MARINE MANAGEMENT SUPPORT:
NINGALOO

CORAL REEF COMMUNITIES, HABITATS AND SUBSTRATES IN AND NEAR SANCTUARY ZONES OF NINGALOO MARINE PARK

Final Report: MMS/NIN/NMP - 78/2004

A collaborative project between
Curtin University, Department of Applied Geology and the Department of Conservation and Land Management's Marine Conservation Branch and Exmouth District Office

Prepared by
L. Cassata and L. Collins

December 2004

Marine Conservation Branch
Department of Conservation and Land Management
47 Henry St
Fremantle, Western Australia, 6160

This report may be cited as:
Cassata, L. and Collins, L. (2004). Coral reef communities, habitats and substrates in and near sanctuary zones of Ningaloo Marine Park. Final Report: MMS/NIN/NMP -78/2004. December 2004. Marine Conservation Branch, Department of Conservation and Land Management, Perth, Western Australia. (Unpublished report).

Copies of this report may be obtained from:

Marine Conservation Branch
Department of Conservation and Land Management
47 Henry St., Fremantle, Western Australia, 6160
Ph: 61-8-9432 5100; Fax: 61-8-9430 5408

Coral reef communities, habitats and substrates in and near Sanctuary Zones of Ningaloo Marine Park

Laura Cassata[1] and Lindsay B. Collins[1]

[1]Department of Applied Geology, GPO Box U1987, Curtin University of Technology, Perth 6845, Western Australia
email: L.Collins@curtin.edu.au

ABSTRACT
As Australia's longest fringing reef, Ningaloo Reef lies close to the mainland of northwest Australia in an area of high tourism potential. The establishment of Sanctuary Zones in and around the northern Ningaloo Marine Park has necessitated improvements in understanding of the biodiversity and distribution of habitats and substrates in the reef lagoon, its seaward barrier and the adjacent shelf environments. Using a combination of video transects in forereef to shelf environments, GPS controlled ground-truthing of colour satellite images and aerial photography for shallow lagoon settings, sixteen habitat types were identified and mapped regionally. Lagoon substrates described in previous reconnaissance were mapped here in greater detail, and some of the first data on poorly known forereef and shelf communities has been analysed from the video transects. There is a strong correlation between reef morphology, inherited substrate type and coral communities across reef lagoons and their associated barriers, where an energy gradient controlled by wave driven and tidal circulation in reef flat and lagoon environments is reflected in the distribution and cover of robust to more delicate coral communities. Morphological controls are less distinct in island-associated habitats, where increased turbidity, differing wave energy and more variable topography result in higher substrate variability and increasing soft coral communities. The data obtained in this study provide a background for management of biodiversity and monitoring of future impacts in some of the Sanctuary Zones likely to experience increased use in the northern Ningaloo Reef.

Keywords: Ningaloo Reef; Marine park; Habitat mapping; Community composition; Benthos; Conservation; Geomorphology; Remote sensing; GIS; Video-transect.

TABLE OF CONTENTS

* * *

LIST OF TABLES

* * *

LIST OF FIGURES

* * *

1 INTRODUCTION

The Ningaloo Reef is one of the declining number of relatively pristine major coral reefs in the world. Much of the 290 km long reef system falls within Ningaloo Marine Park, which extends along the west coast of the Cape Range Peninsula, stretching from about 21°40'S to 23°34'S (Fig 1). This area, managed by the Western Australia Department of Conservation and Land Management (CALM), has been separated into designated Sanctuary, Recreation and General Use Zones. Extensions to the Park and its Sanctuary Zones are currently under consideration, and a new Management Plan is being developed (CALM & MPRA, 2004).

The remote location of the Ningaloo Reef has so far prevented over-development of the area and this provides the opportunity to establish the current conditions as a reference for the evaluation of future changes, induced by either natural processes or human impact.

The reef is exposed to high wave energy and is influenced both by cyclonic storms and tsunamis. Natural events that significantly impact the reef also include extreme low tide events, anoxic conditions resulting from coral spawning, bleaching and predation by the gastropod *Drupella cornus* and the Crown of Thorns starfish *Acanthaster planci* (CALM & MPRA, 2004).

It is estimated that $127 million a year of tourist expenditure is directly attributable to the Ningaloo Marine Park and Cape Range National Park, and this is expected to increase as more people visit the region (CALM & MPRA, 2004). Anthropogenic impacts such as nature-based tourism, and recreational and commercial fishing, could have a potential negative effect on the reef and its habitats as usage increases.

The aim of this paper is to facilitate management of the Ningaloo Marine Park by providing basic information on the present distribution of the communities, habitats, and substrates. Using a combination of methods such as video transects and underwater traverses to ground-truth colour aerial photography and satellite images, and GIS, we have documented coral reef communities and related substrates in some of the Sanctuary Zones and their proposed extensions in the Marine Park, at a level of detail much greater than provided by previous reconnaissance work (see Bancroft & Sheridan, 2000 and Hutchins et al., 1996). The habitat maps generated are intended to provide baseline data for the management of future change from ongoing natural processes and increasing anthropogenic impacts (see Cassata and Collins, 2004).

1.1 SETTING

Ningaloo Reef, Australia's largest fringing coral reef, is approximately 290 km in length and forms a discontinuous barrier adjacent to North West Cape on the coast of Western Australia. The reef encloses a lagoon, which varies in width from 200 m to around 7 km with an average of 2.5 km.

The reef complex includes a narrow reef crest, which is emergent at low water, with well developed spur and groove morphology present on outer reef slopes in depths to 30

m. Several levels of spur and groove are sometimes present. The reef crest is backed by a reef flat which has robust coral communities, as well as coral rubble veneers, and deep grooves floored by sandy sediment, which shallow and broaden to landward. A shallow (0-4 m depth) lagoon of width 1-5 km has rock pavements with sparse corals, and unconsolidated sandy substrates with scattered coral communities. The lagoon shore is sandy or has rock pavements vegetated by macroalgae, with low cliffs and emergent platforms of Last Interglacial reef limestones (Collins et al., 2003). Reef development is interrupted by passes and transverse channels, usually about 200 m wide, which are sites for water exchange between the lagoon and the adjacent shelf.

The complex intertidal and subtidal geomorphology of the reef system is the foundation for a variety of marine habitat types and corresponding high species diversity including dugongs, marine turtles, whale sharks, manta rays and other tropical and subtropical fish, shellfish and molluscs. A total of 217 species and 54 genera of hermatypic corals, with strong Indo-Pacific affinities, have been identified in the Ningaloo Reef (Hatcher, 1991; Veron, 1995) and 112 species of octocorals have been recognized around the Muiron Islands (Hutchins et al., 1996).

Two biotic zones, the northern Australian tropical province and the southern Australian warm temperate province, have a broad overlap on the central west coast (the western coast overlap zone), and Ningaloo Reef lies at the northern extremity of the overlap zone (Morgan and Wells, 1991).

Cape Range is hot and arid. The annual average minimum and maximum temperatures are 17 and 27˚C. Rainfall averages 300 mm but evaporation is 1700-3050 mm annually. Both cyclones (frequency 1 per 3-5 years) and mid-latitude depressions cause peak falls in summer and winter (Hearn et al., 1986). A consequence of this high inter-annual variability is that runoff is confined to stormwater discharge events, which flow through creeks which are often situated near passes in the reef.

Sea surface temperature ranges from a high of 28˚C to a low of 22˚C and is always tropical, and tidal range in the northern part of the reef is 1.7 m.

The mean annual wind speed at Carnarvon, just to the south of the reef, is 6.1 m/s with a mean wind direction of 184˚, which is directly along the line of the northern Ningaloo Reef. Off Northwest Cape, the deepwater wave climate is dominated by year-round long period (14–22 s) swell with a mean annual height of 1.5 m; seas (mean annual height, 1.2 m) are also from the southwest with a significant northwest component (WNI Science and Engineering, unpublished data). Total waves (mean annual height, 2.0 m) regularly reach 3.5–4.0 m in winter and 3.0 m in summer (due to non-cyclonic conditions). The more severe wave conditions experienced during cyclones are poorly documented. Fairweather waves propagate across a narrow, open shelf, and are attenuated by Ningaloo Reef so that wave pumping across the reef, wind waves and tides dominate lagoon circulation (D'Adamo and Simpson, 2001). The regional oceanography is dominated by the Leeuwin Current (Pearce and Griffiths, 1991), a warm low salinity current that flows southward along the adjacent shelf in autumn and winter, close to the reef and coast. The current is an important control on larval delivery, and probably suppresses upwelling, which, though little recorded, probably influences primary productivity off Ningaloo Reef (Simpson and d'Adamo, 2001). The northward Ningaloo Current is active in spring and summer (Taylor and Pearce, 1999), and local and shelf-scale hydrodynamic processes probably influence key ecological processes in the region (Simpson and d'Adamo, 2001).

2 METHODS

2.1 STUDY AREAS

Seven different areas were investigated in this study (Fig 1), including three existing Sanctuary Zones and their proposed extensions (Mangrove, Mandu and Osprey Sanctuary Zones), one new Sanctuary Zone (Lighthouse Sanctuary Zone) and three proposed conservation areas (South Muiron, North Muiron and Sunday Island).

In the three current Sanctuary Zones, Mangrove, Mandu and Osprey, research efforts were focused on both lagoonal benthic distribution and offshore communities. Most of the deep-water data was collected in Mandu Sanctuary Zone, but the resulting information can be used as a model for the other two zones and, possibly, for a much larger area of the Ningaloo Reef offshore environments (see Rees et al., 2004).

Regarding the new Sanctuary Zone and Conservation Areas (Lighthouse, North Muiron, South Muiron and Sunday Island), data were mainly collected offshore, between 5 and 15 metres water depth (mwd) and the community survey was conducted not only inside the proposed boundaries of the zones, but also in the adjacent regions, in order to allow comparisons and considerations for future management plans.

2.2 FIELDWORK

Two different fieldwork approaches were used in this study. In the shallow, lagoonal areas, data were collected for mapping purposes, mainly through direct observations in the course of GPS traverses, often supported by underwater photos (see Appendix A). For the deeper, offshore areas, data mainly consisted of towed video-transects, carried out during several benthic survey cruises, between March 2004 and July 2004 (see Appendix A). Very little or no remote sensing imagery is available for these deeper areas and little is known about the benthic community distribution. Detailed substrate and community mapping here remains unachievable at the moment, but the towed video-transects provided useful basic information about the composition, distribution and biodiversity of the benthic communities.

2.3 DATA ANALYSIS AND PROCESSING

2.3.1 Lagoonal areas

Community/substrate maps and descriptions were produced for the three investigated lagoonal areas, Mangrove, Mandu and Osprey Sanctuary Zones, through the following steps (see Appendix A for details):

- Distinct photo patterns and preliminary geomorphic boundaries were identified using hard copy colour aerial photo interpretation, supported by digital remote sensing imagery;
- Ground-truthing GPS traverses and stations were conducted to establish the accuracy of the traced geomorphic boundaries and to assess their connection with the living benthic communities;

- Final boundaries were determined by analysing, comparing and combining all the achieved groundtruthing information with previously available data;
- Using the software ArcView GIS 3.2 (ESRI), community/substrate regions were outlined as polygons on a georeferenced digital image of the Exmouth region to create the ultimate maps;
- Qualitative descriptions of the 12 different benthic communities identified and shown in the maps were compiled, according to the ground-truthing data and to the available information from previous studies (Bancroft and Sheridan, 2000).

2.3.2 Offshore areas

The video footage from the offshore areas (Mandu, Mangrove and Lighthouse Sanctuary Zones; Muiron and Sunday Islands) was analysed using, as a model, the Australian Institute of Marine Science Automated Video Transect Analysis (AVTAS, English et al. 1994). With this method the footage is automatically forwarded through a set number of frames per transect and lifeform categories within each frame are identified under five fixed points on the video monitor. The lifeform categories identified in the frames and their unique abbreviation codes are listed in Table 1.

In this study, due to the variable, and sometimes very poor, quality of the footage, it was decided to analyse a relatively high number of frames in each transect. Besides, since the transects are rather different from one another, both in biological cover and in length, it was decided to keep constant the time interval between the analysed frames (10 seconds) rather than the number of frames per transect. Given the variable quality of the information and its inconsistent distribution in the tape, this method was chosen to capture the greatest amount of useable data.

Although Table 1 was an adequate reference frame for most of the data analysis, some difficulties arose in assigning categories when the video camera was relatively distant from the sea floor. For example, in those circumstances, it was hard at times to distinguish between turf algae, coralline algae and bare rocky substrate. However, given the close association and gradation between these substrate types (turf and coralline algae are usually a continuous or discontinuous veneer on rock substrate), the effect on data quality was minimised by grouping these categories together.

The result of the footage analysis is, for each transect, a matrix of data (Fig 3a), ready to be used for quantitative and statistical processing (see Cassata and Collins, 2004).
A brief, qualitative description of each video-transect, however, was also recorded to summarise its most important physical and biological features and to report any significant annotation (see Cassata and Collins, 2004, Appendix B).

Once the footage analysis was completed, the data were visualized in xls charts to outline the percent cover along the transect (transect cover) of each lifeform category (Fig 2a), the relative percentages of biotic, abiotic and unidentified (W) substrates (Fig 2b; the abiotic substrate also includes coralline and turf algae for the reasons given above) and the detailed composition of the biotic assemblage (Fig 2c).

To show the benthic cover related to the time and position along each transect, different colours for each lifeform category were directly entered into the xls data matrix (Fig 3b). This processing technique is useful for mapping purposes, since it allows correlation of the biological cover to the physical space, outlining sudden changes of the living communities along the transect, which can be directly interpreted as habitat boundaries.

General community descriptions of the offshore habitats, from the reef crest to the shelf edge, were finally compiled to complete the picture of the Ningaloo Reef benthic communities.

3 RESULTS

3.1 COMMUNITY DESCRIPTION

16 benthic communities, and related geomorphic substrates, were identified in the western reef (Mangrove, Mandu and Osprey Sanctuary Zones), 12 in the lagoon and 4 in the offshore environment. A complete list is given in Table 2; for benthic photos see Figs 15-16.

3.1.1 Lagoonal communities

The reef habitats presented here occupy aerially significant zones in the reef system and are recognisable on satellite images and colour aerial photographs (scale 1:20000). They were mainly described through direct groundtruthing and observations in the course of GPS traverses, supported by underwater photos, and are generally listed in order of decreasing distance from the coast, in a geomorphic sequence from the reef crest to the shoreline.

3.1.1.1 a. Coralline algae/coral community (spur and groove outer reef flat; fig 4a)

This very shallow (< 1 m depth) habitat is located at the back of the reef crest, where the high wave energy has created a distinct "spur and groove" morphology, with rubble to sand in the longitudinal channels and rocky substrate on the spurs. The living community essentially consists of coralline algae (cover ≈ 80%) -encrusting dead corals, rocks and rubble- and hard corals (cover ≈ 20%), mainly small and compact tabular *Acropora* colonies, but also massive and sub massive forms, on the rocky substrate.

3.1.1.2 b. Tabular Acropora community (Rocky middle/inner reef flat; Fig 4b)

This habitat is characterised by extensive growth of tabular *Acropora* on a rocky pavement. The cover varies from about 90% in the middle reef flat down to 50% in the inner reef flat.
The water is slightly deeper (about 1m) and generally less turbulent than in the outer reef flat, allowing more luxuriant growth of the plate forms. Although this habitat does not include a wide variety of coral species, it supports a high diversity and abundance of fish and other coral reef fauna.

3.1.1.3 c. Patchy staghorn, massive and submassive coral community (Back reef lagoon; Fig 4c)

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

3.1.1.4 d. Sparse corals and algae community (Lagoonal sand flat; Fig 4d)

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

3.1.1.5 e. Coral "bommies" and algal patches community (Lagoonal and inter-reef sandy depressions; Fig 4e)

Sandy depressions are found either as large deep regions within the lagoon or as small "holes" and narrow channels inside the reef flat. In both cases they are much deeper (3-15 m depth) than the surrounding areas and have steep edges all around, forming a recognisable and distinctive habitat. This habitat consists of a bare, flat, sandy floor, occasionally interrupted by large clumps of brown and green algae –especially common in the lagoonal widest areas- and by small, diverse coral "bommies" occurring along the steep margins and, scattered, throughout the sandy depressions. *Porites* is the dominant species on the seaward escarpments, coming in clusters of flat topped, truncated colonies, up to 4 m across, with tabular or staghorn *Acropora* often growing on top.

3.1.1.6 f. Macroalgal community (Lagoon, shoreward of reef passes; Fig 4f)

Brown algae up to 0.5 meters high (e.g. *Sargassum* spp.) are the dominant group in this habitat, which is best developed shoreward of the reef passes. These large fleshy macroalgae, together with minor red and green algae, typically colonise a subtidal limestone substratum with a sandy cover up to 10 cm thick (Meagher et al., 1980).
Small patches of hard and soft corals, sponges and ascidians can also be found, associated with the algae, in this type of environment.

3.1.1.7 g. Bare sand (Sublittoral sand; Fig 4g)

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

3.1.1.8 h. Turf algae/mollusc/echinoderm community (Sublittoral limestone platform; Fig 4h)

This habitat occurs as a flat limestone substrate, often contiguous with the rocky shoreline, and supports an intertidal and subtidal fauna, mainly made of molluscs (limpets, chitons, small mussels, cowries, giant clams) and echinoderms (sea cucumbers, starfish, sea urchins), with small, isolated hard and soft coral colonies.
Turf algae (mostly green and red algae of low physical stature) typically grow on this type of substrate as well.

3.1.1.9 i. Encrusting algae/gastropod community (Sublittoral alluvial fans; Fig 5i)

A pebbly substrate is found near shore, in front of the mouths of many ephemeral creeks, and it is usually contiguous with a subaerial alluvial fan. This habitat supports the growth of encrusting coralline algae, turf algae and an intertidal/subtidal faunal community which is particularly rich in gastropods (e.g. Littorinidae, Trochidae, Turbinidae).

3.1.1.10 j. Mangrove community (Mangrove coastal swamps)

Although mangroves are not a common element of the Ningaloo Marine Park, they occur in the studied areas both in Mangrove Sanctuary Zone and, as a sporadic presence, in Osprey Sanctuary Zone.

Three species of mangroves have been recorded in these locations: *Avicennia marina*, *Rhizophora stylosa* and *Bruguiera exaristata*, but *Avicennia marina* is definitely the most common and widespread. Mangroves grow in the upper intertidal zone, on a muddy substrate of carbonate silt and clay with interbedded lenses of sand. This habitat supports a fauna of gastropods, crabs, burrowing worms and insects and it also provides sheltered nursery areas for the juveniles of many species of reef fish.

3.1.1.11 k. Mud flat community (Intertidal mud flats; Fig 5k)

Mud flats occur in the lower intertidal zone of low energy environments, where they form from the deposition of mud in sheltered tidal water. In the study areas the mud flat habitat is found seaward of the mangrove community and the substrate is a flat, rocky limestone platform covered by a veneer of silty fine sand. The living community consists of turf algae, growing on the exposed patches of rock, crabs, small bivalves (*Mytilus*, strongly attached to the rock below) and a few other infaunal benthic invertebrates.

3.1.1.12 l. Salt marsh community (Salt marshes)

Salt marshes are transitional areas between land and ocean, occurring along the intertidal shore of low relief and low energy environments. Periodically flooded by tides and storms, they are subject to rapid changes in salinity, temperature, and oxygen availability. Salt marsh plants and animals, therefore, are adapted to harsh, semi-aquatic conditions and saline soils. In the studied areas, the salt marsh habitat occurs landward of the mangroves. The lower marsh zone is regularly flooded by the rising tides, while the higher marsh zone floods only occasionally, during severe storms and unusually high tides.

The salt marsh community is represented by a salt tolerant vegetation of plants and low shrubs -interspersed with bare salt flats- and by a fauna of crabs, insects, worms, invertebrate larvae and bacteria. This habitat is also a nursery ground for large fish larvae and juveniles and supplies food resources for many birds and fish, which move on and off the marsh surface with the tide.

3.1.2 Offshore communities

Several deep-water habitats were described through the towed video-transect analysis, using both quantitative and qualitative data (transect bar charts and descriptions) as a guide. They occupy four large areas between the reef crest and the shelf edge and are here listed in order of increasing depth.

3.1.2.1 m. Coralline algae/coral community (spur and groove reef slope; Fig 5m)

From the reef crest, narrow, deep channels, filled with sand and coral rubble, perpendicularly stretch for about 1 km seaward, gradually becoming wider and shallower along the reef slope. Despite the significant bathymetric range (5-40 m depth), the resulting “spur and groove” morphology provides a substrate for a relatively uniform community.

The dominant coral is tabular *Acropora*, growing in small, compact colonies, but very diverse hard corals (encrusting, branching, massive and submassive) also grow on the rocky spurs, together with soft corals, *Millepora*, sponges and macroalgae.

The total transect cover of this biotic assemblage ranges between 10% and 30%, with the most luxuriant coral growth between 5 and 10 meters depth (transects MD 1 and MD 2, Fig 6).

Coralline algae encrust dead corals and rocks, as well as the coral rubble accumulated in the grooves, with a total transect cover ranging between 20 and 55% (Fig 6: transects MD 1, 2, 3 and AIMS tows 13, 14).

3.1.2.2 n. Algal/gorgonian/sponge community (reef slope to inner shelf; Fig 5n)

This habitat is found at the boundary between the reef slope and the inner shelf, at a depth of about 50m. At the bottom of the reef slope, the substrate is a mixture of sand and rubble, with a few outcropping rocks from the spur and groove reef structure. Between 30 and 40 meters depth, even where hard substrates are still available, hard corals rapidly disappear, gradually replaced by a mixed deep-water benthic community.

Gorgonians and diverse, colourful sponges are the dominant large organisms in this environment (AIMS tows 11 and 12), with minor soft corals, polychaete worms, ascidians, crinoids, sea whips, sea pens and holothurians (total transect cover 5-10%, Fig 6). Besides this macrofaunal community, however, the substrate is also thoroughly covered by a biological assemblage of smaller organisms. The composition of this assemblage (generally identified in the data matrix as TA, turf algae, or AA, algal assemblage; total transect cover up to 90%, Fig 6) could not be estimated in detail from the videos, due to its small scale, but short green algae (including widespread *Halimeda)* and rhodoliths are important constituents.

Besides the availability of hard substrate, this community is also influenced by the presence of deep-water currents, flowing along the bottom of the reef slope, as clearly documented in the videos.

3.1.2.3 o. Sandflat (continental shelf; Fig 5o)

This habitat includes the flat, sandy areas from the bottom of the reef slope to the shelf break, usually between 60 and 120 metres depth (AIMS tows 1, 2, 7, 8, 9, 10 and 15). The substrate is deep sand, rippled and/or bioturbated, possibly mixed with rubble, and the living community is very scattered (transect cover less than 1%, Fig 6), consisting of sea pens, sponges, crinoids, polychaete worms, sea whips, sea urchins and hydroids.

3.1.2.4 p. Sponge community (Outer shelf; Fig 5p)

Sponge "gardens" occur at the outer edge of the continental shelf, at about 150-200 mwd (AIMS tows 3, 4, 5, 6), where the sudden deepening of the sea floor and the presence of bottom and upwelling(?) currents prevent the rocky substrate from being totally covered by sediments.

The benthic community is virtually made of the same organisms found on the shelf, but their density becomes progressively higher (cover up to about 40%) close to the shelf margin, where the substrate is a mixture of sand, mud and gravel, with flat rocks outcropping occasionally. Sponges luxuriantly grow with a range of species, morphologies and sizes (sponge "gardens"), but crinoids, sea whips, sea pens and gorgonians can be locally abundant as well, with minor hydroids and sea urchins. The presence of currents and nutrients also attracts many fish, including rays and sharks, as documented in the videos.

3.2 COMMUNITY DISTRIBUTION

3.2.1 Lagoonal areas

For the studied lagoonal areas (Mangrove, Mandu and Osprey Sanctuary Zones), three GIS detailed habitat maps were generated (Figs 8, 9 and 10), showing the spatial distribution of the benthic communities. A strong correlation between the habitat distribution and the geomorphological structure of the reef has clearly emerged from this study, with elongate belts of distinct substrates occurring parallel to the shoreline and fairly continuously along the reef trend.

Distinct changes across the lagoon, both in substrate and in biological cover, are thus recognisable in all the studied areas. In particular, from the reef crest to the shore, the observed habitat distribution is (Figs 8, 9 and 10): Coralline algae/coral community on the spur and groove outer reef flat (a), Tabular *Acropora* community on the middle and inner reef flat (b), Patchy staghorn, massive and submassive coral community on the backreef lagoon (c) and Sparse corals and algae community on the lagoonal sand flat (d). The shore can be either sandy (Bare sand, g) or rocky, where the last interglacial substrate outcrops as a sublittoral limestone platform (Turf algae/mollusc/echinoderm community, h).

This general structure is now and then interrupted by reef passes, often in association with current or former ephemeral creeks and channels inland. Due to the strong tidal currents and wave energy, limited groundtruthing was undertaken in the reef passes, but strong coral growth on their edges, with recurrent *Porites* "bommies", was documented (Osprey dinghy traverse, D1).

The habitat maps also show a distinct correlation between reef passes and lagoonal macroalgal assemblages, particularly evident in Osprey Sanctuary Zone (Fig 10).

Zones of reef collapse, resulting in deep, sandy, elongated depressions cutting the reef flat in a N-S direction, are common morphological features as well, and luxuriant coral "bommies" usually grow on their steep edges (*Coral "bommies" and algal patches community*).

Although mangroves are not a common element of the Ningaloo Marine Park, they occur in the studied areas both in Mangrove Sanctuary Zone (Fig 8) -where they occupy a rather large section of the coast, between Low Point and Mangrove Bay- and in Osprey Sanctuary Zone (Fig 10) –where they are just a sporadic presence on the Yardie Creek banks.

Another two habitats, *Mud flat* (k) and *Salt marsh* (l) are only represented in Mangrove Sanctuary Zone (Fig 8) and they are respectively found seaward and landward of the *Mangrove community* (j).

Except for these three habitats, the differences in the community distribution between the three studied areas appear to be mainly due to the different lagoon width. Not all the benthic habitats, indeed, are equally compressed or expanded in accordance with the total lagoon extent. The sand flat habitat, for example, seems to absorb most of the lagoonal width variability, totally disappearing where the lagoon becomes very narrow (for instance at Oyster Stacks, in Mandu Sanctuary Zone, Fig 9) and broadening up to 2 km where the lagoon is much wider (for example in Mangrove Sanctuary Zone, Fig 8). Depending on the availability of sandy substrates, the *Macroalgal community* also follows this trend, reaching its best growth only in the widest and more open areas of the lagoon. The reef flat habitats, on the contrary, are nearly always present (excluding reef passes) and their total breadth does not change much in relation to the lagoon width, ranging from about 200 to 700 meters.

3.2.2 Offshore areas

The results of the towed video-transect analysis from the studied offshore areas (Mandu Sanctuary Zone proposed extension, new Lighthouse Sanctuary Zone, proposed Conservation Areas at North Muiron, South Muiron and Sunday Island) have been synthetised in bar charts, showing, for each transect, the percent cover of all the biotic and abiotic variables (Figs 6, 12, 14, 15 and 16). Their spatial position is shown in location maps (Figs 9, 11 and 13). Comparing graphs and location maps, basic information about the community distribution can be deduced.

3.2.2.1 Mandu Sanctuary Zone extension

Data from this area (Fig 9) cover a considerable bathymetric range, between 5 and 200 meters depth, with 18 video-transects analysed (AIMS tows 1-15 and MD 1-3, Fig 6). This is the only studied area where data from depths greater than 20 m were available. The information collected through the video analysis was used to describe four deep-water benthic communities (see § 3.1.2.), whose spatial distribution, from the reef crest to the shelf edge, mainly depends on the depth.

The shallowest described habitat (*Coralline algae/coral community*, m) is located seaward of the reef crest, on the “spur and groove” reef front, and is biologically and morphologically continuous with the *Coralline algae/coral community* (a) of the outer reef flat. It is represented by 5 quite homogeneous video-transects: MD 1, 2, 3 and AIMS tows 13, 14, collected between 5 and 40 mwd.

On the inner shelf, at the bottom of the reef slope (around 50 mwd), a luxuriant *Algal/gorgonian/sponge community* (n) is recorded by the two AIMS tows 11 and 12.

A nearly bare *Sandflat* (o, with living transect cover < 1%) stretches on the continental shelf, between about 60 and 120 mwd (AIMS tows 1, 2, 7, 8, 9). Offshore from the reef passes, however, where there is no hard substrate available for corals to grow, this habitat extends up to much shallower water (AIMS tows 10 and 15).

Finally, a *Sponge community* (p) occurs on the outer continental shelf, between 120 and 200 mwd, with most luxuriant growth and best cover close to the shelf edge (150-200 mwd). Four AIMS tows (3, 4, 5 and 6) document this peculiar environment.

3.2.2.2 Lighthouse area

Data from the Lighthouse area consist of 21 towed video-transects, organised in seven clusters (Fig 11). With the exception of one cluster (transects LH 019, 020 and 021), carried out perpendicularly to the shoreline, between 4 and 13 mwd, each cluster includes three short (about 200 m) transects conducted along the contour lines, at depths of 5, 10 and 15 metres. The video-transects are located between around 114°7' and 114°10.5' longitude, expressly falling half in and half outside the proposed new Lighthouse Sanctuary Zone, in order to allow comparisons and considerations for future management plans.

As clearly shown by the aerial photos, the reef structure of this northern area of the Cape Range Peninsula is rather different from the typical morphology of the western reef. There is no clear reef crest and, consequently, no sheltered lagoon at its back. A rock substrate with a sand veneer (the relict reef platform from the Last Interglacial reef, exposed in shore platforms) stretches seaward from the shoreline for several hundreds of metres, reaching 1 km width offshore of the North West Cape, supplying a widespread hard substrate for the current coral communities.

This different geomorphological structure reflects a different biological structure as well. Compared with the communities observed at the same depth, on the western side of the Ningaloo Reef (video-transects MD 1, 2, 3 and MG 1, 2, 3) a scarcity of hard corals, and in particular of tabular *Acropora* (dominant in the western reef terrain) is immediately evident, as well as unusual abundance of soft corals and sponges (see Fig 12).

According to the results of the video-transect analysis (Fig 12), the investigated area can be divided into three different zones:

- An eastern sector, highly exposed to swell wave impact and more or less coincident with the proposed Sanctuary Zone, represented by transects LH 001-002, 003, 004, 005, 006, 007, 008 and 010. The substrate is essentially a sandy rock platform, mostly covered by a veneer of coralline and/or turf algae, and the benthic community consists of few hard corals (generally disappearing below 10 mwd), surrounded by organisms usually found in much deeper water, such as soft corals, sea whips, sponges and ascidians. The maximum biodiversity was found at about 10 mwd, where shallow and deep-water organisms coexist in similar proportions.

- A central sector, sheltered and sandy, represented by transects LH 009, 011, 012, 013, 014 and 015, located offshore from a narrow Last Interglacial reef platform. Sea pens, short green algae (*Halimeda*, *Caulerpa*) and seagrass (*Halophila*?) grow on this deep, rippled sand substrate, with very low percent cover and biodiversity.

- A western sector, documented by transects LH 016 and 017, showing a sandy rock platform, mostly covered by coralline and/or turf algae. The benthic community consists of scattered soft corals, sponges and echinoderms (starfish, holothurians and sea urchins, locally very abundant), with a few hard corals on the shallower rocks, and sea whips, ascidians and short green algae in the deeper areas.

3.2.2.3 Muiron Islands

A total of 29 video-tows, collected between 5 and 15 mwd, were analysed from the Muiron Islands (Fig 13) including 12 short (< 400 m) transects from around North Muiron (NM-out 001-012), 12 short (< 400 m) transects from South Muiron (SM-out 001-012) and 5 very long (up to 3 km) transects falling inside the proposed boundary of South Muiron Conservation Area (SMS 001-005).

Although the Muiron Islands are structurally a continuation of the Cape Range Peninsula, their different geomorphic structure and geographical position are responsible for the formation of a completely different marine environment, when compared with the adjacent Ningaloo Reef.

The Muiron Islands are located at the northwest corner of the Exmouth Gulf, whose eastern shoreline consists of an extensive system of mangroves and mud flats. Their proximity to the gulf results in an increased turbidity of the water around the islands, deeply influencing the faunal communities and likely accounting for their great richness in octocorals (Hutchins et al., 1996). The whole area, indeed, is dominated by soft coral communities, both in shallow and in deeper waters (Fig 5, q and r).

The Muirons lie in a location subjected to strong currents in the south west and large ocean swell predominantly from a westerly direction (Hutchins et al., 1996). On the exposed western side of the islands there is neither a clear reef crest nor a sheltered lagoon, but reefs along the coast range from low flat limestone structures offshore to a more dissected system, forming gutters and spurs, close to the coastline. Low limestone cliffs and rocky intertidal platforms, interspersed with sandy beaches, form the shores of this western sector.

On the east coast, more sheltered, there are sandy beaches backed by dunes, and fringing reefs form shallow lagoons, up to 1 km wide, running inshore along both the islands. The reefs provide some protection from easterly swells, but the lagoons are generally less protected than those of the nearby Ningaloo reef (Hutchins et al., 1996).

The video-footage analysis (Fig 14 and 15) outlined a difference in coral distribution and cover between the western and the eastern sides of the islands, as expected due to their different exposure. The high-energy western sector has, in the range of depth investigated (5 to 15 mwd) a much higher coral cover (up to 55% in transect NM-out 003, Fig 15) compared to the east side, where rich benthic communities were only found at 5 mwd, with large coral “bommies” on a sandy floor, while the deeper sites showed poor to very poor faunal assemblages (Figs 14 and 15). It has to be considered, however, that the eastern lagoonal areas, which have been described as very diverse and rich, both in hard and soft corals (Hutchins et al., 1996), were not video sampled because of their shallow location. It is highly likely, indeed, that the sheltered east side has its best coral growth above the 5 mwd contour line.

On the west side of North Muiron Island, high coral cover (>25%) was observed at any depth, with a balance of hard and soft corals at 5 mwd, rapidly shifting towards deeper luxuriant communities dominated by gorgonians and sea whips, with scattered foliose hard corals and sponges.

A slightly different trend was recorded at the west of South Muiron, where the best coral growth seems to be concentrated around the 10 mwd contour line. At 5 mwd most of the widespread hard substrates are colonised by coralline, turf and macro algae, with minor soft and hard corals; while at about 15 mwd an abrupt change in substrate, from rocky to sandy, causes a sudden shift from luxuriant gorgonian and sea whip communities to bare, rippled sand with scattered sea pens and algae.

Two clusters of transects (NM-out 007, 008, 009 and SM-out 010, 011, 012), at the north east and south west tips of the islands, deserve special attention, because they do not seem to follow any of the described trends. Those clusters are both characterised by increasing biodiversity and living cover in deep waters, with well developed benthic communities at 15 mwd: coralline algae, short green algae (*Halimeda*, *Caulerpa*, *Udotea*), encrusting sponges and hydroids cover and stabilise a thin sandy bottom overlying a flat rocky pavement, and gorgonians, sea whips, fleshy soft corals, crinoids, sponges, foliose hard corals, starfish, holothurians and ascidians luxuriantly grow on it. Transect NM-out 009, in particular, is absolutely amazing and this site definitely deserves to be preserved.

3.2.2.4 Sunday Island Conservation Area

Data from Sunday Island Conservation Area consist of seven long (about 1 km) video-transects, conducted along the contour lines, at depths ranging between 4 and 11 metres (Fig 15).

The benthic communities around Sunday Island are similar to those found at the Muiron Islands, and soft corals are again the dominant living organisms. A higher turbidity, however, was noticed in the videos around Sunday Island and this is likely responsible for the much lower coral growth recorded in this area.

The data analysis (Fig 16) clearly shows a different biological trend between the northwestern environment (transects SI 001-004) and the southeastern environment of the island (SI 005-007), with significant rock outcrops and coral “bommies” limited to the northwestern side. Hard and soft corals are just a sporadic presence on the southeastern side, dominated by algae (both turf and macroalgae), sponges, sea whips and gorgonians, with minor giant clams and sea urchins in the shallow waters (SI 005), and holothurians, sea pens, ascidians and zoanthids in the deeper areas (SI 007).

The northwestern side is relatively richer in hard and soft corals, but their total transect cover is always less than 10%, despite the availability of hard substrate; rocks, indeed, often look bare or encrusted by coralline/turf algae only.

4 DISCUSSION AND CONCLUSIONS

Through a combination of remote sensing analysis, ground-truthing in shallow water and video transects in shallow to deep water, this study has provided both qualitative and quantitative data on habitat mapping at Ningaloo Reef, which will be of use in identifying, maintaining and managing biodiversity within and near the Sanctuary Zones investigated. Data on the shallow lagoon communities has utilised and built upon previous reconnaissance studies, but in large measure the descriptions provided of the deeper water substrates are new.

The study has identified a strong correlation between geomorphological structure and biological cover in the northern Ningaloo Reef, not only in the lagoonal areas (where 12 different biological communities and relative substrates have been identified), but also offshore from the reef crest, where the availability of Last Interglacial hard substrates significantly effects the current benthic communities down to as much as 50 mwd. This control is likely to be of regional significance (see Collins et al., 2003).

Reef passes are responsible for water and nutrient exchanges as well as for the energy gradient throughout the lagoon. They were probably initially incised into the reef structure by channels, during Quaternary sea-level lowstand periods, as suggested by their link to current or relict ephemeral creeks, and fresh water inputs occur in those locations even now, following run-off events. Groundwater seeps probably occur preferentially along the passes as well, where fresh water inputs would mix with the active marine circulation, contributing to a more varied environment inshore of reef passes, and perhaps accounting for the relative absence of corals and high concentration of macroalgae in these lagoon locations.

In the actual channels forming the reef passes, only limited groundtruthing was carried out due to the strong tidal currents and wave energy, but the data obtained does not match some of the previous observations (see Bancroft & Sheridan, 2000), which classified these areas as rich coral growth habitats. Usually, deeper parts of the reef passes seem to be predominantly sandy areas colonised by macroalgae, or more mobile sandy substrates influenced by tidally driven sediment transport, with rich coral growth confined to the steep, rocky edges of the channels. More groundtruthing should be undertaken in these critical areas.

Substrate controls in the western fringing reef environments (Mangrove, Mandu, Osprey Sanctuary Zones) include interactions between inherited and modern reef morphology and wave-pumping, tidal and wind-driven circulation. The spur and groove terrain has a wave-influenced substrate, with active sand and coral rubble transport in the grooves, only colonised by coralline algae, and current-swept spurs, where diverse, flattened and robust corals are the most successful.

The island environments (Muiron and Sunday Islands) have different conditions of turbidity and wave exposure, depending on prevailing weather conditions, and communities are mixed, with hard and soft corals as well as short green algae (*Halimeda*, *Caulerpa*), sponges, sea whips and gorgonians.

The Lighthouse Sanctuary Zone, on the North West Cape, lacks a well differentiated lagoon and reef crest, but is frequently dominated by rocky, encrusted pavements. This area has less hard corals and more soft corals than most of the western reef and it is somewhat transitional between the Muirons and the western reef.

The lagoonal and offshore benthic communities identified in Mandu Sanctuary Zone, which is the most deeply investigated shelf area, are more or less representative of most of the western reef; but they have little affinities with communities found around the northern islands, essentially dominated by soft corals. This difference is probably attributable to different wave energy conditions, since the western reef is much more exposed to both swell and storm waves. Of the deeper shelf communities the prolific "sponge gardens" are typical of those described (see Collins, 1988; James et al, 1999) in regional studies of the western Australian shelf.

5 ACKNOWLEDGEMENTS

This research was financially supported by Curtin University (Department of Applied Geology), the Marine Conservation Branch (CALM) of Fremantle, the Department of Conservation and Land Management (CALM) of Exmouth and a postgraduate scholarship from the University of Rome "La Sapienza". The help and assistance of the staff from Curtin University of Technology, Exmouth CALM office, Fremantle MCB office and the Australian Institute of Marine Science (Fremantle office) are gratefully acknowledged, and sincere gratitude for help and support is expressed in particular to Claire Hahesy, Ben Fitzpatrick, Nick D'Adamo, Kevin Bancroft and Luke Smith. The advice and assistance of colleagues in IGCP 464 is gratefully acknowledged. The first author also extends thanks to Francesco Chiocci, for making her trip to Australia possible.

6 REFERENCES

Bancroft, K.P. and Sheridan, M.W. (2000). The major habitats of Ningaloo Marine Park and the proposed southern extensions. Report: MMS/PI/NMP&NSE-26/2000. October 2000. Marine Conservation Branch, Department of Conservation and Land Management, Fremantle, Western Australia.

CALM (Department of Conservation and Land Management) & MPRA (Marine Parks & Reserves Authority) (2004). Ningaloo Marine Park Draft Management Plan and Indicative Management Plans for the Extension to the Existing Park and the Muiron Islands Marine Management Area.

Cassata, L. and Collins, L.B. (2004). Final report: Coral reef communities, habitats and substrates in and near Sanctuary Zones of Ningaloo Marine Park. Technical Report: MMS/NIN/NMP,WPO-78/2004, December 2004. Marine Conservation Branch, Department of Conservation and Land Management.

Collins, L.B. (1988). Sediments and History of the ropersonal ttenest Shelf, a Swell-Dominated, non-Tropical Carbonate margin. In Nelson, C.S., ed: Non-tropical shelf carbonates, modern and ancient Sedimentary Geology, 60: 15-49.

Collins, L.B., Zhu, Z.R., Wyrwoll, K.-H., Eisenhauer, A. (2003). Late Quaternary structure and development of the northern Ningaloo Reef, Australia. Sedimentary Geology 159, 81-94.

D'Adamo, N. and Simpson, C.J. (2001). Review of the oceanography of Ningaloo Reef and adjacent waters. Technical Report:MMS/NIN/NIN-38/2001. Marine Conservation Branch. Department of Conservation and Land Management, Fremantle, Western Australia.

English, S., Wilkinson, C. and Baker, V. (1994). Survey manual for tropical marine resources. ASEAN-Australian Marine Science project: Living Coastal Resources. AIMS Townsville.

Hatcher, B.G. (1991). Coral reefs in the Leeuwin Current-an ecological perspective. Journal of the Royal Society of Western Australia, 74, 115-127.

Hearn, C.J., Hatcher B.G., Masini, R.J. and Simpson, C.J. (1986). Oceanographic processes on the Ningaloo coral reef, Western Australia. Environmental Dynamics Report ED-86-171. Centre for Water Research, University of Western Australia, Nedlands, Western Australia, 6009.

Hutchins, J.B., Slacksmith, S.M., Bryce, C.W., Morrison, S.M. and Hewitt, M.A. (1996). Marine biological survey of the Muiron Islands and the eastern shore of Exmouth Gulf, Western Australia. Pp 135 Western Australian Museum, Perth Western Australia.

James, N.P., Collins, L.B., Hallock, P., Bone. Y. (1999). Sub-Tropical Carbonates in a Temperate Realm: Modern Sediments on the Southwest Australian Shelf. Journal of Sedimentary Research, 69: 1297-1321.

Meagher, T.D. and associates (1980). Biology of the Ningaloo Reef around Low Point, North West Cape. (Unpublished report).

Morgan, G.J. and Wells, F.E. (1991). Zoogeographic provinces of the Humboldt, Benguela and Leeuwin Current systems. Journal of the Royal Society of Western Australia, 74, 59-70.

Pearce, A.E. & Griffit, R.W. (1991). The mesoscale structure of the Leeuwin Current, Journal of Geophysical Research, C96, 16739-16757.

Rees, M., Heyward, A., Cappo, M., Speare, P. and Smith, L. (2004). Ningaloo Marine Park-Initial Survey of Seabed Biodiversity in Intermediate and Deeper Waters (March 2004). Australian Government, Australian Institute of Marine Science and Natural Heritage Trust.

Taylor, J.G. and Pearce, A.F. (1999). Ningaloo Reef currents: implications for coral spawn dispersal, zooplankton and whale shark abundance. Journal of the Royal Society of Western Australia, 82: 57-65.

Veron, J.E.N. (1995). Corals in Space and Time; the Biogeography and evolution of the Scleractinia. University of New South Wales Press, Sydney, 321 p.

7 TABLES

Table 1. Lifeform categories and abbreviation codes (from English et al. 1994).

Lifeform		Code
Dead Coral		DC
Dead Coral with Algae		DCA
Acropora	Branching	ACB
	Encrusting	ACE
	Submassive	ACS
	Digitate	ACD
	Tabular	ACT
Non-Acropora	Branching	CB
	Encrusting	CE
	Foliose	CF
	Massive	CM
	Submassive	CS
Heliopora		CHL
Millepora		CME
Soft Coral		SC
Sponge		SP
Zoanthids		ZO
Others		OT
Sea grasses	Halophila	HALO
Algae	Algal Assemblage	AA
	Halimeda	HA
	Macroalgae	MA
	Turf Algae	TA
	Coralline Algae	CA
Abiotic	Sand	S
	Rubble	R
	Rock	RCK
	Water/unidentified	W

Table 2. List of the 16 benthic communities, and related geomorphic substrates, identified in the western Ningaloo Reef.

	Benthic community	Geomorphic substrate
a	Coralline algae/coral community	Spur and groove outer reef flat
b	Tabular *Acropora* community	Rocky middle/inner reef flat
c	Patchy staghorn, massive and submassive coral community	Back reef lagoon
d	Sparse corals and algae community	Lagoonal sand flat
e	Coral "bommies" and algal patches community	Lagoonal and inter-reef sandy depressions
f	Macroalgal community	Lagoon, shoreward of reef passes
g	Bare sand	Sublittoral sand
h	Turf algae/mollusc/echinoderm community	Sublittoral limestone platform
i	Encrusting algae/gastropod community	Sublittoral alluvial fans
j	Mangrove community	Mangrove coastal swamps
k	Mud flat community	Intertidal mud flats
l	Salt marsh community	Salt marshes
m	Coralline algae/coral community	Spur and groove reef slope
n	Algal/gorgonian/sponge community	Reef slope to inner shelf
o	Sandflat	Continental shelf
p	Sponge community	Outer shelf

8 FIGURES

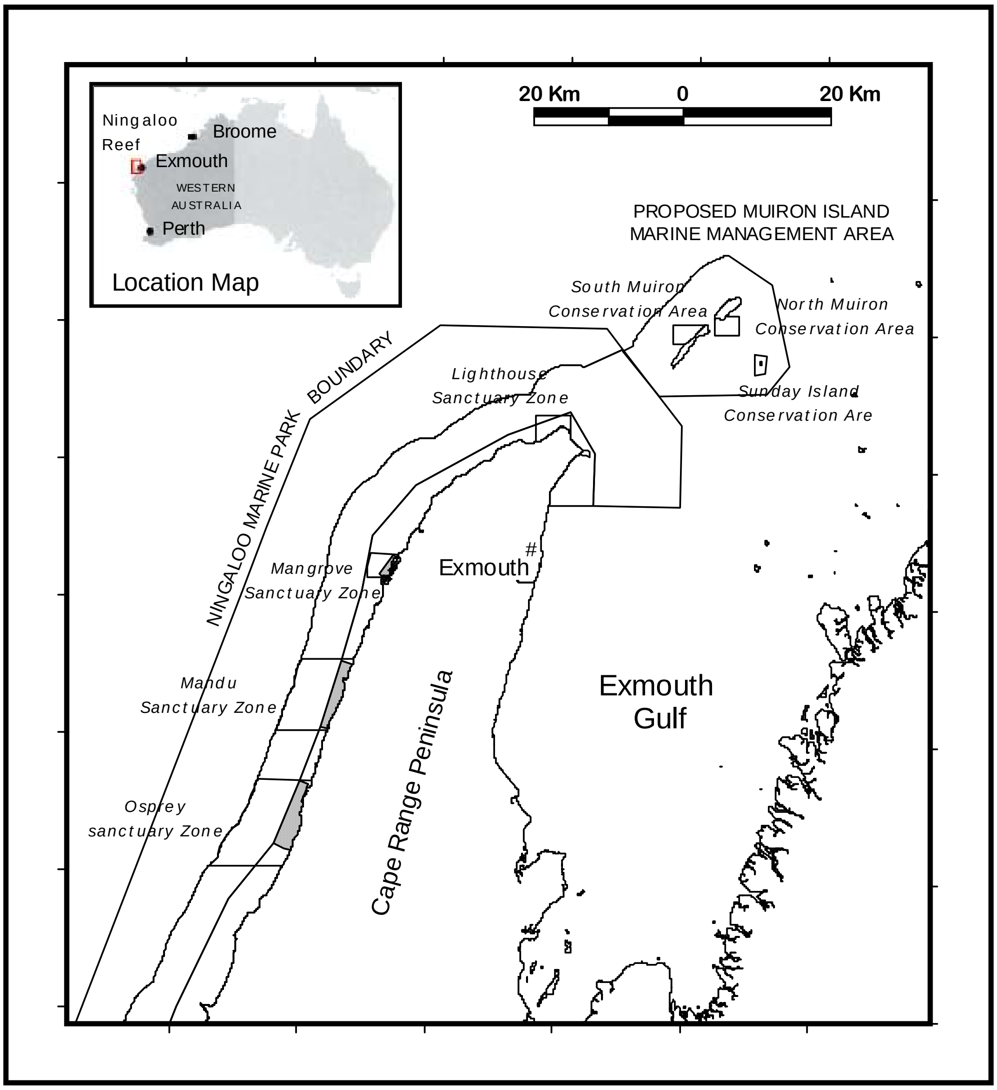

Figure 1. Map of the Cape Range Peninsula, displaying the location of the studied areas: Osprey, Mandu, Mangrove, Lighthouse Sanctuary Zones and South Muiron, North Muiron, Sunday Island Conservation Areas.

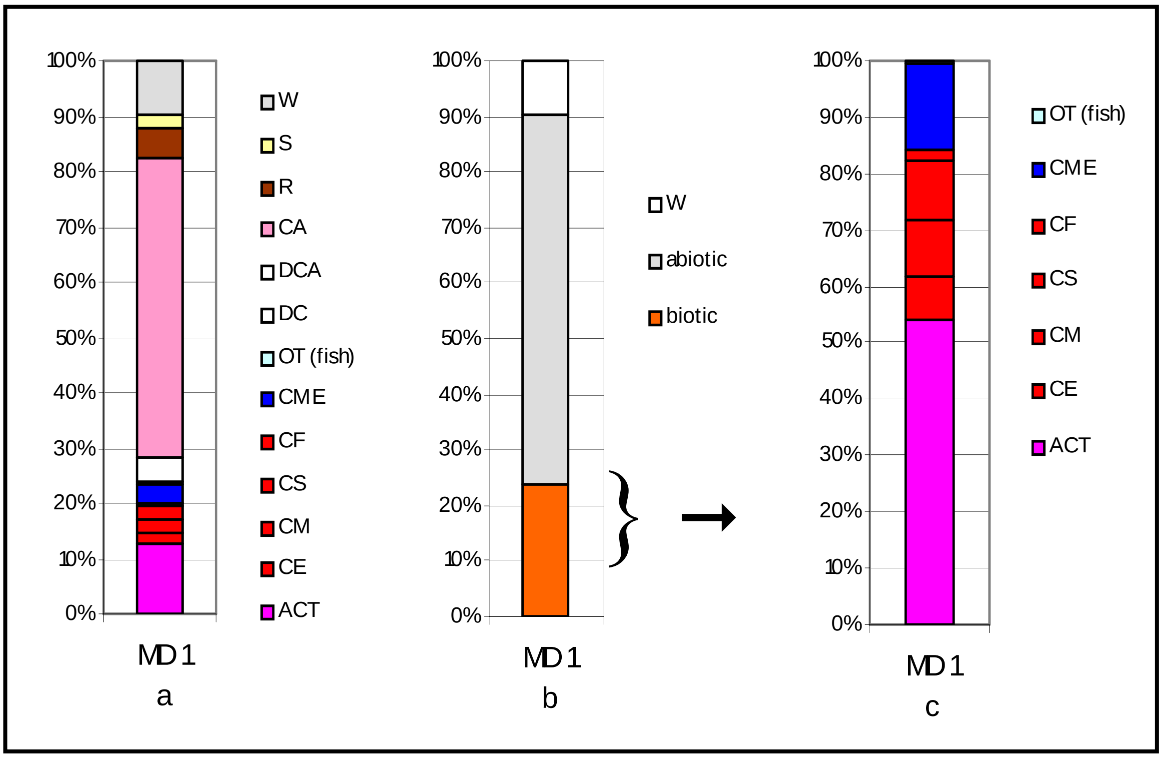

Figure 2. Example of the three types of bar charts produced for each video-transect, showing the percent transect cover of each lifeform category (a), the relative percentages of biotic, abiotic and unidentified (W) substrates (b) and the detailed percent composition of the biotic assemblage (c).

LIGHTHOUSE 005 (29/7/04)

STOP	time code	A	B	C	D	E	Substrate
1	00-30-20-00	SC	OT	W	SP	SP	RCK
2	00-30-30-00	TA	TA	TA	TA	TA	RCK
3	00-30-40-00	CA	CA	CA	CM	CA	RCK
4	00-30-60-00	TA	TA	TA	TA	TA	RCK
5	00-31-00-00	CA	CA	OT	OT	OT	RCK
6	00-31-10-00	TA	TA	TA	SC	SC	RCK
7	00-31-20-00	TA	TA	TA	TA	TA	RCK
8	00-31-30-00	DCA	DCA	CA	CA	CA	RCK
9	00-31-40-00	TA	TA	TA	TA	SC	RCK/S
10	00-31-60-00	W	W	W	W	W	RCK
11	00-32-00-00	SC	TA	TA	TA	TA	RCK
12	00-32-10-00	TA	TA	TA	TA	OT	RCK
13	00-32-20-00	ACT	ACT	TA	TA	TA	RCK
14	00-32-30-00	CA	CA	CA	CA	CA	R
15	00-32-40-00	CA	CA	CA	CA	CA	RCK
16	00-32-60-00	CE	CA	CA	SC	TA	RCK
17	00-33-00-00	CA	SC	CA	SC	CA	RCK
18	00-33-10-00	CA	CA	CA	SC	R	RCK/S
19	00-33-20-00	DCA	W	CA	CA	CA	RCK
20	00-33-30-00	CA	CA	CA	CA	CA	RCK
21	00-33-40-00	CA	CA	CA	CM	CA	RCK
22	00-33-60-00	CE	ACT	ACT	SC	SC	RCK
23	00-34-00-00	CA	CA	CA	CA	CA	RCK/S
24	00-34-10-00	CA	CA	CA	CA	CA	RCK/S
25	00-34-20-00	ACT	CA	CA	CA	CA	RCK
26	00-34-30-00	CA	CA	CA	CA	CA	RCK
27	00-34-40-00	CA	CA	CA	CA	SC	RCK
28	00-34-60-00	CA	CA	CA	CA	CA	RCK
29	00-35-00-00	CA	DCA	CA	CA	CA	RCK
30	00-35-10-00	CE	CA	CA	CA	CA	RCK
31	00-35-20-00	CA	ACT	CA	SC	CA	RCK
32	00-35-30-00	CA	CA	TA	W	TA	RCK
33	00-35-40-00	CA	CA	CA	CA	CA	RCK
34	00-35-60-00	CA	CA	ACT	CA	SC	RCK
35	00-36-00-00	CA	CA	CA	CA	CA	RCK
36	00-36-10-00	CA	CA	CA	CA	DCA	RCK

a

LIGHTHOUSE 005 (29/7/04)

STOP	Time code	A	B	C	D	E	Substrate
1	00-30-20-00	SC	OT	W	SP	SP	RCK
2	00-30-30-00	TA	TA	TA	TA	TA	RCK
3	00-30-40-00	CA	CA	CA	CM	CA	RCK
4	00-30-60-00	TA	TA	TA	TA	TA	RCK
5	00-31-00-00	CA	CA	OT	OT	OT	RCK
6	00-31-10-00	TA	TA	TA	SC	SC	RCK
7	00-31-20-00	TA	TA	TA	TA	TA	RCK
8	00-31-30-00	DCA	DCA	CA	CA	CA	RCK
9	00-31-40-00	TA	TA	TA	TA	SC	RCK/S
10	00-31-60-00	W	W	W	W	W	RCK
11	00-32-00-00	SC	TA	TA	TA	TA	RCK
12	00-32-10-00	TA	TA	TA	TA	OT	RCK
13	00-32-20-00	ACT	ACT	TA	TA	TA	RCK
14	00-32-30-00	CA	CA	CA	CA	CA	R
15	00-32-40-00	CA	CA	CA	CA	CA	RCK
16	00-32-60-00	CE	CA	CA	SC	TA	RCK
17	00-33-00-00	CA	SC	CA	SC	CA	RCK
18	00-33-10-00	CA	CA	CA	SC	R	RCK/S
19	00-33-20-00	DCA	W	CA	CA	CA	RCK
20	00-33-30-00	CA	CA	CA	CA	CA	RCK
21	00-33-40-00	CA	CA	CA	CM	CA	RCK
22	00-33-60-00	CE	ACT	ACT	SC	SC	RCK
23	00-34-00-00	CA	CA	CA	CA	CA	RCK/S
24	00-34-10-00	CA	CA	CA	CA	CA	RCK/S
25	00-34-20-00	ACT	CA	CA	CA	CA	RCK
26	00-34-30-00	CA	CA	CA	CA	CA	RCK
27	00-34-40-00	CA	CA	CA	CA	SC	RCK
28	00-34-60-00	CA	CA	CA	CA	CA	RCK
29	00-35-00-00	CA	DCA	CA	CA	CA	RCK
30	00-35-10-00	CE	CA	CA	CA	CA	RCK
31	00-35-20-00	CA	ACT	CA	SC	CA	RCK
32	00-35-30-00	CA	CA	TA	W	TA	RCK
33	00-35-40-00	CA	CA	CA	CA	CA	RCK
34	00-35-60-00	CA	CA	ACT	CA	SC	RCK
35	00-36-00-00	CA	CA	CA	CA	CA	RCK
36	00-36-10-00	CA	CA	CA	CA	DCA	RCK

b

Figure 3. Example of one data matrix resulting from the video-transect analysis (a). Different colours for each lifeform category were subsequently entered into the matrix (b) to outline sudden changes of the living communities along the transect.

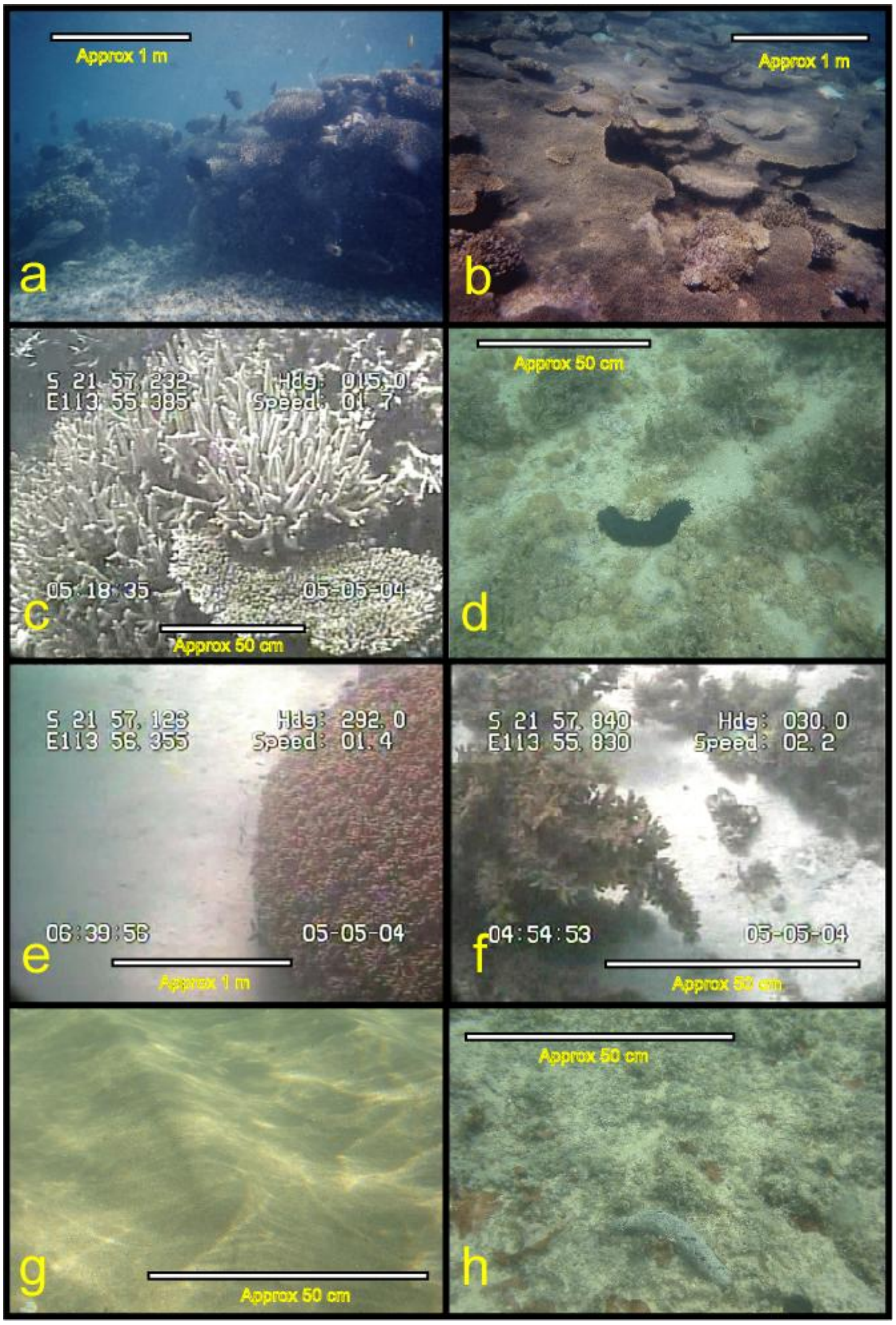

Figure 4. Plate of underwater photos representing the mapped and described benthic communities: a) Coralline algae/coral community (spur and groove outer reef flat), from Mandu S.Z. (MD-S3); b) Tabular Acropora community (rocky middle/inner reef flat), from Mandu S.Z. (MD-S2); c) Patchy staghorn, massive and submassive coral community (backreef lagoon), from Mangrove S.Z. (MG 5); d) Sparse corals and algae community (lagoonal sand flat), from Mandu S.Z. (shoreline station 9); e) Coral "bommies" and algal patches community (lagoonal and inter-reef sandy depressions), from Mangrove S.Z. (MG 6); f) Macroalgal community (lagoon, shoreward of reef passes), from Mangrove S.Z. (MG 4); g) Bare sand (sublittoral sand) from Mandu S.Z. (shoreline station 1); h) Turf algae/mollusc/echinoderm community (sublittoral limestone platform), from Mandu S.Z. (shoreline station 14). Bars are only approximate and indicate foreground scale.

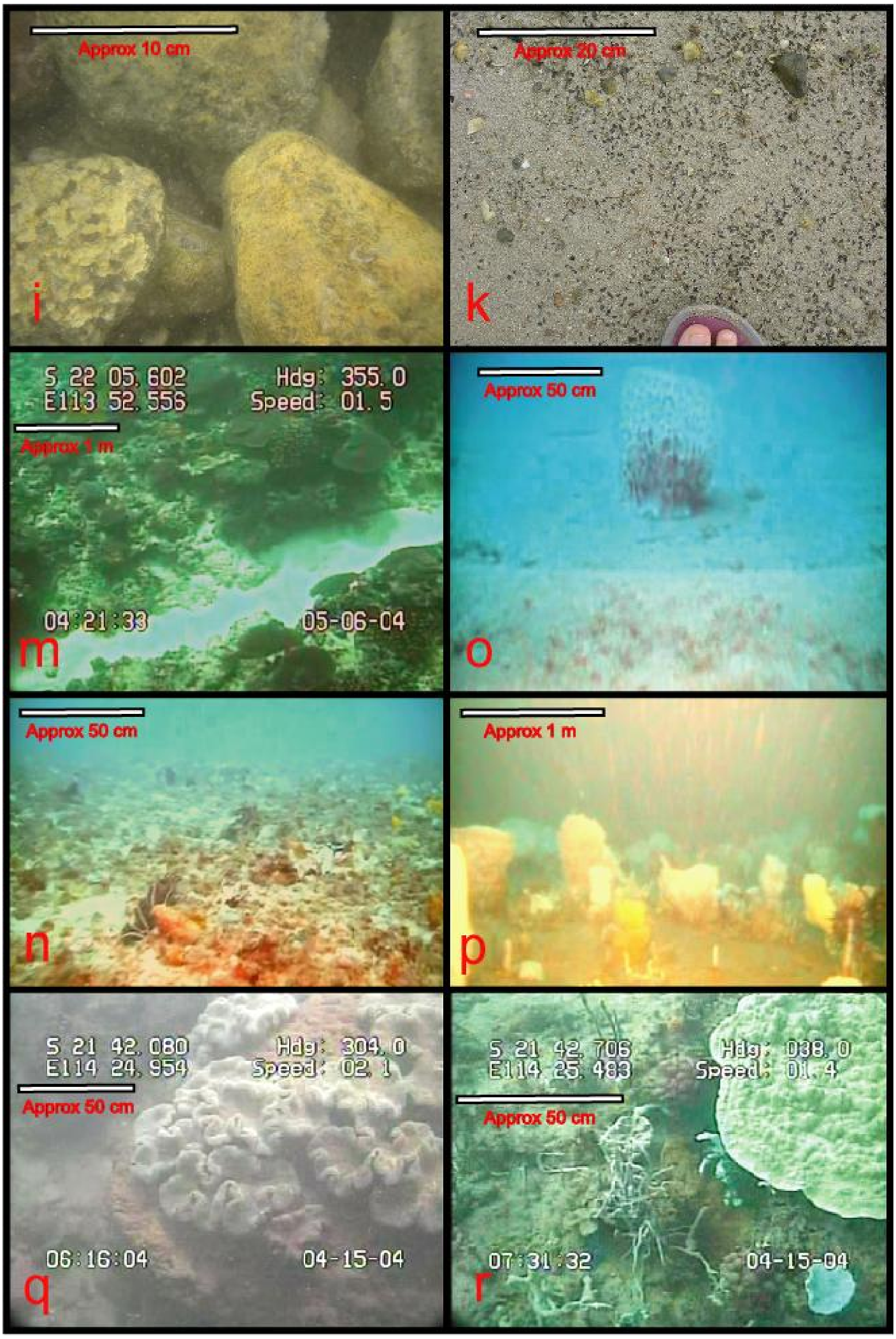

Figure 5. Plate of underwater photos representing the mapped and described benthic communities: i) Encrusting algae/gastropod community (sublittoral alluvial fans), from Mandu S.Z. (shoreline station 17); k) Mud flat community (mud flats), from Mangrove S.Z. (shoreline station 6); m) Coralline algae/coral community (spur and groove reef slope), from Mandu S.Z. (MD 1); n) Algal/gorgonian/sponge community (reef slope to inner shelf), from Mandu S.Z. (AIMS tow 11); o) Sandflat (continental shelf), from Mandu S.Z. (AIMS tow 9); p) Sponge community (outer shelf), from Mandu S.Z. (AIMS tow 3); q) Shallow soft coral community, from Sunday Island (SI 003); r) Deeper soft coral community, from Sunday Island (SI 004). Bars are only approximate and indicate foreground scale.

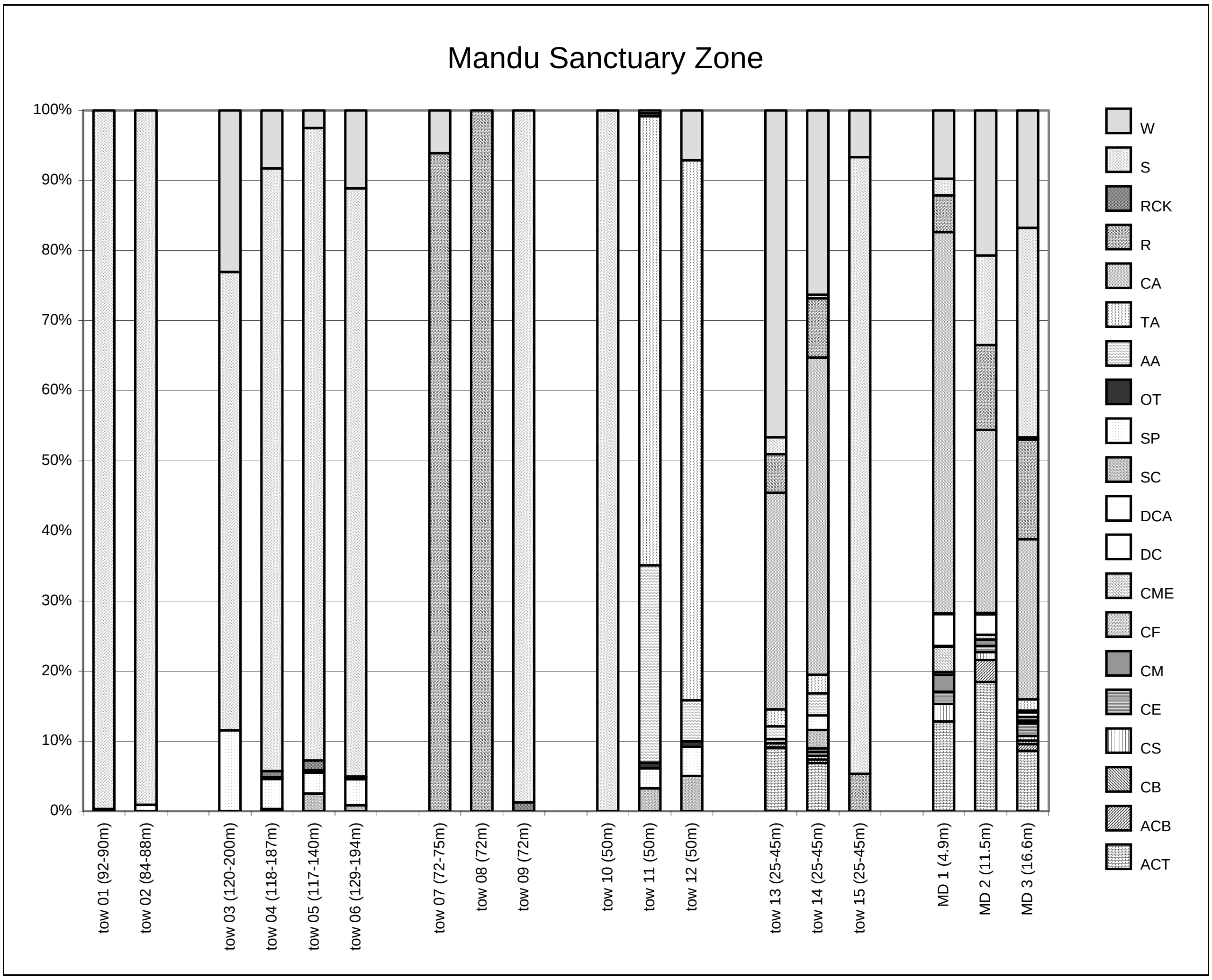

Figure 6. Percent transect cover of each lifeform category in the 18 towed video-transects collected in Mandu Sanctuary Zone. See Table 1 for abbreviation code legend.

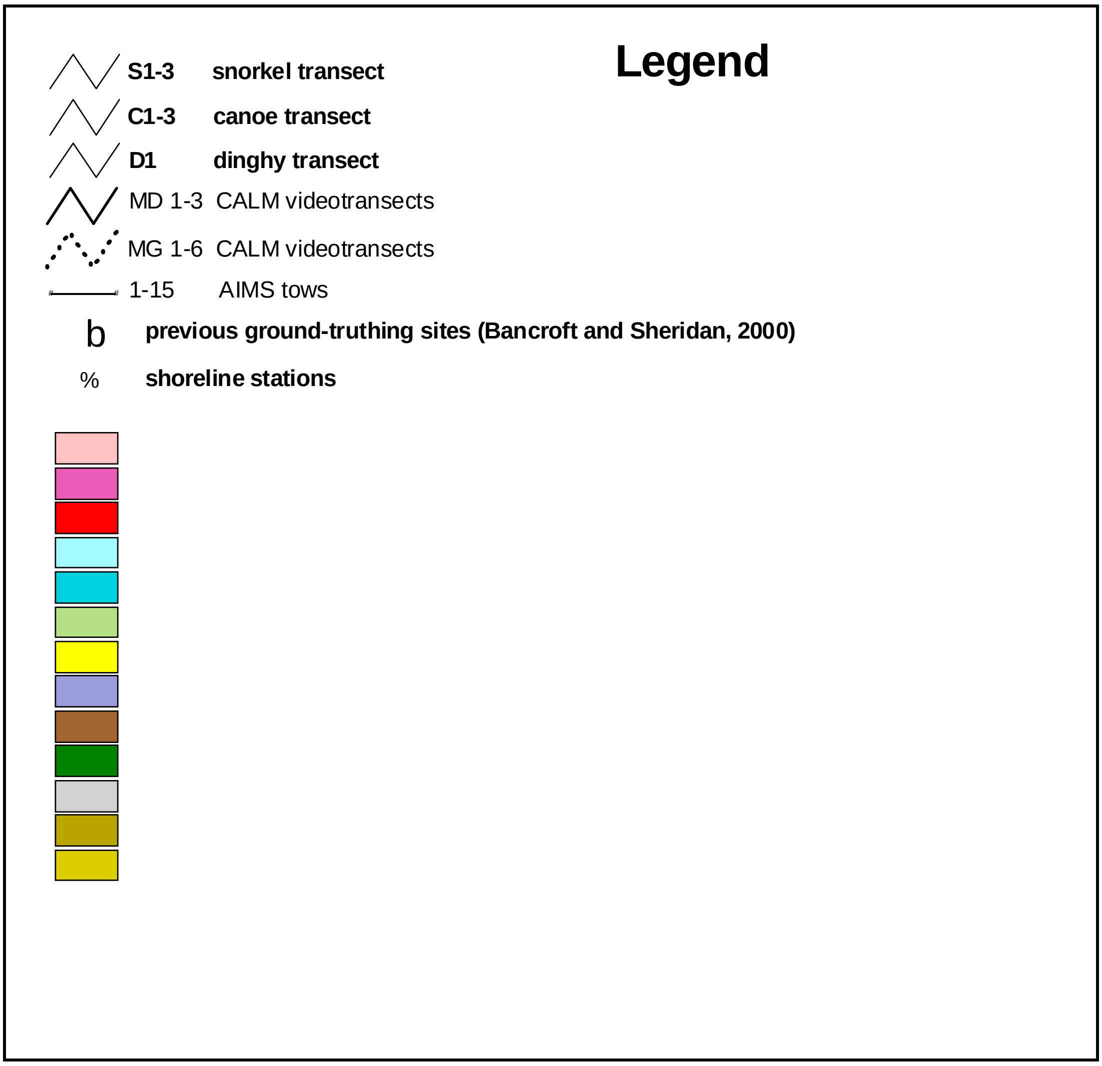

Figure 7. Legend for the habitat maps of Mangrove, Mandu and Osprey Sanctuary Zones.

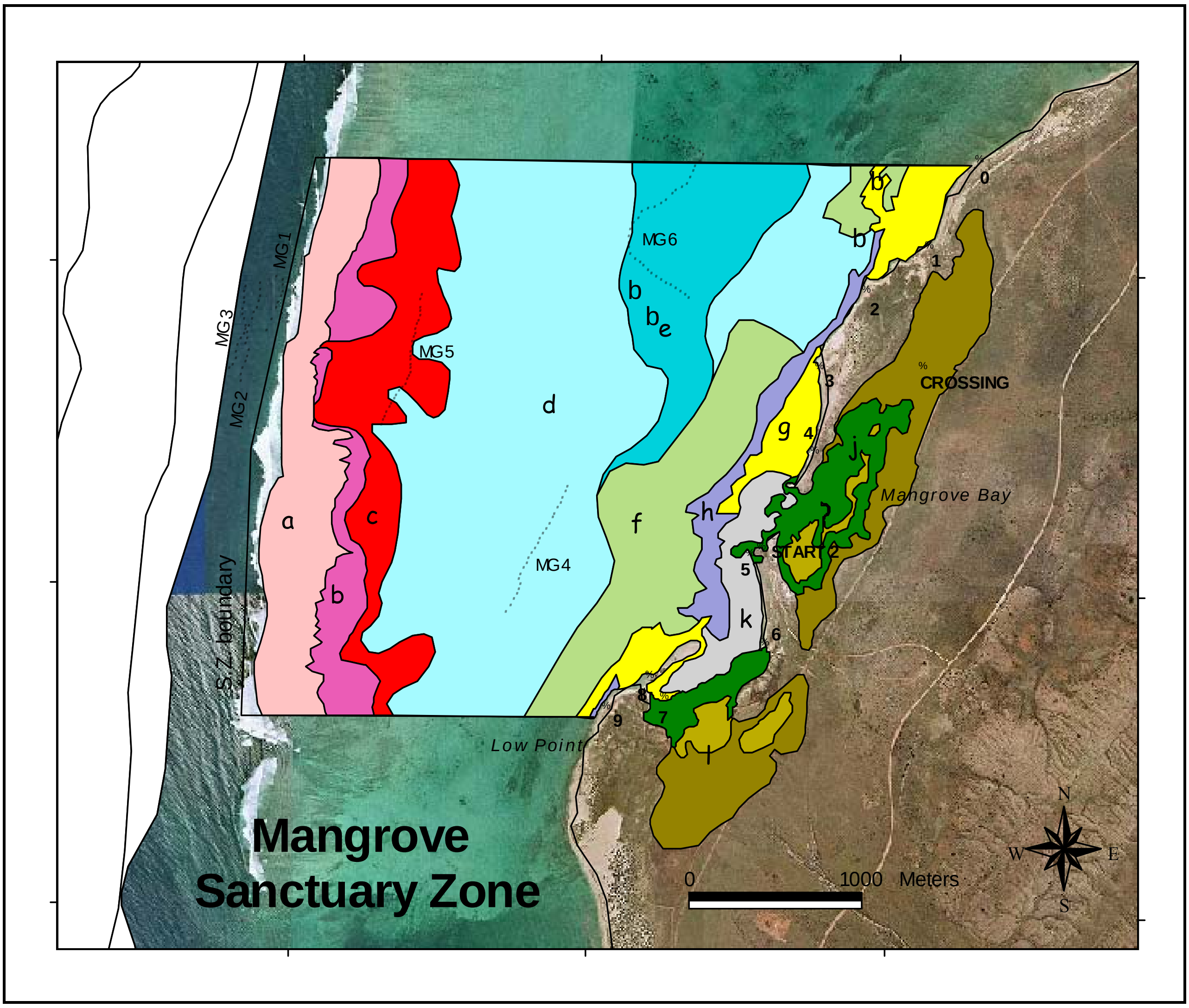

Figure 8. Mangrove Sanctuary Zone habitat map (refer to explanatory legend in Fig 4).

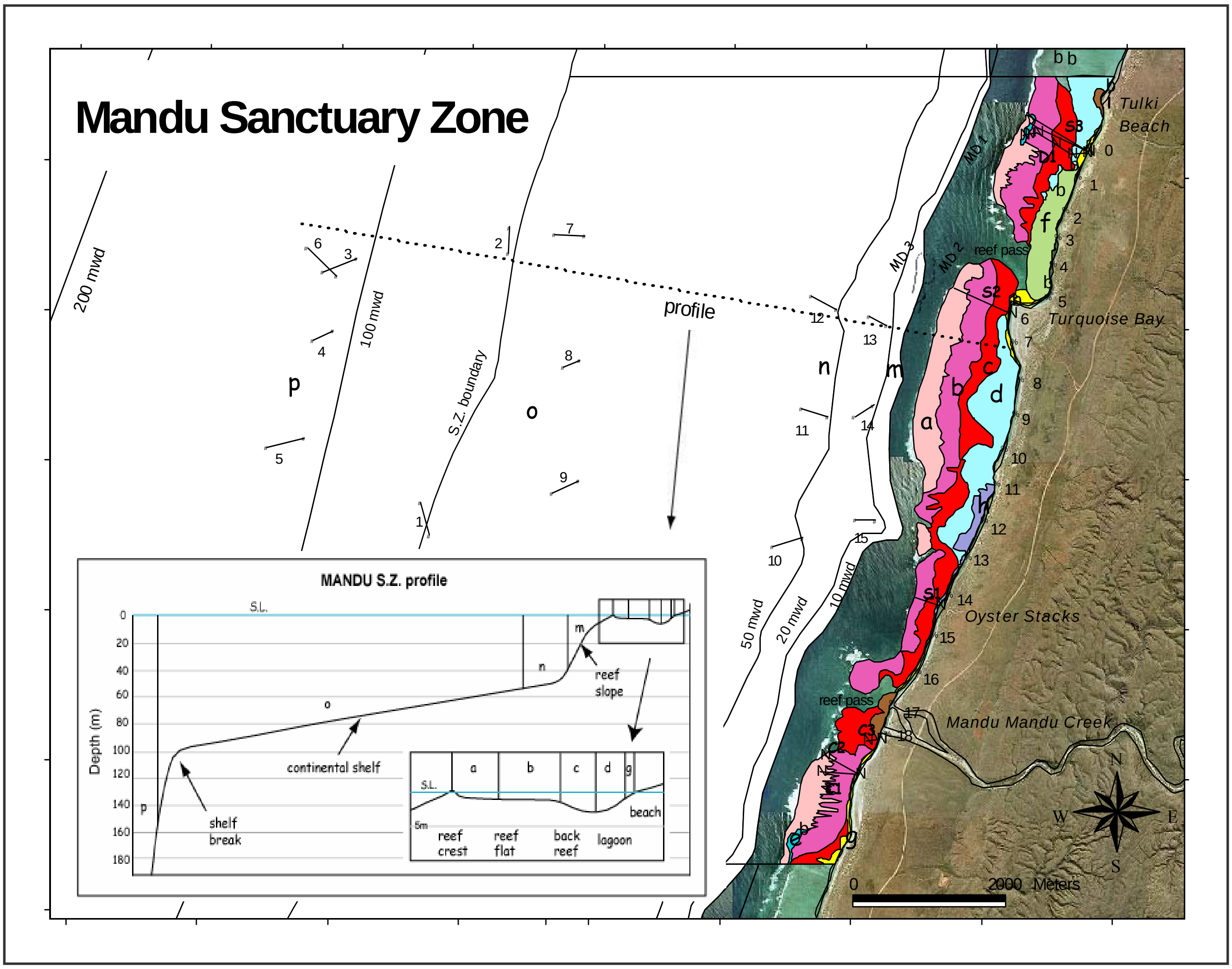

Figure 9. Mandu Sanctuary Zone habitat map (refer to explanatory legend in Fig 4).

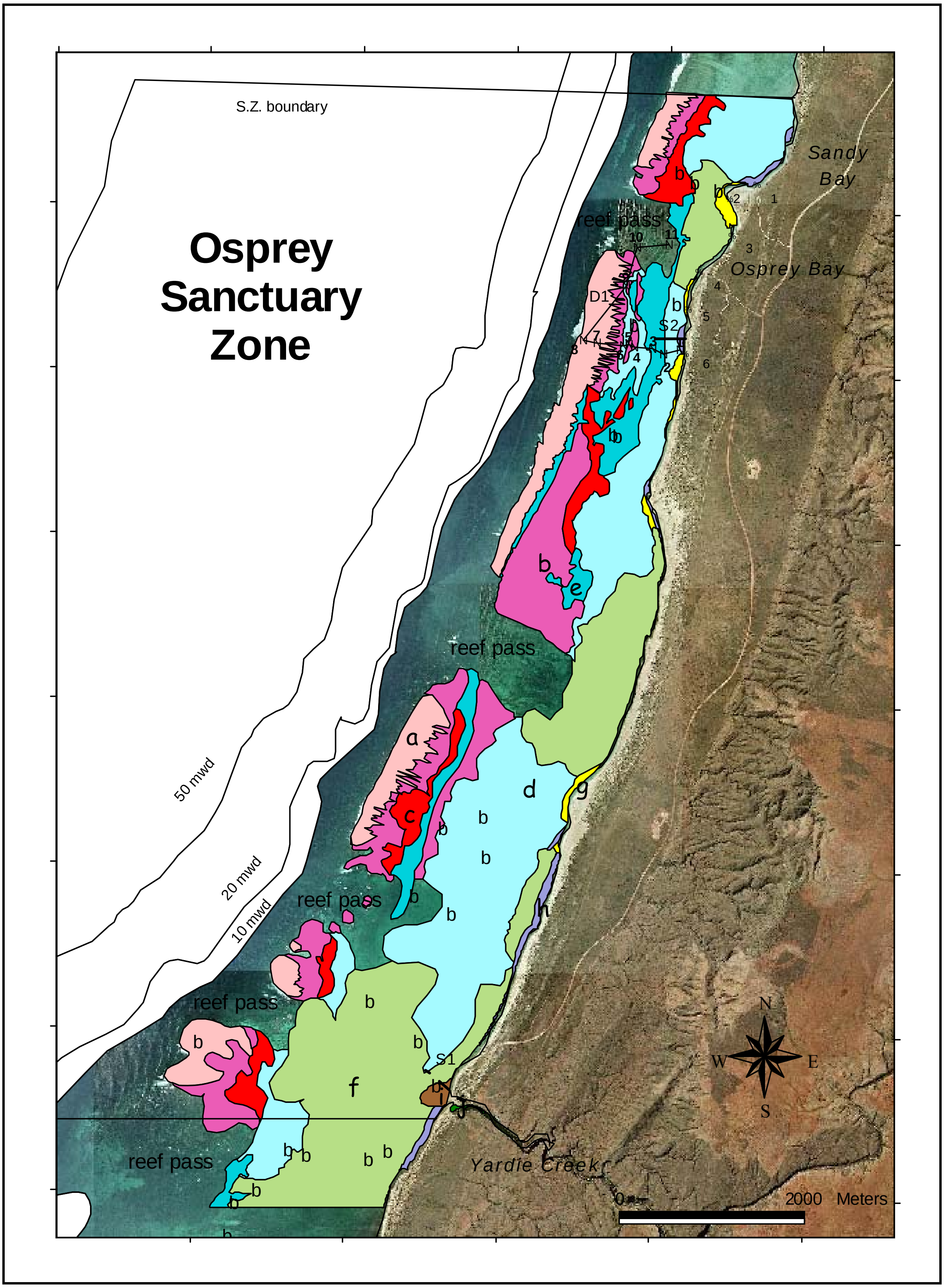

Figure 10. Osprey Sanctuary Zone habitat map (refer to explanatory legend in Fig 4).

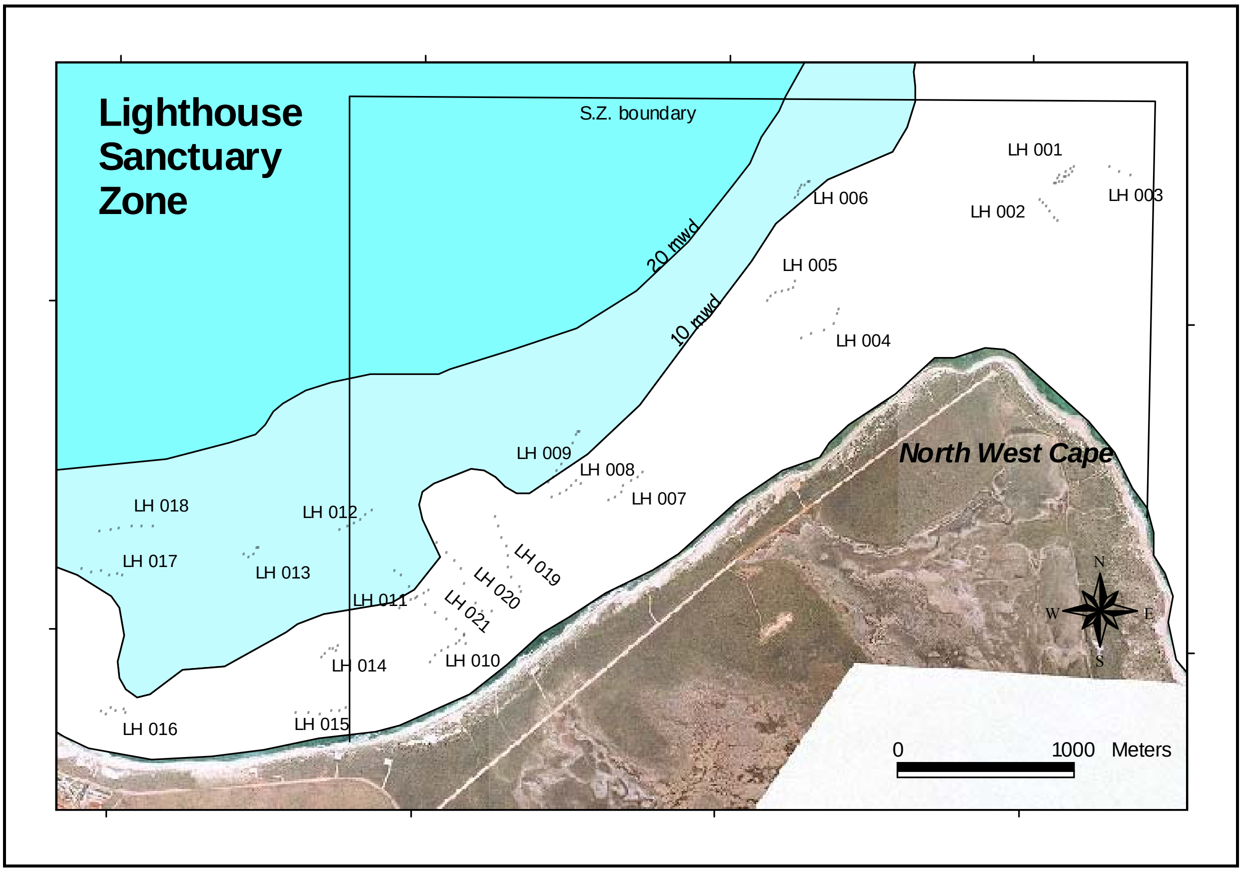

Figure 11. Map of the Lighthouse area showing the 21 video-transect GPS track logs.

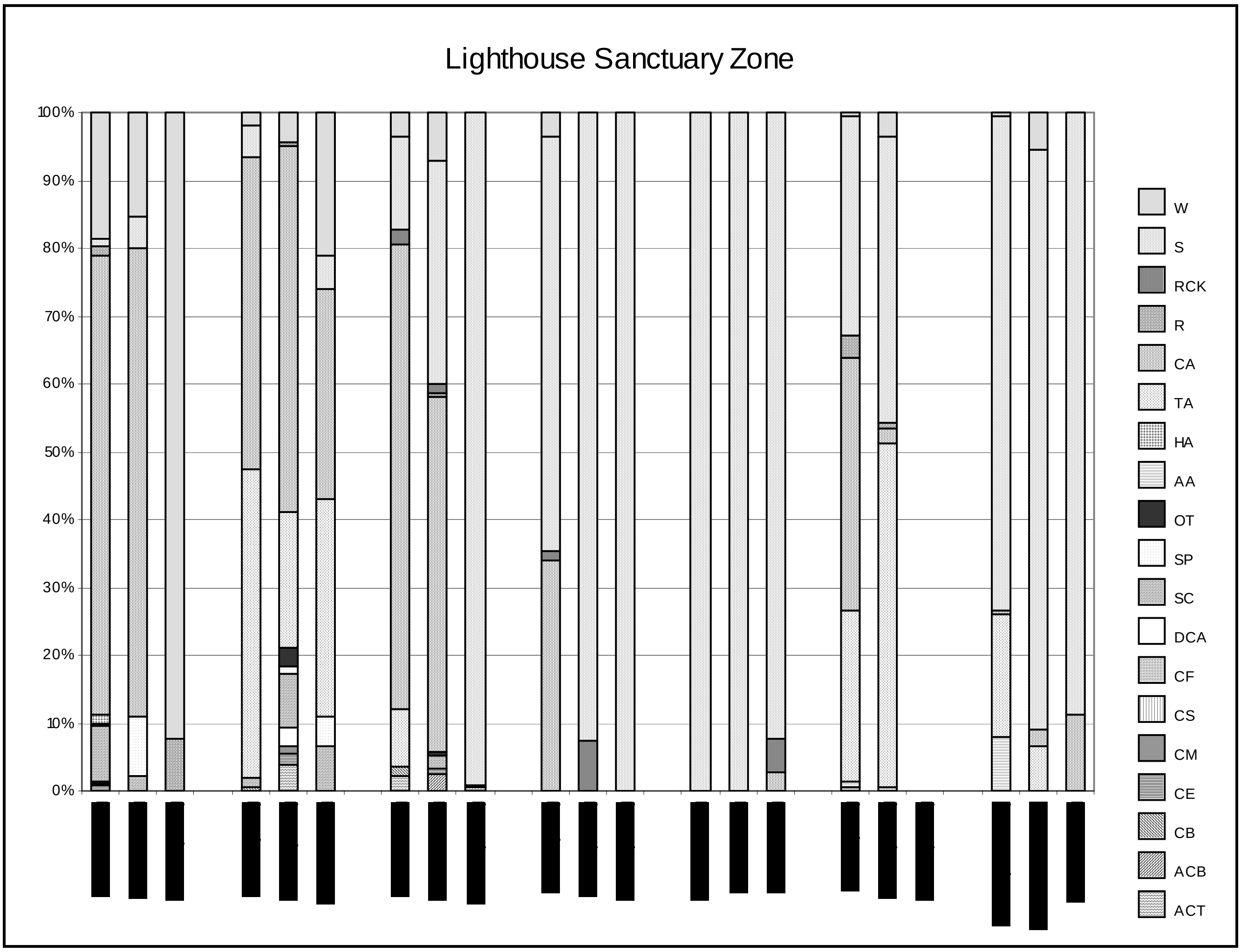

Figure 12. Percent transect cover of each lifeform category in the 18 towed video-transects collected in Lighthouse Sanctuary Zone. See Table 1 for abbreviation code legend

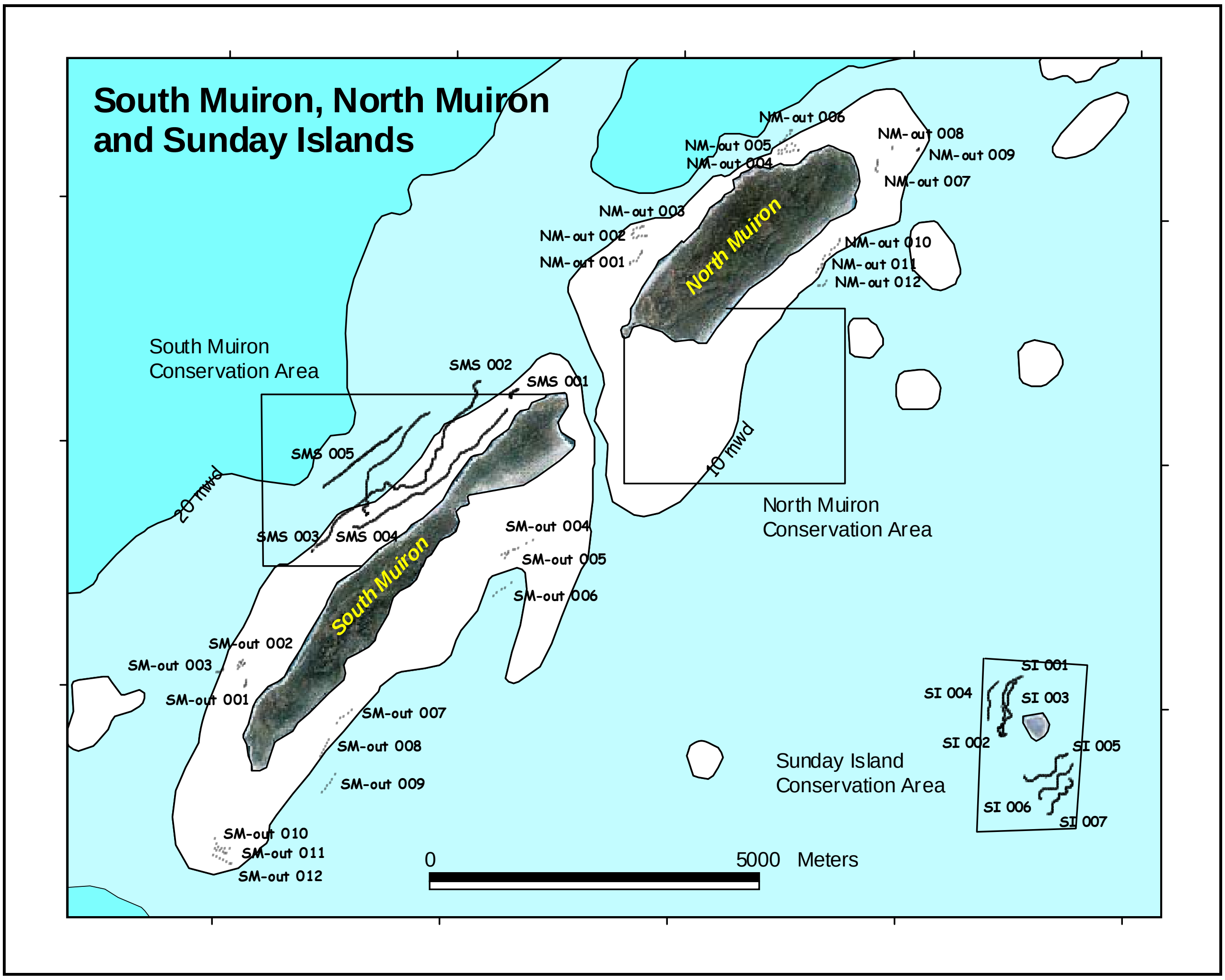

Figure 13. Map showing the GPS track logs of the 36 video-transect carried out around the Muiron and Sunday Islands.

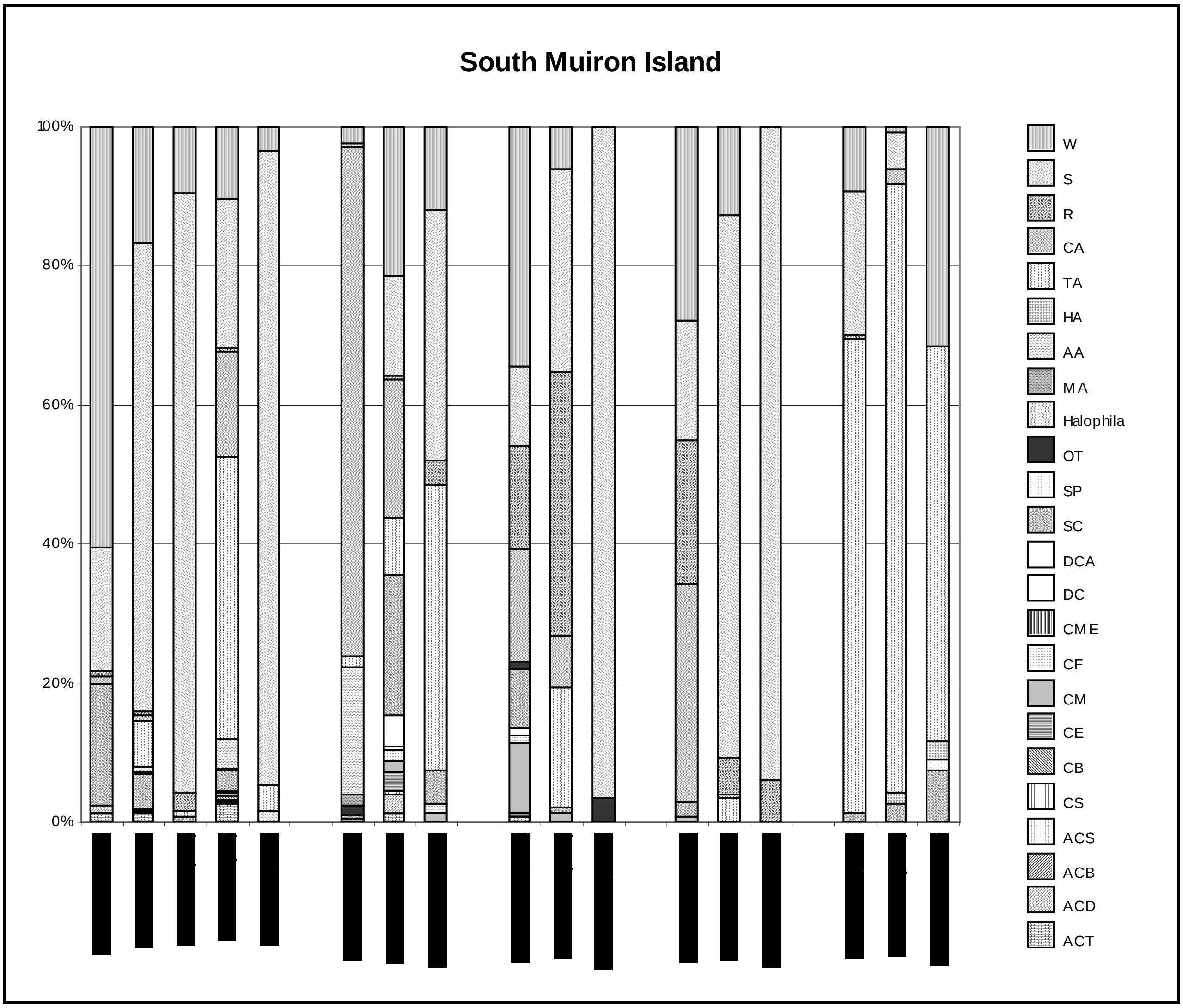

Figure 14. Percent transect cover of each lifeform category in the 17 towed video-transects collected around South Muiron Island. See Table 1 for abbreviation code legend

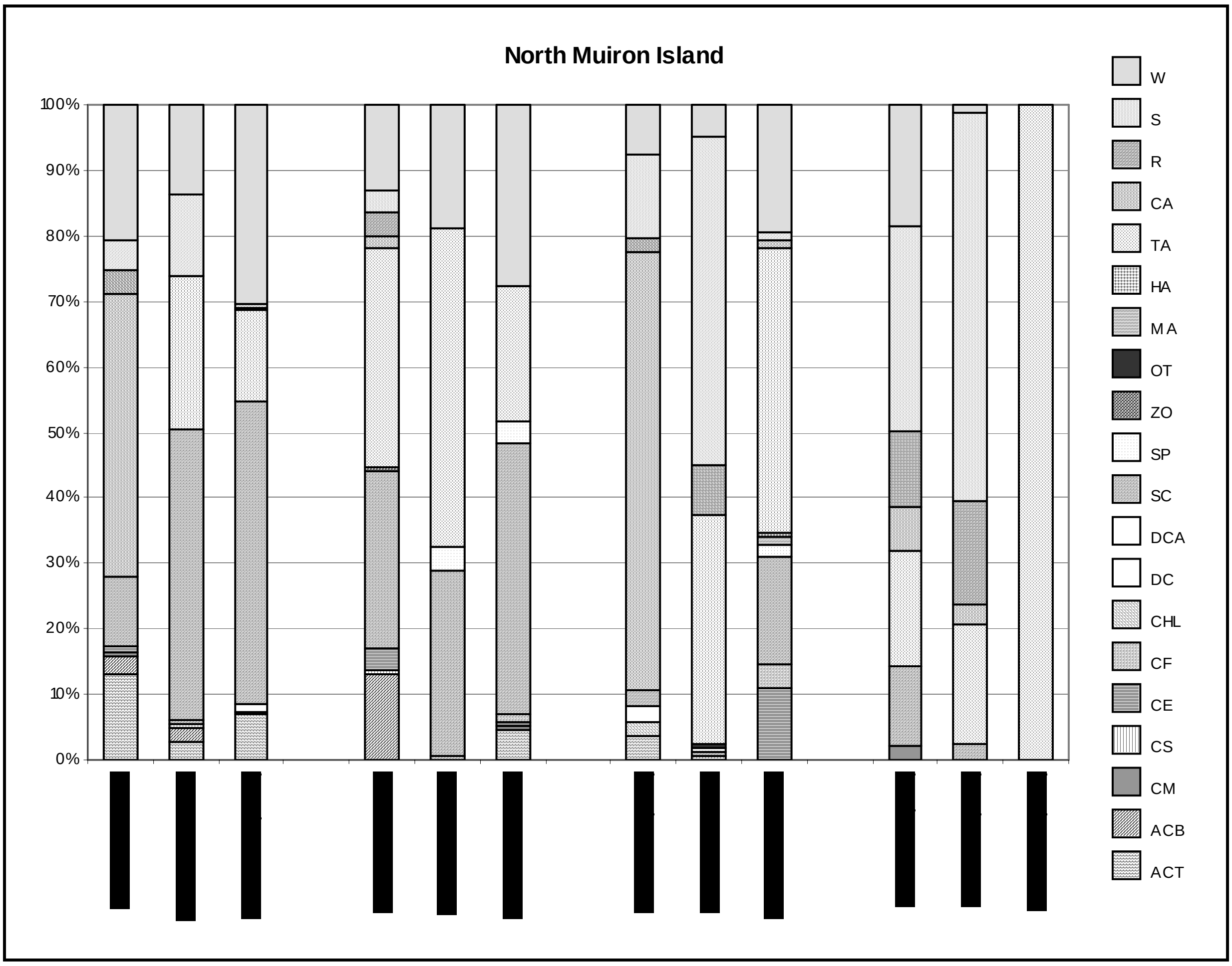

Figure 15. Percent transect cover of each lifeform category in the 12 towed video-transects collected around North Muiron Island. See Table 1 for abbreviation code legend.

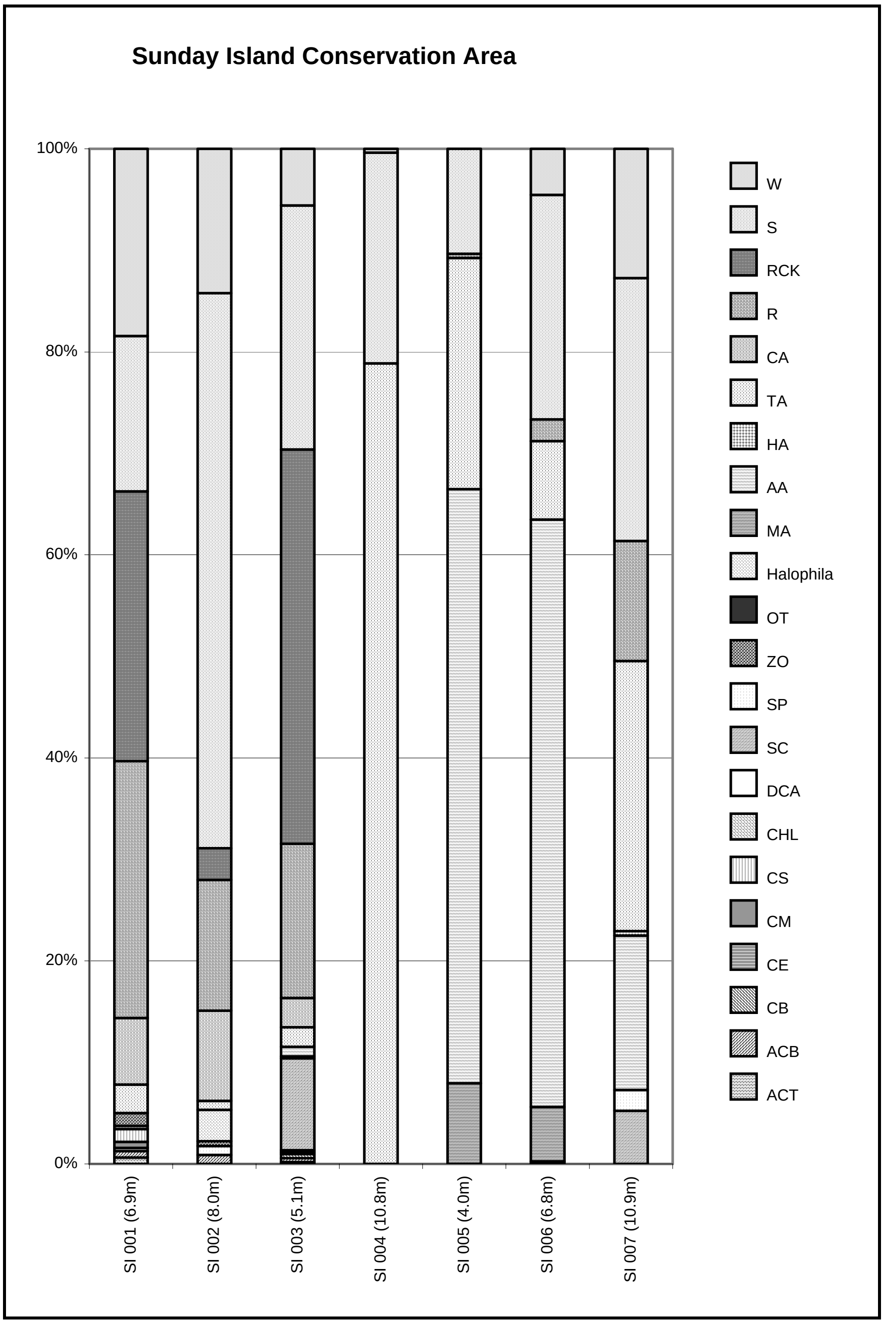

Figure 16. Percent transect cover of each lifeform category in the 7 towed video-transects collected around Sunday Island. See Table 1 for abbreviation code legend.

9 APPENDICES

APPENDIX A: DATA SOURCES AND GPS POSITIONS

DATA	SOURCE
PREVIOUS AVAILABLE DATA - Digigtal Orthophoto/Landsat TM Mosaic of the Exmouth region (2000) - Digital Exmouth region Orthophoto (2003) - Broad scale habitat maps of the Ningaloo Marine Park and related ground-truth data (Bancroft, K.P. and Sheridan, M.W., 2000)	CALM MBC (Fremantle)
- Hard copy aerial photographs (scale 1:20000) of the Cape Range coast (August 1989, July 2003)	DOLA

TOWED VIDEO TRANSECTS (proposed offshore extension of MANDU SZ)

Source: *Ningaloo deeper water seabed biodiversity survey*, March 2004, by AIMS (Fremantle)

	Start lat	*Start long*	*End lat*	*End long*	*depth*
tow 01	-22.12121	113.81104	-22.12493	113.81213	92/90m
tow 02	-22.09052	113.82163	-22.09338	113.82157	84/88m
tow 03	-22.09439	113.80234	-22.09587	113.79805	120/200m
tow 04	-22.10245	113.79944	-22.10346	113.79696	118/187m
tow 05	-22.11445	113.79608	-22.11556	113.79122	117/140m
tow 06	-22.09637	113.79976	-22.09328	113.79593	129/194
tow 07	-22.09137	113.83124	-22.09124	113.82745	72/75m
tow 08	-22.10515	113.83095	-22.10600	113.82889	72
tow 09	-22.11851	113.83107	-22.11994	113.82769	72
tow 10	-22.12439	113.85973	-22.12545	113.85590	50
tow 11	-22.11082	113.86271	-22.11008	113.85933	50
tow 12	-22.09890	113.86356	-22.09757	113.86031	50
tow 13	-22.10054	113.86992	-22.09964	113.86768	25-45
tow 14	-22.10950	113.86844	-22.11077	113.86608	25-45
tow 15	-22.12227	113.86895	-22.12227	113.86643	25-45

SNORKEL/CANOE TRANSECTS AND UNDERWATER PHOTOS

	location	start long	start lat	stop long	stop lat
MD-C1	South Mandu Creek	113.86739	-22.15049	113.86247	-22.15028
MD-C2	south Mandu Creek	113.86739	-22.15049	113.86299	-22.14853
MD-C3	Mandu Creek	113.87001	-22.14653	113.86831	-22.14679
MD-S1	Oyster Stacks	113.87718	-22.13158	113.87425	-22.13073
MD-S2	Turquoise bay	113.88572	-22.09893	113.87840	-22.09635
MD-S3	South Tulki Beach	113.89528	-22.08081	113.88769	-22.07678
OS-S1	North Yardie Creek	113.81124	-22.32319		
OS-S2	South camp site	113.83541	-22.24667		

MANDU and OSPREY SZs lagoonal groundtruthing (April/May 2004)

GEOREFERENCED DESCRIPTION AND PHOTOS OF THE COAST AND BATHYSCOPE PHOTOS OF THE SEA FLOOR ALONG SHORT TRANSECTS (10-50 m) PERPENDICULAR TO THE SHORELINE (MANDU SZ)

	Start long	Start lat		Start long	Start lat
Stop MD 00	113.89528	-22.08081	Stop MD 10	113.88498	-22.11410
Stop MD 01	113.89381	-22.08373	Stop MD 11	113.88416	-22.11798
Stop MD 02	113.89237	-22.08749	Stop MD 12	113.88270	-22.12194
Stop MD 03	113.89144	-22.09045	Stop MD 13	113.88059	-22.12613
Stop MD 04	113.89081	-22.09346	Stop MD 14	113.87840	-22.13035
Stop MD 05	113.89034	-22.09714	Stop MD 15	113.87645	-22.13480
Stop MD 06	113.88587	-22.09777	Stop MD 16	113.87447	-22.13897
Stop MD 07	113.88602	-22.10209	Stop MD 17	113.87145	-22.14250
Stop MD 08	113.88693	-22.10620	Stop MD 18	113.87083	-22.14595
Stop MD 09	113.88635	-22.11015			

MANDU SZ shoreline groundtruthing (1-2/5/2004)

TOWED VIDEO TRANSECTS (MANGROVE and MANDU SZs)

	Lat start	*Long start*	*Lat end*	*Long end*	Depth (av)
MD 1	-22.07888	113.88474	-22.08783	113.88149	4.9 m
MD 2	-22.09448	113.87581	-22.09904	113.87406	11.5 m
MD 3	-22.09862	113.87331	-22.09684	113.87318	16.6 m
MG 1	113.91482	-21.95371	113.91537	-21.95089	5.6 m
MG 2	113.91443	-21.95124	113.91343	-21.95637	10.5 m
MG 3	113.91280	-21.95572	113.91358	-21.95143	14.8 m
MG 4	113.92853	-21.96804	113.93184	-21.96153	1.6 m
MG 5	-21.95846	113.92138	-21.95167	113.92353	1.4 m
MG 6	113.93839	-21.95162	113.93538	-21.94325	3.3 m

MANGROVE and MANDU SZs benthic community survey, 5/5/2004, by CALM (Exmouth)

TOWED VIDEO TRANSECTS (North Muiron, South Muiron, Sunday Island Conservation Areas)

	Lat start	*Long start*	*Lat end*	*Long end*	Depth (av)	
SI 001	21.69710	114.41792	21.70038	114.41515	6.9 m	CALM (Exmouth), April 2004
SI 002	21.70097	114.41504	21.70478	114.41472	8 m	
SI 003	21.70493	114.41527	21.69768	114.41671	5.1 m	
SI 004	21.69725	114.41457	21.70235	114.41315	10.8 m	
SI 005	21.71032	114.41853	21.70725	114.42462	4 m	
SI 006	21.70849	114.42552	21.71321	114.42083	6.8 m	
SI 007	21.71531	114.42213	21.71078	114.42543	10.9 m	
SMS 001	-21.65876	114.34358	-21.65994	114.34209	10.4 m	
SMS 002	21.65787	114.33767	21.67636	114.32163	13.2 m	
SMS 003	-21.68201	114.31360	-21.66241	114.33040	15.6 m	
SMS 004	-21.67854	114.31895	-21.66179	114.34160	5.3 m	
SMS 005	21.67290	114.31497	21.66460	114.32603	16.3 m	
NMS 001						
NMS 002						
NMS 003						
NMS 004						
NMS 005						
NMS 006						
NMS 007						
NMS 008						

TOWED VIDEO TRANSECTS (proposed LIGHTHOUSE SZ)

	Lat start	*Long start*	*Lat end*	*Long end*	Depth (av)	
LH 001	-21.77621	114.16812	-21.77592	114.16875	10.1 m	*Lighthouse S.Z. benthic community survey*, 29/7/2004, by CALM (Exmouth)
LH 002	-21.77860	114.16809	-21.77748	114.16703	4.8 m	
LH 003	-21.77619	114.17201	-21.77576	114.17084	11.6 m	
LH 004	-21.78324	114.15620	-21.78478	114.15422	5.3 m	
LH 005	-21.78190	114.15376	-21.78293	114.15223	10.5 m	
LH 006	-21.77686	114.15443	-21.77770	114.15369	16.6 m	
LH 007	-21.79175	114.14560	-21.79175	114.14560	4.9 m	
LH 008	-21.79243	114.14231	-21.79243	114.14231	11.0 m	
LH 009	-21.78975	114.14211	-21.79238	114.14053	13.3 m	
LH 010	-21.80029	114.13604	-21.80162	114.13422	5.0 m	
LH 011	-21.79799	114.13407	-21.79799	114.13407	10.4 m	
LH 012	-21.79395	114.13085	-21.79503	114.12912	14.3 m	
LH 013	-21.79600	114.12467	-21.79637	114.12384	13.9 m	
LH 014	-21.80092	114.12916	-21.80150	114.12822	9.7 m	
LH 015	-21.80405	114.12961	-21.80429	114.12690	4.8 m	
LH 016	-21.80449	114.11756	-21.80446	114.11623	5.7 m	
LH 017	-21.79753	114.11722	-21.79722	114.11504	10.4 m	
LH 018	-21.79529	114.11596	-21.79504	114.11890	14.2 m	
LH 019	-21.79799	114.13912	-21.79413	114.13759	4.4-12.7 m	
LH 020	-21.79556	114.13441	-21.79897	114.13754	12.7-4.9 m	
LH 021	-21.80063	114.13617	-21.79704	114.13219	4.0-12.0 m	

TOWED VIDEO TRANSECTS (outside North and South Muiron Conservation Areas)

	Lat start	*Long start*	*Lat end*	*Long end*	Depth (av)	
SM-out 001	-21.69949	114.30422	-21.70033	114.30405	3.2 m	*Muiron Islands Conservation Areas benthic community survey*, 30/7/2004, by CALM (Exmouth)
SM-out 002	-21.69732	114.30352	-21.69800	114.30309	8.9 m	
SM-out 003	-21.69787	114.30096	-21.69844	114.29999	15.6 m	
SM-out 004	-21.679350	114.345780	-21.681640	114.341250	5.9 m	
SM-out 005	-21.681960	114.341720	-21.680930	114.343300	9.1 m	
SM-out 006	-21.685420	114.342850	-21.687260	114.340210	12.3 m	
SM-out 007	-21.703130	114.319810	-21.705050	114.317800	4.6 m	
SM-out 008	-21.707380	114.316450	-21.709630	114.315370	9.1 m	
SM-out 00 9	-21.712160	114.317650	-21.714560	114.315720	14.7 m	
SM-out 010	-21.721310	114.300270	-21.722500	114.302270	5.3 m	
SM-out 011	-21.723320	114.301990	-21.722670	114.300110	9.0 m	
SM-out 012	-21.723540	114.299880	-21.724650	114.302690	14.3 m	
NM-out 001	-21.63961	114.36087	-21.64144	114.35918	5.2 m	
NM-out 002	-21.63753	114.36156	-21.63780	114.35961	10.4 m	
NM-out 003	-21.63616	114.36102	-21.63744	114.35929	15.8 m	
NM-out 004	-21.62534	114.38355	-21.62583	114.38064	5.8 m	
NM-out 005	-21.62460	114.38298	-21.62543	114.38052	11.0 m	
NM-out 006	-21.62261	114.38249	-21.62419	114.38071	15.8 m	
NM-out 007	-21.62644	114.39510	-21.62801	114.39515	4.8 m	
NM-out 008	-21.62460	114.39720	-21.62495	114.39735	9.5 m	
NM-out 009	-21.62474	114.40104	-21.62498	114.40088	14.5 m	
NM-out 010	-21.63755	114.38987	-21.64025	114.38739	5.5 m	
NM-out 011	-21.64085	114.38767	-21.64199	114.38664	9.8 m	
NM-out 012	-21.643210	114.387950	-21.643760	114.386840	15.1 m	

GEOREFERENCED DESCRIPTION AND PHOTOS OF THE COAST AND SEA FLOOR BATHYSCOPE PHOTOS ALONG SHORT TRANSECTS (10-50 m) PERPENDICULAR TO THE SHORELINE (MANGROVE and OSPREY SZs)

	Start long	Start lat		Start long	Start lat	
Stop MG 00	113.95447	-21.94417	Stop MG 08	113.93660	-21.97121	MANGROVE and OSPREY SZs shoreline groundtruthing (24-27/7/2004)
Stop MG 01	113.95174	-21.94864	Stop MG 09	113.93413	-21.97286	
Stop MG 02	113.94831	-21.95101	Stop MG 10	113.93220	-21.97844	
Stop MG 03	113.94577	-21.95499				
Stop MG 04	113.94559	-21.95938	Stop OS 1	113.84282	-22.23088	
Crossing	113.95151	-21.95494	Stop OS 2	113.83833	-22.23230	
Start	113.94267	-21.96443	Stop OS 3	113.83935	-22.23613	
Stop MG 05	113.94203	-21.96477	Stop OS 4	113.83668	-22.23980	
Stop MG 06	113.94292	-21.96940	Stop OS 5	113.83417	-22.24368	
Stop MG 07	113.93744	-21.97227	Stop OS 6	113.83390	-22.24818	

DINGHY TRAVERSE (MANDU SZ, south of Tulki Beach)

Station	Easting	Northing	Depth (approx.)
MD 1	798724	7555367	1 m
MD 2	798542	7555352	2 m
MD 3	798331	7555490	1.5 m
MD 4	798097	7555611	1 m
MD 5	797985	7555601	> 3 m
MD 6	797901	7555588	1 m

MANDU SZ lagoonal groundtruthing (25/7/2004)

DINGHY TRAVERSE (OSPREY SZ, south of Osprey Bay)

Station	Easting	Northing	Depth (approx.)
OS 1	792205	7537011	1 m
OS 2	791996	7536975	4 m
OS 3	791870	7537017	3 m
OS 4	791671	7537057	1.5 m
OS 5	791605	7537083	1.5 m
OS 6	791543	7537077	1.5 m
OS 7	791235	7537090	1.5 m
OS 8	791103	7537116	1-2 m
OS 9	791574	7537727	2-3 m
OS 10	791691	7538138	3 m
OS 11	792050	7538174	1-3 m

OSPREY SZ lagoonal groundtruthing (30/7/2004)

APPENDIX B: VIDEO-TRANSECT QUALITATIVE DESCRIPTIONS

MANDU REEF FRONT	
Mandu 1	"Spur and groove" morphology. Tabular, massive, submassive, encrusting, foliose hard corals, sponges and soft corals on the spurs (cover up to 100%); sand and rubble in the grooves (several meters deep). Biodiversity: very high. Video quality: good.
Mandu 2	"Spur and groove" morphology. Channels less deep and wider than in transect 1. Bare, rippled sand with patches of rubble in the grooves. Very divers corals on the spurs, but lower total cover than in transect 1. Abundant coralline algae. Sandy, rippled area from time code 32':24". Biodiversity: high. Video quality: bad (the video camera crashes several times and after that is too far).
Mandu 3	First tape: irregular patches of sand, rubble and low relief rocks, with little coral cover, at the beginning. Then tabular, encrusting and branching corals on rocky substrate (cover < 30%). Most of the corals look dead and encrusted by coralline algae. After time code 50', the video camera crashes and gets stuck to the end of the tape. Video quality: very bad. Second tape: "spur and groove" morphology, with rippled sandy channels and rocky crests, covered by hard corals (mainly tabular *Acropora* in small, compact colonies). Biodiversity: moderate. Video quality: not bad.

MANGROVE REEF FRONT	
Mangrove 1	Flat, rocky area, interrupted by sandy/rubbly channels, about 1 meter deep and 1 meter wide (but now and then deeper and wider). Tabular *Acropora* in small compact colonies, algae, soft corals. Biodiversity: moderate/high. Video quality: not very good.
Mangrove 2	Video camera too far from the floor to identify the benthic organisms. Rocky substrate with very diverse coral morphologies. The channels tend to be deeper than in transect 1 (about 3-4 meters). Biodiversity: moderate/high. Video quality: bad.
Mangrove 3	Low relief rocky spurs (E-W) on a sandy, rippled floor. Very irregular bottom morphology: the video camera crashes several times and after that is too far from the floor to identify the benthic organisms. Green algae, dead corals, coralline algae, hard and soft corals, sponges are present. Biodiversity: high. Video quality: bad.

MANGROVE LAGOON	
Mangrove 4	Bare sand burrowed by sea cucumbers, luxuriant patches of macroalgae and few, scattered soft and hard corals. Minor Halophila. Quality: uniform and not bad.
Mangrove 5	Sandy floor with some rubble and rocky outcrops. Sandy areas: branching, submassive and massive hard corals intervening with luxuriant patches of macroalgae (mainly Sargassum). Few soft corals and Halophila also present. Rocky substrate: tabular *Acropora*, either in small, compact colonies -on isolated outcrops- or in flat extensive growths –where the rocky floor is better developed. Turf algae and encrusting sponges also present. Signs of recent "impact": fresh rubble and upside-down coral colonies. Biodiversity: high. Video quality: not too bad.
Mangrove 6	1) Deep sandy floor with shallow coral "bommies", very rich and diverse: tabular, foliose, encrusting morphologies (time code 31':41"-33':54"). 2) Burrowed, unrippled sand with abundant Halophila and sea cucumbers (time code 33':54"-40':13"). 3) Macroalgal beds (40':13"-45'). 4) Sand and rubble (encrusted or covered in sand) with scattered large coral colonies, mainly staghorn (45'-54'). 5) Bare sand with rare hard corals. Biodiversity: high. Video quality: pretty bad, video camera too far from the floor.

MANDU OFFSHORE (AIMS TOWS)	
Tow 1 (92-90m)	The substrate is a mixture of sand, gravel and mud, apparently bare, but indeed intensely bioturbated (tracks and burrows). The water column often looks turbid. Sea whips and sponges are the most abundant organisms, together with sea pens and sea urchins. Small arborescent Hydroids colonies are also present, but their abundance cannot be fairly estimated because they are only visible when the video camera gets very close to the bottom. Biodiversity: moderate. Quality: not bad.
Tow 2 (84-88m)	The substrate is a mixture of sand, gravel and mud, apparently bare, but indeed intensely bioturbated (tracks and burrows). The water column often looks turbid. Sea whips and sponges are the most abundant organisms, together with sea pens and sea urchins. Biodiversity: low. Quality: not bad.
Tow 3 (120-200m)	The substrate is a mixture of sand, gravel and mud. The water column looks turbid. Sponges of different size and morphology heavily increasing towards the end of the transect (drop off). Shark (time code 48':52":14). Biodiversity: moderate. Quality: not bad.
Tow 4 (118-187m)	The substrate is a mixture of sand, gravel and mud. The water column looks very turbid. Scattered sponges, sea whips, sea pens, crinoids and hydroids, heavily increasing towards the end of the transect (drop off). Shark, rays and other fish. Biodiversity: moderate. Quality: not bad.
Tow 5 (117-140m)	Very burrowed sandy floor. Sponges of different species and size, sea whips, sea pens, gorgonians and other soft corals, crinoids, pencil urchins, fish (01:13:53, 01:19:53:14, stinger ray at 01:07:30:00). The bottom is covered in small leaf-shaped organisms (sea pens? Hydroids?), too far away to be identified. Evidence of currents. Biodiversity: moderate. Quality: not bad.
Tow 6 (129-194m)	Burrowed sandy floor. Sponges of different species and size, sea urchins, sea whips, sea pens, fish, crinoids, especially abundant towards the end. Evidence of bottom currents. No significant change along the transect, same habitat all the way through. Biodiversity: moderate. Quality: not bad.
Tow 7 (72-75m)	Bare rubbly floor with patches of sand. Few crinoids, fish, sea pens, polychaete worms. Biodiversity: low. Quality: not bad.
Tow 8 (72m)	Large, continuous ripples on a gravel/coarse sand bottom. Few sea urchins and fish. Biodiversity: very low. Quality: not too bad.
Tow 9 (72m)	Borrowed gravel/coarse sand bottom, turning into rubble at the end of the tow. Ripples of different size. Sea whips, sponges, sea pens, polychaete worms, crinoids (only towards the end). Biodiversity: low. Quality: not too bad.
Tow 10 (50m)	Intensely bioturbated sandy floor, with “old” ripples. A few sponges and rare crinoids. Biodiversity: very low. Quality: not too bad.
Tow 11 (50m)	Mixed rocky, rubbly and sandy floor, completely encrusted by algae, different, colourful sponges, soft corals, polychaete worms, ascidians, sea pens. This tow definitely looks more “shallow” than the previous ones. Biodiversity: high. Quality: not too bad.
Tow 12 (50m)	Mixed sand and rubble (maybe rhodolites) with many yellow sea pens, sea cucumbers, algae (common *Halimeda*), polychaete worms, foliose sponges, sea whips, gorgonians and other soft corals. Evidence of currents. Biodiversity: very high. Quality: not bad.
Tow 13 (25-45m)	Rocky morphological heights alternated with rubbly/sandy channels. Luxuriant hard corals (mainly tabular *Acropora*) on the heights; dead corals, rubble and coralline algae in the channels. Abundant reef fish. Biodiversity: moderate. Quality: not bad.
Tow 14 (25-45m)	Rocky morphological heights on a rubbly/sandy floor. Luxuriant hard corals (mainly tabular *Acropora*) and sponges on the rocks; coralline algae and sea cucumbers on the rubble/sand. Reef fish. Biodiversity: moderate. Quality: not too bad.
Tow 15 (25-45m)	Bare, rippled sand.

LIGHTHOUSE	
LH 001	Rocky bottom, often covered by a thin layer of sand and/or encrusted by coralline algae. Flat soft corals, gorgonians, sea whips, sea pens, sponges, HA, *Tridacna*, ascidians. Biodiversity: high. Video quality: quite good.
LH 002	The bottom is a rocky surface covered in sand and encrusted by coralline algae and sponges. Biodiversity: low. Video quality: not too bad.
LH 003	Similar to LH 001 and LH002. The video camera is too far. Video quality: very low.
LH 004	The bottom is a rocky surface covered in sand and encrusted by coralline/turf algae. A few hard corals (tabular, foliose, submassive, mushroom), starfish, crinoids, *Halimeda*, *Octopus* (00:25:27:18). Biodiversity: moderate. Video quality: not bad.
LH 005	Rocky surface covered in sand and encrusted by coralline/turf algae. The camera gets very close to the bottom and allows to see clearly many ascidians, besides soft and hard corals, sea pens, sea whips, starfish, large sponges and fish. Biodiversity: high. Video quality: not bad.
LH 006	Flat morphology. Rocky surface covered in sand and encrusted by coralline/turf algae. The habitat looks clearly "deeper" than the previous ones: many sponges and sea whips, starfish, a few short green algae. Biodiversity: moderate. Video quality: not bad.
LH 007	Burrowed sandy floor with outcropping rocks. Several hard corals (*Acropora*, *Pocillopora*) growing on the highest, less sandy spots. Coralline algae and giant clams on the lowest and sandier rocky outcrops. Biodiversity: moderate. Video quality: not bad.
LH 008	Rippled and burrowed sandy floor with outcropping rocks and rubble in the intermediate areas. Hard corals (tabular, submassive, foliose), coralline algae, soft corals, starfish, giant clams, sponges, zoanthids. Biodiversity: high. Video quality: not bad.
LH 009	Rippled sand with green algae (*Halimeda* and *Caulerpa*). From 00:02:54:20, scattered soft and hard corals (flat and foliose). Sea cucumber. Biodiversity: low. Video quality: first tape too far, second not bad.
LH 010	Sandy floor with linear rock outcrops. Small, irregular ripples, clearly due to the waves action. Encrusting coralline algae on the rocks, with little *Halimeda*, a few hard corals (*Acropora*, *Montipora*, *Porites*), encrusting sponges, many ascidians and fish (stinger ray at 00:07:16:16). Biodiversity: generally low, but high in spots. Video quality: quite good.
LH 011	Sandy floor with small, irregular ripples. Few isolated rock outcrops. Biodiversity: low. Video quality: not bad.
LH 012	Sandy, rippled floor with a few sea pens and sea whips. Biodiversity: very low. Video quality: not very good, video camera too far.
LH 013	Sandy, rippled floor with sea pens everywhere. Few crinoids and short green algae. Biodiversity: very low. Video quality: not very good, video camera too far.
LH 014	Sandy floor with large, regular ripples (N-S orientated). Few sea pens and nothing else. Biodiversity: very low. Video quality: not bad.
LH 015	Bare sandy floor with small, very irregular ripples. Few isolated rock outcrops, encrusted by coralline algae, with some red algae, soft corals and sea cucumbers on top. Biodiversity: quite low. Video quality: not bad.
LH 016	Flat rock, covered by a thin layer of sand, emerging from a sandy floor about 1 meter deeper. Large, N-S orientated ripples on the sand. Coralline/turf algae, starfish, sea cucumbers, soft and hard corals on the rocky surface. Biodiversity: moderate. Video quality: not bad.
LH 017	Sandy floor, with large ripples and rubble, gradually turning into a flat rocky surface covered by a thin layer of sand. Scattered sea pens, green algae, few sea whips and ascidians on the sand. Soft corals, sea pens, sea urchins (?) and sponges on the rocky bottom. Biodiversity: low. Video quality: not very good.
LH 019	1) Sand on rock platform, with algae growing higher in the sandy pockets. 2) Sand with small, chaotic ripples gradually becoming larger and more regular seaward. Short green algae (Halophila?). Large school of tiny fish. Biodiversity: low. Video quality: not very good.
LH 020	Sand with large, flat ripples and rare rock outcrops. Biodiversity: very low. Video quality: not good (video camera too far and too fast).
LH 020bis	1) Rocky pavement with rubble and coralline algae on top. 2) Sand with small, discontinuous ripples, getting larger and more regular seaward. Biodiversity: very low. Video quality: not bad.

NORTH MUIRON OUT	
NM-out 001	Rocky substrate. Luxuriant coral habitat (cover up to 100%): soft corals, tabular and branching *Acropora*, *Montipora*, encrusting, submassive and massive hard corals, maybe *Heliopora* (see 00:24:43:14). Coralline algae, rubble and sand on the deepest, spots. Biodiversity: very high. Video quality: not bad.
NM-out 002	Flat rocks on sand. Many soft corals, but also tabular and branching *Acropora*, submassive *Montipora*, foliose hard corals, few sea whips. Cover up to 80%. Biodiversity: very high. Video quality: not very good: a bit too far.
NM-out 003	Similar to NM-out 002. Soft coral habitat (cover up to 100% in spots) on rock platform. Tabular *Acropora* (abundant), encrusting/foliose hard corals (rare), sponges (00:31:39:15), *Heliopora* (rare), sea whips (rare), mushroom corals (rare). Between 00:32:50 and 00:33:50 the video camera is too far (probably due to deeper sea floor), but the coral cover is definitely much lower here. Biodiversity: high. Video quality: not bad.
NM-out 004	Irregular rocks up to 5-6 m high on a flat limestone pavement. The pavement is covered by sand and rubble and is colonised by turf algae (it could also be coarse sand), soft corals, tabular *Acropora*; coral cover 0-40%. On the rocks: tabular *Acropora* and soft corals (very abundant), encrusting, branching and digitate hard corals, Zoanthids, encrusting sponges; coral cover 80-100%. Biodiversity: high. Video quality: bad, due to the uneven morphology (good just on the highest rocks).
NM-out 005	Flat, rocky pavement covered by sponges (mainly encrusting), turf algae, soft corals, foliose hard corals, starfish, sea whips, a few colonies of tabular *Acropora*, fish (little reef fish). Biodiversity: high. Video quality: bad (video camera too far most of the time).
NM-out 006	Flat, rocky pavement covered by turf algae, soft corals, encrusting and foliose hard corals, sponges, sea pens, sea whips, a few colonies of tabular *Acropora*, fish (no reef fish). Biodiversity: high. Video quality: bad (video camera too far most of the time).
NM-out 007	Rocky pavement, encrusted by coralline algae, and sand patches. Scattered hard corals: tabular *Acropora*, *Heliopora*, *Montipora*, encrusting and branching hard corals; a few soft corals (more abundant towards the end of the transect). Biodiversity: high. Video quality: not very good.
NM-out 008	Small rocks (up to few meters across) on sand. Few soft and hard corals, *Heliopora*, encrusting sponges, starfish, sea cucumbers and a lot of fish. Biodiversity: moderate. Video quality: not good (too far).
NM-out 009	Sandy substrate. The bottom is totally covered and/or encrusted by a mixture of short green algae (*Halimeda*, *Udotea* and more), rhodolites, hydroids, gorgonians, encrusting sponges and corals, ascidians, macroalgae (these organisms are only identifiable when the camera gets very close). Larger bottom dwellers, such as sea whips, sea fans, other soft corals, foliose hard corals, macroalgae, sponges and crinoids, are also abundant and more easily identified. Biodiversity: very very high. Video quality: very high. (The best transect I have seen).
NM-out 010	Rocks on a sandy bottom. Soft corals, sea cucumbers, starfish, massive corals. 00:18:17:03 stinger ray. Biodiversity: high. Video quality: low (too far).
NM-out 011	Flat, rocky surface covered by sand and rubble, with few outcropping rocks. Scattered soft corals, a few sea cucumbers, sea pens, gorgonians, sponges, starfish and rare hard corals. Biodiversity: moderate. Video quality: not bad.
NM-out 012	Flat, rocky surface covered by sand and turf algae (abundant Halophila and maybe *Halimeda*). A few soft corals and rare skeletons of sea urchins. Biodiversity: very low. Video quality: not very good.

SOUTH MUIRON OUT	
SM-out 001	Rocky substrate with coralline algae, green algae (sure *Halimeda*, maybe others), macroalgae, corals (mainly soft, but also hard), sea urchins (in every hole), giant clams. Biodiversity: very high. Video quality: not bad.
SM-out 002	Coral habitat: soft and hard corals of different species and morphologies on a rocky surface. Biodiversity: very high. Video quality: good in spots.
SM-out 003	Sand on a rocky, flat platform, outcropping now and then. On the sand: many soft corals (mainly gorgonians and sea whips), short/turf algae (*Halimeda* and others), some foliose hard corals. On the rock: many hard corals (foliose, massive, encrusting), sponges, short/turf algae (*Halimeda*), sea whips, soft corals, sea cucumbers, sea pens, ascidians. Biodiversity: very high. Video quality: not bad.
SM-out 004	Rocks and coral bommies on a sandy/rubbly bottom. Soft corals, *Heliopora*, tabular, massive, foliose and encrusting hard corals (*Acropora*, *Porites*, *Montipora*), sea cucumbers. Biodiversity: very high. Video quality: low, due to the irregular morphology.
SM-out 005	First minute: sand with turf algae (maybe Halophila) on a rocky bottom. Then, rocks outcropping from a sandy/rubbly bottom. Soft corals, Massive and branching hard corals on the rocks. Sea cucumbers and starfish on the sand/rubble. 00:44:20:20 turtle. Biodiversity: moderate. Video quality: not too bad.
SM-out 006	Flat sandy/silty bottom with scattered gorgonians, starfish and crinoids. The sea floor appears intensely bioturbated (echinoid's tracks). From 00:52:00 to 00:53:00, hundreds of irregular sea urchins. Biodiversity: low. Video quality: not bad.
SM-out 007	Rocks and coral bommies on a sandy/rubbly bottom. Soft corals, *Heliopora*, tabular, massive, foliose and encrusting hard corals (*Acropora*, *Porites*, *Montipora*), encrusting sponges, sea cucumbers. Biodiversity: high. Video quality: low, due to the irregular morphology.
SM-out 008	Few rocks and rubble on sand. Soft corals, massive hard corals and sponges on the highest rocks; *Halimeda* and coralline algae on the small rocks; sea whips, short green algae (or maybe Halophila), few starfish and sea cucumbers. Many bivalve shells. Biodiversity: low. Video quality: not bad.
SM-out 009	Sand with little non-coral rubble. Starfish, holothurians (00:11:43:09), short green algae (little *Halimeda* and maybe *Caulerpa*). Abundant bivalve and sea urchin shells. Biodiversity: very low. Video quality: not bad.
SM-out 010	Large rocky outcrops surrounded by sand. The rocks are covered by turf/coralline algae, sponges and a few corals. Small, scattered colonies of tabular *Acropora* and foliose corals. Few starfish and sea cucumbers. Biodiversity: very low. Video quality: not good.
SM-out 011	The substrate seems to be a thin layer of sand on a rocky platform. Turf algae, mainly made of encrusting coralline algae and *Halimeda*, cover and stabilize this bottom, with minor *Caulerpa*, hydroids and small soft corals (total cover up to 100%). Sea whips, sponges, gorgonians and large soft corals are also very abundant, with minor ascidians, starfish and sea pens. Biodiversity: high. Video quality: very good.
SM-out 012	Rocky surface covered by turf algae, mainly made of encrusting coralline algae and *Halimeda*, with minor *Caulerpa*, encrusting sponges, hydroids and small soft corals (total cover up to 100%). Sea fans, crinoids, sea whips and sponges are also abundant, with minor ascidians, sea pens, starfish and sea cucumbers. Biodiversity: high. Video quality: good.

SOUTH MUIRON CONSERVATION AREA (SMS)	
SMS 001	Soft coral habitat. Biodiversity: high. Video quality: very bad (too far and turbid water).
SMS 002	1) Rippled, bare sand. 2) Sand on rocky surface, with algae, sea whips, Halophila, starfish, sponges, sea pens. 3) Rocky substrate with corals (mainly soft), giant clams, turf algae, sea cucumbers. 4) Rippled, bare sand. 5) Corals again, just before the end of the tape. Biodiversity: high in spots; low in total. Video quality: bad (too far).
SMS 003	1) Rocks, with soft and hard corals, on a sandy/rubbly floor. 2) Bare sand, rippled and bioturbated. Biodiversity: low in total. Video quality: very bad (too far).
SMS 004	1) Rocky substrate, covered by a thin layer of sand and encrusted by turf/coralline algae. Sparse tabular *Acropora*, algae, giant clams and many fish (stinger ray at 00:03:12:10). 2) Rippled sand patches surrounding rocky outcrops, covered by luxuriant, very diverse soft and hard corals. Biodiversity: high. Video quality: not bad.
SMS 005	1) Bare, rippled sand. 2) Rocky surface, covered by a thin layer of sand and turf algae. Many sea pens. 3) Sand with sparse outcropping rocks. Biodiversity: very low. Video quality: not bad.

SUNDAY ISLAND	
SI 001	1) Bare, flat rocks on a sandy floor. 2) Rocks with soft and hard corals (massive, submassive, encrusting, tabular), zoanthids and coralline algae. 3) Rippled sand with rubble. 4) Rocks encrusted by coralline and turf algae, with a few corals. Biodiversity: high in spots, low in total. Video quality: not very good. Turbid water.
SI 002	1) Rippled sand with something (rubble? Halophila? *Halimeda*?). 2) Sand and rubble encrusted by coralline algae. 3) Outcropping rocks, with sponges, corals, zoanthids and coralline algae, surrounded by sand and rubble. Biodiversity: high in spots; low in total. Video quality: not very good (camera stuck several times).
SI 003	1) Rubble and rocks encrusted by something unidentifiable (turf algae? Coralline algae). 2) Outcropping rocks with soft and hard corals. 3) Rippled sand. 4) Rocks again with many corals (mainly soft). Biodiversity: high in spots, low in total. Video quality: not very good. Turbid water.
SI 004	1) Unrippled sand covered by turf algae, with some soft corals, sea whips, starfish and macroalgae. 2) Bare, rippled sand. Biodiversity: low. Video quality: not too bad.
SI 005	Sand with algae (from turf to macro). Few outcropping rocks with rare corals and a few giant clams. From 00:05:10 to 00:06:10, lots of sea urchins and few soft corals. Biodiversity: low/moderate. Video quality: bad (too far).
SI 006	Sandy floor covered by algae (from turf to macro). Scattered sea whips, gorgonians and sponges. Biodiversity: low/moderate. Video quality: bad (too far and turbid water).
SI 007	The substrate is essentially a rocky platform covered by a layer of sand. Widespread algae (turf when the sandy layer is thinner). *Halimeda* is also present. Sea whips, gorgonians, soft corals and sponges are abundant, with minor sea cucumbers, sea pens and zoanthids. Biodiversity: high. Video quality: bad (too far and turbid water).