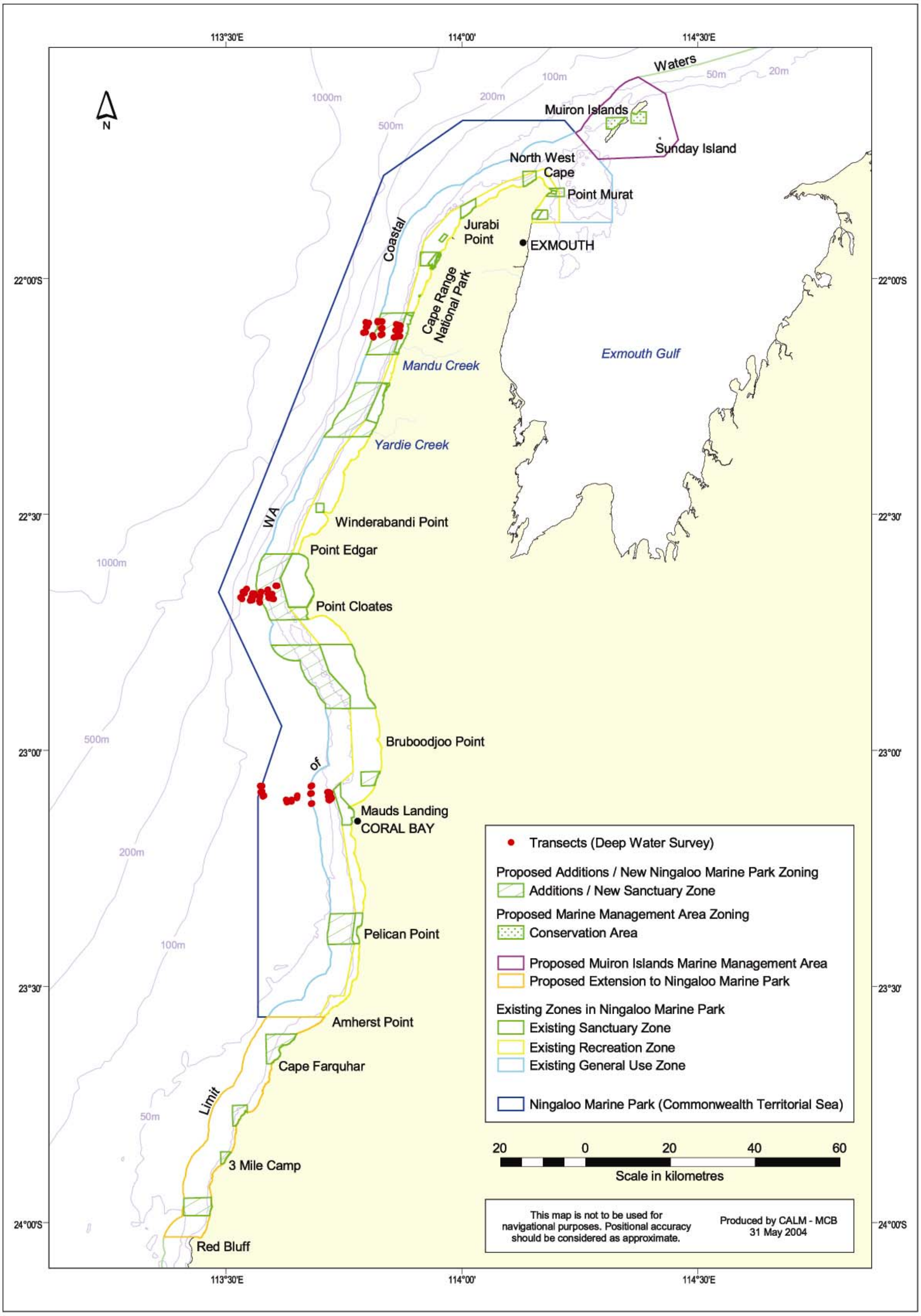

Figure 1. Map displaying the State and Commonwealth Marine Park boundaries and tow locations of the March 2004 survey.

4. Methods

4.1 Equipment

All sampling relied on deployed video equipment. Benthic habitats were surveyed using real-time towed video, while fish communities associated with the seabed were sampled by deploying baited video gear (BRUVS).

4.1.i Towed video sampling.

A portable towed video system was used for all tows. Hardware consisted of a Cunard Series 50 subsea video camera connected to 300m of Seaviewer load-bearing coaxial tow cable. The camera head was supported within a custom designed wing that provided negative lift and maintained a stable attack angle through the water while towing. A single, self-contained Underwater Kinetics Light Cannon 100 HID light, located directly above the camera, was used on all tows.

The wing was deployed over the stern, with the cable supported from a lightweight A-frame on a 200mm diameter nylon block. The video stream was recorded to miniDV tape (Panasonic AY-DVM83PQ) with realtime ship position, from GPS, added to the tape audio track via a Geostamp audio converter by Intuitive Circuits, LCC.

4.1.ii Baited Remote Underwater Video Stations (BRUVS)

The three BRUVS consisted of a galvanized roll-bar frame enclosing a simple camera housing made from PVC pipe with acrylic front and rear ports (Figure 2). Bait arms (20 mm plastic conduit) and 6kg galvanised ballast weights were attached and

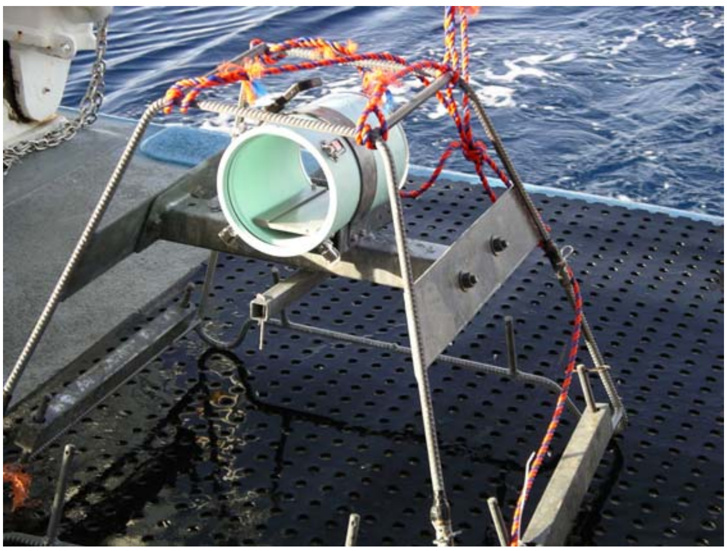

Figure 2. BRUV frame, with ballast and camera housing, as used at Ningaloo.

detached during and after deployment. The 1.5m bait arm held a 350 mm plastic mesh bait canister containing one kilogram of crushed pilchards, *Sardinops neopilchardus*. BRUVS were deployed with 8mm, polyethylene, floating pot ropes and two 30cm surface floats bearing a flag, and were retrieved with a pot hauler.

SonyTM MiniDV Handicams (model TRV19) with wide-angle lenses (0.5X adapters) were used in the housings. Exposure was set to “Auto”, focus was set to “Infinity/manual”, MiniDV tapes (Panasonic AY-DVM83PQ) were loaded, SP recording mode used and time codes were laid on the tapes. The BRUVS were deployed to provide 83 minutes of film and were set equidistantly apart (1km-2km) along depth contours to provide independence of each replicate unit (Cappo et al. 2003, 2004).

4.1.iii Vessels

The project was designed such that the CALM regional office in Exmouth, utilizing their 7m Research vessel Ningaloo 1, would provide vessel assistance. Exposure to open ocean conditions seawards of the reef crest posed a significant risk and the initial survey attempt in the second half of 2003 was commenced but abandoned due to storms. It became evident that a larger type of vessel would be required in order to adequately and safely complete the survey within the set time limits. A second attempt, using the charter vessel Nordon, was undertaken in March 2004 and provided all data for this report.

4.2 Survey Methodology

4.2.i Sample Sites

Three areas of Ningaloo were chosen for sampling. These were blocks adjacent to existing State sanctuary zones at Mandu Mandu, Pt Cloates and Pt Maud, (Figure 3, 4 & 5). These sites were chosen, as they are relatively uniformly spaced approx 50km apart providing an acceptably large spatial scale to exhibit significant differences among sites. Their proximity to Ningaloo Marine Park sanctuary zones was intentional on the assumption that establishment of any future Commonwealth Waters sanctuary zones or representative areas gazetted for restricted use would be aligned with existing shallow water sanctuary zones.

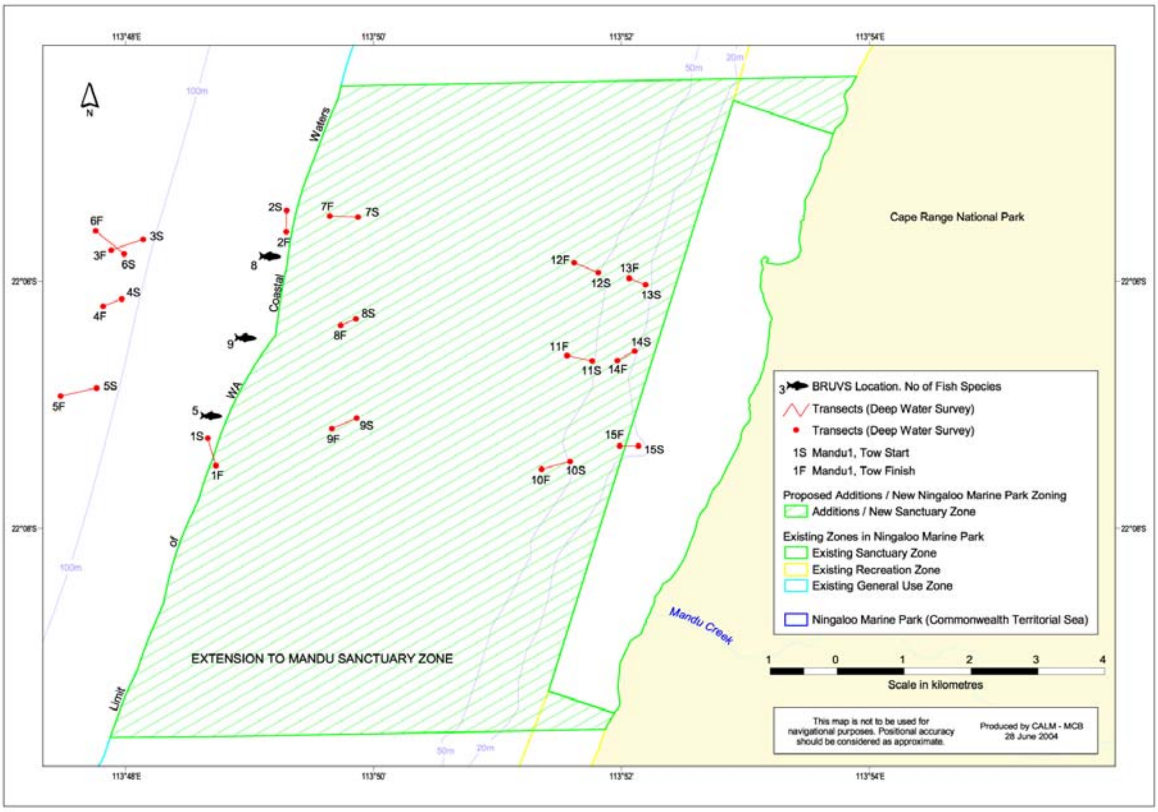

Figure 3. Tow transect and BRUVS locations adjacent to the Mandu Sanctuary Zone.

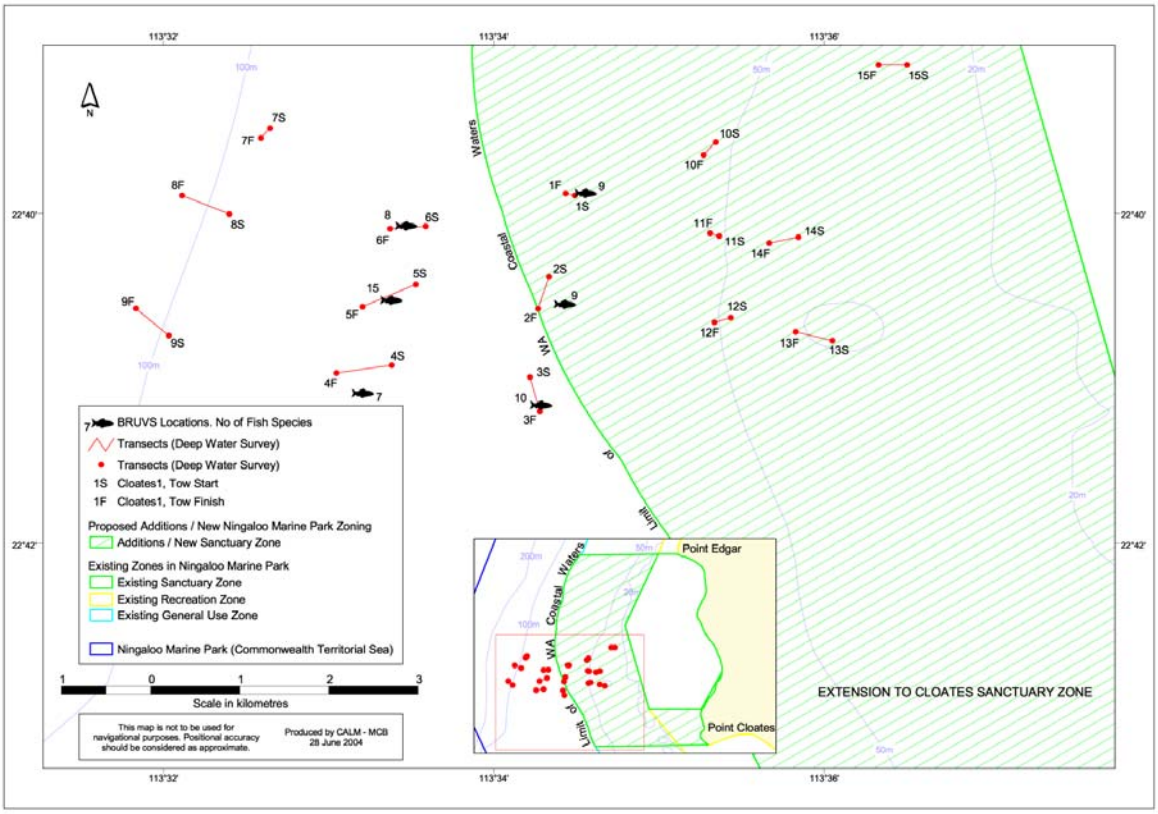

Figure 4. Tow transect and BRUVS locations adjacent to the Cloates Sanctuary Zone.

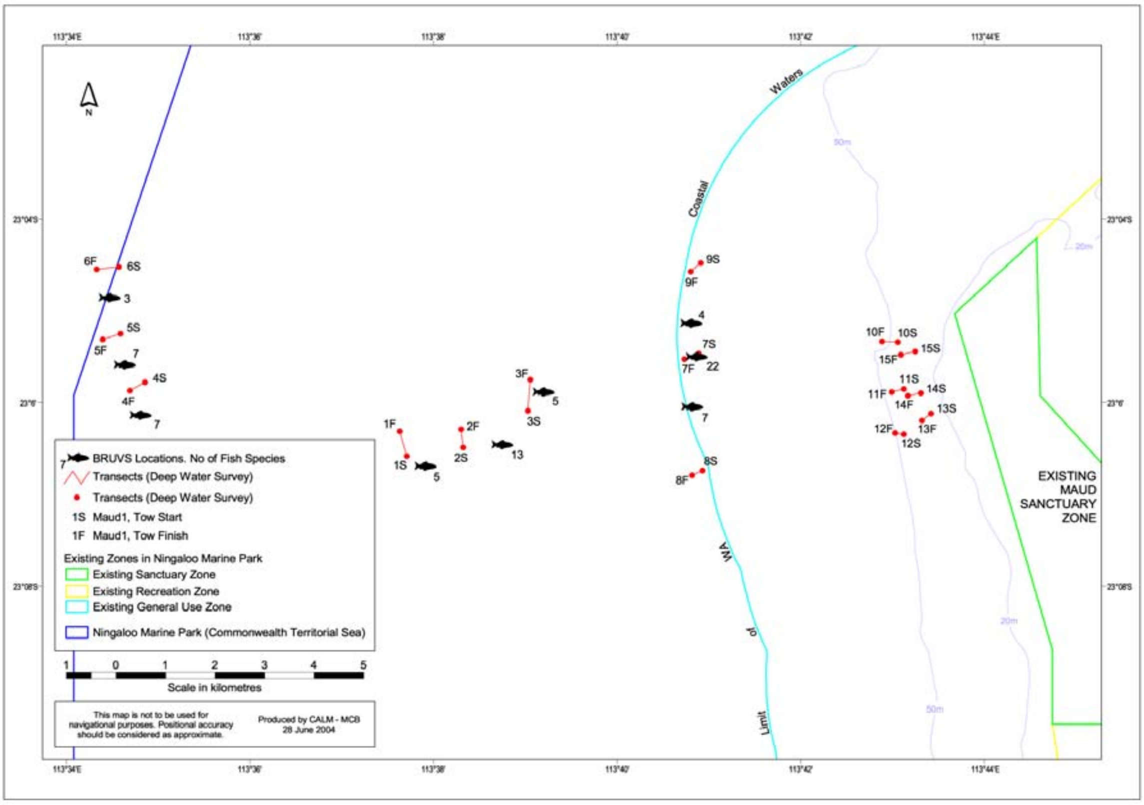

Figure 5. Tow transect and BRUVS locations adjacent to the Maud Sanctuary Zone.

4.2.ii Sampling Transects

CALM Marine Conservation Branch, Fremantle, provided field maps with the northern and southern limits of the sanctuary zones at the reef crest projected westward to the Commonwealth Territorial Sea boundaries of the Ningaloo Marine Park. Typically these areas had a north-south distance of approximately 15km. Sampling was conducted within the bounded area on the basis of replicates within and between depths. Tow transects within five approximate depth zones were targeted at each site. Depending on the site and slope of seabed the depth zones sampled at each site varied (Point Maud deepest site was only 90m whereas Mandu Mandu and Point Cloates were > 150m). At each depth zone a series of tows were completed. These were spaced at approximately 1.5 km intervals (see Figure 3, 4 & 5).

The direction of the tow at any particular station was dictated by weather conditions. Just prior to deployment the vessel was headed into the prevailing wind/swell and speed reduced to dead slow. The camera wing was deployed and cable paid out until the seabed was sighted on the video monitor.

Recording of video signal was commenced and speed was maintained at 1-1.5 knots. The length of each survey was approximately 300m. It was not possible to ascertain the exact location of the camera head and wing, all of the tow position information refers to that of the vessel and it should be noted that potential inaccuracies in position derived from video frames could be up to 200m. The tow cable was actively controlled during the tow in an effort to maintain the camera within one metre of the seabed as much as possible, however on numerous occasions due to current or other physical environmental conditions the tow wing did not “fly” uniformly and straight and the optimum filming perspective proved difficult to acquire.

The maximum depth that could be obtained with this system increased if the vessel speed slowed to 0.5 knots. The greatest depth reached during the survey was 198m under the vessel. During each tow an observer watching the live video feed recorded the nature of the seabed substrate and the relative abundance of the dominant organisms (eg. medium density sponge garden on rubble).

5. Results

5.1 Tow Transects

5.1.i Data Collection

At each of the three survey sites, Mandu Mandu, Point Cloates and Point Maud, 15 video tows undertaken at varying depth ranges. The level of analysis of the video data was broad and descriptive for each transect rather than attempting a quantitative analysis. Pictorial examples of habitat type and descriptive summaries of each tow transect is provided in Appendix 1. The GPS position for the start and end point of each tow together with depth information for the tows is listed in Appendix 2. Tows were generally longer in areas where there were more rapid changes in habitat.

5.1.ii Intra Site Trends ~10km scale

5.1.ii.a Mandu Mandu

Figure 6. Barren sand flat amongst hard coral dominated zone. *Holothuria atra* captured in this frame.

The continental shelf slopes away more rapidly from the coastline at Mandu Mandu than at any other part of the Ningaloo Reef. The benthic habitats in the 30-50m zones are fairly typical with high percent cover of healthy scleractinian corals tending towards soft coral dominance closer to the 50m isobath. An interesting feature was the final transect in the shallow zone where the seabed was completely barren, sandy and featureless with the exception of occasional sand dwelling organisms (Figure 6).

Figure 7. Mixed zone of soft coral, sponge and macroalgae.

Further offshore in the 50-70m zones the hard coral community gave way to soft coral and sponges with some macroalgal species also present (Figure 7). The seabed terrain in this zone was considerably lower profile than the seabed community closer to the reef break. Again there was patchiness in the habitat distribution with large areas of bare sand/silt substrate. Despite the lack of seabed features on the majority of tows in this zone there were pelagic fish species observed patrolling the seabed (Figure 8).

Figure 8. Trevally patrolling the sparse seabed.

As the seabed dropped away beyond the 80m mark the prevalence of filter feeding invertebrates such as the sponges, large gorgonian sea fans and other soft corals, increased (Figure 9). The angle of the seabed slope was acute beyond the 80m isobath. Upwelling from the deeper waters together with harder substrate types may be key forces driving the distribution of these filter-feeding communities that are found in these areas. Evidence of hard substrates was observed on some tows and suspended particulates in the water column, highlighted in the floodlights of the tow, was also a feature. An additional highlight of the deeper water tows at Mandu Mandu was the number and variety of fish observations, (Figure 10), in particular Sandbar sharks (*Carcharhinus plumbeus*), *Carcharhinus leucas* (caught commercially in WA as the Thickskin shark), the silvertip *C. albimarginatus. Pentapodus nagasakiensis,* and *Abalistes stellaris.*

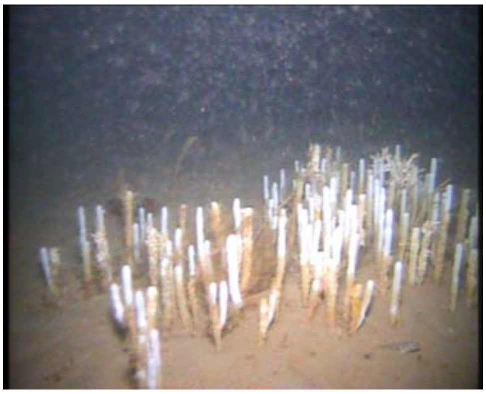

Figure 9. Sponge formations in the deep water off Mandu Mandu.

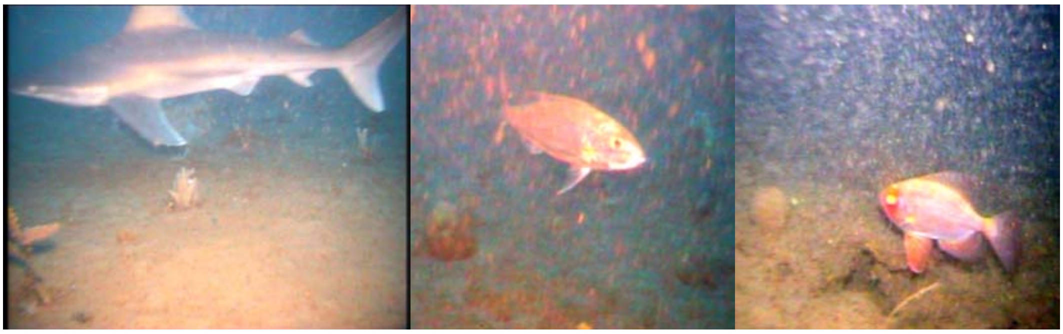

Figure 10. Some of the fish observed in the deeper sites off Mandu Mandu.

5.1.ii.b Point Cloates

The shallowest areas surveyed adjacent to Point Cloates were typical of the habitat expected to be found in this depth range with high percent hard coral in spur and groove formations, (Figure 11). In general, the numbers of fish observed at the shallow water at Point Cloates was higher than the tows carried out in deeper water.

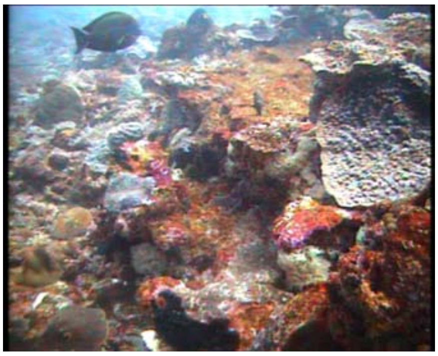

Figure 11. Typical hard coral community of the shallow slope.

In the 50-70m zones, hard corals were rare and were only observed on consolidated outcropping areas of substrate. With increasing depth the dominant benthic organisms shifted to soft corals, sponges some species of macroalgae. Many fish were observed in congregations around these same areas (Figure 12 & 13).

Figure 12. Fish density was greatest near areas of high seabed cover.

Figure 13. Cuttlefish observed in proximity to prominent seabed feature.

Deeper water surveys showed diminishing levels of macroalgae and a seabed community that was increasing dominated by soft corals, sponges and crinoids. A similar pattern was observed on at Mandu Mandu, with an occasional outcrop of hard substrate. (Figure 14). Macroalgae and sclereactinian coral species were absent and the dominating fauna were the sponges and soft corals (Figure 15). Suspended particulate matter in the water column was once again a feature in this zone along with consolidated parts of the seabed. Not as many fish specimens were observed on the tows at Point Cloates as Mandu Mandu.

Figure 14. Outcropping rocky formation seen in the deep waters.

Figure 15. Sponge and soft coral dominated community of the deep slope.

5.1.ii.c Point Maud

The benthic communities found at Point Maud were unique, compared to those of Mandu Mandu or Point Cloates. At Point Maud, hard coral cover was low and soft corals were conspicuous in patches (Figure 16). An interesting feature was the occasional monospecific stand of sea whips (*Juncella sp.*), (Figure 17). These seem to occur randomly and were not associated with hard substrate outcrops.

Figure 16. Soft coral community dominating the seabed near Point Maud.

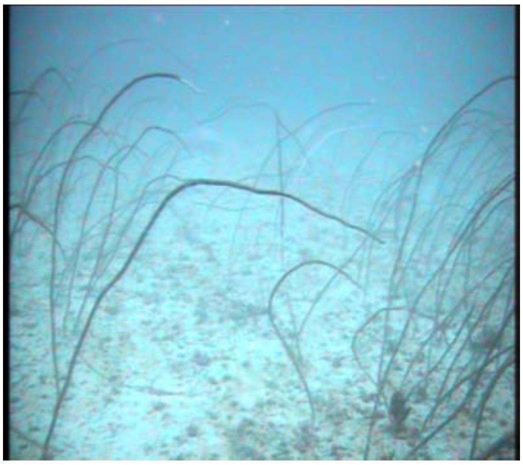

Figure 17. Sea whip gardens a prominent feature of the seabed near Point Maud.

Sponge and soft coral communities, in the 50-70m zones, were rare compared to survey locations further north. Vast expanses of loose sandy substrate were typical in this area, with only the occasional dense aggregations of sponges and soft corals (Figure 18). Numerous fish were seen around these high diversity patches of seabed.

From a depth of 80 metres, the slope of the seabed at Point Maud was slight, compared to the northern locations and as a result the deepest sites sampled were not as comparable with the deep sites at Point Cloates or Mandu Mandu. The benthic cover was very low in all the outer transects with only occasional organisms appearing in the video frame (Figure 19).

Figure 18. Isolated outcrops with diverse sponge and soft coral were rare at Point Maud.

Figure 19. Typical of the deeper zones at Point Maud was sparsely populated sandy substrate.

5.1.iii Inter site trends ~100km scale

When we compare benthic communities at similar depths, between sites, we find they are very similar. The highest percentage cover of organisms was generally observed within the deep hard reef slope zone (30-50m) across all sites. Estimates of percentage cover in this zone were 20-50% and the dominant organisms were scleractinian coral species and to a much lesser extent, sponges and soft corals (Figure 20). Fish densities were the highest in this deep zone, compared to the deeper water surveys. The topography changed rapidly, with spur and groove formations causing patchiness in live cover of benthic organisms. Little or no obvious benthic life forms were observed in the rubble dominated grooves. Seagrasses and macroalgal species were rare or absent within this depth zone.

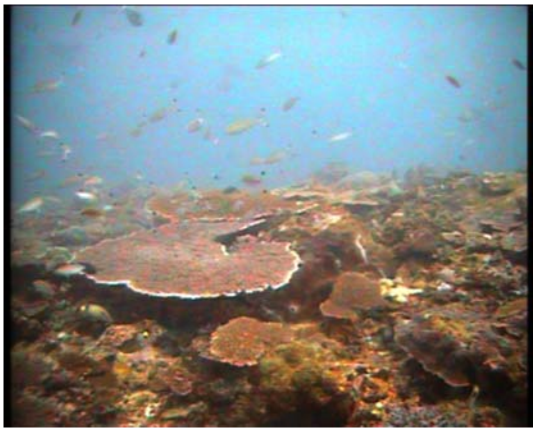

Figure 20. Hard Coral dominated community in the back reef slope.

In the deeper depth zone of 50-70m, the presence of scleractinian corals was extremely rare and the dominant benthic organisms were mainly soft corals and sponges (Figure 21). The soft coral community had high biomass but low diversity –of only a few families (predominantly Anthothelidae, Subergorgiidae, Plexauridae, Ellisellidae), (Dr P.Alderslade pers comm.).

Figure 21. Soft coral and sponge community of the deeper zones.

The deeper sites in the 80-200m zone were dominated by soft corals and sponges. The species in these deeper sites were, predominately, not found at shallower sites. However a few species were observed to occur over all depths sampled. At the deepest site, where sampling was carried out (Mandu Mandu), we found that sponges dominated the benthic community (Figure 22). Of the soft corals only one species of gorgonian from an indiscernible family was present, (Dr P.Alderslade pers. comm.). Once again this zone showed a strong association between numbers of fish and percent cover of organisms.

Figure 22. Steeply sloping deepwater sponge dominated community.

5.2 BRUVS

5.2.i Data Collection

BRUVS were deployed at each of the general locations to provide information on fish community composition in relation to habitat. Nine sets were deployed at Point Maud, and six sets were deployed at Point Cloates, while weather conditions limited the Mandu Mandu sampling to three sets. There were 409 individuals from 52 taxa in 25 fish and elasmobranch families recorded on the

18 BRUVS sets (Appendix 3.). Most taxa were identified to species level, with the notable exception of the very small juveniles of threadfin breams (*Nemipterus* sp), and the small (<60cm total length) sharpnose or sliteye sharks (*R. taylori* or *L. macrorhinos*). Published diagnostic features for these species could not be resolved on the footage.

5.2.ii Relationships Between Habitat and Fish Community

The diversity and abundance of fish differed greatly amongst the coarse habitat types recognised on the BRUVS footage (Table 1.). The sets in “megabenthos” had more than twice as many species and individuals as the sandy habitats, even though fewer sets occurred in such habitat types. There appeared to be a trend in increasing diversity and abundance in habitats with increasing grain size for the sets off Point Cloates, but not for the sets off Maud’s Landing.

Habitat Class	**Mandu**	**Pt Cloates**	**Mauds Landing**	**Total Species**
fine sand		*7*(18)	*28*(110)	*35*(128)
coarse sand	*14*(23)	*19*(22)	*10*(21)	*43*(66)
Megabenthos	*8*(14)	*32*(90)	*35*(111)	*75*(215)
Total Species	*22*(37)	*58*(130)	*73*(242)	

Table 1. Total number of species (in italics) and number of individuals (in brackets) of fish and elasmobranchs recorded by BRUVS at the three sampling locations in each of the coarse habitat types recognised on the baited video footage.

The measures of the various depths, the habitat classes, and the fish species abundance were analysed from multiple BRUVS sites, or “sets”. Multivariate analyses were required to examine the multidimensional relationships among the sites, the environmental variables and fish species. These analyses allowed us to describe the major groupings in the BRUVS data, measure the strength of fish-habitat associations, and identify “indicator species” defining these patterns.

5.2.iii Interpretation of Multivariate Analyses: Biplots

The following guide is provided to aid understanding and interpretation of the results presented in Figure 23.

Ordination methods that represent high-dimensional data in low-dimensional space are used for the analysis of the multivariate depths, habitat classes and fish species abundances. These unconstrained ordination analyses reduce the multivariate data to a set of un-correlated derived variables (which are linear combinations of the original variables), and which have been calculated to account for the maximum amount of variability in the data.

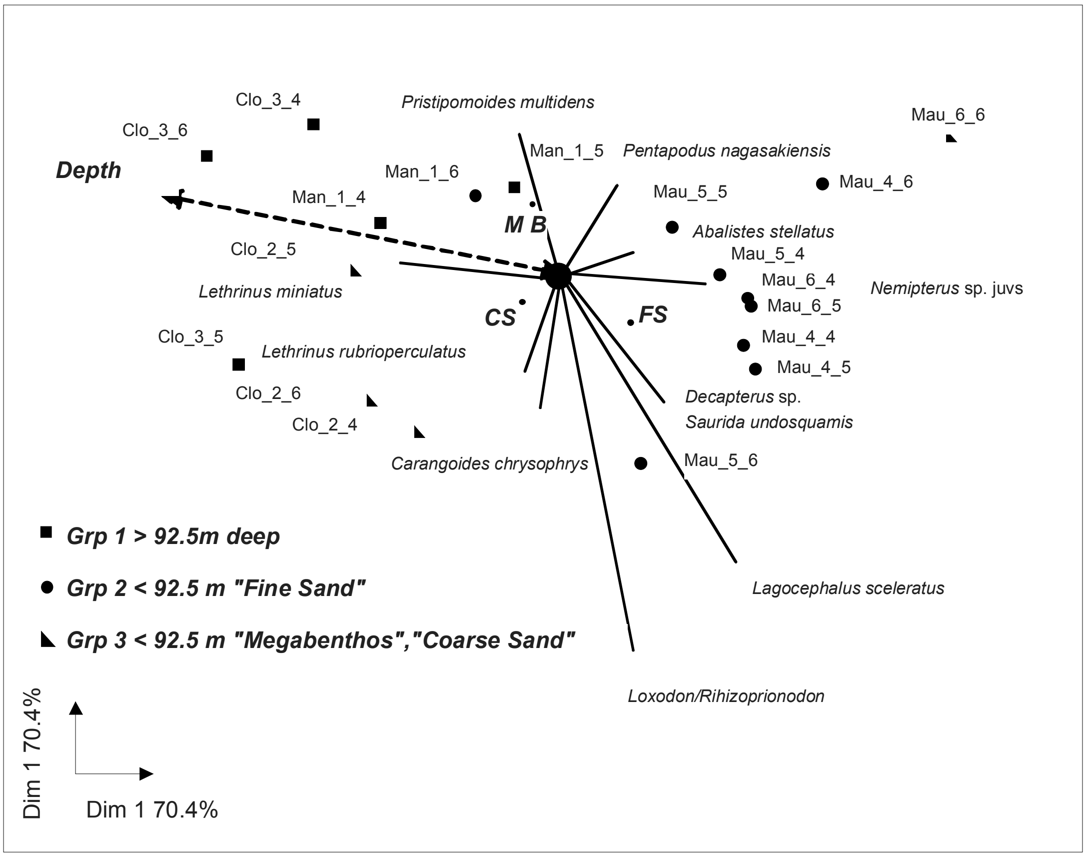

Figure 23. A multivariate biplot showing where each BRUVS set lies in relationship to environmental gradients based on its transformed fish abundance data. The long depth vector shows the strength of this primary factor. The direction and length of species vectors show the strength and direction of correlation of the species abundance with the depth and habitat classes. FS=Fine sand; CS=Coarse sand; MB=Megabenthos.

The “biplot” in Figure 23 represents the first two dimensions (or derived variables) from these analyses that best display the most informative 2-dimensional view of a multidimensional distribution. The biplots show the relationships of the original variables to each other and indicate the relative importance of their role in explaining the observed spatial patterns amongst sites. This is achieved by super-imposing vectors for the original variables (depth/habitat/species) over the plot of points, which represent the spatial patterns among sites.

The biplot graphically display the multivariate relationships of the rows (individual sites (sets) of BRUVS) and columns (depth/habitat class/fish species abundance) of the data matrix on a single two-dimensional plot. The biplot displays both sets of relationships (among sites and among depth/habitat class/fish species abundance) in a single plot.
Each BRUVS is shown on the biplot with different symbols to identify their membership of a group determined by the multivariate analysis.
The depth and species abundances are represented on the biplot as a vector (a line with length and direction). The habitat classes were discrete variables, and their vectors are represented by the direction and length of their displacement from the origin of the biplot. The vectors are labelled with the depths, habitat class and names of some species.
Of the total variation in abundance of all depths, habitat classes and fish species, the percentage explained by each dimension of the biplot is shown in the lower left corner of the plot. The first dimension explains the greatest percentage of the total depth/habitat/fish variance and is shown on the x-axis. The second dimension explains the next largest percentage of the total depth/habitat/fish variance and is shown on the y-axis.

In the biplot in Figure 23, the species vectors generally form an arc defining the gradient (direction) of greatest abundance. The length of a vector approximates the variability (standard deviation) of the associated species. Thus short vectors mean that the species is consistent in abundance among sites and a long vector means that the species is highly variable among sites.

If a BRUVS site has a high abundance of a particular species, the site point and species vector are far away from the origin and in the same direction. If a site has a low abundance of a particular species, the site point and species vector are in opposite directions and far apart. Site points close to the origin represent sites that have typical abundances of all species. Sites that are close together on the biplot have similar proportions of most species.

The angle between two vectors represents the correlation between the two species that the vectors represent. If the angle between them is small (approaching 0°) the species are highly correlated. If the angle is large (approaching 180°) the species abundances are negatively correlated, and if the vectors are at right angles (90°) the species abundances are not correlated with each other.

For ease of interpretation of the biplots only the vectors of those species that correlated highly with the derived dimensions of variability were shown on the plots. Therefore only a small proportion of the species included in each analysis are displayed on the biplots presented here.

To exemplify the points made above, consider the nor-west blowie *Lagocephalus sceleratus* vector. This species had a long vector lying between the “sandy habitat” vectors and about 120° to the depth vector. This implies that the nor-west blowie had moderately high, consistent abundance only in the shallow sandy sites – mostly those off Maud’s Landing. This pattern reflects the data in Table 2.

The analysis using classification and regression trees produced three major groupings. The first major split (Grp 1 in Figure 23.) in the fish abundance data occurred on the basis of water depth, with all the deeper (>92.5 m) sites clustering together, distinct from the shallower sites. This group contained all the sites from the third deployment of BRUVS at Point Cloates, and two of the Mandu sites.

Within the shallower sites (<92.5m) there was a further split into a “Fine Sand” group (Grp2), containing exclusively Maud’s Landing sites, and Grp 3, containing Maud’s Landing, Mandu and Point Cloates sites with “coarse sand” and “megabenthos” habitat classifications.

The indicator species for these three groups are shown in Table 2. The deeper water assemblage was defined best by the abundance of large benthic carnivores. These included the goldspot pigfish *Bodianus perditio*, the red-throat emperor *Lethrinus miniatus* and Jordan's wrasse *Choerodon jordani*, known to eat large molluscs and crustaceans, and the gold-band snapper *Pristipomoides multidens* which consumes these animals and small fish.

Grp 1 "deep-water>92m"	Index	**Grp 2 "shallower (<92m), fine sand"**	Index	**Grp 3 "shallower (<92m), coarse sand/megabenthos"**	Index
Goldspot pigfish *Bodianus perditio*	75.25	Nor-west blowie *Lagocephalus sceleratus*	72.59	Gold-spot trevally *Carangoides fulvoguttatus*	50.00
Red-throat emperor *Lethrinus miniatus*	58.35	Pink threadfin bream *Nemipterus celebicus*	60.00	Spotcheek emperor *Lethrinus rubrioperculatus*	37.50
Gold-band snapper *Pristipomoides multidens*	50.01	Juv. Threadfin bream *Nemipterus sp.*	49.34	Grey gummy shark *Mustelus spA*	37.50
Jordan's wrasse *Choerodon jordani*	40.00	Sliteye shark *Loxodon/Rhizoprionodon*	43.82	Thicklip trevally *Carangoides orthogrammus*	25.00
Blackspot goatfish *Parupuneus spilurus*	40.00	Lizardfish (grinner) *Saurida undosquamis*	39.59	Silvertip whaler shark *Carcharhinus albimarginatus*	25.00
Blue-barred parrotfish *Scarus ghobban*	40.00	Starry triggerfish *Abalistes stellatus*	32.96	Klein's butterflyfish *Chaetodon kleinii*	25.00

Table 2. The top six indicator species for the three groups in the BRUVS data, with an index defined as the product of relative abundance and relative frequency of occurrence of the species within a group. The index had a value of 100 if the species occurred at all BRUVS sites within the group, and did not occur in any other group.

The longer vectors in Figure 23, show a very close correlation between red-throat emperor abundance and increasing depth, but a poor correlation for the gold-band snapper – reflecting its occurrence at both shallow and deep sites, in close correlation with the occurrence of megabenthos habitat.

In the shallower water, the second group of sites in a fine sand habitat (often bioturbated with many small holes) was characterised by the combinations of abundance of nor-west blowies *Lagocephalus sceleratus* (Figure 24C.), threadfin breams *Nemipterus* (2 spp), the lizardfish *Saurida undosquamis*, the small *Loxodon/Rhizoprionodon* shark, and the starry triggerfish *Abalistes stellatus*.

None of these species has economic significance in Australia, and several of them are regarded as serious pests in fishing operations. It is significant that the nor-west blowie and triggerfish are from evolutionarily-advanced families. These species have specialised dentition, enabling them to be omnivorous and exploit a very wide range of poor-quality food sources. The triggerfish has heavily armoured scales and a spine, and the nor-west blowie has powerful toxins and the ability to rapidly inflate its body with water to frustrate predators. These adaptations allow these fish to safely forage in open sandy habitats with no shelter. The lizardfish is an ambush-predator of small fishes, such as the juvenile *Nemipterus* encountered in the fine sand habitats.

The vector for the unidentified, juvenile *Nemipterus sp* in Figure 23. lies directly opposed to depth, indicating the nursery function of shallower, soft sediments. Apart from the indicator species, there was a close correlation between the abundance of the small pelagic scad *Decapterus sp* and the presence of fine sand. The dense bioturbation seen in some fine sand habitats may have been made by polychaete worms and /or callianassid burrowing shrimps. Both groups of animals provide rich food sources for demersal microcarnivores.

The indicator species for the third group, in shallower habitats dominated by coarse sand or megabenthos, included a wide mix of fish functional groups. These were predators of small fish (the piscivorous gold-spot trevally and silvertip whaler shark), small (spotcheek emperor) and larger (thicklip trevally, grey gummy shark) consumers of molluscs and crustacea, and a microcarnivore (Klein's butterflyfish). These predatory fish communities are a highly diverse and have representatives from the major families of predators common to these habitats (Appendix 4.) Fishes able to directly eat sponges and other large benthos such as the angelfish and toadfish were also present.

The greater diversity and wider mix of functional groups in the megabenthos habitats was expected, given the greater structural complexity of such habitats, and the possible provision of detrital subsidies for local food chains provided by the sponges, gorgonians and other animals in the patches.

However, we did not expect that water depth would influence the patterns in fish communities we observed (Figure 23). A larger, cross-shelf sample from Point Cloates and Mandu, with BRUVS set in the full suite of habitats present, would give a better idea of the relative importance of megabenthos gardens and depth. It may be found that megabenthos abundance in the Ningaloo region may be confined to deeper water.

In general terms, the fauna recorded in this pilot study was similar to that found at equivalent latitudes and depths on the east coast, in the Great Barrier Reef region. However, the Ningaloo densities of red-throat emperor (Figure 24B.) were exceptionally high in comparison to the east coast, where the species is found mainly in shallower waters, and the abundance of members of the tropical snapper genus *Lutjanus* were less diverse and abundant than expected from the Great Barrier Reef studies.

Figure 24. Image grabs from the video of the BRUVS. (A) Red Emperor (*Lutjanus sebae*) in 89m off Mandu Mandu, (B) Red Throat Emperor (*Lethrinus miniatus*) in 70m off Point Cloates, (C) North-west Blowie (*Lagocephalus sceleratus*) in 71m off Point Maud.

6. Discussion

These are the first data of their type available for the deeper waters of Ningaloo Marine Park. The data suggest the Commonwealth waters of Ningaloo Marine Park are unlikely to support reef building coral communities, with the possible exception of the shallowest of Commonwealth waters in the very southern end of the park. The most significant finding of this initial survey is that the Commonwealth waters of the Park have some areas of potentially high and unique biodiversity values associated with mid- to deep water filter feeding communities (eg. sponge gardens). Based on the dominant fauna in the videos, four different sponge garden habitats appeared to exist in this small bioregion. The only comparison can be made with the extensive work done by the WA Museum further north in the Dampier Archipelago, and the sponge gardens there do not contain the same species as were seen in the video tows (Dr J. Fromont, pers. comm.). There appears to be a significant difference in species composition from Dampier to Ningaloo. Advice from the WA Museum indicates that typical tropical species in Dampier were notably absent in the Ningaloo videos, whilst other tropical species e.g. *Xestospongia cf. testudinaria* were in sponge garden habitats at Ningaloo but were not present in sponge garden habitats in Dampier. Due to lack of knowledge of the Western Australian sponge fauna in general it is hard to determine the biogeographic relationships of this deepwater Ningaloo biota. It is not similar to shallow water Dampier sponge gardens, however, deeper areas have not been sampled to the north for comparison. Shallow areas of Ningaloo have also not been sampled for sponges, so relationships between shallow reef sponges and the deeper garden habitats cannot be made. It was surprising to see differences between the sponge garden habitats in the videos, to the extent that four different species compositions could be recognized. No sponge garden habitats have been sampled to the south of Ningaloo although some studies have been undertaken in shallow water at the Houtman Abrolhos (Fromont 1999), and there appear to be no similarities with the deepwater sponge gardens seen in the videos.

The Northwest shelf of Australia has been identified as a sponge biodiversity hotspot, from the few surveys that have been conducted in the region (Hooper et al. 2002), all to the north of Ningaloo. Publications on the sponge fauna of the Dampier Archipelago, supporting the claim of high sponge diversity in the northwest, are published or in press (Fromont 2003, 2004, Fromont, et al. in press).

In general terms, the fish fauna recorded in this pilot study was similar to that found at equivalent latitudes and depths in the Great Barrier Reef region. The records of the grey gummy shark are significant from a conservation viewpoint, as this species may have a restricted range and its biology and ecology is very poorly understood.

Commercially and recreationally important species were observed in the Commonwealth waters. The Ningaloo densities of red-throat emperor (Figure 24B.) were exceptionally high in comparison to the east coast, where the species is found mainly in shallower waters, and the abundance of members of the tropical snapper genus *Lutjanus* were less diverse and abundant than expected from the east coast work. Fish diversity was associated with habitats of greater structural complexity and, while these areas will be targeted by recreational and charter fishermen, the depths do not lend themselves to anchoring to the same extent as fishing spots in State waters. It cannot be determined how representative the communities found are for the whole marine park. It seems highly likely, given the spatial variation observed and the high diversity and endemism of the region for some invertebrates such as sponges, that additional notable benthic communities exist in Commonwealth waters at Ningaloo. A much more comprehensive survey, which also includes the collection of voucher specimens, will be required before the gradients of diversity for the dominant filter feeding taxa can be established and any hotspots mapped. Variation in abundance and composition of the benthos observed at Ningaloo, while not unexpected, does appear to happen over both large and small spatial scales. On the Great Barrier Reef it has been shown that benthos can vary by an appreciable amount over relatively short distances—tens of kilometres (Poiner, et al. 1998, cited in Burridge, et al. 2003) both along and across the shelf. A key driver of benthic communities in the mid- and outer shelf waters at Ningaloo may be nutrient inputs from the waters beyond the shelf. Direct observation of sand waves and so on, even in depths of 150m, suggest very strong internal currents are occurring in places along the reef. We also noted some medium to high-density sponge gardens in the deepest tows adjacent to canyons at Mandu Mandu and Pt Cloates, where upwelling and shelf edge turbulence might be expected. However, not all sites in these depths and locations had abundant macrofauna. It seems most likely that suitable substrate for settlement may be the primary limiting factor controlling the abundance of filter feeders. Low, outcropping ledges were often observed in areas supporting rich benthic communities and these ridges may reflect past sea level changes. It is highly likely that the relative hardness of the seabed will be a useful proxy for the presence of filter feeders.

In future surveys of the deeper waters of Ningaloo these observations suggest that a rapid survey, using high-resolution acoustic methods backed with limited video validation, would deliver a cost effective and comprehensive habitat map of the greatest use in identifying the most likely biodiversity hotspots.

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9. Appendices

Appendix 1: Transect details from March 2004 survey.

Mandu Mandu

Site 1: 22° 07.2728S, 113° 48.6623E, 90/92m
Coarse sand and shell grit, mostly bare of biota, infauna burrows present.

Site 2: 22° 05.4311S, 113° 49.2976E, 84/88m
Coarse sand and shell grit, mostly bare of biota but occasional sponges, infauna burrows present.

Site 3: 22° 05.6633S, 113° 48.1402E, 120/200m
Silty sand, initial sparse sponges, infauna burrows present, dense sponges emerging 3 minutes into tow, drop off at end of tow.

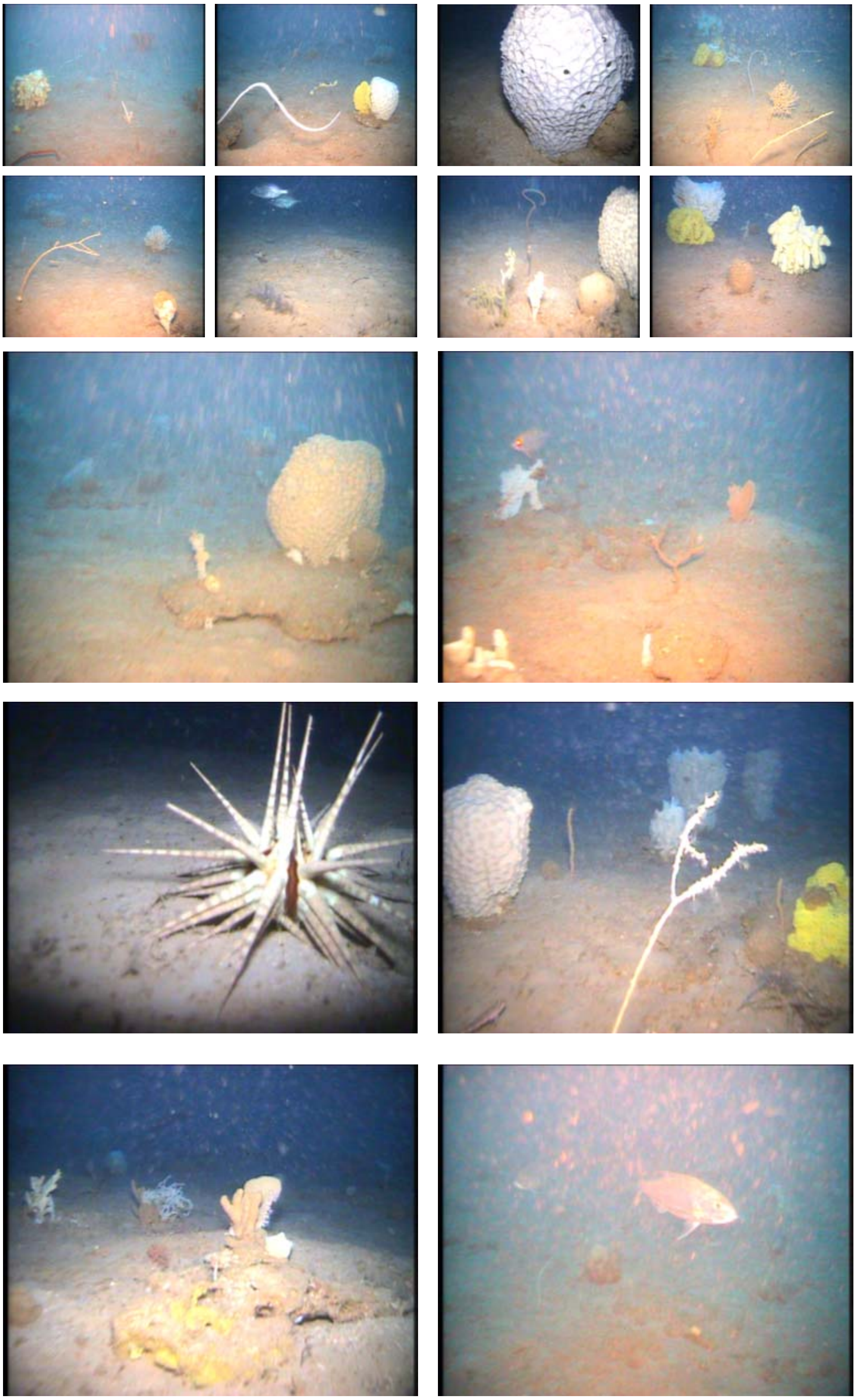


Site 4: 22° 06.1467S, 113° 47.9665E, 118/187m
Coarse sand and occasional rubble, some outcropping low rock ledges, dense sponge gardens at end of tow near steep drop off. Rosy job fish schooling, other fish and sharks present.

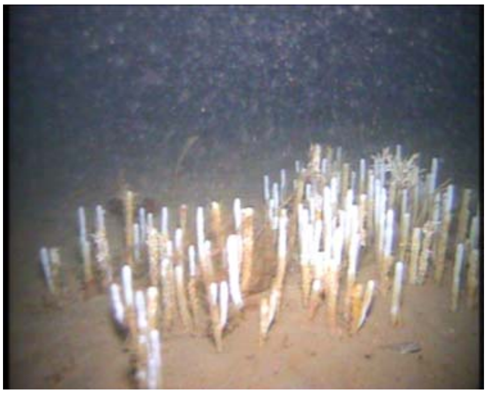




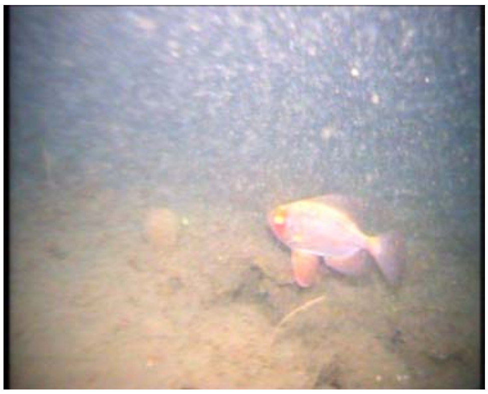

Site 5: 22° 06.8671S, 113° 47.7645E, 117/140m
Coarse sand and occasional rubble, some outcropping low rock ledges, diverse med/high sponge gardens near steep drop off. Rosy job fish schooling, other fish and sharks present.



Site 6: 22^{o} 05.7819S, 113^{o} 47.9858E, 129/194m
Silty sand, medium/dense sponges, infauna burrows present, some outcropping low rock ledges.





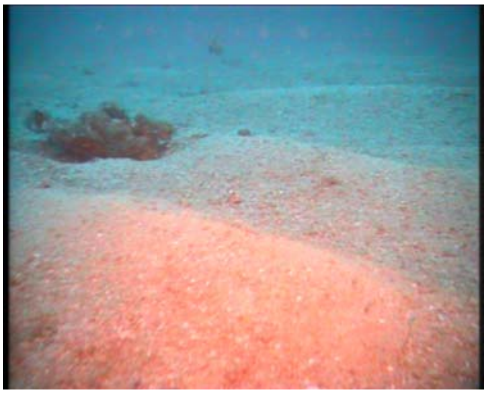



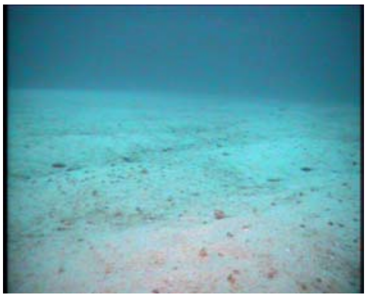
Site 7: 22^{o} 05.4819S, 113^{o} 49.8742E, 72/75m Coarse sand, with shell fragments, very low density, trevally seen on tow.



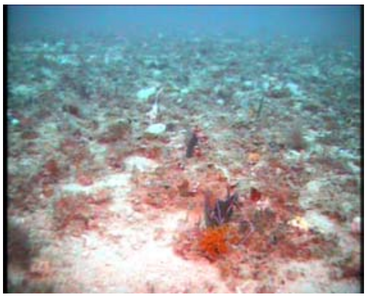
Site 8: 22^{o} 06.3090S, 113^{o} 49.8569E, 72m
Bare sand with slight ripple ridges, occasional sponge or soft coral, sparse.

Site 9: 22^{o} 07.1106S, 113^{o} 49.8639, 72m Bare sand with slight ripple ridges, occasional sponge or soft coral, sparse.



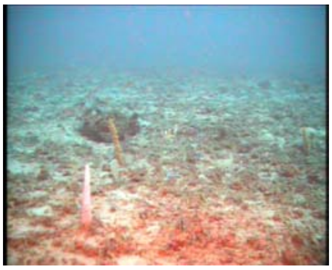



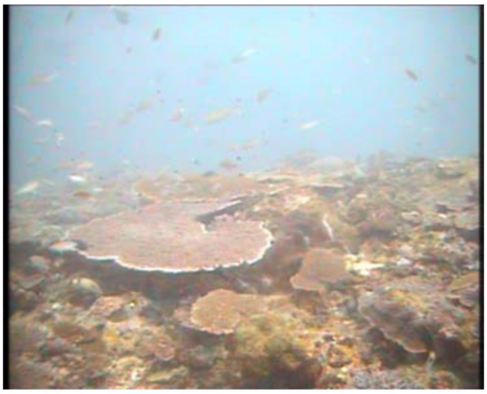
Site 10: 22^{o} 07.4636S, 113^{o} 51.5839E, 50m
Bare sand with slight ripple ridges.



Site 11: 22^{o} 06.6494S, 113^{o} 51.7626E, 50m
Mixed macroalgae on coarse sandy rubble, sponges and soft coral, medium/high density.

Site 12: 22^{o} 05.9337S, 113^{o} 51.8138E, 50m Mixed macroalgae on coarse sandy rubble, sponges and soft coral, medium/high density.





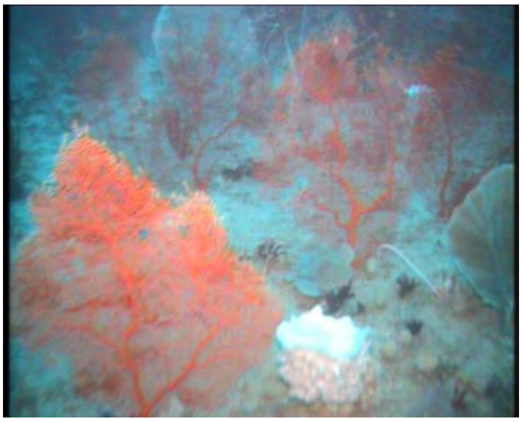
Site 13: 22° 06.0323S, 113° 52.1949E, 35m
Medium/high density hard coral community down to about 35m.

Site 14: 22° 06.5699S, 113° 52.1065E, 35m
Medium/high density hard coral community down to about 35m.

Site 15: 22° 07.3364S, 113° 52.1367E, 35m
Sparse sandy substrate with little or no seabed features.

Point Cloates

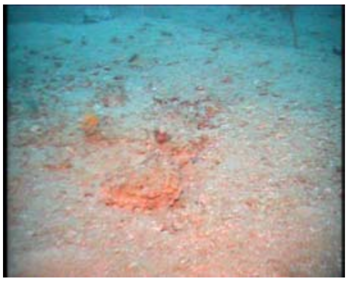
Site 1: 22^{o} 39.8952S, 113^{o} 34.4898E, 63/70m
Coarse sand and patches of rubble, medium density filter feeders, gorgonians more common than sponges. Dense gorgonian forest late in tow.



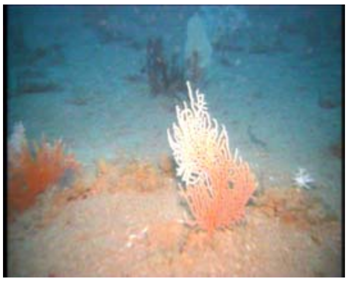

Site 2: 22^{o} 40.3879S, 113^{o} 34.3337E, 71m
Sand/shell grit in waves. Bare patches or low/medium density gorgonians and blade sponges.

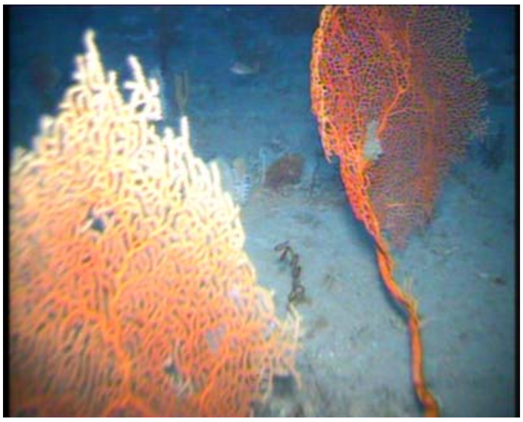


Site 3: 22^{o} 40.9946S, 113^{o} 34.2185E, 70m
Coarse sand, with occasional underlying rock exposed. Small area of good gorgonian forest, consistent low/medium density filter feeders.



Site 4: 22° 40.9233S, 113° 33.3825E, 90/95m
Coarse sand, initially bare or very low abundance of macrofauna. Second half of tow more rubbly/rocky substrate and more sponges and soft coral.






Site 5: 22° 40.4323S, 113° 33.5284E, 90/95m
Coarse sand on hard pavement with medium density sponge and gorgonians.

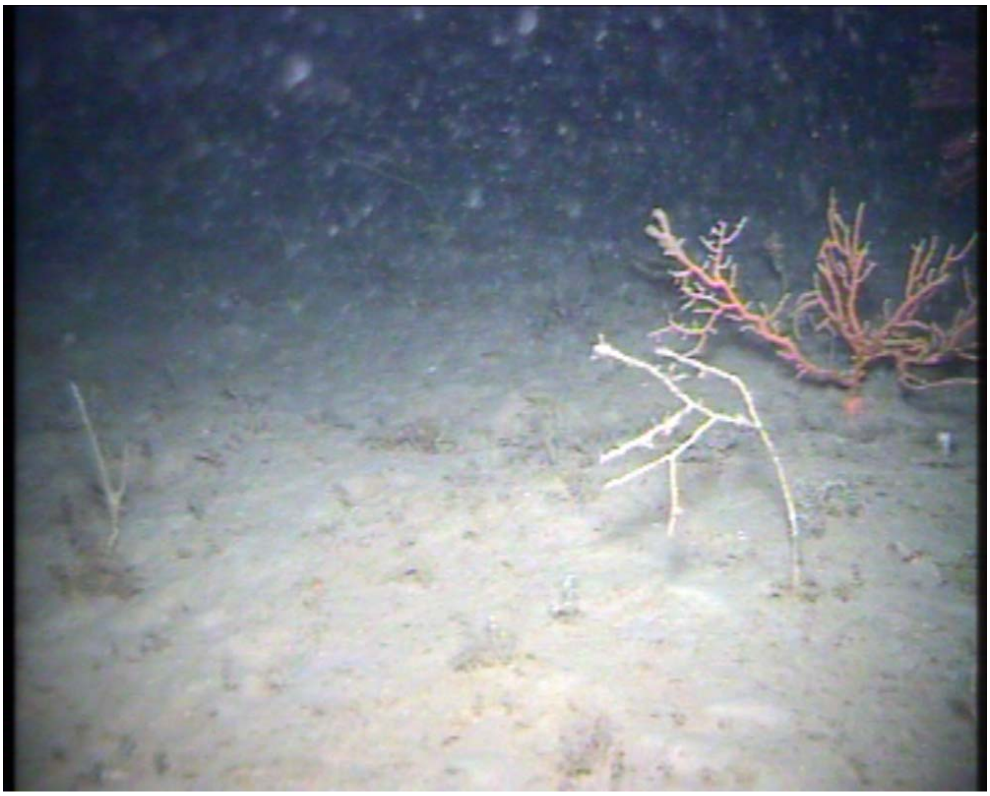


Site 6: 22° 40.0822S, 113° 33.5870E, 90/95m
Coarse sand, good mix of sponges and soft coral in medium/high density.

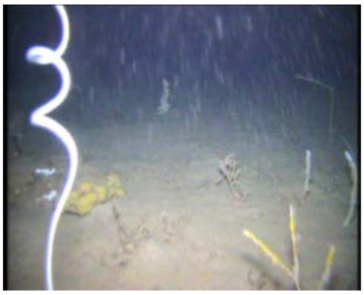


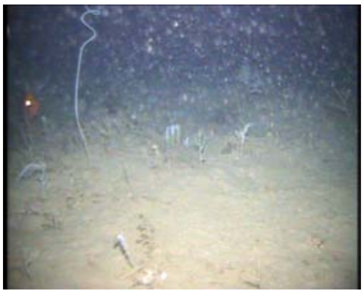


Site 7: 22° 39.4871S, 113° 32.6457E, 150m
Sandy silt, very low abundance of gorgonians and sponges.



Site 8: 22° 40.0071S, 113° 32.3990E, 152/178m
Sandy silt, low sponges, fine specimens of yellow and white sponges.

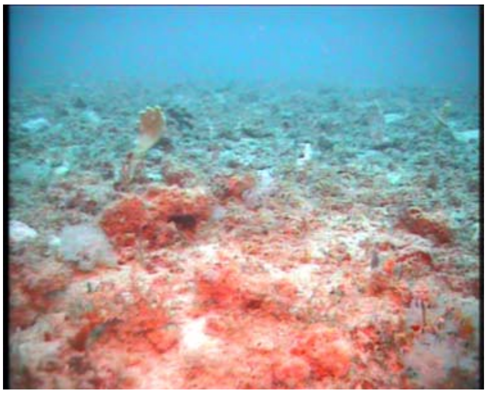




Site 9: 22° 40.7428S, 113° 32.0314E, 150m
Sandy, occasional coarse grit, sparse sponges and soft coral.

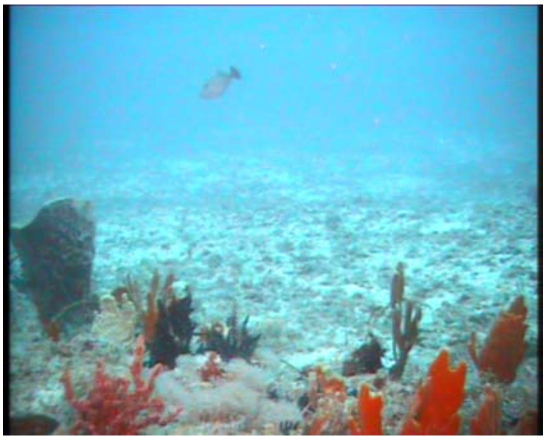


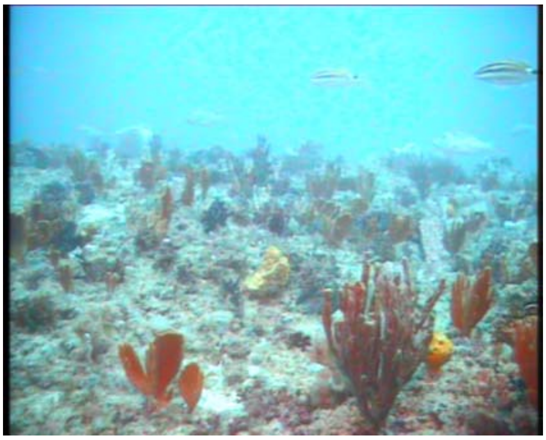


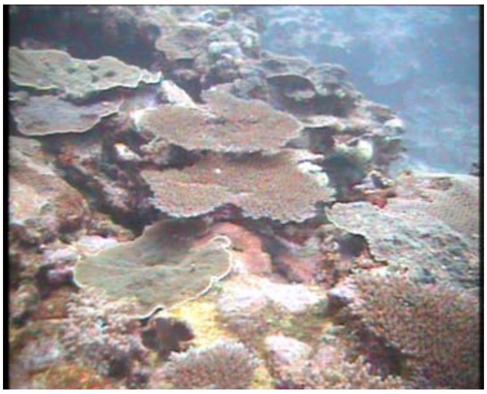
Site 10: 22° 39.5706S, 113° 35.3431E, 50m Rubble and blocky substrate, sparse erect sponges and medium density macroalgae, occasional soft corals.



Site 11: 22° 40.1408S, 113° 35.3652E, 48m
Very good coral reef and fitler feeders right at start then into sparse block zone like Cloates

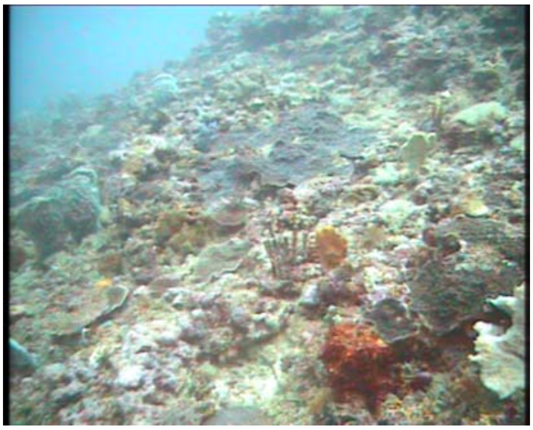


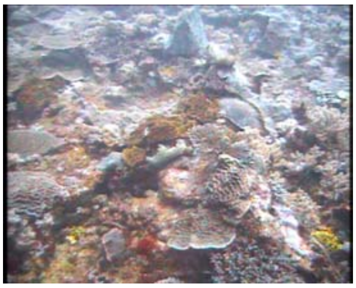


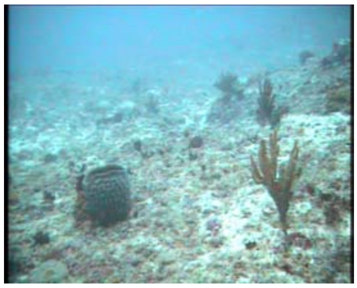


Site 12: 22° 40.6349S, 113° 35.4340E, 40m
Good live reef at 40m then into filter feeders then blocky, macroalgae leading to diverse erect sponge communities.

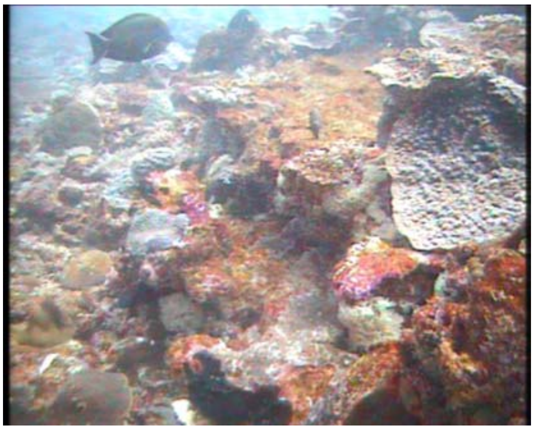
Site 13: 22° 40.7744S, 113° 36.0484E, 26/30m
Good live reef, spur and groove, medium/high density hard coral community.







Site 14: 22° 40.1472S, 113° 35.8426E, 22/30m
Good live reef with medium/high density hard coral community abundant encrusting corals towards the end of the tow.

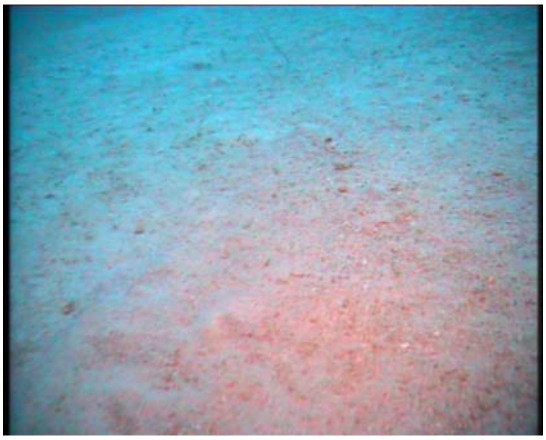



Site 15: 22° 39.1048S, 113° 36.5016E, 26/30m
Coarse white sand in waves. One small patch of corals and sponges 3 mins into tow then back to bare sand.



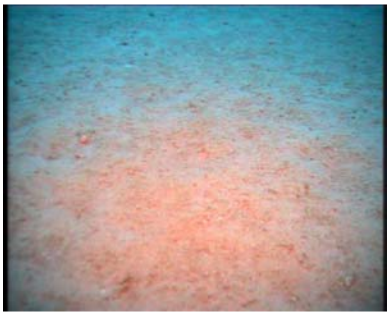
Point Maud

Site 1: 23° 06.5872S, 113° 37.7069, 73/76m
Little or no biota, sand/silt, sparse.



Site 2: 23° 06.4925S, 113° 38.3212E, 70m
Little or no biota, sand/silt, sparse.

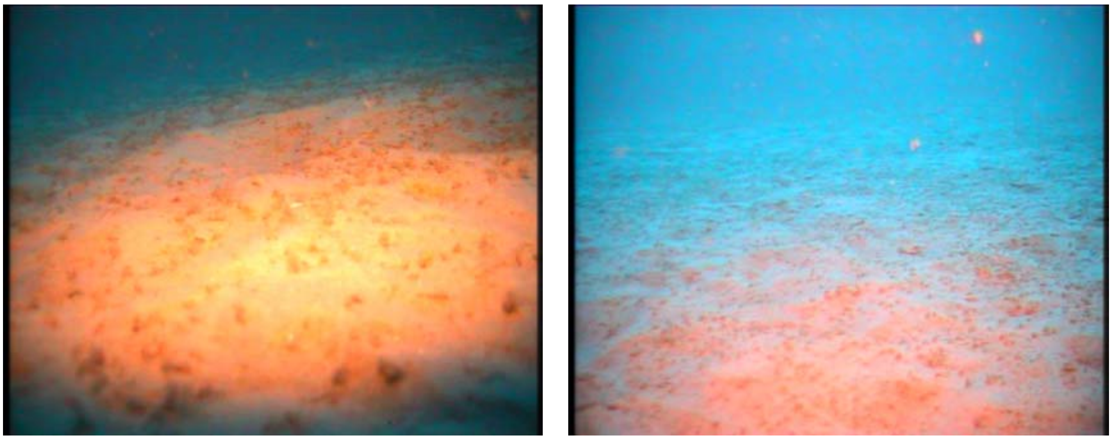
Site 3: 23° 06.0914S, 113° 39.0285E, 70m
Little or no biota, sand/silt, sparse.



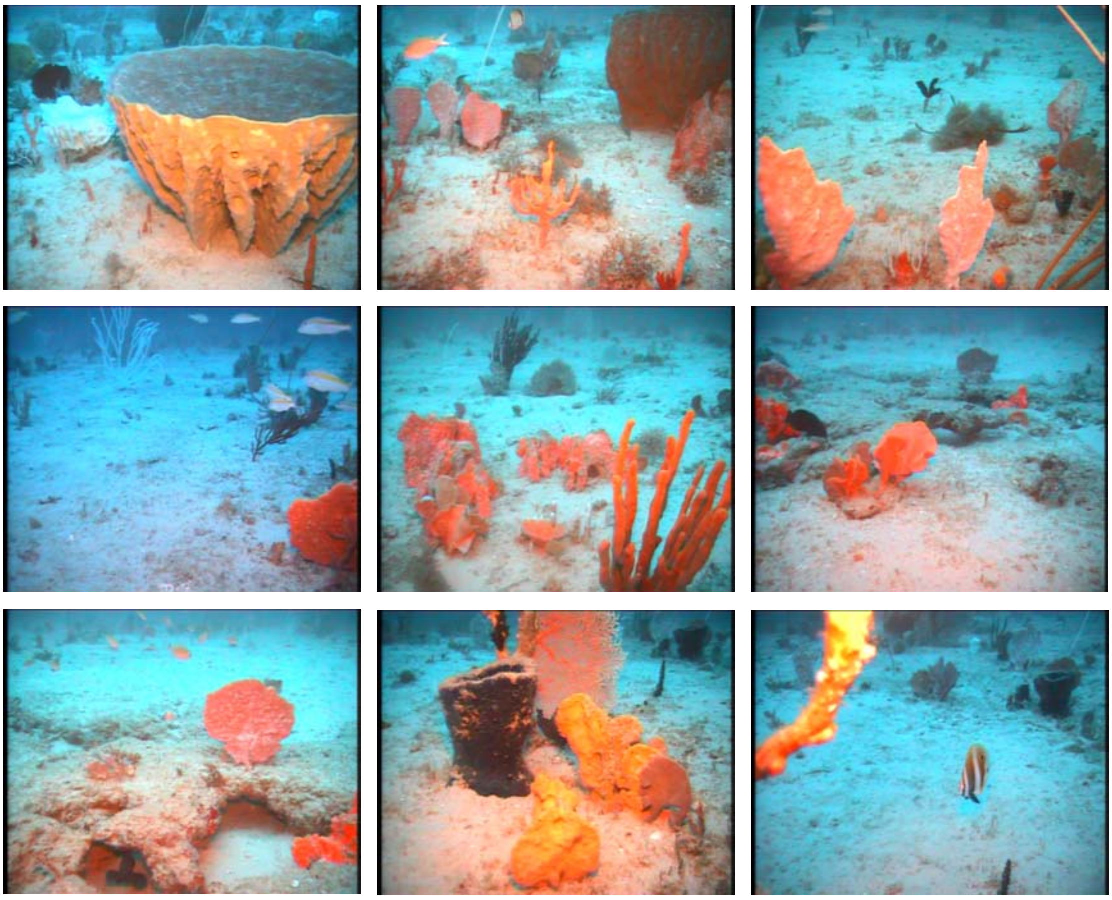
Site 4: 23° 05.7804S, 113° 34.8538E, 87m
Little or no biota, sand/silt, sparse.

Site 5: 23° 05.2529S, 113° 34.5878E, 88m
Little or no biota, sand/silt, sparse.

Site 6: 23^{o} 04.5242S, 113^{o} 34.5698E, 90m
Little or no biota, sand/silt, sparse.



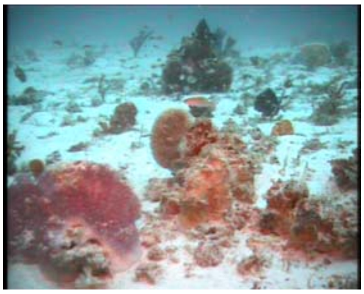
Site 7: 23^{o} 05.4661S, 113^{o} 40.8895E, 66m
White looking sand with rich sponge and soft coral garden, medium/high.

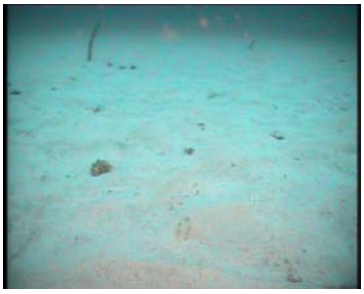


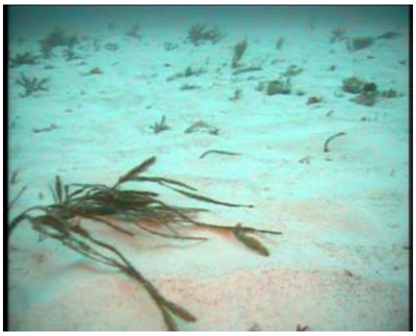
Site 8: 23° 06.7419S, 113° 40.9304, 66m
Little or no biota, sand/silt, sparse.

Site 9: 23° 04.4790S, 113° 40.9091E, 66m
Little or no biota, sand/silt, sparse.

Site 10: 23° 05.3430S, 113° 43.0574, 41/47m
Rubble with sponges at start then sand with nothing at end of tow.



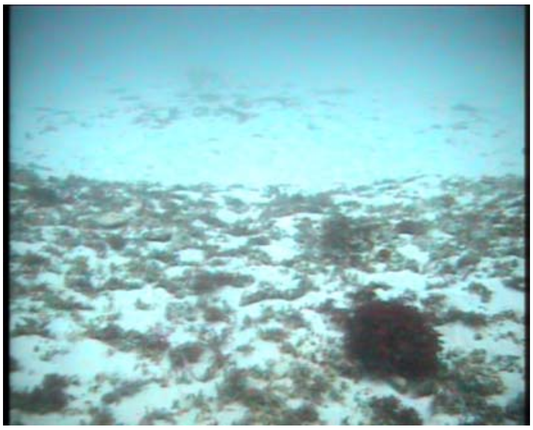


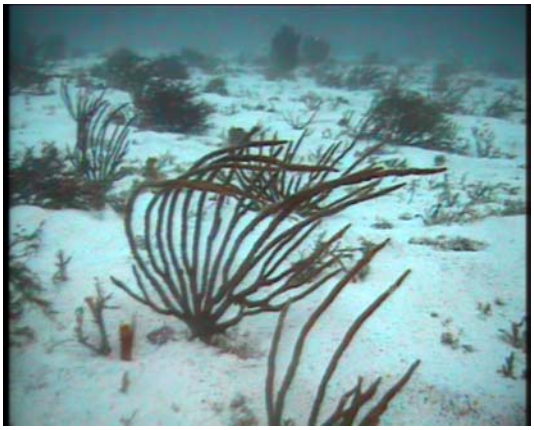


Site 11: 23° 05.8538S, 113° 43.1217E, 41/45m
Sand then patch of rubble, little bit of seagrass the bare sand again.

Site 12: 23° 06.3464S, 113° 43.1246E, 44m
Bare sand with slight ripple ridges.

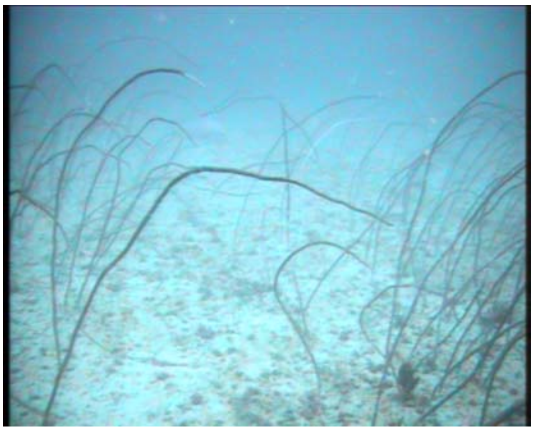
Site 13: 23° 06.1222S, 113° 43.4179E, 30m
Medium rubble and reddish macroalgae. Sand gullies and rubble ridges
Finger like soft corals in medium density.





Site 14: 23° 05.8969S, 113° 43.3090E, 32/39m
Rubble and blocks with macroalgae then sand patches. Same finger soft corals as Tow 1. Medium density mix of filter feeders towards end of tow.

Site 15: 23° 05.4465S, 113° 43.2483E, 32/39m
Rubble, sand and underlying pavement. Low density filter feeders. Seawhip gardens in sparse outrops.



Appendix 2: Location information and depth of tows.

Tow name	Date	Tow start Lat	Town start Long	Tow end lat	Tow end long	Depth
Mandu1	18/03/2004	22 07.2728	113 48.6623	22 7.4955	113 48.7275	92/90m
Mandu2	18/03/2004	22 05.4311	113 49.2976	22 05.6028	113 49.2939	84/88m
Mandu3	23/03/2004	22 05.6633	113 48.1402	22 05.7524	113 47.8829	120/200m
Mandu4	23/03/2004	22 06.1467	113 47.9665	22 06.2073	113 47.8173	118/187m
Mandu5	23/03/2004	22 06.8671	113 47.7645	22 06.9338	113 47.4731	117/140m
Mandu6	23/03/2004	22 05.7819	113 47.9858	22 05.5965	113 47.7558	129/194m
Mandu7	24/03/2004	22 05.4819	113 49.8742	22 05.4742	113 49.6470	72/75m
Mandu8	24/03/2004	22 06.3090	113 49.8569	22 06.3600	113 49.7332	72m
Mandu9	24/03/2004	22 07.1106	113 49.8639	22 07.1965	113 49.6615	72m
Mandu10	24/03/2004	22 07.4636	113 51.5839	22 07.5272	113 51.3540	50m
Mandu11	24/03/2004	22 06.6494	113 51.7626	22 06.6048	113 51.5597	50m
Mandu12	24/03/2004	22 05.9337	113 51.8138	22 05.8542	113 51.6183	50m
Mandu13	24/03/2004	22 06.0323	113 52.1949	22 05.9782	113 52.0609	35m
Mandu14	24/03/2004	22 06.5699	113 52.1065	22 06.6462	113 51.9650	35m
Mandu15	24/03/2004	22 07.3364	113 52.1367	22 07.3364	113 51.9855	35m
Cloates1	19/03/2004	22 39.8952	113 34.4898	22 39.8826	113 34.4349	63/70m
Cloates2	19/03/2004	22 40.3879	113 34.3337	22 40.5812	113 34.2685	71m
Cloates3	19/03/2004	22 40.9946	113 34.2185	22 41.2004	113 34.2788	70m
Cloates4	19/03/2004	22 40.9233	113 33.3825	22 40.9708	113 33.0461	90/95m
Cloates5	19/03/2004	22 40.4323	113 33.5284	22 40.5685	113 33.2051	90/95m
Cloates6	19/03/2004	22 40.0822	113 33.5870	22 40.0965	113 33.3706	90/95m
Cloates7	22/03/2004	22 39.4871	113 32.6457	22 39.5466	113 32.5887	150m
Cloates8	22/03/2004	22 40.0071	113 32.3990	22 39.8934	113 32.1117	152/178m
Cloates9	22/03/2004	22 40.7428	113 32.0314	22 40.5787	113 31.8323	150m
Cloates10	22/03/2004	22 39.5706	113 35.3431	22 39.6498	113 35.2693	50m
Cloates11	22/03/2004	22 40.1408	113 35.3652	22 40.1234	113 35.3086	48m
Cloates12	22/03/2004	22 40.6349	113 35.4340	22 40.7205	113 35.8271	40m
Cloates13	22/03/2004	22 40.7744	113 36.0484	22 40.7205	113 35.8271	26/30m
Cloates14	22/03/2004	22 40.1472	113 35.8426	22 40.1835	113 35.6676	22/30m
Cloates15	22/03/2004	22 39.1048	113 36.5016	22 39.1048	113 36.3299	26/30m
Mauds1	20/03/2004	23 06.5872	113 37.7069	23 06.3156	113 37.6315	73/76m
Mauds2	20/03/2004	23 06.4925	113 38.3212	23 06.2935	113 38.3007	70m
Mauds3	20/03/2004	23 06.0914	113 39.0285	23 05.7503	113 39.0527	70m
Mauds4	20/03/2004	23 05.7804	113 34.8538	23 05.8735	113 34.6890	87m
Mauds5	20/03/2004	23 05.2529	113 34.5878	23 05.3145	113 34.3935	88m
Mauds6	20/03/2004	23 04.5242	113 34.5698	23 04.5487	113 34.3300	90m
Mauds7	21/03/2004	23 05.4661	113 40.8895	23 05.5292	113 40.7313	66m
Mauds8	21/03/2004	23 06.7419	113 40.9304	23 06.7941	113 40.8165	66m
Mauds9	21/03/2004	23 04.4790	113 40.9091	23 04.5741	113 40.8013	66m
Mauds10	21/03/2004	23 05.3430	113 43.0574	23 05.3358	113 42.8856	41/47m
Mauds11	21/03/2004	23 05.8538	113 43.1217	23 05.8862	113 42.9914	41/45m
Mauds12	21/03/2004	23 06.3464	113 43.1246	23 06.3345	113 43.0283	44m
Mauds13	21/03/2004	23 06.1222	113 43.4179	23 06.1996	113 43.3200	30m
Mauds14	21/03/2004	23 05.8969	113 43.3090	23 05.9272	113 43.1672	32/39m
Mauds15	21/03/2004	23 05.4465	113 43.2483	23 05.4804	113 43.0910	32/39m

Appendix 3: Fish Species List compiled from the BRUVS.

Common Name	Species
Amberjack	Seriola dumerili
Angelfish	Genicanthus sp
Blackspot goatfish	Parupuneus spilurus
Black-spot turretfish	Tetrasomus gibbosus
Blotched fantail ray	Taeniura meyeni
Blue-barred parrotfish	Scarus ghobban
Bluer angelfish	Pomacanthus semicirculatus
Blue-spotted leatherjacket	Eubalichthys caeruleoguttatus
Bluespotted tuskfish	Choerodon cauteroma
Blunt unicornfish	Naso fageni
Blunt-headed rockcod	Epinephelus amblycephalus
Brown triggerfish	Sufflamen frenatus
Cobia	Rachycentron canadum
Coral trout	Plectropomus sp
Emperor angelfish	Pomacanthus imperator
Gold-band snapper	Pristipomoides multidens
Goldspot pigfish	Bodianus perditio
Gold-spot trevally	Carangoides fulvoguttatus
Grey gummy shark	Mustelus sp
Grubfish	Parapercis sp
Gulf damsel	Pristotis jerdoni
Japanese butterfish	Pentapodus nagasakiensis
Jordan's wrasse	Choerodon jordani
Klein's butterflyfish	Chaetodon kleinii
Lizardfish (grinner)	Saurida undosquamis
Long-nose trevally	Carangoides chrysophrys
Long-spine snapper	Argyrops spinifer
Moray eel	Gymnothorax sp
Nor-west blowie	Lagocephalus sceleratus
Pink threadfin bream	Nemipterus celebicus
Pink threadfin bream	Nemipterus sp
Red emperor	Lutjanus sebae
Redaxil emperor	Lethrinus sp1
Red-throat emperor	Lethrinus miniatus
Rosy snapper	Pristipomoides filamentosus
Sandbar shark	Carcharhinus plumbeus
Silvertip whaler shark	Carcharhinus albimarginatus
Sliteye/Sharpnose shark	Loxodon macrorhinus/Rhizoprionodon taylori
Smokey chromis	Chromis fumea
Spangled emperor	Lethrinus nebulosus
Spotcheek emperor	Lethrinus rubrioperculatus
Starry triggerfish	Abalistes stellatus
Suckerfish	Echeneis naucrates
Swallowtail sea bream	Gymnocranius elongatus
Thicklip trevally	Carangoides orthogrammus
unidentifed rosy jobfish	Pristipomoides sp
Unknown wrasse	Suezichthys?
Western butterflyfish	Chaetodon assarius
White-blotched rockcod	Epinephelus multinotatus
Yakka	Decapterus sp
Yellow-spotted triggerfish	Pseudobalistes fuscus
Yellowtail angelfish	Chaetodontoplus personifer

Appendix 4: BRUVS location data and species density.

Location	Latitude	Longitude	Depth	# of Sp.	Avg (MAXN)	Habitat Notes
Mandu Mandu 1	22.1077	113.8159	93	9	1.67	flat muddy sand with one medium white sponge and a sea urchin
Mandu Mandu 2	22.1182	113.8113	94	5	2.00	flat coarse sand, with some small gravel
Mandu Mandu 3	22.0967	113.8192	89	8	1.67	flat coarse sediment with gravel
Point Cloates 1	22.6759	113.5737	70	9	1.33	flat coarse sediment with gravel
Point Cloates 2	22.6647	113.5758	72	9	1.29	flat coarse sand/gravel with sparse sea whips, gorgonian fans and bryozoans
Point Cloates 3	22.6861	113.5713	69	10	1.13	coarse sand waves, with sparse rubble in furrows
Point Cloates 4	22.6755	113.5562	94	15	8.50	moderately dense fan gorgonians and some sponge on flat coarse sediments
Point Cloates 5	22.6849	113.5533	94	7	2.57	very flat fine muddy sand
Point Cloates 6	22.6680	113.5577	96	8	4.33	coarse sand, some small rocks, with large macrobenthos of moderate density ; high sea whips, high white gorgonian fans, moderately large dark sponges
Point Maud 1	23.0981	113.6531	71	5	3.00	flat sand with ripples and no visible bioturbation
Point Maud 2	23.1116	113.6316	71	5	4.50	coarse sand, with macrobenthos of sparse density ; high sea whips, gorgonians, low sponges
Point Maud 3	23.1077	113.6456	68	13	3.42	flat coarse sand
Point Maud 4	23.1023	113.5799	88	7	4.00	flat, fine heavily bioturbated muddy sand
Point Maud 5	23.0932	113.5770	88	7	4.29	very flat fine bioturbated sand
Point Maud 6	23.0810	113.5743	92	3	3.00	very flat fine muddy sand
Point Maud 7	23.0856	113.6799	66	4	5.00	very flat fine bioturbated sand
Point Maud 8	23.1008	113.6801	66	7	6.50	very flat, bioturbated muddy sand
Point Maud 9	23.0917	113.6809	66	22	7.71	coarse sand, with some rubble, large sponges, large fans, sea whips, moderately dense

NB* Avg (MAXN) is the average maximum number of fish from each species seen in a single video frame.