Characterising the fish habitats of the Recherche Archipelago

Dr G. Kendrick, Dr Euan Harvey, Dr Justin McDonald,
Professor Chari Pattiaratchi, Mike Cappo, Dr Jane Fromont,
Professor Mark Shortis, Simon Grove, Andy Bickers,
Katrina Baxter, Dr Nisse Goldberg, Mat Kletczkowski, James Butler

University of
Western Australia

Australian Government

Fisheries Research and
Development Corporation

Fisheries Research and Development Corporation Report
Project No. 2001/060

2001/060 - Characterising the fish habitats of the Recherche Archipelago.

Principal Investigators: Dr G. Kendrick[1], Dr Euan Harvey[1], Dr Justin McDonald[1], Professor Chari Pattiaratchi[1], Mike Cappo[2], Dr Jane Fromont[3], Professor Mark Shortis[4], Simon Grove[1], Andy Bickers[1], Katrina Baxter[1], Dr Nisse Goldberg[1], Mat Kletczkowski[1], James Butler[1]

Addresses:

[1] School of Plant Biology (M090)
University of Western Australia
35 Stirling Highway
Crawley, 6009
Western Australia, Australia

[2] Australian Institute of Marine Sciences
PMB No. 3,
Townsville 4810,
Queensland, AUSTRALIA

[3] Western Australian Museum
Locked Bag 49
Welshpool DC 6986
Western Australia, Australia

[4] RMIT University
GPO Box 2476V
Melbourne 3001
AUSTRALIA

University of Western Australia

Australian Government
Fisheries Research and Development Corporation

Characterising the fish habitats of the Recherche Archipelago – FRDC 2001/060 Final Report.
ISBN: 1 74052 122 6

2001/060 Characterising the fish habitats of the Recherche Archipelago

PRINCIPAL INVESTIGATOR: Dr G. Kendrick
ADDRESS:
University of Western Australia
School of Plant Biology (M090)
35 Stirling Highway
Crawley WA 6009
Telephone: 08 6488 3998 Fax: 08 6488 1001

OBJECTIVES

1. To identify, classify and map the distribution of, different benthic habitats in the Recherche Archipelago and link their distributions to bottom type and exposure to swells and currents.
2. To provide detailed ecological information to ensure the responsible management of aquaculture fisheries in the region.
3. To increase community awareness of fish habitats through community involvement in the development of baseline studies and ongoing monitoring programs.

OUTCOMES ACHIEVED TO DATE

1. The design of a hierarchical classification scheme of benthic habitats in the Recherche Archipelago. Modelling of the effectiveness of that classification scheme
2. An extensive habitat map of the Western Recherche Archipelago at both broad and functional habitat classifications and less detailed habitat maps of duke of Orleans Bay and Cape Arid to Middle Island.
3. An oceanographic model of the influence of ocean swells on the Western Recherche Archipelago. This model includes an assessment of swell driven shear at the benthos.

4. A broad scale fisheries-independent non-destructive survey of the demersal fish of the Recherche from Esperance Bay to Cape Arid. The survey was designed to capture habitat differences (habitats defined from the mapping exercise) in fish assemblages
5. A broad scale (within the Western Archipelago) survey of the infauna found in a range of soft bottom habitats (as defined from the mapping exercise) including coarse sands, rhodoliths and sparsely vegetated sands.
6. Fine scale diversity surveys of reef communities on islands in the archipelago from Figure of Eight to Middle Island. These surveys included assessments of macroalgae, sessile invertebrates and reef fish with depth and exposure to ocean swells. Thus they integrate information from both habitat mapping and physical oceanographic modelling.
7. Finally, the project is a joint Esperance community (through the Recherche Advisory Group - RAG), research scientist and resource management project. The commitment of RAG has allowed the researchers to efficiently transfer scientific information to the general public of Esperance and the South Coast of Western Australia and keep the research focussed on management outcomes.

NON TECHNICAL SUMMARY

Extensive broad scale surveys were made in the relatively clear waters of the Recherche Archipelago. Where there was adequate light penetration sidescan sonar was used allowing almost photographic quality imagery of seafloor texture to be obtained from swaths of up to 400 m wide. Drop and towed video systems were used to obtain more detailed information about the physical and biological nature of the seabed in areas identified from the acoustic mapping. A total of 1054 km^2 of habitats were mapped within the Recherche Archipelago. A total of 813 km^2 was mapped in the Esperance region, 142 km^2 in the Cape Arid region and 99 km^2 in the Duke of Orleans region.

Habitats were described as combinations of the identifiable physical and biological characteristics (Appendix 2- Habitat Mapping. Biological factors were classified in terms of observation of cover of dominant community and by the presence of a number of biological assemblages. Physical factors were classified in terms of depth, substrate and relief. These descriptions resulted in a hierarchical classification where broad habitats were further classified into functional habitat types). Of the 5 broad types, sand represented 28.3 % of the area mapped, low profile reef 33.4 %, seagrass 20.1 %, rhodoliths 13.7 % and high profile reefs 4.6 %. These percentages varied across the regions. At a more detailed level of the classification hierarchy, 27 functional habitat types were mapped, reflecting the variation with each of the 5 broad types.

Fish assemblages within these habitats were sampled using baited stereo-video and single camera systems (Main report – Fish Distributions). In this study there were statistically distinctive fish assemblages between Seagrass, Reef, Rhodolith and Sand habitats although Sand and Rhodoliths were very similar. These habitat differences were also apparent in the numbers of species and individuals, with samples from Reef habitats having the greatest mean numbers of species and individuals followed by Seagrass and then Sand and Rhodolith habitats. There were no differences between macroalgal canopy forming species but there was a significant difference in fish assemblages within seagrass and reef habitats with different densities of flora. Changes in the density of flora within specific habitats and relief appear to exert the greatest influence on the structure of reef fish assemblages. Analysis of the sub-habitats based on floral density and relief of reef habitats show that while in some cases distinctive fish assemblages occupy distinctive habitats, normally there is a continuum or transition of species between different combinations of floral density and relief with distinctive fish assemblages at the ends of the continuum.

The benthic macrofaunal communities varied according to the substrate habitat (Appendix 4). Drop camera video surveys indicated a wide variety of soft substrate environments ranging from fine sands to gravel. The character and diversity of soft substrate macrofaunal assemblages were related to the structural complexity of the bottom. Habitat structural complexity was provided by sediment characters, or by biogenic structures, including macroalgae, sessile invertebrates and rhodoliths. Sediments ranged from sand to sandy gravel, with very little mud content. Organic content was significantly correlated to rhodolith content, but not to mud content. Those sediments with a high degree of sorting were associated with low diversity and abundance. The highest diversities and species richness were found in the rhodolith beds. Sediment grain size and sorting are determined by characteristics of near-bed flow regimes (e.g. shear stress (see Apendix 3 for Oceanographic data) that can directly affect the benthos through food and larval supply and particulate flux.

In general, most macroalgae were relatively rare, with >60 % of total species richness from sampled islands contributed <5 g 0.25 m^{-2} (Appendix 5). Macroalgal assemblages showed strong links with exposure, depth, and island location. Differences in assemblages were consistent across islands groups, primarily due to a difference in dominant taxa with exposure. Where *Ecklonia* and *Scytothalia* are clearly dominant at exposed reefs, diversity is reduced compared to assemblages dominated by *Sargassum* and *Cystophora*. The broad distribution of most macroalgae infer that variation in species present among quadrats with niche overlap are common features, making species-specific generalities difficult. How species with low abundances maintain their populations in the relatively exposed archipelago is intriguing and remains to be investigated.

Of the six benthic invertebrate phyla examined in this study, the sponges and the bryozoans were the dominant taxa (Appendix 6). Sponges represented approximately 72% of all fauna collected, bryozoans 10%, ascidians and sea-stars 7%, and hydroids and corals both 2%. A total of 644 individual Demosponges, from 11 out of 15 orders, were collected from 250 quadrats at 10 sites along the Recherche Archipelago.

At the island level all invertebrate fauna showed a similar pattern with variation occurring among islands. This pattern suggests that there was no broad uniform Archipelago wide pattern rather some islands possessed their own suite of fauna. There were no patterns in distribution of sessile benthic invertebrates with exposure in multivariate and univariate analyses. The exception was sponge orders for those islands sampled across two substrata (Figure of 8 and Mondrain Islands) in which there was greater variation between each exposure than within.

As well as characterising the fish distributions within the Recherche Archipelago, this report presents the outcomes of 6 separate components of FRDC 2001/060, and integrates their outcomes. The individual components are as follows:

- Review of existing biological, oceanographic and geomorphological data;
- Benthic habitat mapping in the Recherche Archipelago
- Oceanography of the Recherche Archipelago;
- Sub-tidal soft substrate communities;

- Macroalgal diversity of the Recherche Archipelago;
- Sponge and ascidian communities of the Recherche Archipelago

KEYWORDS: habitat, classification, mapping, oceanography, benthic, algae, infauna, sessile invertebrate

ACKNOWLEDGEMENTS

The FRDC survey 2001/060 "Fish Habitats of the Recherche Archipelego" has as one of its main objectives:

- ***To increase community awareness of fish habitats through community involvement*** *in the development of baseline studies and ongoing monitoring programs.*

The Esperance community has been involved throughout the project as individuals, businesses, community groups, and through the Recherche Advisory Group. The research group has prepared a web page, posters, articles in the popular magazines Landscope and Ecos, regular interviews on ABC Radio, TV and local newspaper articles, educational materials and regularly presented seminars and presentations in Esperance and Perth. The research group has been also involved in helping to run a Tuna Cage Fishing Public Workshop. All of this community activity has been continuously documented as outcomes of our communications strategy at each milestone to FRDC.

As an extension of the FRDC (2001/060) biophysical survey a new program, to develop social and economic profiles of the Recherche Archipelago began in November 2004. Project Manager Neil Lazarow, from the Coastal Cooperative Research Centre (Coastal CRC) is consulting with the Esperance community to map current uses of the Archipelago by locals and visitors alike. This will include a profile of commercial and recreational fishing, tourist operations, commercial shipping and any other ways the Recherche Archipelago is currently used. Information obtained from this project will complement the environmental data obtained by the present three year FRDC project in which RAG has also been a partner. Funding for the project has come from the Department of Conservation and Land Management, RAG, Shire of Esperance and the Coastal CRC.

This project has benefited enormously from the generosity of the Esperance community, whose help, advice and friendship have been instrumental in the development and implementation of the project. Our appreciation and thanks is extended to all who have helped and we specifically would like to thank the following:

- Members of the Recherche Advisory Group (RAG)
- All the volunteers from UWA and Esperance who assisted in the field
- Ross Ainsworth, Sally Castledine and Jane Meiklejohn
- Esperance Freight Lines
- Colin Stewart and the Esperance Port Authority
- Marcus and Michelle Gray
- Peter and Deborah Brown
- Bob and Judy Boord
- Bernie Habberly
- Fud and Faye Mackenzie
- Elaine & Chris Siemer
- Paul Rose
- Kevin McNeil
- Hendrick Rasmussen
- Barry Mercer
- Duke of Orleans Caravan Park
- Neville Longbottom
- Klaus Tiedemann, Tilo Massenbauer, Alan Rose, Conservation and Land Management (CALM), Esperance.
- The staff of Moby Marine
- Nick Middleton
- Peter and Leslie Hudson
- Fugro Survey Pty, Ltd for the generous loan of their Starfix satellite positioning system for the multibeam survey in October 2003.
- Kevin Bancroft, Ray Lawrie and Mark Sheridan, Conservation and Land Management (CALM), Fremantle.

We are also grateful to The Esperance Port Authority, MG Kailis, Portman Ltd and Outokumpou Technology Pty Ltd for cash contributions which made the research program viable.

1.0 GENERAL INTRODUCTION

1.1 Background

The Recherche Archipelago is a chain of approximately 105 islands and 1500 islets extending over 470 km of coastline (230 km linear distance)(Lee & Bancroft, 2001). This region is valued for its relatively untouched wilderness, with a healthy tourism industry. The Archipelago is also valued for its marine resources, and is important for numerous commercial fisheries, such as Abalone, Pilchard, Shark and the Southern Rock Lobster.

Geographical setting

Geology and coastal geomorphology

The geomorphology of the land surrounding the Recherche Archipelago is dominated by isolated, often dome-shaped hills formed by Precambrian metamorphic rocks consisting largely of granite-gneiss (Myers, 1990). The coastline is characterised by arcuate sandy beaches located between the rocky headlands (Sanderson *et al.*, 2000). These headlands, many of which are over 300 m high, are often multiple with small lunate bays and beaches between them. Exposed headlands, facing south and southwest, often have large cliffs or are fronted by steep slopes, which are swept by swell surge (Sanderson *et al.,* 2000). There are also numerous narrow limestone reefs paralleling the shore with the open rocky shores these habitats provide a variety of habitats for marine plants and animals. These rocky shores fall steeply in to the ocean till they reach the ocean floor at depths of 20-30m where the substratum can change abruptly to a sandy substratum

The islands of the Recherche Archipelago are scattered across the entire width of the continental shelf and in geomorphology resemble the granitic headlands of the mainland coast. However, on some islands the granite-gneiss is capped by limestone resulting in a flatter topography where sea-cliffs and shore platforms may be developed (e.g. Goose Island; Fairbridge & Serventy, 1954). The majority of the islands are inaccessible due to their steep dome-shaped sides, only two of the islands, Sandy Hook and Mondrain Islands, have beaches which permit landing from the sea (Fisheries WA, 1999a).

Relative to other areas identified in this review there has been sufficient research on the geology and geomorphology of this region. Fairbridge & Serventy (1954) were one of the first to describe this unique region, since then there have been numerous scientific papers and reports, including ArcInfo digital maps (see Appendix 8.1 R1).

Catchment

The coastal plain catchment is up to 40 km wide in places and consists of numerous small ephemeral streams. In most instances however, the catchment has undergone significant change due to agricultural practices. These changes have put the adjacent streams, pools and inlets at risk to the adverse affects of salinity, sedimentation and eutrophication (Hodgkin & Clark, 1989). Overall the freshwater input into the marine environment is small and intermittent.

Climatic conditions

The Recherche Archipelago experiences a Mediterranean climate, with hot, dry summers and cool, wet winters. In summer temperatures range from 16–26 °C with maximums of 35°C in the January to February period, while winter temperatures, over June to August, average 8-17°C, with minimums of 7°C (Fisheries WA, 1999). Annual rainfall averages 623 mm, the majority falling over the autumn/winter period (May–August), annual evaporation is greatest during the summer months and averaging about 1600 mm (Van Hazel *et al.,* 2001).

In summer the dominant wind direction is from the southeast. The afternoon sea breeze occurs from October to March and in January and February, over 25% of sea breezes exceed 30 km/h. During winter, southwest winds frequently prevail and northwest storm events occur. Periods of calm are few, and occur in autumn and winter (Fisheries WA, 1999).

Oceanography

Previous oceanographic surveys

While there is a small amount of information on the oceanography of this region it is yet to be studied in any great detail, either through field, analytical or numerical modeling methods. Incomplete bathymetry coverage for the Recherche Archipelago is available in ARCINFO GIS digital format as part of the coastal Resource Atlas produced by the WA Department of Transport, Coastal Management Branch. This coverage is not as accurate as the charts published by the Australian Hydrographic Service, R.A.N. However even on these charts many areas are shown as 'un-surveyed' or 'inadequately surveyed'

CSIRO have also collected a range of biological, hydrological and core sample data from this region on a series of voyages from 1951 to 1981 (Appendix 8.1 V1).

Bathymetry

Within the Recherche region the continental shelf is as narrow as 50km in places (Li *et al.,* 1999) widening to as much as 300 km as it approaches the eastern Eucla region (James *et al.,* 1994). The shelf of this region has uneven topography and at the continental slope, drops to approximately 3600 m contrasting greatly with the gently sloping shelf of the main Bight region (Conolly & Von Der Borch, 1967). At the margin of the continental shelf there are numerous deep submarine canyons (Pearce, 2001), for example, Bremer, Stokes and Esperance canyons, the later of which has a vertical relief of approximately 1800 metres (Conolly & Von Der Borch, 1967). In our study area, within the Archipelago the depth of the seafloor averages 40 m, and most of the islands are within the 50m bathymetric contour. However some of the outer islands can rise from as deep as 80 m or more (Australian Hydrographic charts).

Currents, waves and seas

Within the Recherche Archipelago, little is known of currents with the exception of some preliminary modelling of waves and currents currently being undertaken by Dr Charitha Pattiaratchhi at the Centre for Water Research, University of Western Australia.

The southern continental shelf region is storm dominated with high (>2.5m) deep-water wave heights, and long period (> 12s) swell waves, with wavelength of 200m reported (James *et al.,* 2001). This region is characterised by strong thermal fronts as warmer tropical water meets the cooler Southern Ocean waters. The Leeuwin Current flows eastward along the outer continental shelf, with the strongest currents in the autumn/winter period just beyond the shelf break (Godfrey & Vaudrey, 1986). The Leeuwin current has a large influence on the circulation and therefore physical characteristics of the region. Through advection this current prevents water temperatures near the coast from falling below 13°C in winter and maintaining summer temperatures around 22°C (Li *et al.,* 1999). The current is also reported to cause seasonal decreases in salinity during winter and to have an effect on chlorophyll and phytoplankton levels (Van Hazel *et al.,* 2001).

Tides in this region are semi-diurnal with a maximum spring tidal range of 1.1 m (Van Hazel *et al.,* 2001). Localised tidal currents may be experienced between islands or other constrictions, however tidal currents are likely to be insignificant compared with the wind generated currents. Sea surface currents are likely to be significantly higher than those experienced at the sea floor (Pearce, 2001).

For most of the year the Recherche Archipelago is affected by strong, relatively consistent swells from the southwest (Van Hazel *et al.,* 2001). These swells can be reinforced by wind generated waves, and produce a net eastward littoral drift along the south coast (Fisheries WA, 1999). The waves, swell and currents of this region have a significant influence on the coastal geomorphology. James *et al.* (2001) reports that these influences can affect the sorting of sands by oscillatory motion at depths in excess of 100 m. In common with other oceanic waters of the south western Australia the waters off the Archipelago are believed to be nutrient poor.

Biological communities

Previous biological surveys

The study area is encompassed within the WA South Coast region of the Interim Marine and Coastal Regionalisation of Australia (IMCRA Version 3.1) extending from Israelite Bay in the east to Black Head in the west. IMCRA provides users with provincial-scale regionalisations for continental shelf waters, based on classifications of demersal and pelagic fish species diversity and richness

In March 1994 biological ground truthing of the islands within the Recherche Archipelago commenced using methods of 'bounce' diving, vertical video observation, and grab sampling of material (Fisheries, 1999a). In 1998 further ground truthing occurred near Mondrain Island during a voyage of the STS Leeuwin, using drop down TV (Colman, 1997). Currently the ground truth data of a particular area is about 80% accurate.

A broad scale map and classification of the major benthic habitats of Australia's coastline, including the Recherche Archipelago study area, at a scale of 1:100000 was developed by Kirkman (1997). This classification included 180 ground truthing locations. The maps were prepared using the blue band or band 1 of the Landsat TM satellite (Fisheries, 1999a). Bottom types have also been identified by local fishermen (Appendices 8.1 - 3a-3d).

Benthic habitats

Everall (1999) conducted broad scale benthic habitat surveys using towed underwater video cameras. This study identified eight categories of sea bottom (below), however they note that the video tape record of the surveys contain much more information which could be analysed at a more detailed level.

- Dense seagrass
- Medium seagrass
- Sparse seagrass
- Patchy seagrass
- Bare sand
- Flat platform or low profile reef
- Heavy limestone reef
- Granite reef

In 1999 D.A. Lord & Associates identified three broad habitat categories within Esperance bay. Using bounce and drift dives they distinguished: bare sand, seagrass and wrack. Subsequently D.A. Lord & Associates in collaboration with Dr Gary Kendrick at UWA (2001) have conducted an historical mapping study of the benthic habitats in Esperance bay. Using aerial photography, from 1956 to 1995, and an image geo-referencing and rectification technique they identify significant changes in the benthic habitats, particularly seagrass coverage, within the bay.

Invertebrates

There have been relatively little published data on the occurrence, abundance and distribution of benthic invertebrates within the Recherche Archipelago region. However, based on published texts such as Edgar (1997), it is possible to suggest what species are likely to occur (Appendices 8.1 - I1 – I10). It is expected that the invertebrate communities within the Archipelago are abundant, diverse and exhibit a reasonable level of endemism, consistent with that displayed by the south coast marine fauna as a whole. Those invertebrates that have been examined include:

Echinoderms

To date Marsh (1991) is the only published reference on species of echinoderms of the south coast. The author describes the shallow-water echinoderms of the Albany region, South Western Australia. However there have been no intensive collections or taxonomic studies of echinoderms within the Recherche Archipelago, it is believed that the echinoderm assemblages are both diverse and abundant and highly endemic. Based upon the published texts and distribution data it is possible to suggest what species are likely to occur (Appendix 8.1 - I1).

Barnacles

The shallow-water barnacle (Cirripedia: Lepadomorpha, Balanomorpha) fauna of southwestern Australia has a large cosmopolitan component. Jones (1991) describes and provides a key for 31 species of shallow water barnacles (Cirripedia) that have been collected between Albany and the Houtman and Abrolhos Islands. This fauna has a relatively high Australian endemic element and differs markedly from that of northwestern areas (with Australasian, Indian Ocean/Malaysian or Indo-West Pacific affinities). The shallow-water barnacle species (both goose and acorn barnacles) are expected to occur, according to distribution (Appendix 8.1 - I2).

Decapods

Morgan & Jones (1991) record the distribution and habitat of 115 species of decapod crustaceans from the south coast Australia (between Cape Naturaliste and the South

Australian border. Although work has been done the specific abundance and distribution of decapods, with the exception of the Southern Rock Lobster Fishery, decapod research within the study area is generally poor. However, using reference texts to determine relevant distribution, it is possible to suggest which species are likely to occur within the study area (Appendix 8.1 - I3).

Molluscs

The abundance and distribution of molluscs in the study area has yet to be fully established. A small survey was conducted in the Recherche Archipelago by Macpherson (1954) however this provided no quantitative data only providing a description of dead shells collected from beaches in the Archipelago. More research is needed for a greater understanding of species abundances and diversity. Wells & Mulvay (1995) describe the population biology and reproductive ecology of greenlip abalone (Haliotis laevigata) populations at Augusta Esperance and Hopetoun. Alan Longbottom has also compiled an extensive collection and database on molluscs from Esperance region. Based upon the above sources and the references of Macpherson (1954); Wells & Bryce (2000), and; Edgar (1997), the likely occurrence of species within the study area, according to distribution information, has been estimated. Estimates of species occurrence have been made for Chitons (Appendix 8.1 - I4), Prosobranchs (Appendix 8.1 - I5), Sea slugs (Appendix 8.1 - I6), Bivalves (Appendix 8.1 - I7) and Cephalopods (Appendix 8.1 - I8).

Cnidaria

While there have been no intensive collections or taxonomic studies of Cnidaria in the study area Veron & Marsh (1988) make a brief report on coral species that occur in the Recherche region and have a small paragraph discussing the faunal relationships of the south coast. James *et al.,* (1994) also identified four ahermatypic coral species (*Scolymia australis*, *monomyces radiatus*, *Flabellum pavoninum* and a *Charyophillia sp.*) from a single dredge between 180-250 m deep. However there are no published data on other Cnidaria from this region. Based upon the published texts and distribution data Appendix 8.1 - I9 identifies species likely to occur within the study area.

Other invertebrates

Detailed information on the invertebrate fauna from this region is sadly lacking. Britton *et al.* (1991) completed a study on the intertidal fauna of the rocky shores of southwestern Australia identifying patterns in species distribution. Other studies appear opportunistic, such as James *et al.,* (1994) who report a single dredge sample containing numerous sponge, bryozoan, polychaete and ahermatypic coral species. However there are still significant gaps in the published data for many invertebrate phyla from this region. Appendix 8.1 - I10 identifies species from the Porifera, Ctenophora and Chordata that may be expected to occur within the Recherche Archipelago region.

Seagrass and macroalgae

Seagrass

About 60 seagrass species are known worldwide, with one-third of these restricted to southern Australia. The exceptionally clear waters of the southern coast allow seagrasses to grow at depths of up to 30 m (Kirkman & Kuo, 1990) . In his classification of classification of the major benthic habitats of Australia's coastline, including the Recherche Archipelago study area, Kirkman (1997) describes the distribution of sparse to dense seagrass. D.A. Lord & Associates, in collaboration with researchers at UWA (2001), use 42 km of towed video footage to map in detail the distribution of seagrasses within Esperance bay. Other studies that have researched seagrass in this region include, Campey *et al.,* (2000) in their evaluation of the species boundaries among members of the *Posidonia ostenfeldii* complex. Waycott, (1998 & 2000) also sampled seagrasses from this region addressing the genetic variation of individuals within the *Posidonia australis* species.

However, for much of the Recherche Archipelago the exact distribution and abundance of seagrasses is unknown. For the south west coast on the whole there is a high level of endemism with nine out of 17 species being endemic (Kuo & McComb, 1989) (Appendix 8.1 - SG1).

Macroalgae

There have been no intensive collections or taxonomic studies of macroalgae in the study area, however it is believed that the macroalgal community is both diverse and abundant and exhibits a high degree of endemicity. In adjacent regions, such as the Fitzgerald biosphere, numerous macroalgal species have been found to be present (Appendix 8.1 - A1).

Pelagic habitats

Cyanobacteria (non-bloom populations)

There is currently no published information on the distribution and abundance of cyanobacteria within the study site region.

Zooplankton

Relatively little work has been published on zooplankton in this region and a fully comprehensive study has yet to be done. However a study by Gaughan and Fletcher (1997) identified the effects that the Leeuwin Current had on the distribution of carnivorous macrozooplankton in the shelf waters off southern western Australia. They reported low species richness, high variability in abundance, seasonal patterns and a fauna dominated by chaetognaths and siphonophores. They also report a trend for decreasing species richness from west to east.

Planktonic foraminifera

With the exception of Li *et al.,* (1999) there is a paucity of planktonic research in the region. Their study on the foraminifera on the southern shelf of WA identified a total of 21 planktonic species (Appendix 8.1 - I11) and indicated clear planktonic provinces where subtropical species dominated in west and temperate species in the east. With the two provinces overlapping in the Recherche Archipelago between 122 and 124 °E.

Fish

In comparison with other locations around Australia there has been relatively little research into the distribution and abundances of fish species within the Recherche Archipelago region. Those studies that have quantitatively addressed fish diversity and abundance are limited to a survey of the surf zone fish assemblages (Ayvazian & Hyndes 1995) (review & fish species list in Appendix 8.1 - F1), and Gaughan *et al's.*, (2000) study on the mass mortality of the pilchard *Sardinops sagax*. There are also semi-quantitative visual surveys of nearshore reef fish assemblages by Hutchins (1994). The study identified 172 species (91% warm temperate, 7% subtropical) of fish with a distinct "offshore" versus "inshore" effect on diversity of tropical species, attributed to the Leeuwin Current (review & species list in Appendix 8.1 F2). Other work in the area includes age structure and reproductive biology for pilchards (Gaughan *et al.* 2001) and a recent biodiversity study by Hutchins (2001). This study identified that 28% of the shallow water reef fish identified were endemic to the Recherche Archipelago.

Despite the few studies conducted in this region it is expected, based on known distribution data, that the elasmobranch and osteichthyes species listed in Appendices 8.1 - F3 and 8.1 - F4 are likely to occur within the study area.

Australian salmon & herring nursery

The region extending from east of Esperance through to the WA/SA border is an important WA nursery for Australian salmon (*Arripis truttacea*) and Australian herring (*Arripis georgiana*) (Fisheries WA, 1995). This has been confirmed with capture of:

a) Post-larval Australian salmon and herring in plankton trawls from the western Great Australian Bight, &;

b) Small >0 year old Australian salmon and herring at a number of shoreline locations throughout this region.

Leafy and weedy seadragons

Seadragons (Family Sygnathidae) and are only found in Australia's southern waters and both the leafy seadragon (*Pycodurus eques*) and the weedy seadragon

(*Phyllopteryx taeniolatus*) occur within the study area. The area from Albany to Esperance appears to be important for both species of seadragon, with the majority of sightings coming from the reef and seagrass beds associated with the bays, sounds and headlands within this area. Eighteen percent of these sightings have come from the within the Recherche Archipelago (Dragon Search, 1998-2000).

Fishing

Recreational fishing

Since 1987 the number of recreational fishers in the Recherche Archipelago, Western Australia has more than doubled from 284,000 people to between approximately 500,000 and 600,000 people a year. The most targeted inshore species include Australian herring, whiting and Australian salmon (CALM, 1994). Offshore species include queen snapper, bight redfish, samsonfish (*Seriola hippos*), breaksea cod (*Epinephelus armatus*), blue groper and sharks. Netting is undertaken mostly in estuaries, such as Stokes Inlet, Torradup River and Jerdacuttup River, for species such as sea mullet, yelloweye mullet, Australian herring and black bream. In addition, rock lobster potting, squid jigging and diving for abalone occurs in the study area.

Commercial fishing & aquaculture

There are currently six commercial fisheries operating within the Recherche Archipelago region. The largest commercially targeted species are shark, pilchards, southern rock lobster and abalone. Other species caught include queen snapper, red snapper, blue groper and scallops. Commercial fishing within the study region comprises the following managed fisheries:

South coast purse seine fishery

This fishery involves the purse seining of small pelagic fish, primarily pilchards (*Sardinops neopilchardus*), within four prescribed zones along the southern coast and has taken place in the Esperance. Gaughan *et al.,* (2000) identified that the mass mortality events, due to the herpesvirus, are already having effects on this fishery.

Annual catches of pilchards from the region in 1999 were 730 t, considerably less than the expected catch of 4-5000t.

Southern demersal gill net and demersal longline fishery

The demersal gillnet and demersal longline fishery, primarily targets gummy (*Mustelus antarcticus*), whiskery (*Furgaleus macki*) and dusky or bronze whaler (*Carcharhinus obscurus*) sharks and demersal scalefish. Key species of scalefish include deepwater fishes such as leatherjackets (*Monocanthidae spp*.), hapuku (*Polyprion oxygeneios*), blue-eyed trevalla (*Hyperoglyphe antarctica*) and grey-banded rock cod (*Epinephelus septyemfasciatus*), together with species that can be taken closer inshore such as bright redfish (*Centroberyx gerradi*), queen snapper (*Nemadactylus valenciensi*) and blue groper (*Achoerodus gouldii*) (CALM, 1994).

South coast estuarine fishery

The South Coast commercial estuarine fishery operates in all of the South Coast estuaries from west of Albany to the Recherche Archipelago. Catches are dominated by black bream (*Acanthopagrus butcheri*) and to a lesser extent, yelloweye mullet (*Aldrichetta forsteri*) and sea mullet (*Mugil cephalus*). Small catches of blue manna crabs (*Portunus pelagicus*), cobbler (*Cnidoglanis macrocephalus*) and squid are taken in some estuaries.

Esperance rock lobster managed fishery

The Esperance Southern rock lobster fishery is located between 120°E (near Hopetoun) and 125°E (near Point Culver) and south to the limit of the Australian Fishing Zone (AFZ). The rock lobster season operates between 15 November and 30 June and each licence is entitled to 10 pots per metre of boat length, with a maximum entitlement of 90 pots.

South coast demersal trawl fishery

Currently managed under Western Australian State jurisdiction this fishery extends offshore to the 200m isobath between Cape Leeuwin and the Australian Bight. The target species are demersal finfish such as queen snapper, bright redfish, boarfish (*Pentacerotidae spp.*) and deepwater flathead (*Neoplatycephalus conatus*). Scallops (*Pecten spp.*) are also seasonally open (April 1 to November 30) fished within the Archipelago.

Abalone fishery

Abalone is one of the most valuable nearshore resources harvested off the South Coast. Commercial abalone operations are managed in two zones, on either side of Shoal Cape (120°E) (CALM, 1994). The boundaries of the Zone 1 abalone fishery extend from the WA/SA border to Shoal Cape. Areas worked include Sandy Hook Island, Remark Island, Frederick Island, Long Island, the Mart Group and Middle Island. Currently only three species of abalone, Roe's (*Haliotis roei*), greenlip (*H. laevigata*) and brownlip (*H. conicopora*) are targeted.

Off shore tuna fishery

Currently managed by the Australian government, the southern bluefin tuna (*Thunnus maccoyii*) fishery operates from the major South Coast ports, including Esperance.

Aquaculture

Currently, there are no land or sea-based aquaculture activities operating within the study area. However, Fisheries Western Australia identified that the Recherche Archipelago has significant potential for supporting aquaculture enterprises (Fisheries WA, 2000). Areas identified by Fisheries WA as potentially suitable for both land-based and sea-based aquaculture and the relevant selection criteria are outlined in Appendices 8.1 - Aql & 8.1 - Aq2. Candidate species suitable for potential aquaculture ventures were also identified (Appendix 8.1 - AQ3).

Current gaps in knowledge

The Recherche Archipelago region represents a substantial gap in our knowledge of the western Australian coastline. This review has highlighted the limited amount of quantitative data currently available across all groups of organisms. Spatial data in the form of 1:500, 000 maps (Kirkman, 1997), and some towed video (Fisheries, 1999a;

Gaughan, pers comm.) exists however this resource does not have broad scale coverage. Bathymetric data from this area is poor with approximately 33% of the Recherche Archipelago region having inadequate, or no bathymetric information.

BACKGROUND REFERENCES

Ayvazian, S.G. & G.A. Hyndes. (1995). Surf-zone fish assemblages in the south-western Australia: do adjacent nearshore habitats and the warm Leeuwin current influence the characteristics of the fish fauna? Marine Biology. 122: 527-536

Britton *et al.* (1991). identified relationships between topography, substratum and surface temperature in determining the spatial distribution of intertidal fauna of the rocky shores of southwestern Australia.

CALM (1994). A representative marine reserve system for Western Australia. Report of the marine parks and reserves selection working group

Campey, M. L., Waycott, M. & G.A. Kendrick. (2000). Re-evaluating species boundaries among members of the *Posidonia ostenfeldii* species complex (Posidoniaceae) – morphological and genetic variation.

Colman J.G. (1997). Biological verification of the major benthic habitats of the south coast (Mondrain Island - Albany): 10-21 February 1997, Field Program report: MRIP/SC - 2/97. Marine Conservation Branch, CALM, Fremantle.

Conolly, J.R. & C.C. Von Der Borch. (1967). Sedimentation and physiography of the sea floor south of Australia. Sedimentary Geology. 1: 181-220.

Edgar, G.J. (1997) Australian Marine Life: the plants and animals of temperate waters. Reed Books, Hong Kong.

Fairbridge, R.W., & V.N. Serventy. (1954). 1b. Physiography. *In,* The Archipelago of the Recherche: 9-28.

Fisheries WA. (1995). "Draft report of the south coast estuarine fishery working group"

Fisheries WA, Everall Consulting Biologists and Fish Unlimited. (1999). Draft aquaculture plan for the Recherche Archipelago, WA.

Fisheries WA & Everall Consulting Biologists. (1999a). Draft aquaculture plan for the Recherche Archipelago, WA: Benthic habitat survey of the Remark, Mart, Mondrain, Tory and York Island groups in the Recherche Archipelago.

Fisheries WA. (2000). Aquaculture plan for the Recherche Archipelago. Fisheries Management Paper No. 140

Gaughan, D.J. and W.J. Fletcher. (1997). Effects of the Leeuwin current on the distribution of carnivorous macro-zooplankton in the shelf waters off southern Western Australia. Estuarine, Coastal and Shelf Science 45: 89-97

Gaughan, D.J., Mitchell, R.W., & S.J. Blight. (2000). Impact of mortality, possibly due to herpesvirus, on pilchard *Sardinops sagax* stocks along the south coast of Western Australia in 1998-1999. Mar. Freshwater Research, 51: 601-612.

Gaughan, D.J., Baudains, G.A., Mitchell, R.W.D., & T.I. Leary. (2001). Pilchard (*Sardinops sagax*) nursey areas and recruitment process assessment between different regions in southern Western Australia. Fisheries Research Report No. 131.

Gaughan, D.J., White, K.V. and W.J. Fletcher. (2001). The links between functionally distinct adult assemblages of *Sardinops sagax*: larval advection across management boundaries. ICES Journal of Marine Science, 58: 597-606.

Godfrey, J.S., Vaudrey, D.J. & S.D. Hahn. (1986). Observations of the Shelf-edge current South of Australia, Winter 1982" J. Phys. Oceanog. 16: 668-679.

Hodgkin, E.P., & R. Clark. (1989). Estuaries and coastal lagoons of South Western Australia: Estuaries of the shire of Esperance, Stokes Inlet, Oldfield Estuary and ten others. Environmental Protection Authority, Estuarine Studies Series, 5.

Hutchins (1994). "A survey of the nearshore fish fauna of Western Australia's west and southwest coasts - The Leeuwin province". Records of the Western Australian Museum. Supplement # 46

Hutchins, J.B. (2001). Biodiversity of shallow reef fish assemblages in Western Australia using a rapid censusing technique. Records of the Western Australian Museum, 20: 247-270.

James, N.P., Boreen, T.D., Bone, Y., & D.A. Feary. (1994). Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. Sedimentary Geology, 90: 161-177.

James, N.P., Bone, Y., Collins, L.B. & T.K. Kyser. (2001). Surficial sediments of the Great Australian Bight: facies dynamics and oceanography on a vast cool-water carbonate shelf. Journal of Sedimentary Research 71:549-567

Kirkman, H. (1997). Benthic habitat mapping (describes how data was collected and interpreted: i.e. Landsat TM satellite imagery for interpretation and ground truthing via bounce dives).

Kirkman, H. & J. Kuo. (1990). Pattern and process in southern Western Australian seagrasses. Aquatic Botany, 37: 367-382.

Kuo J. & A.J. McComb. (1989). Seagrass taxonomy, structure and development. In Biology of Seagrasses: A Treatise on the Biology of Seagrasses with Special Reference to the Australian region. Larkum, A.W.D., McComb, A.J. & Sheperd, S.A. (eds) pp6-73. Elsevier, Amsterdam.

Lee, S. & K.P. Bancroft. (2001). Review of the existing ecological information for the proposed Recherche Archipelago marine conservation reserve. Literature review. MRI/WSA, EUC/SIN, RAR-51/2001 (Marine Conservation Branch, CALM).

Li, Q., James, N.P., Bone, Y. & B. McGowran. (1999). Paleoceanographic significance of recent foraminiferal biofacies on the southern shelf of Western Australia: a preliminary study. Palaeogeography, Palaeoclimatology, Palaeoecology. 147: 101-120

D.A. Lord & Associates. (1999). Esperance Harbour Redevelopment: Marine Environmental Studies. Report prepared for Environmental risk Solutions, Report No. 99/106/1.

D.A. Lord & Associates. (2001). Interim report on historical benthic habitat mapping in Esperance Bay. Prepared for Esperance Port Authority. Report No. 00/172/1.

Macpherson J.H. (1954). The Archipelago of the Recherche, Part 7, Molluscs. Report of the Australian Geographical Society, 1: 55-63.

Marsh L.M. (1991). Shallow water echinoderms of the Albany region, south-western Australia. In: The Marine Flora and Fauna of Albany, Western Australia, Volume II. Western Australian Museum: 439-482.

Morgan G.J. & D.S. Jones. (1991). Checklist of the marine decapod Crustacea of southern Western Australia. *In* F.E. Wells, D.I. Walker, H. Kirkman & R. Lethbridge (Eds). Proceedings of the Third International Marine Biological Workshop: The Marine Flora and Fauna of Albany, Western Australia, Volume **II**: 483-497. Western Australian Museum, Perth.

Myers, J.S. (1990). "Western Gneiss Terrane" *In* "Geology and Mineral Resources of Western Australia", Geological Survey, Western Australian Memoirs, **3**:13-32.

Pearce, A.F. (2001). Ocean Temperature variability off Esperance, Western Australia. Report prepared for CSIRO Fisheries WA. (unpublished report).

Sanderson, P.G., Eliot, I., Hegge, B., & S. Maxwell. (2000). Regional variation of coastal morphology in southwestern Australia: a synthesis. Geomorphology, 34: 73-88.

Van Hazel, J.H., Pattiaratchi, C., & N. D'Adamo. (2001). Review of the climate and physical oceanography of the Recherche Archipelago and adjacent waters

Veron, J.E.N. & L.M. Marsh. (1988). Hermatypic Corals of Western Australia. Records and annotated species list. Records of the Western Australian Museum, Supplement **29.**

Waycott, M. (1998). Genetic variation, its assessment and implications to the conservation of seagrasses. Molecular Ecology, 7: 793-800.

Waycott, M. (2000). Genetic factors in the conservation of seagrasses. Pacific Conservation Biology, 5: 269-276.

Wells, F.E. & C.W. Bryce. (2000). Seashells of Western Australia. Revised edition. Western Australian Museum, Perth. 207 pp.

Wells, F.E. & C.W. Bryce. (2000). Seaslugs of Western Australia. Western Australian Museum, Perth. 208 pp.

Wells F.E. & P. Mulvay. (1995). Good and bad fishing for *Haliotis laevigata*: a comparison of population parameters. Marine and Freshwater Research, 46: 591-598.

1.2 Need for Study

Fisheries WA have identified the need for a detailed, fish habitat assessment of the Recherche Archipelago in their recently released Aquaculture Plan of the Recherche Archipelago (Fisheries WA 2000). User surveys and community consultation reports completed for this plan describe community and fishing industry concerns for ocean cage fishing in the region without further broad-scale habitat assessments (Fisheries WA 1999b, c). Furthermore, Fisheries WA is soon commencing work on a regional Fisheries Environmental Management Review for the south coast region. The spatial data we intended to collect here will be valuable input for this planning process. As well as the direct need for this information by Fisheries WA, CALM –WA is proposing a Marine Park in the region and will also benefit directly from this project. Previous Fisheries WA sponsored attempts to establish Tuna cage farming and Conservation and Land Management proposals for a Marine Park in the Recherche Archipelago have met with strong, well-organised local opposition. While some of the opposition may be attributed to inadequate community consultation, much of it can be explained by limited or incorrect baseline information.

1.3 OBJECTIVES

1. To identify, classify and map the distribution of benthic habitats in the Recherche Archipelago and link their distributions to bottom type and exposure to swells and currents.
2. To provide detailed ecological information to ensure the responsible management of aquaculture fisheries in the region.
3. To increase community awareness of fish habitats through community involvement in the development of baseline studies and ongoing monitoring programs.

2.0 GENERAL MATERIALS AND METHODS

2.1 Study area

This section focuses on fine-scale detailed sampling in island groups in Esperance Bay (Woody Island and Remark Island groups, Mondrain and Figure of Eight Island) and between Duke of Orleans Bay and Cape Arid (Mart, Twin Peaks and Middle Island). Fish, macroalgae and sessile benthic invertebrates were studied from the same locations and depths at the same time.

2.2 Sampling regime

In October 2002, macroalgae, sessile invertebrates and reef fish assemblages were surveyed in the Recherche Archipelago, by stratifying sampling by depth, exposure and island group. The factor depth was stratified into three groups: <10 m, 10 to 20 m, 20 to 28 m (hereafter referred as >20 m). Exposure was defined as sheltered (mainland-facing side of the island) and exposed (seaward-facing side of the island). Island groups consisted of islands inshore (Woody, Thomas, and Black Island) and offshore (Remark, Long, and Frederick) Esperance Bay as well as Mondrain and Figure of Eight Islands, within the Western Archipelago. In October 2003, macroalgae and sessile invertebrates were also sampled in the Eastern Archipelago at Mart, Middle, and South Twin Peaks Island.

The objective of this study was to characterise the fish and benthic assemblages across a range of spatial scales. This was to investigate large scale patterns between islands of the Recherche Archipelago (10's if kilometres) as well as smaller scale differences between exposed and sheltered sites (100's of metres).

2.2.1 Reef fish (Main report plus appendices 8.4.1-8.4.2)

For reef fish we identified, counted and measured the fork lengths of all reef fish seen within a 25 m long by 5 m wide and 5 m high transect (625 m^3). At each reef, eight replicate transects were recorded at each of three depths (24, 15 and 5 metres) using an underwater stereo-video system. The eight transects at each depth, exposure and reef isolation were pooled, effectively creating one transect of 200 m in length. Within each Reef Isolation category 3 inshore; 3 offshore reefs and 4 for remote reefs were sampled. We sampled when water visibility was greater than 5 m and between 08.00 and 16.00 hrs.

2.2.2 Macroalgae (Appendices 8.5.1-8.5.3)

For macroalgae, at each site divers collected macroalgae (>1 cm long) by hand in 0.25 m^2 quadrats ($n = 6$ per depth stratum), within gently-sloping, granitic reef areas. Algae were sorted, identified to species, wet-weighed, and densities counted. Identifications were confirmed by H.B.S. Womersley (State Herbarium of South Australia, Adelaide). Voucher specimens were deposited at the University of Western Australia Herbarium, designated with the accession prefix: UWARA.

2.2.3 Invertebrate fauna (Appendices 8.6.1-8.6.4)

Benthic invertebrate fauna were collected from horizontal substrata at eight islands: Black, Thomas, Woody, Remarck, Frederick, Long, Figure of Eight and Mondrain. Invertebrate habitats were sampled at sheltered and exposed sites within an island, and at a range of depths: waters 0-10m, 10-20 m, and waters 20-25 m depth, with equal numbers of quadrats taken from each exposure and depth. During the 2002 field program the sampling design was modified to capture habitats associated with vertical substrata in addition to the horizontal substrata to determine if there was variation in species structure, composition & abundance between vertical and horizontal strata. Sampling only occurred at a single depth (approx 15 m). This new sampling regime commenced at Remarck and Mondrain Islands and continued in 2003 for Mart, Southern Twin Peaks and Middle Island.

3.0 Benthic Habitat Mapping in the Recherche Archipelago.

Baxter, K., A. Bickers[1], G. Kendrick[1] & M. Shortis.

3.1 INTRODUCTION

The FRDC survey 2001/060 "Fish Habitats of the Recherche Archipelago" has as its main objective:

"To identify, classify and map the distribution of different benthic habitats in the Recherche Archipelago and link their distributions to bottom type and exposure to swells and current"

This report addresses mapping of benthic habitats of the Recherche Archipelago. It is a relatively unstudied area of the southern West Australian coastline, and consists of 105 islands and 1500 known reefs and islets distributed along 470km of coastline.

The production of maps showing the distribution of seafloor features and characteristics and the organisms that colonise them is fundamental to our goals. Maps of this type are commonly known as 'habitat maps' and are an essential tool in the management of fisheries resources and marine ecosystems. A 'habitat' can be defined simply as 'the place where an organism lives', or more relevantly for the purposes of mapping as 'a distinct association between an identifiable environment and the range of species that live there'. Therefore we describe a habitat not only by the physical factors that characterise an area such as substrate, depth, chemistry and exposure to waves and currents, but also by the associations with the organisms that inhabit the area. These associations are usually simplified or aggregated into a range of standard habitat classifications.

Mapping the nature and distribution of benthic habitats in a large area such as the Recherche Archipelago is generally undertaken across a range of scales using a number of complementary techniques and requires the use of tools that can survey large areas efficiently. Aerial and satellite radiometric and photographic techniques are generally used for terrestrial environments, but the poor propagation of electromagnetic waves (light) in water limits these optical techniques to waters of 15m deep or less in most marine and freshwater areas. Sound however propagates relatively well in water and is commonly used in all sonar systems to obtain information about the depth, water column and nature of the seabed acoustically.

In this study we used a range of optical and acoustic technologies. The relatively clear waters of the Recherche allowed satellite imagery to be used to determine coarse boundaries between habitat types in shallower water (15 – 20 m depths) where there was adequate light penetration. Extensive broad scale surveys were undertaken using sidescan sonar, an established acoustic technique allowing almost photographic quality imagery of seafloor texture to be obtained from swaths of up to 400m wide. Drop and towed video systems were used to obtain more detailed information about the physical and biological nature of the seabed in areas identified from the acoustic mapping. These were supplemented by even finer scale physical sampling by grabs and divers. Collection of field data occurred in the spring and autumn of 2002 and 2003.

The habitat classification and mapping component of the broader FRDC 2001/060 research project has resulted in spatially extensive knowledge of marine habitats, across a range of spatial scales from 100s of square metres to 1000's of square kilometres. The habitat data compliments extensive fish surveys and intensive biodiversity surveys of reef fish, seaweeds, sponges, ascidians corals and infaunal invertebrates. Generalisable predictions as to the distribution of species and the structure of these biotic assemblages have been made in relation to exposure to ocean swells, depth, functional habitat type and location within the Archipelago in the attached individual reports. These predictions suggest that distributions of these organisms can be modelled from a combination of habitat, bathymetry and ocean swell data.

3.2 Study site

Little is known of the spatial extent of the substrates and benthic habitats of the Recherche Archipelago, a large, relatively unstudied area located on the south coast of Western Australia, near Esperance (Figure 3.1). The Esperance coastline consists of granite headlands, coastal embayments and beaches. The Recherche Archipelago lies offshore, consisting of 105 islands and up to 1500 known reefs and islets. The islands are scattered over 470 km of coastline, no further than 60 km offshore and in depths of up to 80 m. In this area the continental shelf encroaches on the mainland to within

50 km (Clarke, 1952). Over 50% of the Archipelago remains uncharted. Winter swells are predominantly from the south west, although wind driven wave action from the south east is a common occurrence during the summer months.

The subtidal geology (substrate and sediment types) of the Recherche are poorly documented, limiting our understanding of the role of geology in shaping the composition of habitats found. It is expected patterns in the terrestrial geology may be repeated offshore, as the predominantly granite, dome shaped islands are similar to the hills and headlands seen on the mainland (Myers, 1990). The granite headlands formed when portions of the earth's crust collided during continental collision, melted and then cooled, about 1200 million years ago (Myers, 1990). The landscape was gradually uplifted and eroded leaving large, steep sided granite domes, or monadnocks, protruding above the generally flat surrounding landscape. Physical and chemical weathering of the granite results in 'onion peeling' of slabs of granite breaking from the surface of the dome. Blocks of granite or 'tors' also weather around the edges and ultimately separate from the granite dome, sliding down near the base, increasing the complexity of nearshore and island bathymetry. In between the isolated islands, flat regions are punctuated unpredictably by limestone reefs, which are often inundated by sand (Myers, 1990; Kirkman, 1996). These reefs are likely to represent former Pleistocene sand dunes (shorelines) that have calcified and then hardened during periods of sea level retreat.

The Archipelago is valued for its marine resources and is an important habitat for numerous commercial fisheries, including abalone, pilchard, shark and the Southern Rock Lobster. Yet habitat information for the Archipelago is scarce. The current lack of knowledge of the extent and type of marine habitats presents significant difficulties for both state and local agencies required to make informed planning decisions about the use and management of marine areas in the Archipelago (Kendrick *et al.*, 2002). In the past, towed video surveys were undertaken in isolated locations (Everall, 1999), and Landsat imagery interpreted to document shallow water habitats in portions of the Archipelago (Kirkman, 1996). From these studies it is generally known that sheltered coastal embayments typically support dense seagrass communities and macroalgae tend to dominate shallower granite and limestone reefs. Deeper reefs (>40m) are often colonised by sponges, bryozoans and ascidians (Kirkman, 1996; Everall, 1999).

In this study a range of methodologies were used to increase our knowledge of the habitats and substrate types within the Recherche Archipelago. Survey data was obtained across the Archipelago from Figure of Eight Island in the west to Middle Island in the east, although given the size of the Archipelago, efforts were concentrated in three main regions: (1) the greater Esperance Bay region (2) the Duke of Orleans region and (3) Cape Arid (Figure 3.2).

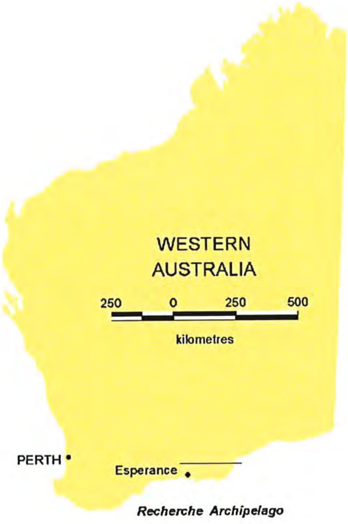


Figure 3.1: Location of Recherche Archipelago in Western Australia.

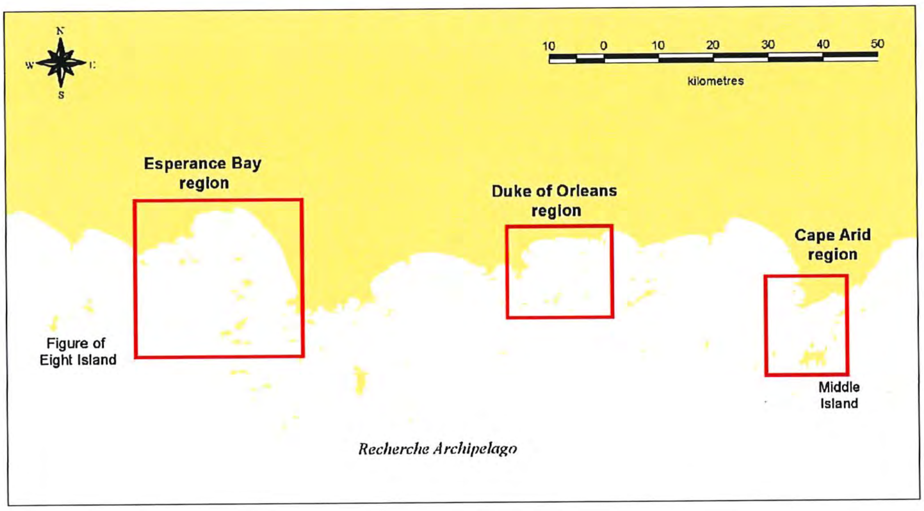


Figure 3.2: Location of study regions in Recherche Archipelago.

3.3 METHODS

Methods will be presented in 5 levels. Firstly, an overview of the mapping programs will be presented. This outlines the methods used to collect and compile habitat data throughout the project. Key stages include the development of a classification scheme and a Geographic Information System or GIS. The GIS was used to collate existing data and the data collected using the different survey methods. Methods used to classify, map and describe the habitats identified are also outlined.

3.3.1 Habitat mapping overview

Mapping field programs were concentrated between Autumn 2002 and Spring 2003 (Table 3.1). Each field program had a different emphasis and extent. The programs are briefly described below.

Table 3.1: Details of mapping surveys of the Recherche Archipelago completed between 2002 and 2003.

Season	Vessels Used	Areas Surveyed	Survey Types	Video	Acoustics
Autumn 2002	Sargassum Barrambie Sea Urchin Jumbo Sarah 3	Esperance Bay Duke of Orleans Cape Arid	Drop Video	3100 drops	n/a
Spring 2002	Sargassum Jumbo Deborah Anne Southern Image	Esperance Bay	Towed Video Sidescan Sonar	14km towed	73km2 sidescan
Autumn 2003	Sargassum Sea Urchin Stacey Jay	Esperance Bay Duke of Orleans	Towed Video Sidescan Sonar	10km towed	144km2 sidescan
Spring 2003	Sargassum Stacey Jay Firebird	Esperance Bay Duke of Orleans Cape Arid	Towed Video Sidescan Sonar Multibeam Sonar	28km towed	211km2 sidescan 11km2 multibeam
			Total	3000 drops 52km towed	428km2 sidescan 11km2 multibeam

A drop video survey was undertaken throughout the Archipelago in Autumn 2002 (Figure 3.3). The 3000 video locations obtained from this survey allowed a hierarchical classification scheme for the area to be devised to classify identifiable or functional habitat types based on combinations of physical and biological variables. As the project progressed, the classification scheme was modified to incorporate knowledge of habitats acquired from an increased familiarity with the region and the techniques used during surveys. The initial video survey covered the full extent of the survey area and allowed for fine scale sampling to be targeted through the Archipelago. It also assisted in the targeting and validation of the acoustic surveys.

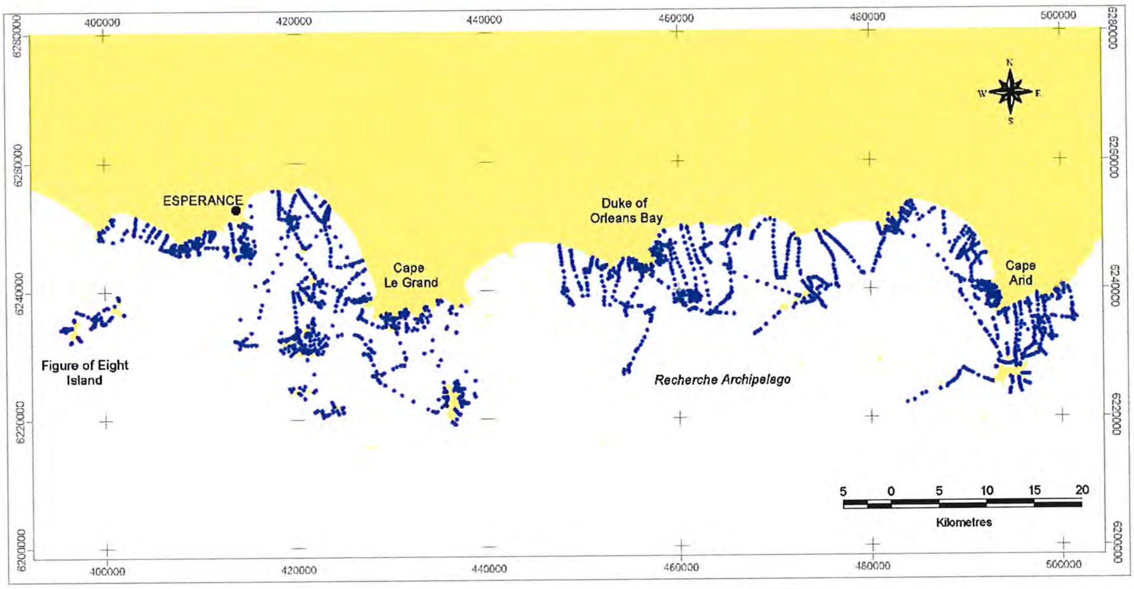


Figure 3.3: Locations of drop videos, dots indicated drop camera locations.

A sidescan sonar was deployed in the field seasons of Spring 2002 and Autumn and Spring of 2003 (Figures 3.4 & 3.5). Although the swaths of sidescan sonar are wide and up to 4 km^2 hr^{-1} of seabed can be covered, the large study area of the Recherche (~ 5000 km^2), the remoteness of some areas and the relatively small weather windows available meant that full coverage could not be achieved. Areas were targeted for either full or partial coverage. Full coverage of representative areas was obtained for Woody and Remark Island groups, allowing detailed analysis of habitat distributions. Partial coverage of between 20 and 50% was achieved using a grid of survey tracks. Information about the seabed was interpolated between tracks.

In the final survey season a multibeam system was deployed in the Recherche (Figures 3.4 & 3.5). This emerging technology acquires not only imagery of the seabed, but accurate fine scale bathymetry with soundings spaced at 1m or less. The swath width of the system used is however significantly smaller than that of the sidescan sonar and only small areas could be surveyed in the available time. The Woody and Remark Island groups were primarily targeted for this survey.

In total, 430 km^2 of sidescan sonar imagery was obtained. This was validated by over 53km of towed video and 3000 drop video locations (Figure 3.6). Eleven square km of multibeam bathymetry was also obtained. Global Positioning System (GPS) technology was used throughout all surveys to facilitate positioning of the data obtained. This allowed the acquired data to be integrated with existing data and compared within a Geographic Information System (GIS). The GIS facilitated interpretation of the data into a habitat map, an aggregation of the area into regions relating to the classification system. Substrate boundaries on the processed sidescan mosaic were outlined visually within the GIS into areas of different texture, patterning or morphology. 'Drop' and towed video were used to verify the boundaries interpreted from the sidescan imagery and provided qualitative information about the substrate and biological communities of each. Aside from the sidescan sonar imagery and video, existing datasets such as satellite imagery (Landsat) and bathymetry were also interpreted to define and validate functional and broad habitat types. From this information, maps were produced of broad and functional habitats, according to a standard classification scheme and the areas of each habitat calculated. Descriptions of physical and biological characteristics were also exported from the GIS and analysed using advanced techniques such as decision trees in attempts to explain the distribution of habitat types.

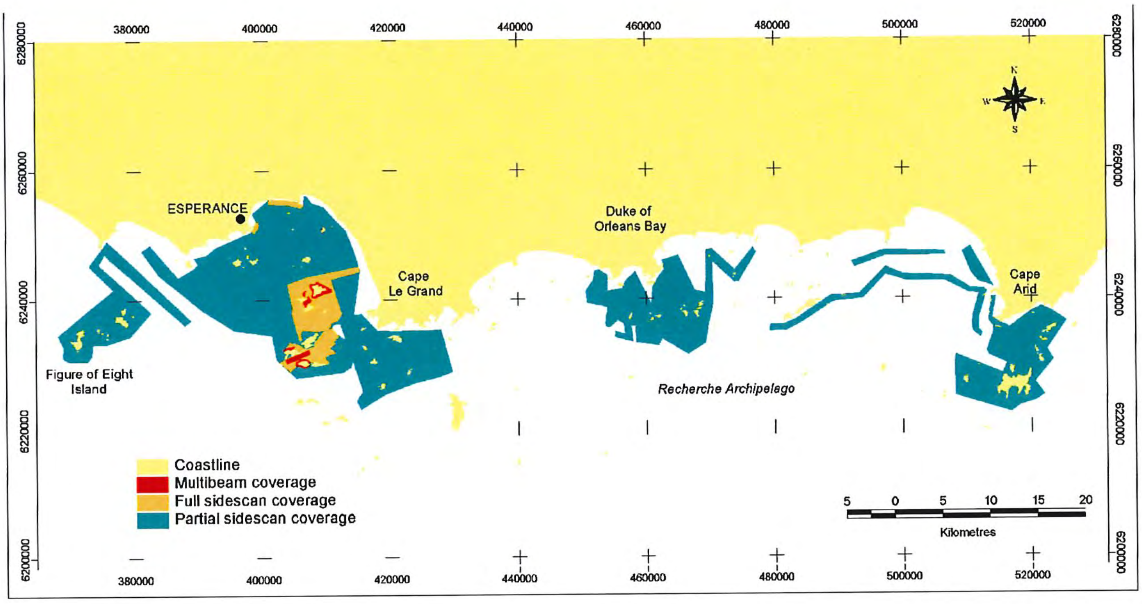


Figure 3.4: Locations of sidescan sonar and multibeam sampling across Recherche Archipelago.

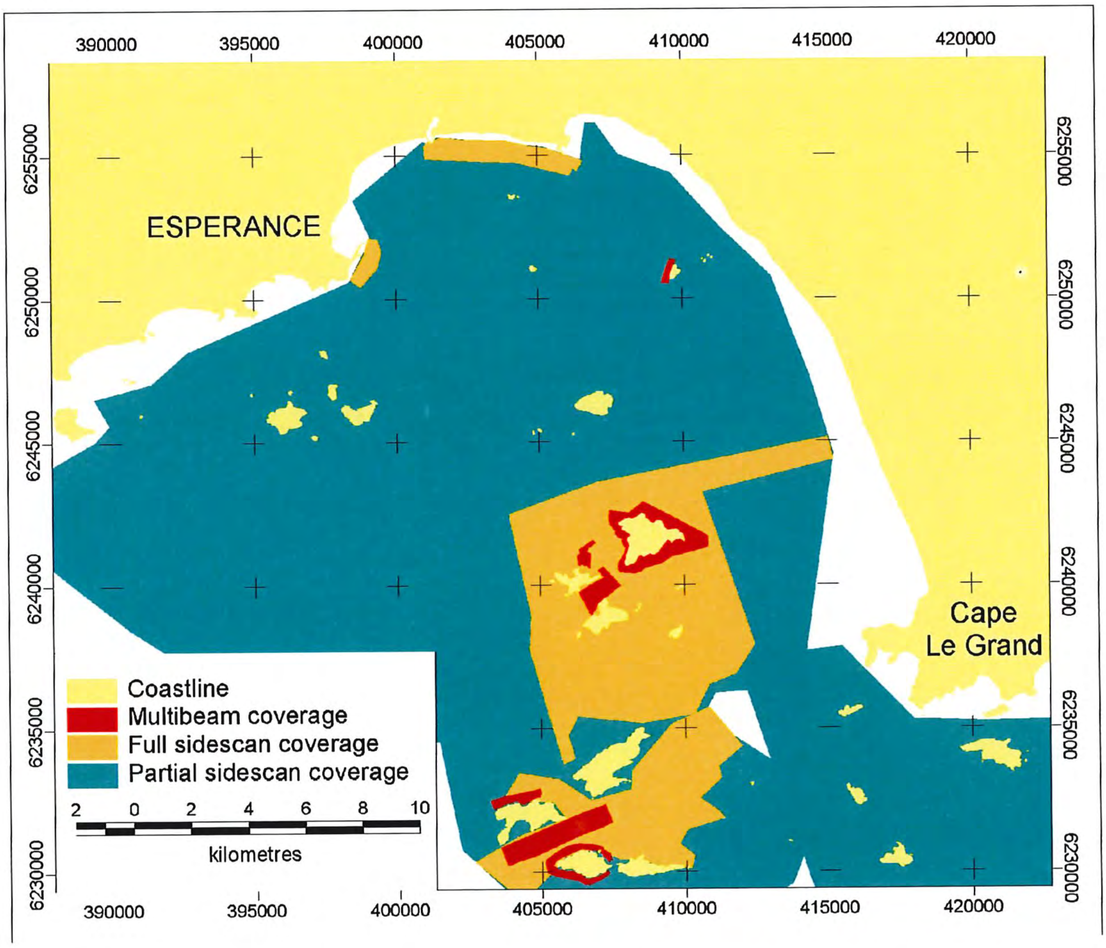


Figure 3.5: Locations of sidescan sonar and multibeam sampling in Esperance Bay.

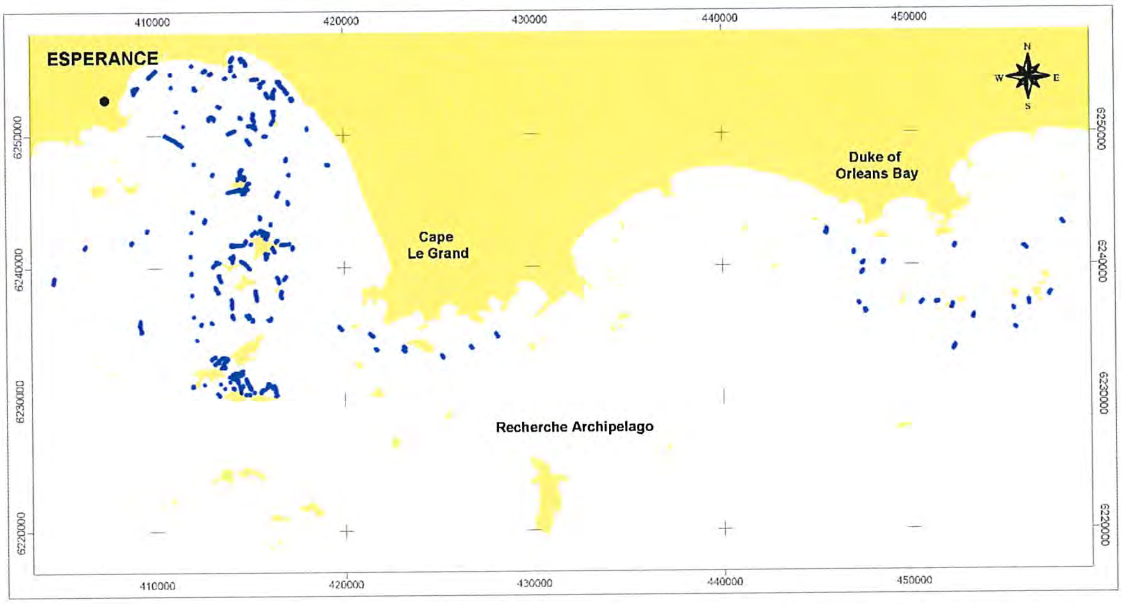


Figure 3.6: Locations of towed video transects used for validating hydroacoustic sampling.

3.3.2 CLASSIFICATION SYSTEMS AND GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Classification Systems

A hierarchical marine classification system was developed for use in the Recherche. As the area had not been extensively surveyed using the techniques employed in this project, the initial classification scheme proposed was conceptual. The scheme was based on the existing State Marine Classification Scheme (Bancroft, 2002) and expert knowledge of the expected range of habitats and communities of the region. Throughout the project it was 'tuned' to be more representative of the habitats encountered and the survey techniques used. The final classification scheme is described here.

Habitats were described as combinations of the identifiable physical and biological characteristics (Table 3.2). Biological factors were classified in terms of observation of cover of dominant community and by the presence of a number of biological assemblages. Physical factors were classified in terms of depth, substrate and relief.

Common combinations of these factors were used to produce the functional, or identifiable habitat descriptions shown in Table 3.3. For instance when substrate is 'reef', relief is 'gently sloping', community is 'macroalgae' and cover is 'dense', the functional habitat description is ‘low profile reef with macroalgae’. These functional types were added to the classification scheme to provide a link between the broad descriptions and fine scale biological data obtained from video or direct sampling methods. The functional types can be aggregated to provide broad habitat descriptions that simplify the detail observed and mapped. This hierarchical classification system allows for the incorporation of information from a range of sensors.

Table 3.2: Classification scheme using physical and biological factors.

PHYSICAL FACTORS		**BIOLOGICAL FACTORS**	
		Dominant Community	Biological assemblages
Substrate Type S1. sand S2. mud S3. rhodoliths S4. reef S5. mixed *Depth*	Qualifiers *Relief* R0. flat R1. gently sloping (5-35°) R2. steeply sloping (35-70 °) R3. vertical walls (70-90 °) and overhangs/caves R4. rippled R5. mega-ripples (>20cm)	H1.Macroalgae / seaweeds	• Canopy 1. Kelp (Ecklonia/ Scytothalia) • Canopy 2. Cystophora/Sargassum/ • Platythalia/Acrocarpia • Rhodophyta (rho) • Phaeophyta (pha) • Chlorophyta (chl)
		H2. Seagrasses	• *Posidonia sinuosa, P. australis, P. angustifolia* (psin) • *Posidonia ostenfeldii* (4 sp) (post) • *Amphibolis* sp. (amph) • *Halophila / Heterozostera / Syringodium* (hhs) • *Thallasodendron* sp (thal)
		H3. Filterfeeders	• Sponges (spg) • Ascidians (asc) • Hard coral (hcr) • Soft coral (scr) • Gorgonians (gor) • Crinoids (crn) • Hydroids (hyd) • Bryozoans (b)
		H4. Unvegetated	
		Cover C3: Dense (>75%) C2: Medium (25-75%) C1: Sparse (5-25%) C4: Bare	

Table 3.3: *Broad and functional descriptions of habitat type*

BROAD HABITAT	*FUNCTIONAL HABITAT TYPE*
High Profile Reef	- High profile reef with filterfeeders - High profile reef with macroalgae and filterfeeders - High profile reef with macroalgae
Low Profile Reef	- Low profile reef with filterfeeders - Low profile reef with macroalgae and filterfeeders - Low profile reef with macroalgae - Sand inundated low profile reef with filterfeeders - Sand inundated low profile reef with macroalgae - Sand inundated low profile reef with macroalgae and filterfeeders - Sand inundated low profile reef with macroalgae and seagrass - Sand inundated low profile reef with seagrass
Sand	- Sand with some vegetation (macroalgae & seagrass) - Bare sand with some macroalgae - Sand with some macroalgae and filterfeeders - Sand with filterfeeders - Megaripples with filterfeeders - Megaripples - Bare sand rippled - Bare sand -

Rhodoliths	- Sand inundated rhodoliths - Sand inundated rhodoliths with macroalgae - Sand inundated rhodoliths with macroalgae and filterfeeders - Sand inundated rhodoliths with macroalgae and seagrass - Sand inundated rhodoliths with sparse seagrass - Rhodoliths bare - Rhodoliths with filterfeeders - Rhodoliths with macroalgae and filterfeeders - Rhodoliths with macroalgae
Seagrass	- Sparse seagrass - Medium Seagrass - Dense Seagrass

Geographical Information Systems (GIS)

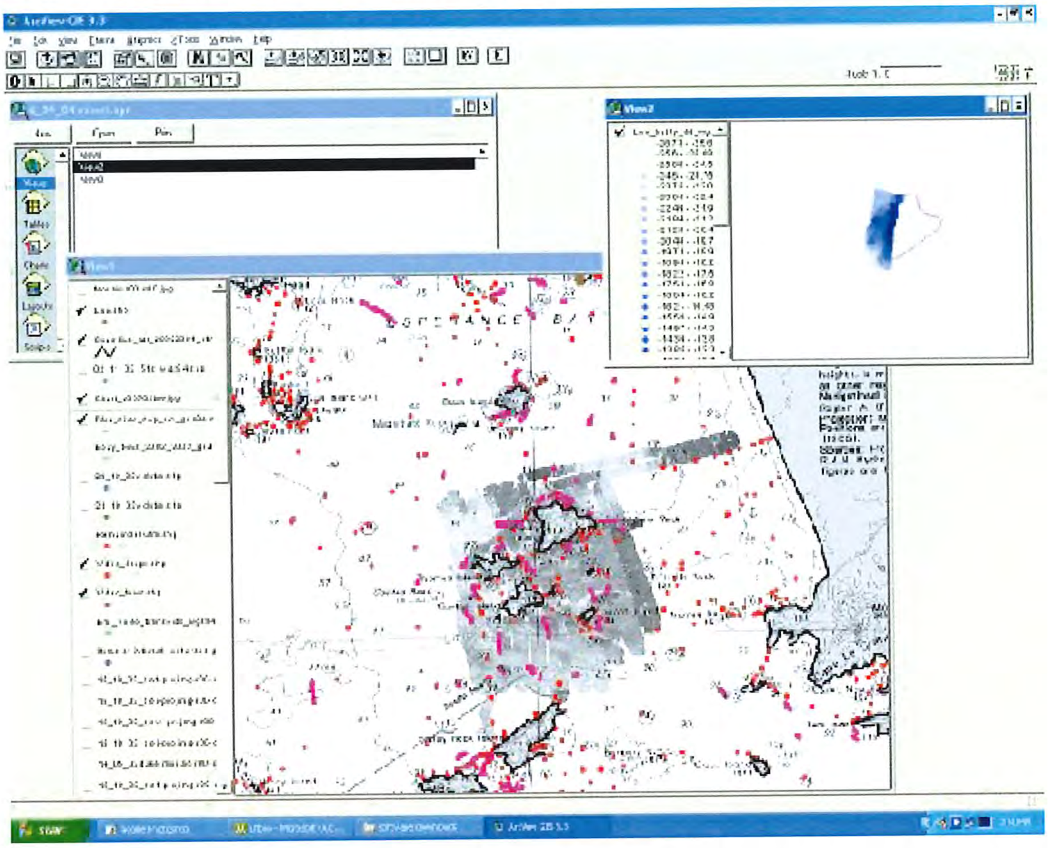


Figure 3.7: GIS system screen view showing chart, sidescan sonar mosaic and video sampling for the Woody Island group

The use of a GIS allowed data to be catalogued and compared on a common platform. Throughout the project the GIS software ArcView 3.2 (ESRI) was used for the creation, manipulation, editing, storage and analysis of datasets. Satellite and acoustic imagery could be displayed relative to the classified video validation. Integration of both 'raw' and classified data sets in the GIS was critical in the production of final classified habitat maps.

3.3.3 Existing Data

Bathymetry

Coarse-scale (100 to 1000m) bathymetric data was obtained from the Royal Australian Navy (RAN) hydrographic office. This data covered most of the Esperance Bay region and isolated areas in the Duke and Cape Arid regions. Additional sounding data was digitised from the bathymetric charts of the area. Bathymetry was also supplemented in some areas with fine resolution multibeam data and single beam echosounder (fish finder) data acquired during the video and sidescan surveys.

Landsat

Landsat data was acquired for the entire survey area from the Australian Centre for Remote Sensing (ACRES). Images were primarily selected for good surface conditions (lack of swell and wind) and maximum light penetration. Imagery acquired during summer 2001 was used when the sun was high and swell low. Lack of cloud cover was also a factor in selection. Image selection was limited as the archival and retrieval system did not cater for selection of water based imagery. Interpretations of Landsat imagery with limited diver based ground truthing performed at the CSIRO were also used to assist in mapping the broad scale habitat boundaries where interpolations between sidescan tracks were required.

Anecdotal

In January 2003, Euan Harvey, Katrina Baxter and Gary Kendrick interviewed prominent commercial and recreational fishermen, tour boat and SCUBA diving operators. Individuals noted areas of interest on bathymetric charts of the Recherche Archipelago. Data such as dominant species, changes in substrate types and site characteristics were recorded and the resulting spatial information saved as layers in the GIS database. The data from these interviews led to the design of the 2002 Autumn drop video surveys.

3.3.4 Details on Survey Techniques

Drop Video Survey

During Autumn 2002, an extensive drop video survey was carried out across the full extent of the survey area. 3000 camera drops were recorded to characterise the types and broad scale distribution of the habitats of the region. This led to the modification of the conceptual classification scheme. Video clips for each drop were recorded with their depth and approximate position. Each video clip was classified according to the biological and physical descriptors in the classification scheme and the final dataset was integrated as a layer into the GIS.

Sidescan Sonar Survey

Sidescan sonar is a technique that is well established in the offshore oil and gas industry but has more recently been applied to habitat mapping. By towing a torpedo like 'fish' (Figure 3.8) behind the vessel at 5 to 7 knots, swaths of acoustic imagery up to 400m wide are acquired (Figure 3.9). This imagery is similar to a black and white aerial photograph. Different habitat types can be distinguished in the image from the varying acoustic signatures of the substrate and organisms that comprise the seabed. These differences were expressed visually in the sidescan record as changes in contrast, intensity, patterning or texture. As the vessels position is continuously recorded from a GPS subsequent swaths can be combined into a map of the seabed known as a 'mosaic'. This mosaic is then segmented according to contrasting areas of texture and intensity that are attributed according to the classification scheme.

A 100kHz Edgetech sidescan sonar coupled with acquisition and processing software from Chesapeake Technologies was used throughout the surveys. The type of equipment, acquisition and processing used throughout the project is described in detail in Bickers (2003) (Figure 3.10).

Figure 3.8: Edgetech 272 Sidescan sonar 'Fish'.

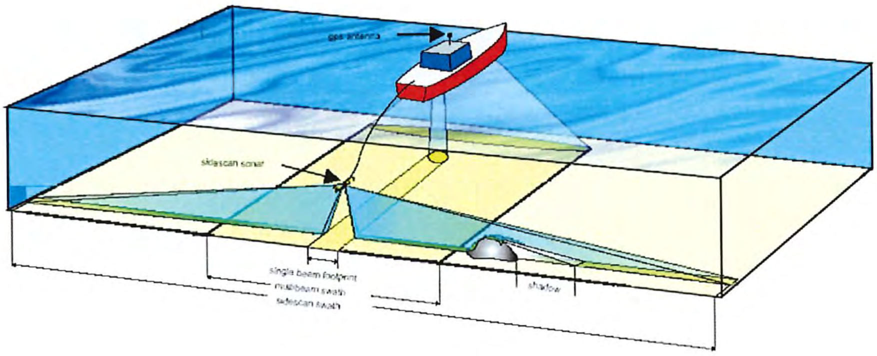


Figure 3.9: Comparison of coverages of different hydroacoustic techniques.

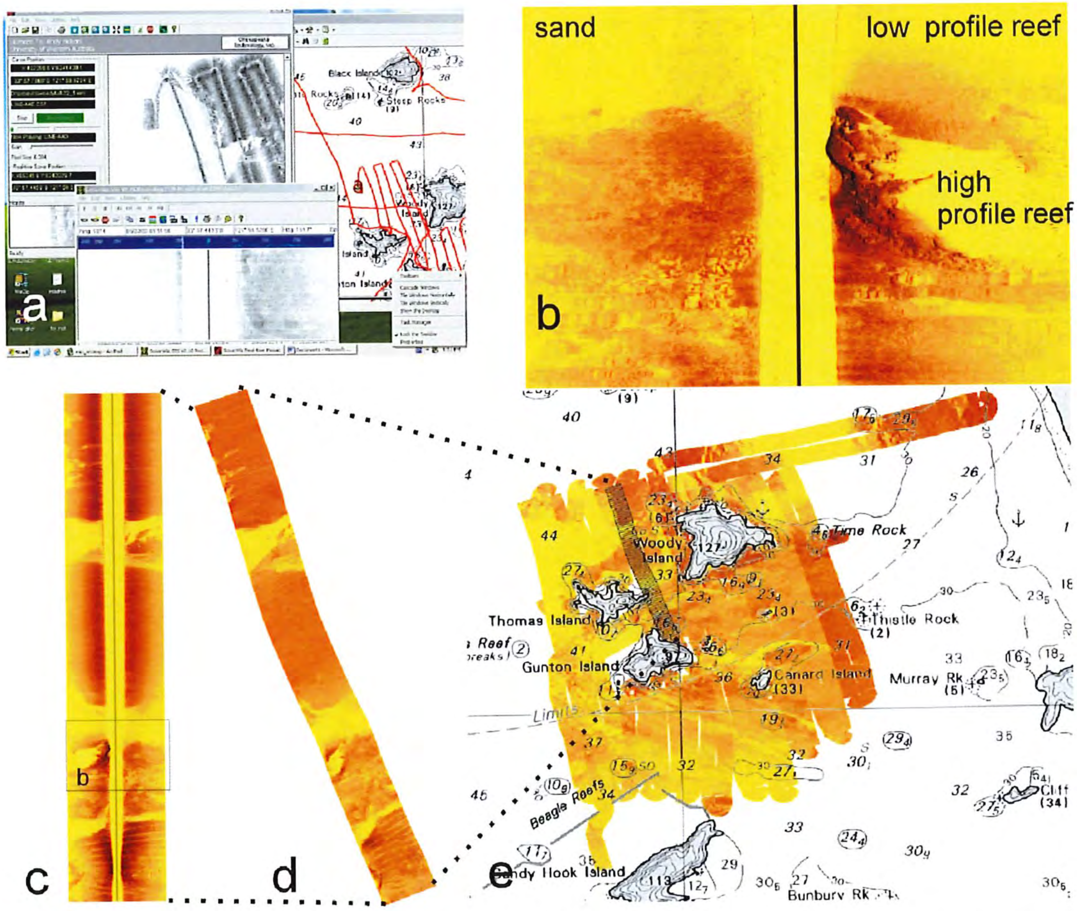


Figure 3.10: Sidescan sonar operation – acquisition to processing showing a) Screen shot of survey software b) Waterfall imagery of part of a sidescan track c) Full waterfall image of the sidescan track shown in b. d) Projected image of the sidescan track shown in c. e) Composite mosaic of sidescan tracks in Woody Island area.

Towed Video Survey

Although sidescan sonar can provide almost photographic quality imagery of the seabed, it's records must be validated to gain more detailed information about the physical and biological character of the seabed. Video is considered an efficient means of obtaining this information and a towed video camera was used extensively to validate selected areas of the sidescan record (Figure 3.11). Towing allows continuous coverage over extended tracks to be acquired. By incorporating a GPS, personal computer and software developed at UWA into the video system, the vessels position could be recorded and displayed live relative to the mosaiced sidescan imagery. This allowed different types of acoustic signature to be accurately targeted for validation. The boundaries between distinct areas on the sidescan record were often chosen for video validation as they show transitions between habitats and allowed confidence in the relative positioning of the sidescan and video to be gained. The video was permanently referenced to points along the vessels track using a text overlay, facilitating further analysis and integration into the GIS (Figure 3.12). Depths were also recorded for each recorded position. A detailed description of the equipment and methodologies used is available in Bickers (2003)

Figure 3.11: Towed video camera body.

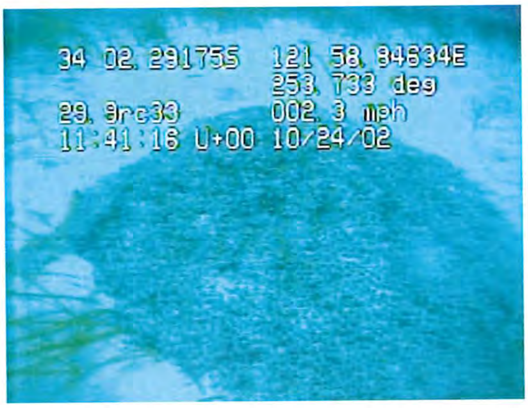


Figure 3.12: Video text overlay showing position, depth, track id and track position reference id.

Multibeam Survey

Multibeam sonar systems are vessel mounted (Figure 3.13) and calculate accurate bathymetry over a wide swath of the seabed. Vessel motion and attitude sensors allow accurate positioning of soundings over the whole swath. The Reson 8125 multibeam used in the Recherche was able to acquire bathymetry over swaths of up to 3.5 times water depth, to a maximum depth of 60m. Selected areas in Esperance bay were chosen for survey with the multibeam sonar due to the limited swath width. A bathymetric grid with a typical spacing of 1m is produced from the data and three dimensional maps of the seabed were created.

Figure 3.13: Hull mounted multibeam head.

Vessels Used

A wide range of vessels was utilized throughout the survey depending on task, area of operation and availability (Table 3.4).

Table 3.4: *Vessel details.*

Vessel	Owner	Description
Firebird	Marcus & Michelle Gray	14m Cray configuration
Jumbo	Marcus & Michelle Gray	17.2m Cray configuration
Sea Urchin	Mackenzie's Island Cruises	8m Noosa Cat
Deborah Anne	Peter & Deborah Brown	6.5m Aluminium monohull
Barrambie	Peter & Deborah Brown	14m Ex Cray configuration
Stacey Jay	Paul Rose	12m Aluminium Fishing Boat
Sara 3	Bob and Judy Boord	12m Riviera
Sargassum	UWA	6.5m Scorpion

The successful outcomes of the project could not have been achieved without the generous support of the owners and skippers including Marcus Gray, Bernie Habberly, Peter Brown, Fud Mackenzie, Bob Boord, Paul Rose, Kevin McNeil, Hendrick Rasmussen and Barry Mercer.

Positional Equipment

Throughout the survey periods a number of DGPS (Differential Geographic Positioning Systems) systems were used to accurately reference the data collected (Table 3.5). All data were recorded in the Geocentric Datum of Australia (GDA), 1994 (or equivalent WGS84).

Table 3.5: Positioning systems.

Manufacturer	Specification	Provider	Season	Accuracy (50% of time)
Fugro	StarFix Satellite Differential	Fugro	Spring 2003	+/- 1m
Leica	RTK Differential Basestation	UniMelb	Autumn 2002 Spring 2002 Autumn 2003	+/- 1m with correction +/- 5m without correction
Garmin	GPS12 AMSA Albany Differential Signal	UWA	Autumn 2002 Spring 2003	+/- 5m with correction +/- 10m without correction

Accuracies refer to the positioning of the systems antenna only and not for the positioning of acquired data that is subject to a range of further errors caused by cable 'layback' and vessel motion. The drop video survey was undertaken using both GPS and DGPS. No correction for camera position was made with reference to the vessel.

Positioning during the Spring 2002 and Autumn 2003 seasons was provided by a Real Time Kinematic (RTK) positioning system with base station deployed by Rodrigo Oñederra of the University of Melbourne. Surveys in Spring 2003 were undertaken exclusively using Fugro Starfix, a satellite differential virtual basestation system provided as part of the Coastal CRC project. From observations of overlapping sidescan tracks taken in different directions it is suggested that the final positional accuracy of the sidescan records is better than 25m.

Habitat Classification

Mapping Habitat Types

Habitat maps were produced using the full range of data stored in the GIS (Figure 3.14). In areas where sidescan was available boundaries were digitized visually around areas of different acoustic signatures in ArcView. This was accomplished with reference to both the raw 'waterfall' tracks and the mosaiced imagery. As full coverage sidescan was not available for all areas, boundaries between sidescan tracks were interpolated with respect to other information such as Landsat imagery and bathymetry. Interpretations of Landsat imagery by the CSIRO were used extensively in this process. In all cases, both drop and towed video surveys were used to verify the boundaries and classifications assigned to habitats mapped using both satellite and sidescan techniques.

The fine scale bathymetry acquired using the multibeam system 3 D models was also used to aid in visualization and classification of habitats (Figure 3.15). Backscatter imagery acquired from sidescan sonar systems (Figure 3.15 a, b) can be draped over the 3 D models (Figure 3.15 c) to produce composite visualizations of habitat (Figure 3.15 e, f). Integrating finer scale validation by video can be used to attribute detailed biological and physical information to each area (Figure 3.15 d, g, f).

Both broad and functional habitats (as detailed in section 3.2.1 Classification Systems) were mapped and recorded in the final GIS dataset. The final habitats represent the greatest extent and highest level of detail that could be interpreted from both the existing and surveyed information.

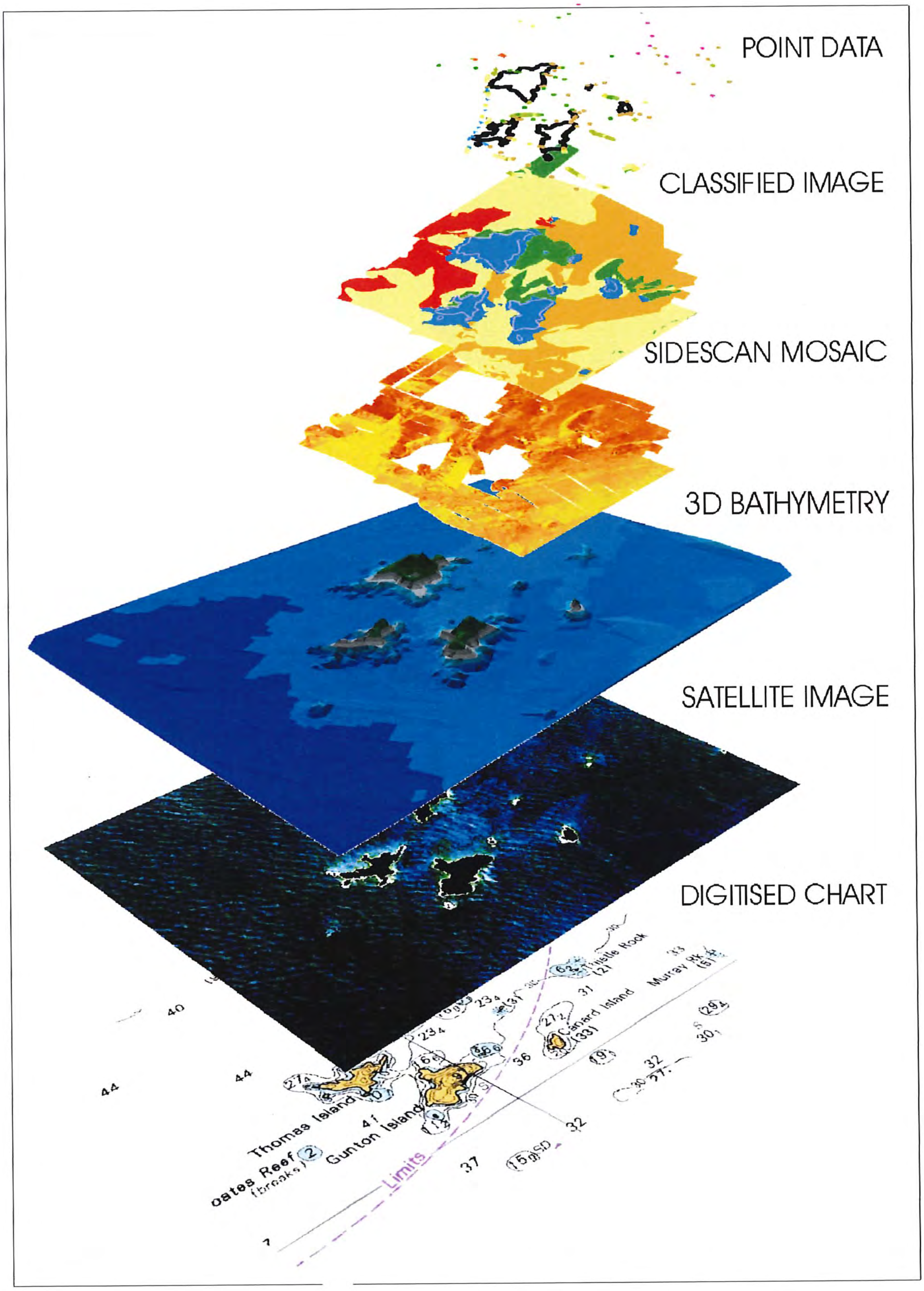


Figure 3.14: Representation of the data used in the creation of the habitat map for the Woody Island area.

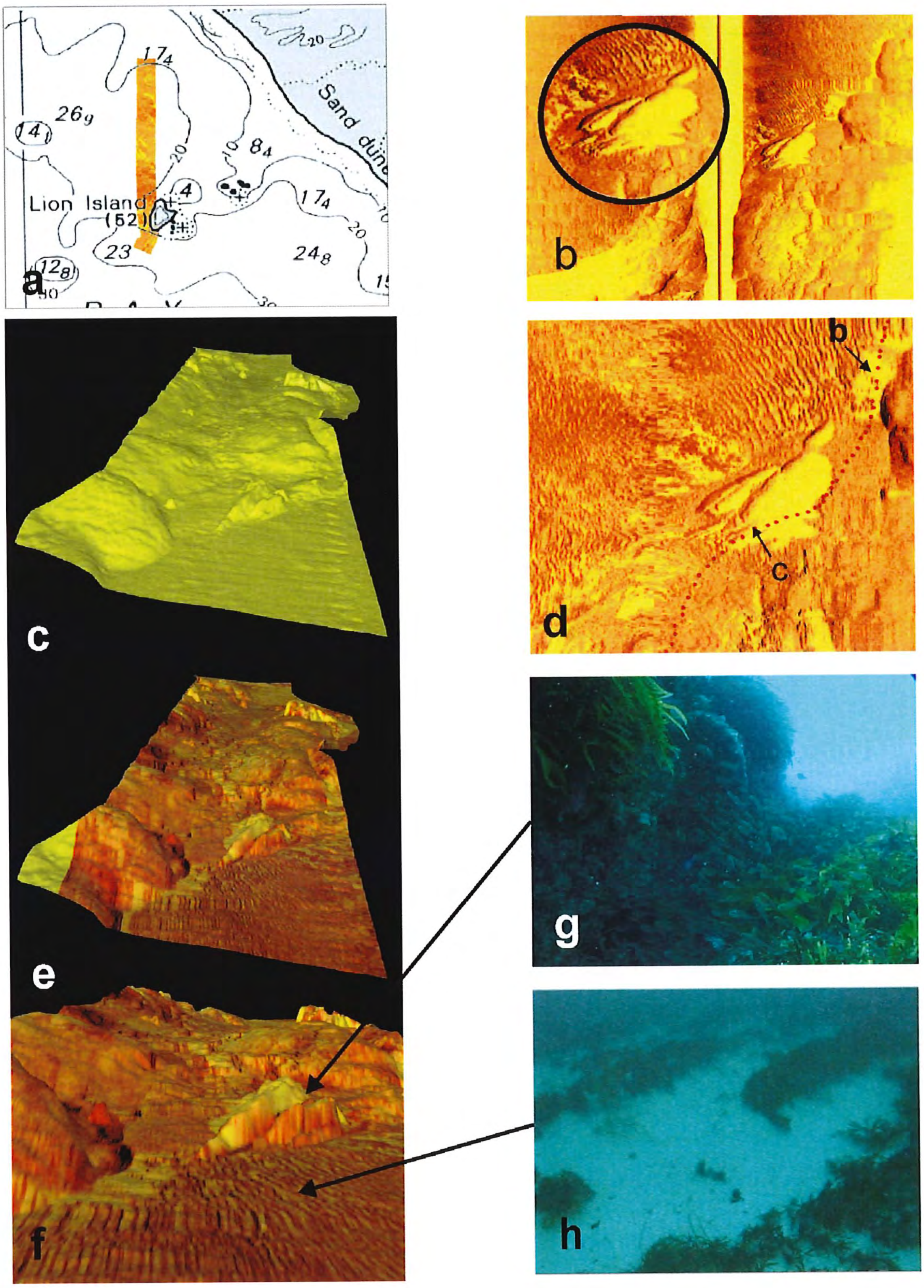


Figure 3.15: Demonstration of how the sidescan, multibeam and video can be integrated for improved visualization – a) Location of single sidescan track near Lion Island. b) Detail of high profile reef, low profile reef and seagrass on waterfall image c) 3D bathymetry plot d) Video transect shown on projected sidescan image e) Sidescan backscatter draped on 3D bathymetry f) Close up of northern view of e. g) Video still image showing high profile reef h) Video still image showing seagrass hummocks.

Identifying Patterns in Habitat Types

Data collected during the drop and towed video survey was used to analyse patterns or relationships in the habitats mapped to (1) tighten the descriptions of habitat mapped and (2) assess what combinations of factors may help explain where particular habitat types are found. The classified video data was exported from the GIS and analysed using decision trees, a type of rule-based classification. Decision trees are ideally suited to classifying complex patterns in ecological data (see Baxter & Shortis, 2002 for a review). Through a process of learning, decision trees classify different patterns in the data (eg. habitat types) according to different combinations of factors (eg. depth; relief; substrate).

Once exported from the GIS the classified video data was analysed using RPART, a decision tree module of the SPLUS statistical program. To 'learn' or classify habitat patterns 2 sets of analysis were undertaken:

1. the *drop and towed* data was used to classify *broad* habitat types
2. the *drop and towed* data was used to classify *functional* habitat types.

To undertake the analysis the data was split into two types:

1. Training data *to learn* habitat patterns (12277 points);
2. Testing data from Woody and Remark Island groups *to validate* the patterns learnt (5985 points).

During the learning phase, video locations are reviewed to assess the factors contributing to the habitat classifications assigned from the video. The data is repeatedly split into classes of common factors for a habitat or a group of habitats. Decisions are made each time the data is split into a habitat or group and a rule is defined to explain what physical factors have contributed to the split. From each decision tree analysis a graphical 'tree' is produced explaining the decision rules. Branches are defined in the tree with corresponding end points, or leaves, representing the dominant habitat type at that point in the tree. The rules can be interpreted to explain the physical conditions that result in the habitat type (eg. if substrate = sand

and depth is greater than 14m and less than 26m, the functional habitat is most likely to be medium seagrass).

An overall accuracy rate is produced, indicating the success of the method (or model) in determining the combinations of factors that limit where a habitat type is found. This overall accuracy rate is a guide that can be tested by applying the decision tree rules to real data. The Woody and Remark Island testing data (5985 tow & drop points) was used to classify or 'predict' habitat types at known locations using the rules produced by each of the 2 decision trees. The accuracy of these predicted outcomes is reported.

3.4 RESULTS

Results will be presented in 3 levels. Firstly, published conference proceedings describing mapping and classification will be presented. These set the scene for the descriptions of broad and functional habitat descriptions. The descriptions are followed by a series of maps of the broad and functional habitats with descriptions of area covered by each habitat type. Metadata for the Recherche Archipelago GIS are presented in Appendix 1.

Peer Reviewed Conference Papers

Refer to Appendix

3.4.1 Habitat Descriptions

The five broad habitat types of high profile reef, low profile reef, rhodoliths, sand and seagrass were mapped in the Recherche Archipelago. The considerable variation existing within these classifications is represented by functional habitat types. Functional habitat types were mapped where possible to reflect this variation, although accurate mapping of boundaries between these more detailed classifications could often not be realistically achieved when video data was widely spaced.

The following sections describe the five broad habitat types. A map of the distribution of each of the habitat types described is shown of the most widely surveyed region of

Esperance Bay. The range per side of the sidescan is shown in meters at the top of each sidescan image.

High Profile Reef

High profile granite reefs were clearly identified and mapped from sidescan records (Figure 3.16 a) and were characterised by a mixture of high and low returns. In many cases the imagery showed clearly the morphology of the reefs found in coastal, island (Figure 3.16 b, d) and isolated locations (Figure 3.16 c, e). Steep reefs, such as the sides of islands, produce high returns near the seabed, which diminish rapidly as the profile reaches the altitude of the sidescan towed body and the signal is scattered away from the transducers. Shadows are also formed behind high relief features in the sidescan record due to the lack of acoustic illumination (Figure 3.16 b, c, d).

Several functional habitat types exist within this broad category. High profile reef was typically dominated by macroalgae (Figure 3.16 f, g), filterfeeders (Figure 3.16 h, i), or a combination of both (Figure 3.16 j, k). The area of overlap was generally between 20 to 35m deep as light penetration reduced and macroalgal cover declined (Figure 3.16 j, k) (see also Goldberg & Kendrick, 2004).

Macroalgal genera such as *Ecklonia*, *Cystophora*, *Scythothalia* and *Sargasssum* dominated in waters less than 30m, but were found in depths of up to 42 metres. Communities of filterfeeders, consisting of sponges and ascidians, were typically found on high relief reefs and vertical walls between 30 and 57 metres (Figure 3.16 h). In some locations between 9 and 22 metres, high profile reefs supported *Turbinaria* coral (Figure 3.16 i). Similarly shaded vertical walls and caves and overhangs in depths < 35 m were covered in a diverse array of filterfeeders (see McDonald and Fromont Appendix 8.6.1 in this report).

Low Profile Reef

Extensive low profile reefs were identified throughout the Archipelago. The range of types of low profile reefs encountered was also extensive and included:

- low relief granite reef adjacent to steely sloping high profile reef

- low profile limestone reef normally associated with coastal and island regions
- sand inundated and unconsolidated reefs with varying degrees of sand inundation and relief from the surrounding substrate.

Low profile reefs were found in all areas, but varied in their morphology with depth. These variations are described here as two broad categories that could be clearly distinguished from the sidescan and video records.

- Shallow (<50m) low profile reefs, dominated by algae and seagrass (Figure 17).
- Deeper (>50m) low profile reef, dominated by filter feeders (Figure 18).

Both of these types of reef exhibit varying degrees of sand inundation and associations with all the other broad habitat classifications. This makes classification and the placing of boundaries between habitat types difficult.

Shallower Low Profile Reefs (Figure 3.17 a)

Densely vegetated and exposed reefs are characterized acoustically by a strong solid return, although not as strong as nearby seagrass (Figure 3.17 b), and are dominated by macroalgal species such as *Scaberia*, *Cystophora*, *Sargassum*, *Osmundaria*, *Caulerpa* and *Ulva* (Figure 3.17 f). Reefs with a varying degree of sand inundation and algal and seagrass coverage (Figure 3.17 g, h). provided acoustic returns of mixed intensity (Figure 3.17 c, d). With higher degrees of sand coverage, particularly in wave dominated areas, the reef was no longer elevated from the sand (Figure 3.17 i) and the true boundaries of the reef were difficult to define from the sidescan alone (Figure 3.17 e) Where seagrass species, such as *Amphibolis griffithii*, *Posidonia* spp. and *Halophila* spp. were interspersed with macroalgae on sand inundated reef, it was difficult to differentiate from a true seagrass classification on the sidescan record. Only closer inspection by video revealed the complex mix of biological communities and substrate combinations.

Deeper Low Profile Reefs (Figure 3.18 a)

These reefs were characterized by filterfeeders (sponges, bryozoans and unusual Alcyonacea soft coral communities) (Figure 3.18 e, f. g). These reefs were typically found in areas of high current flow between major island groups, reflecting the reliance of these communities on currentsthat supply water to filter. The boundaries of these reefs were sometimes difficult to define from the sidescan record especially when inundated with sand (Figure 3.18 b, f, g), although generally the characteristic acoustic signature and the shape of the boundaries of these habitats was easily recognized (Figure 3.18 c, d).

In a number of areas similar communities to those described here were found to be existing where no reef could be identified. Generally the substrate around these communities showed a slight change in height on video records. In these cases it was assumed that the organisms were growing on a low profile reef totally inundated by sand. In other areas invertebrates seemed to be existing without the need of consolidated substrate. Filter feeders were often observed attached to pebbles and coarse substrate trapped in the gutters of rippled sand and round bryozoans (Celleporaria) were also found in sand areas at Remark Island with seagrass and in ripple troughs in isolated offshore locations. "Lolly pop" stalked bryozoans were found carpeting bare sand areas around Woody Island in depths less than 20 metres and dense regions or 'fields' of ascidians (eg. Pyura) were found 30 – 40 metres deep in areas exposed to ocean swells.

Even when these sidescan record showed the presence these communities, video was required in all areas to capture the range of unique biological information.

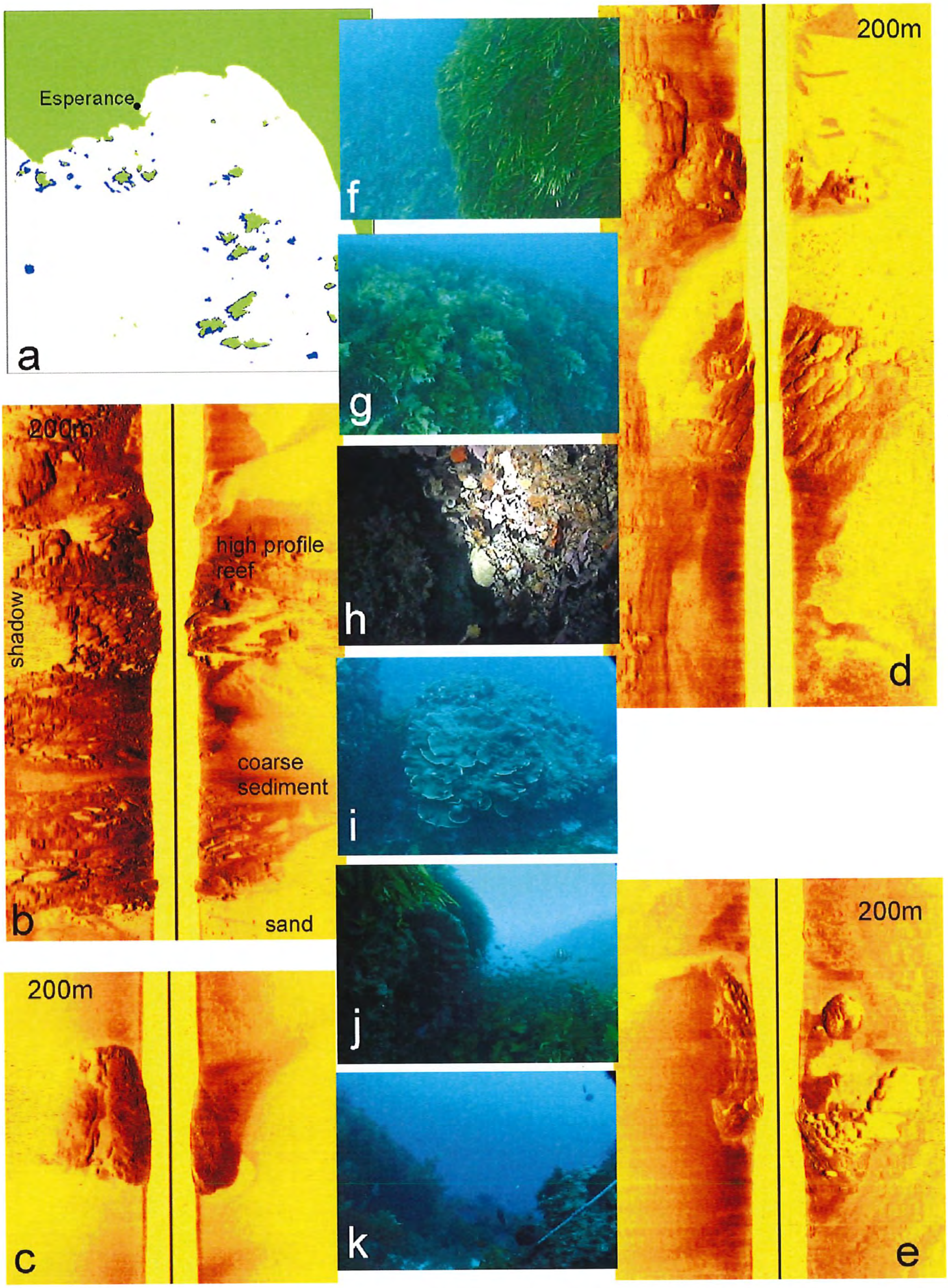


Figure 3.16: Sidescan and video imagery of high profile reef – a) Distribution of high profile reef in Esperance Bay b-e) Sidescan waterfall images showing high profile reefs in different locations f-k) Video stills showing diversity of functional habitats on high profile reef.

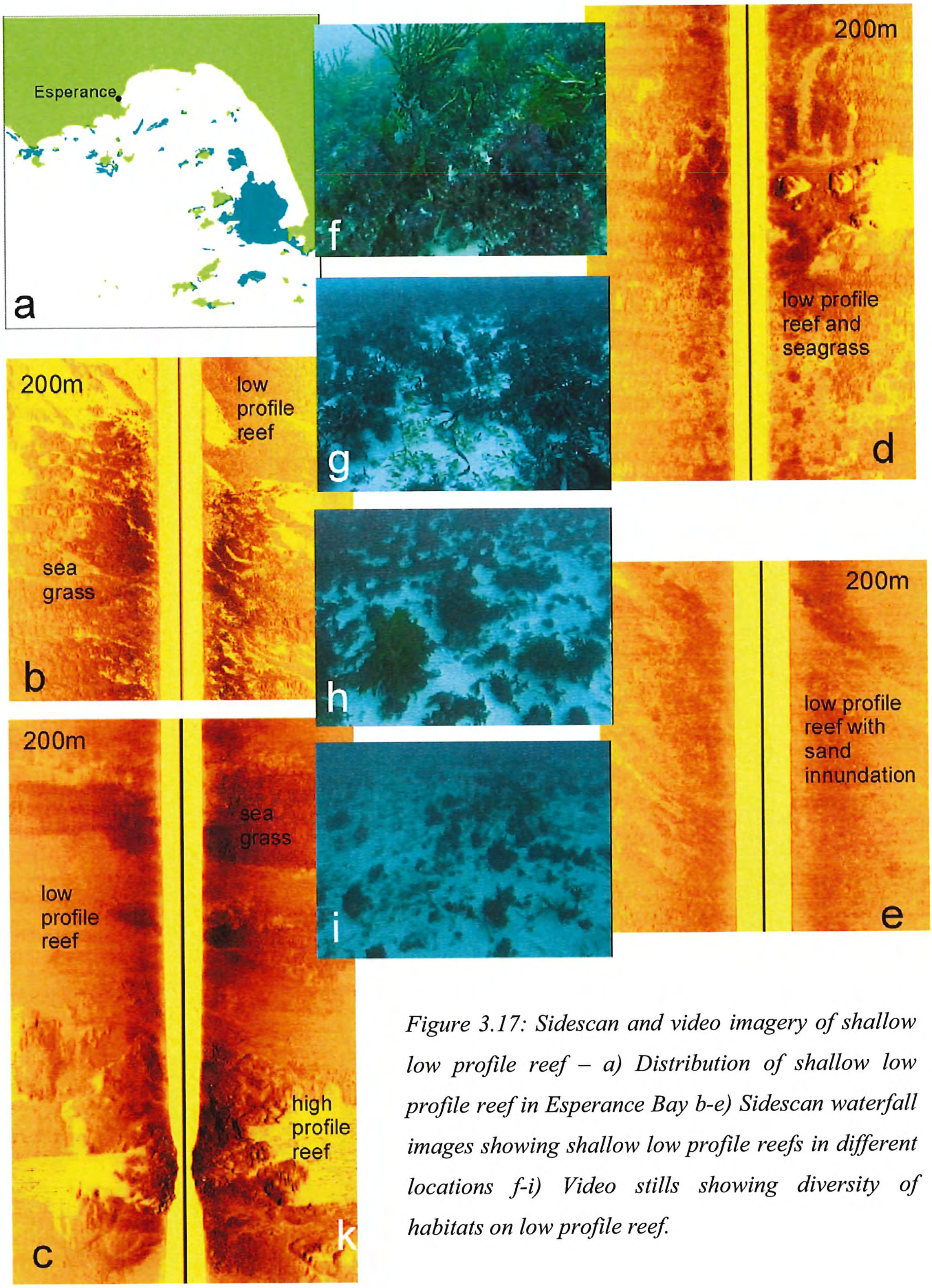


Figure 3.17: Sidescan and video imagery of shallow low profile reef – a) Distribution of shallow low profile reef in Esperance Bay b-e) Sidescan waterfall images showing shallow low profile reefs in different locations f-i) Video stills showing diversity of habitats on low profile reef.

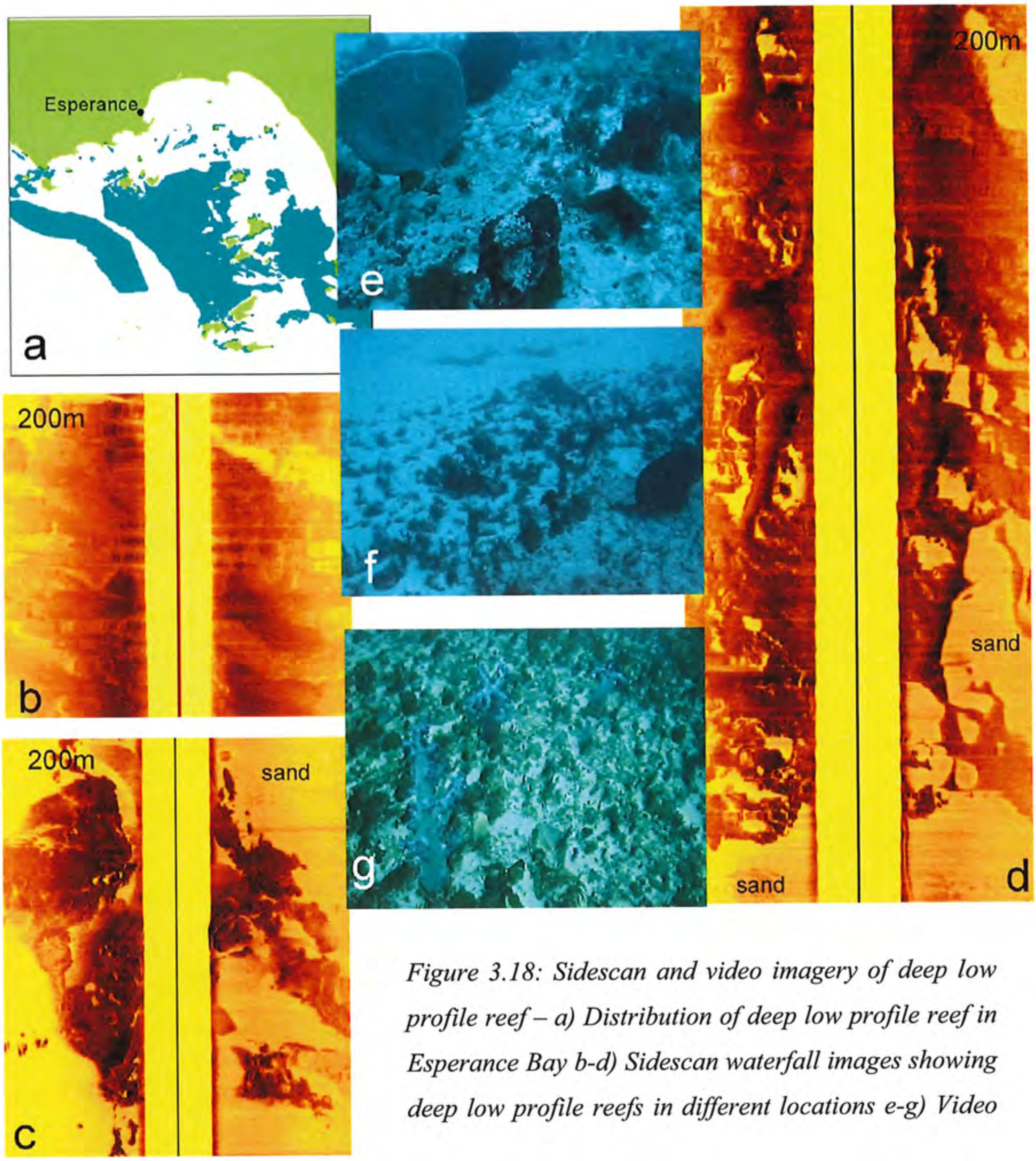


Figure 3.18: Sidescan and video imagery of deep low profile reef – a) Distribution of deep low profile reef in Esperance Bay b-d) Sidescan waterfall images showing deep low profile reefs in different locations e-g) Video

Rhodolith Beds

The survey identified extensive rhodolith (or maerl) beds clearly distinguished from surrounding sand habitats. Rhodoliths are unattached (or free-living) forms of coralline red algae. Dense, extensive beds of many individuals are found over coarse or fine sands (Steller & Foster, 1995; Foster, 2001). Rhodoliths are extensive in the western Archipelago region and were found mainly in high-energy environments between islands and in open offshore waters. Large beds of up to 9000 hectares in size were mapped. One bed stretched for 25km in an east –west direction. The southern extent of this bed was not found after surveying to 55m depth. The true extent of deeper beds, found in waters of up to up to 65m were not determined (Figure 3.19 a).

The coarse, uniform nature of rhodolith beds produce a strong, consistent signal on the sidescan record and clearly defined edges contrast well with the surrounding sand (Figure 3.19 b). Rhodoliths were found between depths of 27 to 65 metres within the Archipelago.

The surface of rhodolith beds that were either flat or rippled could be distinguished from the sidescan record (Figure 3.19 c,d). In some areas tails (or tiger patterns) develop from the main rhodolith bed into the surrounding sand (Figure 3.19 e). This was a characteristic pattern exhibited only by rhodolith beds and has been noted in other areas of the West Australian coastline. Areas of sand inundated rhodoliths were also identified (Figure 3.19 f).

Rhodoliths (Figure 3.19 g, h, i) are a unique substrate and functional habitat, supporting a wide variety of organisms, including macroalgae, sponges, crinoids, polychaete worms, crustaceans, and bivalve molluscs, such as scallops (Steller *et al.*, 2003, see Groves section in this report). The surfaces of rhodolith beds ranged from bare to supporting foliose and filamentous macroalgal species or diverse filter feeder communities (Figure 3.19 g, i), see Goldberg & Kendrick section in this report). These filterfeeders included erect and barrel sponges, ascidians and a variety of bryozoans, such as Celleporaria, a rounded bryozoan (up to 1m in diameter) that were found growing in the troughs of rhodolith sand waves.

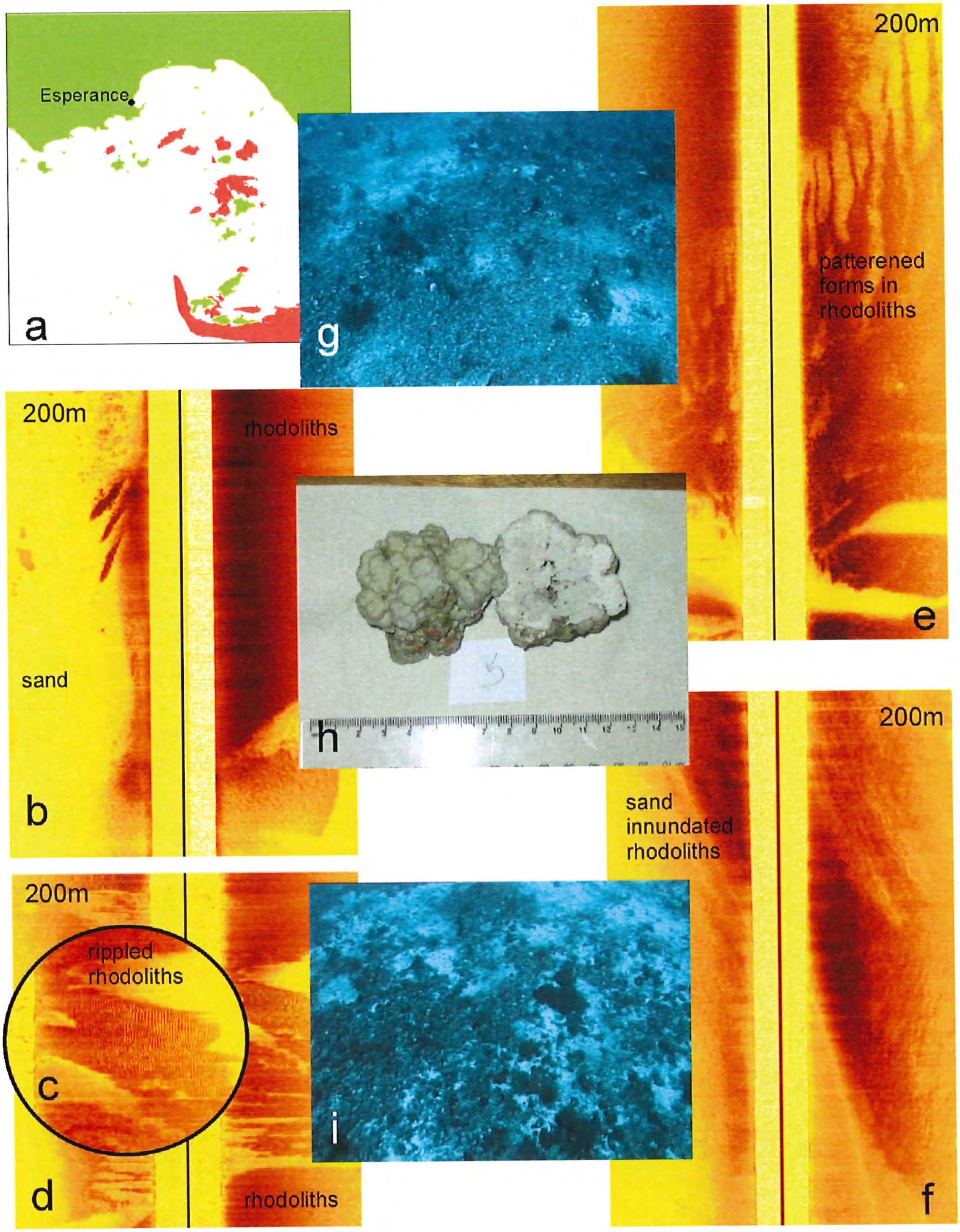


Figure 3.19: Sidescan and video imagery of rhodolith beds – a) Distribution of rhodolith beds in Esperance Bay b-f) Sidescan waterfall images showing rhodolith beds in different locations g,i) Video stills showing rhodolith habitats h) Close up image of rhodoliths.

Sand

Bare sand was a dominant habitat type in all mapped areas (Figure 3.20 a). Areas of rippled sand contrasted well with flat sand on the sidescan record (Figure 3.19 b). Ripples with wavelengths of larger than approximately 1 to 2m could often be clearly distinguished with areas of waves of higher frequencies appearing as darker than the surrounding flat sand on the record, especially when viewed at lower resolutions (Figure 3.19 e, f). It is known however that the appearance of sand ripples on the sidescan record is dependant on the angle of incidence of the sonar beam and ripples will appear much clearer when the beam is at right angles to the ripples.

Ripples were often strongly aligned perpendicular to the prevailing swell and coarse-grained sediments in the troughs of ripples were observed on video (Figure 3.19 d). Ripples were often also found in areas adjacent to reefs (Figure 3.19 g, h, i). Flat or rippled sand regions distinguished on sidescan records were typically absent of any visible biological organisms, although some regions had sparse coverage of macroalgae (Rhodophyta and Phaeophyta) and often the gutters of sand ripples would be filled with coarse material or wrack (Figure 3.19 d).

Seagrass

The extent of seagrass coverage mapped is shown in (Figure 3.20 a). Different levels of cover or patchiness (dense, medium, sparse) could generally be distinguished from the sidescan record but in more complex, mixed regions (such as sand inundated low profile reef) identification of clear boundaries was difficult. Species identified by video and diver surveys within the Archipelago included *Posidonia sinuosa, P.australis, P. denhartogii, P.coriacea, P. ostenfeldii, P.kirkmanii, Amphibolis griffithii, A. antarctica, Halophila* spp.and *Zostera tasmanica.*

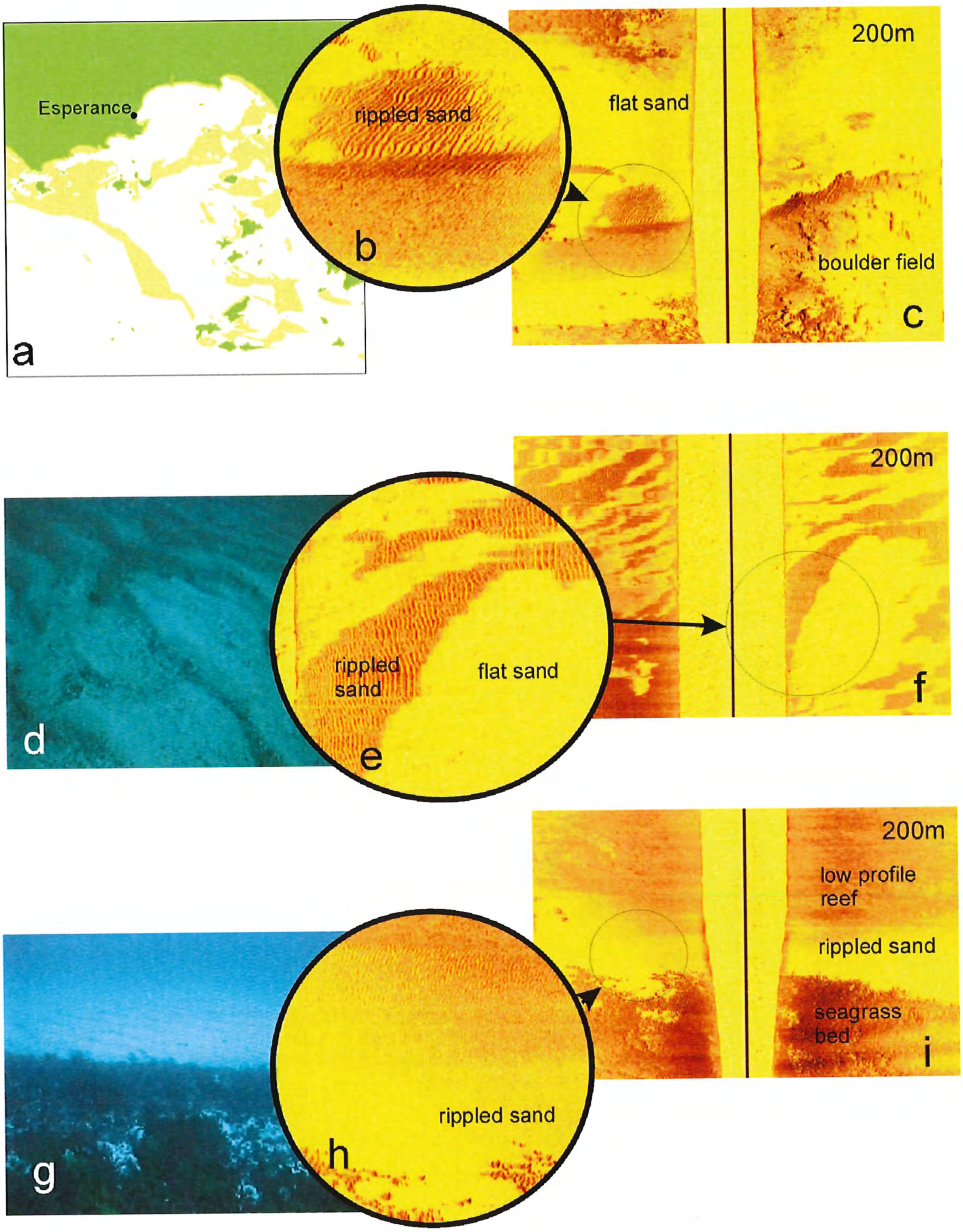


Figure 3.19: Sidescan and video imagery of sand habitats – a) Distribution of sandy bottoms in Esperance Bay b,c,e,f,h,i) Sidescan waterfall images showing sandy bottoms in different locations with insets showing details of ripples d,g) Video stills showing sand ripples.

Dense seagrass has a characteristic coarse, regular texture with a strong return (Figure 3.20 b, c, i) and was typically found in coastal embayments, in the lee of headlands and the leeward sides of offshore islands, in depths of less than 30m. Dense seagrasses were represented by extensive meadows of *Posidonia sinuosa*, *P.australis* and *Amphibolis griffithii* with smaller ephemeral species *Halophila* spp.and *Zostera tasmanica* occupying sand patches and as understory in meadows.

Medium seagrass tended to be found further off the coastline in the broader Esperance Bay and Duke of Orleans regions (Figure 3.20 b, c, j), as well as within the relatively protected waters of offshore island groups (Figure of Eight / Boxer, Woody, Remark and Middle Island). The *P. ostenfeldii* complex and *Amphibolis griffithii* dominated this habitat type.

Sparse seagrass was found adjoining islands that offered slight protection from the prevailing swells. Sparse seagrass was represented by the *P. ostenfeldii* complex and *Amphibolis griffithii* to approximately 32 m (Figure 3.20 d, k, e). Sparse *Halophila spp.*, *Zostera tasmanica* and *P.ostenfeldiii* were often found in deeper waters (>25m), in some cases up to 42 metres deep.

Patchiness of seagrass bed could easily be determined from the sidescan record with hummocks raised from the surrounding sand creating shadows (Figure 3.20 f, l).

On occasions it was found to be difficult to distinguish this drifting wrack from seagrass (Figure 3.20 g).

Using a smaller sidescan sonar range and surveying slowly in shallow areas produced startling results with individual seagrass plants recognizable on the imagery (Figure 3.20 h) and possible identification of characteristic acoustics returns of certain species such as the heterozostera of Figure 3.20 m.

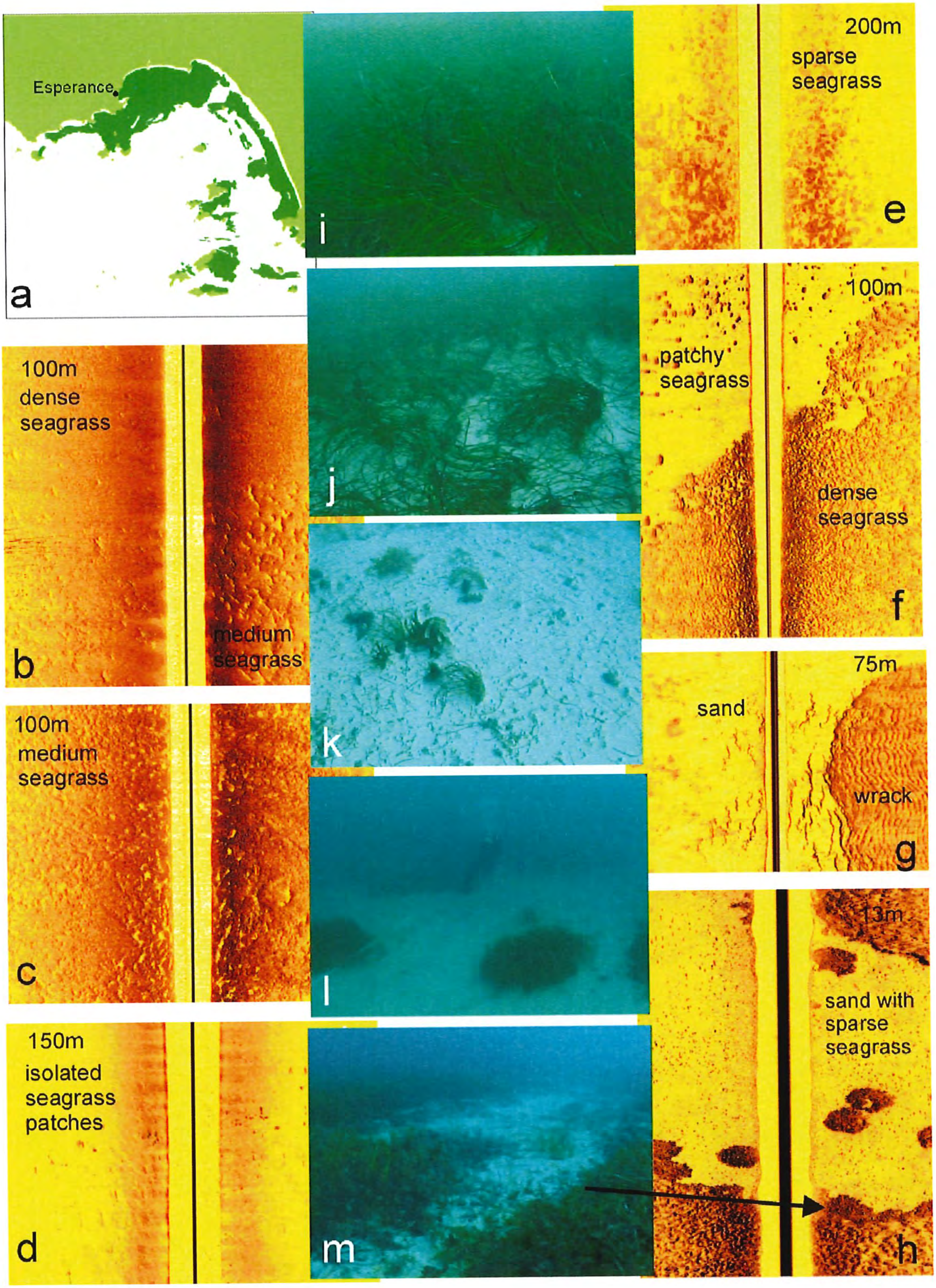


Figure 3.20: Sidescan and video imagery of seagrass beds – a) Distribution of seagrass in Esperance Bay b-h) Sidescan waterfall images showing different coverages of seagrass i-m) Video stills showing diversity of seagrass coverages and species.

3.4.2 CLASSIFICATION USING DECISION TREES

Decision tree analysis was used to test what sets of physical conditions distinguished where habitats were found, producing rules to explain the different combinations. Results are presented graphically as a 'tree' to illustrate the separation of both broad and functional habitat types.

Broad Habitats

Decision trees classified broad habitat types with high overall accuracy (76%) (Figure 3.21), but the results produced were highly generalised. Substrate type was the main factor distinguishing where habitat types were found, with sand being separated from rhodoliths and reefs. Relief defined reef type, and seagrasses were generally found to be in waters less than 33m deep. Depth provided very little distinction on habitat at a broad level.

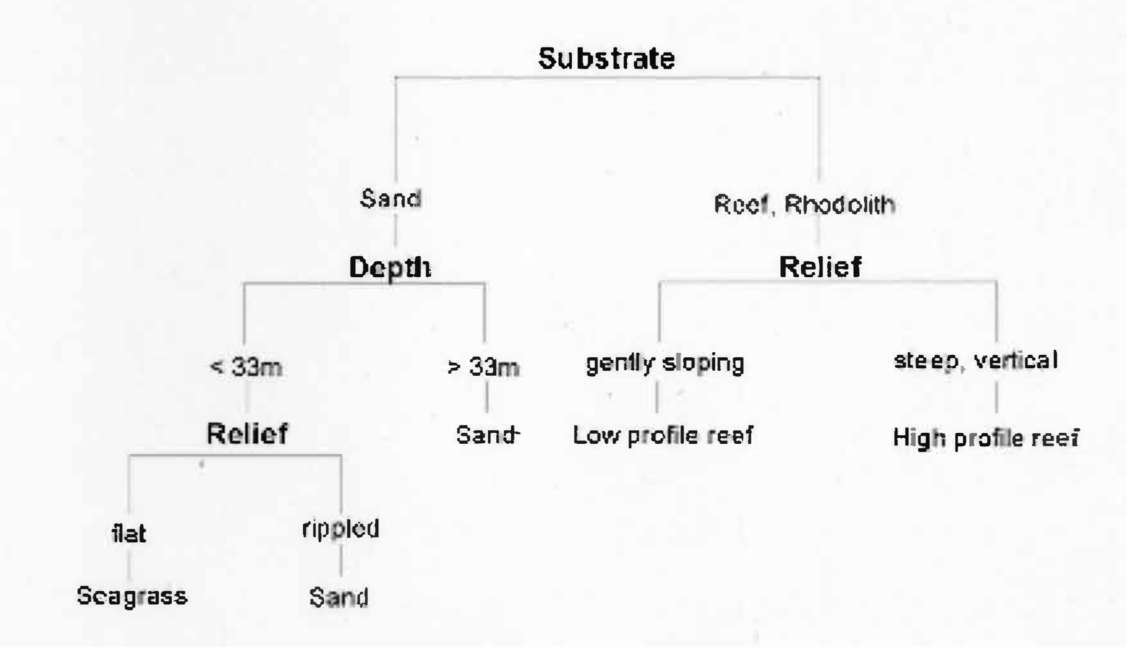


Figure 3.21: Decision tree classification of broad habitat types. Overall accuracy reported of 76% (or misclassification error rate: 2990 / 12277 = 0.2435). The accuracy predicted by validation data from Woody and Remark Island groups = 3497 / 5985 = 58%.

Functional Habitats

Functional habitat types were classified with a 55% overall accuracy rate. When validated using the Woody and Remark Island testing data, the accuracy rate dropped to 41% (Figure 3.22). These lower accuracies, in comparison to the broad classification, imply that the model is not very good at classifying habitats. However, the decision rules provide detail on the physical constraints or bounds of specific functional habitat types using the available data.

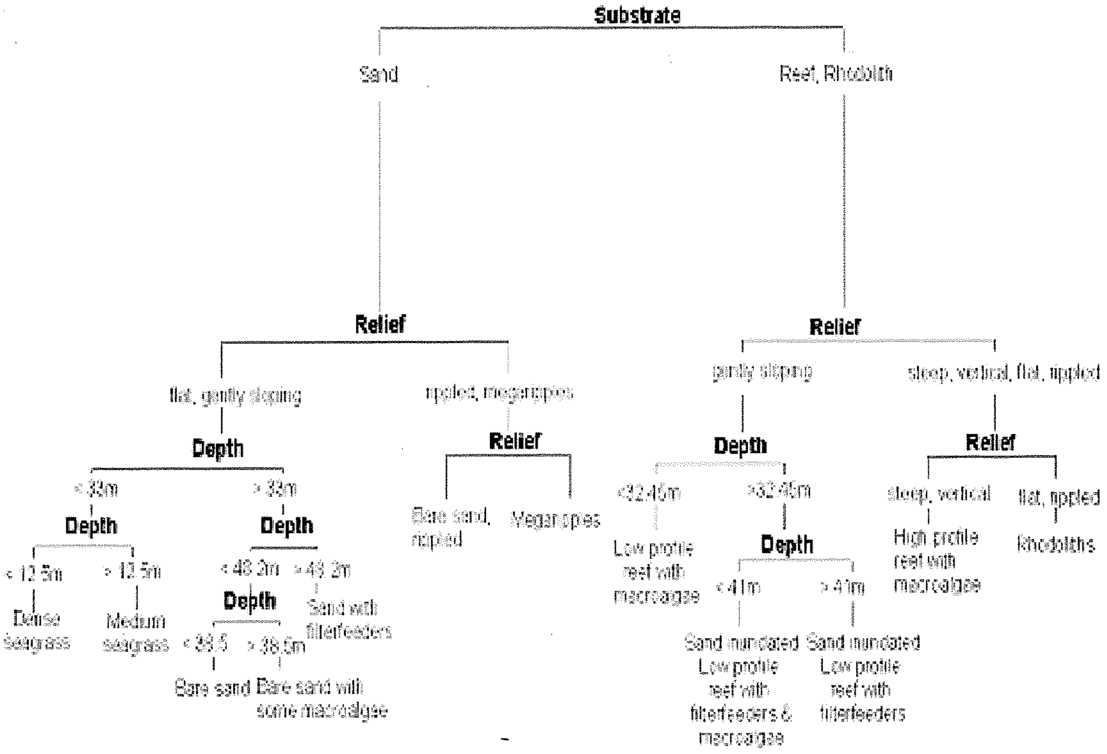


Figure 3.22: Decision tree classification of functional habitat types. Overall accuracy reported of 55% (or misclassification error rate: 0.4552 = 5589 / 12277). The accuracy predicted by validation data from Woody and Remark Island groups : 2483 / 5985 = 41.5%.

If the substrate = sand, the relief is flat and water depth is less than 12.75m then the most likely classification will be *dense seagrass*. If depth is greater than 12.75m and less than 32.95m, *medium seagrass* is the most likely habitat type reported by the model. *Sand regions* deeper than 32.95m and less than 38.35m were most likely to be bare, although sand deeper than 38.35m but less than 48.2m was classified as *bare* *sand with some macroalgae.* Deeper regions greater than 48.2m were dominated by *sand with filterfeeders.*

If the substrate was either reef or rhodolith, and less than 32 m deep, the habitat is most likely to be low profile reef with macroalgae. Sand inundated low profile reef with filterfeeders and macroalgae were most likely to occur between the depths of 32 m and 41m. Sand inundated low profile reef with filterfeeders were found on reefs deeper than 41m.

Substrate explains most of the differences in major habitat types and relief provides distinction among reef and sand areas. However, the combinations of substrate and relief reported strongly reflect the description of categorical habitat factors in the classification scheme. The use of continuous depth data was able to identify finer distinctions of some functional types, including seagrass, deeper filterfeeder communities and overlapping regions of macroalgae and filterfeeders. These rules are less general than those produced for other habitat types (eg. rhodoliths and high profile reef) and are more ecologically meaningful, reflecting the functional detail mapped.

3.4.3 Habitat Maps and Habitat Coverage

A total of 1054km^2 of habitats were mapped within the Recherche Archipelago. A total of 813km^2 was mapped in the Esperance region, 142km^2 in the Cape Arid region and 99km^2 in the Duke of Orleans region. Each region is divided into a series of map sheets as outlined on the map index for each region. A legend and summary of essential information pertaining preceeds the maps and a catalogue of the index and maps is presented for each area in Figure 3.16. Maps of both broad and functional habitat types are included. A summary of the areas occupied by each habitat type within these regions is described below. The areas have been calculated from GIS analysis of the database.

Broad Habitat Coverage

Of the 5 broad types, overall sand represented 28.3% of the area mapped, low profile reef 33.4%, seagrass 20.1%, rhodoliths 13.7% and high profile reefs 4.6%. These percentages varied across the regions (Table 3.6), according to the presence of the habitat type and the total area mapped.

Table 3.6: *Table showing locations of habitat maps.*

TITLE		MAP No.
Essential Information – Legend to Maps		1
Esperance region - map index		2
Esperance Bay to Cull Island	Broad	3
	Functional	4
Wylie Bay to Black Island	Broad	5
	Functional	6
West of Woody Island	Broad	7
	Functional	8
Woody Island to Cape Le Grand	Broad	9
	Functional	10
Remark Island Group	Broad	11
	Functional	12
Duke region – map index		13
Duke of Orleans west	Broad	14
	Functional	15
Duke of Orleans east to Mart Island group	Broad	16
	Functional	17
Cape Arid region – map index		18
Cape Arid	Broad	19
	Functional	20
Cape Arid to Middle Island	Broad	21
	Functional	22

Although many high profile reefs were mapped in the Esperance region, particularly adjoining islands, this diverse habitat make up only a small proportion of the area surveyed (3.1%). High profile reefs made up 10.6% of the area surveyed within the Duke of Orleans region and 9.1% of the Cape Arid region, although less area was mapped within these regions in comparison to Esperance.

Sand (31.2%) and low profile reef (30.9%) make up over half the area surveyed within the Esperance region, as large areas were mapped offshore between islands. Extensive low profile reef was found from south of Cull Island through to the west of the Woody and Remark offshore island groups, as well as from these islands across to Cape Le Grand Extensive low profile reef systems were also mapped in the Cape Arid region (58.6%), particularly between Cape Arid and Middle Island.

Esperance Bay was dominated by seagrass (17.8%), with coverage extending across the Bay, out to Cull Island and around towards Cape Le Grand Seagrass was also found in protected areas in the lee sides of offshore islands groups such as Woody, Remark and Figure of Eight. The area mapped in the Duke of Orleans region was predominantly seagrass (53%). Seagrass was found in coastal embayments from Victoria Harbour to Alexander Bay, as well as in the lee of protected island groups such as the Marts and the Twin Peaks. Seagrass mapped in the Cape Arid region was mainly found in Arid Bay and offshore north of Middle Island.

Rhodolith beds were relatively widespread in the Esperance region (17%), generally found in waters less than 45m deep within Esperance Bay. Rhodoliths were also found further offshore in deeper water south of Remark Island and to some extent west of the Duke of Orleans region (6%). Isolated rhodoliths were observed in video from the Cape Arid region, although the spatial extent of these rhodoliths could not be mapped from the available data.

Table 3.7: Area occupied by each broad habitat type

	Esperance		**Duke of Orleans**		**Cape Arid**		**All regions**	
Habitat type	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	**Total** (km^2)	**Total %**
High profile reef	24.97	**3.1**	10.56	**10.6**	12.75	**9.0**	48.28	**4.6**
Low profile reef	251.57	**30.9**	17.07	**17.1**	83.06	**58.6**	351.70	**33.3**
Rhodoliths	138.15	**17.0**	5.95	**6.0**	0	**0**	144.10	**13.7**
Sand	253.61	**31.2**	13.19	**13.2**	31.25	**22.0**	298.04	**28.3**
Seagrass	144.88	**17.8**	52.85	**53.0**	14.68	**10.4**	212.41	**20.1**
Total	813.18	**100**	99.62	**100**	141.74	**100**	1054.53	**100**

Functional Habitat Coverage

At a more detailed level of the classification hierarchy, 27 functional habitat types were mapped, reflecting the variation with each of the 5 broad types (Appendix 1). Functional habitat types were mapped in the majority of areas, although in some instances where only minimal data was available only a broad habitat type could be defined. Mapping at a functional level preserved considerable detail that would otherwise be amalgamated at a broad level. Within the Esperance region, the areas mapped as sand at a broad level (31.2%) were broken down into bare sand, rippled sand and megaripples (26.6%) as well as sand with biological communities present such as vegetation or filterfeeder communities (4.6%). Unusual stalked bryozoans ("lollypops") at Woody Island were grouped within 'sand with filterfeeders' although the actual community itself represented less than 0.2% of the entire habitat mapped. 'Sand with vegetation and filterfeeders' contained unusual Celleporan bryozoans found in sparse seagrass at Remark Island. This unique habitat that would have otherwise been classified as sand at a broad level represented less than 0.05% of the overall habitat mapped in the region.

In total 30.9% of the Esperance region was mapped as low profile reef at a broad level. Functionally, further distinctions were made so that only 7% remained broadly categorised and 24% was further defined according to degrees of sand inundation and the presence of macroalgae and filterfeeder communities. 'Sand inundated low profile reef with filterfeeders and macroalgae' represented 13.3% of the overall habitat in the region, with large regions of sand with sponges and sparse macroalgae south of Cull Island in the Causeway Channel approach to the Esperance Port limits.

Of the 17% broadly categorised as seagrass, 9.4% overall represented dense seagrass communities found primarily in Esperance Bay. Bare rhodoliths also occupied a considerable portion of the region (13.4%), with other rhodolith beds supporting either vegetation or filterfeeders making up the remaining 3.5% of the overall area mapped.

Of the area mapped in the Duke of Orleans region the majority was dense seagrass (42.2%), primarily within the Duke of Orleans Bay itself. High profile reef with macroalgae (9.0%) extending into low profile reef with macroalgae (8.9%) was also common along rocky headlands and adjacent to islands. In comparison to the Esperance region the proportion of the area assigned to rhodoliths, sand and other types of low profile reef is relatively small. The proportions reported are likely to be a reflection of the area surveyed rather than the true extent of the habitats, as offshore surveys in between islands were limited to broadly spaced transects.

In all 20.8% of the region surveyed in Cape Arid was bare sand, either flat or with megaripples. Medium seagrass (5%) was found predominantly in Arid Bay, and in the lee sides of offshore islands. Dense seagrass (3.5%) was found primarily to the north of Middle Island, adjacent to Goose Island. Extensive low profile reef mapped in between the offshore islands, extending from Cape Arid to Middle Island was sand inundated (50%) with macroalgae and filterfeeders, such as sponges and ascidians. This reef system dominated the habitats mapped in the region.

3.5 DISCUSSION

The information presented here reports on an ambitious, successful and unique habitat mapping program in the Recherche Archipelago. The Archipelago is situated in the Southern Ocean with much of the area off remote and unpopulated coastal regions. The weather and sea conditions are unpredictable and only two periods in Spring and Autumn are considered suitable for fieldwork. Exploiting these periods of relatively good weather during 2002 and 2003, UWA conducted an extensive survey of a large portion of the Archipelago.

Over 1,000 km^2 of benthic habitat was mapped in three areas; Esperance Bay, Duke of Orleans and offshore islands, and Cape Arid to Middle Island. Mapping was generally within the 50 m isobath but covered deeper water in some locations. The mapping relied on combining satellite (Landsat) imagery, sidescan sonar tracks, drop and towed video and sampling of the benthos.

Maps were produced using classifications of 'broad' and 'functional' habitat types. The broad habitat classifications aggregated the seabed types surveyed into five classes according to what could be interpreted from the combined data. These classifications were low profile reef, high profile reef, rhodoliths ,seagrass and sand.

Low profile reef represented 33.3% of the area mapped, sand 28.3%, seagrass 20.1%, rhodoliths 13.7% and high profile reefs 4.6%. The importance of each broad habitat type varied between the regions. These broad habitats were not equally represented across the regions. For example, sand (31%) and low profile reef (31%) were the most common habitat in Esperance Bay, whereas in Duke of Orleans seagrasses (53%) and in Cape Arid, low profile reef (58.6%) were most common. Whether these differences represent a significant shift in habitats, or a function of our mapping design, requires further study.

Within each broad habitat type, functional habitats were mapped, primarily where data was available to identify and interpolate finer biological detail. Thirty one functional habitat types were mapped: 3 for high profile reef; 8 low profile reef including 5 sand inundation categories; 8 sand; 9 rhodoliths, and; 3 seagrass based on their density. These functional habitats give valuable insight into the complexity of some broad habitat types especially the sand and low profile reef habitats.

Utility of Sampling Strategy

The initial video survey carried out in the first field season was useful in defining the range of habitats found in the Recherche and in the development of a classification scheme. In the following field seasons, interpretation of both sidescan and Landsat imagery was successful in identifying the extent of representative habitat types. The use of satellite imagery commonly provided a broad interpretation in shallow waters that allowed specific areas to be targeted for more detailed sidescan survey. Satellite imagery and bathymetry also assisted in the interpolation of habitat boundaries between sidescan tracks. The habitats identified in the sidescan were similarly targeted in a systematic way to identify transitions between and functional detail within habitats using towed video. Coupling mapping techniques in this manner allowed habitat boundaries to be mapped that strongly link substrate with the biological communities present.

High and low profile reef, seagrass, rhodoliths and different sediment types and morphologies were readily identified and mapped from the sidescan and video although lower profile seabed features where sand inundation occurred were found to be harder to identify and map accurately. Low profile reef in particular showed a great range of variation across depths and in degrees of sand inundation. In a number of areas, algae, sponges and other invertebrates normally associated with hard substrates were found to be colonising what superficially appeared to be sand. Although these areas can be identified on the sidescan record, it is difficult to place defined boundaries around their extent and to determine the relationship between the biota and the substrate. Seagrass was found to provide strong acoustic returns. The extent of seagrass beds on sand was easily mapped and at short ranges in shallow water individual plants could be identified. Boundaries were harder to place however where the contrast between the seagrass and the surrounding substrate was not so defined, such as on low profile reef. Rhodolith beds provided a unique acoustic signature and their extent was easily derived from the sidescan record due to the large contrast with the poor backscatter returns from sand. In addition to clearly showing the boundaries and extent of high profile reef, the sidescan record also showed visually the morphology where boulders and tors could be identified. Sand ripples above wavelengths of 1 to 2m were also identified on the sidescan record providing the acoustic beam was incident at angles to the waves.

In areas where sidescan data but no video was available, only broad habitat classifications could be made. An example of this is that although high profile reef could be distinguished readily using sidescan, no information about the communities present could be interpreted without finer scale sampling by video. Acquiring video in the same area allowed classification of high profile reef by the biological community present and therefore by functional habitat. Although it would be desirable to classify all areas by functional habitat, retaining the best level of habitat detail available, this was not possible due to the paucity of video data in many areas. To provide a single classification system for all areas, functional habitat categories were also compiled into broad habitat categories. Maps could therefore be produced at both functional and broad levels. In all cases video records were required to gain detailed information about the substrate and communities of each habitat.

A multibeam survey was conducted to provide more detailed coverage of depth and relief in areas previously surveyed using sidescan and video. To aid classification in these areas 3 D visualisations could be produced by draping sidescan imagery on the bathymetry. Further examination of this data can be used to determine if higher or more accurate levels of classifications can be made using data from this more advanced, but significantly more expensive technique.

Identifying patterns

Aside from mapping habitat types, the ‘drop’ camera video survey was used to analyse relationships in the habitats observed. Classification methods, known as decision trees, were used to assess what combinations of physical factors (eg. depth; relief; substrate) may help explain where particular habitat types are found. The accuracy of the classifications using decision trees was determined by testing the results at known habitat locations surveyed by drop video. Broad habitat types were classified with a high degree of accuracy, although the more detailed, functional habitat types were difficult to accurately discern using only depth, substrate and relief. At both a broad and a functional level, substrate type was found to be the main driver of habitat, greatly influencing the particular type of habitat and biological assemblages found. Identification of finer distinctions of some functional types, including seagrass, deeper filterfeeder communities and overlapping regions of macroalgae and filterfeeders could be made using bathymetric information. For example, on low profile reefs, macroalgae dominated above 32.45m. Overlaps in the presence of filterfeeders and macroalgae were most likely to occur between the depths of 32.45 and 41m, whereas reefs dominated by filterfeeders were found in waters deeper than 41m. Sand dominated by filterfeeeders was generally found in waters deeper than 48m. Although the parameters used (depth, substrate and relief) were successful in explaining the distribution of a number of functional habitat types, it was clear that in order to fully explain habitat distribution, including the distribution of unique assemblages that other parameters must also be taken into account. The inclusion of additional oceanographic data on the range of exposure to waves, swell and currents may tighten our descriptions of where certain habitats may be found. The extent and distribution of rhodoliths beds is for example poorly explained with the available parameters. As they occur across a large range of depths and also form duplexes with sand habitats, additional data, such as exposure, may further explain their distribution and ecological significance as a substrate and habitat. The prediction of the presence of seagrass in less exposed, sheltered conditions and filterfeeders, that depend on currents are good examples of communities that could potentially be predicted using these methods and additional data.

It was expected that the patterns determined could be used to classify or predict the types of habitats found in other areas. Although the video survey data was extensive it did not provide 'full coverage' of the Archipelago. It proved difficult to extrapolate the results in between known points to unsurveyed areas, limiting the extent to which valid predictions could be applied spatially.

The hierarchical level of sampling habitats described in this report is recommended as a means of surveying large areas of the marine environment efficiently. The Landsat supplemented the sidescan and allowed larger areas to be interpreted. The coarse resolution of Landsat (30m) could be overcome in future projects with the use of aerial photography to provide more habitat detail in nearshore environments. The sidescan sonar imagery, in combination with video, was found to be sensitive to mapping the majority of functional habitat types in both nearshore and deeper areas, but was most efficient in waters greater than 20m deep. Representative broad habitat types were clearly distinguished using these methods, although it was not possible to classify all functional habitats in this way. In some cases, distinct, unique habitats were only distinguishable on video (for example, unique bryozoan and soft coral communities) and their extent could not be related to any observable differences on the sidescan or separated from other habitat types that had a similar sidescan return (eg. sand with macroalgae or sparse seagrass).

The inability to resolve functional habitats from the sidescan alone is partly due to the large size of the survey area. This meant that even targeted video data was often sparse and could not capture the full range of diversity that could be identified on the sidescan. This resulted in the reduction in the level of classification to 'broad' in many areas. Differences in survey parameters between days, conditions and vessels exacerbated this effect, varying the quality and appearance of the data made it difficult to apply similar rules of classification across all days. The large range of quality and types of data used to create the final maps mean it is very difficult to attribute accuracy to the maps. Estimates of accuracies are also confounded by the need to classify the data into a finite suite of habitat types. Recently a number of software packages for the automated analysis of sidescan data have come on the market. Further research will examine the use of these packages to make classifications more objective and to try to resolve habitats with greater resolution and confidence from the sidescan imagery.

3.6 CONCLUSIONS

The habitat mapping has resulted in an understanding of the distribution of broad habitats, cover of habitats and diversity of functional habitats within each broad habitat category and has provided invaluable lessons in the design and implementation of surveys of this type.

Use of broad scale techniques (sidescan, landsat) in combination with finer (video) surveys not only allows large areas of common habitats to be mapped accurately but also increases the chance of identifying unique and endemic communities. The maps also provide a invaluable product on which the design of further fine scale sampling and monitoring of the area can be based.

The results from this part of the project form the basis for interpreting broad scale distributions of demersal fish and finer spatial resolution of diversity in soft bottom infaunal communities, seaweeds, sessile invertebrates and fish in the following reports.

3.7 ACKNOWLEDGEMENTS

This report has been funded primarily by Fisheries Research Development Corporation (FRDC) grant 2001/060 "Characterising the Fish Habitats of the Recherche Archipelago", awarded to the Univeristy of Western Australia Marine Science Group.

We would like to thank:

- The Co-operative Research Centre for Coastal Zone, Estuary and Waterway Management, who funded the multibeam survey. In particular, we thank Justy Siwabessy for multibeam data collection and processing and Theresa Leitjen for helping us all the time.
- Alan Jordan, Vanessa Halley and Miles Lawler of the Tasmanian Aquaculture and Fisheries Institute (TAFI) for helpful advice and programming code, particularly during the initial video survey.
- Emma Seager, University of Western Australia, for help in data processing and analysis.
- Kevin Bancroft, Ray Lawrie and Mark Sheridan, Conservation and Land Management (CALM), Fremantle.
- Fugro Pty, Ltd for the generous loan of their Starfix satellite positioning system for the multibeam survey in October 2003.

3.8 REFERENCES

Bancroft, K.P. (2002). Developing a marine ecological community classification scheme. Report MCB-05/2002. Marine Conservation Branch, Department of Conservation and Land Management, 47 Henry St Fremantle, Western Australia, 6160. Unpublished report, January 2002.

Baxter, K. & Shortis, M. (2002). Identifying Fish Habitats: the use of spatially explicit habitat modeling and prediction in marine research. The 14th Annual Colloquium of the Spatial Information Research Centre (SIRC), University of Otago, Dunedin, New Zealand.

Bickers, A. 2003. Cost Effective Marine Habitat Mapping from Small Vessels using GIS, Sidescan Sonar and Video. Coastal GIS Proceedings, Woolongong Papers on Maritime Policy No. 14.

Clarke, E. D. C., & Tarlton, P. (1952). Physiography and other notes on a part of the south coast of Western Australia.

Everall, D. (2000). Aquaculture Plan for the Recherche Archipelago. Fisheries Western Australia, Fisheries Management Paper No. 140

Foster, M.S. (2001). Rhodoliths: between rocks and soft places. Journal of Phycology 37: 659–667.

Goldberg, N.A. & Kendrick, G.K. (2004). Effects of island groups, depth and exposure to ocean waves on subtidal macroalgal assemblages in the Recherche Archipelago, Western Australia. Journal of Phycology 40: 631-641

Kendrick, G.A., Harvey, E., Hill, J., McDonald, J.I. & Grove. S. 2002. Characterising the fish habitats of the Recherché Archipelago: Review of existing information, Fisheries Research Development Corporation Project 2001/060. Report to the FRDC.

Kirkman, H. (1996). Mapping Australia's underwater features. CSIRO Division of Marine Research, Perth, Western Australia.

Myers, J. S. 1990. Western Gneiss Terrane. *Geological Survey, Western Australian Memoirs, Geology and Mineral Resources of Western Australia* (3): 13-32.

Steller, D.L. & Foster, M.S. 1995. Environmental factors influencing distribution and morphology of rhodoliths in Bahia Concepcion, B.C.S., Mexico. Journal of Experimental Marine Biology and Ecology 194: 201–212.

Stellar, D.L., R. Riosmena-Rodriguez, M.S. Foster & Roberts, C.A. 2003 Rhodolith bed diversity in the Gulf of California: theimportance of rhodolith structure and consequences of disturbance. Aquatic Conservation: Marine And Freshwater Ecosystems 13 : S5–S20

3.9 APPENDIX 1: GIS Analysis of habitat coverage

Areas mapped by region

Region	Total area (km2)	% area
Esperance	813.17	77.11
Arid	141.73	13.44
Duke	99.63	9.45
Total	1,054.53	100

Broad Habitats – summary of areas

Broad habitat	Total area (km2)	% of total cover
Sand	298.04	28.3
Low profile reef	351.70	33.4
Seagrass	212.41	20.1
Rhodoliths	144.10	13.7
High profile reef	48.28	4.6
Total	1,054.53	100.0

Functional Habitats – summary of areas

Functional habitat	Total area (km2)	% of total cover
Bare sand	215.91	**20.47**
Sand inundated low profile reef with filterfeeders and macroalgae	185.56	**17.60**
Dense seagrass	123.03	**11.67**
Rhodoliths	117.04	**11.10**
Low profile reef	62.05	**5.88**
Sparse seagrass	44.66	4.23
Medium seagrass	44.32	4.20
Sand inundated low profile reef with macroalgae and seagrass	34.05	3.23
Sand inundated low profile reef with filterfeeders	33.07	3.14
Sand with vegetation	28.75	2.73
High profile reef with macroalgae	27.13	2.57
Bare sand rippled	25.93	2.46
Low profile reef with macroalgae	19.90	1.89
Megaripples	18.55	1.76
High profile reef with filterfeeders and macroalgae	12.31	1.17
Sand inundated rhodoliths	9.86	0.94
High profile reef	8.46	0.80
Low profile reef with filterfeeders and macroalgae	7.88	0.75
Rhodoliths with filterfeeders	5.94	0.56
Sand inundated rhodoliths with macroalgae	5.40	0.51
Bare sand with some macroalgae	4.53	0.43
Sand inundated low profile reef with macroalgae	3.91	0.37
Sand inundated rhodoliths with filterfeeders and macroalgae	3.23	0.31
Sand inundated low profile reef	3.16	0.30
Rhodoliths with macroalgae	2.98	0.28
Low profile reef with filterfeeders	2.36	0.22
Sand with filterfeeders	1.39	**0.13**
Megaripples with filterfeeders	1.35	0.13
Sand	0.50	0.05
High profile reef with filterfeeders	0.49	0.05
Sand with vegetation and filter feeders	0.44	0.04
Seagrass	0.40	0.04
	1,054.53	100.00

Esperance region – Summary of Broad and Functional areas

Broad habitat	**Total area (km2)**	**Total %cover**
Sand	253.61	31.19
Low profile reef	251.57	30.94
Seagrass	144.88	17.82
Rhodoliths	138.15	16.99
High profile reef	24.97	3.07
	813.17	100.00

Functional habitat	**Total area (km2)**	**Total % cover**
Bare sand	195.72	**24.07**
Rhodoliths	117.04	**14.39**
Sand inundated low profile reef with filterfeeders and macroalgae	108.27	**13.31**
Dense seagrass	76.11	**9.36**
Low profile reef	60.03	7.38
Sparse seagrass	37.18	4.57
Sand inundated low profile reef with macroalgae and seagrass	33.93	4.17
Sand inundated low profile reef with filterfeeders	32.99	4.06
Medium seagrass	31.19	3.84
Sand with vegetation	28.75	3.54
Bare sand rippled	18.69	2.30
High profile reef with macroalgae	12.79	1.57
Sand inundated rhodoliths	9.86	1.21
Low profile reef with macroalgae	7.56	0.93
High profile reef with filterfeeders and macroalgae	6.21	0.76
High profile reef	5.90	0.73
Sand inundated rhodoliths with macroalgae	5.39	0.66
Bare sand with some macroalgae	4.53	0.56
Sand inundated rhodoliths with filterfeeders and macroalgae	3.23	0.40
Rhodoliths with macroalgae	2.98	0.37
Sand inundated low profile reef	2.64	0.33
Sand inundated low profile reef with macroalgae	2.43	0.30
Low profile reef with filterfeeders	2.36	0.29
Megaripples	2.02	0.25
Sand with filterfeeders	1.39	**0.17**
Megaripples with filterfeeders	1.35	0.17
Low profile reef with filterfeeders and macroalgae	1.13	0.14
Sand	0.47	0.06
Sand with vegetation and filter feeders	0.44	0.05
Seagrass	0.40	0.05
High profile reef with filterfeeders	0.18	**0.02**
	813.17	100.00

Duke of Orleans region - Summary of Broad and Functional areas

Broad habitat	**Total area (km2)**	**Total % cover**
Seagrass	52.85	53.0
Low profile reef	17.07	17.1
Sand	13.19	13.2
High profile reef	10.56	10.6
Rhodoliths	5.95	6.0
	99.63	100.0
Functional habitat	**Total area (km2)**	**Total % cover**
Dense seagrass	42.01	**42.17**
High profile reef with macroalgae	9.01	**9.04**
Low profile reef with macroalgae	8.88	8.91
Bare sand	7.35	7.37
Sand inundated low profile reef with filterfeeders and macroalgae	6.41	6.43
Medium seagrass	6.06	6.08
Rhodoliths with filterfeeders	5.94	5.97
Bare sand rippled	5.81	5.83
Sparse seagrass	4.79	4.80
Low profile reef with filterfeeders and macroalgae	1.51	1.51
High profile reef	0.83	0.83
High profile reef with filterfeeders and macroalgae	0.45	0.45
High profile reef with filterfeeders	0.28	0.28
Low profile reef	0.12	0.12
Sand inundated low profile reef with macroalgae and seagrass	0.12	0.12
Sand inundated low profile reef	0.05	0.05
Sand	0.03	0.03
Sand inundated rhodoliths with macroalgae	0.01	0.01
	99.63	100.0

<u>Cape Arid region - Summary of Broad and Functional areas</u>

Broad habitat	**Total area (km2)**	**Total % cover**
Low profile reef	83.06	58.6
Sand	31.25	22.0
Seagrass	14.68	10.4
High profile reef	12.75	9.0
	141.73	100.0

Functional habitat	**Total area (km2)**	**Total % cover**
Sand inundated low profile reef with filterfeeders and macroalgae	**70.88**	**50.0**
Megaripples	16.53	11.7
Bare sand	12.84	9.1
Medium seagrass	7.07	5.0
High profile reef with filterfeeders and macroalgae	5.65	4.0
High profile reef with macroalgae	5.34	3.8
Low profile reef with filterfeeders and macroalgae	5.24	3.7
Dense seagrass	4.91	3.5
Low profile reef with macroalgae	3.47	2.4
Sparse seagrass	2.69	1.9
Low profile reef	1.90	1.3
High profile reef	1.73	1.2
Sand inundated low profile reef with macroalgae	1.47	1.0
Bare sand rippled	1.43	1.0
Sand inundated low profile reef	0.47	0.3
Sand inundated low profile reef with filterfeeders	0.08	0.1
High profile reef with filterfeeders	0.03	0.0
	141.73	100.0

4.0 Prediction and measurement of wave energy and bottom shear stress for Esperance Bay.

David Johnson[1] and Charitha Pattiaratchi[1].

1. Centre for Water Research Report No. WP 2051 DJ. University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009.

4.1 INTRODUCTION

Hydrodynamic conditions experienced at the sea bed are the result of water motion caused by waves and currents. In the Esperance Bay region, which has an energetic wave climate with large Southern Ocean swells propagating into the area from offshore, wave motion is the dominant process. Measurement and prediction of the properties of the wave field, (i.e. the wave height, wave period and wave direction of incoming waves) over the region of interest at different times allows calculation of the near bed conditions in terms of the wave induced flow and bed shear stresses.

The ocean wave field is a complex mixture of many component waves, all possessing different periods and directions. The instantaneous wave motion experienced at any point can be considered as the sum of all these component waves.

To characterise the wave field, in general, three primary parameters are used:

- Significant wave height, equal to the average of the highest third of waves;
- Peak spectral period, the period of the component wave with the highest energy;
- Peak spectral direction, the direction of component wave with the highest energy.

The distribution in space and time of the wave field and hence the three defining parameters is determined by the offshore wave field and its transformation as it propagates into the region of interest. As waves travel into water that is of a depth comparable to their wavelength, they refract (wave directions tend to turn perpendicular to bottom contours) and shoal (waves heights change as the speed at which wave energy travels changes). Wave energy is also dissipated due to bottom friction in shallow water, which is the reason for wave induced shear stress at the sea bed.

The near bed orbital velocity, the oscillatory flow caused by a wave's motion, depends on the wave height, period and direction. The orbital flow speed varies, relative to the wave height, with both the wave period and water depth. The shear stress experienced by the bed is determined by the wave orbital velocity and the hydraulic roughness of the bed itself.

This component of the study describes the distribution in both time and space of wave energy in the Esperance Bay region (Figure 4.1). The analysis of wave conditions has been undertaken through both direct measurement, and prediction, using a sophisticated numerical model, of the wave conditions in the region of interest.

4.2 Methods

4.2.1 Measured wave data from Esperance Bay

An InterOcean S4 was deployed, in a frame at 12m depth in the north eastern part of Esperance Bay (Figure 4.1). The horizontal water velocity and pressure was sampled at 2Hz. Data segments of 18-minute duration were recorded every two hours. Data were collected over three periods during 2002-2003 and include both winter and summer periods:

11th June – 21st July 2002
12th February - 19th March 2003
24th May – 7th June 2003

Spectral analysis was carried out on each data segment to determine the significant wave height, peak spectral period and peak spectral direction[1]. Results of the analysis are shown in Figures 4.2 to Figure 4.4.

The mean significant wave height for all measurements was 1.1 m and the measured maximum wave height was is 3.3 m. Wave heights were lower during the summer period and also showed a longer time gap between periods of high swell. Note that

---

[1] The details of the calculation of these parameters are described in the Appendix.

the significant wave heights at the instrument location will be smaller than offshore conditions as wave energy is dissipated with the bay.

The peak periods were mainly in the range 12 s to 16 s, consistent with the dominance of the wave energy by remotely generated swell. There were some shorter periods corresponding to locally generated sea. The exceptionally long periods of over 18 s coincided with times of low significant wave heights. As the lower period wave components in the sea state are attenuated more by bottom friction than the long period waves, it appears that the longest period components of the wave field become dominant at the instrument location during times of very low swell heights.

Winter directions were consistently from the WSW, with a mean of 240o. During the summer there were periods with waves from the south that coincided with lower wave heights and shorter periods. This is consistent with periods of easterly winds during which the waves would be expected to propagate into the bay from the southeast. In all cases, the wave direction at the instrument will be partially refracted perpendicular to the shoreline, with this effect is greatest for the longer period waves.

4.2.2 Modelling the wave field for Esperance Bay

To provide a complete spatial map of the typical characteristics of the wave field, the wave conditions were hindcast for the year 2002 using a numerical model. Based on known conditions offshore, the distribution of wave heights, periods and directions were simulated for each day in 2002. From this data, the flow velocities and shear stresses at the bed were estimated.

4.2.3 The Wave Propagation Model

Initial numerical simulations of the wave conditions across the Esperance Bay region were carried out using REFDIF (Kirby and Dalrymple 1994), as reported in Milestone Report 4. However, the model was shown to have unacceptable levels of noise related to wave propagation around the many islands in the Esperance Bay domain. An alternative numerical model, SWAN, was found to perform far better in the complex geometry of the model domain.

SWAN (Simulating WAves Nearshore) is a state of the art wave propagation model, the result of current knowledge regarding the generation, propagation and transformation of wave fields in the nearshore. The model is available under a public license, and is described fully in the user manual (Holthuijsen *et al.*, 2004). SWAN calculates the transformation of the directional wave spectrum over arbitrary bathymetry, providing spatial and temporal maps of energy contained in the component waves of different periods and directions.

It should be noted that SWAN does not simulate diffraction, and differs in this respect to REFDIF. This should have little effect except in the immediate shadow zones of the islands. For monochromatic waves, the lack of diffraction leads to unrealistic total shadows behind the islands; however, because a directional spectrum is modelled in the SWAN simulations, a significant amount of wave energy still enters the shadow region and the lack of diffraction should be small except within one to two wavelengths of the island (Booij, 1992).

The model domain was discretised on a square spatial grid of 363 by 284 grid points with 100m spacing. The model was run in stationary mode for a particular offshore wave field. The stationarity means that the conditions in the Bay are in equilibrium with the offshore conditions, which is a good assumption for the scale of the model domain, as wave energy propagates through the domain much faster than significant changes in the offshore wave climate. In this work, a directional spread of waves at the peak spectral period is simulated. The directional spectra is represented in 40 directional bins of 3 degree width limited to a sector 60 degrees each side of the offshore wave conditions. Only one period (the peak spectral period) is simulated, so non-linear transfer of energy between different frequencies is not included.

The wave spectrum at the outer (offshore) boundaries of the model domain wave data at any particular time was determined from the known wave peak period and significant wave height (described in Section 0), and by assuming the directional spread for the formula of is 10 (Mitsuyasu, 1975). Dissipation of waves by friction was included in the simulations and used the JONSWAP formula (Hasselmann *et al.* 1973), with a friction factor of 0.038.

4.2.4 Wave climate data for model boundary conditions

Wave climate data, consisting of significant wave height, peak period and peak direction at 3 hourly intervals for year 2002, was been obtained from hindcasts of the NOAA WaveWatch3 (WW3) global wave model. The data were from the WW3 model grid point closest to the modelling domain at 34°S, 121.25°E (UTM Easting

338382 zone 51 Northing 6236463; approximately 40km to the west of the model boundary) at the 00:00 cycle were used as boundary conditions. In the absence of a wave rider buoy deployed in the offshore region, these are the best available data for providing appropriate model boundary conditions.

In contrast to the measured inshore wave data, which represents a wave field that has been significantly transformed within the bay, the WW3 data provide information on the deep water conditions further offshore, and provide insight in itself. The mean significant wave height was 2.2m, with a maximum of 5.6m (Figures 4.5 and 4.6). The significant wave height rarely drops below 1m and the minimum was 0.8m. The directional distribution was dominated by waves from the SW quadrant, mainly in a tight directional band between 200° and 230° compass direction (Figures 4.7 and 4.8). This corresponds to swell generated by the Southern Ocean lows, which subsequently propagates north-eastwards towards the mainland. These swell waves have periods of 10-16 s. There was a secondary grouping of wave directions in the Eastern quadrant (80° to 110°) generated by easterly wind patterns which generate a relatively local sea in the Bight with a much shorter wave period. Note that the grouping of the wave climate into these two main groups is also reflected in the double peak in the wave period distribution (Figure 4.9).

Table 1. The percentage of total time, mean peak spectral period (Tp) and significant wave height (Hs) for the periods when waves are from the east or south-west directional bands.

Direction	% Time	Mean T_p [s]	Mean H_s [m]
80° – 110°	8	6.3	1.8
180° – 230°	80	12.2	2.2

4.3 Results

The results from SWAN are daily predictions of significant wave height and peak spectral direction. Examples of the predictions are shown in Figures 4.10 to Figure 4.12, corresponding to typical wave conditions experienced within the region:

- Summer swell waves from the SSW (10-16s peak period)
- Locally generated easterly waves (4 – 9s peak period)
- Large winter swell from the SW (10-16s peak period)

The variation in spatial distribution of wave heights is clear, particularly between the swell and easterly waves (Figure 4.10 and 4.11). In particular, some regions normally shadowed from the SW swell are exposed to the easterly waves. During the easterly wave periods, there is almost complete shadowing along the whole eastern margin of the Bay. The model results show a well defined difference between the weather and shadowed side of the various islands in the usual SW swell conditions. The effect of refraction is seen, as wave directions are turned perpendicular to the bottom contours. Maximum and root mean squared (RMS) wave heights were calculated for the region from the daily results, and these are shown in Figure 4.14 and 4.15. As wave energy is proportional to the square of the wave height, the RMS wave height gives a better representation of the typical wave height. The maximum, minimum and mean peak spectral directions were also calculated from the daily results.

4.3.1 Model validation

To validate the numerical model, the predicted and measured wave conditions at the S4 deployment location were compared. In general the agreement was very good, especially considering the location of the instrument at the furthest inshore extent of the domain. The poorest agreement was with the smaller wave heights, which had relatively little influence on the RMS values, and of course no effect on maximum values. SWAN appeared to slightly overestimate the maximum and RMS significant wave heights. Overall, the good correspondence with the measurements gives a high level of confidence for the model predictions.

4.3.2 Wave orbital velocities and bottom shear stress

The peak orbital velocity, which is the maximum velocity of the water at the seabed, and peak shear stress due to the wave motion are the two defining hydrodynamic variables in terms of conditions for the seabed for biota. The numerical model solution yielded a spatial distribution of wave heights. From the wave heights, the peak orbital bed velocities, $U_{\max}$, were calculated by:

$$U_{\max} = \frac{\pi H_s}{T_p} \frac{1}{\cosh(kh)} \tag{1}$$

where k is the local wavenumber (2π divided by wave length) and h is the water depth. Whilst the details of the calculation of wavenumber are not important, it is worth noting that except in very shallow water, longer period waves generate greater peak orbital velocities than shorter period of the same wave height.

Although a real sea has a varying orbital velocity corresponding to the variable periods and wave heights, the characteristic peak orbital bed velocity can be calculated for a characteristic wave with significant wave height at the peak spectral period. The largest wave encountered in a given sea state is usually twice the significant wave height so an upper bound for the bottom orbital velocity could be estimated as $2U_{\max}$.

The peak shear stress, $\tau_{\max}$, is the greatest shear stress experienced by the seabed during one wave period. This is calculated directly from $U_{\max}$ by:

$$\tau_{\max} = \frac{1}{2}\rho f_w U_{\max}^2 \qquad (2)$$

where ρ is the density of water and f_w is the *friction factor.* The friction factor depends on both the wave parameters and the *bottom roughness,* R, as (approximation of Grant and Madsen, 1986):

$$\begin{aligned} f_w &= \exp\left[-7.02 + 5.5(A_0/R)^{-0.12}\right] \\ A_0 &= \frac{T_p}{2\pi}U_{\max} \end{aligned} \qquad (3)$$

For initial shear stress calculations, a spatially uniform bed roughness of 0.001 was used – this is not realistic for all types of bottom substrate that are present in many locations. In addition, the presence of biota such as sea grasses may significantly increase the friction factor. However, it is expected that a spatially variable friction factor will be implemented, utilising knowledge about the composition of the bed and benthic biota. The shear stress is easily calculated without having to rerun the model simulations, using equations (1) to (3).

The peak bottom orbital velocity for the three days shown in Figures 4.10 to 4.12 are shown in Figures 4.18 to 4.20. The highest values are in the shallow water around the coasts, where water depth becomes the dominant factor in determining the bottom velocities. Note also the relatively smaller values for the easterly waves in the deeper water, due to their shorter period.

For each daily map of bottom orbital velocity, there is a corresponding map of peak shear stress – note that the bottom shear stress is roughly proportional to the square of the bottom orbital velocity. The series of daily shear stresses for all of 2002 were used to generate spatial distributions of maximum, minimum, mean and RMS peak shear stress. These data are shown in Figure 4.18.

The distribution of shear stress closely mirrors that of the peak orbital velocity, but is even more accentuated in terms of difference between high and low values because of the quadratic dependence on the bottom velocity.

4.3.3 GIS layers

From the modelling study, a number of products were generated for incorporation into a GIS. These were GIS grid layers of the spatial distribution of:

- Significant wave height: Maximum, minimum, RMS and mean.
- Peak spectral direction: Maximum, minimum and mean.
- Peak bottom orbital velocity: Maximum, minimum, RMS and mean

The daily results of wave height, peak direction and orbital velocity were also provided.

The calculation of shear stress from the orbital velocities, is made in the GIS based on a roughness length GIS layer, estimated from the benthic survey results.

4.4 References

Booij, N., L.H. Holthuijsen and P.H.M. de Lange, (1992) The penetration of short-crested waves through a gap, *Proc. 23rd Int. Conf. Coastal Eng*, Venice 4-9 Oct., 1992, New York, 1993, 1044-1052

Grant, W. D., and Madsen, O.S. (1986) The continental-shelf bottom boundary layer, *Annual Review of Fluid Mechanics*, **18**, 265-305

Hashimoto, N. Nagai, T and Asai, T. (1993) Modification of the extended maximum entropy principle for estimating directional spectrum in incident and reflected wave field. *Rept. Of P.H.R.I.* **32**(4) 25-47

Hasselmann, K., T.P. Barnett, E. Bouws, H. Carlson, D.E. Cartwright, K. Enke, J.A. Ewing, H. Gienapp, D.E. Hasselmann, P. Kruseman, A. Meerburg, P. Müller, D.J.

Olbers, K. Richter, W. Sell and H. Walden (1973) Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP), *Dtsch. Hydrogr. Z.* Suppl., **12**, A8

Holthuijsen, L.H., Booij, N., Ris, R.C., Haagsma, I.J.G, Kieftenburg, A.T.M.M., Kriezi, E.E., Zijlema, M. and van der Westhuysen, A.J. (2004) SWAN Cycle III version 40.31 User Manual. Available: http://fluidmechnaics.tudelft.nl/swan

Johnson, D. (2002) DIWASP, a directional wave spectra toolbox for MATLAB®: User Manual. *Research Report WP-1601-DJ (V1.1)*, Centre for Water Research, University of Western Australia. Available: http://www2.cwr.uwa.edu.au/~johnson/diwasp/diwasp.html

Mitsuyasu, H. (1975) Observation of the directional wave spectrum of ocean waves using a cloverleaf buoy. *J. Phys. Oceanogr.*, **5**, 750-760

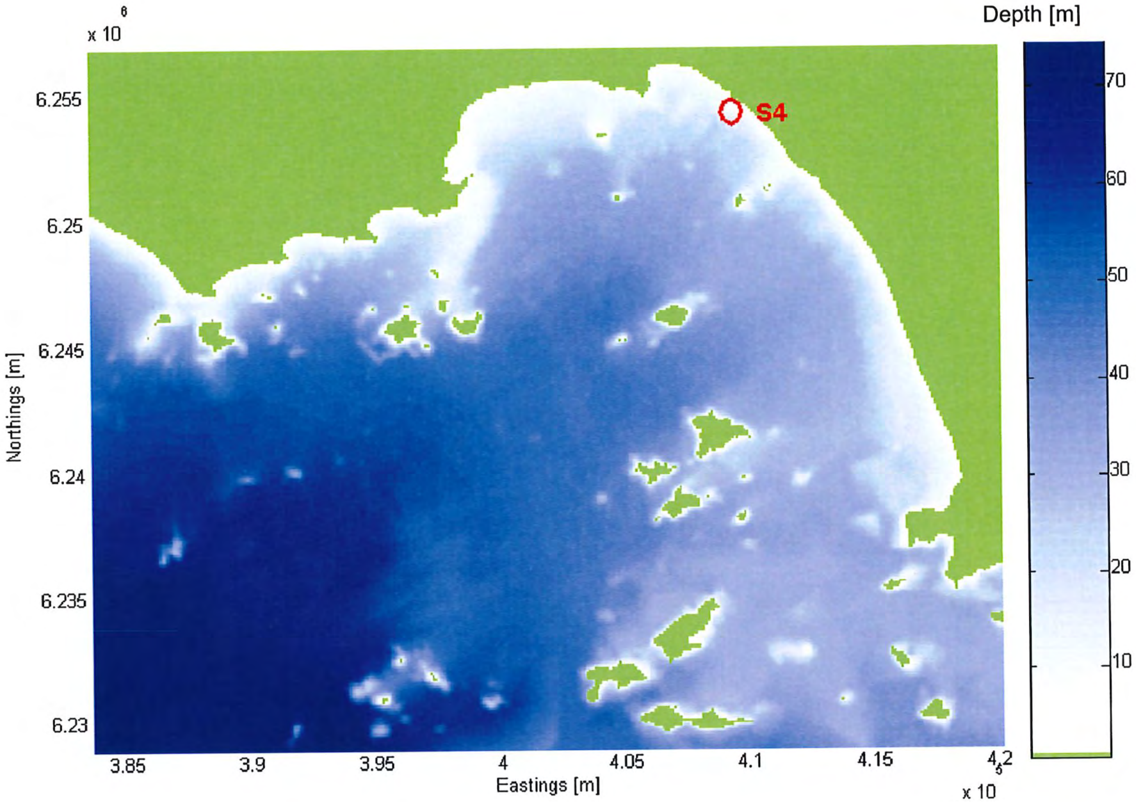


Figure 4.1 Esperance Bay region showing the domain used for the numerical modelling. The location of the S4 wave recorder is indicated as a red circle.

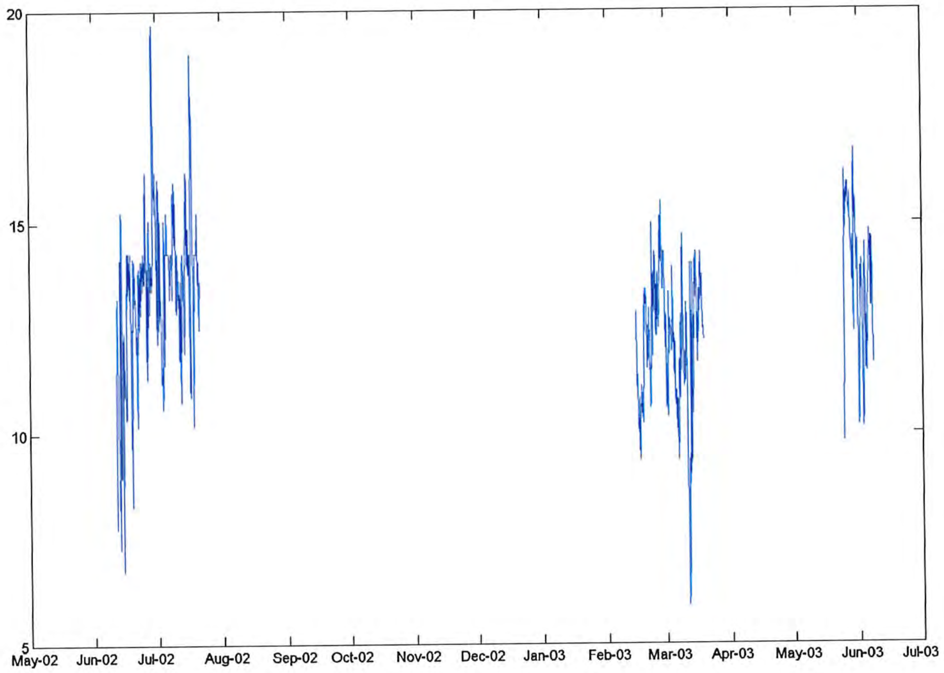


Figure 4.2. Peak wave period at north-eastern Esperance Bay.

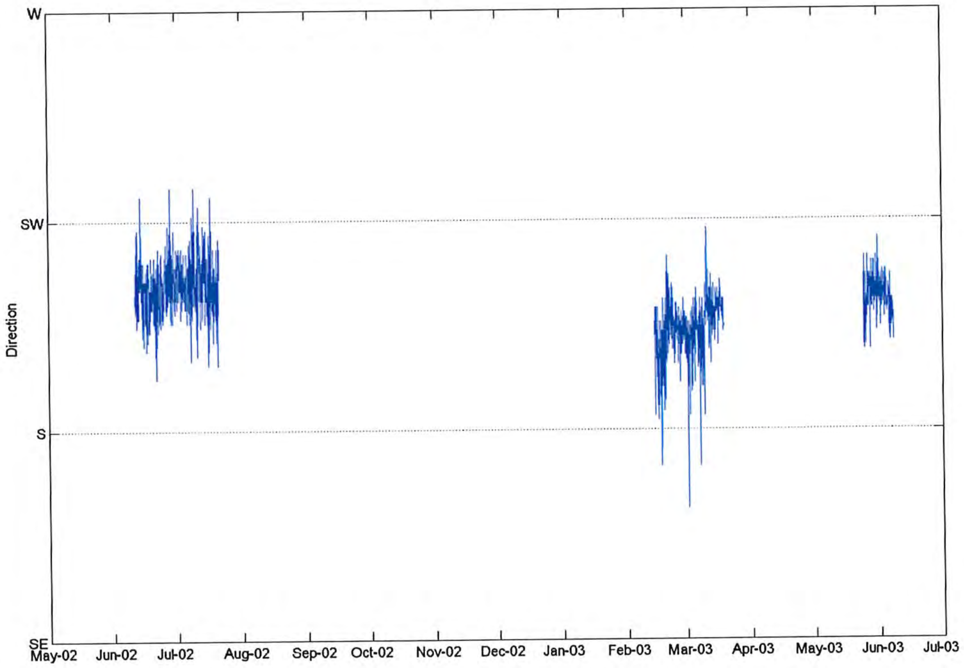


Figure 4.3. *Peak direction at north-eastern Esperance Bay.*

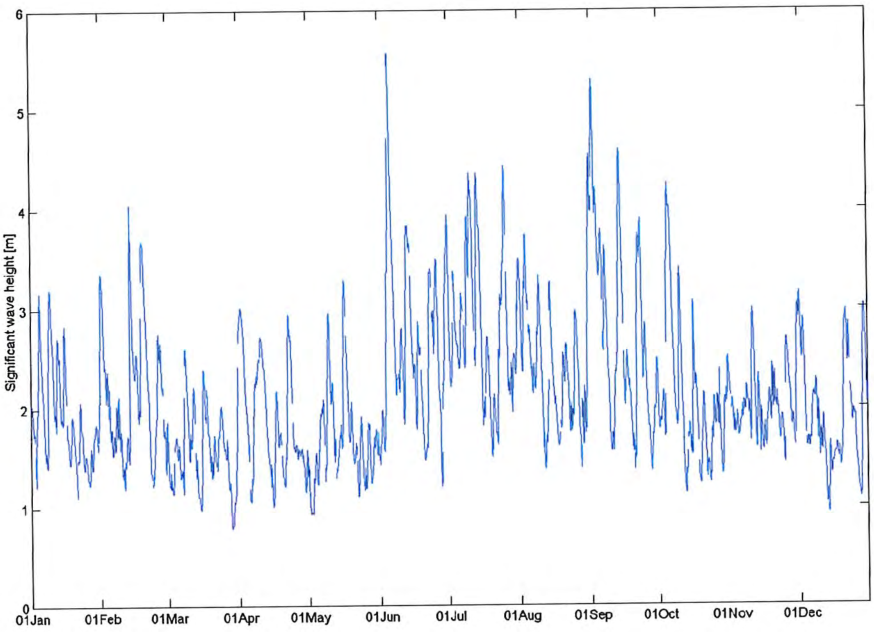


Figure 4.4 Time-series of significant wave height (H_s) for offshore conditions for 2002.

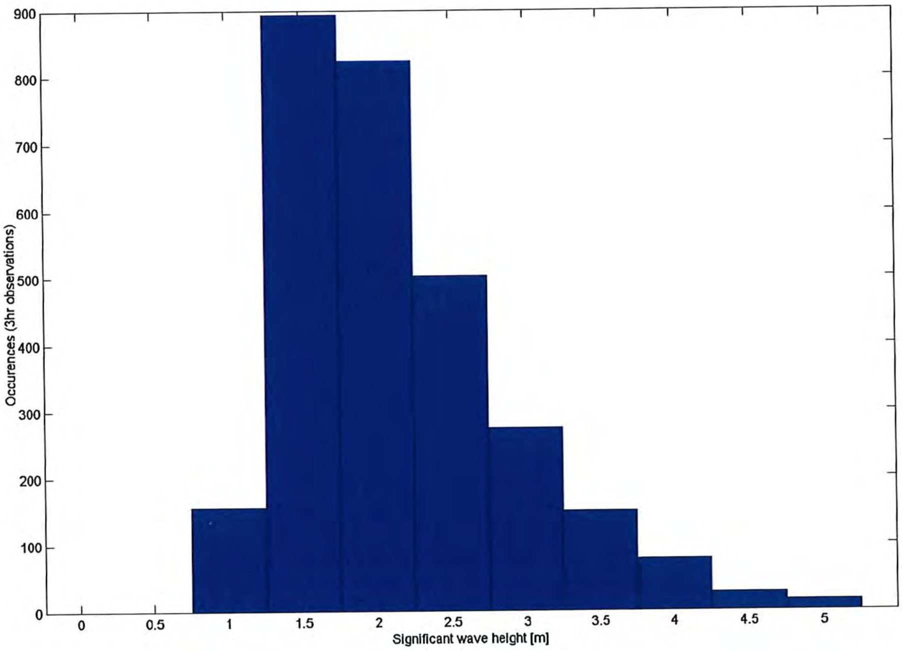


Figure 4.5. Histogram of significant wave height (H_s) for offshore conditions for 2002.

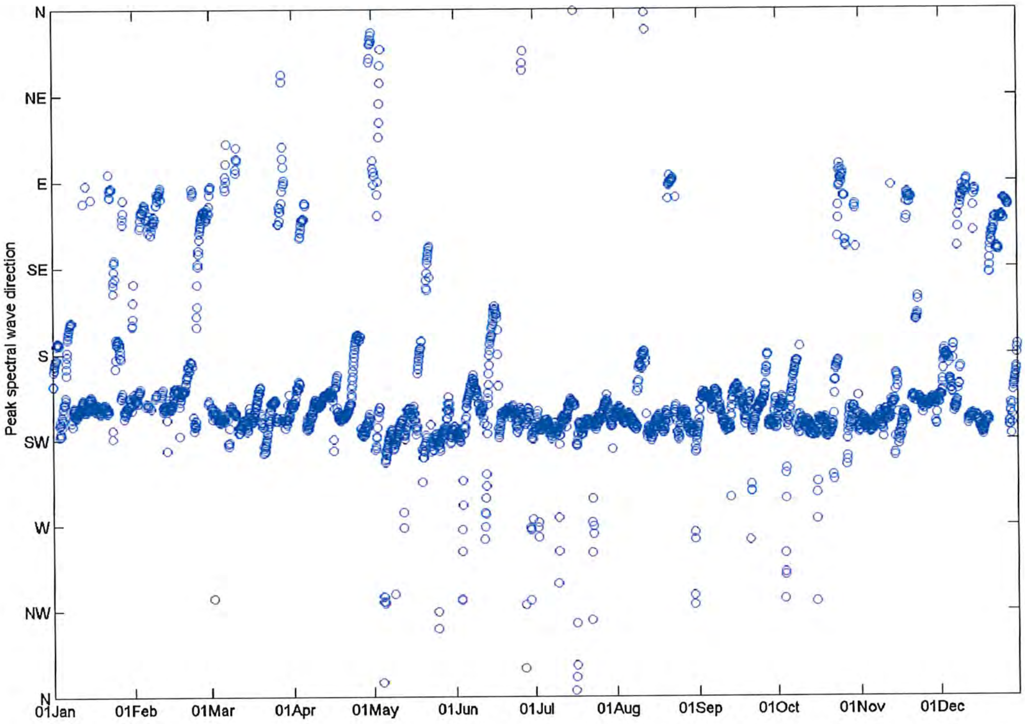


Figure 4.6. Time-series of peak spectral direction (D_p) for offshore conditions for 2002.

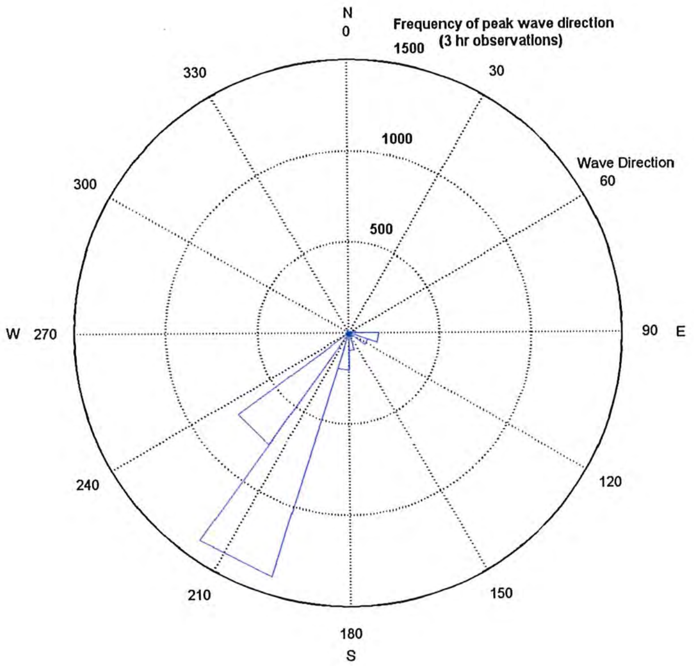


Figure 4.7. Directional histogram of peak spectral direction (D_p) for offshore conditions for 2002.

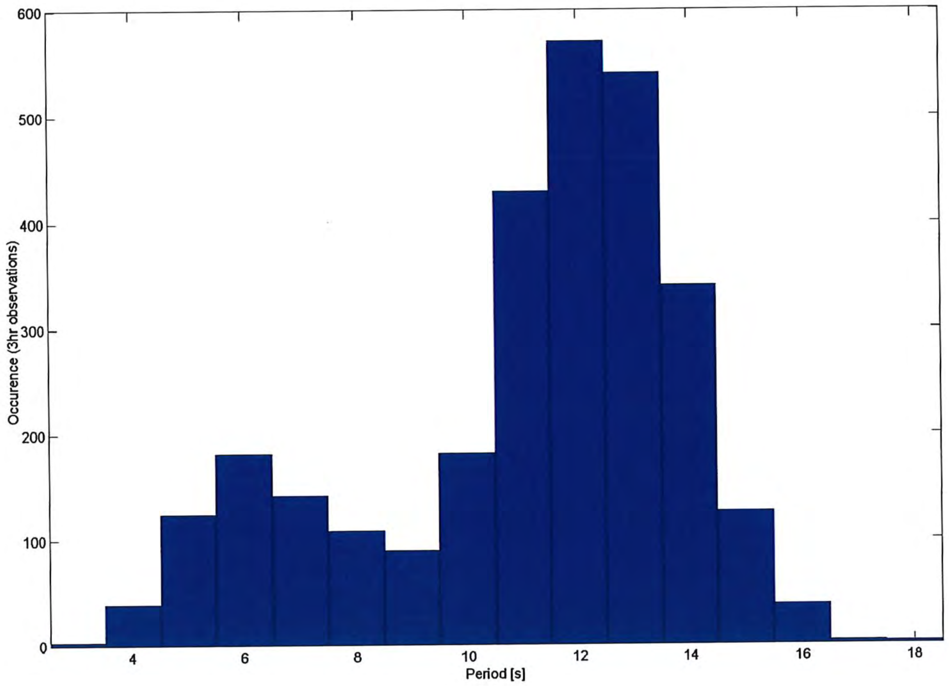


Figure 4.8. Histogram of peak spectral period (T_p) for offshore conditions for 2002.

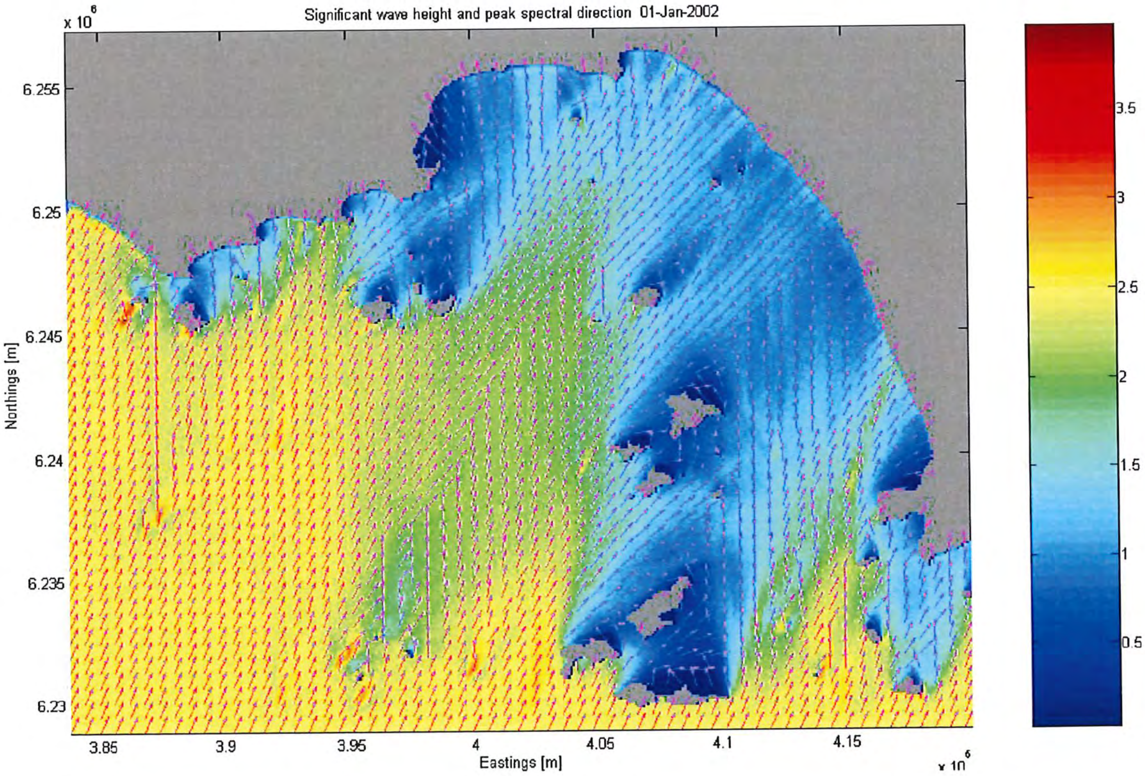


Figure 4.9. SWAN prediction of significant wave height and peak spectral direction for typical summer conditions. Peak period is 11.14s.

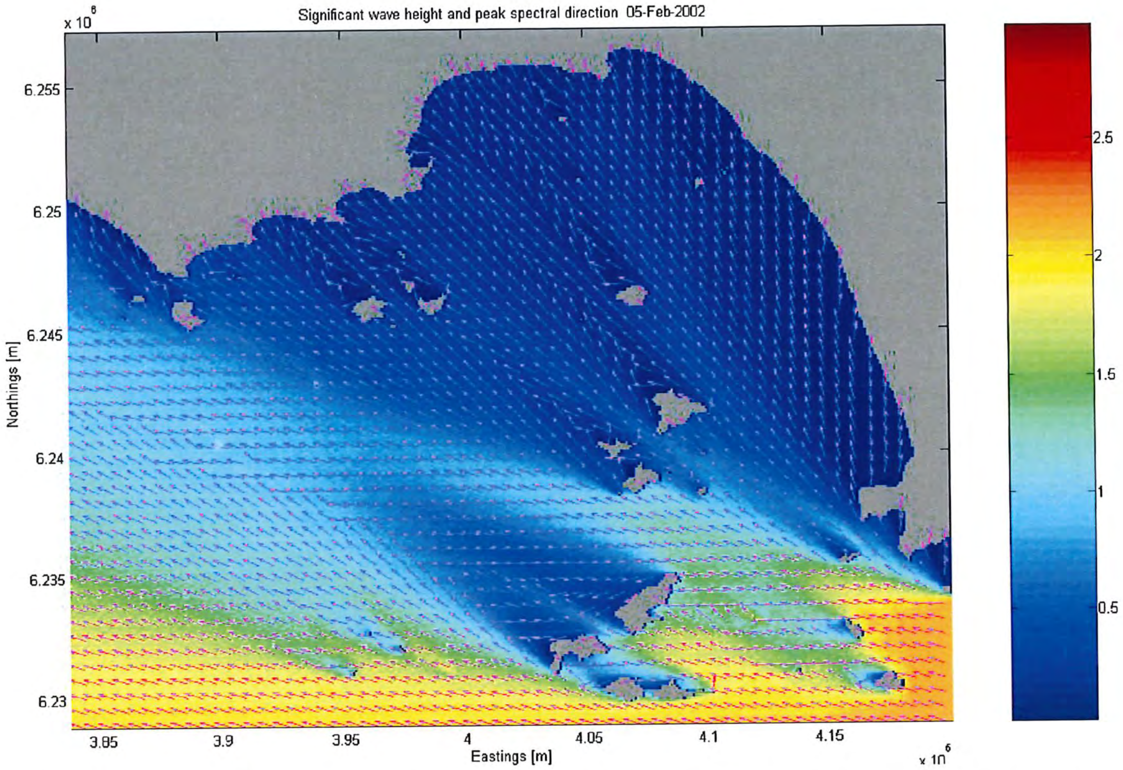


Figure 4.10. SWAN prediction of significant wave height and peak spectral direction for easterly wind conditions. Peak period is 7.0s.

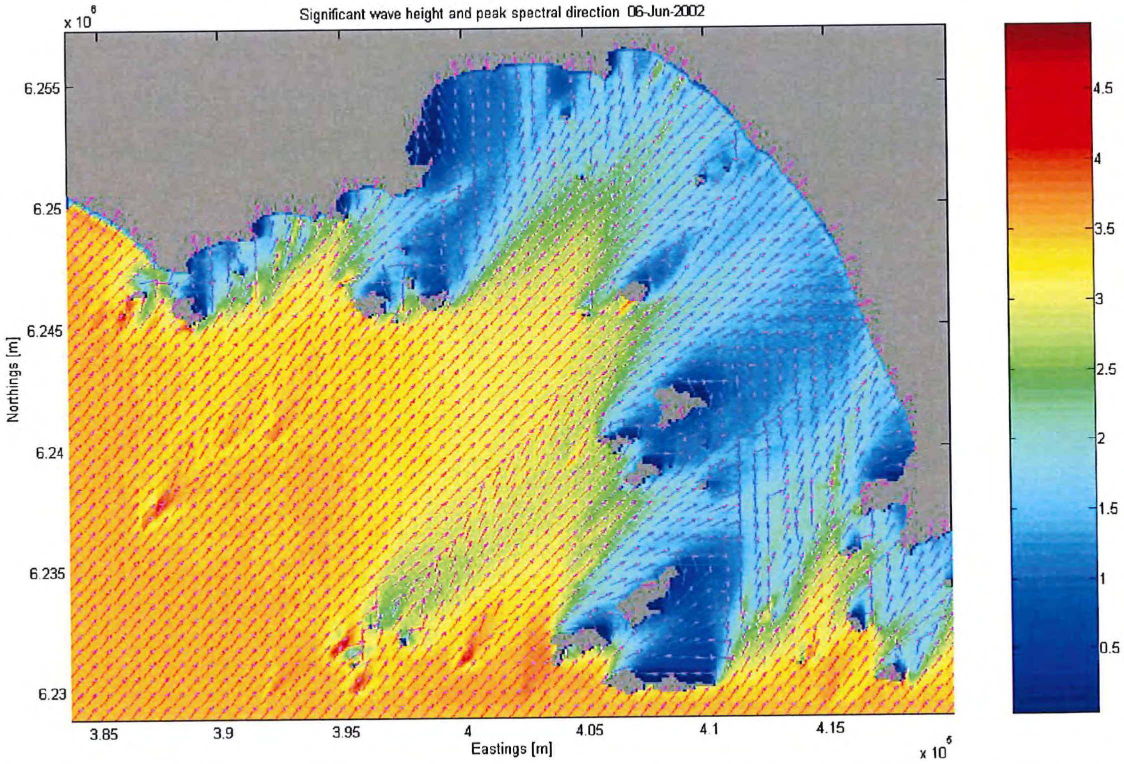


Figure 4.11. SWAN prediction of significant wave height and peak spectral direction for typical winter conditions.

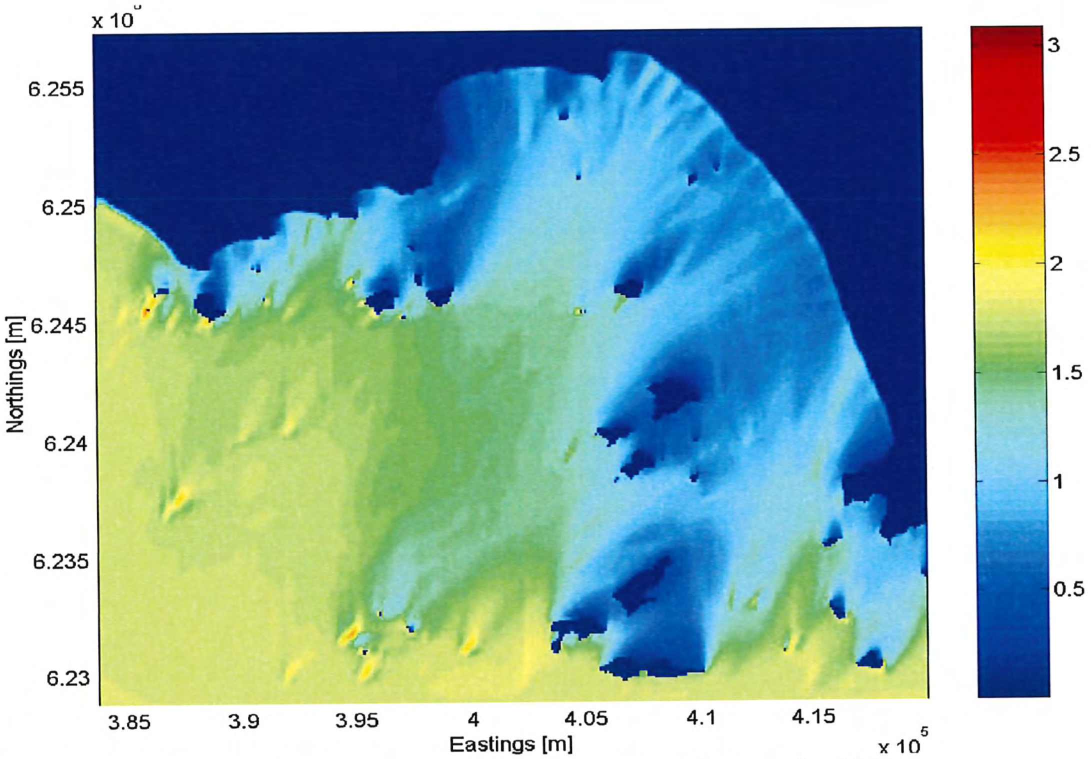


Figure 4.12. RMS wave height for all of the daily SWAN predictions for 2002.

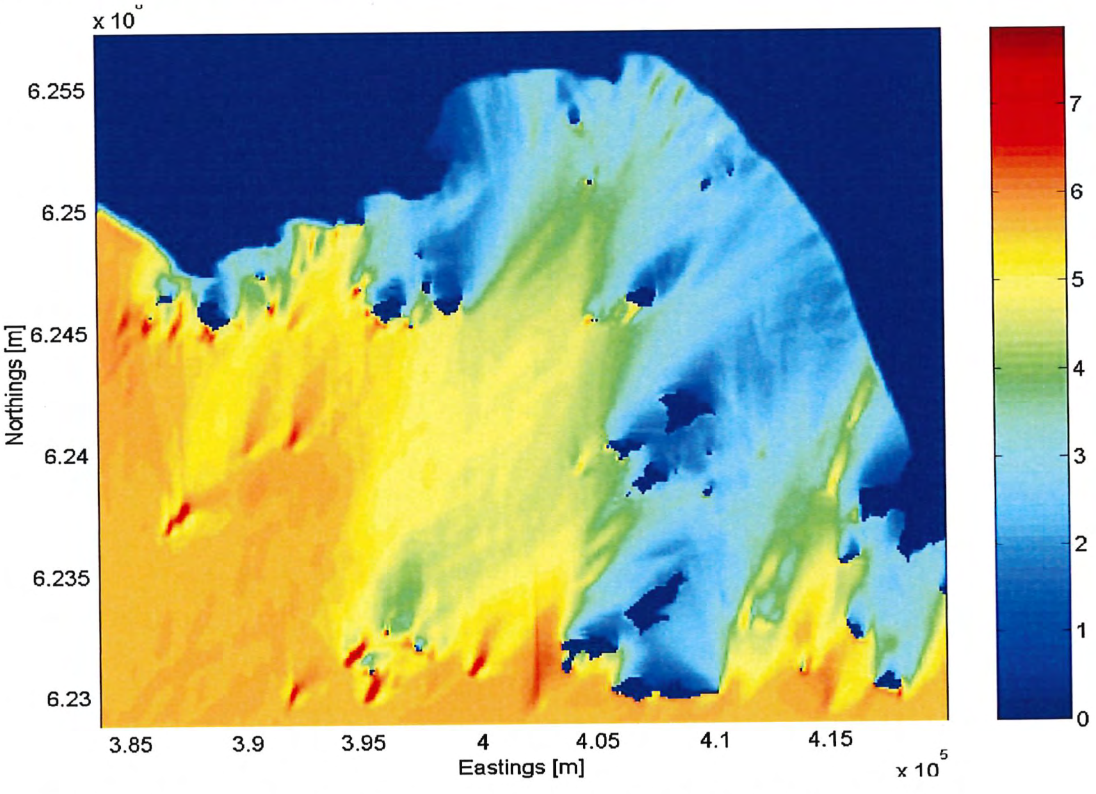


Figure 4.13. Maximum wave height for all of the daily SWAN predictions for 2002.

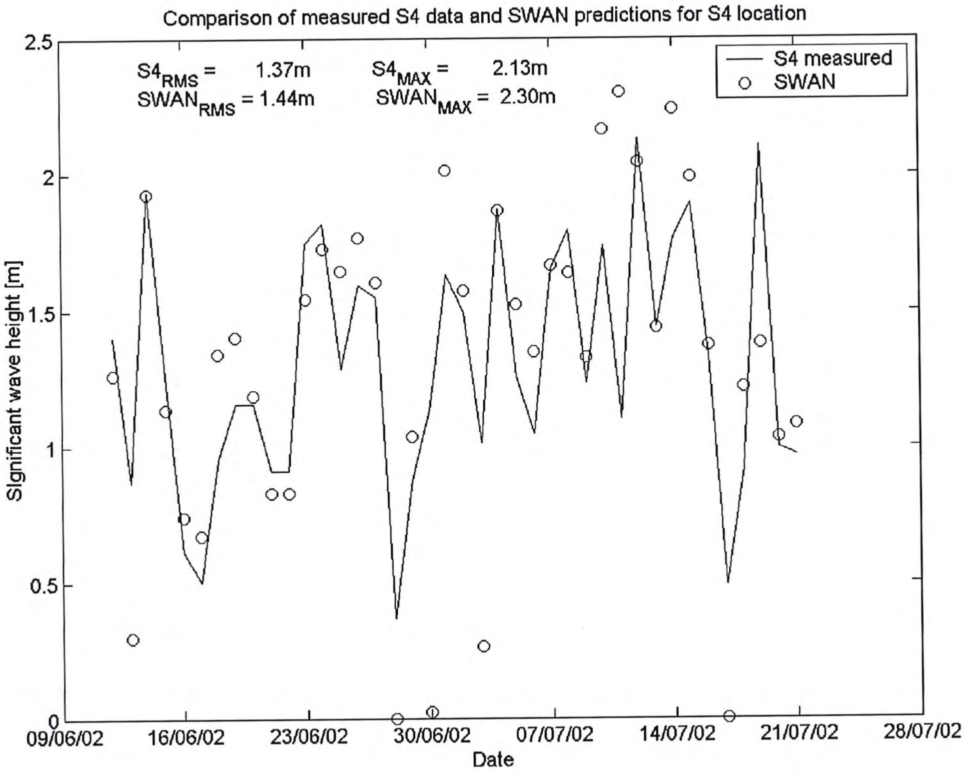


Figure 4.14. Validation data from S4 (measured) and SWAN (modelled).

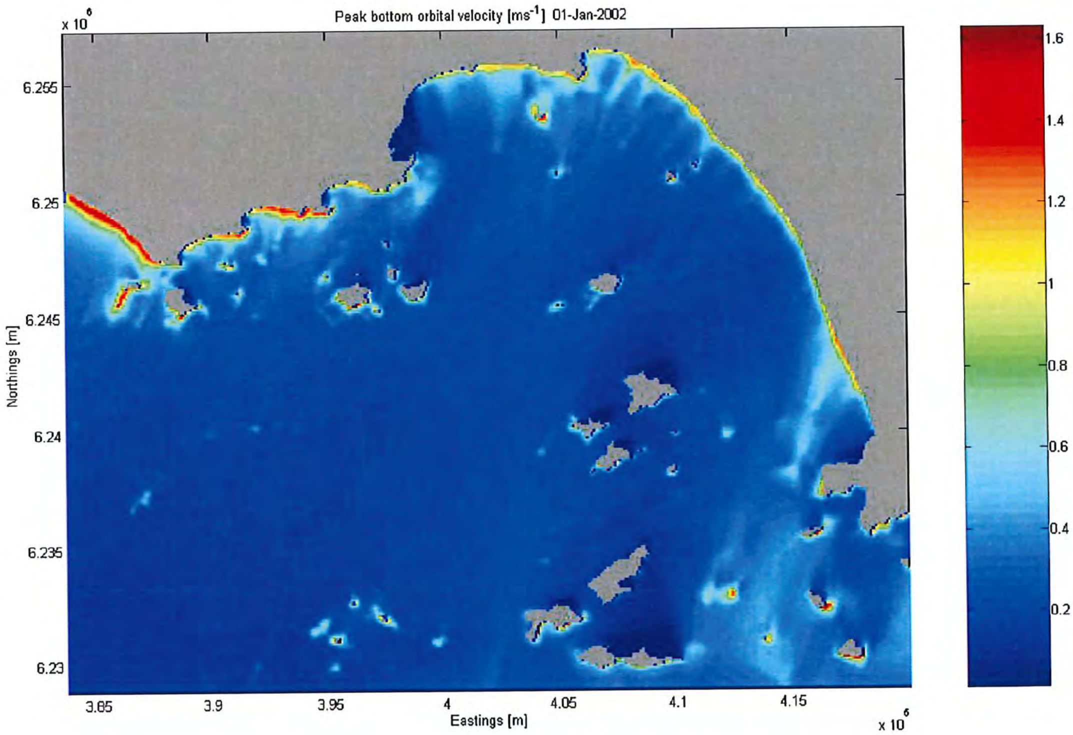


Figure 4.15. Peak bottom orbital velocity in typical summer swell conditions.

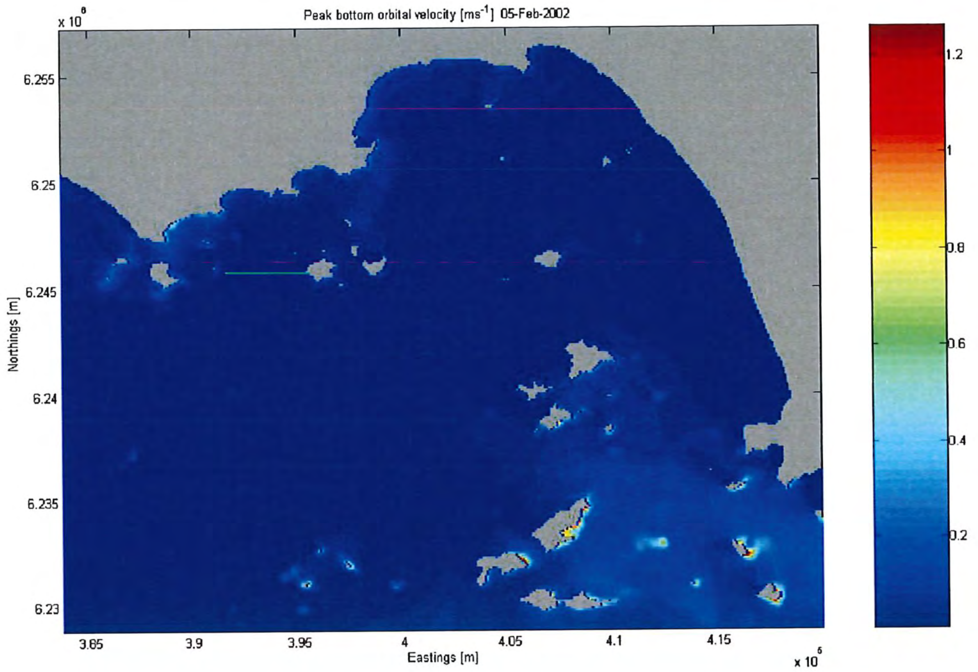


Figure 4.16. Peak bottom orbital velocity in easterly sea conditions.

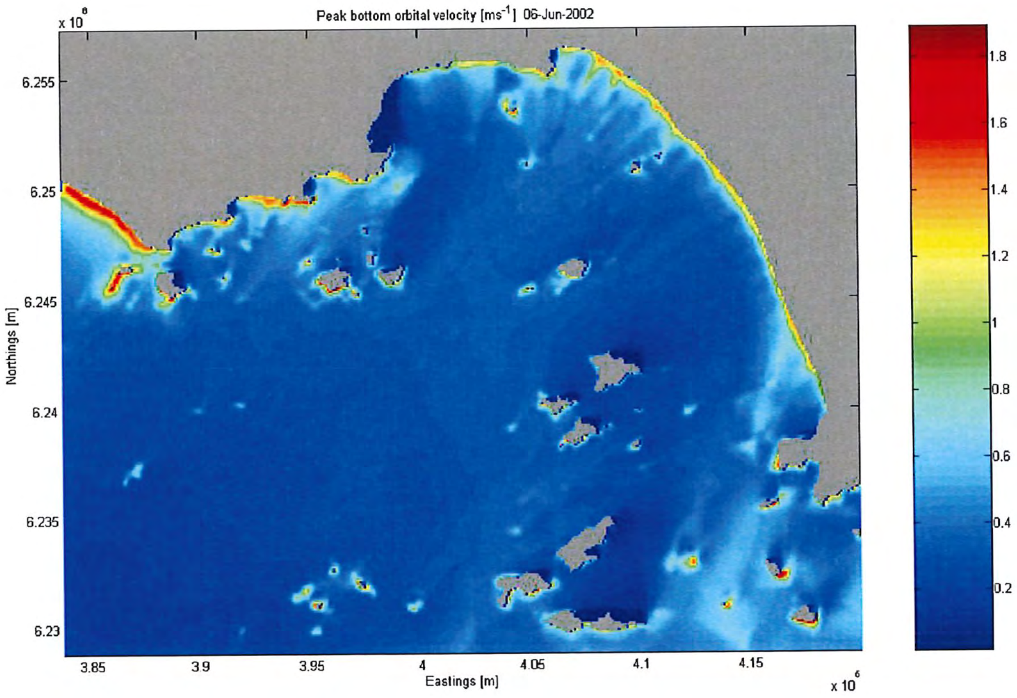


Figure 4.17. Peak bottom orbital velocity in typical winter swell conditions.

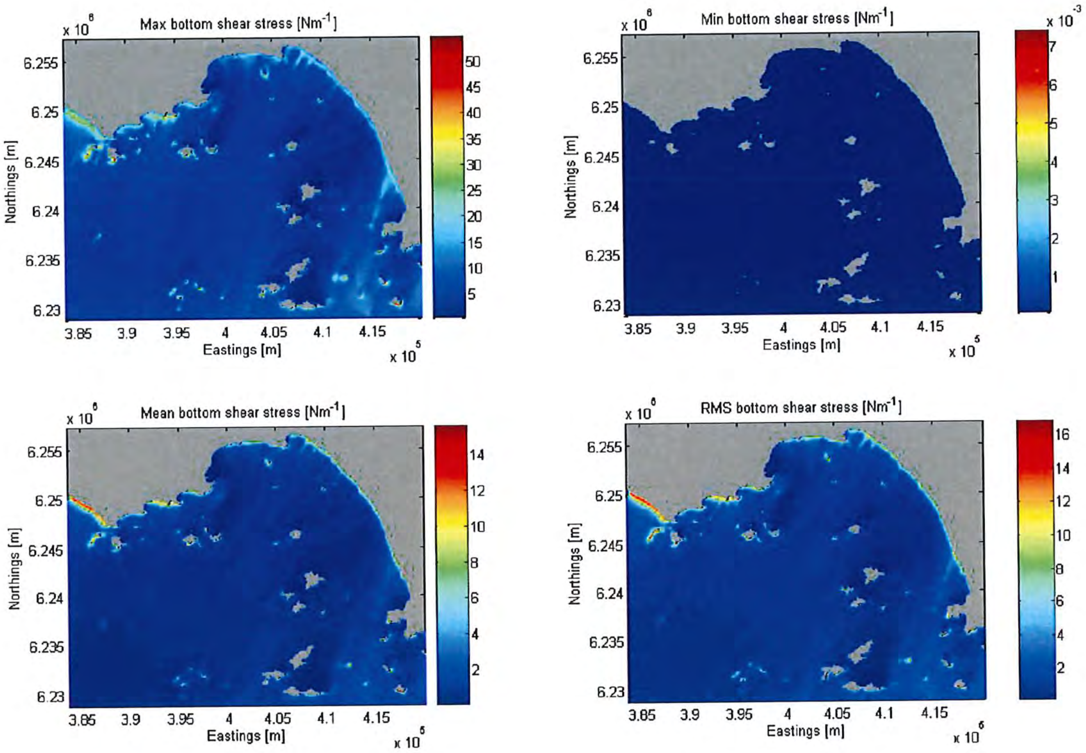


Figure 4.18. Maximum, minimum, RMS and mean shear stress for a uniform roughness length of 0.001.

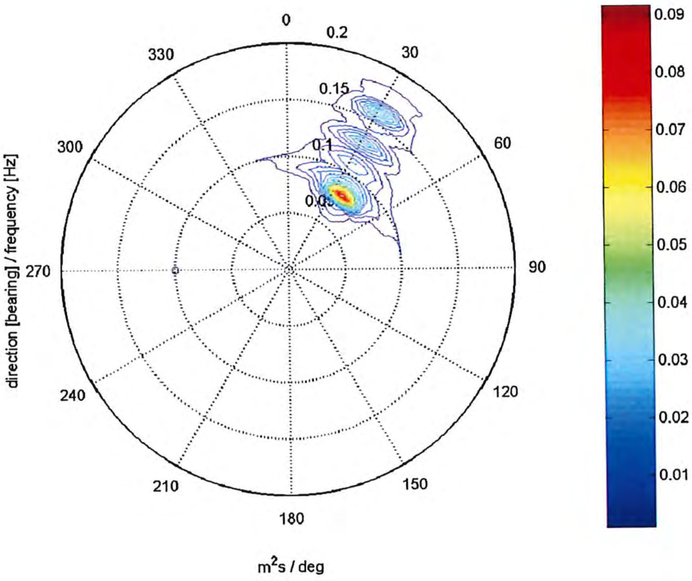


Figure 4.19. Directional spectra estimated using DIWASP with EMEP method for 15 minutes of S4 data starting at 12:00:00 June 12th 2002. Note that in these spectra, the direction is the propagation direction of the waves.

4.5 APPENDIX A: Wave data analysis.

The InterOcean S4 is deployed in a frame with the sensors 0.6m above the seabed. The instrument measures pressure, current velocity and direction at 2Hz. The instrument was set to sample for 15 minutes (3000 datapoints) every two hours for each deployment.

Raw data from the instrument is converted to equivalent meters of seawater (pressure) and east and north velocity components. Each sample block of 18 minutes is processed using DIWASP software (Johnson, 2002) with the EMEP (Hashimoto 1993) estimation algorithm. The output of the software is a directional wave spectrum, such as shown in Figure 19. Any real ocean wave field can be considered to be composed of many waves with different frequencies and direction of propagation; the directional spectra shows the relative amount of wave energy for a given direction and frequency.

From the directional spectra, summary wave field parameters are generated:

Significant wave height [H_s].

This is defined as the average height of the highest 1/3 waves and is commonly used in visual estimates of sea state. Individual waves may be up to twice the significant wave height. In typical ocean wave spectra, this can be related to the total spectral energy density by $H_s = 4\sqrt{M_0}$ where M_0 is the zeroth spectral moment (equivalent to the total wave density).

Peak period [T_p].

The spectral peak period is the wave period with the greatest energy when summed over all the directions. This is the same as the period corresponding to the highest point on a (non-directional) frequency spectra.

Peak direction [D_p].

The spectral peak direction is the wave direction with the greatest energy when summed over all the frequencies. This may not necessarily correspond to the direction of the point of highest energy in the directional spectra. For presentation of results, this is converted to the conventional swell specification of the direction of origin of the waves.

5.0 The influence of habitat on the structure of the demersal fish assemblages in the Recherche Archipelago.

Euan Harvey[1], Mike Cappo[2], Simon Grove[1], Gary Kendrick[1] and Matt Kleczkowski[1].

[1] School of Plant Biology (M090), Faculty of Natural and Agricultural Science, University of Western Australia, 35 Stirling Highway, Crawley 6009, Western Australia.
[2] Australia Australian Institute of Marine Science, PMB 3, Townsville MC, Queensland 4810.

5.1 INTRODUCTION

Few studies have investigated the relationship between habitat and the structure of demersal fish assemblages across multiple habitat types in Western Australia. Due to the increasing use of habitat as a surrogate for fisheries management, and marine-park planning (Harman *et al.* 2003) the relationship between habitats and demersal fish assemblages requires further investigation in Western Australia. Despite the growing number of studies linking the composition of fish assemblages to the structure of benthic habitats, few have examined what habitat characteristics are important to fishes. Consequently, it is uncertain whether particular species of sessile organisms colonising the seafloor, or the overall physical structure provided by the substrate and attached biota determine the structure of local fish assemblages. Understanding how various structural components of habitats influences the structure fishes assemblages will be an important component of fisheries management in the future if management is to become spatially explicit.

Fish assemblages have been found to be non-randomly distributed in relation to a variety of habitat characteristics including depth (Holbrook *et al.* 1990, Connell and Lincoln-Smith 1999, Hyndes *et al.* 1999), vertical relief (Carr 1991, Yoklavich *et al.* 2000, Harman *et al.* 2003) and substratum type (Carr 1991, Holbrook *et al.* 1990, Jenkins and Wheatley 1998, Harman *et al.* 2003).

The structure of benthic habitats strongly affects the recruitment, and subsequent persistence of demersal fish assemblages. Highly structured habitats have been shown to support a correspondingly high diversity, and total density of newly settled larvae and early recruits (Levin 1993, Freidlander and Parrish 1988). This pattern is preserved in adult populations, with complex habitats also supporting high species diversity and total density of older residents.

Three dimensional structure in fish habitats provides a surface for settling larvae and refuge from predators for all life stages (Jenkins and Wheatley 1998). These provisions are afforded by both the physical (substrate) and biological (sessile biota) components. Prior studies have identified that the nature of the substrate and its attached vegetation are linked the structure of demersal fish assemblages (Choat and Ayling 1987, Mahon and Smith 1989, Dean *et al.* 2000, MacArthur and Hyndes 2001).

Variation in fish assemblage structure due to substrate type and relief

The geology of the underlying substrate has been shown to affect the distribution of many demersal fishes (Williams and Bax 2001, Williams et al 2001, Pihl and Wennhage 2001). Habitats, such as mud bottoms on the continental slope and sandy areas of the continental shelf support well-differentiated fish assemblages (Demestre *et al.* 2000). At similar depths differences in assemblage structure have been found between low relief mud/cobble substrata, and high relief rock walls, ridges, and boulder fields (Yoklavich *et al.* 2000).

Similar patterns in relation to substrate type and relief have been found on shallow temperate reefs in Western Australia. Low relief limestone and granite reefs shared a similar number of species, but the limestone reefs supported a greater number of individuals of all species (Harman *et al.* 2003). In this case, the substrate indirectly influenced fishes by directly influencing the initial attachment and overall composition of algal assemblages (Harman *et al.* 2003). However, high relief limestone reefs were characterised by ledges, holes and overhangs and were found to support more species and individuals than low relief limestone reefs.

The influence of reef architecture on fish assemblage structure

In shallow reef environments the structural complexity, or rugosity of reefs influences the composition of demersal fishes (Alvezion and Brooks 1975, Choat and Ayling 1987, McCormick and Choat 1987, Holbrook *et al.* 1990). Reefs with high substrate rugosity have the highest diversity and biomass of demersal fishes. Similarly, the number, and size of holes within a reef has been positively correlated to species richness and the total abundance of fishes (Hixon and Beets 1993, Friedlander and Parrish 1998). It is thought that highly textured, complex habitats attract a wider range of fish species by providing a greater range of opportunities for feeding and shelter (Alevizon and Brooks 1975, Friedlander and Parrish 1998).

Vegetation

On temperate reefs, the architecture and density of macro-algae directly effects the distribution of demersal fishes. Algal habitats are thought to provide invertebrates and fishes a refuge from predation, and a direct or indirect source of food (Levin 1994, Carr 1994). Studies on kelp-forest fishes have demonstrated that macro-algal density can influence initial patterns of recruitment as well as patterns of adult abundance (Carr 1994, Schmitt and Holbrook 1990). Similarly, sandy substrates colonised by seagrasses have been shown to support more species and a higher fish density than adjacent areas of bare sand (Jenkins et al. 1997, Guidetti 2000, MacArthur and Hyndes 2001, Travers and Potter 2002). Like macroalgal habitats, protection from predators and an abundant food supply underlie the diversity of fishes in seagrass meadows.

In comparison with other locations around Australia there has been relatively little research into the distribution and abundances of fish species within the Recherche Archipelago. Those studies that have quantitatively addressed fish diversity and abundance are limited to a survey of the surf zone fish assemblages (Ayvazian and Hyndes 1995) and a study on the mass mortality of the pilchard Sardinops sagax (Gaughan et al. 2000). There are also semi-quantitative visual surveys of nearshore reef fish assemblages by Hutchins (1994) which was presented in a broader analysis of reef fish biodiversity in Hutchins (2001).

This report examines patterns in the spatial distribution of demersal fish in the temperate coastal waters (3-85m) of the Recherche Archipelago, south-western Australia. In particular, we were interested in whether there were different fish assemblages (species compositions and relative abundances) inhabiting the four major benthic habitats (Seagrass, Reef, Rhodoliths and Sand) in the region, and whether there were differences in fish assemblages associated with these habitats at regional scales of 50 to 100 km separation. We also investigated whether percent cover of epiflora and topography influenced the structure of fish assemblages within these habitats.

5.2 METHODS

The composition, density and distribution of marine fish assemblages in topographically complex habitats are difficult to assess comprehensively due to the heterogeneity of fish habitats, variability in the patterns of behaviour and abundance of demersal fishes and sampling bias (Alevison and Brooks, 1975, Cappo et al. 2003). The problems and advantages and disadvantages of different techniques have been discussed and reviewed in detail (Cappo and Brown 1996, Cappo et al. 2003). Numerous comparative studies have documented bias and selectivity amongst sampling methods (eg Harmelin-Vivien and Francour 1992, Hickford and Schiel 1995, Cappo and Brown 1996). The use of baited underwater video stations has been increasing (Willis and Babcock 2000, Willis et al. 2000, Denny and Babcock 2004, Cappo et al. 2004). We chose to use baited underwater video stations (BUVS) as they could be used to sample multiple habitats and depths in a consistent, comparable and non destructive manner (Cappo et al. 2003). One of the other advantages of BUVS is that they could be deployed from small (6-8m) research vessels. A disadvantage of BUVS is that they do not sample small cryptic fishes well (eg Cappo 2004). Many of these cryptic species are best sampled by trawl (eg. Pipefishes in seagrass) but trawl techniques are not amenable to comparisons across habitats which contain rocky or rougose, hard substrates. One of the criticisms of using bait is that it may attract fishes from other habitats to the cameras, providing false information on the presence of a particular species within a habitat. Trials with baited and unbaited cameras (Harvey et al. this volume) demonstrate that baited cameras sample more individuals and more species than unbaited cameras in the same habitats. Greater numbers of species and individuals results in a stronger discrimination between fish assemblages in different habitats (Harvey et al. this volume). Logic would dictate that if species of fish were frequently attracted across habitat boundaries by the bait the assemblages of fishes within habitats would be similar.

5.2.1 Data collection

Major benthic habitats of the Recherche Archipelago were identified during an initial habitat survey in April and May of 2002 using drop video. Between the 26th of May and 13th of June 2002 fish assemblages within these habitats were sampled using baited stereo-video (Harvey and Shortis 1996, 1998, Harvey *et al.* 2001a, b, 2002) and single camera systems (Cappo *et al.* 2004). A total of 219 BUVS were deployed in Esperance Bay, Duke of Orleans Bay, and Cape Arid (Figure 5.1). Bait bags which extended approximately 1.2 m in front of the BUVS were baited with ~ 1 kg of pilchards and left at a site for one hour. One hour sampling times were chosen on the basis of observed species accumulation during a one-day pilot study. Arrival of new species of fish was found to plateau within approximately forty minutes. Sampling of fish during the study was limited to daylight hours (08:00 – 16:00) with BUVS not being deployed within two hours of dawn or dusk to avoid the crepuscular behaviour of some fish species (Colton and Alevizon, 1981, Hobson *et al.* 1981, Harvey *et al.* this Volume).

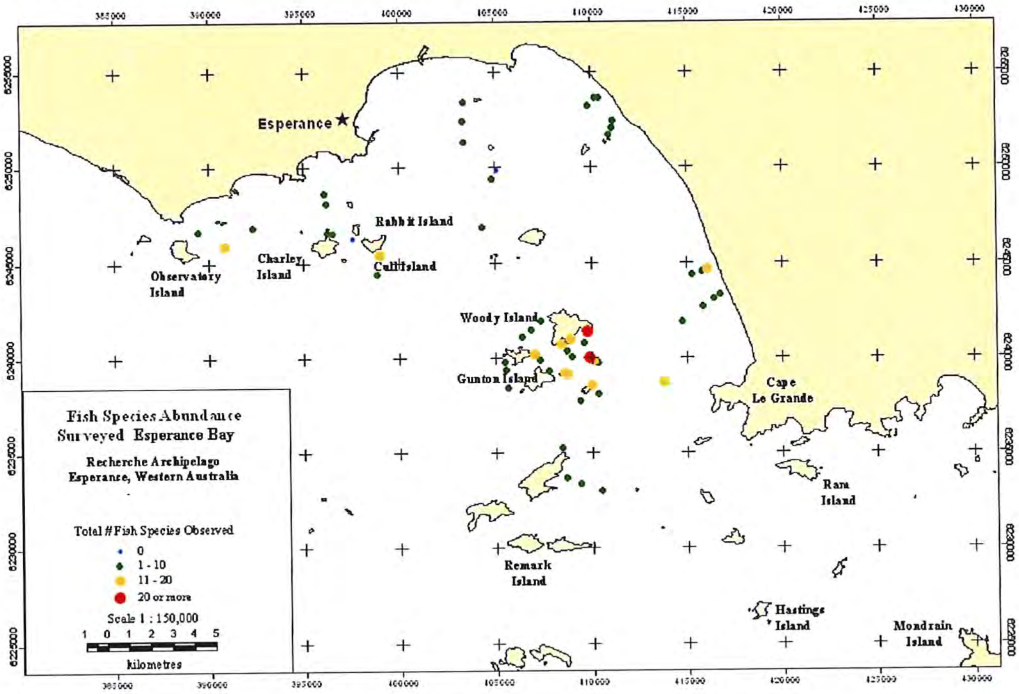


Figure 5.1: Sampling sites throughout the Recherche Archipelago.

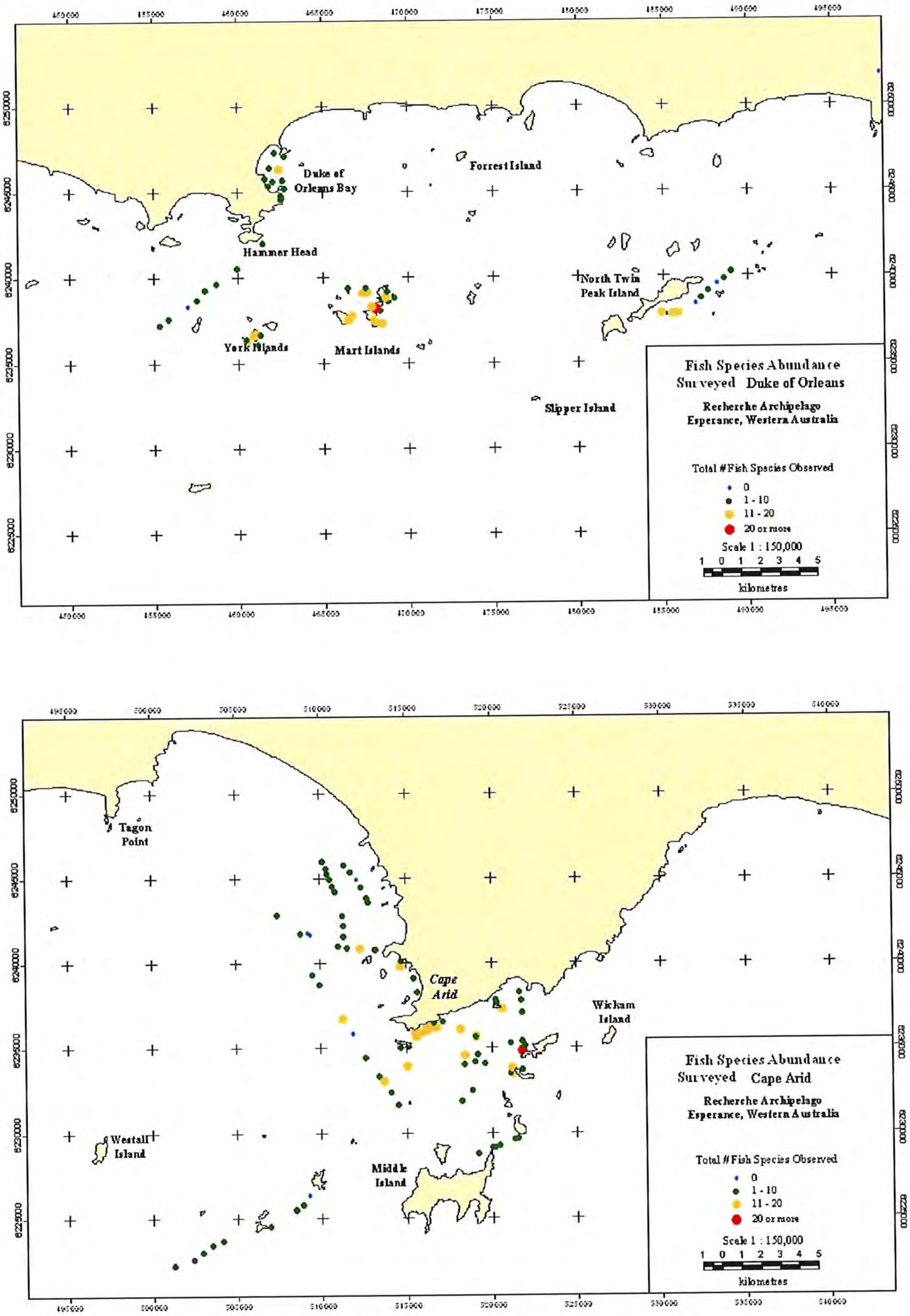


Figure 5.1 continued.

Cameras were set at least 500m from one another to minimise the possibility of individual fish being recorded on more than one camera during a series of deployments. The sampling regime obtained a 'snap-shot' of fish assemblages present within a habitat during daylight hours across contrasting habitat types.

5.2.2 Habitats sampled

Reef

Reef habitats sampled by BUVS consisted of granitic reefs of varying topography, characterised by the cover of macro-algae and sessile invertebrates, such as sponges, ascidians and corals.

From video footage recorded by the BUVS as they were lowered to the bottom we reclassified reef into sub-habitats based on topography. Reefs with large boulders or which were steeply sloping where classified as High Profile Reef (HPR) while flat or gently sloping reefs were categorized as Low Profile Reef (LPR).

High profile reefs were typically dominated by large kelps such as *Ecklonia*, *Cystophora*, *Scythothalia* and *Sargasssum* in waters less than 30m.

More densely vegetated types of low profile reefs were characterised by Macroalgal species such as *Scaberia*, *Cystophora*, *Sargassum*, *Osmundaria*, *Caulerpa* and *Ulva*.

Low profile reefs exhibited varying degrees of sand inundation, prompting a further categorisation of Sand Inundated Low Profile Reef (SI_LPR). Depending on the water depth SI_LPR also had mix of macroalgae, seagrass and filterfeeders.

Sand

Sand habitats sampled by BUVS were divided into sub-habitats based on densities of associated biota. Bare Sand (BS) had no epibenthos associated with it. Other sub-habitats included Sand with sparse vegetation (ie macroalgae) (S/SV), Sand With Filterfeeders (eg sponges, bryozoa, ascidians) (S/F) and Sand With Macroalgae and Filterfeeders (S/MF). These latter categories could be difficult to distinguish from Sand inundated Low Profile Reef, and doubtlessly overlap exists. All fish video samples in sand habitats were in water depths greater than 20m.

Rhodoliths

Rhodoliths are unattached (or free-living) forms of coralline red algae found over sand substrates. Rhodoliths are extensive in the western Archipelago region and were found mainly in high-energy environments between islands and in open offshore waters. Rhodoliths were found between depths of 27 to 65 metres within the

Archipelago. Rhodolith beds ranged from bare to supporting various densities of foliose and filamentous macro-algal species or diverse filter feeder communities which where classified as Rhodliths with Macro-algae (Rhod/M) including erect and barrel sponges, ascidians and a variety of bryozoans.

Seagrass

Seagrass (SG) species identified by video and diver surveys within the Archipelago included *Posidonia sinuosa*, *P.australis*, *P. denhartogii*, *P.coriacea*, *P. ostenfeldii*, *P.kirkmanii*, *Amphibolis griffithii*, *A. antarctica*, *Halophila* spp.and *Zostera tasmanica*. These are found on sand substrates, with varying levels of cover.

Dense seagrasses (D SG) were represented by extensive meadows of *Posidonia sinuosa*, *P.australis* and *Amphibolis griffithii*. Medium seagrass (M SG) is dominated by the *P. ostenfeldii* complex and *Amphibolis griffithii*. Sparse seagrass (S SG) was represented by the *P. ostenfeldii* complex and *Amphibolis griffithii*. Within those sites sampled by BUVS, seagrass density was generally depth related with the dense seagrass habitats being shallow and the sparse seagrass habitats deeper.

We have not classified seagrasses by genera because many of the beds sampled were comprised of mixed species (eg. *Amphibolis* and *Posidonia* grew together in the same stand). Furthermore, the cover of seagrass of similar gross morphology is more important for marine fishes than the actual species (Worthington *et al.* 1991, 1992).

5.2.3 Analysis of video tapes

Of the 219 BUVS deployed we analysed tapes from only 188, with 31 deployments being discarded due to poor visibility (less than 5m) or because BUVS orientation on the seafloor limited the amount of habitat viewed. When we reviewed the tapes we recorded the time the BUVS settled on the seabed and, for each species, the time of first sighting (*TFAP*), time of first feeding at the bait (*TFF*), the maximum number seen together in any one time on the whole tape (*MaxN*), time at which *MaxN* occurred, and the intraspecific and interspecific behaviour.

We used *MaxN* as we were concerned that individual fish could be counted repeatedly when leaving and then entering the field of view during tape interrogation. The n_{peak} of Priede *et al.* (1994), the *MAXNO* of Ellis and DeMartini (1995), the *MAX* of Willis and Babcock (2000) and the *MaxN* of our study are all homologous. This statistic under-estimates the true abundance of fish recorded. The occurrence of separate visits by different individuals of the same species is recorded as $MaxN$=1 and only a portion of a partially visible fish school contributes to $MaxN$. This usage results in conservative estimates of abundance in high-density areas, and therefore differences detected between areas of high and low abundance (eg inside and outside marine protected areas) are also likely to be more conservative (Willis *et al.* 2000, Cappo *et al.* 2003).

The video recordings were broken into 60 one-minute time intervals from the time the video cameras came to rest on the seafloor. The maximum number of species i at any time t ($MaxN_{i,t}$) was recorded during each minute, but the final measure of relative abundance used in analyses was the highest $MaxN_{it}$ over the whole tape record.

5.2.4 Data Analysis

Multivariate analysis

All multivariate analyses were undertaken in PRIMER (Plymouth Routines in Multivariate Ecology) V5 (Clarke and Gorley, 2001). Data was entered into a site by species matrix which was then used to create a triangular similarity matrix based on the Bray-Curtis similarity coefficient. We used a square root transformation on all data. One-way and two way crossed analyses of similarities (ANOSIM) were used to test for differences between habitats. Two-dimensional ordinations were created by non-metric multidimensional scaling (MDS). Similarity of Percentages (SIMPER) was used to identify key species contributing to the patterns between habitats.

Univariate

For each habitat the mean number individuals ($MaxN_i$) and species (Nsp) sampled per habitat were plotted. A one way analysis of variance (ANOVA) was used to test the differences in $MaxN_i$, Nsp and key species between habitats. The use of ANOVA, like many statistical procedures, is based on the assumption that samples from different populations have the same variance. The distribution of the residuals usually were strongly skewed to the right, therefore the data required transformation to eliminate the problems associated with having large outliers and unusual observations (Rotchell *et al.* 2001). Homogeneity of variances were examined using Cochran's test (Winer

1991). Many of the variances were heterogeneous ($P<0.05$) so all data was ln(x+1) transformed to correct this. All data were retested with Cochran's test prior to analysis to ensure that transformation had corrected hetroscedastic data.

5.3 RESULTS

To test whether there were differences in the demersal fish assemblages between the habitats at a coarse level of classification (Seagrass, Reef, Rhodoliths and Sand) and between three different locations (Esperance Bay, Duke of Orleans Bay and Cape Arid), each separated by approximately 50 km we used a two way crossed ANOSIM with location as the first factor and habitat as the second. This analysis revealed no statistically significant differences in the demersal fish assemblages between locations (Global R = 0.048, 2.9% significance) (See Table 5.1 for pair-wise comparisons). There where significant differences in the fish assemblages between habitats (Global R = 0.509, 0% significance).

Table 5.1: Pair-wise tests of differences for a two way crossed ANOSIM between the demersal fish assemblages sampled at different locations (Esperance Bay, Duke of Orleans Bay and Cape Arid) and between major benthic habitats (Seagrass, Reef, Rhodoliths, Sand). 5000 permutations.

Location	**R Value**	**Significance %**
Esperance Bay vs. Duke of Orleans Bay	0.084	2
Esperance Bay vs. Cape Arid	0.055	7.9
Duke of Orleans Bay vs. Cape Arid	0.019	19.8
Habitat		
Seagrass vs. Reef	0.598	0.1
Seagrass vs. Rhodoliths	0.042	29.7
Seagrass vs. Sand	0.237	0.1
Reef vs. Rhodoliths	0.742	0.1
Reef vs. Sand	0.614	0.1
Rhodoliths vs. Sand,	0.069	25.9

Each of these four major habitats were examined separately to determine whether there were distinctive fish assemblages within the reclassified sub habitats.

Seagrass

Samples from seagrass habitats were subdivided according to seagrass cover; Dense (D SG), Medium (M SG) and Sparse Seagrass (S SG). There where significant differences in the fish assemblages between the three different coverages of seagrass (Global R = 0.349, 0% significance) with pair-wise comparisons showing differences between each combination of the three (Table 5.2).

Table 5.2: *Pair-wise tests of differences between the demersal fish assemblages sampled within Sparse (S SG), Medium (M SG) and Dense seagrass (D SG) habitats. 5000 permutations.*

Seagrass density	R Value	Significance %
S SGvs. M SG	0.28	2.7
S SG vs. D SG	0.531	0
M SG vs. D SG	0.271	0.1

SIMPER analysis showed that differences between densities of seagrass were attributable to seven species of fish. A one way ANOVA showed that there were significant differences in the relative abundances of five of the seven species (Figure 5.2).

Upeneichthys vlamingii was more abundant in M SG than either D SG or S SG with significant differences (Tukeys pair-wise comparisons) between M SG and D SG. *Notolabrus parilus* was significantly more abundant in D SG and M SG while *Myliobatus australis* was more abundant in M SG and S SG than D SG. *Scobinichthys granulatus* was more abundant in D SG with significant differences between D SG and M SG, S SG and M SG and S SG. *Pseudocaranx dentex* was more abundant in D SG and least abundant in S SG while *Parequula melbournensis* had lowest relative abundances in D SG with M SG and S SG being similar. There were no significant differences in the relative abundances of *Meuschenia hippocrepis.*

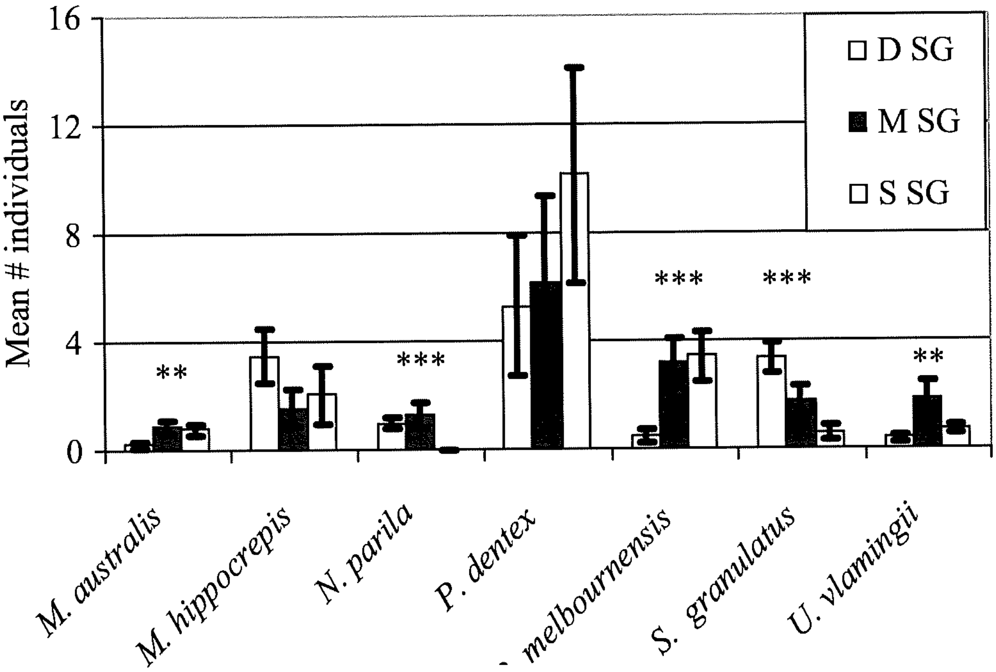


*Figure 5.2: Mean number of individuals (MaxNi) of seven species in Dense (D SG), Medium (M SG) and Sparse (S SG) seagrass. N = 19 D SG, N= 11 M SG, N= 14 S SG. Error bars = ± 1 SE. * indicates the level of significance for a one way ANOVA; * = P<0.05, ** = P<0.01, *** P<0.001.*

Sand and Rhodoliths

Because the initial one way ANOSIM on the four major habitats showed there were little in the way of statistical differences between Sand and Rhodolith habitats we have incorporated Rhodoliths into Sand sub-habitats. Sand habitats were divided into Bare Sand (BS), Sand with filter feeders (S/F), Sand with filterfeeders and macro-algae (S/F&M), Sand with sparse vegetation (S/SV) and Rhodoliths (Rhod).

One way ANOSIM showed there where slight statistically significant differences in the fish assemblages across the habitats (Global R = 0.115, 2% significance) with pair-wise comparisons showing there were statistically significant differences between BS and S/SV (Table 5.3).

Table 5.3: Pair-wise tests of differences between the demersal fish assemblages sampled within Sand and Rhodolith habitats. BS = Bare Sand, S/F = Sand with filter feeders, S/F&M = Sand with filterfeeders and macro-algae, S/SV = Sand with sparse vegetation and Rhod = Rhodoliths. 5000 permutations.

Habitat	R Value	Significance %
BS vs. S/F	0.171	5.9
BS vs. S/SV	0.119	3.9
BS vs. Rhod	0.112	11.5
BS vs. S/F&M	0.171	7.6
S/F vs. S/SV	0.104	12.9
S/F vs. Rhod	0.099	13.9
S/F vs. S/F&M	-0.115	92.1
S/SV vs. Rhod	-0.045	70.95
S/SV vs. S/F&M	-0.047	65.9
Rhod vs. S/F&M	-0.025	56.4

Reefs

Reef habitats were initially subdivided into Low Profile Reefs (LPR), High Profile Reefs (HPR) and Sand Inundated Low Profile Reef (SI/LPR). There were very slight, but significant differences in Reef sub-habitats (Global R = 0.159, 1.5% significance). However, pair-wise comparisons showed there were strong statistical differences between the Low and High Profile reefs when compared with Sand Inundated Low Profile Reefs (Table 5.4).

Table 5.4: Pair-wise tests of differences between the demersal fish assemblages sampled within Sand and Rhodolith habitats. LPR = Low Profile Reefs, HPR = High Profile Reefs and SI/LPR = Sand Inundated Low Profile Reef. 5000 permutations.

Habitat	R Value	Significance %
LPR vs. HPR	0.019	38.4
LPR vs. SI/LPR	0.311	0.5
HPR vs. SI/LPR	0.482	0.0

Simper analysis identified twelve species that were responsible for these differences. A one-way ANOVA showed that there significant differences in the relative abundances of *Achoerodus gouldii, Meuschenia galii* and *Meuschenia hippocrepis* which were significantly (Tukeys pair-wise comparisons) less abundant in SI/LPR than either LPR or HPR which were similar (Figure 5.3).

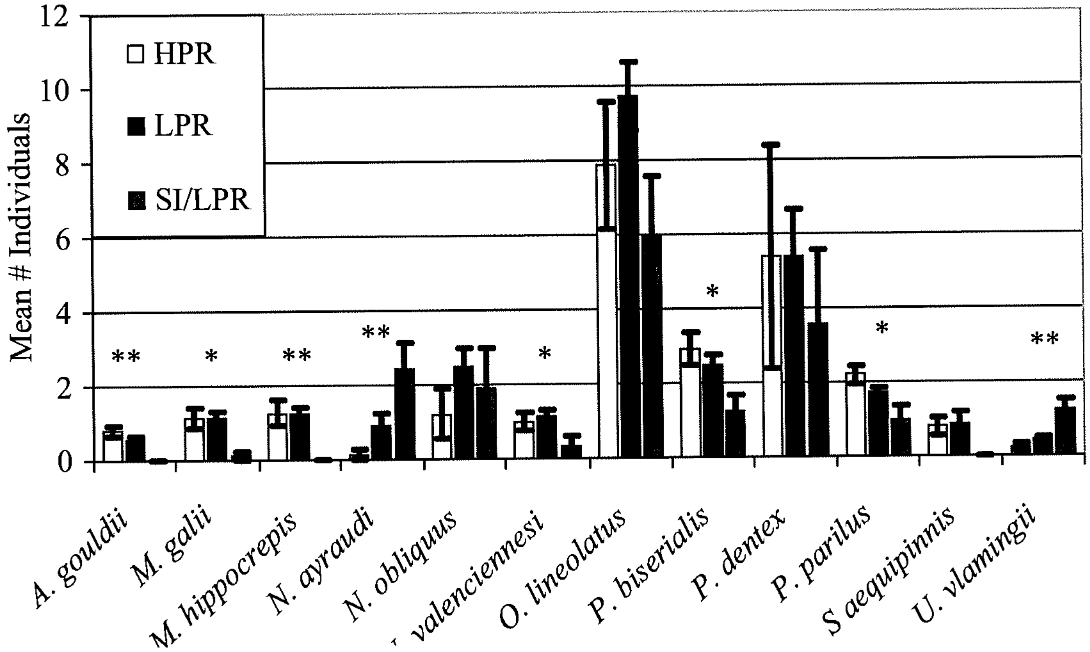


*Figure 5.3: Mean number of individuals (MaxNi) of twelve species in High Profile Reef (HPR), Low Profile Reef (LPR) and Sand Inundated Low Profile Reef (SI/LPR). N = 15 HPR, 55 LPR, 9 SI/LPR. Error bars = ± 1 SE. * indicates the level of significance for a one way ANOVA; * = P<0.05, ** = P<0.01, *** P<0.001.*

Nelusetta ayraudi and Upeneichthys vlamingi were significantly more abundant in SI/LPR than either LPR or HPR which were similar (Figure 5.3). *Pseudolabrus biserialis* and *Notolabrus parilus* were most abundant in HPR and least in SI/LPR with significant differences (Tukeys pair-wise comparisons) between these two habitats. *Nemadactylus valenciennesi* displayed a similar pattern, but with significant differences between these LPR and SI/LPR habitats. There were no statistical differences in the relative abundances of *Opthalmolepis lineolatus, Neatypus obliquus, Pseudocaranx dentex* or *Scorpis aequipinnis.*

Macro-algal Canopy

The effect of different types of macro-algal canopy on the relative abundance and composition of reef fish assemblages was examined using only those samples where macro-algae could be clearly identified from the video-tape. Macro-algae canopies were categorised into four types. 1) Kelp (*Ecklonia/Scytothalia* canopy); 2) SCAP (*Sargassum/Cystophora /Acrocarpia/Platythalia* canopy); Mixed (a mixture of the above canopy types) and 4) Other (Non canopy macro-algal cover).

A one-way ANOSIM returned a small Global R value (Global R = 0.014, 32.4% significance) indicating that there were no differences across the four categories of canopy. Pair-wise comparisons showed there no meaningful significant differences between Kelp and Mixed canopies and Mixed and Other canopies (Table 5.5).

Table 5.5: *Pair-wise tests of differences between the fish assemblages sampled within Reef habitats of different macro-algal canopy categories. Kelp =* Ecklonia/Scytothalia *canopy, SCAP =* Sargassum/Cystophora /Acrocarpia/Platythalia *canopy, Mixed = a mixture* Ecklonia/Scytothalia/Sargassum/Cystophora /Acrocarpia/Platythalia *of Sand Inundated Low Profile Reef and Other = non canopy species. 5000 permutations.*

Habitat	R Value	Significance %
Kelp vs. SCAP	-0.011	55.1
Kelp vs. Mixed	0.113	2
Kelp vs. Other	-0.03	63.3
SCAP vs. Mixed	-0.014	58.4
SCAP vs. Other	0.028	29.2
Mixed vs. Other	0.087	4.5

These results suggest that macro-algae canopy type has little influence on the structure of reef fish assemblages. Therefore, we tested whether the density of macro-algae was an important factor in influencing the composition and relative abundances of temperate algae dominated reef fish assemblages.

Macro-algal density

The density of macro-algae on samples recorded from reefs where categorised as Dense (100-60% coverage); Medium (59-30% coverage) and Sparse (29-0%

coverage). A one-way ANOSIM showed there were slight, but significant differences across the three densities of macro-algae (Global R = 0.245, 0% significance) with significant pair-wise differences between Dense and Medium and Dense and Sparse (Table 5.6).

Table 5.6: *Pair-wise tests of differences between the fish assemblages sampled within Reef habitats of different macro-algal density categories. 5000 permutations.*

Habitat	R Value	Significance %
Dense vs. Medium	0.169	0
Dense vs. Sparse	0.551	0
Medium vs. Sparse	0.125	11.1

SIMPER analysis showed there were twelve species that were responsible these differences. *Meuschenia flavolineata*, *Meuschenia galii*, *Meuschenia hippocrepis* and *Notolabrus parilus* were most abundant in Dense and least in Sparse algal habitats with significant differences (Tukeys pair-wise comparisons) between Dense and Medium and Dense and Sparse habitats (Figure 5.4). *Opthalmolepis lineolatus* and *Pseudocaranx dentex* displayed similar trends with abundances increasing from Sparse to Dense algae, but these differences were not statistically significant. *Achoerodus gouldii* and *Nemadactylus valenciennesi* were more abundant in Dense and Medium algae than Sparse, but there were no significant differences between Dense and Medium algal habitats. *Upeneichthys vlamingi* and *Nelusetta ayraudi* were most abundant in Sparse and least in Dense macro-algal habitats significant differences (Tukeys pair-wise comparisons) between Dense and Medium and Dense and Sparse macro-algal habitats. There were no statistical differences for, *Neatypus obliquus* or *Pseudolabrus biserialis*.

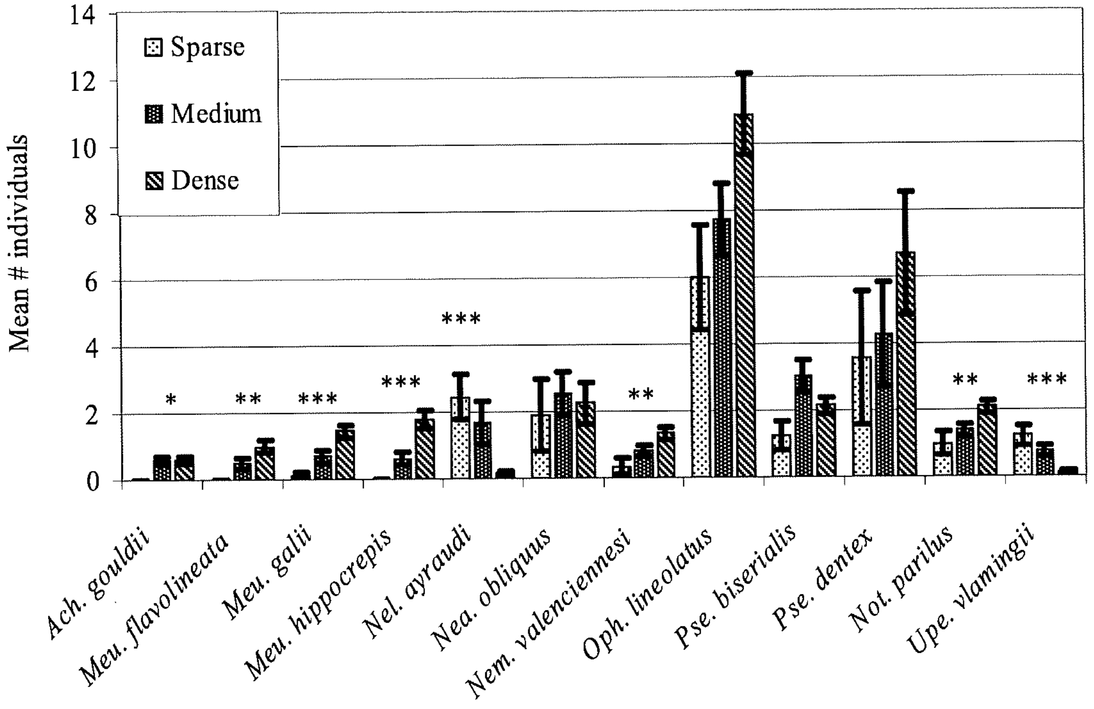


Figure 5.4: *Mean number of individuals* ($MaxN_i$) *of twelve species in Dense (100-60% coverage), Medium (59-30% coverage) and Sparse (29-0% coverage) algal canopies. N = 36 Dense, 28 Medium, 9 Sparse. Error bars = ± 1 SE. * indicates the level of significance for a one way ANOVA; * = P<0.05, ** = P<0.01, *** P<0.001.*

Fish habitat category refinement

The analyses above show that that different densities of seagrass and macro-algae result in different species compositions and relative abundances being recorded within the sub-habitats.

To visualise how these sub-habitat classifications separate from the initial analysis undertaken with only the four major habitats (Seagrass, Reef, Rhodoliths and Sand) we have compared MDS plots based on the four major habitats (Figure 5a) and the nine sub-habitats (Figure 5.5b). The nine sub-habitat classifications used in the comparison were: Reef Dense Macro-algae (R DM), Reef Medium Macro-algae (R MM), Sand Inundated Reef Sparse Macro-algae (SIR/SM), Vegetated Sand (VS), Bare Sand (BS), Dense Seagrass (D SG), Medium Seagrass (M SG), Sparse Seagrass (S SG) and Rhodoliths (Rhod). The category "Reef unknown" (RU) refers to reef samples where the macro-algal cover could not be determined from the video.

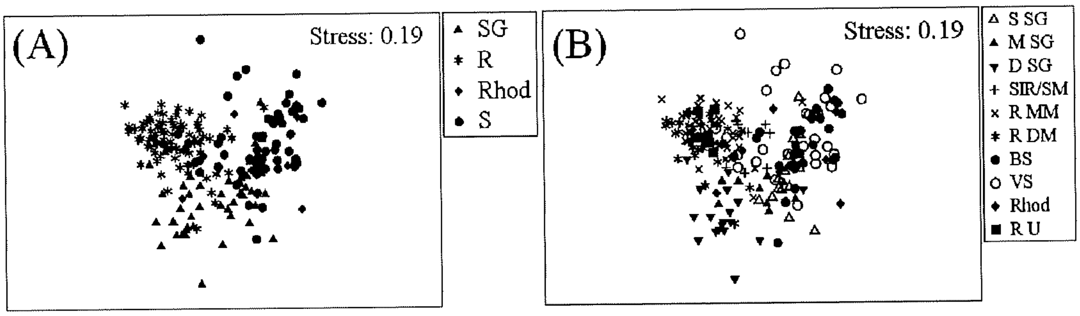


Figure 5.5: *Non metric Multidimensional Scaling Plots based on four habitat categories (A) and nine habitat categories (B).*

It should be noted that the sub-habitat categories are depth related (Table 5.7). Soft substrate habitats without seagrass tend to be deeper while seagrass habitats are shallower. Among both seagrass and reef habitats vegetation density decreases with depth. The MDS plots (Figures 5.5A and B) show that there is a continuous shift in assemblage structure between different habitats and that discrete assemblages are detected at either end of this continuum.

Table 5.7: *Distribution of sub-habitats in relation to depth. R DM = Reef Dense Macro-algae Reef, R MM = Medium Macro-algae, SIR/SM = Sand Inundated Reef Sparse Macro-algae, VS = Vegetated Sand, BS = Bare Sand, D SG = Dense Seagrass, M SG = Medium Seagrass, S SG = Sparse Seagrass, Rhod = Rhodoliths and RU = Reef unknown.*

Depth (m)	BS	Rhod	VS	S SG	M SG	D SG	SIR/SM	R DM	R DM	RU
0-10					1	8			10	
10-20				2	3	10		4	14	2
20-30	4		7	8	7	1	3	9	10	2
30-40	17	5	10	4			5	15	2	2
40-60	6	4	5				1			
60-90	1		6							

Numbers of species and Individuals

One-way ANOVA was performed on the mean numbers of species and individuals for the nine sub-habitat categories. To calculate the mean number of individuals we tallied the *$MaxN_i$* values for each species recorded for each sample within habitat. The one-way ANOVA showed that there were significant differences between habitats for the mean number of species (Species $_{(9,\ 187)}$, MS = 0.1587, F = 24.87, p = 0.000) and the mean numbers of individuals (Individuals $_{(9,\ 187)}$, MS = 0.4369, F = 11.32, p = 0.000). The greatest mean number of species (Figure 5.6A) and individuals (Figure 5.6B) were found in the reef macro-algae habitats (decreasing with algae density) followed by the seagrass habitats (again decreasing with density).

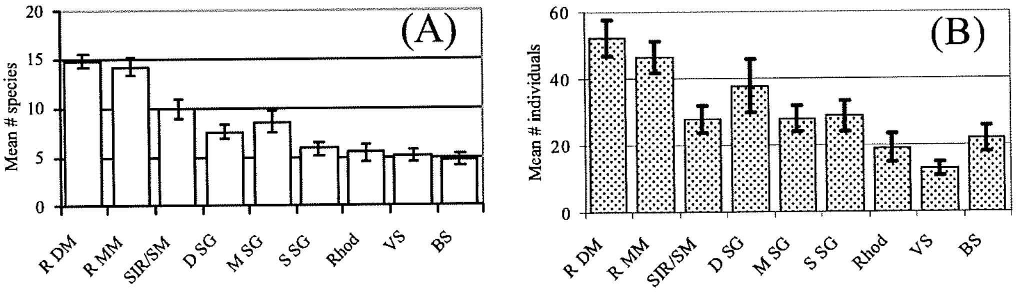


Figure 5.6: *Mean number of species (A) and individuals (B) for nine sub-habitats. R DM = Reef Dense Macro-algae Reef, R MM = Medium Macro-algae, SIR/SM = Sand Inundated Reef Sparse Macro-algae, VS = Vegetated Sand, BS = Bare Sand, D SG = Dense Seagrass, M SG = Medium Seagrass, S SG = Sparse Seagrass, Rhod = Rhodoliths and RU = Reef unknown. Error bars = ±1 SE.*

Relationship of fish species to habitat

Table 5.8 shows the percentage of samples within each habitat category where each fish species was seen. The species are grouped according to their main associations. Species picked by SIMPER analysis as characterising each habitat are shown in bold type. These are species which contribute most to the average similarity within the habitat category (generally those with a higher average abundance within the group, but also with consistent representation across the samples of the group). The SIMPER procedure also examines the species responsible for the dissimilarities between each habitat group (i.e good discriminating species). These average dissimilarities are represented in an ordination plot (Figure 5.7). The relative average dissimilarities between habitat groups are reflected in relative distance on the 2d Ordination.

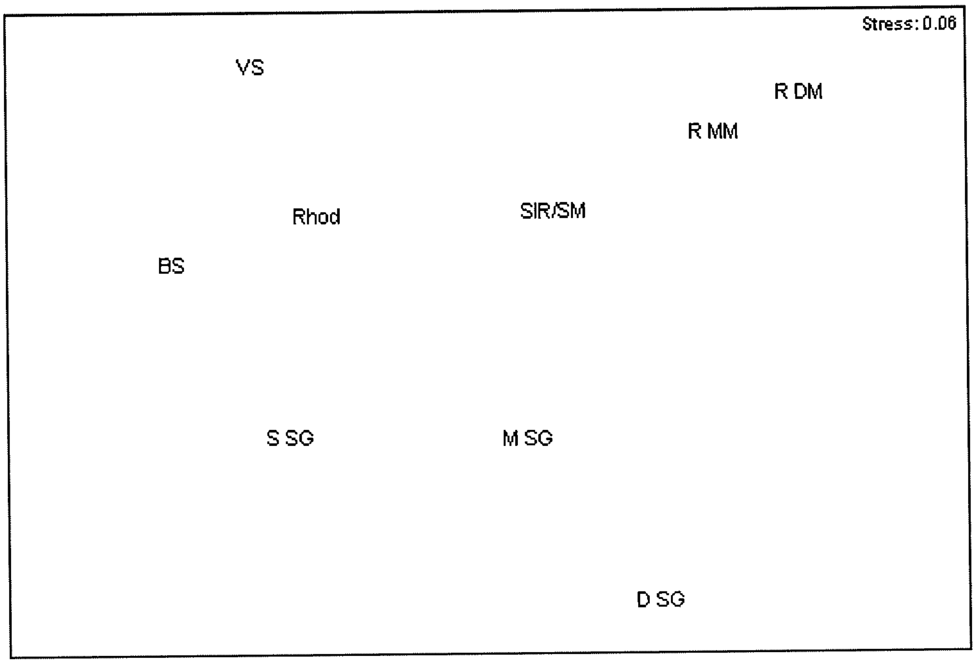


Figure 5.7: *Non metric MDS plot of habitats based on between group average dissimilarities. R DM = Reef Dense Macro-algae Reef, R MM = Medium Macro-algae, SIR/SM = Sand Inundated Reef Sparse Macro-algae, VS = Vegetated Sand, BS = Bare Sand, D SG = Dense Seagrass, M SG = Medium Seagrass, S SG = Sparse Seagrass, Rhod = Rhodoliths.*

Table 5.8: *Percentage of samples within each habitat category where fish species were seen. Species picked by SIMPER analysis as characterising each habitat are shown in bold type. (Note: The SIMPER analysis is based on square root transformed* MaxN$_i$ *data, while the figures are based on presence/absence in each video sample). R DM = Reef Dense Macro-algae Reef, R MM = Medium Macro-algae, SIR/SM = Sand Inundated Reef Sparse Macro-algae, VS = Vegetated Sand, BS = Bare Sand, D SG = Dense Seagrass, M SG = Medium Seagrass, S SG = Sparse Seagrass, Rhod = Rhodoliths and RU = Reef unknown.*

Association	Common name	Genus species	BS	Rhod	VS	S SG	M SG	D SG	RU	R DM	R MM	SIR/SM
All Habitats	Samsonfish	*Seriola hippos*	14		4	7	9		17	8	11	22
	Skipjack Trevally	*Pseudocaranx dentex*	**54**	**56**	39	**71**	**55**	**47**	**83**	**69**	**54**	**78**
Reef macroalgae	Banded Sweep	*Scorpis georgianus*	4		7			5		28	36	
	Barber Perch	*Caesioperca rasor*			4					11	21	
	Black Headed Puller	*Chromis klunzingeri*						5		**42**	25	33
	Black Spotted Wrasse	*Austrolabrus maculatus*		11	11			5	17	17	46	22
	Black-banded Seaperch	*Hypolectrodes nigrorubrum*								3	18	11
	Blue Groper	*Achoerodus gouldii*	4	11			9	5	**67**	**56**	**54**	
	Blue-lined Leatherjacket	*Meuschenia galii*			4		18	5	**83**	**75**	46	11
	Breaksea Cod	*Epinephelides armatus*							33	3	18	
	Common Bullseye	*Pempheris multiradiata*								3	4	
	Dusky Morwong	*Dactylophora nigricans*	4		4					8	4	

	Footballer Sweep	*Neatypus obliquus*	11	11	14			5	33	**50**	**50**	56
	Gulf Gurnard Perch	*Neosebastes bougainvilli*									7	
	Harlequin Fish	*Othos dentex*			4				17	14	25	
	Herring Cale	*Odax cyanomelus*					9		17	53	7	
	Horseshoe Leatherjacket	*Meuschenia hippocrepis*						5	**67**	**81**	36	
	Long-finned Pike	*Dinolestes lewini*			4			5	33	25	21	11
	Magpie Perch	*Cheilodactylus nigripes*			4				17	39	25	
	Mculloch's Scalyfin	*Parma mccullochi*								11		
	Moonlighter	*Tilodon sexfasciatum*	4		7		9	5	17	31	29	44

Table 5.8 continued

Association	Common name	Genus species	BS	Rhod	VS	S SG	M SG	D SG	RU	R DM	R MM	SIR/SM
Reef macroalgae	Old Wife	*Enoplosus armatus*								6		
	Oriental Bonito	*Sarda orientalis*	4							3		
	Queen Snapper	*Nemadactylus valenciennesi*	7	11	21		9	5	**83**	**75**	**61**	22
	Red Banded Wrasse	*Pseudolabrus biserialis*	11	11	18		9	5	**83**	**86**	**86**	**56**
	Red Snapper	*Centroberyx gerrardi*			4				33	3	14	
	Rough Bullseye	*Pempheris klunzingeri*						5		14	11	11
	Sargeant Baker	*Aulopus purpurissatus*			11				17	3	11	11
	Sea Sweep	*Scorpis aequipinnis*						5	17	39	36	
	Silver Drummer	*Kyphosus sydneyanus*						5		39	29	
	Six-spined Leatherjacket	*Meuschenia freycineti*								6		
	Spiny-tailed Leatherjacket	*Bigener brownii*								6		
	Splendid Perch	*Callanthias allporti*							17	6	14	
	Striped Stingaree	*Trygonoptera ovalis*								3	4	
	Swallowtail	*Centroberyx lineatus*			4		9	5	33	17	25	
	Varied Catshark	*Parascyllium variolatum*								3		11
	Victorian Scalyfin	*Parma victoriae*					9	5	17	25	11	
	Western Foxfish	*Bodianus frenchii*							17	25	29	
	Western King Wrasse	*Coris auricularis*	7	22	7			5	33	28	36	44

	Western Rock Blackfish	*Girella tephraeops*								42	32	
	Western Talma	*Chelmonops sp.*								6	4	
	Yellow-striped Leatherjacket	*Meuschenia flavolineata*					9	5		**67**	29	
	Zebra Fish	*Girella zebra*								8	14	

Table 5.8 continued

Association	Common name	Genus species	BS	Rhod	VS	S SG	M SG	D SG	RU	R DM	R MM	SIR/SM
Seagrass	Bridled Leatherjacket	*Acanthaluteres spilomelanurus*				7	9	32			7	
	Rough Leatherjacket	*Scobinichthys granulatus*				29	**64**	**100**		14	11	22
	Sea Trumpeter	*Pelsartia humeralis*						**47**				
	Senator Wrasse	*Pictilabrus laticlavius*					27	16		8		
	Stars and Stripes Leatherjacket	*Meuschenia venusta*					9	5				
	Toothbrush Leatherjacket	*Penicipelta vittiger*			4	36	**55**	**74**			11	
	Whiting sp	*Sillago sp.*				21						
	Yellowtail	*Trachurus novaezelandiae*	11	33		21	18	**53**			4	
Any vegetation	Australian Herring	*Arripis georgianus*					9	11		11		
	Brown Spotted Wrasse	*Pseudolabrus parilus*	11	11	18		**55**	**79**	**100**	**94**	**82**	**67**
	False Senator Wrasse	*Pictilabrus* species						5		3		
	Maori Wrasse	*Ophthalmolepis lineolatus*	18	22	21	7	**55**	37	**100**	**97**	**93**	**78**
	Port-Jackson Shark	*Heterodontus portusjacksoni*			4	7	9	5		11		
	Rainbow Cale	*Odax acroptilus*						5		3		
	Snook	*Sphyraena novaehollandiae*					9	32		17	4	
	Western Wirrah	*Acanthistius serratus*					9			3		

Medium-sparse vegetation	**Blue-spotted Goatfish**	*Upeneichthys vlamingii*	14	11	29	**64**	**82**	37	17	8	**61**	**78**
	Castelnau's Wrasse	*Dotalabrus aurantiacus*					18				4	
	Eagle ray	*Myliobatis australis*	43	22	29	**64**	**64**	16	50	28	**54**	**56**
	Gummie Shark	*Mustelus antarcticus*	7	22	18	21	27			14	11	33
	Prickly Toadfish	*Ontusus brevicaudus*			4	21	9	5		3		
	School Shark	*Galeorhinus galeus*			4	7	9					
	Southern Silverbelly	*Parequula melbournensis*	**54**	**78**	**54**	**79**	**82**	16		8	36	**56**

Table 5.8 continued

Association	Common name	Genus species	BS	Rhod	VS	S SG	M SG	D SG	RU	R DM	R MM	SIR/SM
Bare sand sparse veget.	**Chinaman Leatherjacket**	*Nelusetta ayraudi*	**82**	**67**	**71**	**43**	18	16		11	39	**67**
	Fiddler Ray	*Trygonorrhina fasciata*	14	33	7	7	9				4	22
	Knifejaw	*Oplegnathus woodwardi*			7							
	Smooth Stingray	*Dasyatis brevicaudata*	14	**44**	4	14					4	11
	Southern Blue-spotted Flathead	*Platycephalus speculator*	**57**	11	14	29	9					
	Spotted Grubfish	*Parapercis ramsayi*		22	21						4	11
	Stinkfish	*Callionymus* sp.	4	11								
	Unknown Pigfish Wrasse				14							
	Velvet Leatherjacket	*Parika scaber*			7							
Rare	Long Snouted Boarfish	*Pentaceropsis recurvirostris*	4				9				4	
	Pencil Shark	*Hypogaleus hyugaensis*										11
	Weed Whiting						9					
	Globe Fish	*Diodon nicthemerus*								3		
	Rusty Catshark	*Paracyllium ferrugineum*									4	
	Silver Spot	*Threpterius maculosus*								3		

	White-barred Boxfish	*Anoplocapros lenticularis*									4	
	Yellow Headed Hulafish	*Trachinops noarlungae*								3		
	Western Kelpfish	*Chironemus georgianus*								3		
	Snakeskin Wrasse	*Eupetrichthys angustipes*									4	
Rare pelagic	Pilchards	*Sardinops neopilchardus*				7						
	Barracouta	*Leionura atun*		11							4	
	Blue Mackerel	*Scomber australasicus*					9					
	Western Australian Salmon	*Arripis truttaceus*							17			

The main discriminating species determined by the SIMPER analysis in determining the pattern shown in the ordination are as follows.

Bare Sand vs Vegetated Sand: Bare Sand had higher abundances of *Nelusetta ayraudi*, *Pseudocaranx dentex* and *Parequula melbournensis*. *Platycephalus speculator* were only seen in bare sand habitat.

Bare Sand vs Sand-inundated LPR: Nelusetta ayraudi, *Pseudocaranx dentex* and *Parequula melbournensis* and *Platycephalus speculator* were important species. Also reef/vegetation associated species (*Ophthalmolepis lineolatus*, *Pseudolabrus parilus*, *Pseudolabrus biserialis*) became more important in the Sand-inundated LPR habitat.

Bare sand vs Sparse seagrass: Seagrass associated species (*Penicipelta vittiger*) and sparse-medium vegetation associated species (*Upeneichthys vlamingii*, *Myliobatis australis*, *Parequula melbournensis*) were more abundant.

Sparse seagrass vs medium seagrass: Increases in seagrass were characterised by increases in vegetation associated species (eg *Upeneichthys vlamingii*, *Pseudolabrus parilus*, *Ophthalmolepis lineolatus*) as well as seagrass specific species such as *Penicipelta vittiger* and *Scobinichthys granulatus*. There was also a decrease in *Nelusetta ayraudi* and *Pseudocaranx dentex* which are characteristic of barer habitats.

Medium seagrass vs dense seagrass: Increasing seagrass density was characterised by increases in seagrass associated species such as *Penicipelta vittiger* and *Scobinichthys granulatus*, *Trachurus novaezelandiae* and *Pelsartia humeralis*, which was only seen in dense seagrass samples. *Notolabrus parilus* abundances also increased.

There was a decrease in species characterising sparser vegetation (*Upeneichthys vlamingii*, *Myliobatis australis*, *Parequula melbournensis*).

Reef dense macro-algae vs Reef medium macro-algae: Decreasing density of macro-algae was characterised by a decrease in *Meuschenia hippocrepis*, *Meuschenia galii*, *Chromis klunzingeri* and *Ophthalmolepis lineolatus* and an increase in *Pseudolabrus biserialis* and *Neatypus obliquus*.

Reef medium macro-algae vs Sand-inundated Low Profile Reef: Medium macro-algae reef samples are distinguished from the Sand-inundated low profile reef by increases in vegetation associated species such as *Ophthalmolepis lineolatus*, *Pseudolabrus biserialis*, *Neatypus obliquus*, *Notolabrus parilus* and *Chromis klunzingeri*. Increased numbers of species associated with sparser vegetation (*Nelusetta ayraudi*, *Upeneichthys vlamingii* and *Parequula melbournensis*) distinguish the Low profile sand inundated reef from the Medium Reef.

Reef medium macro-algae vs Medium Seagrass: Medium seagrass was distinguished from Medium macro-algal reef by increased abundances of Seagrass associated species such as *Penicipelta vittiger* and *Scobinichthys granulatus* as well as *Upeneichthys vlamingii* and *Parequula melbournensis*, although the later two species these are associated with sparse to medium vegetation generally, but more strongly with seagrass. Reef Medium macro-algae samples were distinguished from the Medium seagrass by reef associated species such as *Pseudolabrus biserialis*, *Neatypus obliquus*, and *Chromis klunzingeri*. Vegetation associated species such as *Ophthalmolepis lineolatus* and *Notolabrus parilus* are also more strongly associated with Reefs.

5.4 DISCUSSION

Habitat structures, created by the substrate and its attached biota have been shown to exert species-specific effects on the capacity of fishes to obtain food and avoid predators (Holbrook *et al.* 1990, Hixon and Beets 1993). Consequently, benthic habitats support distinct assemblages of demersal fishes, each adapted to utilise particular components of available structure (Choat and Ayling 1987, Schmitt and Holbrook 1990, Friedlander and Parrish 1998, Travers and Potter 2002).

Because the physical structure of benthic habitats varies in space the structure of fish assemblages varies greatly at scales ranging from less than 1m, to thousands of kilometres (Choat and Ayling 1987, McCormick and Choat 1987, Friedlander and Parrish 1998, Connell and Lincoln-Smith 1999, Demestre *et al.* 2000, Williams and Bax 2001, Williams *et al.* 2001).

In temperate regions of Australia distinct differences in assemblage structure have been documented between seagrass meadows, algal reefs and adjacent areas of bare sand (Jenkins and Wheatley 1998, MacArthur and Hyndes 2001, Travers and Potter 2002).

In this study we found statistically distinctive fish assemblages between Seagrass, Reef, Rhodolith and Sand habitats although Sand and Rhodoliths were very similar. These habitat differences where also apparent in the numbers of species and individuals sampled with samples from Reef habitats having the greatest mean numbers of species and individuals followed by Seagrass and then Sand and Rhodlith habitats. Our finding of more species in Seagrass habitats in comparison to Sand is similar to other studies (Jenkins and Wheatley 1998, Guidetti 2000, McArthur and Hyndes 2001, Travers and Potter 2002). However, our results differ to Jenkins and Wheatley (1998) who sampled more species within Seagrass habitats than on Reefs. We believe this is an artefact of their sampling technique. Seine nets are good at sampling small cryptic fishes in seagrass (eg. Pipefishes), which the BUVS do not detect, however seines do not sample reef fish assemblages, or the broad range of species that comprise many demersal fish assemblages adequately because of the large range of morphologies and sizes. With the BUVS we sampled small *Chromis klunzingeri* of approximately 2 cm in length and *large Dasyatis brevicaudata* of 350 cm on length.

Given the outcomes of previous research in Western Australia (Harman *et al.* 2003, Watson *et al.* In press) which found different reef fish assemblages on high and low relief limestone reefs we were surprised that there were no differences between high the high and low granitic reefs in the Recherhce Archipelago. We found no differences between canopy forming species, but we did find a significant difference in fish assemblages within seagrass and reef habitats with different densities of flora. This is supported by Jenkins and Wheatley (1998) who found that the presence of structure was more important than its type.

Alevizon and Brooks (1975) found in reef habitats that the physical relief of reefs and the amount and composition of underlying macroscopic epiflora were responsible for differences in reef fish assemblages. Similarly, in this study we have found that changes in the density of flora within specific habitats and relief appear to exert the greatest influence on the structure of demersal fish assemblages. Our analysis of the sub-habitats based on floral density and relief of reef habitats show that while in some cases distinctive fish assemblages occupy distinctive habitats normally there is a continuum or transition of species between different combinations of floral density and relief with distinctive fish assemblages at the ends of the continuum.

One the potential criticisms of this study is our use of baited underwater video as a sampling tool. A criticism that could made is that the potential artifacts associated with inferring fish-habitat associations due to the use of bait which could attract species across habitat boundaries. This is a possible bias which we can not control for, however we did not see any evidence to suggest this occurred. Research comparing baited and unbaited underwater video cameras (see the next section) demonstrated that the use of bait actually strengthens discrimination of demersal assemblages between habitats. If species were being attracted for example from seagrass habitats onto reef we would see a decrease in the strong differences we have been detected between habitats. If this were the case our results would be more conservative than what the assemblages patterns actually present. Additionally, many species were only found in one of the four major habitats. We believe that the home range specificity demonstrated by many demersal fishes (Edgar *et al.* 2004) and the risk of predation (Connell 2002) would overcome would overcome the drive for many fishes to search out a bait tens to hundreds of metres away. While there were some species recorded in multiple habitats these species are cosmopolitan and found in many habitats. These cosmopolitan species where found in the same habitats in unbaited remote underwater video drops (See Harvey *et al.* next section).

All marine fish sampling techniques have some bias associated with them and do not sample all fishes (see Cappo *et al.* 2004). We believe that baited remote underwater video is one of the better and most cost effective techniques for sampling and differentiating demersal fish assemblages across a wide range of habitats and depths on the continental shelf.

5.5 REFERENCES

Alevizon, W.S. & M.G. Brooks. 1975. The comparitive structure of two western Atlantic reef fish assemblages. Bulletin of Marine Science 252: 482-490.

Ayvazian, S.G. & G.A. Hyndes. 1995. Surf-Zone Fish Assemblages in South-Western Australia - Do Adjacent Nearshore Habitats and the Warm Leeuwin Current Influence the Characteristics of the Fish Fauna. Marine Biology 122: 527-536.

Cappo, M., & I. Brown. 1996. Evaluation of sampling methods for reef fish populations of commercial and recreational interest, CRC Reef Research Centre, Technical Report No. 6, Townsville, CRC Reef Research Centre, 72 pp.

Cappo, M., Harvey, E., Malcolm, H. & P. Speare. 2003. Potential of video techniques to monitor diversity, abundance and size of fish in studies of Marine Protected Areas. In: “Aquatic Protected Areas - what works best and how do we know?", (Eds Beumer, J.P., Grant, A., and Smith, D.C.) World Congress on Aquatic Protected Areas proceedings, Cairns, Australia, August 2002. p 455-464.

Cappo, M., Speare, P. & G. De'ath. 2004. Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. Journal of Experimental Marine Biology and Ecology 302: 123-152.

Carr, M. 1991. Effects of macroalgal dynamics on recruitment of a temperate reef fish. Journal of Experimental Marine Biology and Ecology 146: 113-137.

Carr, M.H. 1994. Effects of Macroalgal Dynamics On Recruitment of a Temperate Reef Fish. Ecology 75: 1320-1333.

Choat, J.H. & A.M. Ayling. 1987. The Relationship between Habitat Structure and Fish Faunas On New-Zealand Reefs. Journal of Experimental Marine Biology and Ecology 110: 257-284.

Clarke, K. R. & R. N. Gorley. 2001. "Primer v5: User Manual/Tutorial." (Primer-E Ltd.: Plymouth, UK.)

Colton, D.E. and W.S. Alevizon (1981) Diurnal variability in a fish assemblage of a Bahamian coral reef. Environmental Biology of Fish 6: 341-345.

Connell, S.D. & M.P. Lincoln-Smith. 1999. Depth and the structure of assemblages of demersal fish: Experimental trawling along a temperate coast. Estuarine Coastal and Shelf Science 48: 483-495.

Connell, S.D. 2002. Effects of a predator and prey on a foraging reef fish: implications for understanding density-dependent growth. Journal of Fish Biology 60: 1551-1561.

Dean, T.A., Haldorson, L., Laur, D.R., Jewett S.C. & A. Blanchard. 2000. The distribution of nearshore fishes in kelp and eelgrass communities in Prince William Sound, Alaska: associations with vegetation and physical habitat characteristics. Environmental Biology of Fishes 57: 271-287.

Demestre, M., Sanchez, P. & P. Abello. 2000. Demersal fish assemblages and habitat characteristics on the continental shelf and upper slope of the north-western Mediterranean. Journal of the Marine Biological Association of the United Kingdom 80: 981-988.

Denny, C.M. & R.C. Babcock. 2004. Do partial marine reserves protect reef fish assemblages? Biological Conservation 116: 119-129.

Edgar, G.J., Barrett, N.S. & A.J. Morton. 2004. Biases associated with the use of underwater visual census techniques to quantify density and size structure of fish populations. Journal of Experimental Marine Biology and Ecology 308(2): 269-290.

Ellis, D.M. & E.E. Demartini. 1995. Evaluation of a Video Camera Technique For Indexing Abundances of Juvenile Pink Snapper, Pristipomoides-Filamentosus, and Other Hawaiian Insular Shelf Fishes. Fishery Bulletin 93: 67-77.

Friedlander, A.M. & J.D. Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224: 1-30.

Gaughan, D.J., Mitchell, R.W. & S.J. Blight. 2000. Impact of mortality, possibly due to herpesvirus, on pilchard *Sardinops sagax* stocks along the south coast of Western Australia in 1998-1999. Marine and Freshwater Research 51: 601-612.

Guidetti, P. 2000. Differences among fish assemblages associated with nearshore Posidonia oceanica seagrass beds, rocky-algal reefs and unvegetated sand habitats in the Adriatic Sea. Estuarine Coastal and Shelf Science 50: 515-529.

Harman, N., Harvey, E.S. & G.A. Kendrick. 2003. Differences in fish assemblages from different reef habitats at Hamelin Bay, south-western Australia. Marine and Freshwater Research 54: 177-184.

Harmelin-Vivien, M.L. & P. Francour. 1992. Trawling or Visual Censuses - Methodological Bias in the Assessment of Fish Populations in Seagrass Beds. Marine Ecology-Pubblicazioni Della Stazione Zoologica Di Napoli I 13: 41-51.

Harvey, E., Fletcher, D. & M. Shortis. 2001a. A comparison of the precision and accuracy of estimates of reef-fish lengths determined visually by divers with estimates produced by a stereo-video system. Fishery Bulletin 99: 63-71.

Harvey, E., Fletcher, D. & M. Shortis. 2001b. Improving the statistical power of length estimates of reef fish: a comparison of estimates determined visually by divers with estimates produced by a stereo-video system. Fishery Bulletin 99: 72-80.

Harvey, E., Fletcher, D. & M. Shortis. 2002. Estimation of reef fish length by divers and by stereo-video - A first comparison of the accuracy and precision in the field on living fish under operational conditions. Fisheries Research 57: 255-265.

Harvey, E.S. & M.R. Shortis. 1998. Calibration stability of an underwater stereo-video system: Implications for measurement accuracy and precision, Marine Technology Society Journal 32(2), 3-17.

Harvey, E. & M. Shortis. 1996. A system for stereo-video measurement of sub-tidal organisms. Marine Technology Society Journal 29: 10-22.

Hobson, E.S., McFarland, W.N. & J.R. Chess. (1981). Crepuscular and nocturnal activities of Caliafornian nearshore fishes, with consideration to scotopic visual pigments and photic environment. Fishery Bulletin **53**: 181-188.

Hutchins, J.B. 1994. A survey of the nearshore fish fauna of Western Australia's west and southwest coasts - The Leeuwin province. Records of the Western Australian Museum. Supplement # 46.

Hutchins, J.B. 2001. Biodiversity of shallow reef fish assemblages in Western Australia using a rapid censusing technique. Records of the Western Australian Museum, 20: 247-270.

Hickford, M.J.H. & D.R. Schiel. 1995. Catch Vs Count - Effects of Gill-Netting On Reef Fish Populations in Southern New-Zealand. Journal of Experimental Marine Biology and Ecology 188: 215-232.

Hixon, M.A. & J.P. Beets. 1993. Predation, Prey Refuges, and the Structure of Coral-Reef Fish Assemblages. Ecological Monographs 63: 77-101.

Holbrook, S.J., Schmitt, R.J. & R.F. Ambrose. 1990. Biogenic Habitat Structure and Characteristics of Temperate Reef Fish Assemblages. Australian Journal of Ecology 15: 489-503.

Hyndes, G.A., Platell, M.E., Potter, I.C. & R.C.J. Lenanton. 1999. Does the composition of the demersal fish assemblages in temperate coastal waters change with depth and undergo consistent seasonal changes? Marine Biology 134: 335-352.

Jenkins, G.P. & M.J. Wheatley. 1998. The influence of habitat structure on nearshore fish assemblages in a southern Australian embayment: Comparison of shallow seagrass, reef-algal and unvegetated sand habitats, with emphasis on their importance to recruitment. Journal of Experimental Marine Biology and Ecology 221: 147-172.

Jenkins, G.P., Black, K.P., Wheatley, M.J. & D.N. Hatton. 1997. Temporal and spatial variability in recruitment of a temperate, seagrass-associated fish is largely determined by physical processes in the pre- and post-settlement phases. Marine Ecology Progress Series 148 (1-3): 23-35.

Levin, P. 1993. Habitat structure, con specific presence and spatial variation in the recruitment of a temperate reef fish. Oecolgia 94: 176-185.
Levin, P.S. 1994. Small-Scale Recruitment Variation in a Temperate Fish - the Roles of Macrophytes and Food-Supply. Environmental Biology of Fishes 40: 271-281.

MacArthur, L.D. & G.A. Hyndes. 2001. Differential use of seagrass assemblages by a suite of odacid species. Estuarine Coastal and Shelf Science 52: 79-90.

Mahon, R. & R.W. Smith. 1989. Demersal Fish Assemblages on the Scotian Shelf, Northwest Atlantic - Spatial-Distribution and Persistence. Canadian Journal of Fisheries and Aquatic Sciences 46: 134-152.

McCormick, M.I. & J.H. Choat. 1987. Estimating Total Abundance of a Large Temperate-Reef Fish Using Visual Strip-Transects. Marine Biology 96: 469-478.

Pihl, L. & H. Wennhage. 2002. Structure and diversity of fish assemblages on rocky and soft bottom shores on the Swedish west coast. Journal of Fish Biology 61: 148-166.

Priede, I.G., Bagley, P.M., Smith, A., Creasey, S. & N.R. Merrett. 1994. Scavenging Deep Demersal Fishes of the Porcupine Seabight, Northeast Atlantic - Observations By Baited Camera, Trap and Trawl. Journal of the Marine Biological Association of the United Kingdom 74: 481-498.

Rotchell, J.M., Clarke, K.R., Newton, L.C. & D.J. Bird. 2001. Hepatic metallothionein as a biomarker for metal contamination: age effects and seasonal variation in European flounders (Pleuronectes flesus) from the Severn Estuary and Bristol Channel. Marine Environmental Research 52: 151-171.

Travers, M.J. & I.C. Potter. 2002. Factors influencing the characteristics of fish assemblages in a large subtropical marine embayment. Journal of Fish Biology 61: 764-784.

Williams, A. & N.J. Bax. 2001. Delineating fish-habitat associations for spatially based management: an example from the south-eastern Australian continental shelf. Marine and Freshwater Research 52: 513-536.

Williams, A., Koslow, J.A. & P.R. Last. 2001. Diversity, density and community structure of the demersal fish fauna of the continental slope off western Australia (20 to 35 degrees S). Marine Ecology-Progress Series 212: 247-263.

Willis, R., Millar, R.B. & R. Babcock. 2000. Detection of spatial variability in relative density of fishes of fishes: comparison of visual censuses, angling and baited underwater video. Marine Ecology Progress Series. 198: 249-260.

Willis, T.J. & R.C. Babcock. 2000. A baited underwater video system for the determination of relative density of carnivorous reef fish. Marine and Freshwater Research 51: 755-763.

Yoklavich, M.M., Greene, H.G., Cailliet, G.M., Sullivan, D.E., Lea, R.N. & M.S. Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fishery Bulletin 98: 625-641.

Watson, D. L., Harvey, E. S., Anderson, M. J., Kendrick, G. A. (in press) A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques. Marine Biology (accepted July 2005).

Winer, B., Brown, D.R. & K.M Michels. 1991. Statistical Principals in Experimental Design. McGraw-Hill, New York, USA.

Worthington, D.G., Westoby, M. & J.D. Bell. 1991. Fish Larvae settling in seagrass: Effectgs of leaf density and an epiphytic alga. Australian Journal of Ecology: 16(3): 289-293.

Worthington, D.G., Ferrell, D.J., McNeill, S.E. & J.D. Bell. 1992. Effects of the shoot density of seagrass on fish and decapods: Are correlations evident of larger spatial scales? Marine Biology 116(1): 139-146.

6.0 The influence of Reef Isolation, Exposure and Depth on the structure and relative abundances of the shallow water reef fish assemblages of the Recherche Archipelago, South Western Australia.

Euan S Harvey[1] and Gary A Kendrick[1]

[1] School of Plant Biology (Botany M090), University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009.

6.1 INTRODUCTION

One of the major goals of reef fish ecologists is to understand the processes that influence the spatial and temporal structure of fish assemblages. This information is critical to fisheries managers, especially at a time when the concept of spatial management of fish populations and marine ecosystems by protecting essential fish habitat is gaining popularity.

Processes that influence the diversity, composition and spatial distribution of reef fish assemblages fall into two broad categories; ecological and physical. The majority of research has concentrated on ecological processes. These processes include predation (Hindell *et al.* 2000, Leis and Carson-Ewart 2002), intra- and inter-specific competition (Leis and Carson-Ewart 2002), recruitment (Leis and Carson-Ewart 2002) and food availability (Connell 2002, Wellenreuther and Connell 2002).

Physical processes such as habitat type and complexity (Harman *et al.* 2003, Anderson and Millar 2004), oceanographic features (water temperature, salinity and water movement) (Lecchini *et al.* 2003) and wave exposure also influence the structure of reef fish assemblages (Letourneur 1996, Clark 1997, Bellwood *et al.* 2002, Fulton and Bellwood 2004). Water depth is routinely cited as a variable that structures different fish assemblages (Callaway *et al.* 2002, Lorance *et al.* 2002, Travers and Potter 2002).

In this report we describe the shallow (25 m and less) reef fish assemblages of the western Recherche Archipelago, South Western Australia, and investigate whether:

1. depth and wave exposure influence the assemblage structure and relative abundances of reef fishes;
2. differences in reef fish assemblages exist between inshore, offshore and remote reefs.

6.2 METHODS

6.2.1 Data collection

Data were collected in the western Recherche Archipelago, south-western Australia between the 14th of October and 4th of November 2002 (Figure 6.1). The Recherche Archipelago is a chain of approximately one hundred and five islands and one thousand five hundred islets extending over 470 kms of coastline (Kendrick *et al.* 2002). The numerous islands provide a unique opportunity to observe how depth and exposure interact to structure shallow temperate reef fish assemblages.

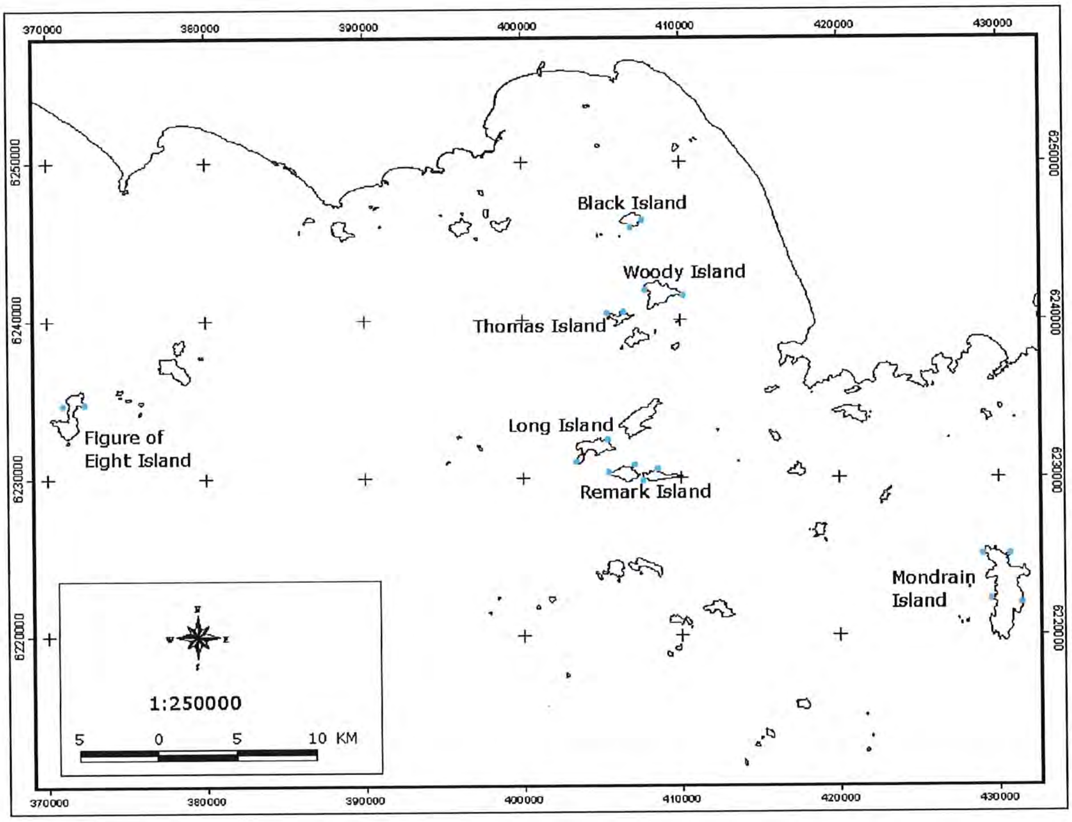


Figure 6.1: Sampling location in the Recherche Archipelago, Western Australia.

We sampled reef fish assemblages on granite reefs at eight islands. Each island was classified based on its distance offshore from Bandy Creek, a location in Esperance

Bay used by both recreational and commercial fishermen for launching and mooring boats. "Inshore" islands (Woody, Black and Thomas Islands, Figure 6.1) were all within 10 to 16 kilometres (km) of Bandy Creek while "Offshore" islands (Long, Remark and Frederick Islands) were 20 to 26 km Bandy Creek. The "Remote" islands (Mondrain and Figure of 8) were more than 35 km from Bandy Creek.

All of the islands were steep sided granite domes with similar underwater substratum and topography. The reefs around the islands were covered by a thick layer of macrophytes dominated by an *Ecklonia radiata*/fucoid over story assemblage, that included *Sargassum* and *Cystophora* species (Goldberg and Kendrick 2004). Within Inshore, Offshore and Remote islands we sampled three reefs that were sheltered from (NE aspect), and three reefs exposed to (SW aspect) the predominant south-westerly swell. We conducted transects at one exposed and sheltered site at each island, with the exception of Mondrain Island where we sampled two sites at each exposure due to it size (Figure 6.1). At each reef we used an underwater stereo-video system (Harvey and Shortis, 1996) to record fish within eight replicate 25 x 5 x 5m (625 m^3) transects at each of three depths (5, 15 and 24 metres). A minimum fifteen metre gap existed between the end of one transect and the start of another to minimise fish disturbance. We post processed the recordings to identify, count and measure the fork lengths of all reef fish seen. Sampling between 08.00 and 16.00 hours when water visibility was greater than 5m.

We chose to use an underwater stereo-video system to maximise the accuracy and precision of length estimates and to minimise observer and inter-observer variability (Harvey *et al.* 2001a, b, 2002a, 2004). The stereo-video system does not adequately sample small cryptic fishes, which are most effectively sampled by icthyocides (Willis *et al.* 2000, Ackerman and Bellwood, 2000). This study focuses on conspicuous reef fish species longer than 50 mm. The stereo-video system consisted of two Sony TRV 900E digital video cameras in underwater housings mounted on a base bar. A custom built synchronising diode was used to match images from the left and right video cameras. A detailed explanation of the design, calibration, measurement and examples of measurement accuracy and precision may be found elsewhere (Harvey and Shortis, 1996, 1998, Shortis and Harvey 1998, Harvey *et al.* 2001, 2002a, b, 2003, 2004).

6.2.2 Analysis of imagery

Video imagery from a transect were frame-grabbed in Audio Video Interleaved (AVI) format using a DV Raptor© frame grabber on a Personal Computer (PC). Two AVI files containing images from the left and right cameras were then imported into Vision Measurement System (VMS), a stereo-photo comparator (Shortis and Robson, 2001). Paired images within the AVIs were synchronised using LEDs mounted on a bar in front of the cameras and measurements of the fork length and position of target reef fish made. Measurements were made by locating the snout and the tail fork of the target fish within the synchronised video streams using cursor positioning and mouse clicks. The two pairs of image coordinates are converted into coordinates in three dimensional object space (x, y and z) and an estimator of the quality (root mean square residual, also known as residual parallax) and precision of the measurement is logged. To obtain length measurements the three-dimensional distances between consecutive point measurements (snout and tail fork) are computed automatically. The range from the snout of the fish to the central point between the camera lenses and the angle of the point of interest relative to the camera centres are also automatically computed. These values were used to define whether a fish was inside or outside the boundaries of the transect (Harvey *et al.* 2004). Measurements of the length of fish were disregarded if made at distances greater than 8 m, as previous research has shown that measurement accuracy and precision degrades rapidly with this system beyond that distance (See Harvey *et al.* 2002b).

6.2.3 Statistical analysis

Differences in the reef fish assemblage structure between inshore, offshore and remote reefs, shelter and depth were assessed using a four-way mixed model non-parametric multivariate analysis of variance (PERMANOVA) (Anderson and Robinson 2001, Anderson 2005). The experimental design consisted of four factors: distance from shore (three levels, fixed), reef (three levels nested within distance, random), shelter (two levels, fixed), and depth (three levels, fixed). We used scale invariant binomial deviance as a dissimilarity measure (see Anderson and Millar 2004) and a ln (x+1) transform. For each term in the analysis 4999 permutations of the raw data units were computed to obtain *P*- values.

The species richness, total number of individuals and the abundances of key species which had sufficient numbers of individuals were analysed using univariate analysis of variance. Key species influencing the structure of reef fish assemblages were identified using Similarity of Percentages (SIMPER). These species included *Chromis klunzingeri, Kyphosus sydneyanus, Ophthalmolepis lineolatus, Pseudolabrus biserialis, Achoerodus gouldi, Nemadactylus valenciennesi, Scorpis aequipinnis,* and *Girella zebra.* Due to the predominance of zeroes, and the variability between samples, normality was not a reasonable assumption. We analysed the data using multivariate ANOVA and the same model described above (4999 permutations). Because we used only one variable, the analysis was based on Euclidean distance (Anderson and Millar 2004).

6.3 RESULTS

We recorded 5295 fish from 50 species and 22 families (Table 6.1). In four transects at one site on an offshore exposed reef we recorded 1633 *Pseudocaranx dentex*, a schooling carangid which we have removed from subsequent analysis.

Table 6.1: List of reef fishes sampled.

Common Name	Scientific Name	Family
Banded Sweep	*Scorpis georgianus*	Scorpididae
Barber Perch	*Caesioperca rasor*	Serranidae
Bicolour Scalyfin	*Parma bicolor*	Pomacentridae
Black-headed Puller	*Chromis klunzingeri*	Pomacentridae
Blue-lined Hulafish	*Trachinops brauni*	Plesiopidae
Blue-lined Leatherjacket	*Meuschenia galii*	Monacanthidae
Blue-spotted Goatfish	*Upeneichthys vlamingii*	Mullidae
Breaksea Cod	*Epinephelides armatus*	Serranidae
Brown-spotted Wrasse	*Notolabrus parilus*	Labridae
Common Bullseye	*Pempheris multiradiata*	Pempheridae
Dusky Morwong	*Dactylophora nigricans*	Cheilodactylidae
Footballer Sweep	*Neatypus obliquus*	Scorpididae
Harlequin Fish	*Othos dentex*	Serranidae
Herring Cale	*Odax cyanomelas*	Odacidae
Horseshoe Leatherjacket	*Meuschenia hippocrepis*	Monacanthidae
Long-finned Pike	*Dinolestes lewini*	Dinolestidae

Long-snouted Boarfish	*Pentaceropsis recurvirostris*	Pentacerotidae
Magpie Perch	*Cheilodactylus nigripes*	Cheilodactylidae
Maori Wrasse	*Opthalmolepis lineolatus*	Labridae
McCulloch's Scalyfin	*Parma mccullochi*	Pomacentridae
Moonlighter	*Tilodon sexfasciatum*	Scorpididae
Old Wife	*Enoplosus armatus*	Enoplosidae
Queen Snapper	*Nemadactylus valenciennesi*	Cheilodactylidae
Red-banded Wrasse	*Pseudolabrus biserialis*	Labridae
Rough Bullseye	*Pempheris klunzingeri*	Pempheridae
Rough Leatherjacket	*Scobinichthys granulatus*	Monacanthidae
Sea Sweep	*Scorpis aequipinnis*	Scorpididae
Senator Wrasse	*Pictilabrus laticlavius*	Labridae
Sergeant Baker	*Aulopus purpurissatus*	Aulopidae
Silver Drummer	*Kyphosus sydneyanus*	Kyphosidae
Skipjack Trevally	*Pseudocaranx dentex*	Carangidae
Snook	*Sphyraena novaehollandiae*	Sphyraenidae
Southern Silverbelly	*Parequula melbournensis*	Gerreidae
Southern Yellowtail Scad	*Trachurus novaezelandiae*	Carangidae
Spiny-tailed Leatherjacket	*Acanthaluteres brownii*	Monacanthidae
Splendid Perch	*Callanthias australis*	Serranidae
Striped Stingaree	*Trygonoptera ovalis*	Urolophidae
Swallowtail	*Centroberyx lineatus*	Berycidae
Tommy Rough	*Arripis georgianus*	Arripidae
Victorian Scalyfin	*Parma victoriae*	Pomacentridae
Western Blue Devil	*Paraplesiops meleagris*	Plesiopidae
Western Blue Groper	*Achoerodus gouldii*	Labridae
Western Foxfish	*Bodianus frenchii*	Labridae
Western King Wrasse	*Coris auricularis*	Labridae
Western Rock Blackfish	*Girella tephraeops*	Kyphosidae
Western Talma	*Chelmonops curiosus*	Chaetodontidae
Westrern Sea Carp	*Aplodactylus westralis*	Aplodactylidae
Yellow-headed Hulafish	*Trachinops noarlungae*	Plesiopidae
Yellow-striped Leatherjacket	*Meuschenia flavolineata*	Monacanthidae
Zebra Fish	*Girella zebra*	Kyphosidae

Reef fish assemblage

PERMANOVA recorded significant effects for all main factors and interactions for reefs within Distance * Shelter * Depth (Table 6.2). Significant interactions were recorded for Reefs nested within Distance * Shelter, Reefs nested within Distance * Depth, Shelter * Depth and Reefs nested within Distance * Shelter * Depth indicating there was significant variability in the fish assemblages between reefs within distance/shelter/depth combinations. Pair wise comparisons of the Reefs nested within Distance * Shelter * Depth interaction showed that at remote sites there was no difference between reefs at the same shelter and depth combination with the exception of sheltered reefs at 5m at Figure of 8 and Mondrain 1. At offshore exposed sites there was no difference between reefs at a similar depth. At sheltered offshore reefs there were differences between all three reefs at 24m.

Table 6.2: *PERMANOVA of ln (x +1) transformed abundance data for assemblage data based on the binomial deviance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	11.771	3.333	**0.023**
Re(Di)	6	3.531	2.796	**0.000**
Sh	1	17.422	4.376	**0.003**
De	2	25.381	13.413	**0.000**
Di*Sh	2	6.324	1.588	0.140
Di*De	4	2.810	1.485	0.157
Re(Di)*Sh	6	3.981	3.152	**0.000**
Re(Di)*De	12	1.892	1.498	**0.008**
Sh*De	2	6.844	3.801	**0.001**
Di*Sh*De	4	2.593	1.440	0.140
Re(Di)*Sh*De	12	1.800	1.425	**0.017**
Residual	378	1.263		
Total	431			

At 15m, the reefs at Fredrick and Long were different to reefs at Remark Island while at 5m, Long and Remark differed. At exposed inshore reefs there was no difference between reefs at 24m, but at 15 and 5m Woody and Black Islands were different.

Species richness

For species richness significant main effects were record for Reefs nested within Distance and Depth. Significant interactions were recorded for Reefs nested within Distance * Shelter and Reefs nested within Distance * Depth (Table 6.3). Pair wise comparisons of Reefs within Distance at the same depth displayed a trend of greater differences between reefs at remote reefs at the same depth as opposed to inshore reefs and on shallower reefs which were not significantly different. This trend was influenced by depth with no differences between reefs at a depth of 24m at either remote, offshore or inshore reefs. At Inshore reefs the only difference that existed in species richness was between Woody and Thomas Islands at 15m. Offshore reefs at 5m and 15m at Remark and Frederick Islands were different, while at Remote sites one of the reefs at 15m at Mondrain Island was different to the other which was similar to the reef at Figure of 8.

Pair wise comparisons of the Reefs nested within Distance * Shelter interaction showed there was significant variation between the number of species recorded at reefs within the same Distance and Shelter combination. There were no differences at Inshore sheltered reefs, but at Inshore exposed reefs Woody Island recorded a higher mean number of species than reefs at Black Island. At offshore sheltered reefs Remark Island had a lower mean species than Long Island, while at exposed offshore sites, reefs at Frederick Island had a higher mean species than reefs at either Remark or Long Islands. The remote sheltered reef at site one on Mondrain Island had higher mean species than either the second reef at Mondrain Island or the reef at Figure of 8 Island.

Pair wise comparisons for Depth showed differences between reefs at 5m in comparison to both 15m and 24m. Reefs at 5m had lower mean numbers of species in comparison to 15m and 24m.

Table 6.3: *PERMANOVA of ln (x +1) transformed abundance data for total numbers of species based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	5.382	3.613	0.096

Re(Di)	6	1.490	6.340	**0.000**
Sh	1	6.927	3.493	0.115
De	2	5.717	12.476	**0.001**
Di*Sh	2	7.061	3.560	0.084
Di*De	4	0.731	1.595	0.233
Re(Di)*Sh	6	1.983	8.442	**0.000**
Re(Di)*De	12	0.458	1.951	**0.025**
Sh*De	2	0.764	1.995	0.181
Di*Sh*De	4	0.165	0.431	0.779
Re(Di)*Sh*De	12	0.383	1.629	0.087
Residual	378	0.235		
Total	431			

Number of individuals

For the total numbers of individual fish recorded per transect significant main effects were found for Reefs nested within Distance and Depth. Significant interactions were recorded for Reefs nested within Distance * Depth and Reefs nested within Distance * Shelter (Table 6.4). The pair wise comparisons of Reefs nested within Distance * Depth interaction showed that there were no differences between reefs at Remote sites at depths of 5m and 24m. Significant differences were recorded at reefs at 15m with reefs at the second site on Mondrain Island having lower mean numbers of individual fish than reefs at either the reef one on Mondrain Island or Figure of 8 Islands. At Offshore reefs there were no differences at depths of 24m, but at depths of 5m and 15m reefs at Frederick Island had higher mean numbers of individual fish than reefs at Remark Island.

At Inshore sites there were no differences between reefs at 15m depth. At depths of 5m reefs at Woody Island had higher mean numbers of individual fish recorded per transect than at Black Island, but at depths of 24m this was reversed with reefs at Woody Island having less individuals per transect than reefs at Black Island.

For the Reefs nested within Distance * Shelter interaction pair wise comparisons revealed that at Remote exposed sites reefs differed between Figure of 8 Island, which tended to have higher mean numbers of individual fish per transect than reefs at either of the Mondrain Island sites. At Remote sheltered reefs the second site at Mondrain

Island was similar to Figure of 8 Island, having lower mean numbers of fish per transect than recorded at the site one on Mondrain Island. Offshore exposed reefs transects at Frederick Island had higher mean numbers of individuals than reefs at Remark or Long Islands. Offshore sheltered reefs transects at Frederick and Long Island contained similar mean numbers of individual fish and were significantly different to Remark Island, which had lower mean values. At Inshore Exposed reefs no differences were recorded but at Inshore Sheltered reefs Thomas Island had higher mean numbers of fish than either Black or Woody Islands which were similar.

For the main effect depth, more individuals were recorded at 15m and 24m than on reefs at 5m.

Table 6.4: *PERMANOVA of ln (x +1) transformed abundance for total numbers individuals based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	15.080	4.341	0.068
Re(Di)	6	3.474	5.380	**0.000**
Sh	1	14.954	3.699	0.106
De	2	7.899	4.985	**0.027**
Di*Sh	2	11.088	2.743	0.142
Di*De	4	2.038	1.286	0.332
Re(Di)*Sh	6	4.043	6.261	**0.000**
Re(Di)*De	12	1.585	2.454	**0.004**
Sh*De	2	1.848	2.002	0.178
Di*Sh*De	4	1.034	1.120	0.394
Re(Di)*Sh*De	12	0.923	1.429	0.155
Residual	378	0.646		
Total	431			

Key species

Chromis klunzingeri

For *Chromis klunzingeri* significant main effects were recorded for Distance, Shelter and Depth. Interactions were recorded for Distance * Shelter and Shelter * Depth (Table 6.5). Pair wise comparisons for the Shelter * Depth interaction showed that there were more individuals at Exposed reefs at 15m than at depths of 5m or 24m. At Sheltered reefs there were more individuals recorded on reefs at 15m and 24m than at 5m (Figure 6.2) and generally there were more individuals on sheltered reefs than on exposed reefs at all depths. The Distance * Shelter interaction revealed that as distance from shore increased the abundance of *Chromis klunzingeri* decreased. Also that for Inshore and Offshore reefs more individuals were recorded on Sheltered rather than exposed reefs (Figure 6.3).

Table 6.5: *PERMANOVA of ln (x +1) transformed abundance for* Chromis klunzingeri *based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	11.628	9.959	**0.023**
Re(Di)	6	1.168	1.873	0.090
Sh	1	22.640	20.346	**0.002**
De	2	6.527	7.323	**0.009**
Di*Sh	2	5.927	5.327	**0.031**
Di*De	4	0.749	0.841	0.524
Re(Di)*Sh	6	1.113	1.785	0.106
Re(Di)*De	12	0.891	1.430	0.148
Sh*De	2	4.811	5.765	**0.015**
Di*Sh*De	4	1.053	1.262	0.330
Re(Di)*Sh*De	12	0.834	1.339	0.203
Residual	378			
Total	431			

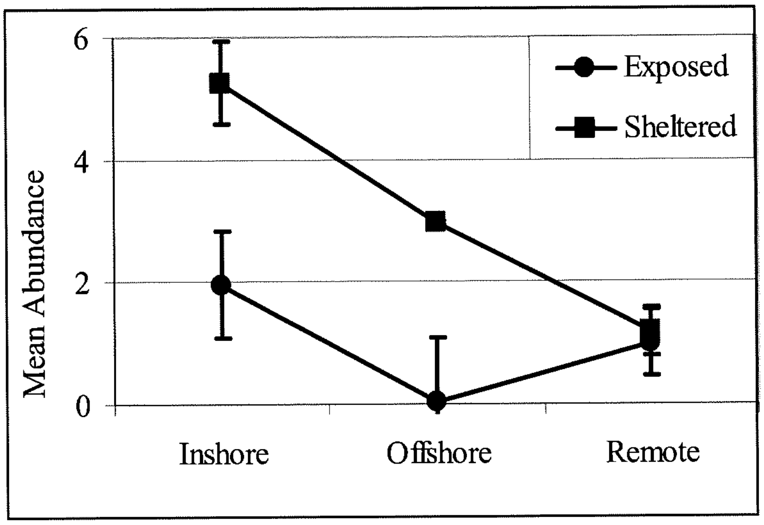


Figure 6.3: Interactions between Distance and Exposure for Chromis klunzingeri, ± *1 SE.*

Kyphosus sydneyanus

For *Kyphosus sydneyanus* significant main effects were recorded for Depth only. Interactions were recorded for Reefs nested within Distance * Shelter (Table 6.6). Pair wise comparisons of Reefs nested within Distance * Shelter showed the interaction can be attributed to differences between reefs at Offshore Exposed and Sheltered sites. Exposed reefs at Frederick had higher mean numbers of *Kyphosus sydneyanus* than reefs at Remark Island where no individuals were recorded. At Sheltered Offshore sites differences between reefs was caused by very low numbers of *Kyphosus sydneyanus* at Long Island reefs in comparison to reefs at Frederick Island. The depth main effect was caused by higher mean numbers of *Kyphosus sydneyanus* being recorded at depths of 5m than on reefs at either 15m or 24m.

Ophthalmolepis lineolatus

Significant main effects were recorded for *Ophthalmolepis lineolatus* for Reefs nested within Distance and Depth. Interactions were recorded between Reefs nested within Distance * Shelter, Reefs nested within Distance * Depth and at the lowest end of the model (Reefs nested within Distance * Shelter * Depth) (Table 6.7). Pair wise comparisons for the Reefs nested within Distance * Shelter * Depth interaction showed that there were no significant differences between reefs at any of the Depth and Shelter combinations at Inshore sites. At Offshore sites differences existed between Exposed reefs at 15m between Frederick and Remark and Long Islands due to higher mean numbers of *Ophthalmolepis lineolatus* being recorded at Frederick Island. The same pattern was observed at reefs at 24m depth at Sheltered sites. The reefs sampled at Frederick Island again had higher mean numbers of fish than Long or Remark Islands, where no fish were recorded. At Remote sheltered reefs at 5m, site two on Mondrain Island recorded no fish, making it different from reefs at the other two sites. The same pattern was repeated at Remote Exposed sites with reefs at 24m at Figure of 8 Island having significantly higher numbers of fish than found on the comparable reef at site two on Mondrain Island.

The significant differences in depth were caused by more fish being found at deeper reefs (15m and 24m) than on shallow reefs (5m).

Table 6.6: *PERMANOVA of ln (x +1) transformed abundance for* Kyphosus sydneyanus *based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	1.643	4.242	0.083
Re(Di)	6	0.387	1.554	0.156
Sh	1	0.765	1.315	0.309
De	2	7.480	22.040	**0.000**
Di*Sh	2	0.805	1.383	0.325
Di*De	4	0.511	1.506	0.239
Re(Di)*Sh	6	0.582	2.334	**0.033**
Re(Di)*De	12	0.339	1.362	0.175
Sh*De	2	0.015	0.060	0.945
Di*Sh*De	4	0.374	1.451	0.274
Re(Di)*Sh*De	12	0.258	1.033	0.417
Residual	378	0.249		
Total	431			

Table 6.7: *PERMANOVA of ln (x +1) transformed abundance for* Ophthalmolepis lineolatus *based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	1.195	0.775	0.486
Re(Di)	6	1.541	6.801	**0.000**
Sh	1	1.466	2.317	0.184
De	2	6.178	14.015	**0.001**
Di*Sh	2	0.230	0.363	0.705
Di*De	4	0.820	1.860	0.183
Re(Di)*Sh	6	0.633	2.793	**0.010**
Re(Di)*De	12	0.441	1.946	**0.029**
Sh*De	2	1.538	3.169	0.074
Di*Sh*De	4	0.135	0.278	0.877
Re(Di)*Sh*De	12	0.485	2.142	**0.018**
Residual	378	0.227		
Total	431			

Pseudolabrus biserialis

For *Pseudolabrus biserialis* significant main effects were recorded for Shelter and Depth (Table 6.8). Interactions were recorded for Reefs nested within Distance * Shelter * Depth, Shelter * Depth and Reefs nested within Distance * Shelter. Pair wise comparisons of the Reefs nested within Distance * Shelter * Depth interaction showed no differences between reefs at Remote sites for all Shelter and depth combinations. This pattern persisted at Offshore sites, with exception of Exposed reefs at 15m where transects at Remark Island recorded more individuals than at Frederick or Long Islands. The only difference found between reefs at Inshore sites was on Sheltered reefs at 24m where transects at Black and Thomas Islands recorded more individuals than at Woody Island.

Table 6.8: *PERMANOVA of ln (x +1) transformed abundance for* Pseudolabrus biserialis *based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	0.095	0.623	0.522
Re(Di)	6	0.152	1.172	0.325
Sh	1	2.774	7.345	**0.039**
De	2	5.356	41.083	**0.000**
Di*Sh	2	1.205	3.192	0.115
Di*De	4	0.041	0.314	0.865
Re(Di)*Sh	6	0.378	2.907	**0.008**
Re(Di)*De	12	0.130	1.004	0.444
Sh*De	2	1.243	4.840	**0.027**
Di*Sh*De	4	0.487	1.894	0.181
Re(Di)*Sh*De	12	0.257	1.978	**0.024**
Residual	378	0.130		
Total	431			

Pair wise comparisons of the Shelter * Depth interaction show significant differences between the numbers of fish recorded at Sheltered and Exposed sites at all depths with the exception of reefs at 5m where very low numbers of *Pseudolabrus biserialis* were recorded (Figure 6.4).

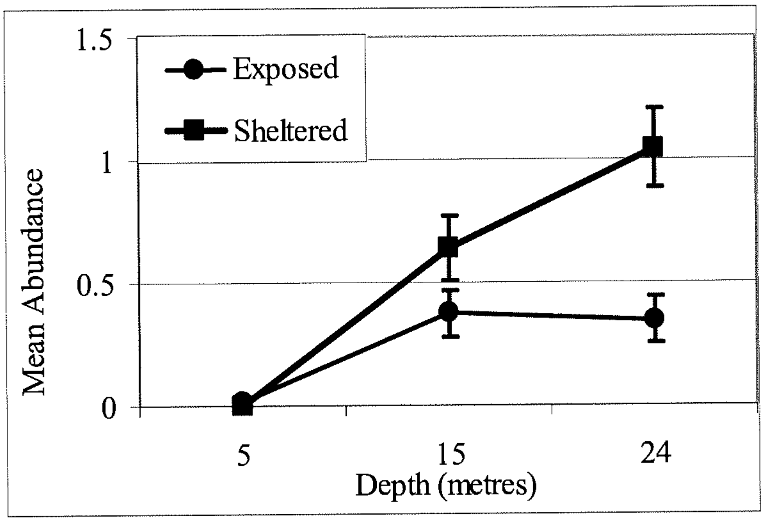


Figure 6.4: *Interactions between Depth and Exposure for* Pseudolabrus biserialis, ± *1 SE.*

Achoerodus gouldi

For *Achoerodus gouldi* the only significant main effect recorded was for Reefs nested within Distance. Interactions were recorded for Reefs nested within Distance * Shelter * Depth, Shelter * Depth and Reefs nested within Distance * Shelter (Table 6.9). Pair wise comparisons for the Reefs nested within Distance * Shelter * Depth interaction show there were no differences in the abundance of *Achoerodus gouldi* at Inshore reefs at any combinations of Shelter or Depth. At Offshore Sheltered reefs there were differences between reefs at 15m. This was caused by higher mean numbers of fish being recorded at Frederick Island than at Remark, with no fish being recorded at Long Island. At Remote sites there was no difference between reefs at a depth of 5m, but at 15m and 24m Figure of 8 had more fish at exposed reefs than other sites. At Sheltered sites the reef at site one on Mondrain Island had more fish than the other two reefs.

Table 6.9: *PERMANOVA of ln (x +1) transformed abundance for* Achoerodus gouldi *based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	2.082	4.559	0.065
Re(Di)	6	0.457	3.665	**0.002**
Sh	1	0.004	0.004	0.948
De	2	0.523	3.457	0.065

Di*Sh	2	0.266	0.233	0.815
Di*De	4	0.265	1.750	0.200
Re(Di)*Sh	6	1.142	9.167	**0.000**
Re(Di)*De	12	0.151	1.213	0.265
Sh*De	2	0.572	2.083	0.172
Di*Sh*De	4	0.169	0.617	0.665
Re(Di)*Sh*De	12	0.275	2.204	**0.010**
Residual	378	0.125		
Total	431			

Nemadactylus valenciennesi

For *Nemadactylus valenciennesi* the only significant main effect was depth. Interactions were recorded for Distance * Shelter, Shelter * Depth and Distance * Shelter * Depth (Table 6.10).

Pair wise comparisons showed differences in depth at Offshore Sheltered sites with *Nemadactylus valenciennesi* being less abundant at depths of 5m in comparisons to 15m and 24m depths (Figure 6.5). The same pattern occurred at Remote Exposed sites. At Offshore Exposed sites more fish were recorded at 15m than at 5 or 24m depths.

Table 6.10: *PERMANOVA of ln (x +1) transformed abundance for* Nemadactylus valenciennesi *based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	0.255	1.488	0.344
Re(Di)	6	0.171	1.509	0.178
Sh	1	0.689	5.037	0.055
De	2	1.589	12.097	**0.001**
Di*Sh	2	0.973	7.117	**0.016**
Di*De	4	0.218	1.657	0.221
Re(Di)*Sh	6	0.137	1.205	0.316

Re(Di)*De	12	0.131	1.158	0.306
Sh*De	2	0.711	16.092	**0.000**
Di*Sh*De	4	0.363	8.207	**0.002**
Re(Di)*Sh*De	12	0.044	0.390	0.970
Residual	378	0.113		
Total	431			

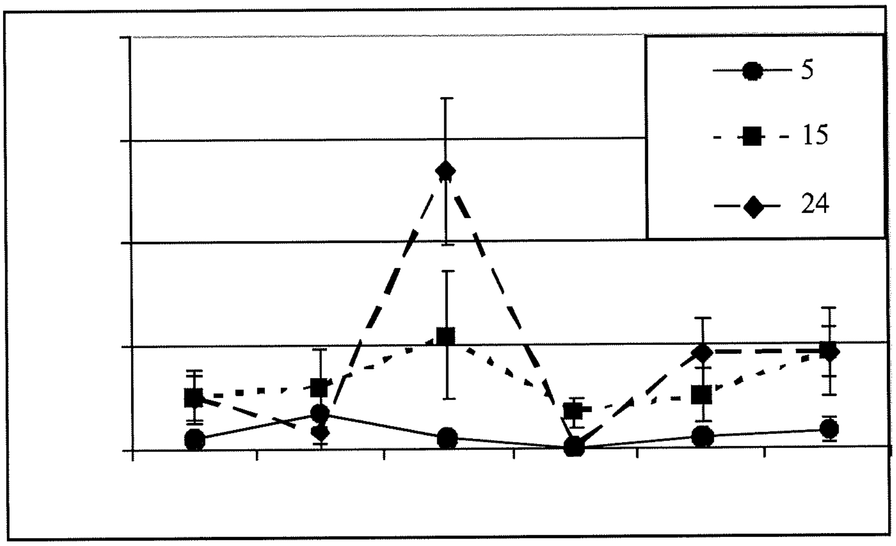


Figure 6.5: *Interactions between Depth, Distance and Exposure for* Nemadactylus valenciennesi, ± *1 SE. In = Inshore, Off = Offshore, Rem = Remote, Shel = Sheltered and Exp = Exposed sites.*

Scorpis aequipinnis

No main effects were recorded for *Scorpis aequipinnis*. A significant interaction occurred for Reefs nested within Distance * Shelter (Table 6.11). Pair wise comparisons of the Reefs nested within Distance * Shelter showed that significant differences existed between reefs at Remote Sheltered sites. The reef at site one of Mondrain Island had significantly higher numbers of *Scorpis aequipinnis* than either the second Mondrain Island site or the reef at Figure of 8 Island.

Girella zebra

For *Girella zebra* significant main effects were recorded for Distance and Depth. Significant interactions were recorded for Reefs nested within Distance * Shelter and Reefs nested within Distance * Shelter * Depth (Table 6.12). Pair wise comparisons for the Reefs nested within Distance * Shelter * Depth interaction revealed there were no significant differences between reefs at different Depth and Shelter combinations with the exception of Remote Exposed sites between reefs at 5m depth. At Figure of 8 Island there were many more fish recorded than at either of the reefs at Mondrain Island. Depth effects were the result of more fish being recorded at 5m than at 15m or 24m. Similarly, Distance effects were the result of more fish being recorded at Remote sites than at Offshore or Inshore sites.

Table 6.11: *PERMANOVA of ln (x +1) transformed abundance for* Scorpis aequipinnis *based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	0.258	0.619	0.555
Re(Di)	6	0.416	1.266	0.277
Sh	1	2.570	2.564	0.152
De	2	2.362	4.087	0.050
Di*Sh	2	0.471	0.470	0.668
Di*De	4	0.222	0.384	0.824
Re(Di)*Sh	6	1.002	3.052	**0.005**
Re(Di)*De	12	0.578	1.760	0.050
Sh*De	2	0.169	0.341	0.720
Di*Sh*De	4	0.322	0.651	0.643
Re(Di)*Sh*De	12	0.494	1.505	0.122
Residual	378	0.328		
Total	431			

Table 6.12: *PERMANOVA of ln (x +1) transformed abundance for* Girella zebra *based on the Euclidean distance dissimilarity measure. Distance (Di), Shelter (Sh) and Depth (De) are fixed factors while reef (Re) is a random factor nested in Distance.* P-*values were obtained using 4999 permutations of the given permutable units for each unit.*

Source	df	MS	F	P(perm)
Di	2	2.686	11.362	**0.014**
Re(Di)	6	0.236	1.924	0.074
Sh	1	1.032	1.146	0.367
De	2	1.373	7.665	**0.006**
Di*Sh	2	0.791	0.879	0.519
Di*De	4	0.285	1.591	0.234
Re(Di)*Sh	6	0.900	7.324	**0.000**
Re(Di)*De	12	0.179	1.457	0.135
Sh*De	2	0.130	0.578	0.611
Di*Sh*De	4	0.164	0.728	0.639
Re(Di)*Sh*De	12	0.225	1.832	**0.039**
Residual	378	0.123		
Total	431			

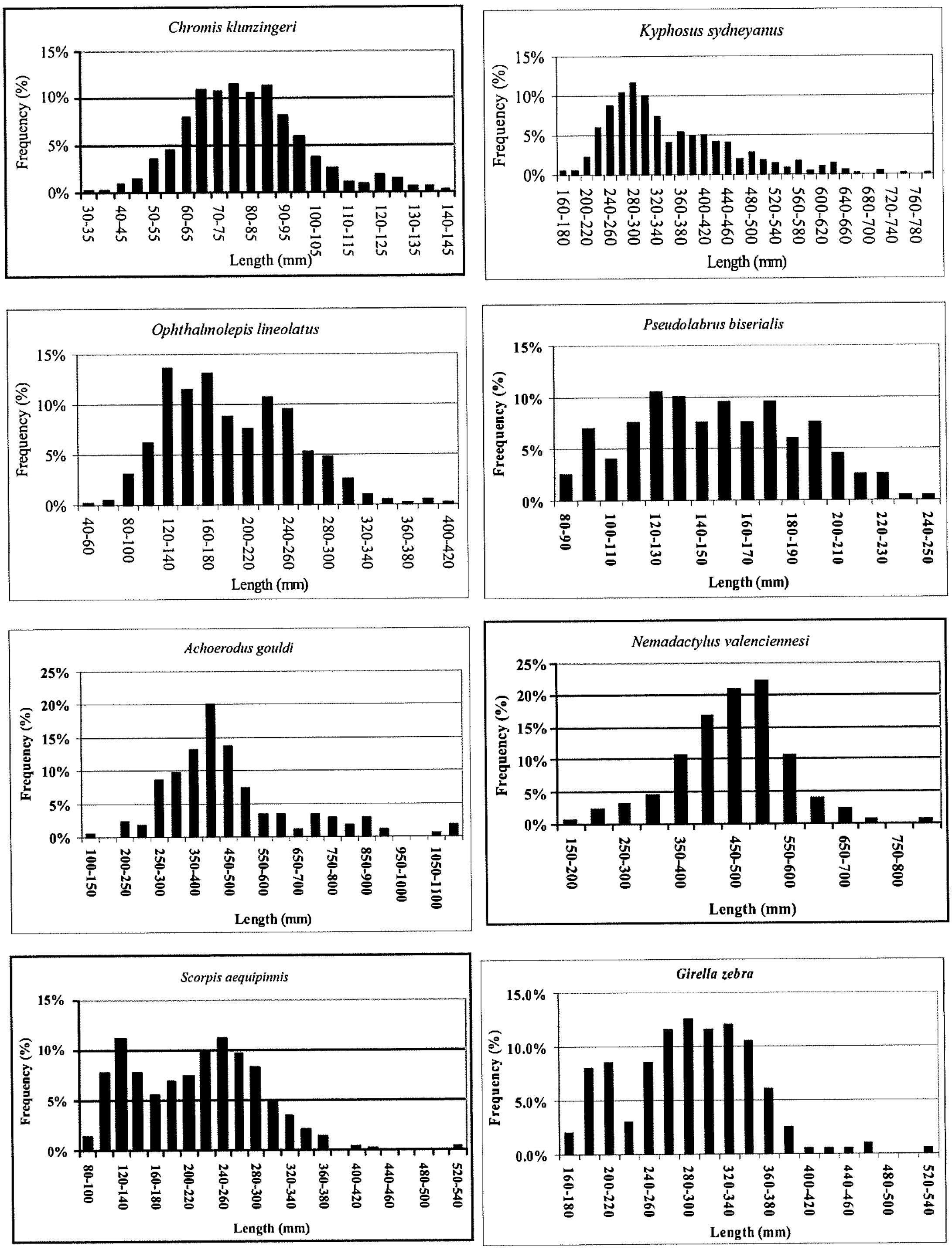


Figure 6.6: *Length frequency histograms for eight species from the Recherche Archipelago.*

6.4 DISCUSSION

The Recherche Archipelago lies within the Leeuwin ecological Province (Hutchins 1994). Previous research into reef fish assemblages in the region has been limited to semi-quantitative visual surveys of nearshore reef fish assemblages (Hutchins 1994, 2001). These studies identified 172 species (91% warm temperate, 7% subtropical) of fish with a distinct "offshore" versus "inshore" effect on diversity of tropical species, attributed to the Leeuwin Current. 28% of the shallow water reef fish identified were endemic to the Recherche Archipelago.

Our quantitative study identified 50 species, being focussed on the conspicuous, relatively large species of demersal fish. In this study we investigated whether Reef Isolation, Exposure and Depth influenced the assemblage structure and length frequency of reef fish assemblages within a *Ecklonia radiata*/fucoid dominated granite reef habitat. We limited the study to the same habitat as spatial variation in the complexity of reef habitats has been shown to affect the assemblage structure of reef fish populations (Curley *et al.* 2002, Harman *et al.* 2003).

Exposure

Wave exposure is suggested as one of the key physical factors influencing the distribution and abundance of individual species and the overall reef fish assemblage structure (Fulton and Bellwood, 2004). In this study, exposure was found to have slight but significant effect at the assemblage level and influenced four of eight species. More individuals were recorded on exposed reefs and more species on sheltered reefs. Fulton and Bellwood (2004) investigated the relationship between fin morphology and swimming performance on the distribution of temperate and tropical labrids in relation to wave exposure. They suggest that because of drag created by different fin and body shapes and different sizes, some species may not be able to swim strongly enough to maintain position on exposed reefs and will be at a distinct disadvantage in comparison to their faster swimming counterparts. Of the three species with significant main effects for wave exposure in the Recherche Archipelago *Chromis klunzingeri* is a poor swimmer. *Chromis klunzingeri* is three times more abundant at sheltered reefs than it is at exposed reefs. Conversely, *Scorpis aequipinnis* is a large strong fish and a powerful swimmer. It was two times more abundant on exposed reefs than on sheltered reefs. *Nemadactylus valenciennesi* is a large powerful species and a strong swimmer and therefore might be expected to be more prevalent on exposed reefs. This species consumes crustaceans, worms, mollusc and echinoderms and has large pectoral and ventral fins. It can often been seen using these for fine movements when hovering over sediments or crevices and therefore we would expect to find it more commonly occurring on sheltered reefs. It is approximately twice as common on sheltered reefs as it is on exposed reefs.

The last species, *Pseudolabrus biserialis* is a small labrid with pectoral fins which it uses to flap its way through the water, using its tail only when disturbed. Given the theory put forward by Fulton and Bellwood (2004) we would expect this fish to be more abundant on sheltered reefs. It is two times more abundant on sheltered reefs than on exposed reefs.

Depth

Previous studies have shown how the numbers and diversity of fish are affected by depth on both temperate and tropical reefs (Meekan and Choat, 1997, Freidlander and Parish 1998, Brook 2002, Shepherd and Brook, 2003, Lecchini *et al.* 2003, Anderson and Millar 2004). On temperate reefs in New Zealand, Anderson and Millar (2004) found that depth had a significant effect on the composition of a reef fish assemblage, species richness and the number of individuals with more species and individual fish found deeper. The multivariate analysis on the whole reef fish assemblage showed that there were significant differences in the reef fish assemblage structure between shallow (5m) and deeper (15 and 24m) reefs. Six of the eight key species had a significant depth effect. Two of the species were more abundant on shallower reefs (*Kyphosus sydneyanus* and *Girella zebra*) while the mean abundances of the remaining four species increased with depth (*Chromis klunzingeri*, *Ophthalmolepis lineolatus*, *Pseudolabrus biserialis*, *Nemadactylus valenciennesi*). The effect of depth is difficult to separate from habitat, particularly in vegetated habitats (as in Travers and Potter 2002) because increasing depth alters the spectral range of the available light, and consequently the nature of the vegetated habitat. *Kyphosus sydneyanus* and *Girella zebra* are both herbivores and their preference for the shallower depth zone will most likely be related to the availability of particular types of algae to graze on in this zone.

Differences between Inshore, Offshore and Remote reefs.

Hutchins (1994, 2001) recorded no obvious differences in the fish faunas between the mainland and the offshore islands. In this study it was apparent that there were significant differences in the reef fish assemblage structure between Inshore, Offshore and Remote reefs. However, the variation caused by combinations of depth and exposure was far greater. Reef Isolation affected the distribution of four of the eight trophic groups, and although there were significant differences for the mean numbers of species and individuals these were caused by a decrease in abundances at Offshore reefs, with Inshore and Remote reefs being similar. For four of eight species tested Exposure appeared to affect their spatial distributions. *Kyphosus sydneyanus* and *Girella zebra* were all more abundant at Remote reefs while *Chromis klunzingeri* was most abundant at Inshore reefs.

One of the main consistent patterns emerging from the data was the variability in the structure of the fish assemblage and the abundance of several key species between reefs at the same depth, exposure and distance combination.

6.5 CONCLUSION

Reef Isolation, Exposure and Depth all influence the spatial distribution and structure of reef fish assemblages. While each exerts an influence, it is their combined effects, and in particular of the effect of exposure and depth which appear to have the greatest overall influence. It is also apparent that these physical forces influence the distribution of different reef fishes in different ways and have the greatest influence at the species level.

6.6 ACKNOWLEDGEMENTS

The authors acknowledge grants and financial aid from the Fisheries Research and Development Corporation (FRDC 2001/060) and the Coastal and Estuary Waterway Management Cooperative Research Centre. The authors are grateful to David Abdo and Justin McDonald for comments and suggestions on this manuscript. Additionally, our thanks to David Gull and Nicole Harman who assisted with field work and the analysis of video tape recordings. Field logistics were greatly supported by Peter Hudson of Esperance Fishing and Diving.

6.7 REFERENCES

Ackerman, J.L. & D.R. Bellwood. 2000. Reef fish assemblages: a re-evaluation using enclosed rotenone stations. Marine Ecology-Progress Series 206: 227-237.

Anderson, M.J. 2005. PERMANOVA: a FORTRAN computer program for permutational multivariate analysis of variance. Department of Statistics, University of Aukland, New Zealand.

Anderson, M.J. & R.B. Millar. 2004. Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand. Journal of Experimental Marine Biology and Ecology 305: 191-221.

Anderson, M.J. & J. Robinson. 2001. Permutation tests for linear models. Australian and New Zealand Journal of Statistics 43 (1): 75-88.

Bellwood, D.R., Wainwright, P.C., Fulton, C.J. & A. Hoey. 2002. Assembly rules and functional groups at global biogeographical scales. Functional Ecology 16: 557-562.

Brook, F.J. 2002. Biogeography of near-shore reef fishes in northern New Zealand. Journal of the Royal Society of New Zealand 32: 243-274.

Callaway, R., Alsvag, J., de Boois, I., Cotter, J., Ford, A., Hinz, H., Jennings, S., Kroncke, I., Lancaster, J. & G. Piet. 2002. Diversity and community structure of epibenthic invertebrates and fish in the North Sea. ICES Journal of Marine Science 59: 1199-1214.

Clark, B.M. 1997. Variation in Surf-zone Fish Community Structure Across a Wave-exposure Gradient. Estuarine, Coastal and Shelf Science 44: 659-674.

Connell, S.D. 2002. Effects of a predator and prey on a foraging reef fish: implications for understanding density-dependent growth. Journal of Fish Biology 60: 1551-1561.

Curley, B.G., Kingsford, M.J. & B.M. Gillanders. 2002. Spatial and habitat-related patterns of temperate reef fish assemblages: implications for the design of Marine Protected Areas. Marine and Freshwater Research 53: 1197-1210.

Friedlander, A.M. & J.D. Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224: 1-30.

Fulton, C.J. & D.R. Bellwood. 2004. Wave exposure, swimming performance, and the structure of tropical and temperate reef fish assemblages. Marine Biology 144: 429-437.

Goldberg, N.A. & G.A. Kendrick. 2004. Effects of island groups, depth, and exposure to ocean waves on subtidal macroalgal assemblages in the Recherche Archipelago, Western Australia. Journal of Phycology 40: 631-641.

Harman, N., Harvey, E.S. & G.A. Kendrick. 2003. Differences in fish assemblages from different reef habitats at Hamelin Bay, south-western Australia. Marine and Freshwater Research 54: 177-184.

Harvey, E., Cappo, M., Shortis, M., Robson, S., Buchanan, J. & P. Speare. 2003. The accuracy and precision of underwater measurements of length and maximum body depth of southern bluefin tuna (*Thunnus maccoyii*) with a stereo-video camera system. Fisheries Research 63: 315-326.

Harvey, E., Fletcher, D. & M. Shortis. 2001a. A comparison of the precision and accuracy of estimates of reef-fish lengths determined visually by divers with estimates produced by a stereo-video system. Fishery Bulletin 99: 63-71.

Harvey, E., Fletcher, D. & M. Shortis. 2001b. Improving the statistical power of length estimates of reef fish: a comparison of estimates determined visually by divers with estimates produced by a stereo-video system. Fishery Bulletin 99: 72-80.

Harvey, E., Fletcher, D. & M. Shortis. 2002a. Estimation of reef fish length by divers and by stereo-video - A first comparison of the accuracy and precision in the field on living fish under operational conditions. Fisheries Research 57: 255-265.

Harvey, E. & M. Shortis. 1996. A system for stereo-video measurement of sub-tidal organisms. Marine Technology Society Journal 29: 10-22.

Harvey, E., Shortis, M., Stadler, M. & M. Cappo. 2002b. A comparison of the accuracy and precision of measurements from single and stereo-video systems. Marine Technology Society Journal 36: 38-49.

Harvey, E.S., Fletcher, D., Shortis, M.R. & G.A. Kendrick. 2004. A comparison of underwater visual distance estimates made by SCUBA divers and a stereo-video system: Implications for underwater visual census of reef fish abundance. Marine and Freshwater Research 55: 573-580.

Harvey, E.S. & M.R. Shortis. 1998. Calibration stability of an underwater stereo-video system: Implications for measurement accuracy and precision. Marine Technology Society Journal 32: 3-17.

Hindell, J.S., Jenkins, G.P. & M.J. Keough. 2000. Evaluating the impact of predation by fish on the assemblage structure of fishes associated with seagrass (Heterozostera tasmanica) (Martens ex Ascherson) den Hartog, and unvegetated sand habitats. Journal of Experimental Marine Biology and Ecology 255: 153-174.

Hutchins 1994. A survey of the nearshore fish fauna of Western Australia's west and southwest coasts - The Leeuwin province. Records of the Western Australian Museum. Supplement # 46
Hutchins, J.B. 2001. Biodiversity of shallow reef fish assemblages in Western Australia using a rapid censusing technique. Records of the Western Australian Museum, 20: 247-270.

Kendrick, G.A., Harvey, E., Hill, J., McDonald, J.I. & S. Grove. 2002. Characterising the fish habitats of the Recherche Archipelago: Review of exisiting information. Fisheries Research and Development Corporation 2001/060. http://www.marine.uwa.edu.au/recherche/Research/review/Review.pdf

Lecchini, D., Adjeroud, M., Pratchett, M.S., Cadoret, L. & R. Galzin. 2003. Spatial structure of coral reef fish communities in the Ryukyu Islands, southern Japan. Oceanologica Acta 26: 537-547.

Leis, J.M. & B.M. Carson-Ewart. 2002. In situ settlement behaviour of damselfish (Pomacentridae) larvae. Journal of Fish Biology 61: 325-346.

Letourneur, Y. 1996. Dynamics of fish communities on Reunion fringing reefs, Indian Ocean .1. Patterns of spatial distribution. Journal of Experimental Marine Biology and Ecology 195: 1-30.

Lorance, P., Souissi, S. & F. Uiblein. 2002. Point, alpha and beta diversity of carnivorous fish along a depth gradient. Aquatic Living Resources 15: 263-271.

Meekan, M.G. & J.H. Choat. 1997. Latitudinal variation in abundance of herbivorous fishes: A comparison of temperate and tropical reefs. Marine Biology 128: 373-383.

Shepherd, S.A. & J.B. Brook. 2003. Encounter 2002 Expedition to the Isles of St Francis, South Australia: Reef fishes. Transactions of the Royal Society of South Australia 127: 269-279.

Shortis, M. R. & Harvey, E. S. 1998. Design and calibration of an underwater stereo-video system for the monitoring of marine fauna populations. International Archives Photogrammetry and Remote Sensing. 32(5): 792-799.

Shortis, M. R., & S. Robson. 2001. VMS Reference and User Guide. http://www.geomsoft.com.au

Travers, M.J. & I.C. Potter. 2002. Factors influencing the characteristics of fish assemblages in a large subtropical marine embayment. Journal of Fish Biology 61: 764-784.

Wellenreuther, M. & S.D. Connell. 2002. Response of predators to prey abundance: separating the effects of prey density and patch size. Journal of Experimental Marine Biology and Ecology 273: 61-71.

7.0 General conclusions

7.1 Habitat and fish

When collecting habitat data for the purpose of managing and conserving fish assemblages, a number of key concepts come from this research:

- Plans that aim to manage and conserve fish biodiversity need to incorporate all habitat types across a range of depth and exposure gradients.
- Inshore and offshore fish assemblages in the same habitats and depths are also different and need to be managed accordingly.
- When habitat maps are to be used as a tool for managing fish assemblages, data collection and interpretation will need to use classification schemes that incorporate measures of substratum type, topographic complexity and the cover and density of epiflora and fauna.
    - In the case of seagrasses, habitat maps will need to differentiate between seagrass densities.
    - Depth and exposure will also need to be incorporated into any designs.

These recommendations are the result of not only distinct differences in the fish assemblages being detected between broad habitat categories, but also within epibenthic habitats containing different densities of plants and animals and canopy cover. Depth is a key factor structuring fish assemblages, however more research is required within the same habitats across a broader range of depths to determine what range of depths fish assemblages are affected over.

7.2 Habitat and biodiversity

The Recherche Archipelago is species rich for marine macroalgae, sessile invertebrates, infaunal invertebrates and reef fish. Significant patterns in abundance of individuals species and assemblage structure were observed with habitat (as defined in the mapping report), depth, exposure to ocean swells and geographical isolation of islands and reefs.

These statistically significant patterns directly relate to the functional habitat classification we have been using to map benthic habitats. Thus functional habitats appear to be good surrogates of overall biodiversity. Further investigations are continuing on modelling diversity from habitat distributions

8.0 List of Appendices.

8.1 Literature review appendices - Review of existing biological, oceanographic & geomorphological data from the Recherche Archipelago (as at April 2002).

8.2 Habitat maps

Mapping publications

- 8.2.1 Identifying Fish Habitats: the use of spatially explicit habitat modeling and prediction in marine research by Katrina Baxter and Dr Mark Shortis
- 8.2.2 Broad Scale Classification and Prediction of Marine Habitats: integrating GIS and rule based modeling by Katrina J. Baxter
- 8.2.3 Cost Effective Marine Habitat Mapping from Small Vessels using GIS, Sidescan Sonar and Video by Andrew Neil Bickers

8.3. Infauna - Soft substrate macrofaunal communities in the western archipelago by Simon Grove

8.4. Fish publications

- 8.4.1 The effect of bait on the discrimination of benthic marine fish assemblages sampled with underwater video stations by Euan Harvey, Mike Cappo, James Butler, Gary Kendrick.
- 8.4.2 The effect of white and red illumination on temperate water fish assemblages sampled at night with baited underwater video stations by Euan Harvey, James Butler.

8.5 Algal publications

- 8.5.1 Linking contemporary patterns to historical events: A comparison of macroalgal diversity within the Recherche Archipelago, Western Australia, and with the south coast of Australia by N.A. Goldberg, G.A. Kendrick
- 8.5.2 A catalogue of the marine macroalgae found in the western islands of the Recherche Archipelago (Western Australia, Australia), with notes on their

distribution in relation to island location, depth, and exposure to wave energy by N.A. Goldberg and G.A. Kendrick.

- Appendix 8.5.3 A catalogue of marine plants from the Recherche Archipelago by N.A. Goldberg and G.A. Kendrick.

8.6 Sponge and ascidian communities

- 8.6.1 Report on the sponge and Ascidian Communities by Justin I. McDonald & Jane Fromont
- 8.6.2 Solitary Ascidiacea from shallow waters of the Recherche Archipelago, Western Australia by Justin I. McDonald
- 8.6.3 The invasive pest species Ciona intestinalis (Linnaeus, 1767) reported in a harbour in southern Western Australia by Justin I. McDonald
- 8.6.4 Asteroidea from shallow waters of the Recherche Archipelago by Justin I. McDonald and Loisette Marsh

APPENDIX 8.1: Review of existing biological, oceanographic & geomorphological data from the Recherche Archipelago (as at April 2002).

Some general sources of information:

CALM. (1994). A representative marine reserve system for Western Australia. Report of the marine parks and reserves selection working group

CALM. (1998). South Coast terrestrial and marine reserve integration study. Project #713, National Reserve System Co-operative Program (Appendix II contains Part V Marine Reserves on the South Coast from CALM, 1994)

CSIRO Marine Data Centre, Hobart: www.marine.csiro.au/datacentre (for data request forms)

*Metadata sheets available via search on Marlin at: www.marine.csiro.au/marlin

*For Cruise reports contact: CSIRO Marine Library: library@hba.marine.csiro.au

Edgar, G.J. (1997). Australian Marine Life: the plants and animals of temperate waters. Reed Books, Hong Kong.

Fisheries WA. (2000). Aquaculture plan for the Recherche Archipelago. Fisheries Management Paper No. 140

Fisheries WA, Everall Consulting Biologist and Fish Unlimited. (1999). Draft aquaculture plan for the Recherche Archipelago, WA.

Fisheries WA & Everall Consulting Biologists. (1999a). Draft aquaculture plan for the Recherche Archipelago, WA: Benthic habitat survey of the Remark, Mart, Mondrain, Tory and York Island groups in the Recherche Archipelago.

Lee, S. & K.P. Bancroft. (2001). Review of the existing ecological information for the proposed Recherche Archipelago marine conservation reserve. Literature review. MRI/WSA, EUC/SIN, RAR-51/2001 (Marine Conservation Branch, CALM).

South Coast Management Group. (2001). Southern Shores 2001-2021: A strategy to guide coastal and marine planning and management in the South Coast Region of Western Australia.

Stoddart, J.A., Wajon, J.E., Simpson, C.J., & P.M. Royce. (1991). A preliminary assessment of the marine impacts of the wreck of the *Sanko Harvest* at Esperance, Western Australia.

Van Hazel, J.H. (2001). The climate and physical oceanography of the Recherche Archipelago and adjacent waters. Unpublished thesis.

Van Hazel, J.H., Pattiaratchi, C., & N. D'Adamo. (2001). Review of the climate and physical oceanography of the Recherche Archipelago and adjacent waters

Wells, F.E., Walker, D.I., Kirkman, H. & R. Lethbridge. (eds). The Marine Flora and Fauna of Albany, Western Australia, volumes 1 and 2.

CATEGORY

3. Sea floor

LAYER NAME

3.1. Bathymetry

SUBJECT

Bathymetry

PRIMARY SOURCE

AGSO 30 Arc second gridded bathymetry (Digital - ASCII)

Navy (Australian Hydrographic Office)

SECONDARY SOURCE

CALM, WALIS

Australian Hydrographic Service, Nautical Charts: (Digital Raster or hardcopy)

Aus119 Approaches to Esperance

Aus119 Esperance

Aus4726 Cape Leeuwin to Esperance

Aus4727 Esperance to Whitby Isles

CONTACT

Mark Bolger, mark.bolger@defence.gov.au, Australian Hydrographic Office

COMMENTS

have emailed Mark Bolger with a request for bathymetric data, waiting for reply

CATEGORY

3. Sea floor

LAYER NAME

3.2. bottom sediment distribution

SUBJECT

Bottom sediment distribution

PRIMARY SOURCE

Cann, J.H., & Clarke, J.D.A. (1993) The significance of *Marginopora vertebralis* (Foraminifera) in surficial sediments at Esperance, Western Australia, and in last interglacial sediments in northern Spencer Gulf, South Australia. Marine Geology, 111: 171-187.

Conolly, J.R. & Von Der Borch, C.C. (1967) Sedimentation and physiography of the sea floor south of Australia. Sedimentary Geology. 1: 181-220.

Cooney, P.M. (1974) Geology of the Recherche Archipelago based on a seismic survey WA-47P for Continental Oil Co. (unpublished report by WA Geol. Surv.)

James, N.P., Bone, Y., Collins, L.B. & Kyser, T.K. (2001) Surficial sediments of the Great Australian Bight: facies dynamics and oceanography on a vast cool-water carbonate shelf. Journal of Sedimentary Research 71:549-567

Li, Q., James, N.P., Bone, Y. & McGowran, B. (1999) Paleoceanographic significance of recent foraminiferal biofacies on the southern shelf of Western Australia: a preliminary study. Palaeogeography, Palaeoclimatology, Palaeoecology. 147: 101-120

SECONDARY SOURCE

AuSEABED, www.es.usyd.edu.au/geology/centres/osi/auseabed/au7_web2.html

Stagg, H.M.J. *et al.,* (1990) Basins of the Great Australian Bight Region: geology and Petroleum potential (Recherche sub-basin) BMR & SADME:

CONTACT

Lindsay Collins, Curtin University, School of Applied Geology, Head of Applied Geology head@lithos.curtin.edu.au

COMMENTS

Dept of Mineral and Petroleum Resources is sending three reports including above mentioned 1974 unpublished report

Cann, J.H., & Clarke, J.D.A. (1993) - Determined relative abundance of selected species of foraminifera in the sediments of samples taken within Esperance Bay. No quantitative data.

CATEGORY

4. Geomorphology

LAYER NAME

4.1. Geomorphology

SUBJECT

Geomorphology

PRIMARY SOURCE

Fairbridge, R.W., & Serventy, V.N. (1954) 1b. Physiography. *In,* The Archipelago of the Recherche: 9-28.

Hodgkin, E.P., & Clark, R. (1987) Estuaries and coastal lagoons of South Western Australia: Wellstead Estuary. Environmental Protection Authority, Estuarine Studies Series, 1.

Hodgkin, E.P., & Clark, R. (1989) Estuaries and coastal lagoons of South Western Australia: Estuaries of the shire of Esperance, Stokes Inlet, Oldfield Estuary and ten others. Environmental Protection Authority, Estuarine Studies Series, 5.

Myers, J.S. (1990). "Western Gneiss Terrane" *In* "Geology and Mineral Resources of Western Australia", Geological Survey, Western Australian Memoirs, **3**:13-32.

Sanderson, P.G., Eliot, I., Hegge, B., & Maxwell, S. (2000) Regional variation of coastal morphology in southwestern Australia: a synthesis. Geomorphology, 34: 73-88.

Von Der Borch, C.C. (1968) Southern Australian submarine canyons: their distribution and ages. Marine Geology, 6: 265-266.

Also geology:

Esperance Digital Geology 1:250 000. ArcInfo (hardcopy map can also be purchased) from NGIS Australia (ngis@ngis.com.au or ph: 9277 9600)

Hawkins, L.V., Hennion, J.F., Nafe, J.E., & Doyle, H.A. (1965) Marine seismic studies on the continental margin to the south of Australia. Deep-Sea Research, 12:479-495.

James, N.P., Boreen, T.D., Bone, Y., & Feary, D.A. (1994) Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. Sedimentary Geology, 90: 161-177.

Morgan, K.H., Horwitz, R.C., & Sanders, C.C. (1967) Structural layering of the rocks of the Archipelago of the Recherche. Report of the Dept. Mines. W.A.

Revill, K., Roach, I., & Stagg, H.M.J. (1987) Rig seismic research cruises 10 & 11, Southern margin of Australia. Bureau of Mineral Resources, Geol. & Geophysics.

Twidale, C.R. and Bourne, J.A. (1998) Origin and age of Bornhardts, southwest Western Australia. Australian Journal of Earth Sciences, 45:903-914

SECONDARY SOURCE

CALM (1994) A representative marine reserve system for Western Australia. Report of the marine parks and reserves selection working group

Fisheries WA & Everall Consulting Biologists (1999) Draft aquaculture plan for the Recherche Archipelago, WA: Benthic habitat survey of the Remark, Mart, Mondrain, Tory and York Island groups in the Recherche Archipelago.

Fisheries WA, Everall Consulting Biologist and Fish Unlimited (1999) Draft aquaculture plan for the Recherche Archipelago, WA.

Lee, S. & Bancroft, K.P. (2001) Review of the existing ecological information for the proposed Recherche Archipelago marine conservation reserve. Literature review. MRI/WSA, EUC/SIN, RAR-51/2001 (Marine Conservation Branch, CALM).

COMMENTS

Lee & Bancroft cite Myers (1990) but this is geology rather than geomorphology

Sanderson *et al.,* (2000) when discussing the coastline refers to Woods, P.J., Webb, M.J., & Elliot, I.G. (1985) Western Australia. In: Bird, E.C.F., Schwartz, M.L. (Eds.), The world's coastline. Van Nostrand-Reinhold, New York :929-947. (need copy)

CATEGORY

5. Oceanography

LAYER NAME

5.1. Currents

SUBJECT

Leeuwin current
summer counter current
island eddies
summer upwelling

PRIMARY SOURCE

Church, J.A., Cresswell, G.R., & Godfrey, J.S. (1989) The Leeuwin Current. Papers from the workshop on Poleward flowing undercurrents on Eastern boundaries.

Cresswell, G.R., & Vaudrey, D.J. (1978?) Satellite-tracked bouy data report 1: Western Australian releases 1975 & 1976.

Cresswell, G.R. (1991) The Leeuwin Current - observations and recent models. Journal of the Royal Society of Western Australia, 74: 1-14.

CSIRO (1962) Aust. Oceanogr. Cruise, Rep. No. 16

CSIRO (1988) Current-meter data from the Leeuwin Current interdisciplinary experiment. Rep. No. 198.

CSIRO Franklin voyage 94/07 data, CSIRO (but data is outside state territorial waters) - surface currents and depth profiles (see figure 4.7 of van Hazel 2001 for location of data stations near the Recherche)

Godfrey, J.S. & Vaudrey, D.J. & Hahn, S.D. (1986). Observations of the Shelf-edge current South of Australia, Winter 1982" J. Phys. Oceanog. 16: 668-679.

Herzfeld, M. (1997) The annual cycle of sea surface temperature in the Great Australian Bight. Prog. Oceanog, **39**: 1-27.

Legeckis, R., & Cresswell, G. (1981) Satellite observations of sea-surface temperature fronts off the coast of western and southern Australia. Deep-Sea Research, 28: 297-306.

Pattiaratchi (1998). "Assessment and modelling of oceanographic conditions at four potential sites for Tuna fattening in Esperance" Centre for Water Research (UWA). Current circulation patterns in Esperance Bay predicted from wave modelling, fig 4.13-24.

Pearce, A.F. (2001) Ocean Temperature variability off Esperance, Western Australia. Report prepared for CSIRO Fisheries WA. (unpublished report).

Smith, R.L., Huyer, A., Godfrey, J.S., & Church, J.A. (1991) The Leeuwin current off Western Australia, 1986-1987. Journal of Physical Oceanography, 21: 323-345.

- only has data for North West Cape (22°S) to the Albany region (35°S).
-

Van Hazel, J.H., Pattiaratchi, C., & D'Adamo, N. (2001) Review of the climate and physical oceanography of the Recherche Archipelago and adjacent waters.

- Section 4.3 modelling of currents from barotropic forcing

SECONDARY SOURCE

Crossland, C.J. & Wells, F.E. (1985) A selected bibliography of marine and estuarine studies (other than physical oceanography) in Western Australia. CSIRO Report 160.

Van Hazel, J.H., Pattiaratchi, C., & D'Adamo, N. (2001) Review of the climate and physical oceanography of the Recherche Archipelago and adjacent waters

- Section 5.4, figures 5.4, 5.4, 5.8, 5.9. Poor quality satellite imagery, refers to Pearce & Pattiaratchi (1999).

Van Hazel, J.H., Pattiaratchi, C., & D'Adamo, N. (2001) Review of the climate and physical oceanography of the Recherche Archipelago and adjacent waters.

- Section 4.1.3, figures 4.5, 4.6, appendices C and D, same as above. Section 4.1.4, speculation on island eddies. Section 4.2.1, figures 4.8-12, analysis of data from Franklin voyage 94/07. Section 4.4. prediction of summer upwelling patterns.

Pearce and Pattiaratchi (1997) "Applications of satellite remote sensing to the marine environment in WA", J. Royal Soc. WA 80: 1-14

Pearce and Pattiaratchi (1999) "The Capes Current: a summer counter current flowing past Cape Leeuwin and Cape Naturaliste", WA. Continental Shelf Research, 19, 401-420.

Other possible sources cited in Van Hazel thesis:
Pattiaratchi, C. & Buchan, S. (1991) Implications of long-term climate change for the Leeuwin current. J. Roy. Soc. WA 74.

Herzfeld, M & Tomczak, M (1997) Numerical modelling of sea surface temperature and circulation in the Great Australian Bight. Progress in Oceanography, 39:29-78

Cresswell, G.R. and Peterson, J.L. (1993) The Leeuwin current south of western Australia. Aust. J. of Marine and Freshwater Res. 44:285-303

Pearce, A.F. and Walker, D.I. (eds) The Leeuwin current. Royal Society of Western Australia, Journal, 74

Lee & Bancroft. refers to Fisheries WA (1999) and Pearce & Pattiaratchi (1997); also refers to modelling of currents done by Centre for Water Research (UWA) (reported in Fisheries WA, State of the Fisheries report 1998/1999).

Fisheries WA (1998) A proposal for the establishment of Southern Bluefin Tuna farming at three sites in Esperance Bay by the Pearling and Aquaculture Program. Refers to Pattiaratchi.
CONTACT. Charitha Pattiaratchi, Centre for Water Research, UWA) or
Alan Pearce (CSIRO Marine, Watermans)

CATEGORY

5. Oceanography

LAYER NAME

5.2. Water temperature

SUBJECT

Water temperature

PRIMARY SOURCE

A.F. Pearce (unpublished report) Ocean Temperature variability off Esperance, Western Australia. Report prepared for CSIRO Fisheries WA

Pearce's temperature data comes from 4 sources:

1. Reynold's SST's derived from satellite data.
   Reynolds, R.W. & Smith, T.M. (1994) Improved global sea surface temperature analyses using optimal interpolation, Journal of Climate 7: 929-948.
2. National Tidal Facility Seaframe station on wharf (water T, sea T, wind, sea-level) maintained by Flinders Uni (Flinders Institute for Atmospheric and Marine Sciences, contact: Paul Davill and Allan Suskin)
3. Fisheries WA temperature loggers on seabed near wharf (contact Stuart Blight and Rod Lenanton) - stopped operating 1995
4. satellite thermal images (from NOAA satellite 2 km resolution, afternoon); satellite images originally in 1 km resolution (contact Peter Saunders at DOLA)

CSIRO Marine Voyages (appendix V1)

LANDSAT satellite images may be higher resolution than NOAA, and go back to 1970's; but would have to pay for these.

IRI/LDEO Climate Data Library web site: ingrid.ldgo.columbia.edu/
monthly estimates of sst blended from ship, buoy and bias-corrected satellite data (Reynolds and Smith, 1994), 1 degree grid.

Esperance Coastal Data Station 1979-1981 (Temperature, salinity, nutrients): contact CSIRO Marine Data Centre, Hobart

Fisheries WA (2000) cites pers. comm. from L Hudson suggesting that local dive shop has records of water temperature.

SECONDARY SOURCE

van Hazel (2001) section 4.1.1 (summary from data at IRI/LDEO website) and Appendix B (satellite imagery showing sea-surface temperature - source not indicated), figure 4.1 graph showing temperature variation. Section 4.2.2, figures 4.13-19 on Franklin voyage CTD data.

van Hazel *et al.* (2001), section 5.1, figure 5.1, same as above.

CONTACT

Tony Reese at Data Centre CSIRO Marine
Charitha Pattiaratchi, Centre for Water Research, UWA)
Alan Pearce (CSIRO Marine, Watermans)

COMMENTS

Alan Pearce is happy to assist if you want more temperature data from satellite imagery, please talk to him. Alan Pearce also maintains a temperature logger on Woody Island (since ~April 2001)

CATEGORY

5. Oceanography

LAYER NAME

5.3. Water salinity

SUBJECT

Water salinity

PRIMARY SOURCE

IRI/LDEO Climate Data Library web site: ingrid.ldgo.columbia.edu/

CSIRO Marine Voyages (see summary at beginning of document)

Esperance Coastal Data Station 1979-1981 (Temperature, salinity, nutrients): contact CSIRO Marine Data Centre, Hobart

SECONDARY SOURCE

van Hazel (2001) summarises salinity (data from IRI/LDEO web site?) section 4.1 and figure 4.2. Section 4.2.2, figures 4.15-19 on Franklin voyage CTD data.

van Hazel *et al.* (2001) section 5.1 and figure5.2, as above.

CONTACT

Tony Reese at Data Centre CSIRO Marine
Charitha Pattiaratchi, Centre for Water Research, UWA)
Alan Pearce (CSIRO Marine, Watermans)

CATEGORY

5. Oceanography

LAYER NAME

5.4. Water quality

SUBJECT

chlorophyll

PRIMARY SOURCE

Satellite data used by van Hazel:

(1) SeaWiFS (Sea-viewing Wide Field of view Sensor)

(2) CZCS (Coastal Zone Colour Scanner)

Kinhill Engineers (1991). "Report on visit to the areas of the Sanko Harvest grounding, Esperance. February 1991

(Table 4 for chlorophyll levels)

IRI/LDEO Climate Data Library web site: ingrid.ldgo.columbia.edu/

CSIRO Marine Voyages (see summary at beginning of document)

SECONDARY SOURCE

van Hazel *et al.* (2001) section 5.2, figures 5.4 (SeaWiFS- satellite images) 5.5 (CZCS satellite images), 5.6, 5.7 (seasonal variation graphs)

van Hazel (2001) section 4.1.2, appendices C & D, and figures 4.3 & 4.4, as above, but with more interpretation of images

CONTACT

Tony Reese at Data Centre CSIRO Marine

Charitha Pattiaratchi, Centre for Water Research, UWA)

Alan Pearce (CSIRO Marine, Watermans)

CATEGORY

5. Oceanography

LAYER NAME

5.4. Water quality

SUBJECT

nutrients

PRIMARY SOURCE

Kinhill Engineers (1991). "Report on visit to the areas of the Sanko Harvest grounding, Esperance. February 1991

(Table 1-3 for nutrients)

CSIRO Marine Voyages (see summary at beginning of document)

Esperance Coastal Data Station 1979-1981 (Temperature, salinity, nutrients): contact CSIRO Marine Data Centre, Hobart

IRI/LDEO Climate Data Library web site: ingrid.ldgo.columbia.edu/

SECONDARY SOURCE

van Hazel *et al.* (2001) section 5.3

van Hazel (2001) section 4.2.3, figures 4.20-21, nitrate and phosphorous levels from Franklin voyage 94/07, but data is outside state territorial waters

CONTACT

Tony Reese at Data Centre CSIRO Marine

Charitha Pattiaratchi, Centre for Water Research, UWA)

Alan Pearce (CSIRO Marine, Watermans)

CATEGORY

5. Oceanography

LAYER NAME

5.6. Wave height, period and direction

SUBJECT

Wave height, period and direction

PRIMARY SOURCE

Russell, K.L. (1984). Analysis of PWD Esperance location 16 wave data December 1982-1983. RK Steedman & Assoc's Report 242.

Pattiaratchi (1998). "Assessment and modelling of oceanographic conditions at four potential sites for Tuna fattening in Esperance" Centre for Water Research (UWA). 1 year of wave height data from Magistrate rock, figures 4.1-6; predicted wave heights for tuna sites, figures 4.8-11. Data from Russell (1984).

SECONDARY SOURCE

Van Hazel, J.H., Pattiaratchi, C., & D'Adamo, N. (2001) Review of the climate and physical oceanography of the Recherche Archipelago and adjacent waters.

- Section 2.2.1, figures 2.9-12 (surface gravity waves), refers to Pattiaratchi (1998). Section 2.2.4, figures 2.14-15 (continental shelf waves and storm surge), refers to Provis & Radok.

van Hazel et al. (2001). Section 4.1 (gravity waves, as above), section 4.4 (continental shelf waves and storm surge, as above)

van Hazel has a lot of data on waves but it is not clear where all the data came from (possibly from Russell 1984?)

CONTACT

Charitha Pattiaratchi, Centre for Water Research, UWA)

COMMENTS

Ask Charitha Pattiaratchi about Provis & Radok (1979) reference

Pattiaratchi (1998) 1 year of wave height data from Magistrate rock, figures 4.1-6; predicted wave heights for tuna sites, figures 4.8-11. Data from Russell (1984).

CATEGORY

6. Biology Marine

LAYER NAME

6.1. Benthic flora

SUBJECT

Benthic flora

Benthic habitat mapping

PRIMARY SOURCE

Coastal Resource Atlas, WA Dept of Transport, Coastal Management branch, data as ArcInfo GIS. (ground-truthing indicates inaccurate at local scale), probably also available from CALM Fremantle.

CALM (1998). South coast terrestrial and marine reserve integration study. Final Report: MRIP/SC - 10/1997. Marine Conservation Branch, CALM, Fremantle. Appendix IV - Kirkman, H. (1997) Benthic habitat mapping (describes how data was collected and interpreted: i.e. Landsat TM satellite imagery for interpretation and ground truthing via bounce dives).

> *Also Excel spreadsheet is available from CALM of results of bounce dives.
>
> *Although some reports claim that drop-down TV was used near Mondrain Island (in the Recherche) on the Leeuwin voyage (as proposed in Colman, 1997), Colman has informed me that that their survey was restricted to the Fitzgerald Biosphere as reported in CALM (1998)

D.A. Lord & Associates (1999) Esperance Harbour Redevelopment: Marine Environmental Studies. Report prepared for Environmental risk Solutions, Report No. 99/106/1. December 1999. (Environmental Risk Solutions (2000) Esperance Port Upgrade Facilities - Public Environmental Review. Prepared for the Esperance Port Authority, January 2000) - bounce and drift dives

D.A. Lord & Associates (2001) Interim report on historical benthic habitat mapping in Esperance Bay. Prepared for Esperance Port Authority. Report No. 00/172/1. - historical mapping used aerial photo interpretation; results of towed underwater video will be reported in a subsequent report (report lists sources of aerial photographs, their coverage and their quality)

D.A. Lord & Associates (2001) Esperance Bay: Interim report on seagrass monitoring offshore of breakwater. Prepared for Esperance Port Authority. Report No. 00/172/2.

D.A. Lord & Associates (2001) Notification of maintenance dredging at Bandy Creek Harbour. prepared for Department of Transport (lists seagrass species observed during dive surveys in the vicinity of the Port of Esperance; and describes grain sizes for sediment to be dredged)

Fisheries WA & Everall Consulting Biologists (1999a) Draft Aquaculture Plan for the Recherche Archipelago, WA: Benthic habitat survey of the Remark, Mart, Mondrain, Tory and York Island groups in the Recherche Archipelago. (reports the taking of underwater video transects, the existence of Excel spreadsheets of field survey results and the conversion of data to ArcView GIS: Chris Dibden is trying to track this information down for us)

Murdoch University (1996) Southern Western Australian Seagrass Study. Final report to Australian Heritage Commission.

Wells (1997) site assessment for Fisheries WA (1988, see below)

SECONDARY SOURCE

Habitat mapping

Colman J.G.(1997) Biological verification of the major benthic habitats of the south coast (Mondrain Island - Albany): 10-21 February 1997, Field Program report: MRIP/SC - 2/97. Marine Conservation Branch, CALM, Fremantle.

CALM (1998). South coast terrestrial and marine reserve integration study. Final Report: MRIP/SC - 10/1997. Marine Conservation Branch, CALM, Fremantle. Sections 1.4 & 1.5.

Fisheries WA (1998) A proposal for the establishment of Southern Bluefin Tuna farming at three sites in Esperance Bay by the Pearling and Aquaculture Program. Refers to site assessment by Wells (1997) and ecological literature review by Bowman Bishaw Gorham (environmental
consultants)

Seagrass

Campey, M. L., Waycott, M. & Kendrick, G.A. (2000) Re-evaluating species boundaries among members of the *Posidonia ostenfeldii* species complex (Posidoniaceae) – morphological and genetic variation.

Kuo J. & Kirkman H. (1995). *Halophila decipiens* Ostenfeld in estuaries of south western Australia. Aquatic Botany, 51: 335-340.

Kirkman, H. & Kuo, J. (1990) Pattern and process in southern Western Australian seagrasses. Aquatic Botany, 37: 367-382.

Kuo J. & McComb A.J. (1989) Seagrass taxonomy, structure and development. In Biology of Seagrasses: A Treatise on the Biology of Seagrasses with Special Reference to the Australian region. Larkum, A.W.D., McComb, A.J. & Sheperd, S.A. (eds) pp6-73. Elsevier, Amsterdam.

Walker, D.I. (1991) The effect of sea temperature on seagrasses and algae on the Western Australian coastline. J. Roy. Soc. WA. 74: 71-77.

Waycott, M. (1998) Genetic variation, its assessment and implications to the conservation of seagrasses. Molecular Ecology, 7: 793-800.

Waycott, M. (2000) Genetic factors in the conservation of seagrasses. Pacific Conservation Biology, 5: 269-276.

Macroalgae

Womersley, H.B.S. (1984 & 1987) The Marine Benthic Flora of Southern Australia. Part I & II, Government Printer, Adelaide

Womersley, H.B.S. (1990). Biogeography of Australasian marine macroalgae. In: M.N. Clayton & R.J. King (eds), Biology of Marine Plants, pp367-381. Longman Cheshire, Melbourne.

Womersley, H.B.S. (1994) The marine benthic flora of southern australia. Part IIIA. Australian Biological Resources Study, Canberra.

Womersley (1984) indicates Prof A McComb at UWA is the expert in physiology of benthic flora, and Mr G. Smith at Murdoch Uni is a taxonomist

have done a search for DEP reports on web (as direct enquiries of DEP personnel revealed no knowledge of any reports), see list printed out of (1) DEP bulletins for Esperance Port Authority and (2) two Environmental Impact Assessments (from search of WALIS)

CONTACT

Chris Dibden at Fisheries WA, ph: 9482 7367, cdibden@fish.wa.gov.au
Kevin Bancroft at CALM Fremantle, ph: 9432 5102, kevinb@calm.wa.gov.au
Bruce Hegge DAL PH: 9389 9669 bhegge@dalord.com.au

COMMENTS

Vicki Gouteff, Librarian at WAMRL: is tracking down reports for us and will mail them
Bruce Hegge says that (1) Geraldton Port Authority is doing a survey on Introduced Marine Pests for Esperance Port soon and (2) aerial photography of Esperance is due soon.
Have requested data from AIMS Data Centre via e-mail but received no reply (contact Scott Bainbridge: s.bainbridge@aims.gov.au ph (07) 4753 4377

CATEGORY

6. Biology Marine

LAYER NAME

6.2. Infauna (sea-floor)

PRIMARY SOURCE

Di Jones (WA Museum) suggests looking for papers by Chris Erseus and Ray Gibson on worms and Pat Hutchings (Australian Museum, Sydney) on marine polychaetes (check Albany workshop papers)

CATEGORY

6. Biology Marine

LAYER NAME

6.4 Epifauna (top layers)

SUBJECT

decapod crustaceans

PRIMARY SOURCE

Morgan G.J. and Jones, D.S. (1991). Checklist of the marine decapod Crustacea of southern Western Australia. *In* F.E. Wells, D.I. Walker, H. Kirkman & R. Lethbridge (Eds). *Proceedings of the Third International Marine Biological Workshop: The Marine Flora and Fauna of Albany, Western Australia,* Volume **II**: 483-497. Western Australian Museum, Perth.

*Some of the species described are from the Recherche area. Paper also discusses the faunal relationships of the marine decapods of the SW and western coasts.

Gibson, R. & Jones, D.S. (1990). A new species of *Carcinonemertes* (Nemertea: Enopla: Carcinonemertidae) from the egg masses of *Naxia aurita* (Latreille) (Decapoda: Brachyura: Majidae) collected in the Albany region of Western Australia. *In* F.E. Wells, D.I. Walker, H. Kirkman & R. Lethbridge (Eds). *Proceedings of the Third International Marine Biological Workshop: The Marine Flora and Fauna of Albany, Western Australia,* 1988. Volume **1**: 333-437. Western Australian Museum, Perth.

*Species described also from the Recherche area.

SECONDARY SOURCE

Edgar, G.J. (1997) Australian Marine Life: the plants and animals of temperate waters. Reed Books, Hong Kong.

Fisheries Department (1986) Fisheries management paper No. 4 "The Esperance rock lobster working group" WA

Jones, D.S. & Morgan G.J. (1994). *A field guide to the crustaceans of Australian waters.* Reed/Western Australian Museum. 216 pp. (new edition due out in next few months).

Lee & Bancroft (2001), section 4.5.2; appendix 17 lists species likely to occur according to Morgan & Jones (1991), Edgar (1997); section 7.4 (rock lobster fishery)

Melville-Smith, R (in press) extract from State of the fisheries report: South Coast Rock Lobster Fishery Status Report (e-mailed)

Sheperd, S.A. & Thomas, I.M. (1982) Marine Invertebrates of southern Australia. Part I. Government Printer, Adelaide.

Sheperd, S.A. & Thomas, I.M. (1989) Marine Invertebrates of southern Australia. Part II. Government Printer, Adelaide.

CONTACT

Di Jones, WA Museum
Roy Melville-Smith, Fisheries WAMRL, Rock Lobster, rmsmith@fish.wa.gov.au PH: 9246 8406

CATEGORY

6. Biology Marine

LAYER NAME

6.4 Epifauna (top layers)

SUBJECT

Cirripedia (shallow water barnacles)

PRIMARY SOURCE

Jones, D.S. (1990d). The shallow-water barnacles of southern Western Australia. *In* F.E. Wells, D.I. Walker, H. Kirkman and R. Lethbridge (Eds). *Proceedings of the Third International Marine Biological Workshop: The Marine Flora and Fauna of Albany, Western Australia, 1988*. Volume **1**: 333-437. Western Australian Museum, Perth.

> *Some of the species described are from the Recherche area. Paper also discusses the faunal relationships of the barnacles of the SW and western coasts.

Jones, D.S., Anderson, J.T. & Anderson, D.T. (1990). A checklist of the Australian Cirripedia (Thoracica, Acrothoracica). *Technical Reports of the Australian Museum*, No.**3**: 1-38.

> *Some of the species described are from the Recherche area. Paper also discusses the faunal composition of the barnacles of the south coast in relation to other areas of Australia.

SECONDARY SOURCE

Lee & Bancroft (2001), section 4.5.2; appendix 16 lists species likely to occur according to Jones (1991), Edgar (1997)

CONTACT

Di Jones (WA Museum) PH 9427 2700

CATEGORY

6. Biology Marine

LAYER NAME

6.4 Epifauna (top layers)

SUBJECT

greenlip abalone (*Haliotis laevigata*)
Roe's abalone (*Haliotis roei*)
brownlip abalone (*Haliotis conicopora*)

PRIMARY SOURCE

Wells F.E. & Mulvay P. (1995) Good and bad fishing for *Haliotis laevigata*: a comparison of population parameters. Marine and Freshwater Research, 46: 591-598.

- Sampled abalone (*Haliotis laevigata),* from sites at Esperance & Cape Arid. Produced size frequency statistics but not density data. Describes the population biology and reproductive ecology of populations at Augusta Esperance and Hopetoun.

SECONDARY SOURCE

Lee & Bancroft (2001) section 4.5, 7.6.

CATEGORY

6. Biology Marine

LAYER NAME

6.4 Epifauna (top layers)

SUBJECT

molluscs

PRIMARY SOURCE

Alan Longbottom has a collection and database on molluscs from Esperance region

Harris, D.C., Joll, L.M., & Watson, R.A. (1999) The Western Australian scallop industry. Fisheries Research Report No. 114.

Macpherson J.H. (1954). The Archipelago of the Recherche, Part 7, Molluscs. Report of the Australian Geographical Society, 1: 55-63.

* No Quantitative data – description of dead shells collected from beaches in the Archipelago

Wells, F.E. (1980). The distribution of shallow-water marine prosobranch gastropod molluscs along the coastline of Western Australia. *Veliger* **22** (3): 232-247.

SECONDARY SOURCE

Lee & Bancroft (2001), section 4.5.3; appendix 18, 19, 20, 21, 22 lists species of molluscs likely to occur in region (i.e. chitons, prosobranchs, seas slugs, bivalves and cephalopods, respectively)

Wells, F.E. (1984). *A guide to the common molluscs of south-western Australian estuaries.* Western Australian Museum, Perth. 112 pp. (Photography by C.W. Bryce)

Wells, F.E. & Bryce, C.W. (2000). *Seaslugs of Western Australia.* Western Australian Museum, Perth. 208 pp.

Wells, F.E. & Bryce, C.W. (2000). *Seashells of Western Australia.* Revised edition. Western Australian Museum, Perth. 207 pp.

CONTACT

Alan LongBottom, Grasspatch, Esperance (Associate of the WA Museum) PH: 0427 757 030

Shirley Slack-Smith , WA Museum PH 9427 2700 (has a collection of molluscs but not in database, would be slow process to sort through collection)

CATEGORY

6. Biology Marine

LAYER NAME

6.4 Epifauna (top layers)

SUBJECT

echinoderms

PRIMARY SOURCE

Marsh L.M. (1991). Shallow water echinoderms of the Albany region, south-western Australia. In: The Marine Flora and Fauna of Albany, Western Australia, Volume II. Western Australian Museum: 439-482.

> *This is the only published information on species of echinoderms of the south coast.

SECONDARY SOURCE

Lee & Bancroft (2001), section 4.5.1; appendix 15 lists species likely to occur according to Marsh (1991)

DATA FORMAT

CONTACT

Loisette Marsh (WA Museum)

CATEGORY

6. Biology Marine

LAYER NAME

6.4 Epifauna (top layers)

SUBJECT

Cnidaria

PRIMARY SOURCE

James, N.P., Boreen, T.D., Bone, Y., & Feary, D.A. (1994) Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. Sedimentary Geology, 90: 161-177.

- single dredge between 180-250 m deep – identified four ahermatypic coral species including: *Scolymia australis, monomyces radiatus, Flabellum pavoninum* and a *Charyophillia sp.*

Veron, J.E.N. & Marsh, L.M. (1988). Hermatypic Corals of Western Australia. Records and annotated species list. *Records of the Western Australian Museum*, Supplement **29.**

*Column on coral species that occur in the Recherche and a paragraph discussing the faunal relationships of the south coast.

SECONDARY SOURCE

Lee & Bancroft (2001), section 4.5.4; appendix 23 lists species likely to occur according to Vernon & Marsh (1988), Edgar (1997)

CATEGORY

6. Biology Marine

LAYER NAME

6.4 Epifauna (top layers)

SUBJECT

other invertebrates

PRIMARY SOURCE

Britton *et al.* (1991) identified relationships between topography, substratum and surface temperature in determining the spatial distribution of intertidal fauna of the rocky shores of southwestern Australia.

Fromont, J.(1998). Revision of the marine sponge genus *Caulospongia* Saville Kent, 1871 (Demospongiae: Hadromerida). Part 1. Morphological and skeletal characters. *Records of the Western Australian Museum*, **19**: 65-89.

> *Some of the species are described from the South coast, and were collected in the Recherche area.

SECONDARY SOURCE

Lee & Bancroft (2001), section 4.5.5; appendix 24 lists invertebrates likely to occur in the region according to Edgar (1997)

Morgan, G.J. & Wells, F.E. (1991). Zoogeographic provinces of the Humboldt, Benguela and Leeuwin Current systems. *Journal of the Royal Society of Western Australia* 74: 59-69.

CONTACT

Jane Fromont WA Museum Ph: 9427 2745 (provided ist on publications by WAM for the Recherche area).

CATEGORY

6. Biology Marine

LAYER NAME

6.5. Fish

SUBJECT

Fish

PRIMARY SOURCE

Ayvazian, S.G. & Hyndes, G.A. (1995). Surf-zone fish assemblages in the south-western Australia: do adjacent nearshore habitats and the warm Leeuwin current influence the characteristics of the fish fauna? Marine Biology. 122: 527-536

*Lists fish caught by seine net at Esperance (see Appendix F1)

* Suzy Ayvazian has an Access DB with data but is unpublished yet

Dragon Search (for sightings of leafy and weedy seadragons)

Fisheries WA (1987) A development plan for the south coast inshore trawl fishery. Fisheries Management paper No. 13.

Fisheries WA & Everall Consulting Biologists (1999) Draft aquaculture plan for the Recherche Archipelago, WA: Draft user profile of the Recherche Archipelago and the adjacent coast.

Fisheries WA & Everall Consulting Biologists (1999) Draft aquaculture plan for the Recherche Archipelago, WA: Report on community consultations.

Gaughan, D.J. and Fletcher, W.J. (1997). Effects of the Leeuwin current on the distribution of carnivorous macro-zooplankton in the shelf waters off southern Western Australia. Estuarine, Coastal and Shelf Science 45: 89-97

Gaughan, D.J., Mitchell, R.W., & Blight, S.J. (2000) Impact of mortality, possibly due to herpesvirus, on pilchard *Sardinops sagax* stocks along the south coast of Western Australia in 1998-1999. Mar. Freshwater Research, 51: 601-612.

Gaughan, D.J., Baudains, G.A., Mitchell, R.W.D., & Leary, T.I. (2001) Pilchard (*Sardinops sagax*) nursey areas and recruitment process assessment between different regions in southern Western Australia. Fisheries Research Report No. 131.

Gaughan, D.J., White, K.V. and Fletcher, W.J. (2001). The links between functionally distinct adult assemblages of *Sardinops sagax*: larval advection across management boundaries. ICES Journal of Marine Science, 58: 597-606.

> *No quantitative data. Aging of sardine (*Sardinopsis sagax)* larvae using otolith techniques suggest that larvae from Western Australian populations can be passively transported close to the central coast of Southern Australia by the Leeuwin Current.
>
> Possible implications for management of fisheries. Westward migration of juveniles required to maintain functionally distinct adult assemblages (FDAAs) at Albany, Bremer Bay and Esperance.

Hancock, D.A. (1980) Fisheries management – Esperance. Fisheries Research Seminar.

Hutchins (1994). "A survey of the nearshore fish fauna of Western Australia's west and southwest coasts - The Leeuwin province". Records of the Western Australian Museum. Supplement # 46

Hutchins, J.B. (2001) Biodiversity of shallow reef fish assemblages in Western Australia using a rapid censusing technique. Records of the Western Australian Museum, 20: 247-270.

> *Same data set from Hutchins (1994) for the Recherche area. Surveyed sites expanded northwards to Kimberly and including offshore atolls. Analysis targeted 18 families. Identified Four assemblages: Southwest (Recherche to Pt Denniston and Kalbarri); northwest (Abrolhos and Shark Bay to Dampier); offshore atolls; and Kimberley.
>
> Non-quantitative data: Densities classed as rare, occasional, frequent or abundant)

Sites in the southwest region are inhabited by fauna with a relatively high proportion of endemic species. (28% for the Recherche).

*Hutchins, will be presenting more data on fishes around Recherche at 2003 Workshop in Esperance (this data not available until then)

Hyndes, G.A., & Potter, I.C. (1997) Age, growth and reproduction of *Sillago schomburgkii* in south-western Australia, nearshore waters and comparisons of life history styles of a suite of *Sillago* species. Experimental Biology of Fishes, 49: 435-447.

Hyndes, G.A., Platell, M.E., & Potter, I.C. (1998) Age composition, growth, reproductive biology, and recruitment of King George Whiting, *Sillaginodes punctata*, in coastal waters of southwestern Australia. Fishery Bulletin, 96: 258-270.

Hyndes, G.A., Platell, M.E., Potter, I.C., & Lenanton, C.J. (1999) Does the composition of the demersal fish assemblages in temperate coastal waters change with depth and undergo consistent seasonal changes? Marine Biology, 134: 335-352.

*No quantitative data for the Esperance area. Lower west coast of WA (Perth to Cape Naturaliste) 200km range. 9 sites in water depths 5-15m or 20-35m within 20km from shore.

Sampled with otter trawl net- Composition of fish fauna influenced by distance from shore as well as by water depth. Most sites underwent consistent, cyclic seasonal changes attributed to patterns of migration including: Movements of certain species from nursery grounds to deeper waters; Migrations into and off sandy areas of inner continental shelf; migrations to spawning areas; and movements to areas where detached macrophytes accumulate in winter.

Potter, I.C., & Hyndes, G.A. (1999) Characteristics of the ichthyofaunas of southwestern Australian estuaries, including comparisons with holarctic estuaries and estuaries elsewhere in temperate Australia: A review. Australian Journal of Ecology, 24: 395-421.

*Recreational fishing catch and effort data: Neil Sumner at WAMRL has applied for FRDC funding to do survey in 2002 (will start July if successful)

Walker, M.H., Blight, S.J., & Clarke, D.P. (1989) A description of the British united Trawlers/Southern Ocean Trawlers operation in the Great Australian Bight during the period 19.11.77 to 28.5.79. Fisheries Research Report No. 85.

Walker, M.H., & Clarke, D.P. (1989) The demersal trawl resources of the Great Australian Bight as indicated by the fishing operations of the stern trawlers Orthello, Orsino and Cassio in the period 19.11.77 to 28.5.79. Fisheries Research Report No. 86.

SECONDARY SOURCE

Lee & Bancroft (2001), section 4.4, section 6 (recreational fishing), section 7 (commercial fishing)

Hutchins B. & Swainston R. (1986). Sea fishes of southern Australia. Swainston Publishing, Perth.

Hutchins B. & Thompson M. (1983). The Marine and Estuarine Fishes of South-western Australia, a Field guide for divers and anglers. Western Australian Museum.

Gomon M.F., Glover, J.C.M. & Kuiter, R.H. (1994). The fishes of Australia's south coast. State Printer, Adelaide.

Last, P.R. & Stevens, J. (1994) The Sharks and Rays of Australia. CSIRO, Melbourne.

<u>for herring and salmon:</u>

Fisheries WA (1995) . "Draft report of the south coast estuarine fishery working group"

<u>for shark:</u>

Fisheries Department (1986). "Fisheries management paper No. 1: The report of the southern WA shark working group"

<u>for fishing: recreational and commercial:</u>

CALM (1994). "A representative marine reserve system for WA"

for recreational fishing:

Fisheries WA (1998/1999). State of the fisheries report 1998/1999

Fisheries WA (1999/2000). State of the fisheries report 1999/2000

CONTACT

Neil Sumner, WAMRL, Ph: 9246 8438

Barry Hutchins, WA Museum PH 9427 2700 (will only supply published data)

COMMENTS

Comment from Barry Hutchins re: Fishes

Re the Recherche, I have published a fish list for the area (Hutchins, 1994, Rec. West. Aust. Mus. Suppl. 46: 1-66).

The fish fauna is also referred to in another paper of mine in press (Rec. West. Aust. Mus.) which is due out shortly - Biodiversity of shallow reef fish assemblages in Western Australia using a rapid censusing technique.

Finally I am preparing an annotated checklist of the fishes of the Archipelago but I have not decided where or when it will be published.

CATEGORY

6. Biology Marine

LAYER NAME

6.6. Marine Pests

SUBJECT

Sabella spallanzanii (fanworm)

PRIMARY SOURCE

Esperance Port Authority

SECONDARY SOURCE

Lee and Bancroft (2001) cite G. Clapin pers. com.

CATEGORY

6. Biology Marine

LAYER NAME

6.7. Marine mammals

SUBJECT

Cetaceans

Pinnipeds:

NZ Fur Seal (Arctocephalus forsteri)

Australian Sea Lion (Neophoca cinerea)

PRIMARY SOURCE

See extensive references list from Oswald: Appendix III in CALM (1998)

SECONDARY SOURCE

CALM (1998). South coast terrestrial and marine reserve integration study. Final Report: MRIP/SC - 10/1997. Marine Conservation Branch, CALM, Fremantle. Last paragraph, section 1.4, pg 8. Figures 7 & 8 for distribution sites around Recherche. Also: Appendix III: Oswald, H. (1997) A review of Marine Mammals

APPENDICES I1 – I11 Invertebrates

APPENDIX I1: Shallow-water echinoderm species expected, according to distribution information, to occur within the study area (from Marsh, 1991).

Crinoidea Feather Stars

COMASTERIDAE

Cenolia trichoptera

Cenolia tasmaniae

Oxycomanthus muelleri

Comatulella brachiolata

APOROMETRIDAE

Aporometra occidentalis

PTILOMETRIDAE

Ptilometra macronema

ANTEDONIDAE

Antedon incommoda

Echinoidea (Sea urchins)

CIDARIDAE

Phyllacanthus irregularis

Goniocidaris tubaria

DIADEMATIDAE

Centrostephanus tenuispinus

TEMNOPLEURIDAE

Temnopleurus michaelseni

Amblypneustes pallidus

Holopneustes porosissimus

ECHINOMETRIDAE

Heliocidaris erythrogramma

FIBULARIIDAE

Fibularia oblonga

LAGANIDAE

Peronella lesueuri

SCHIZASTERIDAE

Echinocardium cordatum

Holothurioidea (Sea cucumbers)

CUCUMARIIDAE

Pentacta anceps

Ocnus calcareus

Neoamphicyclus lividus

Lipotrapeza vestiens

HOLOTHURIIDAE

Holothuria hartmeyeri

STICHOPODIDAE

Stichopus ludwigi

Stichopus mollis

APODIDAE

Leptosynapta dolabrifera

Asteroidea (Starfish)

LUIDIIDAE

Luidia australiae

ASTROPECTINIDAE

Astropecten preissi

Bollonaster pectinatus

GONIASTERIDAE

Tosia australis

Pentagonaster duebeni

OREASTERIDAE

Anthaster valvulatus

Nectria multispina

Nectria saoria

Nectria wilsoni

Nectria macrobrachia

ASTEROPSEIDAE

Petricia vernicina

OPHIDIASTERIDAE

Austrofromia polypora

ASTERINIDAE

Patiriella calcar

Patririella gunnii

Patririella brevispina

Paranepanthia grandis

Nepanthia troughtoni

ECHINASTERIDAE

Echinaster arcystatus

Echinaster glomeratus

Echinaster varicolor

Plectaster decanus

ASTERIIDAE

Allostichaster polyplax

Coscinasterias calamaria

Coscinasterias muricata

Uniophora dyscrita

Ophioroidea (Brittle stars)

OPHIOMYXIDAE

Ophiomyxa australis

GORGONOCEPHALIDAE

Conocladus australis

Astroboa ernae

EURYALIDAE

Euryale aspera

OPHIACANTHIDAE

Ophiacantha alternata

Ophiactis tricolor

Ophiactis resiliens

AMPHIURIDAE

Amphipholis squamata

Amphiura constricta

Amphiura multiremula

OPHIOTRICHIDAE

Ophiothrix caespitosa

Ophiothrix spongicola

Macrophiothrix michaelseni

OPHIOCOMIDAE

Clarkcoma canaliculata

Clarkcoma pulchra

OPHIONEREIDAE

Ophionereis schayeri

Ophionereis semoni

OPHIODERMATIDAE

Ophiarachnella ramsayi

Ophiopeza cylindrical

Ophiopsammus assimilis

Ophioconis opacum

APPENDIX I2: Shallow-water barnacle species that are expected, according to distribution information, to occur within the study area (after Edgar, 1997; & Jones, 1991).

SCALPELLIDAE

Smilium peronii

IBLIDAE

Ibla quadrivalvis

LEPADIDAE

Lepas anserifera

Lepas pectinata

Lepas australis

POECILASMATIDAE

Trilasmis kaempferi

TETRACLITIDAE

Epopella simplex

Tetraclitella purpurascens

ARCHAEOBALANIDAE

Eliminus modestus

Eliminus covertus

BALANIDAE

Balanus variegatus

Austromegabalanus nigrescens

APPENDIX I3: Marine decapod (crustacean) species that are expected, according to distribution information, to occur within the study area (after Edgar, 1997; & Morgan & Jones 1991).

PENAEIDAE (Prawns, shrimps)

Metapenaeopsis lindae

ALPHEIDAE (Pistol shrimps)

Alpheus edwardsii

Alpheus euphrosyne richardsoni

Alpheus novaezealandiae

Alpheus parasocialis

Alpheus strenuus cremnus

Alpheus villosus

Athanas granti

Synalpheus neomeris

Synalpheus streptodactylus

Synalpheus tumidomanus

PANDALIDAE (Pandalid shrimps)

Chlorotocella leptorhynchus

RHYNCHOCINETIDAE (Hinge-back shrimps)

Rhynchocinetes australis

HIPPOLYTIDAE (Hippolytid shrimps)

Hippolyte australiensis

PALAEMONIDAE (Palaemonid shrimps)

Macrobrachium intermedium

Palaemontes australis

NEPHROPIDAE

Metanephrops andamanicus

Metanephrops boschmai

AXIIDAE

Axius waroona

PALINURIDAE (Rock lobster)

Jasus edwardsii (Southern rock lobster)

SCYLLARIDAE (Shovel-nosed lobsters)

Ibacus alticrenatus (Wollongong bug)

Ibacus peronii (Balmain bug)

DIOGENIDAE (Diogenid hermit crabs)

Dardanus arrosor

Paguristes frontalis

Paguristes sulcatus

Paguristes tuberculatus

Cancellus typus

Trizopagurus strigimanus

UPOGEBIIDAE

Upogebia bowerbankii

Upogebia tractabilis

CALLIANASSIDAE (Ghost shrimps)

Callianassa aequimana

Callianassa ceramica

PAGURIDAE (Pagurid hermit crabs)

Pagurixus handrecki

Pagurus sinuatus

LOMISIDAE (Hairy stone crabs)

Lomis hirta

PORCELLANIDAE (Porcelain crabs)

Petrocheles australiensis

Pisidia dispar

Polyonyx transversus

Porcellana gravelei

GALATHEIDAE (Squat lobsters)

Galathea australiensis

Galathea magnifica

Phylladiorhynchus pusillus

HIPPIDAE

Hippa australis

DROMIIDAE (Sponge crabs)

Cryptodromia octodentata

Dromidia australis

Dromidiopsis excavata

Petalomera lamellata

Petalomera lateralis

LEUCOSIIDAE (Pebble crabs)

Ebalia tuberculosa

Ebalia intermedia

Ebalia dentifrons

Philyra laevis

Merocryptus lambriformis

Myra mammillaris

HYMENOSOMATIDAE

Amarinus laevis

Elamena abrolhensis

Halicarcinus ovatus

Halicarcinus rostratus

Trigonoplax longirostris

PINNOTHERIDAE (Pea crabs)

Pinnotheres hickmani

OCYPODIDAE (Stalk-eyed crabs)

Macrophtalmus punctulatus

GRAPSIDAE (Shore crabs)

Cyclograpsus audouinii

Leptograpsodes octodentatus

Leptograpsus variegatus (Swift-footed crab)

Plagusia chabrus (Red bait crab)

CORYSTIDAE

Gomeza bicornis

PORTUNIDAE (Swimming crabs)

Nectocarcinus integrifrons (Red swimmer crab)

Nectocarcinus tuberculosus (Red swimmer crab)

Ovalipes australiensis (Surf crab)

Portunus pelagicus (Blue manna crab)

Portunus sanguinolentus

Macropipus corrugatus

Megametope carinatus

Pseudocarcinus gigas (Giant crab)

XANTHIDAE (Stone crabs)

Actaea peronii occidentalis

MENIPPIDAE

Hypothalassia armata

Ozius truncatus

PILUMNIDAE (Hairy shore crabs)

Actumnus setifer

Pilumnus acer

Pilumnus etheridgei

Pilumnus tomentosus

Pilumnopeus serratifrons

GONEPLACIDAE (Goneplacid crabs)

Georgeoplax glabra

Litocheira bispinosa

MAJIDAE (Spider crabs)

Antilibinia lappacea

Achaeopsis ramusculus

Cyrtomaia maccullochi

Ephippias endeavouri

Huenia australis

Huenia halei

Leptomithrax gaimardii

Leptomithrax sternocostulatus

Naxia aurita

Naxia spinosa

Paramithrax barbicornis

Paratymolus latipes

Pippacirama tuberculosa

Platymaia wyvillethomsoni

Rochinia mosaica

Schizophrys rufescens

Platymaia wyvillethomsoni

Schizophrys rufescens

Rochinia mosaica

APPENDIX I4: Polyplacophora (chiton) species that are expected, according to distribution information, to occur within the study area (WA Museum, pers. comm.).

ISCHNOCHITONIDAE

- *Ischnochiton torri*
- *Ischnochiton contractus*
- *Ischnochiton lineolatus*
- *Ischnochiton verconis*
- *Stenochiton longicymba*
- *Ischnochiton cariosus*

LORICIDAE

- *Lorica paucipustulosa*

ACANTHOCHITONIDAE

- *Acanthochitona bednalli*
- *Acanthochitona sueurii*

CHITONIDAE Chitons

- *Clavariona hirtosa*
- *Chiton torrianus*
- *Onithochiton occidentalis*

CRYPTOPLACIDAE

- *Cyptoplax striata*

APPENDIX I5: Prosobranch species that are expected, according to distribution information, to occur within the study area (WA Museum, pers. comm.).

PATELLIDAE (Patellid Limpets)

- *Patella chapmani*
- *Patella laticostata*
- *Patella peronii*

ACMAEIDAE (Acmaeid Limpets)

- *Asteracmea axiaerata*
- *Asteracmea crebristriata*
- *Asteracmea roseoradiata*
- *Asteracmea stowae*
- *Asteracmea illibrata*
- *Collisella onychitis*
- *Collisella septiformis*
- *Naccula compressa*
- *Naccula punctata*
- *Notoacmea conoidea*
- *Notoacmea flammea*
- *Patelloida alticostata*
- *Patelloida insignis*
- *Patelloida mufria*
- *Patelloida nigrosulcata*
- *Patelloida profunda*

NERITIDAE (Nerites)

- *Nerita altramentosa*

PHENACOLEPADIDAE (Sugar Limpets)

- *Phenacolepas calva*

SCISSURELLIDAE (Little Slit Shells)

- *Incisura vincentiana*
- *Sinezona atkinsoni*
- *Sinezona beddomei*

HALIOTIDAE (Abalone)

- *Haliotis conicopora*
- *Haliotis cyclobates*
- *Haliotis elegans*
- *Haliotis laevigata*
- *Haliotis roei*
- *Haliotis scalaris*
- *Haliotis semiplicata*

FISSURELLIDAE

(Keyhole & Slit Limpets)

- *Diodora lincolnensis*
- *Amblychilepas javanicensis*
- *Amblychilepas nigrita*
- *Amblychilepas oblonga*
- *Cosmetalepas concatenatus*
- *Macroschisma bakiei*
- *Macroschisma producta*
- *Emarginula candida*
- *Emarginula dilecta*
- *Emarginula patula*
- *Emarginula subtilitexta*
- *Emarginula devota*
- *Hemitoma subemarginata*
- *Montfortula rugosa*

Scutus antipodes

Tugali cicatricosa

TURBINIDAE (Turban Shells)

Argalista corallina

Austroliotia australis

Austroliotia densilineata

Austroliotia pulcherrima

Munditia mayana

Munditia subquadrata

Phasianella australis

Phasianella solida

Phasianella variegata

Phasianella ventricosa

Tricolia gabiniana

Tricolia rosea

Tricolia tomlini

Turbo jourdani

Turbo torquatus

Turbo undulatus

Turbo gruneri

Turbo pulcher

Australium aureum

Australium squamiferum

Australium tentorium

CAMPANILIDAE (Lighthouse Shells)

Campanile symbolicum

BATILLARIIDAE

(Southern Mud Creepers)

Batillariella estuarina

Velacumantus australis

Zeacumantus diemenesis

CERITHIIDAE (Creepers)

Bittium granarium

Bittium icarus

DIALIDAE (Dialids)

Diala monile

DIASTOMATIDAE (Diastomas)

Diastoma melanioides

LITIOPIDAE (Litiopids)

Alba translucida

PLESIOTROCHIDAE

Plesiotrochus crinitus

Plesiotrochus monachus

TROCHIDAE (Top Shells)

Calliostoma comptum

Calliostoma hedleyi

Calliostoma legrandi

Calliostoma zietzi

Calliostoma armillatum

Calliostoma rubiginosum

Calliostoma spinulosum

Calliostoma incertum

Astele ciliare

Astele subcarinatum

Astele multigranum

Euchelus ampullus

Euchelus profundior

Granata imbricata

Herpetopoma annectans

Herpetopoma aspersa

Herpetopoma fenestrata

Herpetopoma pumilio

Herpetopoma scabriusculus

Botelloides bassianus

Spectamen marsus

Austrocochlea concamerata

Austrocochlea constricta

Austrocochlea crinita

Austrocochlea rudis

Cantharidella beachportensis

Cantharidus pulcherrimus

Fossarina legrandi

Nanuka flindersi

Notogibbula lehmanni

Notogibbula pulcherrimus

Jujubinus lepidus

Phasianotrochus apicinus

Phasianotrochus bellulus

Phasianotrochus eximius

Phasianotrochus irisodontes

Thalotia conica

Thalotia chlorostoma

Clanculus consobrinus

Clanculus denticulatus

Clanculus dunkeri

Clanculus euchelioides

Clanculus flagellatus

Clanculus leucomphalus

Clanculus limbatus

Clanculus maxillatus

Clanculus ochroleucus

Clanculus personatus

Clanculus philippi

Clanculus plebejus

Clanculus ringens

Clanculus undatus

Clanculus weedingi

Leiopyrga octona

Ethminolia vitiliginea

TURRITELLIDAE (Screw Shells)

Archimediella occidua

Colospira accisa

Colospira smithiana

Colospira bundilla

Colospira mediolevis

Colospira wollumbi

Gazameda iredalei

Gazameda tasmanica

LITTORINIDAE (Periwinkles)

Bembicium auratum

Bembicium vittatum

Laevilittorina johnstoni

HIPPONICIDAE (Horse hoof Limpets)

Antisabia foliacea

Hipponix australis

CALYPTRAEIDAE (Slipper Shells)

Cheilea occidua

Zeacrypta immersa

CAPULIDAE (Cap Limpets & Trichotropes)

Capulus violaceus

XENOPHORIDAE (Carrier Shells)

Xenophora flindersi

CYPRAEIDAE (Cowries)

Cypraea reevei

Cypraea fallax

Cypraea comptoni

Cypraea piperita

Cypraea pulicaria

Cypraea armeniaca

Cypraea friendii vercoi

Cypraea marginata

Cypraea rosselli

NATICIDAE (Sand & Moon Snails)

Natica sertata

Natica sagittata

Natica subcostata

Natica zonalis

Natica zonulata

Friginatica beddomei

Polinices conicus

Sinum zonale

Eunaticina albosutura

Eunaticina umbilicata

BURSIDAE (Frog Shells)

Bursa humilis

CASSIDAE (Helmet Shells)

Cassis fimbriata

Semicassis labiata

Semicassis paucirugis

Semicassis pyrum

Semicassis royanum

Semicassis adcocki

Semicassis semigranosum

Semicassis sinuosum

FICIDAE (Fig Shells)

Ficus eospila

Thalassocyon bonus

RANELLIDAE (Tritons & Trumpets)

Ranella australasia

Cabestana tabulata

Charonia lampas

Cymatium parthenopeum

Sassia subdistorta

TONNIDAE (Tun Shells)

Tonna variegata

CERITHIOPSIDAE (Cerithiopsids)

Ataxocerithium beasleyi

Ataxocerithium serotinum

Zaclys styliferus

Specula regina

Seila crocea

Euseila pileata

TRIPHORIDAE (Triphoras)

Isotriphora nivea

Eutriphora cana

Teretriphora spica

Latitriphora latilirata

Nototriphora vestita

Hedleytriphora elata

Hedleytriphora fasciata

Aclophoropsis festiva

Obesula mamillata

Monophorus angasi

Inella intercalaris

EPITONIIDAE (Wentletraps)

Epitonium helicornum

Epitonium jukesianum

Epitonium tacitum

Opalia granosa

Opalia australis

JANTHINIDAE (Violet Sea Snails)

Janthina exigua

Janthina janthina

Janthina pallida

MURICIDAE (Murex Shells & Relatives)

Maculotriton bicolor

Fusus bednalli

Pterynotus angasi

Coralliophila mira

Coralliophila wilsoni

Bedeva hanleyi

Bedeva paivae

Dermomurex angustus

Pterynotus triformis

Pterynotus undosus

Murexiella brazieri

Muricopsis diamanthina

Muricopsis planilirata

Lepsiella flindersi

Lepsiella reticulata

Lepsiella vinosa

Thais orbita

Prototyphis angasi

Tripterotyphis robustus

Typhis philippensis

TURBINELLIDAE (Vase & Pagoda Shells & Relatives)

Vasum flindersi

COLUMBELLIDAE (Dove Shells)

Anachis beachportensis

Anachis cominelliformis

Mitrella acuminata

Mitrella austrina

Mitrella semiconvexa

Pseudamycla dermestoidea

Pyrene bidentata

BUCCINIDAE (Buccinid Whelks)

Buccinulum bednalli

Cominella eburnea

Cominella lineolata

Cominella torri

Cominella tasmanica

Cominella lineolata

Kapala kengrahami

Fusinus australis

Fusinus tessellatus

Fusinus undulatus

Latirus pulleinei

Pleuroploca australasia

Cyllene sulcata

Nassarius ephamillus

Nassarius pauperatus

Nassarius burchardi

Nassarius pyrrhus

Fusus bednalli

Fusus reticulatus

VOLUTIDAE (Volutes)

Amoria exoptanda

Amoria grayi

Lyria mitraeformis

Cymbiola irvinae

Ericusa fulgetra

Ericusa papillosa

Livonia nodiplicata

Livonia roadnightae

Notopeplum translucidum

OLIVIDAE (Olives, Olivellas & Ancillids)

Alcospira edithae

Alcospira marginata

Alcospira oblonga

Amalda coccinata

Exiquaspira ornata

Gracilispira albanyensis

Gracilispira lineata

Gracilispira monolifera

Belloliva triticea

Oliva australis

HARPIDAE (Harp Shells)

Austroharpa loisae

MARGINELLIDAE

Alaginella borda

Dentimargo allporti

Dentimargo jaffa

Dentimargo kemblensis

Dentimargo lodderae

Dentimargo mayii

Gibberula diplostreptus

Gibberula subbulbosa

Mesoginella turbinata

Ovaginella tenisoni

Persicula albomaculata

Persicula deburghi

Volvarina occidua

MITRIDAE (Mitres)

Mitra carbonaria

Mitra glabra

Cancilla citharoidea

Cancilla strangei

VOLUTOMITRIDAE (Volutomitrids)

Peculator bacatus

Peculator porphyria

COSTELLARIIDAE (Costellate Mitres)

Austromitra analogica

Vexillum acromiale

Vexillum apicitinctum

Vexillum lincolnense

Vexillum corallinum

Vexillum marrowi

CANCELLARIIDAE (Nutmegs)

Cancellaria spirata

Cencellaria undulata

Inglisella fischeri

TURRIDAE (Turrids)

Crassispira harpularia

Daphnella botanica

CONIDAE (Cone Shells)

Conus anemone

Conus clarus

Conus gabelishi

Conus klemae

Conus rutilus

TERREBRIDAE (Pencil Shells)

Terebra albida

OVULIDAE (Egg & Spindle Cowries)

Phenacovolva philippinarum

TRIVIINAE (Bean Cowries)

Trivia merces

APPENDIX I6: Opisthobranch (sea-slug) species that are expected, according to distribution information, to occur within the study area (after Wells & Bryce, 1993).

CEPHALASPIDAE (Bubble Shells)

BULLIDAE

Bulla quoyii

AGLAJIDAE (Tailed Slugs)

Philinopsis troubridgensis

Anaspidea

AKERIDAE

Akera soluta

APLYSIIDAE (Sea hares)

Aplysia gigantea

Notaspidea (Side-gilled sea slugs)

TYLODINIDAE

Tylodina corticalis

UMBRACULIDAE

Umbraculum sinicum

PLUEROBRANCHIDAE

Pluerobranchus peroni

Berthellina citrina

Sarcoglossa (Sarcoglossans)

JULIIDAE (Bivalved gastropods)

Ascobulla fischeri

Volvatella ventricosa

OXYNOIDAE

Oxynoe viridis

ELYSIIDAE (Elysiids)

Elysia australis

Elysiella pusilla

Elysia filicauda

Pattyclaya brycei

Nudibranchia (Nudibranchs)

POLYCERIDAE (Polycerids)

Polycera hedgpethi

Thecacera pacifica

DORIDIDAE

Aphelodoris cf. lawsae

Sclerodoris spp.

Discodoris cf. crawfordi

Neodoris chrysoderma

Hoplodoris nodulosa

Doris cf. cameroni

Halgerda graphica

Rostanga calumus

CHROMODORIDIDAE

Hypselodoris infucata

Chromodoris epicuria

Chromodoris westraliensis

Chromodoris alternata

Mexichromis macropus

Ceratosoma amoena

Ceratosoma brevicaudatum

Cadlina nigrobranchiata

Glossodoris undaurum

Orodoris miamirana

Verconia verconis

DENDRODORIDIDAE

Dendrodoris aurea

Dendrodoris albopurpurea

Dendrodoris carneola

Dendrodoris nigra

Dendrodoris albobrunnea

Dendrodoris denisoni

AEOLIDIIDAE

Spurilla australis

Spurilla major

GLAUCIDAE

Austraeolis ornata

Phyllodesmium spp.

MADRELLIDAE

Madrella sanguinea

TRITONIIDAE (Tritoniids)

Marionia spp.

HANCOCKIIDAE

Hancockia burni

SCYLLAEIDAE

Scyllaea pelagica

TETHYIDAE

Melibe australis

APPENDIX I7: Bivalve species that are expected, according to distribution information, to occur within the study area (after WA Museum, pers. comm.; & Macpherson, 1954).

ARCIDAE (Arks)

- *Arca squamosa*

NUCULANIDAE (Beaked Nut shells)

- *Nuculana crassa*

GLYCYMERIDAE (Dog Cockles)

- *Glycymeris striatularis*
- *Glycymeris radians*

MALLEIDAE (Hammer Oysters)

- *Vulsella spongiarium*
- *Malleus meridianus*

PECTINIDAE (Scallops & Fan Shells)

- *Chlamys aktinos*
- *Pecten fumatus*
- *Chlamys asperrimus*

SPONDYLIDAE (Thorny Oysters)

- *Spondylus tenellus*

LIMIDAE (File Shells)

- *Lima lima*
- *Limatula strangei*
- *Austrolima nimbifera*

MYTILIDAE (Mussels)

- *Brachidontes ustulatus*
- *Brachidontes erosus*
- *Brachidontes rostratus*
- *Xenostrobus pulex*
- *Xenostrobus inconstans*
- *Mytilus edulis*
- *Modiolus cottoni*
- *Modiolus albicostus*
- *Amygdalum beddomei*
- *Musculus cummingianus*

PTERIIDAE (Pearl Oysters)

- *Electroma georgiana*

ANOMIIDAE (Jingle Shells, Windowpane Shells)

- *Anomia trigonopsis*

OSTREIDAE (Oysters)

- *Saccostrea cuccullata*
- *Ostrea angasi*

PINNIDAE (Pen Shells)

- *Pinna bicolor*

CARDITIDAE (Cardita Clams)

- *Cardita crassicosta*
- *Venericardia rosulenta*
- *Venericardia sowerbyi*

CRASSATELLIDAE (Crassatellas)

- *Eucrassatella donacina*

CHAMIDAE

- *Chama ruderalis*

LUCINIDAE

- *Anodontia perplexa*
- *Divalucina cumingi*

Codokia lacteola

ERYCINIDAE

Scintilla spp.

Lasaea australis

Ephippodonta lunata

Mylitta deshayesii

CARDIIDAE (Cockles)

Acrosterigma reeveanum

Fulvia tenuicostata

Cardium cygnorum

Cardium flavum

Cardium racketti

MESODESMATIDAE (Wedge Shells)

Paphies elongata

Paphies cuneata

Anapella cycladea

SOLENIDAE (Razor Shells)

Solen vaginoides

VENERIDAE (Venus shells)

Tawera lagopus

Eumarcia fumigata

Venerupis exotica

Venerupis galactites

Katelysia rhytiphora

Katelysia scalarina

Katelysia peronii

Bassina disjecta

CLEIDOTHAERIDAE

Cleidothaerus albidus

TELLINIDAE (Tellins)

Tellina deltoidalis

Tellina marginaritina

Tellina albinella

Pseudarcopagia piratica

DONACIDAE (Pipis)

Donax deltoides

PSAMMOBIIDAE (Sunset Shells)

Gari livida

Sanguinolaria biradiata

MACTRIDAE (Trough Shells)

Spisula trigonella

Mactra pura

Mactra rufescens

Lutraria rhynchaena

AMPHIDESMATIDAE

Amphidesma angustata

ALOIDIDAE

Aloidis iredalei

HIATELLIDAE

Hiatella australis

PHOLADIDAE (Angel wings)

Barnea australasiae

APPENDIX I8: Cephalopod species that are expected, according to distribution information, to occur within the study area (after Edgar, 1997; & WA Museum, pers. comm.).

LOLIGINIDAE (Squid)

Sepioteuthis australis

IDIOSEPIIDAE (Pygmy Squid)

Idiosepius notoides

SEPIOLIDAE (Dumpling Squids)

Sepioloidea lineolata

Euprymna tasmanica

SEPIIDAE (Cuttlefish)

Sepia apama

OCTOPODIDAE (Octopus)

Hapalochlaena maculosa

Octopus spp.

ARGONAUTIDAE (Argonauts)

Argonauta nodosa

APPENDIX I9: Cnidaria species that are expected, according to distribution information, to occur within the study area (after Edgar, 1997; & Veron & Marsh 1988).

HYDROIDA (Hydroids)

Gymnangium superbum

Stereotheca elongata

Halocordyle disticha

Solanderia fusca

Turritopsis nutricula

Velella velella

SIPHONOPHORA (Siphonophores)

Physalia physalis (Bluebottle)

ACTINIARIA (Anemones)

Actinia tenebrosa

Oulactis macmurrichi

Aulactinia veratra

Phylyctenactis

Actinothoe glandulosa

ZOANTHIDEA (Zoanthids)

Zoanthus praelongus

Epizoanthus sabulosus

SCLERACTINIA (Stony corals)

Plesiastrea versipora

Coscinaraea marshae

Coscinaraea mcneilli

Culicia tenella

Scolymia australis

Turbinaria mesenterina

Turbinaria reniforms

Turbinaria frondens

Symphyllia wilsoni

Favites spp.

CERIANTHARIA (Tube anemones)

Pachycerianthus spp. (Purple-tipped)

ANTIPATHARIA (Black corals)

Antipathes spp.

ALCYONACEA (Soft corals)

Carijoa spp.

Mopsella zimmeri

Mopsella klunzingeri

SEMAEOSTOMEAE (Jellyfish)

Cyanea capillata (Lion's mane jellyfish)

Pelagia noctiluca

Aurelia aurita

CUBOMEDUSAE (Box jellyfish)

Carybdea rastoni

APPENDIX I10: Other invertebrate species that are expected, according to distribution information, to occur within the study area (after Edgar, 1997).

PORIFERA

Leucosolenia spp.

Tethya ingallis

Chondrilla australiensis

Echinoclathria laminaefavosa

CTENOPHORA

Beroe cucumis

CHORDATA

Ascidiacea (Ascidians)

ASCIDIIDAE

Ascidia sydneiensis

Phallusia obesa

STYELIDAE

Cnemidocarpa radicosa

Polycarpa viridis

Botrylloides magnicoecum

Botrylloides leachi

Botrylloides perspicuum

PYURIDAE

Herdmania momus

Pyura australis

Pyura gibbosa

Pyura spinifera

Pyura stolonifera

CLAVELINIDAE

Clavelina ostrearum

Clavelina cylindrica

Clavelina pseudobaudinensis

Clavelina molluccensis

PYCNOCLAVELLIDAE

Pycnoclavella aurantia

Pycnoclavella diminuta

HOLOZOIDAE

Sigillina australis

Sycozoa cerebriformis

Sycozoa pulchra

Sycozoa pedunculata

POLYCITORIDAE

Polycitor giganteus

Cystodytes dellachiajei

POLYCLINIDAE

Aplidium clivosum

DIDEMNIDAE

Didemnum mosleyi

Didemnum spongioides

Thaliacea (Salps)

Pyrosoma atlanticum

Pegea confoederata

BRACHIOPODA

Magellania flavescens

PHORONIDA

Phoronis australis

BRYOZOA

Lichenopora echinata

Membranipora membranacea

Bugula dentata

Adeona grisea

Triphyllozoon moniliferum

APPENDIX I11: Planktonic foraminifera species identified along the southern shelf of Western Australia (from Li et al., 1999).

(NB. * denotes temperate species dominant within study region)

*Globigerina bulloides**

*Globigerina falconensis**

Globigerinella cf. *calida*

Globigerinella siphonifera

*Globigerinita glutinata**

*Globigerinooides rubber**

Globigerinooides trilous

Globigerinooides conglobatus

*Globorotalia inflata**

Globorotalia menardii

Globorotalia truncatulinoides

Globorotalia crassaformis

Globorotalia hirsute

*Globorotalia Scitula**

*Globoturboratalita rubescens**

*Neogloboquadrina dutertrei**

Neogloboquadrina pachyderma

*Orbulina universa**

Pulleniatina obliquiloculata

*Tenuitella sp.**

*Turborotalita quinqueloba**

APPENDICES F1-F4 Fish species

APPENDIX F1 – Ayyazian & Hyndes (1995) Surf-zone fish study

Ayvazian, S.G. & Hyndes, G.A. (1995) Surf-zone fish assemblages in south –western Australia: do adjacent nearshore habitats and the warm Leeuwin Current influence the characteristics of the fish fauna? *Marine Biology* 122: 527-536.

Surf-zone fish assemblages in South Western Australia.

Surveyed from 1991-1992. Sites from Geraldton to Recherche Archipelago

Sampled using seine net: max depth 1.5m, area 274m^2, triplicate samples.

Greater species numbers (20-66) found on west coast site than south coast sites (11 to 16 species). Identifies a smaller contribution of transient species on the south coast (absence of tropical species). Attributed to 2 factors: adjacent nearshore habitats (eg limestone reefs and seagrass beds) producing more sheltered and temporally stable surf zones, and more microhabitats; and the reduced influence of the Leeuwin Current on the south coast. South coast assemblages had decreased proportion of benthic invertevores, and increased proportion of zooplantivores. (reflecting increased exposure of surf zones)

<u>Recherche Archipelago</u>

Site located here grouped by multivariate analysis with site near Albany(?). Species found:

Spratelloides robustus

(high density >100/m2)

Aldrichetta forsteri (low density 1-9/m2)

Sillago bassensis

Lesuerina sp.

Mugil cephalus

Lepatherina presbyteroides

Platycephelus speculator

Cnidoglanis macrocephalus

Cristiceps australis

Ammotretis elongates

Haletta semifasciata

Arripis georgianus

Iso rhothophilus

Allanetta mugiloides

APPENDIX F2 – Hutchins (1994) Near-shore reef fish study

Hutchins, B. (1994) A Survey of the Nearshore Reef Fish Fauna of Western Australia's West and South Coasts. *Records of the Australian Museum* Supplement No. 46: 66pp.

Survey from 1976-1993 along west and south coasts of Western Australia. Used visual survey technique. Quantitative data not included in report. Examined distributions of tropical, sub tropical and warm temperate species. Found "offshore" versus "inshore" effect on diversity of tropical species, attributed to the Leeuwin Current.

Recherche Archipelago

172 species found: 91% warm temperate, 7% subtropical.

Survey sites: Sandy Hook, Long, Frederick, Gull, Rob, Mondrain Islands. Lucky Bay (mainland reefs). Israelite Bay reefs, Six Mile Island, Dempster Point, Point Malcom, No differences found between Lucky Bay (mainland) and offshore Islands. Israelite Bay lacked many of species of western area of Archipelago (reefs shallow <10m and lacking habitat diversity.

10 most abundant species:

Chromis klunzingeri

Trachinops noalungae

Pempheris klunzingeri

Austrolabrus maculates

Scorpis aequipinnis

Ophthalmolepis lnieolatus

Siphonognathus beddomei

Notolabrus parilus

Pseudolabrus biserialis

Parma victoriae

Subtropical species (relatively low numbers) maintained by recruitment from areas further west by Leeuwin Current.

APPENDIX F3: Elasmobranch species that are expected, according to distribution information, to occur within the study area (after Gommon *et al.*, 1994; Dr. Barry Hutchins, pers. comm.).

Common name - Scientific name

Port Jackson shark - Heterodontus portusjacksoni

Bronze whaler - Carcharhinus brachyurus

Pencil shark - Hypogaleus hygaensis

School shark - Galeorhinus galeus

Gummy shark - Mustelus antarcticus

Whiskery shark - Furgaleus macki

Smooth-headed hammerhead - Sphyrna zygaena

White pointer shark - Carcharodon carcharias

Grey nurse shark - Carcharias taurus

Black-spotted catshark - Aulohalaelurus labiosus

Draughtboard shark - Cephaloscyllium laticeps

Gulf wobbegong - Orectolobus ornatus

Cobbler carpet shark - Orectolobus tentaculatus

Varied catshark - Parascyllium variolatum

Striped stingaree - Trygonoptera ovalis

Spotted stingaree - Urolophus gigas

Smooth stingray - Dasyatis brevicaudata

Eagle ray - Myliobatis australis

APPENDIX F4: Osteicthyes (bony fish) species that are expected, according to distribution information, to occur within the study area (after Gommon *et al.*, 1994; Dr. Barry Hutchins, pers. comm.).

Common Name - Scientific name

Shortfinned worm eel - Muraenichthys australis
Longsnout boarfish -Pentaceropsis recurvirostris
Longfinned worm eel - Muraenichthys breviceps
Knifejaw - Oplegnathus woodwardi
Green moray - Gymnothorax prasinus
Western kelpfish - Chironemus georgianus
Umbrella conger - Gnathophis umbrellabia
Silver spot - Threpterius maculosus
Blue sprat - Spratelloides robustus
Western Australian seacarp - Aplodactylus westralis
Beaked salmon - Gonorynchus greyi
Western crested morwong - Cheilodactylus gibbosus
Cobbler - Cnidoglanis macrocephalus
Redlip morwong - Cheilodactylus rubrolabiatus
Pink-headed frogfish - Batrachomoeus rubricephalus
Dusky morwong - Dactylophora nigricans
Sponge anglerfish - Echinophryne reynoldsi
Jackass fish - Nemadactylus macropterus
Smooth anglerfish - Phyllophryne scortea
Queen snapper - Nemadactylus valenciennesi
Dwarf shore-eel - Alabes hoesei
Yelloweye mullet - Aldrichetta forsteri
Smoothsnout clingfish - Aspasmogaster liorhyncha
Flattail mullet - Liza argentea
Western clingfish - Aspasmogaster occidentalis
Sea mullet - Mugil cephalus
Tasmanian clingfish - Aspasmogaster tasmaniensis
Snook - Sphyraena novaehollandiae
Western cleaner clingfish - Cochleoceps bicolor
Blackhead puller - Chromis klunzingeri
Spadenose clingfish - Cochleoceps spatula
Golden scalyfin - Parma bicolor
Green clingfish - Cochleoceps viridis
McCullochs scalyfin - Parma mccullochi
Longsnout clingfish - Parvicrepis spp.
Blue groper - Achoerodus gouldii
Smallfin clingfish - Parvicrepis parvipinnis

Common name – Scientific name

Blackspotted wrasse - Austrolabrus maculatus
Finetooth beardie - Eeyorius hutchinsi
Foxfish - Bodianus frenchii
Largetooth beardie - Lotella rhacina
Western King wrasse - Coris auricularis
Bastard red cod - Pseudophycis breviuscula
Little rainbow wrasse - Dotalabrus alleni
Slender blindfish - Dermatopsis multiradiatus
Castlenau's wrasse - Dotalabrus aurantiacus
Southern pygmy blindfish - Ogilbia spp.
Snakeskin wrasse - Eupetrichthys angustipes
Silver fish - Lepthatherina presbyteroides

Brownfields wrasse - Halichoeres brownfieldi
Surf sardine - Iso rhothophilus
Orangespotted wrasse - Notolabrus parilus
Red snapper - Centroberyx gerrardi
Maori wrasse - Ophthalmolepis lineolata
Swallowtail - Centroberyx lineatus
Senator wrasse - Pictilabrus laticlavius
Little pineapplefish - Sorosichthys ananassa
False senator wrasse - Pictilabrus viridis
Roughy - Trachichthys australis
Redband wrasse - Pseudolabrus biserialis
Knight fish - Cleidopus gloriamaris
Blue rock whiting - Haletta semifasciata
Macleays crested pipefish - Histiogamphelus cristatus
Little rock whiting - Neoodax balteatus
Brushtail pipefish - Leptoichthys fistularius
Rainbow cale - Odax acroptilus
Smooth pipefish - Lissocampus caudalis
Herring cale - Odax cyanomelas
Javelin pipefish - Lissocampus runa
Tubemouth - Siphonognathus argyrophanes
Sawtooth pipefish - Maroubra perserrata
Pencil weed whiting - Siphonognathus beddomei
Leafy seadragon - Phycodurus eques
Sharpnose weed whiting - Siphonognathus caninus
Weedy seadragon - Phyllopteryx taeniolatus
Longray rock whiting - Siphonognathus radiatus
Spotted pipefish - Stigmatophora argus
Longtail weed whiting - Siphonognathus tanyourus
Port Phillip pipefish - Vanacampus margaritifer
Wavy grubfish - Parapercis haackei
Goblinfish - Glyptauchen panduratus
Tommyfish - Limnichthys fasciatus
Little scorpionfish - Maxillicosta scabriceps
Flathead sandfish - Lesueurina platycephala
Gurnard perch - Neosebastes pandus
Common stargazer - Kathetostoma laeve
Western red scorpion cod - Scorpaena sumptuosa
Jumping blenny - Lepidoblennius marmoratus
Minor gunard - Lepidotrigla spinosa
Notched threefin - Norfolkia incisa
Spiny gunard - Lepidotrigla papilio
Southern crested weedfish - Cristiceps australis
Latchet - Pterygotrigla polyommata
Kuiters weedfish - Heteroclinus spp.
Whitenose pigfish - Perryena leucometopon
Whitleys weedfish - Heteroclinus spp.
Warty prowfish - Aetapcus maculatus
Fewray weedfish - Heteroclinus spp.
Longhead flathead - Leviprora inops
Hutchins weedfish - Heteroclinus spp.
Yank flathead - Platycephalus speculator
Recherche weedfish - Heteroclinus spp.
Tassel-snouted flathead - Thysanophrys cirronasus
Adelaide weedfish - Heteroclinus adelaide
Western wirrah - Acanthistius serratus
Kelp weedfish - Heteroclinus eckloniae
Barber perch - Caesioperca rasor
Large-eye weedfish - Heteroclinus macrophthalmus
Breaksea cod - Epinephelides armatus
Earspot snakeblenny - Ophiclinops hutchinsi
Harlequin fish - Othos dentex
Variegated snakeblenny - Ophiclinops varius
Red seaperch - Hypoplectrodes cardinalis

Adelaide snakeblenny - Ophiclinus antarcticus

Black-banded seaperch - Hypoplectrodes nigroruber

Blackback snakeblenny - Ophiclinus gracilis

Bluedevil - Paraplesiops meleagris

Variable snakeblenny - Ophiclinus ningulus

Western bluedevil - Paraplesiops sinclairi

Whiteblotch snakeblenny - Ophiclinus pectoralis

Blue-lined hulafish - Trachinops brauni

Painted stinkfish - Eocallionymus papilio

Yellow-headed prettyfin - Trachinops noarlungae

Flathead goby - Callogobius depressus

West Australian jewfish - Glaucosoma hebraicum

Twospot goby - Eviota bimaculata

Sea trumpeter - Pelsartia humeralis

Longfin goby - Favonigobius lateralis

Woods siphon fish - Siphamia cephalotes

Bluespot goby - Pseudogobius olorum

Scarlet cardinalfish - Vincentia badia

Barracouta - Leionura atun

Smooth cardinalfish - Vincentia macrocauda

Dusky marine gudgeon - Thalasseleotris adela

Orange cardinalfish - Vincentia punctata

Frigate mackeral - Auxis thazard

Longfin pike - Dinolestes lewini

Skipjack tuna - Katsuwonus pelamis

King George whiting - Sillaginodes punctata

Blue mackerel - Scomber australasicus

Silver whiting - Sillago bassensis

Elongate flounder - Ammotretis elongatus

Tailor - Pomatomus saltatrix

Southern sole - Aseraggodes haackeanus

Skipjack trevally - Pseudocaranx dentex

Harrowed sole - Zebrias cancellatus

Sand trevally - Pseudocaranx wrighti

Spinytail leatherjacket - Acanthaluteres brownii

Samson fish - Seriola hippos

Bridled leatherjacket - Acanthaluteres spilomelanurus

Pomfret - Brama brama

Toothbrush leatherjacket - Acanthaluteres vittiger

Australian herring - Arripis georgiana

Southern pygmy leatherjacket - Brachaluteres jacksonianus

Western Australian salmon - Arripis truttacea

Black reef leatherjacket - Eubalichthys bucephalus

Silverbelly - Parequula melbournensis

Bluetail leatherjacket - Eubalichthys cyanoura

Red snapper - Chrysophrys auratus

Mosaic leatherjacket - Eubalichthys mosaicus

Mulloway - Argyrosomus hololepidotus

Yellowstriped leatherjacket - Meuschenia flavolineata

Red mullet - Upeneichthys vlamingii

Sixspine leatherjacket - Meuschenia freycineti

Woodwards pomfret - Schuettea woodwardi

Bluelined leatherjacket - Meuschenia galii

Slender bullseye - Parapriacanthus elongatus

Horseshoe leatherjacket - Meuschenia hippocrepis

Orangelined bullseye - Pempheris spp.

Stars-and-stripes leatherjacket - Meuschenia venusta

Rough bullseye - Pempheris klunzingeri

Chinaman leatherjacket - Nelusetta ayraudi

Common bullseye - Pempheris multiradiata

Rough leatherjacket - Scobinichthys granulatus

Buffalo bream - Kyphosus sydneyanus

White-barred boxfish - Anoplocapros lenticularis

Rock blackfish - Girella tephraeops

Shaws cowfish - Aracana aurita

Zebrafish - Girella zebra

Ornate cowfish - Aracana ornata

Footballer sweep - Neatypus obliquus

Rigid boxfish - Caprichthys gymnura

Sea sweep - Scorpis aequipinnis

Spiny boxfish - Capropygia unistriata

Banded sweep - Scorpis georgiana

Prickly pufferfish - Contusus brevicaudus

Moonlighter - Tilodon sexfasciatum

Ringed pufferfish - Omegophora armilla

Western butterflyfish - Chaetodon assarius

Small-spined porcupinefish - Allomycterus pilatus

Squareback butterflyfish - Chelmonops curiosus

Globefish - Diodon nicthemerus

Old wife Enoplosus armatus

Short sunfish - Mola ramsayi

Short boarfish - Parazanclistius hutchinsi

Oblong sunfish - Triurus laevis

APPENDIX AQ1 - Potential land-based aquaculture ventures

Areas identified by Fisheries WA as potentially suitable for land-based aquaculture and the relevant selection criteria:

Potential land-based sites:

- Bandy creek;
- Areas of industrial zoned land in Esperance;
- Rural land east of Esperance and east of Duke of Orleans Bay;
- Crown and freehold land at Wharton, Duke of Orleans Bay, perhaps in conjunction with infrastructure and backup facilities at Condingup.

Selection criteria:

- Water quality;
- Topography, soil type and surrounding land use;
- Legal issues;
- Access to site;
- Capital cost;
- Conservation sensitivity;
- Utilities, &
- Proximity to market.

APPENDIX AQ2 - Potential sea-based aquaculture ventures

Areas identified by Fisheries WA as potentially suitable for sea-based aquaculture and the relevant selection criteria.

Potential sea-cage sites:

- York Group
- Mart Group
- Remark Group
- Tory Island
- Mondrain Island

Mondrain, York and Tory Islands were considered unsuitable for large-scale sea cage aquaculture. Many sites throughout the Archipelago were considered suitable for the location of barrels and bottom cages for abalone growout.

Selection criteria:

- water depth;
- waves;
- currents and flushing;
- salinity;
- water temperatures;
- contamination;
- nutrient status of water;
- algal blooms;
- wind;
- sea floor topography;
- access;
- land-based infrastructure, and;
- visual impact.

APPENDIX AQ3 Candidate species for potential aquaculture activities

PRIMARY *

Common Name	Species Name	Culture method
Abalone	*Haliotis spp.*	Land-based; Sea cage
Marron	*Cherax tenuimanus*	Ponds; Land-based
Yabby	*Cherax albidus*	Land-based dams
Pink snapper	*Pagrus auratus*	Sea cage; Land-based tanks/ponds
Silver perch	*Bidyanus bidyanus*	Pond/land-based
Southern bluefin tuna	*Thunnus maccoyii*	Sea cage

SECONDARY **

Common Name	Species name	Culture method
Oysters	*Saccostrea spp.*	
Oysters	*Ostrea spp.*	Racks, long lines
Dhufish	*Glaucosoma hebraicum*	Tank/cage
Marine aquarium spp.		Various Tanks
Yellowtail kingfish	*Seriola spp.*	Sea cage; Land-based
Flounder	*Pseudorhombus spp.*	Sea cage; Land-based tanks/ponds
Trout (Rainbow)	*Onchorynchus mykiss*	
Trout (Brown)	*Salmo trutta*	Sea cage; Land-based ponds/tanks
Black bream	*Acanthopagrus butcheri*	Sea cage; Land-based tanks/ponds

* The primary species are those considered to have good prospects for aquaculture development.

** The secondary species are those considered to have aquaculture potential in the future, subject to the development of suitable culture technologies.

Candidate species for potential aquaculture activities were based on the consideration of the following criteria:

- market potential;
- known culturing techniques;
- level of technology required to culture new species;
- any existing (or planned) sources for fry or fingerlings from within the region;
- suitability with the culture systems predicted for the Recherche, and;
- suitability of the species to the area.

APPENDIX A1: Species of algae identified by Dr John Huisman (Murdoch University) and Dr Gary Kendrick (University of Western Australia)(source Capes survey, 1999)

Acanthophora dendroides	*Acrocarpa robusta*
Acrocarpa sp	*Adelophyton sp*
Amphiroa gracilis	*Amphiroa anceps*
Apjohnia laetevirens	*Antithamnion hanowioides*
Aserococcus bullosus	*Areschougia sp*
Callophycus harveyanus	*Botryocladia sonderi*
Callophycus sp	*Callophycus oppositifolius*
Carpopeltis elata	*Callophyllus sp*
Carpopeltis spongeaplexus	*Carpopeltis sp*
Caulerpa flexilis	*Caulerpa brownii*
Caulerpa hedleyi	*Caulerpa germinata*
Caulerpa obscura	*Caulerpa longifolia*
Ceramium sp	*Caulerpa simpliciuscula*
Champia sp	*Champia compressa*
Claviclonium ovatum	*Cladisiphon sp*
Codium sp	*Caulocystis uvifera*
Ceoloclonium sp	*Codium spongiosum*
Craspedocarpus sp	*Colpomenia sp*
Curdiea obesa	*Crustose corallines*
Cutleria sp nov	*Cutleria multifida*
Cystoseira grevillei	*Cystoseira trinodis*
Cystophora monilifera	*Cystophora harveyi*
Cystophora pectinata	*Cystophora moniliformis*
Cystophora retorta	*Cystophora racemosa*
Cystophora sp2	*Cystophora sp1*
Dasyphylla priessi	*Dasyclonium incisum*
Dictyopteris australis	*Dasya sp*

Dictyopteris plageogramma	*Dictyopteris muelleri*
Dictyota naevosa	*Delisea pulchra*
Dilophus fastigiatus	*Dictyota sp*
Dictyosphaeria sericea	*Dilophus sp*
Dictymenia tridens	*Dictymenia sonderi*
Echinothamnion mallardiae	*Echinothamnion hystrix*
Ecklonia radiata	*Ecklonia radiata with multiple holdfasts*
Erythroclonium sonderi	*Epiphloea bullosa*
Euptilocladia spongeosa	*Erythroclonium minuta*
Galaxaura marginata	*Euptilocladia articulata*
Glossophora nigricans	*Gloiosaccion brownii*
Griffithsia sp	*Gracilaria preissiana*
Halimeda cuneata	*Griffithsia teges*
Haloplegma preissii	*Halopteris sp*
Haraldiophyllum erosum	*Haloplegma sp2*
Heterosiphonia crassipes	*Hennedya crispa*
Hemineura frondosa	*Heterosiphonia muelleri*
Hyroclathrus clathratus	*Haliptilon roseum*
Hypnea ramentacea	*Hypoglossum sp*
Jania pulchella	*Hypnea sp*
Kuetzingia canaliculata	*Jania sp*
Laurencia cruciata	*Laurencia brongniartii*
Laurencia filiformis	*Laurencia elata*
Laurencia sp2	*Laurencia sp1*
Lobophora variegata	*Lobospira bicuspidata*
Metamastophora flabellata	*Melobesia sp*
Metagoniolithon stelliferum	*Metagoniolithon radiatum*
Myriodesma serelata	*Myriodesma quercifolia*
Pachydictyon sp	*Myriodesma sp*
Peyssonnelia novae-hollandiae	*Padina sp*
Peyssonnelia sp	*Peyssonnelia rubra*

Platyhalia angustifolia	*Phaecelocarpus sp*
Plocamium cartilagineum	*Platyhalia quercifolia*
Plocamium preissianum	*Plocamium mertensii*
Psilothalia sp	*Polysiphonia sp*
Pterocladia lucida	*Pterocladia capillacea*
Pterocladia sp	*Pterocladia rectangularis*
Rhodymenia sonderi	*Rhipiliopsis robusta*
Sargassum sub-genus sargassum	*Rhodopeltis australis*
Sargassum sub-genus arthrophycus	*Sarconema filiforme*
Sargassum linearifolium	*Sargassum fallax*
Sargassum podocanthum	*Sargassum pinnate species*
Sargassum spinuligerum	*Sargassum sp*
Sargassum varians	*Sargassum tristichum*
Scinaia sp	*Scaberia agardhii*
Sporochnus sp	*Scytothalia dorycarpa*
Tylotus obtusatus	*Spyridia dasyoides*
Zonaria sp	*Thuretia quersifolia*
	Vidalia spiralis
	Zonaria turneriana

APPENDIX SG1: Seagrass species found within the Recherche Archipelago region (after Campey *et al.,* (2000); D.A. Lord & UWA (2001); Kirkman (1997); Walker, (1991); Waycott, (1998 & 2000)).

Amphibolis antarctica
Amphibolis griffithii
Halophila decipiens
Halophila ovalis
Halophila ovata
Heterozostera tasmanica
Posidonia angustifolia
Posidonia australis
Posidonia coriacea
Posidonia denhartogii
Posidonia kirkmani
Posidonia ostenfeldii
Posidonia sinuosa
Syringodium isoetifolium
Thalassodendron pachyrhizum

APPENDIX V1: CSIRO biological, hydrological and core sample data from the Recherche Archipelago region on a series of voyages from 1951 to 1981.

DATA SOURCE	DATA TYPE	DATA FORMAT	CRUISE NAME	YEAR	MORE INFO	COMMENT LOCATION
National Geophysical Data Centre	core		Eltanin ELT35	1968 - 1972	see files: ngdc*	south of Recherche
National Geophysical Data Centre	core		Robert Conrad RC08	1964	see files: ngdc*	south of Recherche
National Geophysical Data Centre	core		Vema VM16 - VM33	1960 - 1976	see files: ngdc*	south of Recherche
National Geophysical Data Centre	core		Horizon LSDH	1962	see files: ngdc*	south of Recherche
National Geophysical Data Centre	core		Argo MSN	1961	see files: ngdc*	south of Recherche
National Geophysical Data Centre	core		Discovery	1951	see files: ngdc*	south of Recherche
CSIRO Marine, Data Centre	biological	not digitised	Diamantina DM1/60	1960	see printouts from MARlin	exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Diamantina DM1/60	1960	see printouts from MARlin	exact location uncertain
CSIRO Marine, Data Centre	biological	not digital	Diamantina DM1/61	1961		exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Diamantina DM1/61	1961		exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Diamantina DM7/69	1969		exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Diamantina DM2/71	1971		exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Diamantina DM3/71	1971		exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Diamantina DM2/72	1972		exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Diamantina DM4/73	1973		exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Diamantina DM1/75	1975		exact location uncertain
CSIRO Marine, Data Centre	hydrology	ascii text	Courageous 031	1978	see printouts from MARlin	Great Australian Bight
CSIRO Marine, Data Centre	hydrology	ascii text	Courageous 032	1978		Great Australian Bight
CSIRO Marine, Data Centre	hydrology	ascii text	Courageous 033	1978		Great Australian Bight
CSIRO Marine, Data Centre	biological	oracle db	Courageous 046	1979		Great Australian Bight
CSIRO Marine, Data Centre	hydrology	ascii text	Courageous 046	1979		Great Australian Bight

CSIRO Marine, Data Centre	biological	oracle db	Courageous 047	1979		Great Australian Bight
CSIRO Marine, Data Centre	hydrology	ascii text	Courageous 047	1979		Great Australian Bight
CSIRO Marine, Data Centre	biological	not digitised	Courageous 048	1979		exact location uncertain
CSIRO Marine, Data Centre	biological	not digitised	Soela SO1/80	1980	see printouts from MARlin and cruise summary	marginal to Recherche
CSIRO Marine, Data Centre	hydrology	ascii text	Soela SO1/80	1980		marginal to Recherche
CSIRO Marine, Data Centre	biological		Soela SO3/80	1980		outside Recherche area
CSIRO Marine, Data Centre	hydrology		Soela SO3/80	1980		outside Recherche area
CSIRO Marine, Data Centre	hydrology		Soela SO6/80	1980		outside Recherche area
CSIRO Marine, Data Centre	biological	not digitised	Soela SO6/80	1980	see printouts from MARlin and cruise summary	includes Cape Le Grand
CSIRO Marine, Data Centre	biological	not digitised	Soela SO3/81	1981	see printouts from MARlin and cruise summary	includes Salisbury and Cooper Islands
CSIRO Marine, Data Centre	biological		Soela SO5/81	1981		Great Australian Bight
For Cruise reports contact: CSIRO Marine Library: library@hba.marine.csiro.au						
World Data Centre for Marine Geology and Geophysics: www.ngdc.noaa.gov/mgg/curator/curator.html						

Appendix 8.2 Habitat maps

ESSENTIAL INFORMATION

LEGEND TO MAPS

Habitats have been broadly classified into 5 major types although considerable biological variation and 'functional' detail is observed within these.

Functional descriptions of habitat have been nested within the broad types, in areas where more detailed data was available to classify with.

5 Broad Habitat types

- 🟦 High profile reef
- 🟦 Low profile reef
- 🟥 Rhodoliths
- 🟨 Bare sand
- 🟩 Seagrass

Functional Habitat Types

- 🟦 High profile reef
  - ▨ High profile reef with filterfeeders
  - ▥ High profile reef with filterfeeders and macroalgae
  - ▨ High profile reef with macroalgae
- 🟦 Low profile reef
  - ▨ Low profile reef with filterfeeders
  - ▥ Low profile reef with filterfeeders and macroalgae
  - ▨ Low profile reef with macroalgae
  - ▥ Sand inundated low profile reef
  - ▨ Sand inundated low profile reef with filterfeeders
  - ▥ Sand inundated low profile reef with filterfeeders and macroalgae
  - ▨ Sand inundated low profile reef with macroalgae
  - ▤ Sand inundated low profile reef with macroalgae and seagrass
- 🟩 Mainland / Island
- 🟥 Rhodoliths
  - ▨ Rhodoliths with filterfeeders
  - ▨ Rhodoliths with macroalgae
  - ▨ Sand inundated rhodoliths
  - ▥ Sand inundated rhodoliths with filterfeeders and macroalgae
  - ▨ Sand inundated rhodoliths with macroalgae
- 🟨 Bare sand
  - ▨ Bare sand rippled
  - ▨ Bare sand with some macroalgae
  - ▥ Megaripples
  - ▥ Megaripples with filterfeeders
  - ▨ Sand with filterfeeders
  - ▨ Sand with vegetation
  - ▨ Sand with vegetation and filterfeeders
- 🟩 Seagrass
  - 🟩 Sparse seagrass
  - 🟩 Medium seagrass
  - 🟩 Dense seagrass

Habitat mapping in the Recherche Archipelago

Habitat maps of the seafloor have been compiled in this report using a range of information sources, including: sidescan sonar images, satellite imagery, video footage and depth data.

Habitat boundaries were defined using either:

(i) actual data or
(ii) expert interpolation of boundaries between known habitat types

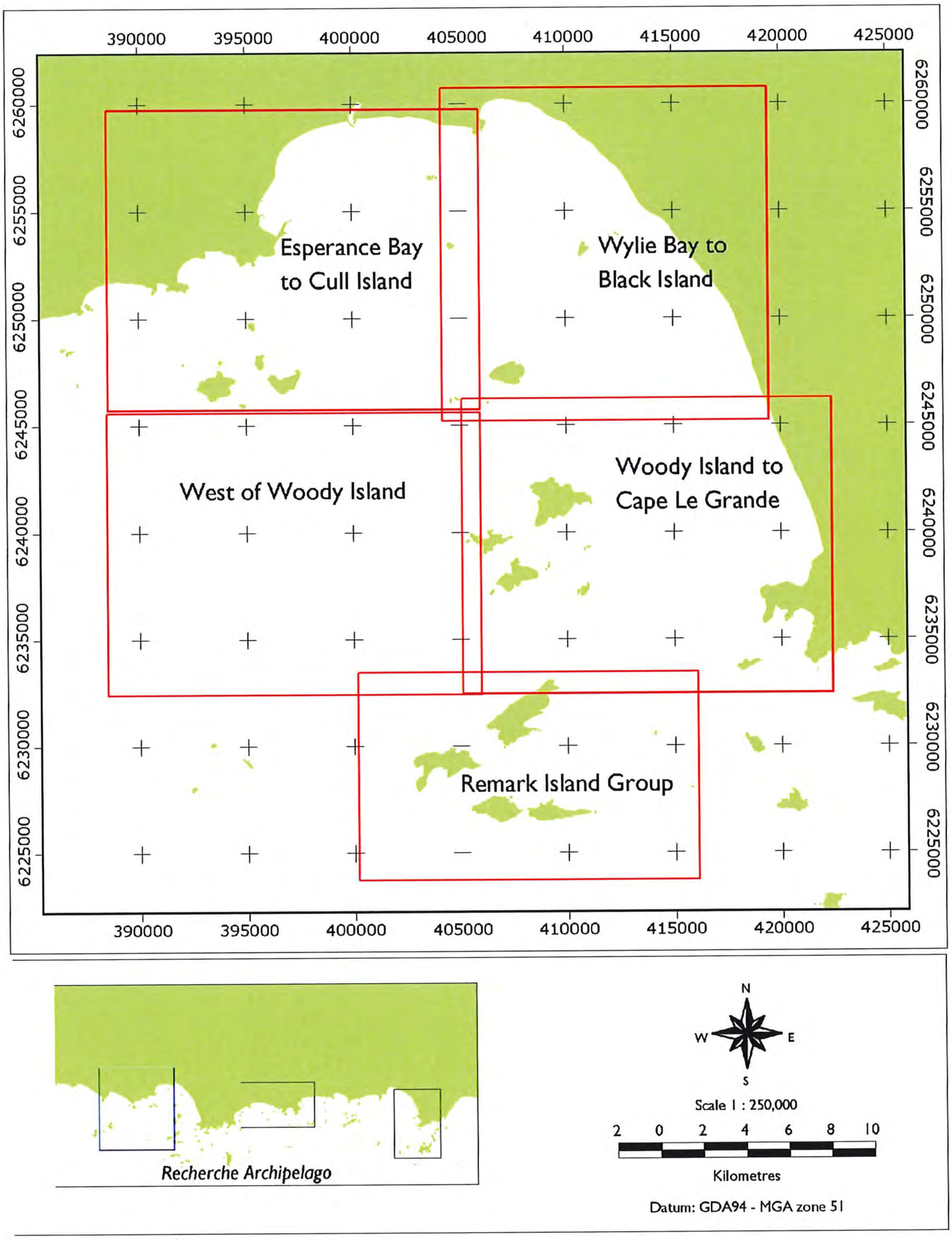
Please note:
UWA have attempted to ensure the interpretations in this report are accurate given the available data and knowledge at the time of report completion.

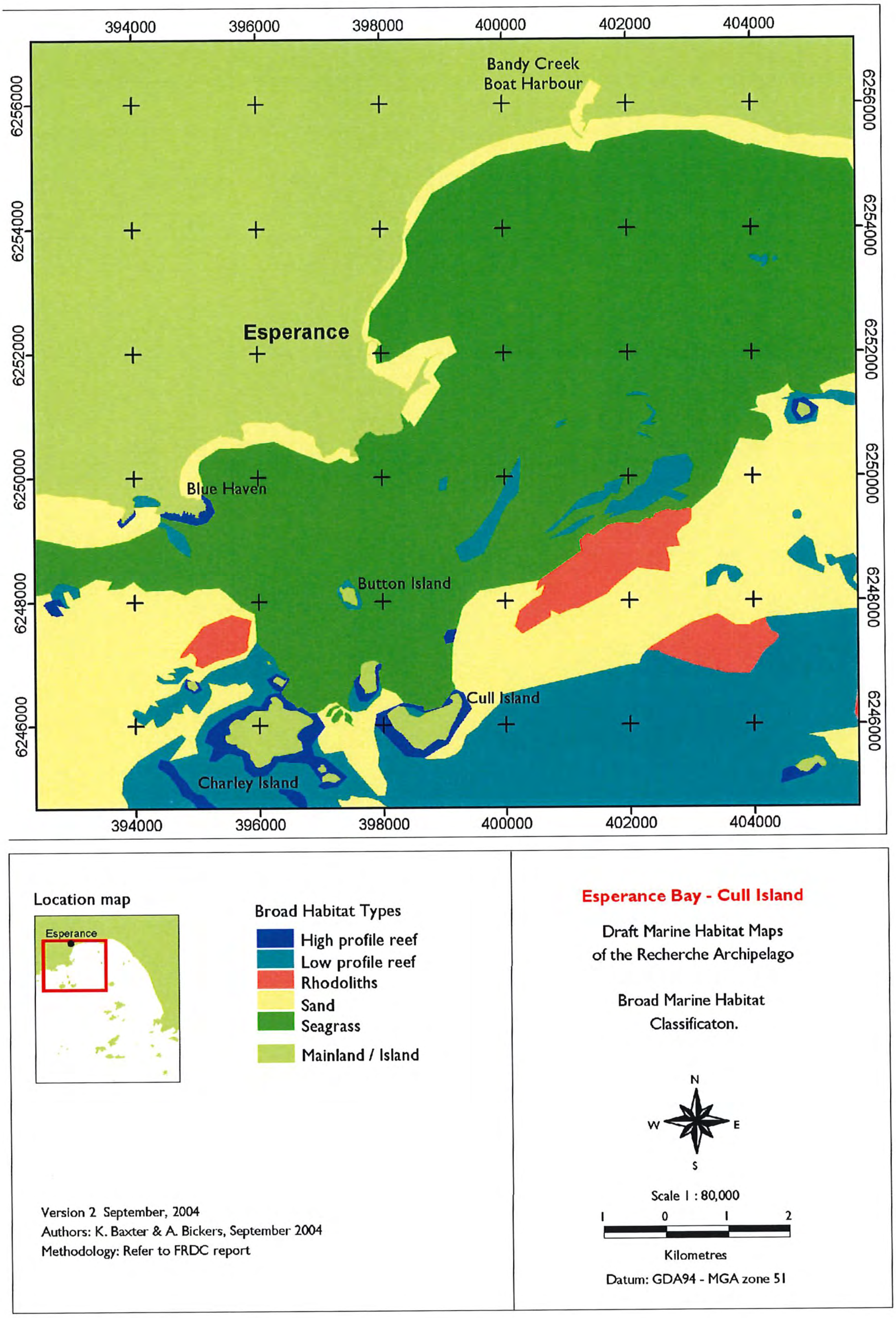
It should be noted that habitat distributions, particularly seagrass and low profile reef, can vary seasonally and between years, due to growth or sand movement.

Readers should not rely solely on these maps for decisions on current distributions. Similarly, broad defined habitat types may contain considerable biological variation within the mapped boundaries.

These habitat maps should not be used for navigation purposes.

Draft Marine Habitat Maps of the Recherche Archipelago
ESPERANCE REGION
1 : 80,000 map index





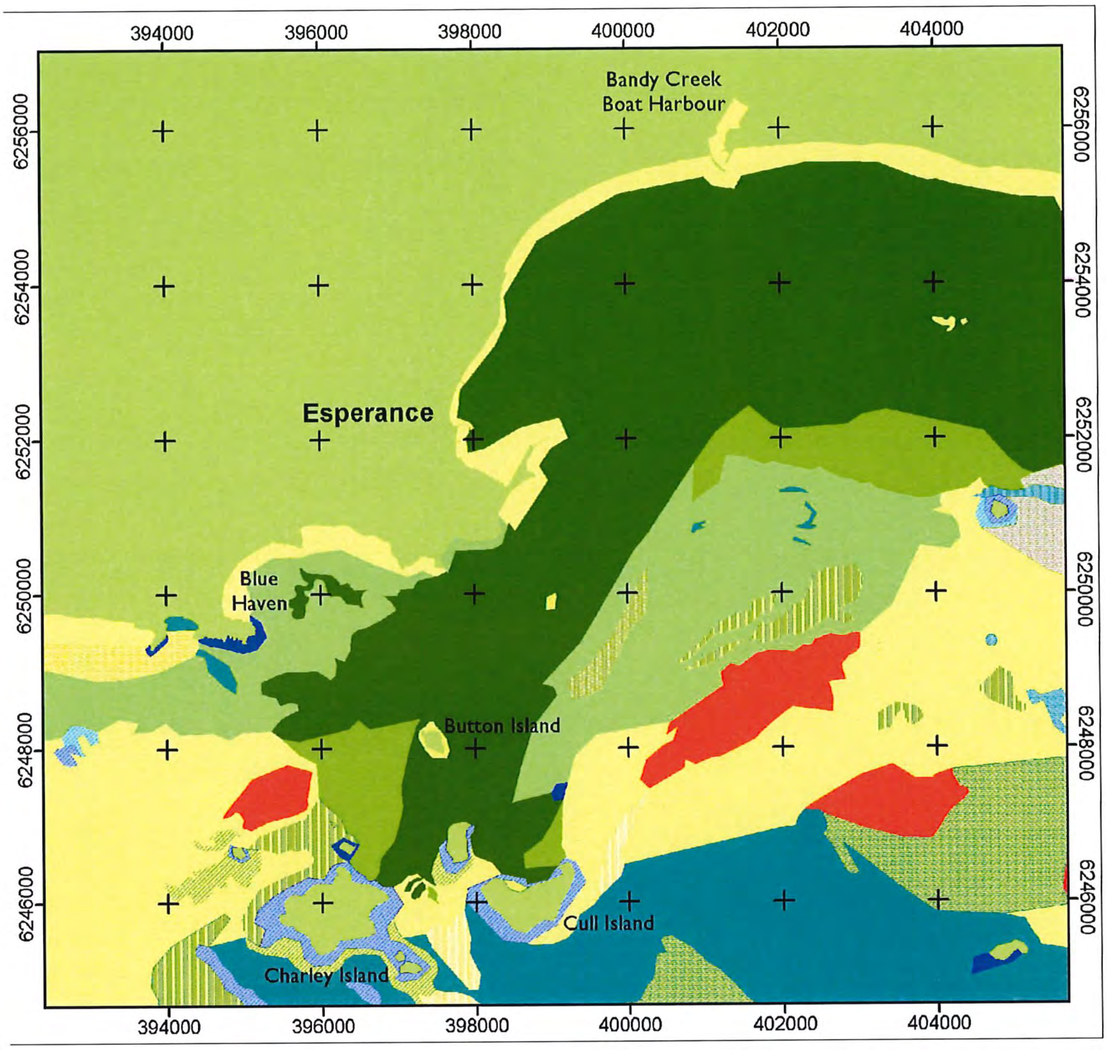
Esperance Bay - Cull Island

Draft Marine Habitat Maps
of the Recherche Archipelago

Broad Marine Habitat
Classificaton.

Datum: GDA94 - MGA zone 51

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report



Location map

For Functional Habitat legend details see the Essential Information document.

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

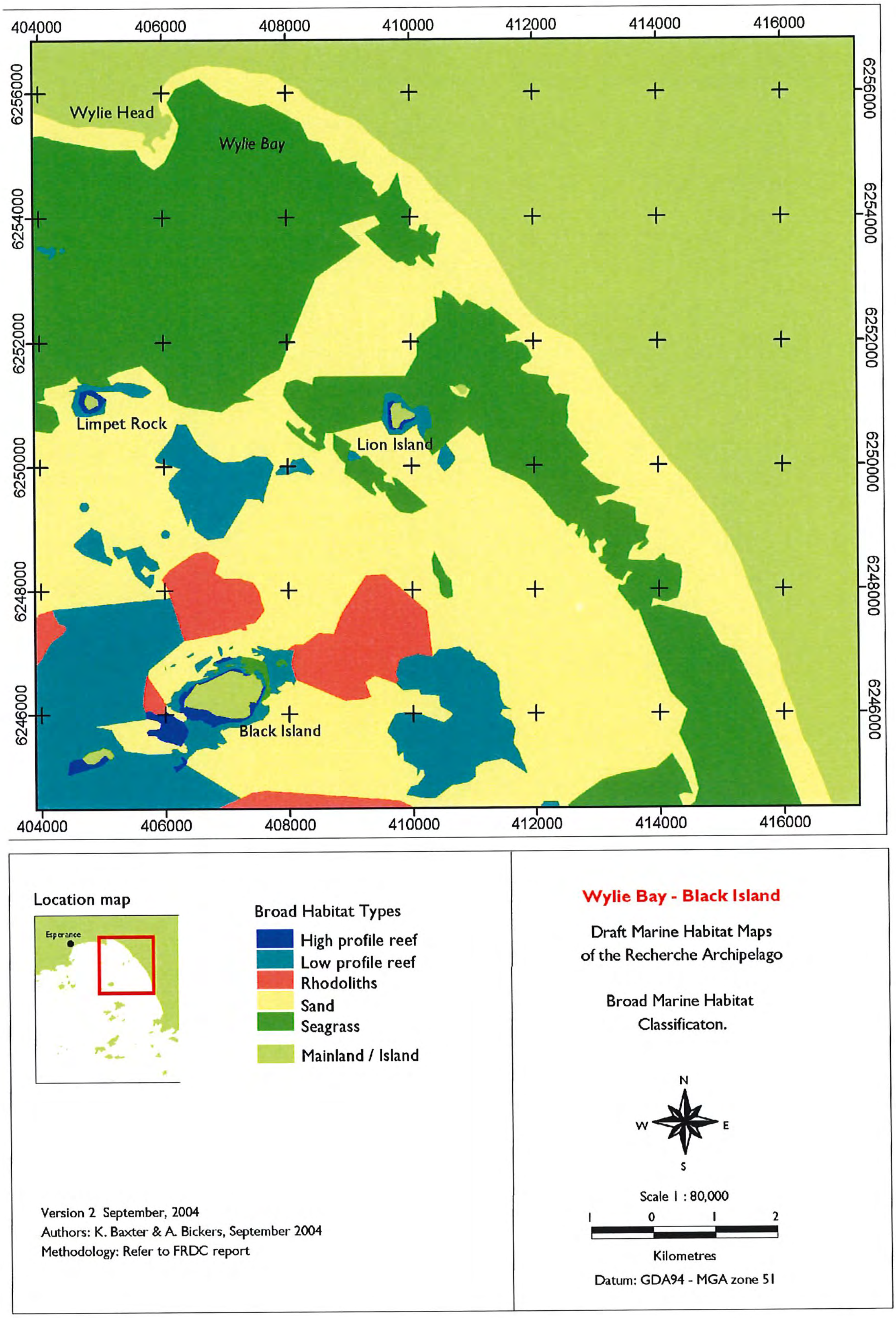
Esperance Bay - Cull Island

Draft Marine Habitat Maps
of the Recherche Archipelago

Functional Marine Habitat
Classificaton.

N
W E
S

Scale 1 : 80,000
1 0 1 2
Kilometres
Datum: GDA94 - MGA zone 51



Wylie Bay - Black Island

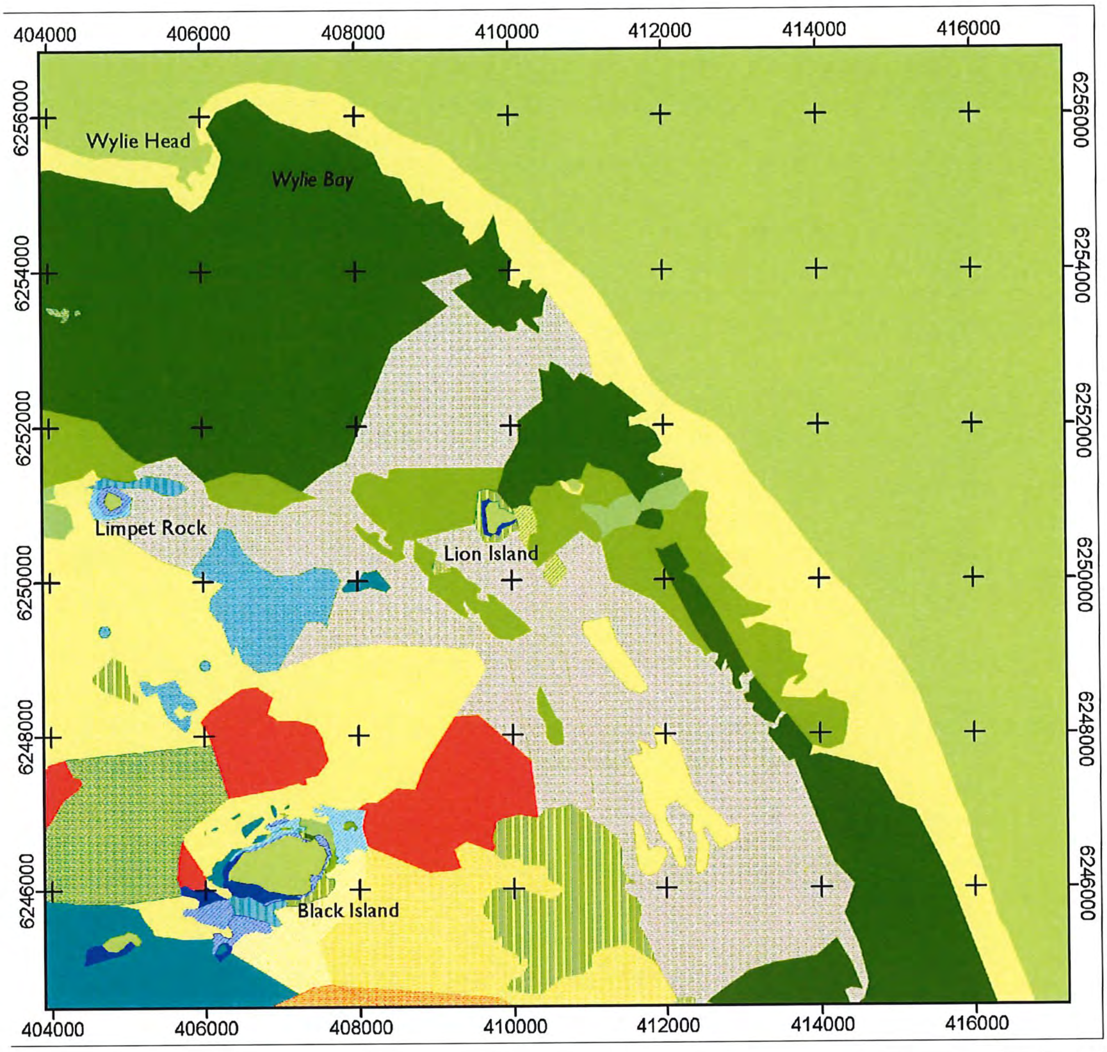
Draft Marine Habitat Maps
of the Recherche Archipelago

Broad Marine Habitat
Classificaton.

Scale 1 : 80,000

Datum: GDA94 - MGA zone 51

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report



Location map

For Functional Habitat legend details see the Essential Information document.

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

Wylie Bay - Black Island

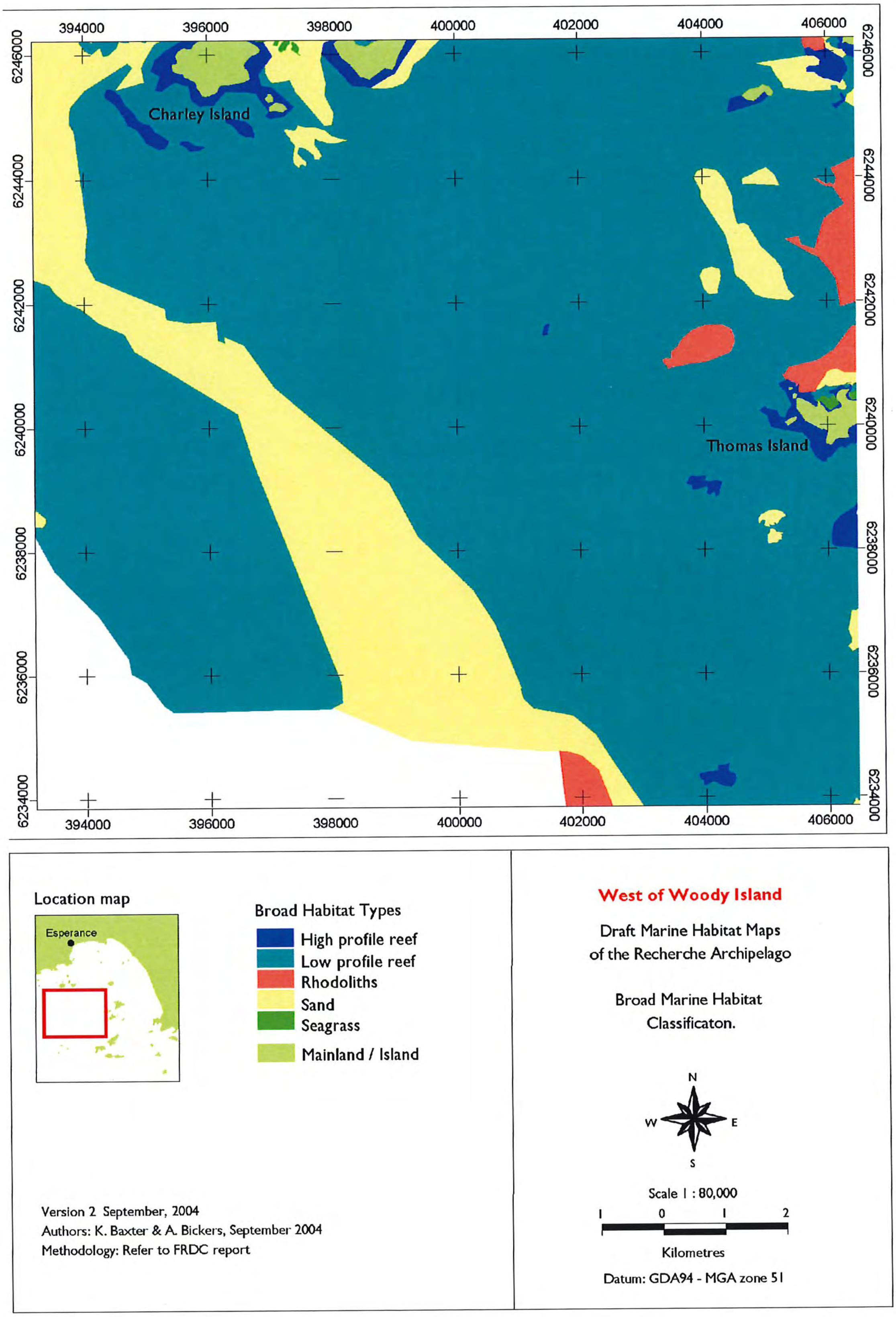
Draft Marine Habitat Maps
of the Recherche Archipelago

Functional Marine Habitat
Classificaton.

Scale 1 : 80,000

Kilometres

Datum: GDA94 - MGA zone 51



West of Woody Island

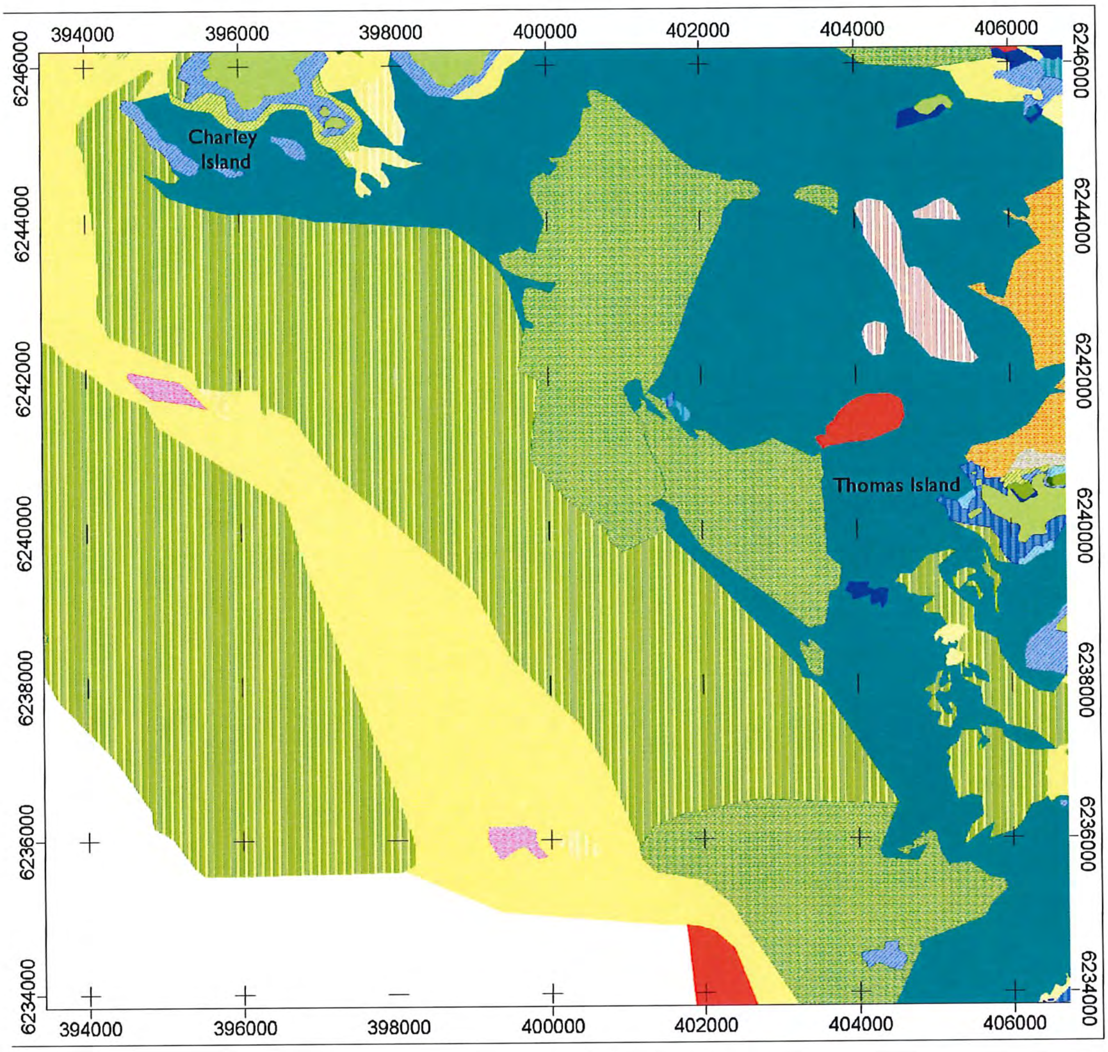
Draft Marine Habitat Maps
of the Recherche Archipelago

Broad Marine Habitat
Classificaton.

Scale 1 : 80,000

Datum: GDA94 - MGA zone 51

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report



Location map

For Functional Habitat legend details see the Essential Information document.

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

West of Woody Island

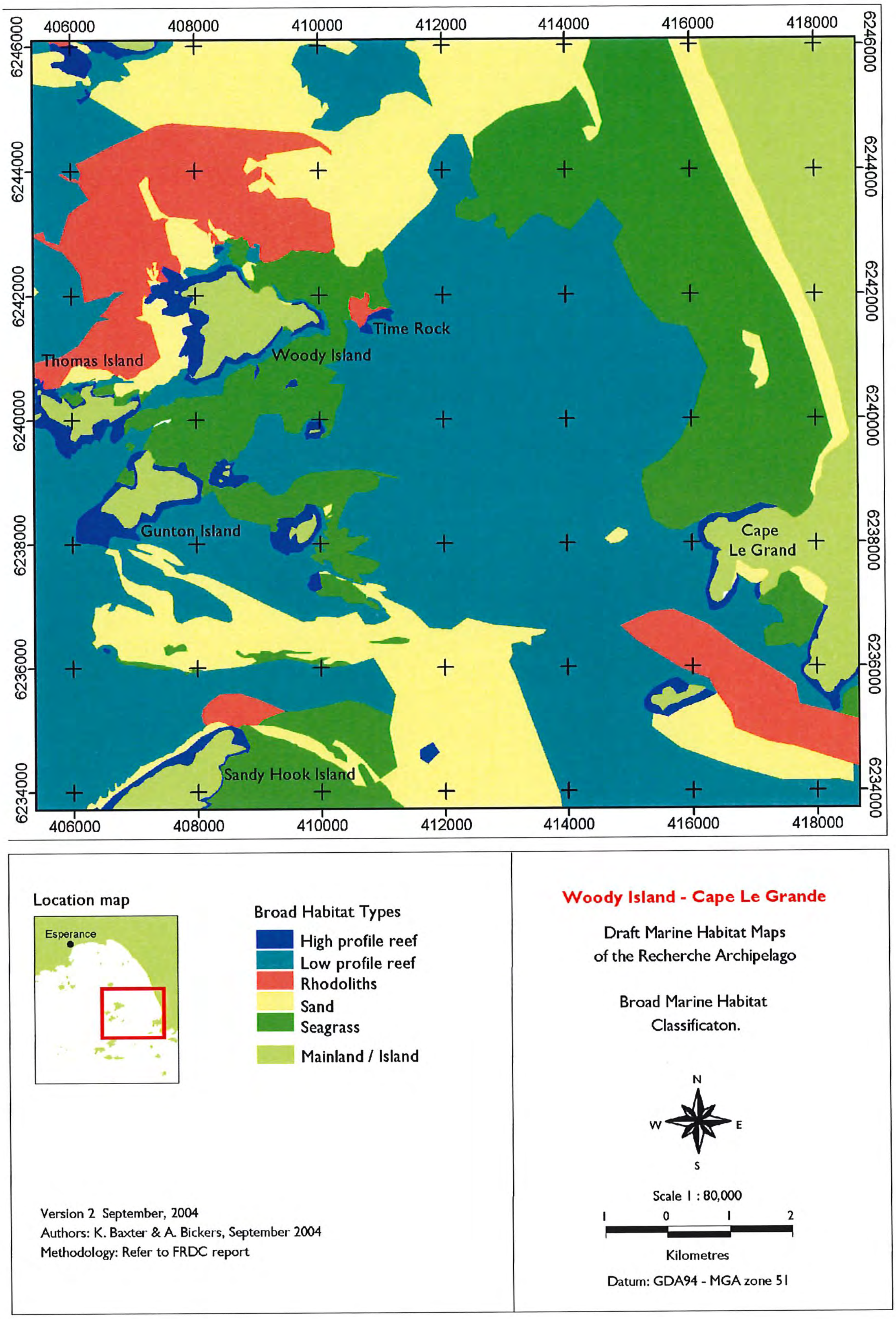
Draft Marine Habitat Maps
of the Recherche Archipelago

Functional Marine Habitat
Classificaton.

N
W E
S

Scale 1 : 80,000
1 0 1 2
Kilometres

Datum: GDA94 - MGA zone 51



Woody Island - Cape Le Grande

Draft Marine Habitat Maps
of the Recherche Archipelago

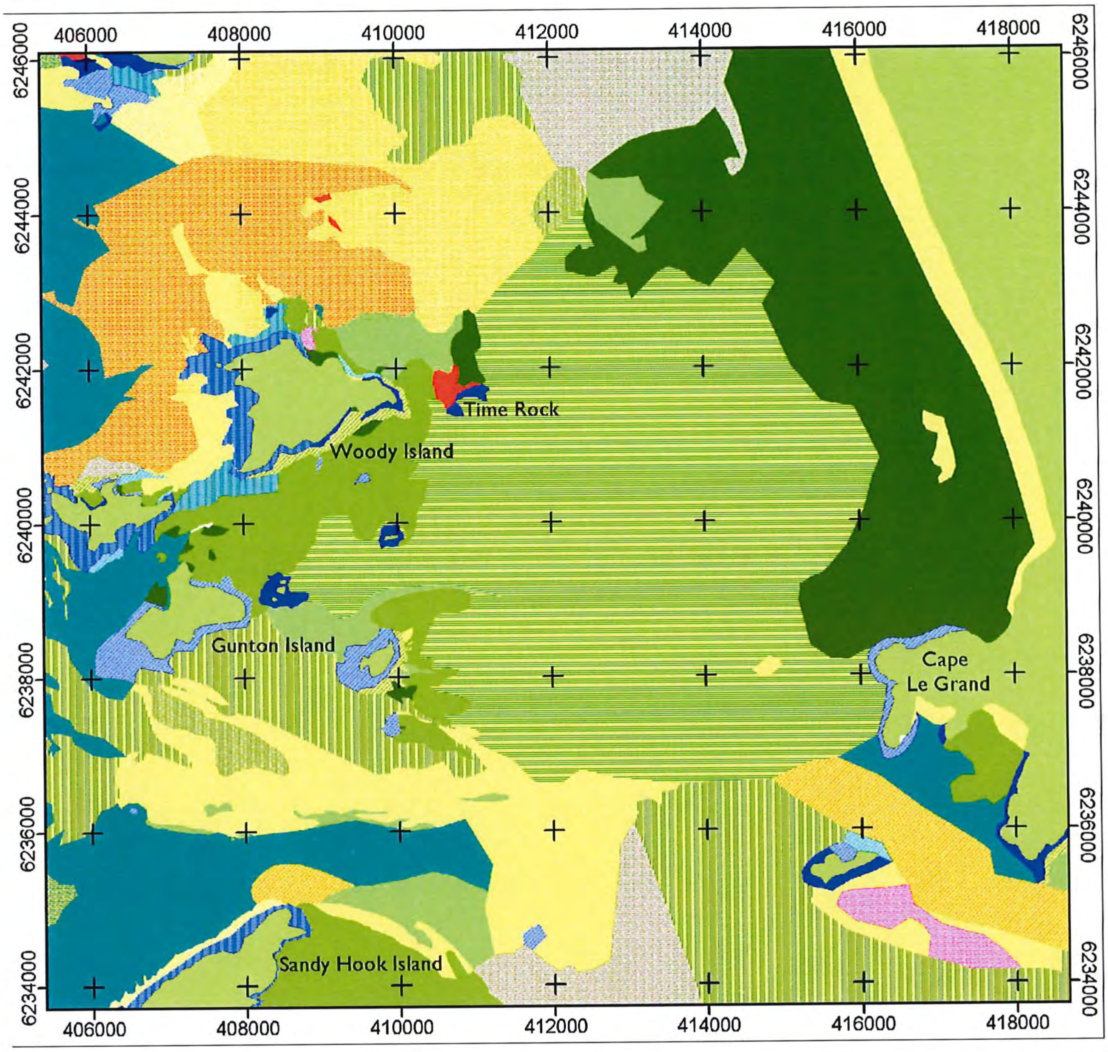
Broad Marine Habitat
Classificaton.

Broad Habitat Types

- 🟦 High profile reef
- 🟦 Low profile reef
- 🟥 Rhodoliths
- 🟨 Sand
- 🟩 Seagrass
- 🟩 Mainland / Island

Datum: GDA94 - MGA zone 51

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report



Location map

For Functional Habitat legend details see the Essential Information document.

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

Woody Island - Cape Le Grande

Draft Marine Habitat Maps of the Recherche Archipelago

Functional Marine Habitat Classificaton.

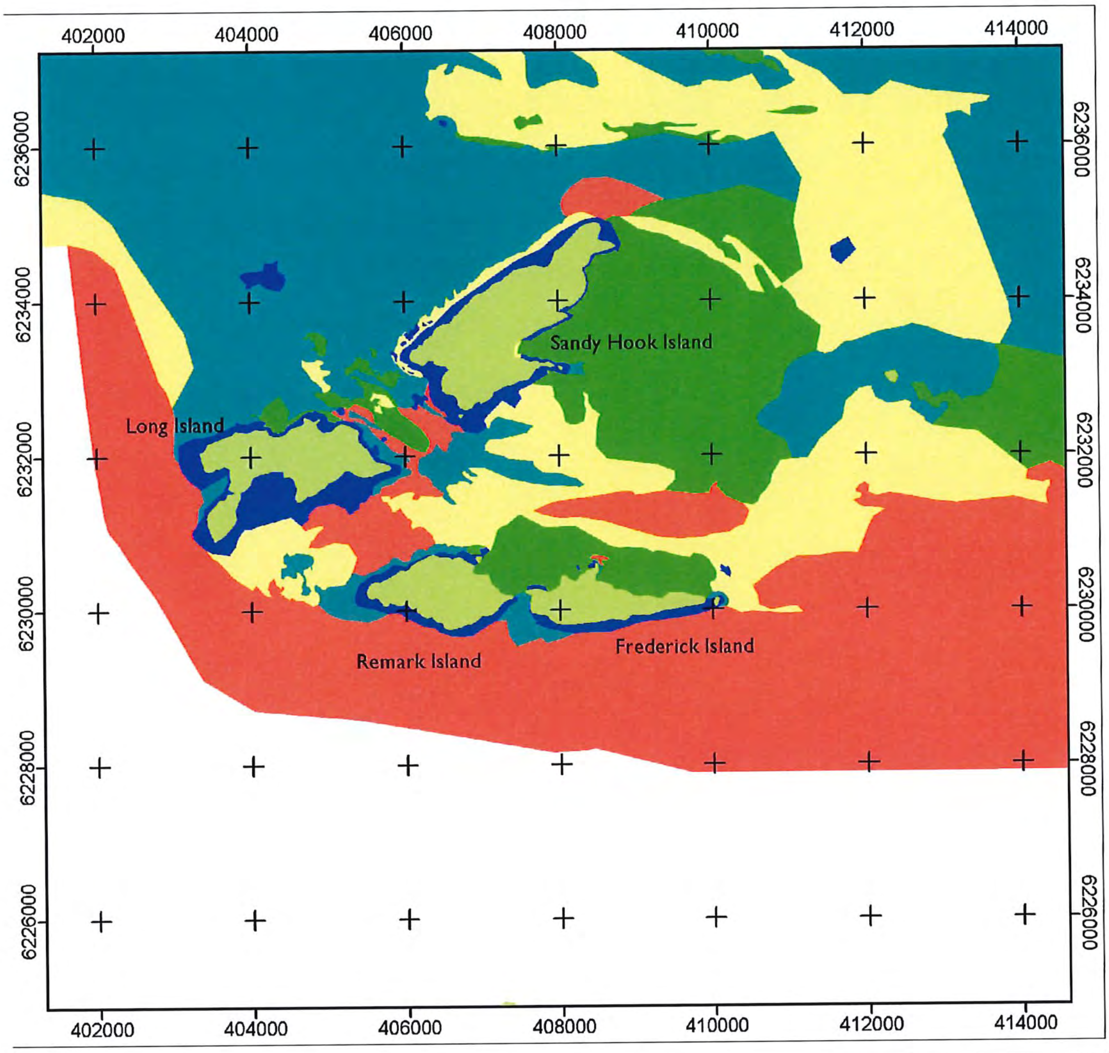
N
W E
S

Scale 1 : 80,000

1 0 1 2

Kilometres

Datum: GDA94 - MGA zone 51



Location map

Broad Habitat Types

- 🟦 High profile reef
- 🟦 Low profile reef
- 🟥 Rhodoliths
- 🟨 Sand
- 🟩 Seagrass
- 🟩 Mainland / Island

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

Remark Island Group

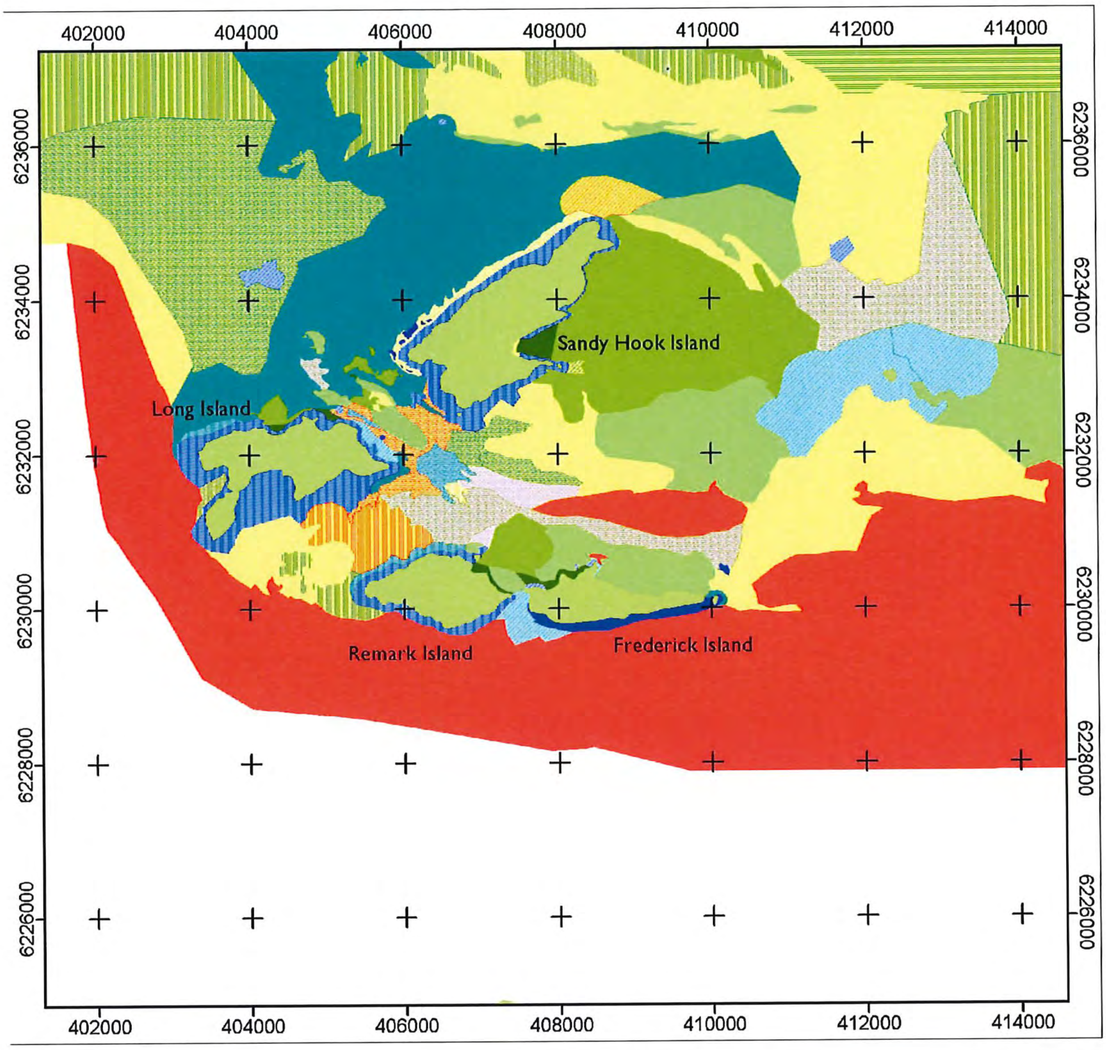
Draft Marine Habitat Maps
of the Recherche Archipelago

Broad Marine Habitat
Classificaton.

Scale 1 : 80,000

Kilometres

Datum: GDA94 - MGA zone 51



Location map

For Functional Habitat legend details see the Essential Information document.

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

Remark Island Group

Draft Marine Habitat Maps
of the Recherche Archipelago

Functional Marine Habitat
Classificaton.

N
W E
S

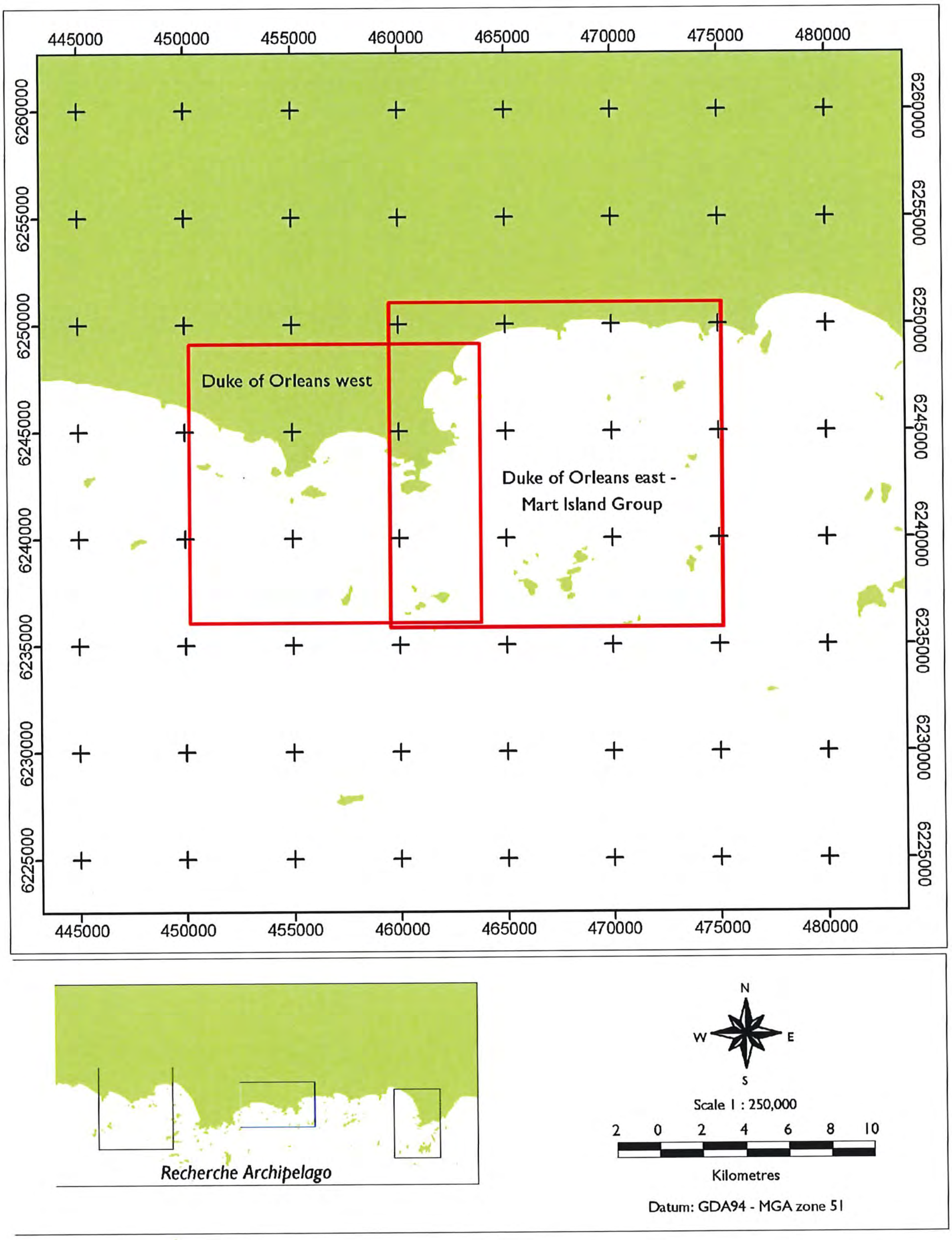
Scale 1 : 80,000

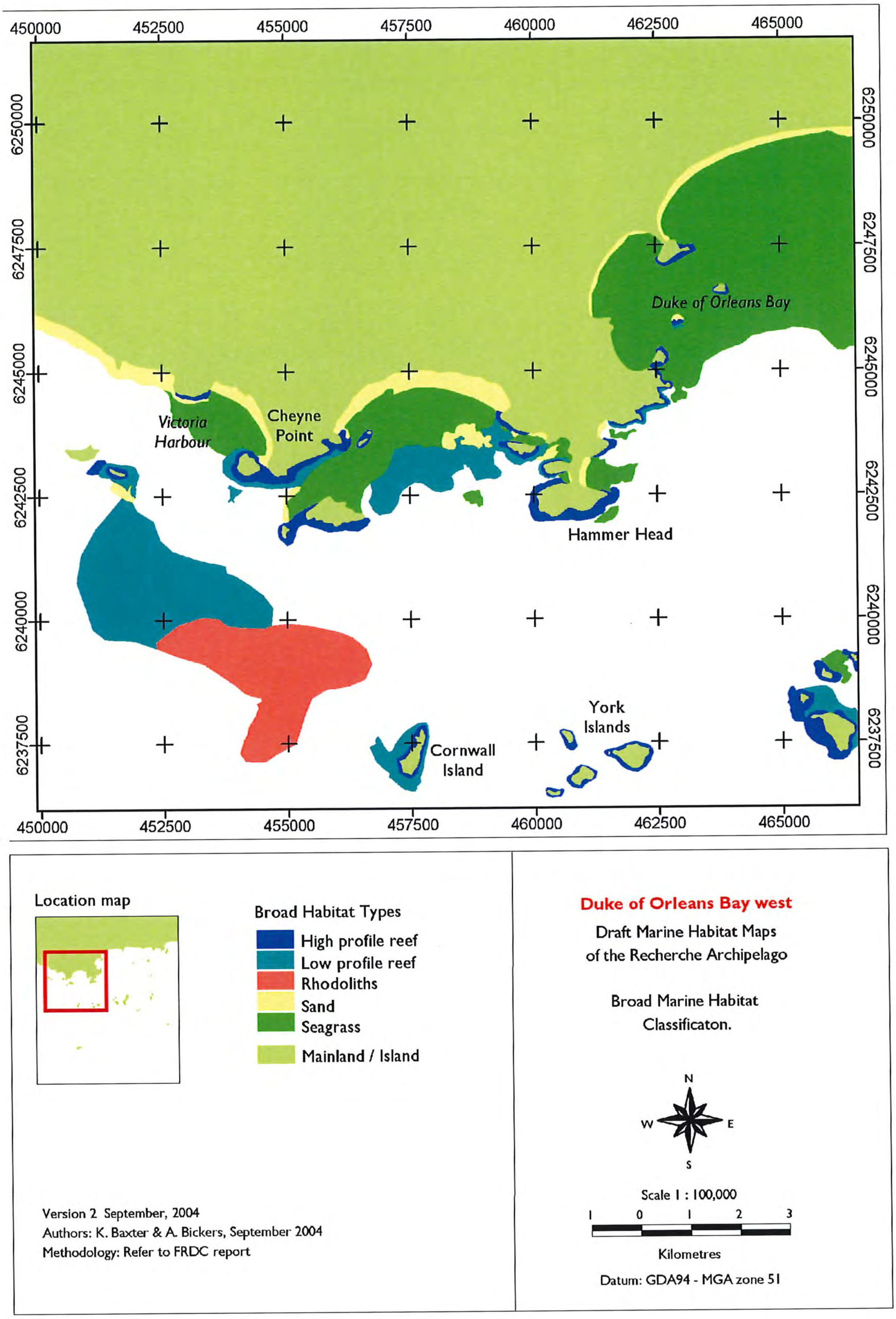
1 0 1 2

Kilometres

Datum: GDA94 - MGA zone 51

Draft Marine Habitat Maps of the Recherche Archipelago
DUKE OF ORLEANS REGION
1 : 100,000 map index





Duke of Orleans Bay west

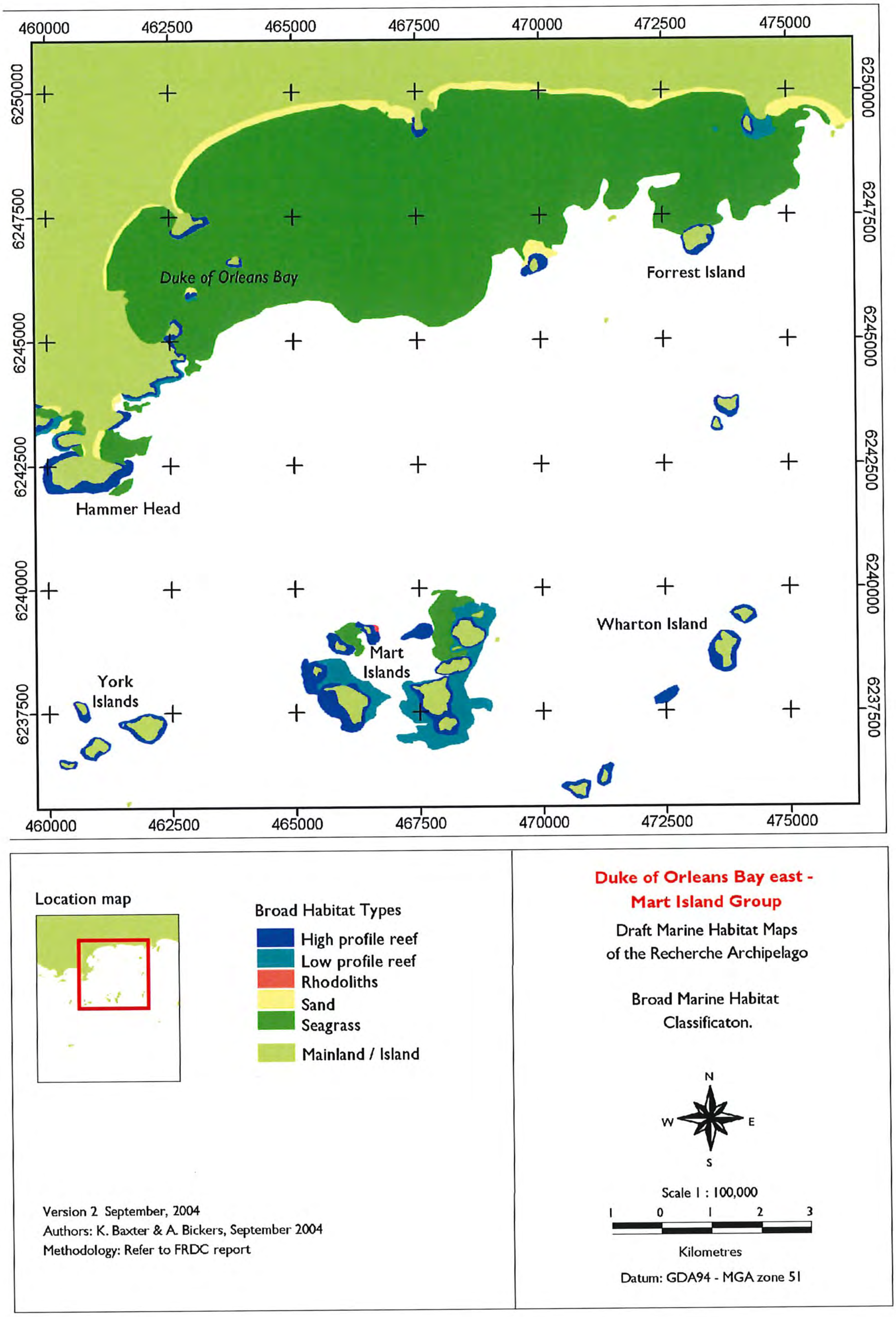
Draft Marine Habitat Maps
of the Recherche Archipelago

Broad Marine Habitat
Classificaton.

Scale 1 : 100,000

Datum: GDA94 - MGA zone 51

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report



Duke of Orleans Bay east - Mart Island Group

Draft Marine Habitat Maps
of the Recherche Archipelago

Broad Marine Habitat
Classificaton.

Broad Habitat Types

- 🟦 High profile reef
- 🟦 Low profile reef
- 🟥 Rhodoliths
- 🟨 Sand
- 🟩 Seagrass
- 🟩 Mainland / Island

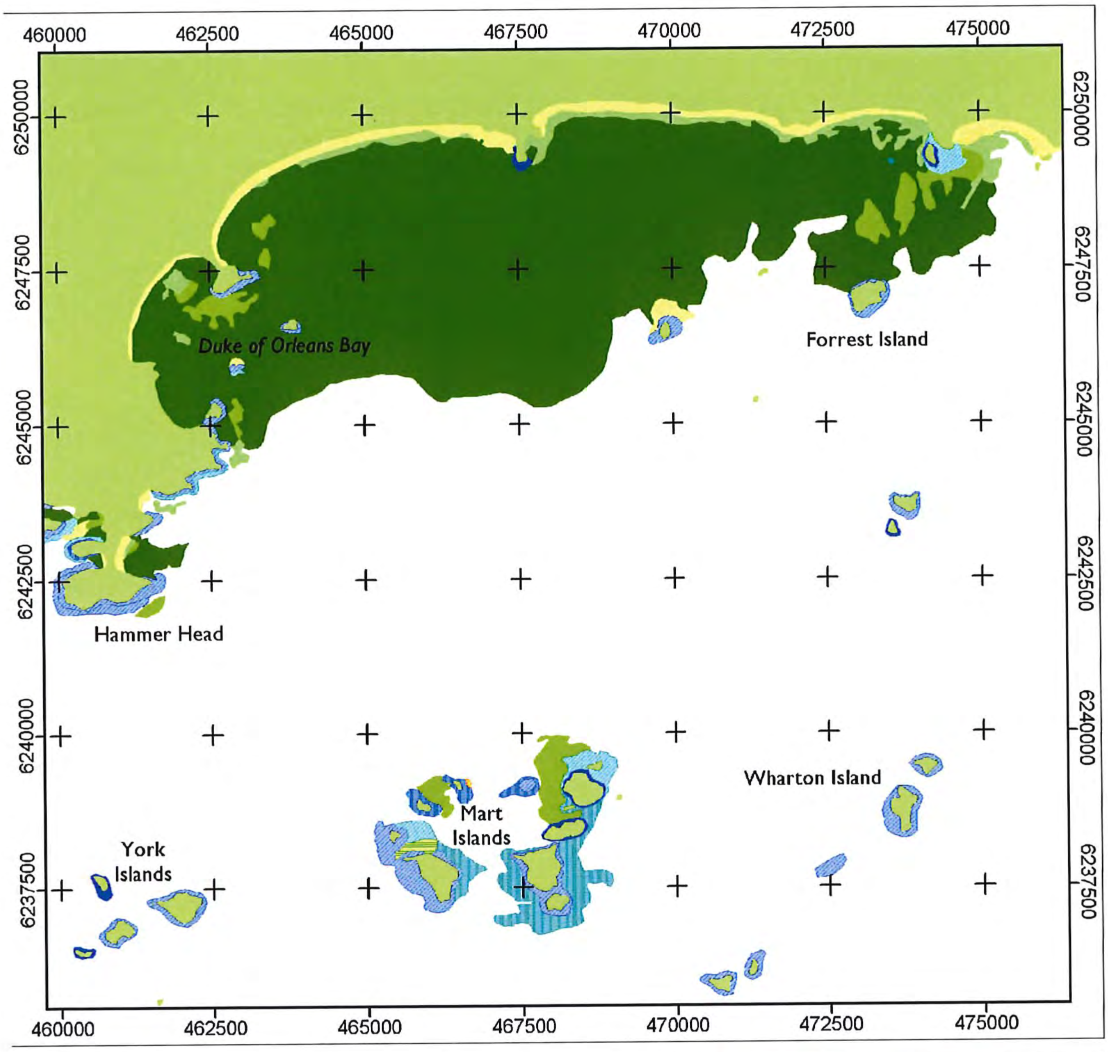
Scale 1 : 100,000

1 0 1 2 3

Kilometres

Datum: GDA94 - MGA zone 51

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report



Location map

For Functional Habitat legend details see the Essential Information document.

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

Duke of Orleans Bay east - Mart Island Group

Draft Marine Habitat Maps of the Recherche Archipelago

Functional Marine Habitat Classificaton.

N
W E
S

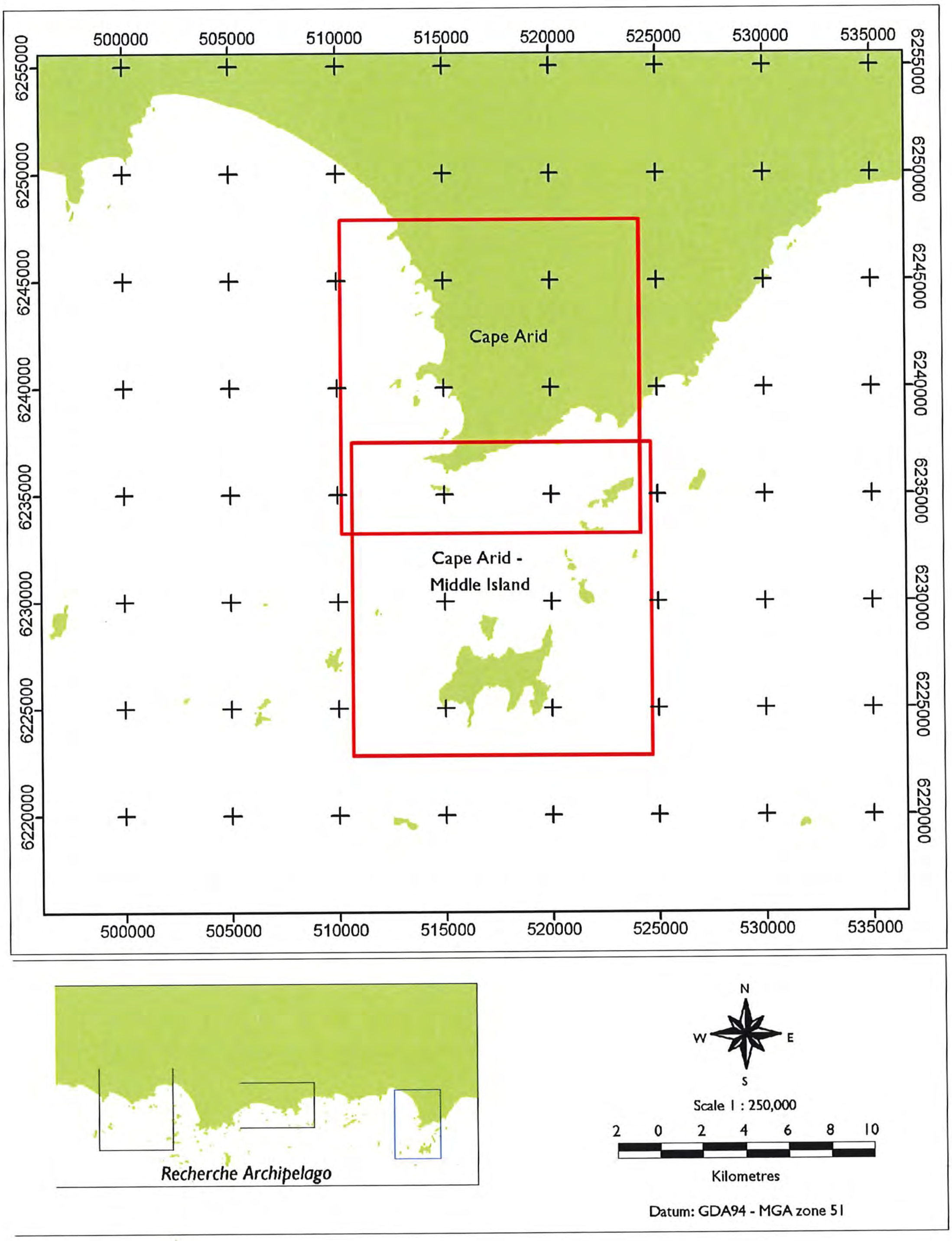
Scale 1 : 100,000

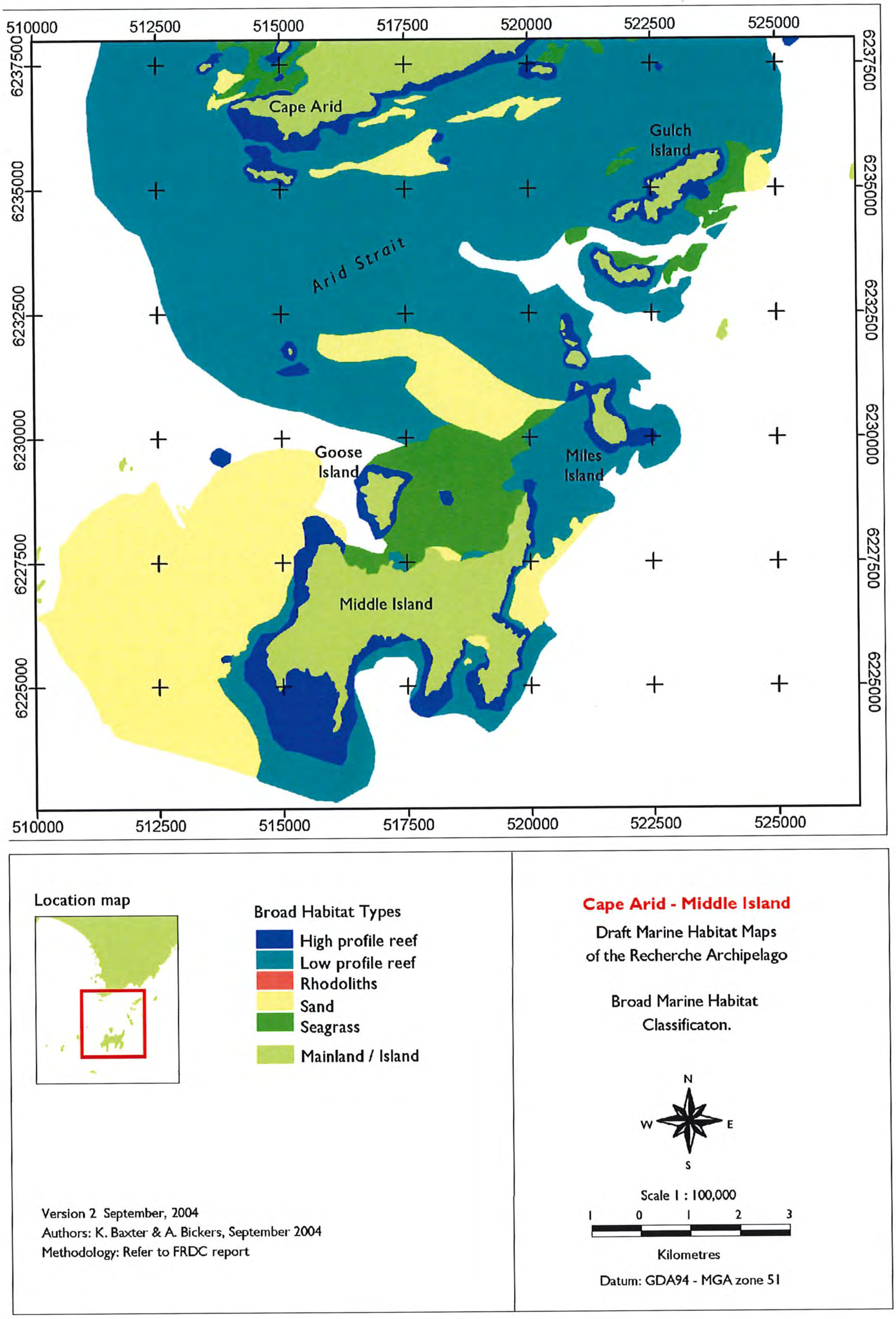
1 0 1 2 3

Kilometres

Datum: GDA94 - MGA zone 51

Draft Marine Habitat Maps of the Recherche Archipelago
CAPE ARID REGION
1 : 100,000 map index





Cape Arid - Middle Island

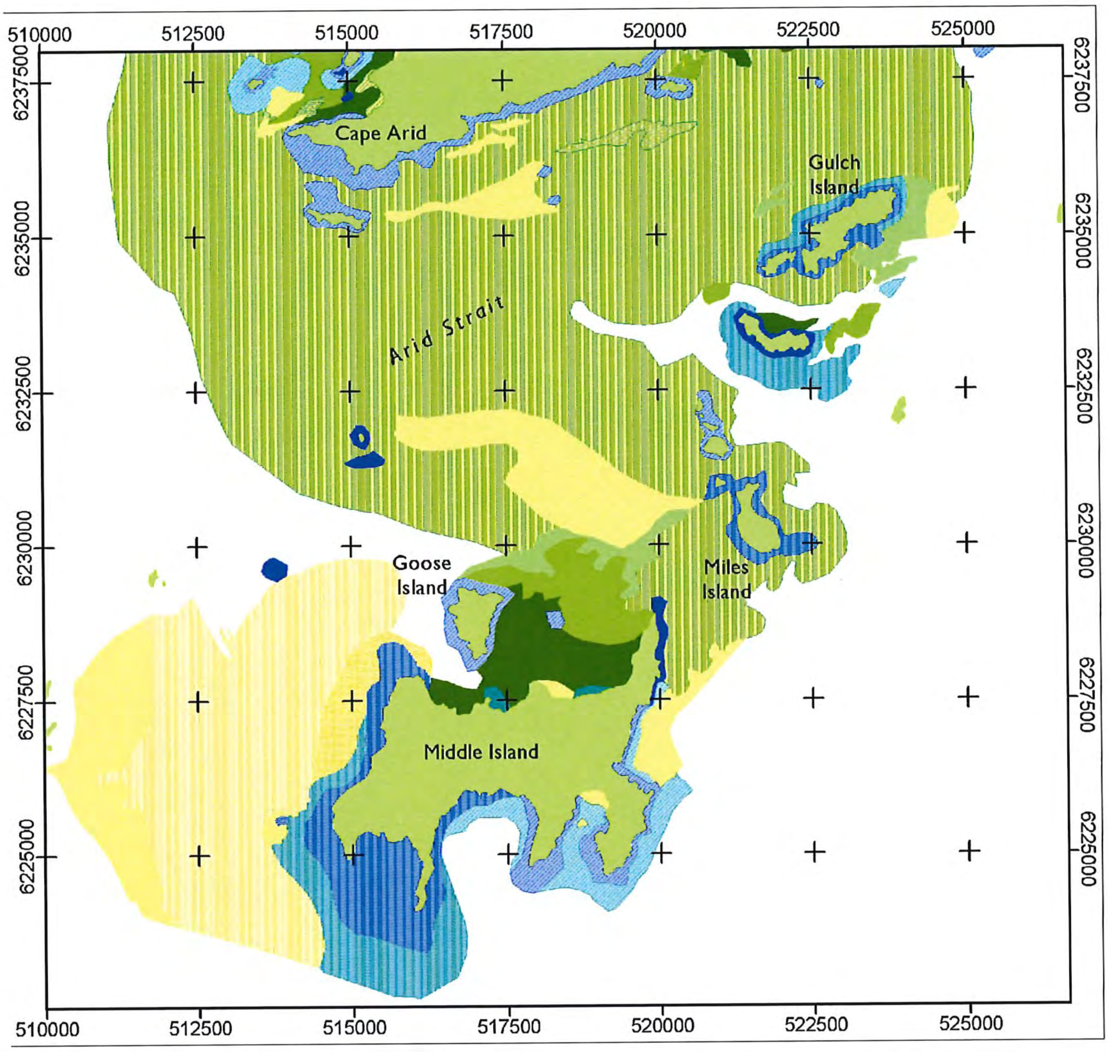
Draft Marine Habitat Maps
of the Recherche Archipelago

Broad Marine Habitat
Classificaton.

Scale 1 : 100,000

Datum: GDA94 - MGA zone 51

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report



Location map

For Functional Habitat legend details see the Essential Information document.

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

Cape Arid - Middle Island

Draft Marine Habitat Maps
of the Recherche Archipelago

Functional Marine Habitat
Classificaton.

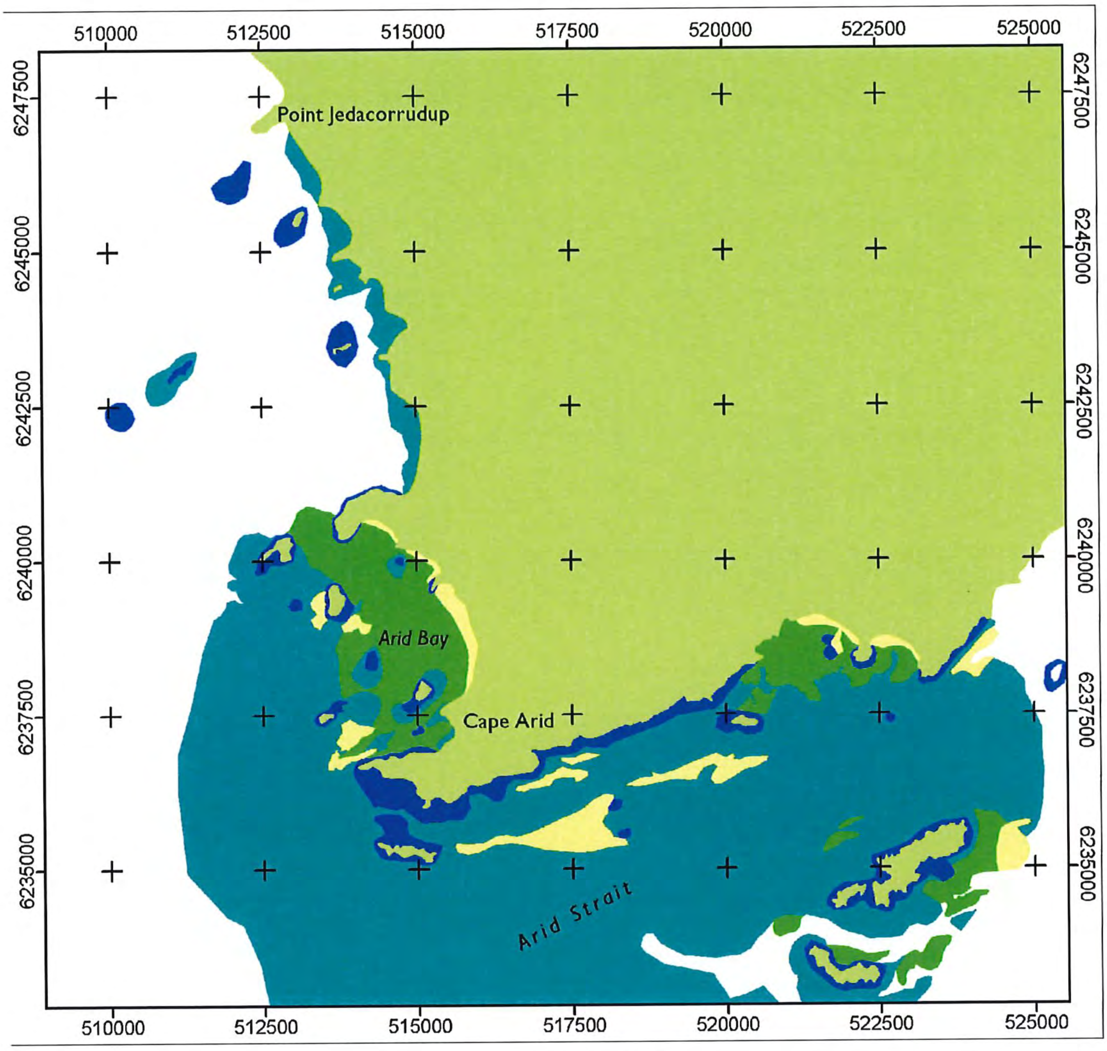
N
W E
S

Scale 1 : 100,000

1 0 1 2 3

Kilometres

Datum: GDA94 - MGA zone 51



Location map

Broad Habitat Types

- 🟦 High profile reef
- 🟦 Low profile reef
- 🟥 Rhodoliths
- 🟨 Sand
- 🟩 Seagrass
- 🟩 Mainland / Island

Cape Arid

Draft Marine Habitat Maps
of the Recherche Archipelago

Broad Marine Habitat
Classificaton.

N
W E
S

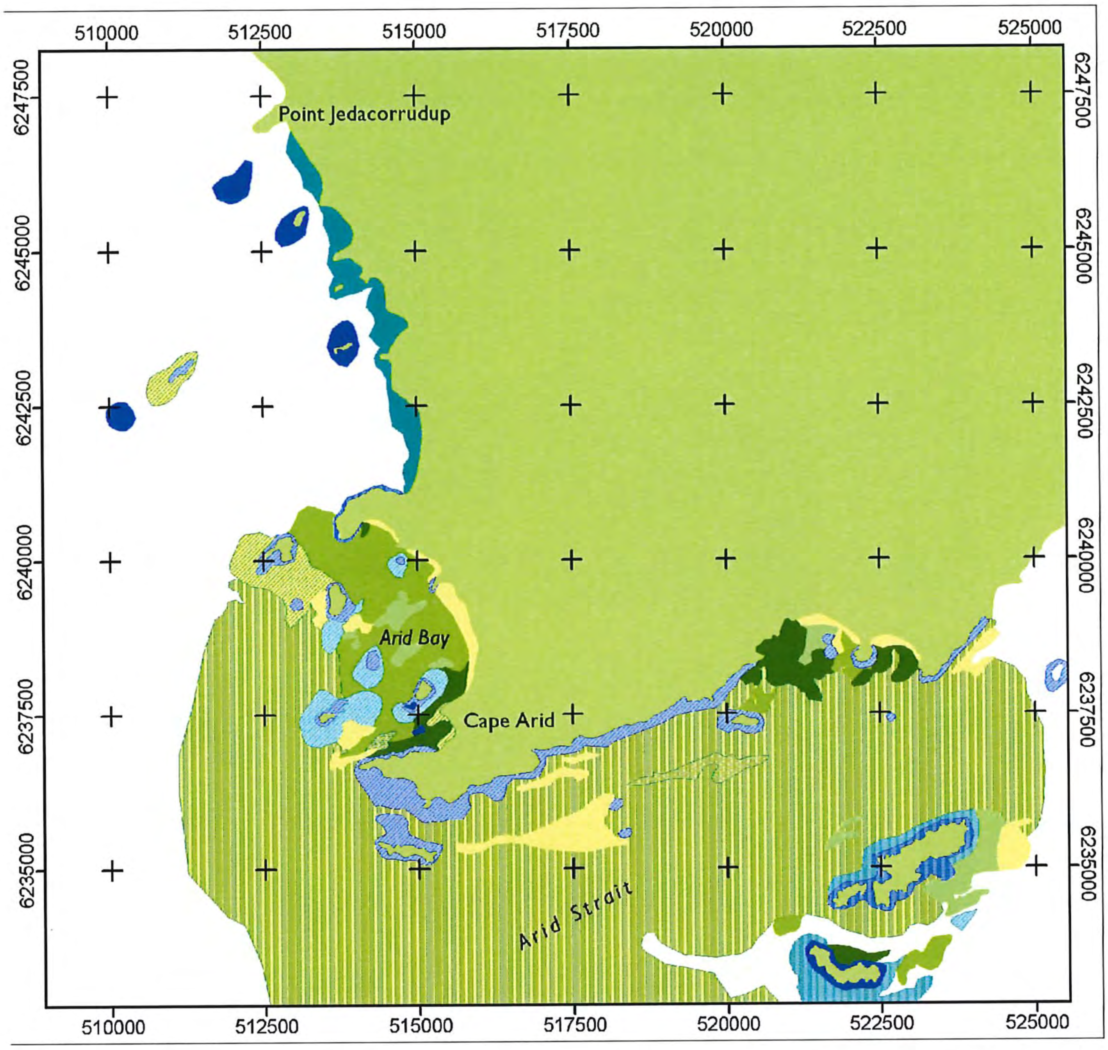
Scale 1 : 100,000

1 0 1 2 3

Kilometres

Datum: GDA94 - MGA zone 51

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report



Location map

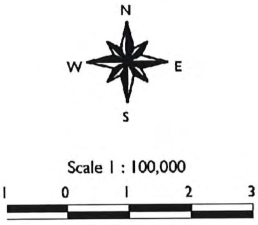
For Functional Habitat legend details see the Essential Information document.

Version 2 September, 2004
Authors: K. Baxter & A. Bickers, September 2004
Methodology: Refer to FRDC report

Cape Arid

Draft Marine Habitat Maps
of the Recherche Archipelago

Functional Marine Habitat
Classificaton.



Scale 1 : 100,000

Kilometres

Datum: GDA94 - MGA zone 51

Identifying Fish Habitats: the use of spatially explicit habitat modeling and prediction in marine research

Katrina Baxter and Dr Mark Shortis
Department of Geomatics
University of Melbourne, Victoria, Australia
Phone: +61 3 8344 6806 Fax: +61 3 9347 2916
Email: k.baxter1@pgrad.unimelb.edu.au

Presented at SIRC 2002 – The 14th Annual Colloquium of the Spatial Information Research Centre
University of Otago, Dunedin, New Zealand
December 3-2002

ABSTRACT

New methods of optimally identifying and predicting marine habitat occurrence are needed to help best address management issues such as marine reserve designation, fisheries stock assessment and aquaculture planning across large areas. A combination of video sampling, acoustic remote sensing and learning-based classification methods are proposed as a means of optimally identifying marine habitats. More commonly used in the identification of terrestrial landscape patterns, learning based classifiers, such as decision trees and artificial neural networks have the advantage of being able to accurately and rapidly identify patterns in complex systems. Opportunities exist to use similar techniques to both classify and predict the distribution of marine habitats. Both decision trees and neural networks are assessed as a means of deciding upon the most appropriate method for developing a spatially explicit marine habitat model, with reference to a case study within the Recherché Archipelago, Western Australia. Classifying habitats, predicting habitats and also understanding the importance of particular variables that define habitats are feasible outcomes through the adoption of a learning-based classification approach.

***Keywords and phrases*:** marine habitats, spatial analysis, acoustics, decision trees, neural networks

1.0 INTRODUCTION

Marine researchers and managers are often required to understand patterns and processes operating across large areas and at a variety of scales to best address management issues such as marine reserve designation, fisheries stock assessment and aquaculture planning. Depending on the management question the area of interest may vary from the scale of an individual reef or habitat to very large geographic areas with significant variation in marine habitat types. Often presented with the difficultly that data a) do not exist for the areas of interest or b) are scarce and expensive to collect, researchers and managers require optimal mapping techniques to intelligently, accurately and cost-effectively survey and classify large areas of marine habitat.

Australia's Ocean Policy recommends the use of acoustic remote sensing devices along with visual methods, such as video, as a means of broadly sampling large areas of the marine environment (National Oceans Office, 1998). Recent advances in high-resolution acoustic sensors, such as side scan sonar and multibeam swath mappers, hold great promise for the development of optimal habitat mapping methodologies, enabling broad scale imagery of seafloor texture and depth to be acquired in both shallow and deep water habitats (Hughes-Clarke, 1998; Kvitek *et al*, 1999; Mayer *et al*, 2000;

Kloser *et al*, 2001a; Kloser *et al*, 2001b; Ferns and Hough, 2002). It is expected that this 3 dimensional (or rather 2.5d) data of the seafloor will significantly improve our ability to describe marine habitats, but as with any new technology underpinning research is needed to develop appropriate methods of interpreting and classifying the data (Kloser *et al*, 2001b). In this sense, many lessons can be learnt and applied from the classification of terrestrial landscapes, which has been the focus of a number of geographic disciplines, including remote sensing, physical geography, landscape ecology and spatial analysis. Research directions in these fields have shown a shift from classification of landscape features using single variables alone (e.g. pixel value) to those classification algorithms that allow the use of multiple variables to describe and also predict pattern.

Learning based classification approaches such as Artificial Neural Networks (ANN's) and Decision Tree classifiers are known for their abilities to learn and also generalise patterns in complex non-linear datasets using multiple variables. Such techniques have been increasingly applied within terrestrial remote sensing, yielding significant improvements in accuracy over traditional regression and maximum likelihood techniques (Benediktsson *et al*, 1990, Foody and Arora, 1997). More recently, learning based approaches have been applied in ecological modelling to classify and also predict the occurrence of environmental patterns. A key focus of this paper is to review the use of learning based classifiers to quantitatively classify landscape pattern and illustrate the potential for similar methods to be applied to the marine environment.

Future research directions in marine habitat mapping seek to not only improve the accuracy of habitat classification, but also develop the ability to *predict* the occurrence of habitats from physical and biological parameters that can be remotely sampled (Kvitek *et al*,. 1999; Kloser and Penrose, 2000; Kloser *et al,* 2001b). Learning based classification approaches offer a potential means of achieving these objectives and providing new insights into understanding the relationships contributing to those patterns, in not only 2 but also 3 dimensions.

2.0 SPATIAL APPROACHES TO MARINE HABITAT MAPPING

Mapping of marine habitats is often undertaken by research and management agencies for a variety of purposes including:

- Assessment of habitat change due to natural or human impacts (e.g. climate change, oil spills, trawl disturbance)
- Monitoring and protecting important habitats (e.g. marine reserves, spawning areas, harvest closure areas)
- Design and location of marine reserves and aquaculture projects
- Species distributions and stock assessment

(Kvitek *et al*, 1999)

There are many parameters that can contribute to the distribution and abundance of species and habitats including: depth, exposure, substrate type, surface roughness, relief, sediment type, temperature, current and the presence of other species. Methods used to either directly or remotely sample these habitat parameters can include: diver transects; diver video; stereo video; 'drop' or towed video; aerial photography, satellite and acoustic imagery, such as sidescan sonar and multibeam swath mappers. The goal of the habitat mapping exercise will dictate the appropriate resolution required and the corresponding methods to be used, although increasingly large area mapping is best undertaken using a combination of remotely sensed data and direct observations, as a means of validating habitats and reducing overall costs associated with direct sampling methods such as diving (Kvitek *et al*, 1999; Kracker, 1999; Kloser *et al*, 2001a).

Initially, satellite methods were used to broadly quantify reef habitats, using Landsat TM and SPOT imagery (for a review see Green *et al*, 1996 and Mumby, 2000). However, the coarse pixel resolution (30m$_2$ for Landsat TM, 10m$_2$ for SPOT) and subsequent lack of habitat detail have prevented satellite methods from being widely used by management agencies. Aerial photography has been one of the most common methods of delineating marine habitats across large areas. Ground truth data collected by diver or towed video has been used to classify aerial imagery of these shallow water habitats to quantify biodiversity (Mumby *et al*, 1998), detect reef health (Thamrongnawasawat and Catt, 1994; Baxter, 1998) and changes in the extent of seagrass beds (Mulhearn, 2001; Kendrick *et al*, 2002a; Kendrick *et al*, 2002b). Classified habitats can then be incorporated into a Geographic Information System (GIS) and used by management agencies for reserve planning, biodiversity assessment and monitoring (Sotheran *et al*, 1997; Kvitek *et al*, 1999; Ferns and Hough, 2000; Donoghue & Mironet, 2002). The finer resolution of data acquired from aerial photography (0.5-10metres) represents a significant advantage over satellite imagers and is a useful method of habitat mapping in shallow water environments. However, due to the limits of light penetration, only habitats up to maximum depths of 15 to 20 metres can be delineated.

Advances in acoustic remote sensing have helped overcome the limitation of light penetration. Technologies, such as sidescan sonar and multibeam swath mapping, have delivered opportunities to remotely sample seafloor bathymetry and texture in waters as deep as 200 metres (Hughes-Clarke *et al*, 1996; Blondel and Murton, 1997; Mayer *et al*, 2000; Kloser *et al*, 2001a; Brown *et al*, 2002). Acoustic sensors have been used for broad scale purposes such as pipeline planning across the seafloor (Mayer et al, 2000), fisheries stock assessment (Kloser *et al*, 1996; Diachok et al, 2001) and the detection of mid ocean ridges (Wright, 1999). More recently, research has focussed on detection of seafloor habitat characteristics at depths and scales appropriate to management of marine reserves and the assessment of human impacts (McRea *et al,* 1999; Brown *et al*, 2002; Ferns and Hough, 2002). Investigations into the detection of seafloor targets using multibeam technology illustrate features less than 1m$_2$ may now be discerned (Hughes-Clarke, 1998; Kenny et al, 2000; Galway, 2000). It is expected improved classification of seafloor texture will result, allowing large areas to be classified and features of interest to be accurately identified. Direct sampling locations can be intelligently chosen from images of seafloor texture, ultimately resulting in significant time and cost savings. Similarly, such high-resolution depth data will be a welcome addition to the data needs of marine researchers, enabling terrain models of the seafloor to be developed that will allow powerful visualisation of the seafloor and derivation of additional factors such as slope, relief and surface roughness.

Together with direct sampling techniques such as video, acoustic devices provide a very powerful tool-kit for optimal habitat mapping and biodiversity assessment (Kloser *et al*, 2001b). Although multibeam swath mapping tools promise markedly superior improvements in habitat mapping compared to other acoustic methods, much work still needs to be done to improve the accuracy and interpretation of the data collected (Kloser *et al*,. 2001b). For this reason, the technology should not be widely lauded as a panacea. The future of habitat mapping should focus on utilising these new technologies as tools for obtaining data as inputs to broader, spatially explicit classification and modelling approaches. Access to multibeam technology is currently expensive and it is unlikely the immediate benefits will be widely available to state management agencies, who at best have meagre budgets for habitat mapping. Concurrent research investigating methods that will benefit not just acoustic image classification but habitat mapping as a whole are needed.

As marine habitat mapping is still in its infancy, opportunities exist to draw from the experiences of other fields of research. Significant parallels exist between marine and terrestrial landscape classification techniques (Kracker, 1999). In this sense, there is rationale in reviewing the development of landscape classification and modelling methodologies that have successfully identified techniques for classifying complex systems. Optimal marine habitat mapping will benefit from the development and application of methodologies that utilise multiple variables and allow not only classification but also the spatial prediction of habitat characteristics.

3.0 LEARNING BASED CLASSIFICATION APPROACHES – POTENTIAL APPLICATION IN THE MARINE ENVIRONMENT

Learning based classification methods, such as neural networks and decision trees, provide an attractive approach to modelling ecological systems, due to their ability to learn and predict patterns of a non-parametric nature (Dowla and Rogers, 1995; German *et al*, 1997; Özesmi and Özesmi, 1999; Drumm *et al*, 2000). Multiple variables can be included in the analysis, using either an unsupervised or supervised approach. As new example or training data are added, output feature classes are adjusted to account for the occurrence of different patterns or groupings of features (White, 1989; German *et al*, 1997; Dzeroski, 2001). This improved understanding of what makes one pattern structurally different from another can then be used to predict the occurrence of a feature class or clusters of classes given input variables from new observations or test data. In this sense, learning based classification approaches have a number of advantages over traditional data classification techniques, particularly those that rely on a single data source such as remotely sensed images.

This ability to learn and 'generalise' makes neural networks and decision trees highly suited to classifying complex environments where there are likely to be many variables contributing to the formation of pattern (Dowla and Rogers, 1995; Dzeroski, 2001). However, differences exist in the way decision trees and ANN's classify patterns and express relationships between variables defining the pattern. The advantages and limitations of both decision trees and ANN's are reviewed below with respect to applications in terrestrial classification, remote sensing and ecological modelling. Opportunities to apply similar learning based classification approaches within marine research to identify habitat classes and the variables that best define them are outlined.

3.1 Artificial Neural Networks

Neural networks have been used extensively in the field of remote sensing, with accuracies achieved often being higher than those achieved by traditional data classification techniques, such as maximum likelihood methods (Bendiktsson *et al,* 1990; Lek *et al*, 1996; Foody and Arora, 1997, Evans, 1998; Berberoglu *et al*, 2000). Like traditional classification techniques, some neural networks require training data to guide the classification process, others can adopt an unsupervised approach that requires no coaching or guidance of what defines a

particular class. ANN's *learn* patterns and trends in the data, adjusting weightings between input variables and the relationships they form. This is significant in that the relationships amongst the data are always being evaluated and the modeling algorithm updated after each iteration (White, 1989). In this respect ANN's are time saving, especially when classifying complex systems whereby the types of information needed to separate classes are likely to be numerous. Atkinson and Tatnall (1997) cite one of the advantages of using neural networks with remote sensing data is the ability to be able to "incorporate different types of data into the analysis" although initially very few studies utilised remote sensing data with inputs other than spectral data (although see Fitzgerald and Lees, 1992). Increasingly, digital elevation models and their derived outputs, such as slope, relief and aspect have been used with remote sensing data as inputs to neural network models to predict terrestrial landscape features such as soil erosion, salinity and vegetation cover type (Ellis, 1997; Evans, 1998; Blackard & Dean, 1999). More recently, a number of ecological studies have used a mix of physical and biological descriptors (including satellite remote sensing data) to understand associations between: macroinvertebrates and water quality (Chon *et al*, 1996); trout density and stream habitat variables (Lek *et al*, 1996); and water quality parameters and algal blooms (Recknagel *et al*, 1997; Karul *et al*, 2000).

ANN's have been applied to estimate and *predict* the spatial distributions of certain species or habitats as functions of environmental parameters. Recknagel *et al*,. (1997) used ANN's with input variables of nutrient levels, light and temperatures, depth and water retention time to successfully predict the locations of algal blooms in four freshwater systems. GIS data of reef habitat at the Cook Islands was included within a neural network to predict sea cucumber habitat preferences (Drumm *et al*,. 1999). The presence of rubble was found to be the most important factor influencing the occurrence and density of sea cucumbers (Drumm *et al*,. 1999).

Spatial models for habitat selection have been developed using neural networks to predict the probable nesting locations of blackbirds and marsh wrens (Özesmi and Özesmi, 1999) and also to predict the suitability of coastline segments for colonisation and breeding by New Zealand fur seals (Bradshaw *et al*, 2002). Pup condition (over a 3 year period) was used as a surrogate indicator of relative prey availability in surrounding waters. Similarly, the proximity of breeding sites to deep bathymetry offshore was used as a factor indicating the degree of upwelling and hence food availability. When predicted breeding ground preferences were compared to actual breeding colonies, both coastal substrate type and food availability factors improved the classification and prediction accuracy, indicating the importance of the factors in influencing seal colonisation (Bradshaw *et al*, 2002). The ability to extract inferences or rules from ANN's to derive an understanding of the importance of different variables is discussed below in section 3.3.

3.2 Decision Trees

Decision tree classifiers are also able to extract information about the importance of particular variables in defining a particular pattern or relationship. Through an iterative process input data is split into 'branches' or sub-classes based on common attributes. These commonalities define *rules* by which splits in the classification are made, resulting in a tree-like decision structure. The decision rules of the tree can either reinforce current knowledge about relationships between variables in the system or define new understandings about how the observed pattern is formed (Dzerovski, 2001). Decision trees can be formulated using two general approaches. Input features can be assigned to different classes or subclasses according to decision rules defined either by (1) 'expert' knowledge or (2) machine learning techniques. Expert decision trees, as the name suggests, enable knowledge to be added to the model about how classes may be split, using some previous understanding of how the phenomena are to be classified (e.g. from literature, experiments, expert or local knowledge). Expert knowledge has not been used widely in ecology and natural resource management modelling (see Dzeroski *et al*, (1997) for a review of limitations).

Many of the common decision tree algorithms (eg. Classification and Regression Tree or CART® and ID3) allow decision rules to be induced directly from training data, through a process of machine learning (Quinlan, 1986; Lees and Ritman, 1991; Guissan and Zimmermann, 2000). Machine learning decision models have been developed for: the identification of dominant algal species and the prediction of algal blooms (Kompare and Dzeroski, 1995); predicting salinity risk (Evans *et al,* 1996); modeling areas at risk of soil erosion (Ellis, 1997); predicting antelope habitat (Bell, 1999); classifying water quality indicators (Dzeroski *et al*, 1997); mapping wetland habitat (Huang and Jensen, 1997); determining relationships between soil habitat characteristics and insect populations (Kampichler *et al*, 2000); distinguishing forested and non-forested areas to develop habitat suitability models for brown bears (Kobler & Adamic, 2001); and identifying the influence of deer population size on vegetation quality (Debeljak *et al*, 2001). Further use of machine learning within decision tree classifiers is reviewed in Guissan and Zimmermann (2000).

Decision trees that develop rule based classifications using machine learning are often likened to ANN's that identify and learn patterns in the data using sample data to train on, although significant differences exist in the way the knowledge within each of the models is represented. A disadvantage of using traditional neural networks is that it is difficult to impose prior knowledge about relationships within the classification structure (Guissan and Zimmermann, 2000). In contrast, decision trees (including both expert and machine learning systems) include a knowledge base that contains the rules in the form of if –then statements that split data into information classes. In many instances in ecological modelling it can be highly beneficial to include some prior knowledge about the system under study. For example, if it were known that a particular marine habitat is found only on leeward sides of an island, between a certain depth range, it would be useful and time saving to input this information within the model to reduce mis-classifications and overall error.

3.3 Transparency and Rule Extraction

Decision tree based models have in the past offered a more transparent means of analyzing multi-dimensional datasets than traditional neural networks. Decision trees have provided a relatively easy to understand model that extracts rules as to how classes are separated, offering an improved understanding of the importance of particular variables in defining pattern (Breiman *et al*, 1984; Dzeroski *et al*, 1997; Kampichler *et al*, 2000; Guissan and Zimmermann, 2000; Dzeroski, 2001). In many instances, ANN's have been a black box, from which it is difficult to extract rules and subsequently inferences about the system (Caudill, 1991; Guissan and Zimmermann, 2000; Dzeroski, 2001). In recent years, efforts have been made to improve the transparency of ANN's, with the formation of rule extraction methods (Fu, 1994; Setiono and Liu, 1997; Purvis *et al*, 1997; Drumm *et al*, 1999). Ozesmi and Ozesmi (1999) successfully predicted the nesting locations of blackbirds and marsh wrens using a neural network 'perception' model designed to give an increased understanding of the relationships between the different input variables. Drumm *et al* (1999) generated rule sets from ANN's to successfully identify the influence of rubble and sand variables on the habitat preferences of sea cucumbers. Bradshaw *et al* (2002) generated extraction rules to provide some additional insight in understanding fur seal colonisation. The results of the network classification and rule extraction successfully corresponded to existing understanding of the system, however complex associations that were difficult to understand were also derived from rule extraction, suggesting additional information may assist in future understanding of the system.

In many instances, the relationships between factors that define a class are not always clear-cut but rather can be quite fuzzy, particular in environmental models. Fuzzy neural networks have been developed to analyse vague or uncertain relationships in a systematic fashion, incorporating human-like reasoning to derive decision rules (Purvis *et al*, 1997). Combining the attributes of decision trees, fuzzy logic and neural networks, fuzzy neural networks would appear ideally suited to understanding complex environmental systems. Applied previously to determine land use suitability using topography and climate variables (Purvis *et al*, 1997), fuzzy neural networks offer both inference and predictive qualities. Kampichler *et al* (2000) recommended that if the goal of a learning based classification approach is to predict the occurrence of pattern, ANN's are the are the proper tools for achieving that goal. If, however, the understanding of abundance and diversity patterns is also desired, then tree-based models may be more appropriate (Kampichler *et al*, 2000). Fuzzy neural networks offer a combined approach that warrants further comparison with both decision trees and ANN's. The successful application of learning based classification techniques in terrestrial and ecological modeling suggests similar techniques could be adopted to classify and predict marine habitats. A suggested approach is outlined below with reference to the Recherché Archipelago, Western Australia.

4.0 SPATIALLY EXPLICIT MARINE HABITAT MODELING AND PREDICTION

Developing new methods of classification and utilising innovative technologies to better characterise marine habitats is of key relevance to management agencies. Managers require knowledge of the distribution of habitats with verifiable accuracy and reliability. Learning based classifiers can associate measures of accuracy to different classification outcomes, allowing reasoned information to be provided to decision makers. Combined remote sensing and learning based classification approaches can offer a simple modeling environment to not only classify pattern across large areas but also provide reliable measures of classification accuracy from which predictions of habitat occurrence can be made. As marine data collection is inherently costly, predicting the occurrence of habitats allows resources to be spent in areas of importance. For instance, areas that can be distinguished with high accuracy will not need to be sampled, however fuzzy areas where habitats are not easily distinguished from one another may need to be surveyed in more detail. On this basis, the application of learning based classifiers within marine environments would appear highly suitable to both marine researchers and management agencies.

A learning based classification and prediction approach is proposed for delineating fish habitats within the Recherché Archipelago, Western Australia. Located on the south coast of Western Australia near the town of Esperance (Figure 1), the Archipelago is a chain of approximately 105 islands and 1500 islets extending over 470 km of coastline (230 km linear distance) (Lee & Bancroft, 2001). The Archipelago is valued for its marine resources and is an important habitat for numerous commercial fisheries, including Abalone, Pilchard, Shark and the Southern Rock Lobster. The area has also been identified as suitable for a number of aquaculture programs, including the rearing of Southern Blue Fin tuna. However, substantial gaps exist in our knowledge of the marine habitats of the Recherché Archipelago (Kendrick et al, 2002a). Bathymetric data from this area is poor with approximately 33% of the Recherché Archipelago region having inadequate, or no bathymetric information (Kendrick et al, 2002a). The oceanography of the region is yet to be studied in any great detail, either through field, analytical or numerical modelling methods (van Hazel *et al,* 2001). Regional habitat data has only been interpreted at coarse scales from Landsat TM data (Kirkman, 1997) and a broad scale benthic habitat survey conducted using towed underwater video (Fisheries WA & Everall, 1999). The towed video identified eight categories of sea bottom including: Dense seagrass; Medium seagrass; Sparse seagrass; Patchy seagrass; Bare sand; Flat platform or low profile reef; Heavy limestone reef; and Granite reef. Despite these general observations, Fisheries WA and Everall (1999) note that the video record of the surveys contains much more information that could be analysed at a more detailed level to accurately define habitats.

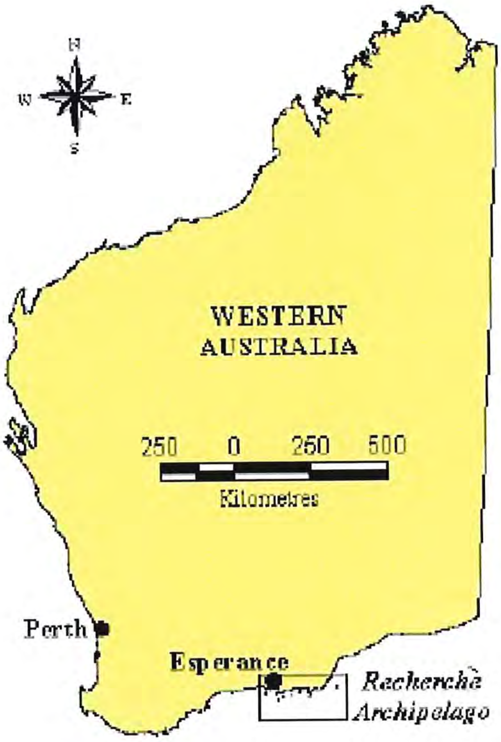


Figure 1: Location of the Recherché Archipelago

This current lack of knowledge presents significant difficulty for both state and local agencies required to make informed planning decisions about the use of marine areas in the Archipelago. The Recherché is a priority area identified by the West Australian Marine Parks and Reserves Authority to undergo the process of marine reserve planning (CALM, 1994). It is expected that this will occur in 2004-2005 given the extensive commercial fisheries within the Archipelago and the popularity of the region for tourism and recreational fishing. A research program, funded by the Fisheries Research Development Corporation (FRDC), has begun to characterise fish habitats of the Archipelago. A primary objective of the overall project is to collect baseline data to enable government agencies and the community to make decisions about the use and management of marine areas and reserves.

The research intends to develop intuitive data collection and classification methods that allow optimal distinction and prediction of marine habitats across the Archipelago. Given the sheer size of the study area, a combination of video sampling, acoustic remote sensing and learning-based classification methods are proposed as a means of optimally identifying habitats. A 'drop camera' video survey has been undertaken to broadly characterise representative habitats of the region. Variables suspected of defining the habitat type, such as exposure, depth, relief, substrate and dominant species types have been characterised at 3000 spatially referenced locations during an eight-week survey (figure 2). A relational marine database management structure has been established within a GIS to act as a framework for streamlining classification of the data, and has been

designed to be adaptable to either a GIS or a learning based classification environment. The architecture of both the GIS database and the marine classification system that it is based upon is such that it is simple enough to be integrated with other systems and applications (Huber and Schneider, 1999) yet practical and easily integrated with the existing state marine classification system (Bancroft, 2002).

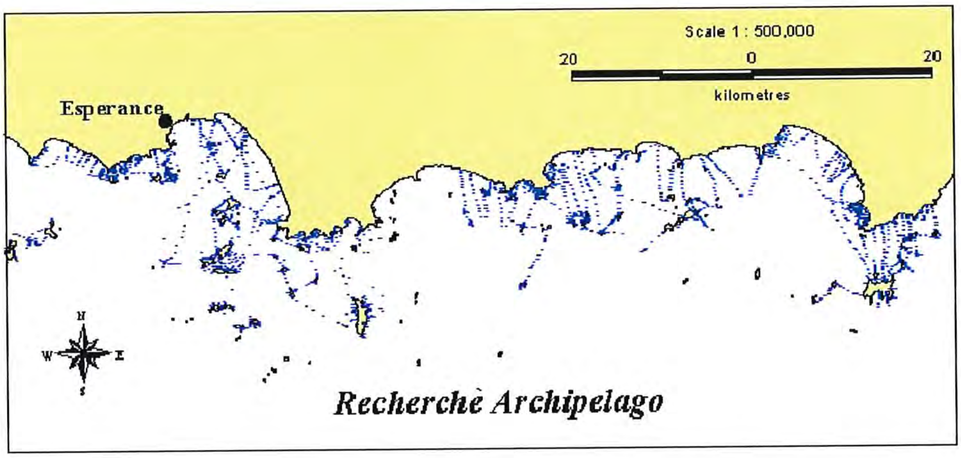


Figure 2: Drop camera video habitat survey locations, Recherché Archipelago.

Derived variables, such as distance to island, slope and surface roughness can also be included in the habitat model. Remotely sensed imagery, such as aerial photography, sidescan sonar and multibeam swath mapper, will be collected to broadly characterise the spatial extent of habitats, through either spectral or textural classification. Processed data can then be used as an additional input to the learning classifier to refine overall habitat classification. Validation of habitat classes, through further ground truth, will allow not only evaluation of the accuracy of the classification approach but will also provide a means for optimising further field sampling. Researchers can focus on discriminating or quantifying the diversity of habitats that are not classified as accurately as others or are of specific interest. From a practical viewpoint, this limits the need for extensive and expensive field surveys, allowing researchers to concentrate their efforts according to their research goals.

The predictive powers of learning based classifiers will also assist in optimising marine field research across large areas. Classifiers, such as neural networks, can be utilised to recognise relationships amongst input features (eg. depth, exposure) to predict the occurrence of output classes (e.g. habitat type). Through a process of weighting and error minimisation the ability of the model to separate habitats and predict habitat occurrence can be explained in terms of a probability or percentage error (Özesmi and Özesmi, 1999). The probability of a habitat being accurately classified can also be represented spatially (see Özesmi and Özesmi, 1999). Assignment of this degree of error or reliability is of key relevance to management agencies, particularly when faced with making difficult planning decisions.

Training learning based classifiers to predict the occurrence of a particular feature in the marine environment need not be limited to habitats. The potential of learning based classifiers to predict habitat occurrence based on relationships between variables contributing to pattern will also help the definition of surrogate habitats. Surrogates or 'indicator species' represent a suite of species commonly found in or associated with a similar habitat. Identifying surrogates offers a means of optimally characterising habitats and habitat diversity across large areas in a cost effective manner. Similarly, prediction of the habitat preferences of particular species can be derived using learning based classification methods. Within 300 of the 'drop camera' locations surveyed within the Recherché Archipelago, fish populations have also been surveyed, using stereo video. Stereo video techniques, developed to accurately and precisely determine the size and age class of marine fauna such as reef fish (see Harvey and Shortis, 1996; Harvey *et al*, 2001) will be used to obtain age-length characteristics of a range of species associated with a particular habitat type. The inclusion of such data in a learning based classifier can identify the habitat preferences of particular species. These fish habitat associations can then be used as a basis for reserve planning that protects not only habitat but also a variety of fish age classes.

5.0 CONCLUSION

Improving the accuracy and cost-effectiveness of mapping marine habitats across large areas requires a new approach. In order to reliably detect and also predict the occurrence of habitats future work needs to overcome the current limitations of traditional classification techniques. This paper proposes the use of decision trees, neural networks and fuzzy neural networks as a means of developing a spatially explicit habitat model to accurately delineate and predict marine habitats. Learning based classifiers and the inferences that may be produced from them can better assist in understanding the processes contributing to habitat formation and the habitat preferences of particular species. The development of simple rules by which habitat relationships can be easily understood will be of practical use to community and management agencies involved in reserve planning and marine management. Decision tree classifiers are ideally suited to this task, however algorithms are increasingly being developed to improve the transparency of neural networks (see Purvis *et al*, 1997; Drumm *et al*, 1999; Özesmi and Özesmi, 1999; Bradshaw *et al*, 2002). Improved understanding of the relationships within neural networks, combined with their predictive abilities makes them an attractive tool for habitat mapping and reserve planning in marine environments.

The success of any model is its interaction with real world problems and decision-making processes (Huber & Schneider, 1999). ANN's, decision trees and fuzzy neural networks will be evaluated within the Recherché Archipelago given the multiple objectives of the habitat mapping exercise. A learning based classification approach, evaluating each method, will allow habitats to be classified and predicted in a spatial explicit modeling environment. The importance of this work will be to provide an efficient means to extract rules from which the community can further understand the processes of habitat formation and researchers can evaluate optimal habitat mapping methodologies. It is hoped that advances in the application of marine remote sensing can be made whilst at the same time highlighting the application of learning based classification approaches in the marine environment (Wright and Goodchild, 1997; Kracker, 1999).

ACKNOWLEDGEMENTS

This research is supported by grant FRDC2001/060 "Characterising the fish habitats in the Recherché Archipelago, Western Australia", awarded by the Fisheries Research and Development Corporation over the period 2001-2004. The research program is jointly carried out by the University of Western Australia, the Australian Institute of Marine Science, the University of Melbourne, the Western Australia Museum and the people of the Esperance region.

REFERENCES

Atkinson, P.M. & A.R.L. Tatnall (1997) Introduction: neural networks in remote sensing. International Journal of Remote Sensing 18, pp699-709.

Bancroft, K.P. (2002). Developing a marine ecological community classification scheme. Report MCB-05/2002. Marine Conservation Branch, Department of Conservation and Land Management, 47 Henry St Fremantle, Western Australia, 6160. Unpublished report, January 2002.

Baxter, K. (1998). Monitoring Coral Reefs at a High Resolution: a Study of Pattern Using Aerial Photography and Image Processing Techniques, Great Barrier Reef, Australia. Unpublished Honours thesis, School of Tropical Environment Studies and Geography (TESAG), James Cook University, Townsville, Australia.

Bell, J.F. (1999). Tree based methods. *In:* Fielding, A.H. (Ed.), Machine Learning Methods for Ecological Applications. Kluwer, pp. 89–105.

Berberoglu S., C.D. Lloyd, P.M. Atkinson & P.J. Curran (2000). The integration of spectral and textural information using neural networks for land cover mapping in the Mediterranean. *Computers & Geosciences* 26, pp385-396.

Benediktsson, J. A., P. H. Swain & O.K. Ersoy (1990). Neural network approaches versus statistical methods in classification of multisource remote sensing data. *IEEE transactions on Geoscience and Remote Sensing* 28(4), pp540-551.

Blackard, J.A. & D.J. Dean (1999). Comparative accuracies of artificial neural networks and discriminant analysis in predicting forest cover types from cartographic variables. *Computers and Electronics in Agriculture* 24, pp131-151.

Blondel, P. & B.J. Murton (1997). Handbook of seafloor sonar imagery. Chichester, England. Wiley-Praxis Publishing.

Bradshaw, C.J.A., L.S. Davis, M. Purvis, Q. Zhou & G.E. Benwell (2002). Using artificial neural networks to model the suitability of coastline for breeding by New Zealand fur seals *(Arctocephalus forsteri)*. *Ecological Modelling* 148:111-131

Breiman, L., J.H. Friedman, R.A. Olshen & C.J. Stone (1984). Classification and Regression Trees. Chapman and Hall, New York.

Brown, C.J., K.M. Cooper, W.J. Meadows, D.S. Limpenny, & H.L. Rees (2002). Small-scale mapping of seabed assemblages in the Eastern English Channel using sidescan sonar and remote sampling techniques. *Estuarine, Coastal and Shelf Science* 54, pp263-278.

CALM (1994). A representative marine reserve system for Western Australia. Report of the marine parks and reserves selection working group. Marine Conservation Branch, Department of Conservation and Land Management, 47 Henry St Fremantle, Western Australia, 6160.

Caudill, M. (1991). Neural network training tips and techniques. *AI Expert*, January 1991, pp56–61.

Chon, T.S., Y.S. Park, K.H. Moon, & E.Y. Cha (1996). Patternising communities by using an artificial neural network. *Ecological Modelling* 90, pp69–78.

Diachok, B. Liorzou, and C. Scalabrin. (2001). Estimation of the number density of fish from resonance absorptivity and echo sounder data. *ICES Journal of Marine Science* 58(1), pp137-153

Debeljak, M., S. Dzeroski, K. Jerina, A. Kobler & M. Adamic¡ (2001). Habitat suitability modelling of red deer (*Cervus elaphus, L.*) in South-Central Slovenia with classification trees. *Ecological Modelling* 138(1–3), pp321–330.

Donoghue, D.N.M. & N. Mironnet (2002) Development of an integrated geographical information system prototype for coastal habitat monitoring. *Computers &Geosciences* 28, pp129 –141

Dowla, F.U. & L.L. Rogers (1995). Solving Problems in Environmental Engineering and Geosciences with Artificial Neural Networks. MIT Press, Cambridge, Massachusetts. pp1-14.

Drumm, D., M. Purvis & Q. Zhou (2000). Spatial ecology and artificial neural networks: modeling the habitat preference of the sea cucumber *(Holothuria leucospilota)* on Rarotonga, Cook Islands. The 11th Annual Colloquium of the Spatial Information Research Centre, University of Otago, Dunedin, New Zealand, December 13-15th 1999

Dzeroski, S., J. Grbovic, W.J. Walley, & B. Kompare (1997). Using machine learning techniques in the construction of models: II data analysis with rule induction. *Ecological Modelling* 95, pp95–111.

Dzeroski, S. (2001). Applications of symbolic machine learning to ecological modeling. *Ecological Modelling* 146, pp263–273

Ellis, F.G. (1997). Evaluating techniques for soil erosion modeling: a role for Artificial Intelligence? PhD thesis, Australian National University.

Evans, F. H., P. C. Caccetta, & R. Ferdowsian (1996). Integrating remotely sensed data with other spatial data sets to predict areas at risk from salinity. *Proceedings of the 8th Australasian Remote Sensing Conference*

Evans, F. (1998). An investigation into the use of maximum likelihood classifiers, decision trees, neural networks and conditional probabilistic networks for mapping and predicting salinity. MSc thesis. University of Western Australia.

Ferns. L.W. and D. Hough (Eds.) (2000). *Environmental Inventory of Victoria's Marine Ecosystems Stage 3 (2nd Edition) - Understanding biodiversity representativeness of Victoria's rocky reef*s. Parks, Flora and Fauna Division, Department of Natural Resources and Environment, East Melbourne, Australia.

Ferns, L.W. & D. Hough (Eds.) (2002). *High Resolution Marine Habitat Mapping of the Bunurong Coast (Victoria) – Including the Bunurong Marine and Coastal Par*k. Parks, Flora and Fauna Division, Department of Natural Resources and Environment, East Melbourne, Australia.

Fisheries WA & Everall Consulting Biologists (1999). Draft aquaculture plan for the Recherché Archipelago, WA: Benthic habitat survey of the Remark, Mart, Mondrain, Tory and York Island groups in the Recherché Archipelago.

Fitzgerald, R.W. & B.G. Lees (1992). The application of neural networks to the floristic classification of remote sensing and GIS data in complex terrain. In: American Society of Photogrammetry and Remote Sensing (Eds.), Proceedings of the XVII Congress ASPRS, Bethesda, MD, pp. 570–573.

Foody, G.M. and M.K. Arora (1997). An evaluation of some factors affecting the accuracy of classification by an artificial neural network. *International Journal of Remote Sensing* 18, pp799-810.

Fu, M. (1994) Rule Generation from Neural Networks. *IEEE Transactions on Systems, Machines and Cybernetics* 28(8), pp1114-1124.

Galway, S. (2000). Comparision of Target Detection Capabilities of the Reson Seabat 8101 and Reson Seabat 9001 Multibeam Sonars. Accessed 10th August 2002. http://www.omg.unb.ca/omg/papers/MBSS_TermPaper.pdf

German, G., M. Gahegan, & G. West (1997). Predictive assessment of neural network classifiers for applications in GIS. *Proceedings of the 2nd International Conference on Geocomputation*, pp41-50.

Green E.P., P.J. Mumby, A.J. Edwards & C.D. Clark (1996) A review of remote sensing for the assessment and management of tropical coastal resources. *Coastal Management* 24, pp1–40

Guissan, A. & N.E. Zimmermann (2000) Predictive habitat distribution models in ecology. *Ecological Modelling* 135, pp147–186

Harvey, E. & M. R. Shortis (1996). A system for stereo-video measurement of sub-tidal organisms. *Marine Technology Society Journal* 29(4), pp10-22.

Harvey, E., D. Fletcher & M.Shortis (2001). A comparison of the precision and accuracy of estimates of reef fish lengths determined visually by divers with estimates produced by a stereo-video system, Fishery Bulletin 99(1), pp63-71

Huang, X. & J.R. Jensen (1997) A machine-learning approach to automated knowledge-base building for remote sensing image analysis with GIS data. *Photogrammetry, Engineering and Remote Sensing* 63(10), pp1185–1194.

Huber, M. & D. Schneider (1999) Spatial data standards in view of models of space and the functions operating on them. *Computers and Geosciences* 25, pp25-38.

Hughes Clarke, J.E., L.A. Mayer, & D.E. Wells (1996) Shallow-water imaging multibeam sonars: A new tool for investigating seafloor processes in the coastal zone and on the continental shelf. *Marine Geophysical Research* 18, pp607-629.

Hughes-Clarke, J.E. (1998) Detecting small seabed targets using high frequency multibeam sonar. *Sea Technology*, June 1998

Kampichler, C., S. Dz¡eroski & R. Wieland (2000). The application of machine learning techniques to the analysis of soil ecological databases: relationships between habitat features and Collembola community characteristics. *Soil Biology & Biochemistry* 32, pp197–209.

Karul, C., S. Soyupak, A.F. Cilesiz, N. Akbay & E. Germen (2000) Case studies on the use of neural networks in eutrophication modeling. *Ecological Modelling* 134, pp145–152

Kendrick, G.A., E. Harvey, J. Hill, J.I. McDonald & S. Grove. (2002a) Characterising the fish habitats of the Recherché Archipelago: Review of existing information, Fisheries Research Development Corporation Project 2001/060. Report to the FRDC.

Kendrick, G.A., M.J. Aylward, B.J. Hegge, M.L. Cambridge, K. Hillman, A. Wyllie & D.A. Lord (2002b). Changes in seagrass coverage in Cockburn Sound, Western Australia between 1967 and 1999. *Aquatic Botany* 73, pp75-87.

Kenny A. J., E. Andrulewicz, H. Bokuniewicz, S. E. Boyd & J. Breslin (2000). An overview of seabed mapping technologies in the context of marine habitat classification. ICES ASC September 2000: Theme session on classification and mapping of marine habitats.

Kirkman, H. (1997). Mapping Australia's underwater features. CSIRO Division of Marine Research, Perth, Western Australia.

Kloser, R. J., J. A. Koslow & A. Williams (1996). Acoustic assessment of the biomass of a spawning aggregation of orange roughy (*Hoplostethus atlanticus*, Collett) off south-eastern Australia, 1990-93. *Marine and Freshwater Research*, 47 (8), pp1015-1024.

Kloser, R.J. & J.D. Penrose (2000). Optimal seabed habitat mapping using multibeam acoustics with associated physical and visual sampling devices – at sea trials. Australian Acoustical Society Conference, Joondalup, Australia. 15-17 November 2000.

Kloser, R.J., N.J. Bax, T. Ryan, A. Williams & B.A. Barker (2001a). Remote sensing of seabed types in the Australian South East Fishery; development and application of normal incident acoustic techniques and associated 'ground truthing ' *Marine & Freshwater Research* 52 , pp475 –89

Kloser, R.J., A. Williams, & A. Butler (2001b). Acoustic, biological and physical data for seabed characterisation. Final Report to the National Oceans Office. Project OP2000-SE02.

Kobler, A. & M. Adamic (2000). Identifying brown bear habitat by a combined GIS and machine learning method. *Ecological Modelling* 135, pp291–300

Kompare, B. & S. Dzeroski (1995). Getting more out of data: automated modelling of algal growth with machine learn-ing. In: Proc. International Conference on Coastal Ocean Space Utilization. University of Hawaii, Hawaii, pp. 209-220.

Kracker, L. (1999). The Geography of Fish: the use of remote sensing and spatial analysis tools in fisheries research. *The Professional Geographer* 51(3), pp440-450

Kvitek, R., P. Iampietro, E. Sandoval, M. Castleton, C. Bretz, T. Manouki, & A. Green (1999). Final Report - Early Implementation Of Nearshore Ecosystem Database Project. Report for California Department of Fish and Game Nearshore Ecosystem Database Project

Lee, S. & K.P. Bancroft (2001). Review of the existing ecological information for the proposed Recherché Archipelago marine conservation reserve. Literature review. MRI/WSA, EUC/SIN, RAR-51/2001 (Marine Conservation Branch, CALM).

Lees, B.G. & K. Ritman (1991). Decision-tree and rule-induction approach to integration of remotely sensed and GIS data in mapping vegetation in disturbed or hilly environment. *Environmental Management* 15, pp823–831.

Lek, S., M. Delacoste, P. Baran, I. Dimopoulos, J. Lauga & S. Aulagnier (1996). Application of neural networks to modelling nonlinear relationships in ecology. *Ecological Modelling* 90, pp39–52.

Mayer, L.. M. Paton, L. Gee, J. Gardner and C. Ware (2000). Interactive 3-D Visualization: A Tool for Seafloor Navigation, Exploration and Engineering. Accessed 14th April 2002. http://www.ccom.unh.edu/vislab/PDFs/3DGIS.pdf

McRea, J.E., H.G. Greene, V.M. O'Connell & W.W. Wakefield (1999). Mapping marine habitats with high resolution sonar. *Oceanologica Acta* 22(6), pp679-686.

Mulhearn, P.J. (2001). Mapping seabed vegetation with sidescan sonar. Defence Science and Technology Organisation, Report TN-0381, Sydney Maritime Operations Division.

Mumby, P.J. (2000). Remote sensing of tropical coastal resources: progress and fresh challenges for the new millennium. In: Sheppard C.R.C. (ed) Seas at the millennium, vol 3. Elsevier, London, pp 283–291

Mumby, P.J., E.P. Green, C.D. Clark, & A.J. Edwards (1998). Digital analysis of multispectral airborne imagery of coral reefs. *Coral Reefs* 17(1): pp59-69

National Oceans Office (1998). Australia's Ocean Policy. Report to the Commonwealth Government.

Özesmi, S.L., & U. Özesmi (1999) An artificial neural network approach to spatial habitat modelling with interspecific interaction. *Ecological Modelling* 116, pp15–31.

Purvis, M., Kasabov, N., Benwell, G., Zhou, Q., and Zhang, F. (1997). Neuro-fuzzy methods for Environmental Modelling. In: *Proceedings of the Second International Symposium on Environmental Software Systems.* Whistler, Canada. pp30 - 37

Quinlan, J.R. (1986). Induction of Decision Trees. *Machine Learning* (1), pp81-106.

Recknagel, F., M. French, P. Harkonen & K. Yabunaka (1997). Artificial neural network approach for modelling and prediction of algal blooms. *Ecological Modelling* 96, pp.11-28.

Setiono, R. and H. Liu (1997). NeuroLinear: From Neural Networks to Oblique Decision Rules. *Neurocomputing* 17(1), pp.1-25.

Sotheran I.S., R.L. Foster-Smith & J. Davies (1997). Mapping marine benthic habitats using image processing techniques with a raster based geographic information system. *Estuarine & Coastal Shelf Science* 44(suppl A), pp25–31

Thamrongnawasawat T., and Catt P., 1994, High resolution remote sensing of reef biology: the *application of digitised air photography to coral mapping.* Proceedings of the 7th Australasian Remote Sensing Conference, Melbourne. *pp690–697.*

Van Hazel, J.H., C. Pattiaratchi & N. D'Adamo (2001). Review of the climate and physical oceanography of the Recherche Archipelago and adjacent waters. A report prepared for the Department of Conservation and Land Management of Western Australia by Centre for Water Research, The University of Western Australia.

White H. (1989) Learning in Artificial Neural Networks: A statistical Perspective. *Neural Computation* 1(2), pp425-464.

Wright, D.J. (1999) Getting to the bottom of it: Tools, techniques, and discoveries of deep ocean geography. *The Professional Geographer* 51(3), pp 426-439.

Wright, D. J. and Goodchild, M. F. (1997) Data from the deep: implications for the GIS community. *International Journal of Geographical Information Systems* 11(6), pp523-528.

Broad Scale Classification and Prediction of Marine Habitats: integrating GIS and rule based modelling

Katrina J. Baxter

Faculty of Engineering, Royal Melbourne Institute of Technology,
Melbourne VIC 3000

Abstract

Often presented with the difficulty that data do not exist for areas of interest or are scarce and expensive to collect, the challenge for marine geographers is to develop optimal mapping techniques to intelligently classify large areas of marine habitat in an accurate, timely and costeffective manner. Representative habitat types can be surveyed using a range of methods, including video and remote sensing technologies, such as Landsat and sidescan sonar. This paper outlines a methodology for integrating data from a range of sources to (1) classify and (2) predict marine habitats using GIS and rule-based classification. Rule based classification methods, such as decision trees and genetic algorithms, are discussed to illustrate how rules can be derived from physical factors to help define habitat type and extent. These rules may then be applied in a GIS context to predict habitat distribution and community composition in areas that are unsurveyed. The methodology is discussed with reference to mapping and predicting habitats within the Recherché Archipelago, Western Australia.

Introduction

Traditionally, marine ecologists have characterised shallow water marine habitats according to their biological community composition, typically using direct sampling methods such as grab sampling and diver surveys. However, such an approach may not be cost effective when attempting to characterise the extent of habitats across large areas. Whilst recognising that biological sampling is still important, methods are required that address the paucity of spatial data available for mapping habitat extent.

Increasingly large area habitat mapping is best undertaken using a combination of remotely sensed data and video observations, as a means of providing a broad spatial context to marine research that is not achieved through traditional biological sampling methods alone (Kvitek *et al.*, 1999; Kracker, 1999; Kloser *et al.*, 2001). A number of remote survey methods can be used to classify marine habitats and their spatial boundaries from either a spectral or textural signature (for a full review of habitat mapping methods, their resolution and cost refer to Kvitek *et al.*, 1999). Spectral methods, including aerial photography and satellite imagery are very cost effective in terms of coverage but their value in delineating habitats is limited to shallow waters, due to the limits of light penetration. Advances in textural or acoustic remote sensing have helped overcome the limitation of light penetration and technologies, such as sidescan sonar and multibeam swath mapping, have delivered opportunities to remotely sample seafloor texture and depth in waters as deep as 200 metres (Mayer *et al.*, 2001; Kloser *et al.*, 2001; Brown *et al.*, 2002; Ferns & Hough, 2002). However, acquisition costs for these acoustic methods are several orders of magnitude higher than spectral techniques (Kvitek *et al.*, 1999), prohibiting most management agencies from obtaining full coverage of actual habitat types using these methods alone.

Given the limitations of equipment and budget constraints, gaps in habitat coverage will exist across large sections of the marine environment. An improved understanding of what factors or processes might contribute to the formation of particular habitat types would assist in addressing these gaps. Usually some combination of biological, oceanographic and physical factors are presumed to control the distribution of species and resulting habitat types (Day & Roff, 2000). These factors may include: depth, exposure, substrate type, relief, surface roughness, temperature, current strength and the presence or absence of other species. A number of these factors may be relatively easily collected by the sensor itself or derived retrospectively using the analysis capabilities of Geographic Information Systems (GIS). Significant opportunities exist to learn more about how these physical factors control marine habitat formation.

There are few examples of the classification of marine habitat types in a spatial context using physical factors (although see De'ath & Fabricius, 2000; Barrett *et al.*, 2001; Roff *et al.*, 2003) and even fewer still of how these factors might be used to predict where habitats occur in areas that are unsurveyed (except see Zacharius *et al.*, 1999 and Bradshaw *et al.*, 2002). In this sense, many lessons can be learnt and applied from the classification of terrestrial landscapes, which has been the focus of a number of research areas, including soil science, remote sensing, landscape ecology and spatial analysis. Research directions in these fields have shown a shift from classification of landscape features using single factors alone (e.g. pixel value) to those rule based classification techniques that allow the use of multiple factors to describe and also *predict* pattern in a spatial context (for review see Baxter & Shortis, 2002).

Applied in a marine context, these methodologies are expected to produce relatively easy to understand rules as to how important physical factors are in shaping habitats. Rules derived from physical factors may be sufficiently reliable indicators or "surrogates" of marine habitat types, just as habitats may acts as effective indicators of species community composition (Zacharius *et al.*, 1999; Day & Roff, 2000; Barrett *et al.*, 2001). As yet these methodologies and analyses are largely unrealised in the marine environment and few guidelines exist to integrate the research objectives of marine ecologists and geographers. This paper outlines opportunities for integrating existing, derived or newly captured data from a range of survey methods to facilitate the classification and prediction of representative habitat types and species composition, at a range of scales consistent with ecological and management objectives. The proposed methodology is outlined with particular reference to mapping and predicting the habitats of the Recherché Archipelago.

Habitat mapping in data poor regions – application to the Recherché Archipelago

Substantial gaps exist in our knowledge of the marine habitats of the Recherché Archipelago (Kendrick *et al.*, 2002). Located on the south coast of Western Australia near the town of Esperance (Figure 1), the Archipelago is a chain of approximately 105 islands and 1500 islets extending over 470 km of coastline (230 km linear distance) (Lee & Bancroft, 2001). The Archipelago is valued for its marine resources and is an important habitat for numerous commercial fisheries, including Abalone, Pilchard, Shark and the Southern Rock Lobster. The current lack of knowledge of the extent and type of marine habitats presents significant difficulties for both state and local agencies required to make informed planning decisions about the use and management of marine areas in the Archipelago. A research project, funded by the Fisheries Research Development Corporation (FRDC), is underway to provide baseline information about the distribution of habitats within the Archipelago (see Kendrick *et al.*, 2002 and Baxter & Shortis, 2002). Given the sheer size of the study area, a combination of video sampling, acoustic remote sensing and rule-based classification methods is proposed as a means of optimally identifying habitats and their biological and physical characteristics.

Key stages of the Recherché project are briefly outlined below to illustrate the integration of GIS and rule based classification in a marine context. Stages include: (1) classification scheme design (2) collection of data sources using a range of survey methods (3) integration of data into a GIS to produce classified and derived datasets (4) development of rule based classification techniques to predict probable habitat types and (5) predicting species-habitat associations (Figure 2). The project is currently in stages 2 and 3. Future stages are briefly outlined to illustrate the potential application of the methodology for marine habitat mapping and prediction. Although issues of scale, habitat validation and accuracy assessment are also fundamental to the classification and prediction results, these will be the subjects of future publications.

Classification scheme

A hierarchical marine classification scheme was established, in conjunction with a relational GIS database to assist data collection and enable comparison of information collected from different data sources (eg. diver, video, Landsat and sidescan). The scheme was based on physical descriptors of the observed habitat, such as depth, substrate, relief, dominant habitat type and the degree of cover. The presence (and absence) of other biological components of that habitat (in terms of observed species groups) was also noted. More specific habitat classifications can be described by querying physical and biological factors of the scheme. For example, substrate = reef, relief = gently sloping (5-25 degrees), habitat = macroalgae, cover = dense equates to low profile reef with dense macroalgae. The scheme underlies each stage of the project. The input, processing and production of data and habitat boundaries from a range of data sources and spatial resolutions is accommodated by the scheme, linking the ecological aspects of habitat mapping with the data collection and analysis stages.

Data collection and development of GIS data sources

In any region a range of data sources may be available to assist in classifying habitat types. Cost restraints usually dictate that survey methods are determined by what can be mapped from available data or readily obtained using a combination of remote sensors and inexpensive sampling methods, such as video (Day & Roff, 2000; Kloser *et al.*, 2001). Data to classify habitat types within the Recherché Archipelago has been derived from existing data sources or collected using a variety of survey methods for input and processing within a GIS (Figure 3).

Video and sidescan sonar have primarily been used within the Archipelago to collect new information on habitat types and physical factors that may explain their formation. A 'drop camera' video survey was undertaken to define representative habitats at 3000 locations. Habitats from the video were defined according to the physical factors identified in the classification scheme, such as depth, relief, substrate and exposure, as well as the dominant biological components observed. This data is primarily intended for use in identifying representative habitats, as well as in analysis that derives rules by which habitats are classified and predicted. The data can also be used to undertake simple mapping of habitat boundaries, although the discrete nature of the video drops limits the actual coverage of the survey, despite the number of samples. To avoid misleading representations of the complex distribution of habitat types in between these video drops, other indicators of the spatial extent of habitats are needed to map marine habitats. Sidescan surveys were conducted to provide spatial data layers such as habitat type, substrate type and surface roughness across broad areas. Video was used to validate differences in the sidescan record and will also be used to test the results of future habitat predictions.

Establishing a GIS provides a basic framework for integrating a wide variety of data sources in a standard way (Bartlett, 2000). The data can be readily used to undertake simple mapping and validation of habitat boundaries or to maximise the full potential of the data, the GIS can be used to derive additional factors, or combinations of factors. These factors or GIS layers can then be exported for analysis using other methods, such as rule-based classification, to derive rules by which habitats can be predicted in areas that are unsurveyed (see Figure 3). For a 7 x 7 km test area in Esperance Bay, data layers have been compiled of habitat types and physical factors for use as training datasets in the rule based classification stage of the project (Figure 4). The data layers will be used to not only map but also predict the occurrence of habitat types. The habitat layer has been developed using a combination of video, sidescan and Landsat imagery. Readily obtained, existing Landsat TM imagery can been used to broadly characterise the spatial extent of habitats in shallow waters (less than 30m deep). Trial enhancement and classification methodology was applied to the imagery to broadly define bare substrates from vegetated habitat types in shallow areas (personal communication, Ross Dodds). Accuracy assessments of the classification using video validation data indicate an overall accuracy of 84%. Producer accuracy results indicated bare areas were identified correctly 74% of the time and vegetated areas in 86% of cases.

Utilised across the Archipelago in conjunction with sidescan mapping, this approach will further assist in characterising the spatial extent of habitat types. Physical factors identified as being important in determining habitat type such as, depth, relief, exposure and current strength have also been compiled for the test area. Relief and slope layers were interpolated in unsurveyed areas from existing bathymetry data. The layers were validated using depth data collected during the video survey. Other important factors, such as exposure to swell and current strength have been derived from an existing oceanographic model of the Archipelago (Pattiarachi, 1998).

Habitat Prediction – applying rule based classification methods

Through a process of iterative learning, rule-based classification methods, such as decision trees and genetic algorithms, are able to classify a single response variable (eg. habitat type) using a number of explanatory variables (eg. depth; relief; substrate etc). The data is repeatedly split into two mutually separable groups. From all possible splits, the classifier chooses a split that maximises the homogeneity of the two groups, each time defining a rule to explain the split (for a review refer to De'ath & Fabricius, 2000 or Anderson *et al.*, 2002). The rules are presented as a series of if–then statements, which can then be applied to physical data within a GIS to classify and predict habitat occurrence in a spatial context (Anderson *et al.*, 2002).

Future work will use rule-based methods to classify and predict the spatial extent of habitats, initially within the test area, using different combinations of physical factors. The data layers compiled will be used, as opposed to discrete data points (such as video), allowing the model to define spatial regions or probable habitats for areas that have similar physical characteristics (Anderson *et al.*, 2002). Certain factors (eg. substrate and relief) may be the major determinants of particular classes (or habitat types) (De'ath & Fabricius, 2000; Anderson *et al.*, 2002). Similarly, some classes (or habitat types) may be explained well by the physical inputs available, others not so, limiting the ability of the process to predict their distribution. This may be a function of the training data or alternatively, these classes may be extraordinary or rare habitats (eg. sponge gardens or temperate water corals) that are difficult to characterise (Day and Roff, 2000).

Over time as our knowledge of habitats and their specific characteristics improves, so to will be ability to classify and predict them (Roff *et al.*, 2003). The proposed methodology establishes a framework that works toward continual improvement of the classification and prediction of habitats, allowing new factors or combinations of factors to be easily added to the classification 'framework' as they become available. Different scenarios can be modelled that exclude different factors, accounting for the likelihood that different factors or layers of information will typically be available for large areas. Given the data available, realistic mapping and prediction outputs can then be set. For example, if only depth and relief data are available, but substrate type is known to be a major influence on habitat formation, then the value of predictive modelling will be limited and cannot substitute the value of actual habitat surveys. From a practical viewpoint, rule-based classification methods can assist in optimising future field surveys. Efforts can be focussed on discriminating habitats that are not easily classified or are of specific importance to particular research and management objectives.

Linking biological data to predict probable species composition of habitat types

Ultimately, rules used to map habitats on broad scales could be used to infer or predict species composition within those habitats. The combination of GIS and rule-based classification is an effective technique for quantitatively assessing broad scale biological composition of large areas (Zacharius *et al.*, 1999). Such a method provides a link between the more commonly used species level approach that assesses biological composition and the proposed regional habitat level approach that utilises easily defined physical factors. As with habitat prediction, regional and state agencies can use defined species-habitat associations for the purposes of identifying, conserving and managing representative, distinct and rare communities effectively across large areas (Zacharius *et al.*, 1999; Day and Roff, 2000). Similarity in the abundance of species is commonly compared to identify groups of species sharing similar characteristics using clustering or multidimensional scaling techniques. This data can then be used to quantitatively determine the likely abundance of particular species within habitat types mapped by the GIS. The species composition can be stored as linked attributes to habitat types. The habitat preferences of particular species can also be determined and "hot spots" of species abundance or diversity outlined. Species composition data for macroalgae, seagrass, sponges, soft sediment fauna and fish have recently been collected within the Recherché Archipelago and can be combined with predicted habitat distribution outputs. For example, fish populations have been surveyed using stereo video within 300 of the 'drop camera' locations surveyed within the Archipelago. Stereo video techniques, developed to accurately and precisely determine the size and age class of marine fauna such as reef fish (see Harvey *et al.*, 2001), will be used to obtain age-length characteristics of a range of species associated with a particular habitat type. Fish habitat associations may then be used as a basis for reserve planning that protects not only representative habitats but also a variety of fish age classes.

Conclusions

It is expected improved habitat mapping technologies will become available in the future, although the use of these survey methods will most likely still be constrained by the costs of surveying large areas at appropriate scales. To address the inevitable data gaps created by these limitations, analysis methodologies are needed to quantitatively predict marine habitats in areas unsurveyed (Zacharius *et al.*, 1999; Roff *et al.*, 2003). Up until this point, most habitat mapping research has focussed primarily on data collection methodologies. There are few established guidelines to assist new habitat mapping projects in integrating different data sources and more importantly, applying appropriate analysis techniques to identify how best to classify and predict habitats. The proposed methodology applied to the Recherché, incorporates not only data survey and management but integrates actual analysis and prediction. The development of predictive analysis methods provides an opportunity to obtain an increased understanding of what factors are driving habitat formation, satisfying the goals of both ecologists and marine geographers. Although the methodology is still in development, it establishes a repeatable basis or framework for the results of this research to be related to similar research examples implemented in the future by marine geographers and GIS analysts.

Acknowledgments

This research is supported by Fisheries Research and Development Corporation grant 2001/060 "Characterising the fish habitats in the Recherché Archipelago, Western Australia", awarded for the period 2001-2004. The research program is jointly carried out by the University of Western Australia, Royal Melbourne Institute of Technology, the Australian Institute of Marine Science and the people of the Esperance region, who have helped make the extensive data collection possible. Special thanks to Andy Bickers for the development of the field data collection equipment and his ongoing advice and enthusiasm. Other researchers involved in the project, including Dr Mark

Shortis, Dr Gary Kendrick, Dr Euan Harvey, Nisse Goldberg and Simon Grove have provided valuable advice and assistance in field research, data collation and development of prediction concepts.

References

Anderson, R.P., Lew, D. & Townsend Peterson, A. 2002. Evaluating predictive models of species' distributions: criteria for selecting optimal models. *Ecological Modelling*, 162: 211–232.

Bancroft, K.P. 2002. Developing a marine ecological community classification scheme. Report MCB-05/2002. Marine Conservation Branch, Department of Conservation and Land Management, 47 Henry St Fremantle, Western Australia, 6160. Unpublished report, January 2002.

Barrett, M., Sanderson, J.C. , Lawler, M., Halley, V. and Jordan, A. 2001. Mapping of Inshore Marine Habitats in South -eastern Tasmania for Marine Protected Area Planning and Marine Management. Marine Research Laboratories, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania.

Bartlett, D.J. 2000. Working on the frontiers of science: Applying GIS to the coastal zone. In Wright, D.J. and Bartlett, D.J. (eds) *Marine and Coastal Geographical Information Systems*.Taylor & Francis, London, pp11-24.

Baxter, K. & & Shortis, M. 2002. Identifying Fish Habitats: the use of spatially explicit habitat modeling and prediction in marine research. The 14th Annual Colloquium of the Spatial Information Research Centre (SIRC), University of Otago, Dunedin, New Zealand.

Bradshaw, C.J.A., Davis, L.S., Purvis, M., Zhou, Q. & G.E. Benwell, G.E. 2002. Using artificial neural networks to model the suitability of coastline for breeding by New Zealand fur seals *(Arctocephalus forsteri*). *Ecological Modelling* 148:111-131

Brown, C.J., Cooper, K.M. Meadows, W.J. Limpenny, D.S. & Rees, H.L. 2002. Small-scale mapping of seabed assemblages in the Eastern

English Channel using sidescan sonar and remote sampling techniques. *Estuarine, Coastal and Shelf Science* 54: 263-278.

Day, J.C. and Roff, J.C. 2000. Planning for Representative Marine Protected Areas: A Framework for Canada's Oceans. Report prepared for World Wildlife Fund Canada, Toronto.

De'ath, G. & Fabricius, K. 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. *Ecology* 81: 3178-3192.

Ferns, L.W. & Hough, D. (Eds.) 2002. *High Resolution Marine Habitat Mapping of the Bunurong Coast (Victoria) – Including the Bunurong Marine and Coastal Par*k. Parks, Flora and Fauna Division, Department of Natural Resources and Environment, East Melbourne, Australia.

Harvey, E., Fletcher, D. & Shortis, M. 2001. A comparison of the precision and accuracy of estimates of reef fish lengths determined visually by divers with estimates produced by a stereo-video system, *Fishery Bulletin* 99(1):63-71

Kendrick, G.A., Harvey, E., Hill, J., McDonald, J.I. & Grove. S. 2002. Characterising the fish habitats of the Recherché Archipelago: Review of existing information, Fisheries Research Development Corporation Project 2001/060. Report to the FRDC.

Kloser, R.J., Williams, A. & Butler, A. 2001. Acoustic, biological and physical data for seabed characterisation. Final Report to the National Oceans Office. Project OP2000-SE02.

Kracker, L. 1999. The Geography of Fish: the use of remote sensing and spatial analysis tools in fisheries research. *The Professional Geographer* 51(3): 440-450

Kvitek, R., Iampietro, P., Sandoval, E., Castleton, M., Bretz, C., Manouki, T, & Green, A. 1999. Final Report - Early Implementation Of Nearshore Ecosystem Database Project. Report for California Department of Fish and Game Nearshore Ecosystem Database Project

Lee, S. & Bancroft, K.P. 2001. Review of the existing ecological information for the proposed Recherché Archipelago marine conservation reserve. Literature review. MRI/WSA, EUC/SIN, RAR-51/2001 (Marine Conservation Branch, CALM).

Mayer, L., Paton, M., Gee, L., Gardner, J. and Ware, C. 2000. Interactive 3-D Visualization: A Tool for Seafloor Navigation, Exploration and Engineering. Accessed 14th April 2002. http://www.ccom.unh.edu/vislab/PDFs/3DGIS.pdf

Pattiaratchi, C.B. 1998. Assessment and modelling of oceanographic conditions at four potential sites for tuna fattening in Esperance. Report prepared for Fisheries WA. UWA, Centre for Water Research reference WP 1391 CP.

Roff, J.C., Taylor, M.E., & Laughren, J. 2003. Geophysical approaches to the classification, delineation and monitoring of marine habitats and their communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 13: 77-90.

Zacharias, M.A., Morris, M.C. & Howes, D.E. 1999. Large scale characterization of intertidal communities using a predictive model. *Journal of Experimental Marine Biology and Ecology*, 239: 223-241.

Figure 1.

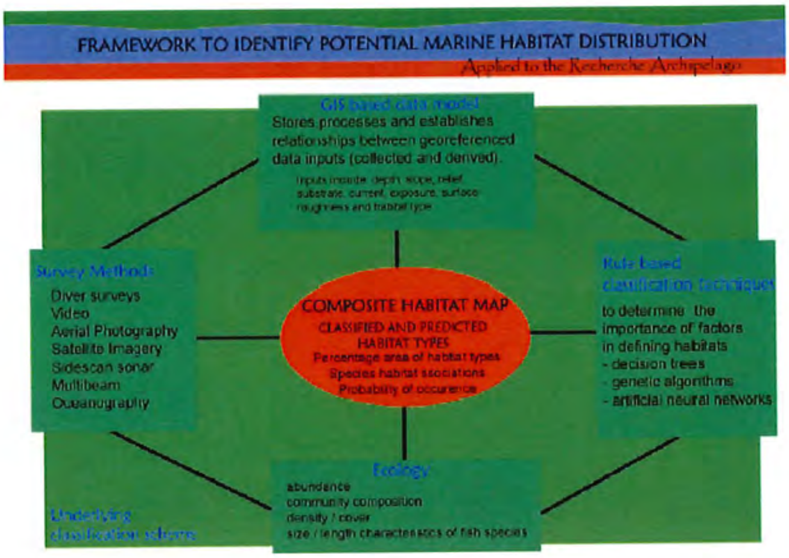


Figure 2.

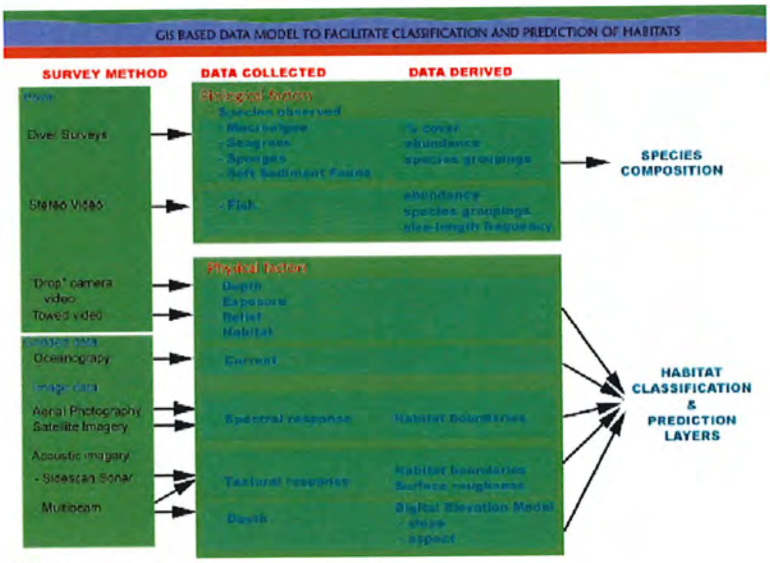


Figure 3.

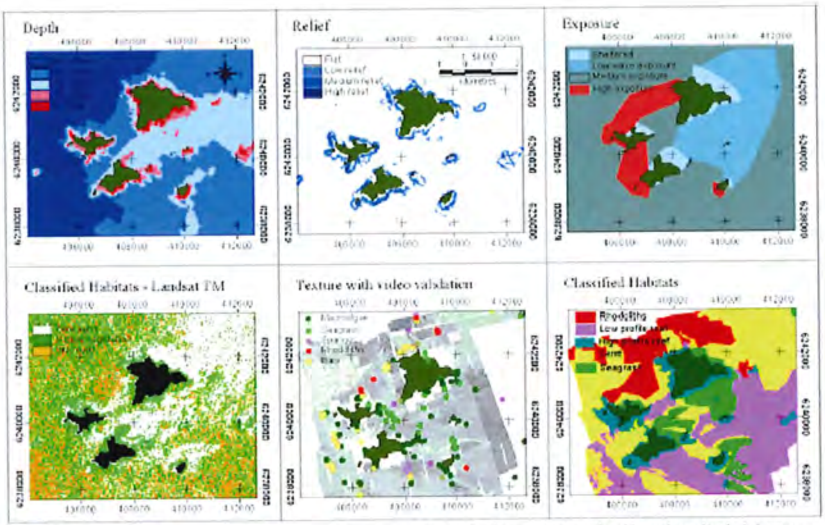


Figure 4. Spatial inputs used to classify and predict habtiat types

Figure 4.

Cost Effective Marine Habitat Mapping from Small Vessels using GIS, Sidescan Sonar and Video.

Andrew Neil Bickers

Ph.D. Student / Engineer

Marine Science Group, School of Plant Biology, University of Western Australia, Hackett Drive, Crawley, WA 6009.

andyb@cyllene.uwa.edu.au

Abstract

High frequency sidescan sonar has been popular for mapping and visualisation of the sea floor since the early 1980's. In the past decade the availability of affordable portable personal computer based digital acquisition and processing software has breathed new life into this technology. Similar improvement in video technology has bred underwater video systems that are reliable, small and inexpensive. This evolution has been supported by the rapid exploitation of Global Positioning Systems (GPS) and Geographical Information System (GIS) technology.

Here I describe the packaging of all these technologies into a cost-effective system for mapping shallow water continental shelf habitats. This paper details the fusion of commercially available sidescan equipment and third party software with video system hardware and software developed by the author into a portable package that can be deployed efficiently from vessels as small as 7 m. GIS software such as ArcGIS™ was used intensively for navigation, interpretation and visualisation during both data acquisition and processing.

The utility of surveying using the combined sidescan and towed video system is demonstrated by mapping coastal benthic habitats from the Recherche Archipelago, Western Australia. Over 60 km^2 was mapped for as part of a larger Fisheries Research Development Council (FRDC) project characterising the fish habitats of the Recherche Archipelago. The results demonstrate how accurate and efficient seabed mapping can be performed in shallow water and details of the required infrastructure and capital outlay are provided.

Introduction

The nearshore benthic marine environments of Australia contain a diverse range of habitats including temperate and tropical reefs, seagrass meadows and a variety of vegetated and unvegetated sediments. Effective environmental management of these areas requires the production of base maps of physical and biological resources. Much effort has recently been directed towards the mapping and classification of marine areas in terms of their diversity and spatial distribution of habitats. Scientists often assess habitats to understand the distribution and relative abundance of marine resources (Stanbury & Starr, 1999). Habitat is normally defined as the place in which a species lives (e.g. rocky sub-tidal habitat) or as being characterised by the dominant life form (e.g. kelp forest habitat) (Kvitek, et al., 1999; Greene, et al., 1999). Resource management agencies are becoming ever more reliant on maps of habitat type at different scales to predict the real or potential distribution of species or communities that are difficult to survey directly (Davies, et al., 1997). Marine habitat mapping is also identified by the Australian Government (IMCRA, 1998) as an important component of micro-scale regionalisation, through assessment of the spatial extent and boundaries of ecological units. This mapping is currently underway in many coastal regions to assess the current and potential impacts of coastal developments on the near shore marine environment (e.g. mining, port developments and aquaculture).

Due to the poor propagation of electro-optical waves in water, the use of hydro-acoustics is widely accepted as the only way to map the seafloor on a broad scale at any significant depth (Blondel, 1997). This differs markedly from the techniques used in the production of habitat maps in terrestrial systems which are typically produced by cost effective optical and radar remote sensing techniques deployed using planes or satellites. Video systems may provide an easily interpretable record of the seabed, but their field of view is limited and dependant upon sea state and water conditions. New airborne electro-optical techniques such as CASI and LIDAR have significantly improved survey speeds, but are limited by resolution, cost and water penetration. (Kvitek, et al., 1999).

Various hydro-acoustic (sonar) systems are used in mapping the surface of the seabed. All rely on analysis of the timing, strength and angle of the reflected waves received from a transmitted sonic pulse incident on the seafloor. Where single beam echo sounders in combination with digital acoustic ground discrimination systems can provide water depth and indices relating to the nature of the substrate below the vessel, multibeam and sidescan sonars provide continuous information about the seabed over a wide swath. Sidescan sonar provides little information about the bathymetry of the area surveyed, but the acoustic ‘backscatter’ recorded is of a high resolution and infers much about the texture of the seabed. Although multibeam systems can be used to provide both bathymetry and information about the substrate, the textural information obtained is generally of a lower resolution than for sidescan. Records obtained from both types of systems require processing and interpretation and, with accurate vessel positioning, successive swaths can be mosaicked into composite acoustic images of the seabed.

Sidescan sonar is a proven technology which has historically been used for detection and monitoring of objects on the seabed. In the last ten years however, it has become commonly employed in broad scale characterisation of the seabed itself. This usually involves either visual or automated segmentation of the acoustic image into discernibly different textural regions which are then related to habitat type or dominant biota. As with most remote sensing techniques, the objects of interest may be below the resolving capabilities of the equipment and supplementary data is required to accurately identify the substrate and community of each area. This supplementary data can take many forms, depending on the accuracy and type of information that is required, but is commonly obtained by diver, grab or video (Kvitek, et al., 1999; Blondel, 1997).

It is important to note that the improved availability of accurate positioning from the Global Positioning System (GPS) satellite array and the development of personal computer based sonar acquisition and processing systems at reasonable cost, has allowed the exploitation of these technologies by agencies and institutions that it would not have previously been available to. The advent of desktop and portable Geographical Information Systems (GIS) means that biological and physical data referenced to geographic coordinates can now be merged, layered, analysed and displayed at many scales (Kvitek, et al., 1999; Stanbury & Starr, 1999).

The aim of the research described here was to provide a continuous map of the distribution and boundaries of the main types of benthic habitats and dominant communities of the area surrounding the Woody Island group in the Recherche Archipelago, Western Australia using sidescan sonar and video techniques.

The results demonstrate how accurate and efficient seabed mapping can be performed in shallow water from vessels as small as 7 m without large capital outlay and infrastructure.

Methods

A combination of sidescan, video, GPS and GIS was used by the University of Western Australia in this study to perform benthic mapping of shallow continental shelf habitats. The system is based on a traditional analogue sidescan system combined with a contemporary digital acquisition and processing system. Classification of the sidescan imagery

into habitat types is supported with independent data sourced from georeferenced towed video. The utility of this combination is tested by mapping coastal benthic habitats from the Recherche Archipelago, Western Australia.

The Recherche Archipelago is located on the South coast of Western Australia. This region of open coast comprises about 150 islands and 1500 known 'extrusions' and comprises large zones of unsurveyed territory. The islands are scattered over 470 km of coastline, no further than 60 km offshore and in depths of up to 80 m. In this area the continental shelf encroaches on the mainland to within as little as 50 km (Clarke, 1952). Islands are formed from granite and gneiss which are similar to the isolated often dome shaped hills that dominate the coastline of the area (Myers, 1990). These islands are separated from each other and the mainland by sandy habitats, punctuated unpredictably by reefs which are often inundated by sand. More sheltered sandy areas typically support dense seagrass communities with the shallower reefs being dominated by algae. Reefs found in deeper water may be colonised by sponges, bryozoans and ascidians.

This study was carried out during May 2003 in calm to moderate conditions with seas and swell to 1m and winds to 20 knots. Two days of sidescan sonar survey were undertaken followed by a day of video validation. Classifications of points from a previous drop video survey were also used.

The following sections outline the acquisition, processing, analysis and display methods for the sidescan and video data.

Sidescan Sonar Acquisition and Processing

Sidescan sonars utilise two sensors each ensonifying a 'swath' of seafloor each side of a towed torpedo-shaped 'fish'. These transducers produce a thin fan shaped beam that is concentrated on the seabed in a line that runs from below the fish, perpendicularly out to the maximum range on each side. The forward motion of the device allows the beams to cover a wide swath of the seabed (Figure 1). The two transducers simultaneously emit a sonic pulse at a particular frequency. As the transmitted pulse interacts with the seafloor at angles off normal, most of the energy is reflected away from the transducer. The small amount of this backscattered energy that is received, is amplified and recorded by a digital acquisition system. This recording occurs over an extended period allowing for returns to be obtained out to the selected maximum ground range. The line of data obtained after each pulse, is considered a function of time. Using the speed of sound in water the distance from the fish for each position along this line can be predicted (Fish & Carr, 1991). Signal levels are digitally sampled and as the transducers move forward

subsequent lines of data are built up to form an acoustic image of the area. This image is a record of the instantaneous intensity of the backscatter and is affected by the following factors in decreasing order of importance.

- Sonar frequency (higher frequencies give higher resolution but attenuate more quickly with range than lower frequencies).

- The geometric relationship between the transducer and the target object (slope).
- Physical characteristics of the surface (texture)
- Nature of the surface (composition, density)

(after Kvitek, et al., 1999)

The unprocessed signal shown in Figure 2 shows a number of distinct areas. The nadir is shown as a black central line. This is an artifact of the emitted pulse. The water column below the fish is shown by the lighter area each side of the nadir and the width of this is dependant on the altitude of the fish above the seabed. The imagery each side of the water column represents the texture of the substrate and its benthos. Areas of that produce a stronger return are shown as darker.

Although this image yields much information about the composition and communities of the seabed it can be subjected to further processing. The water column is removed by 'bottom tracking' and 'slant range' geometric distortions which compress the record of areas near the transducer are corrected. Corrections can also be made to the data to compensate for radiometric distortions related to the attenuation of signal with distance and grazing angle (Fish & Carr, 1991; Blondel, 1997). As the position and heading of the vessel for each ping is recorded from the GPS, the processed data can be displayed correctly in geographical space. Compensation can also be made for the 'layback', which is the distance the towed body trails behind the GPS antenna mounted on the vessel. A fully processed example is shown in Figure 3. Multiple vessel tracks can be processed into a full coverage mosaic of the area surveyed.

The equipment used in surveys described here is comprised of a standard Edgetech 272T 100 kHz towed fish and 260TH surface unit. This type of system has a maximum range of 200 m per side (dependant on depth) and good quality images can be obtained at speeds of up to 6 or

7 knots. Although this unit is capable of providing a thermal paper chart output, signals are routed to a laptop based digital acquisition system. This commercially available system is supplied by ChesapeakeTechnologies of Mountain View, California in the form of three programs- SonarWiz, SonarWeb and Real Time Mosaicking (RTM). In order to maintain versatility the laptop, sounder and GPS are mounted in a ruggardised plastic case and can be powered by a 12v deep cycle lead acid battery.

While surveying, SonarWiz software is used to acquire sidescan data through an analogue to digital card mounted in the laptop. For each survey track this provides an industry standard XTF™ file containing position, heading, depth obtained from single beam echo sounder and backscatter amplitude information for each ping. There are a maximum of 4096 samples recorded per channel for each ping in 256 (8 bit) quantised levels. RTM software displays the positioned sonar output in real-time and ArcPad is used to provide live navigational capabilities. The screen grab shown in Figure 4 shows an example of the sonar acquisition software, RTM and ArcPad running simultaneously.

Postprocessing and mosaicking is completed using SonarWeb software, producing a composite image with a resolution of typically 1 m per pixel. This fully processed sidescan mosaic is then segmented visually into areas of different texture, patterning or morphology. Suitable tracks for video data collection are identified that will sample representative examples of the acoustically distinct regions of the sidescan mosaic. Areas to be sampled are chosen to include transitions, boundaries and patchy areas as well as areas of specific interest. Centres of visually similar regions are also commonly sampled as these can assist in gaining an idea of the differences in density of benthos compared with the periphery of the same region. Quite rapidly a ‘library’ of identifiable textures is created which reduces the need to sample similar textures again.

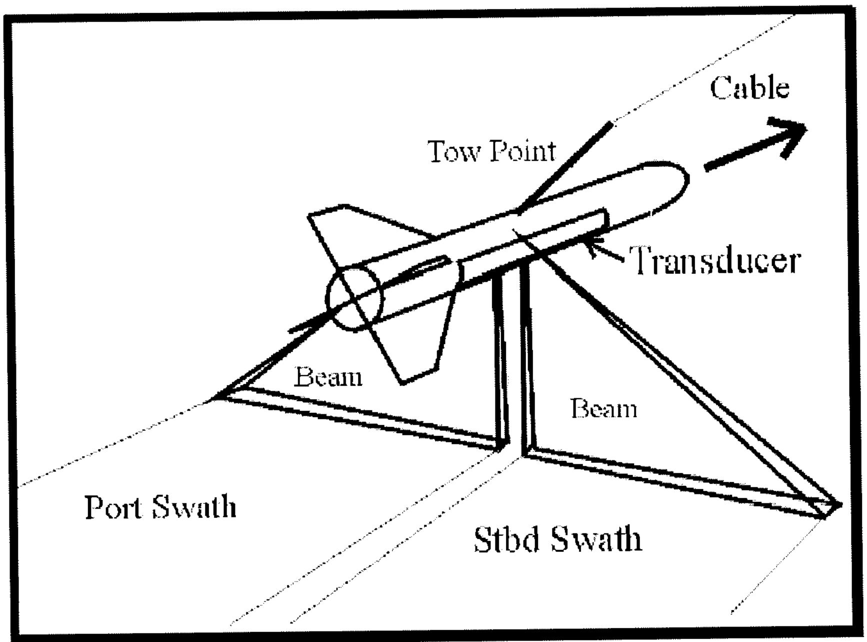


Figure 1: Sidescan sonar operation showing swath extent.

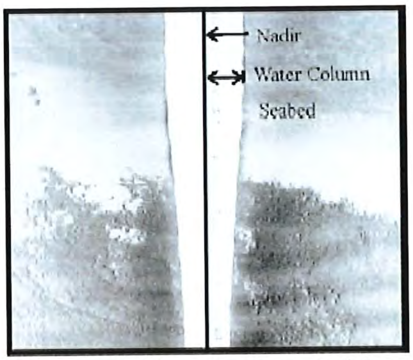


Figure 2:Unprocessed sidescan record showing water column, nadir and backscatter information.

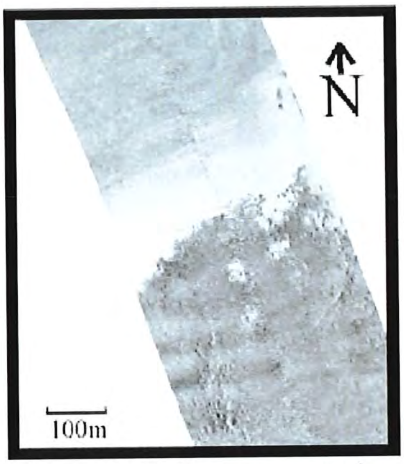


Figure 3:Fully processed sidescan record of Figure 2 with water column removed.

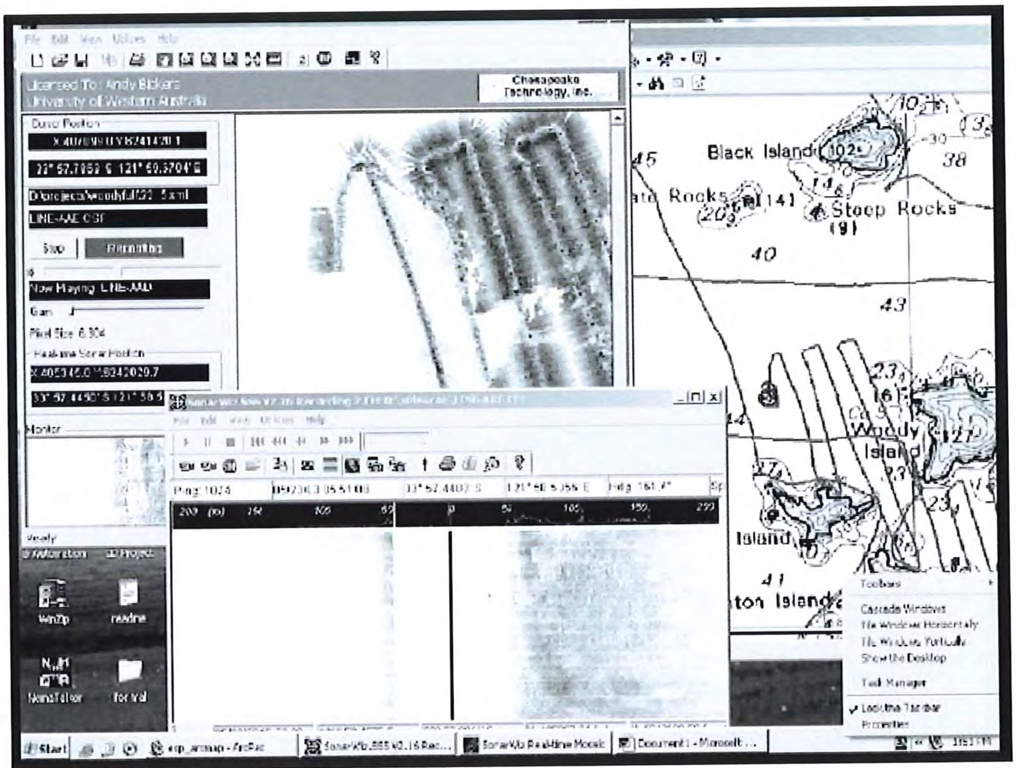


Figure 4: Screen view of sidescan survey in operation showing navigation and live acquisition and mosaicking.

Video Acquisition and Processing

Video is an efficient means of gaining a permanent record of both the substrate and epibenthos. A towed camera system is used that provides live video to the surface via a cable. On deck, the hardware used for the sidescan is also used for the video system. To assist in obtaining and recording accurate positioning of the camera a number of innovations have been made that exploit the processing and interfacing capabilities of a personal computer. ArcPad is used to provide live vessel positioning, using both the digitised chart and the processed sidescan mosaic as a backdrop. This ensures that the areas, boundaries and transitions that are to be videoed can be accurately targeted. The availability of live video on the surface allows real time confirmation of the location of boundaries and changes in habitat type or benthic and community structure that have been observed on the acoustic image.

In order to accurately georeference the video, in house software developed in Visual Basic by the author is used to read National Marine Electronics Association (NMEA) strings from the GPS and single beam echo sounder and perform the following functions.

- Record depth, vessel position, heading and other GPS data in user definable time increments to a text file with respect to a unique alphanumeric identifier.
- Estimate layback as a function of the depth and calculate the position of the camera using this estimate, vessel position and an implementation of Vincentys algorithm (Vincenty, 1975).
- Send commands to video text overlay unit to imprint this information continuously on the video image (Figure 5).

The utility of this system is that videos can be visually classified with reference to a unique positional identifier displayed on the screen. This links the video to positions and other data recorded in the text file. Classifications of benthic habitat or community type made from the video can then be added to the text file with relation to their recorded position, unique identifier or time. Most GIS systems can then import this classified file as X-Y data into a track log. The information that is associated with each point, such as habitat classification, is used to form a table of attributes related to each recorded position.

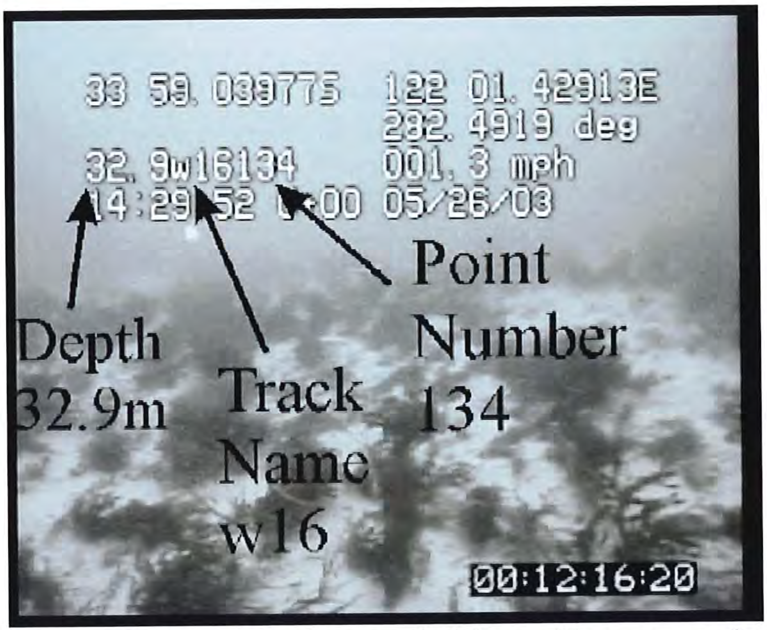


Figure 5: Example frame of video with text overlay showing unique identifiers and depth.

Analysis and Data Display Methods

The use of GIS is fundamental to the combination, display and analysis of the sidescan and video data. The processed sidescan mosaic and classified video tracks can be added as layers to any existing available data sets for the surveyed area. These data sets may be as simple as a digital chart, coastline or point, contour or 3D bathymetry, but can include any physical or biological information obtained from previous surveys. It is essential however that the data is georeferenced and that the datum and coordinate system is known so the information can be converted or displayed in a common form.

Most GIS systems can display points or polygons coloured with respect to a column of data in the attribute table. The points overlaid on a portion of sidescan mosaic in Figure 6 are represented according to the broad habitat classification made during video processing. The inset image shows at the same location the areas segmented from the sidescan record. These have been labeled with a habitat class based on the overlaid video track. This illustrates how video transects allow identification of the areas distinguishable in the sidescan record. Although the use of the processed sidescan data can determine much about the spatial extent and boundaries of habitat and community types, reference to the higher resolution raw sidescan record may also be necessary for accurate identification.

Classification and visualisation can be aided with the use of a function such as "Hyperlink" in ArcGIS that allows logical addresses of video clips or still images to be referenced to points along the video track.

The still or video images can then be invoked by placing the cursor over the referenced points. Third party software such as Image Mapper™ is also available that will output maps of data layers with points and hyperlinks in an HTML format that can be viewed on any web browser.

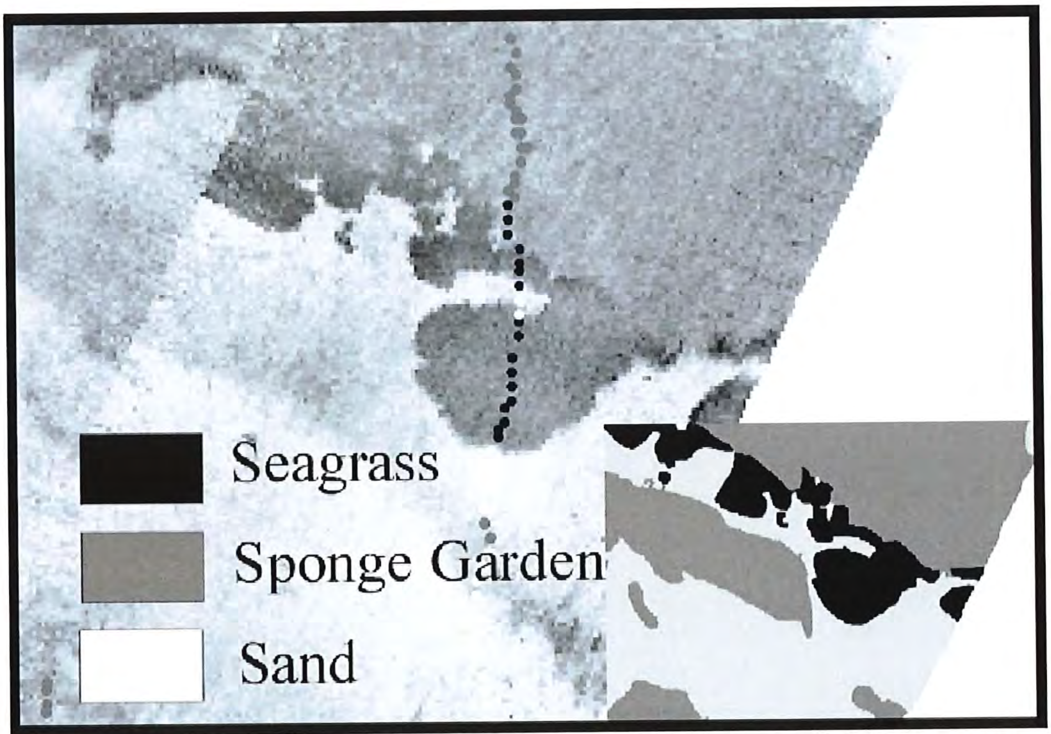


Figure 6: An example of an interpretation of sidescan and video to create a habitat map. The video track classified according to habitat type is overlaid on the processed and segmented sidescan record to allow classification of the sidescan record (inset).

Results

During habitat mapping in the Recherche Archipelago, certain habitats and community structures have been found to be easily identifiable from the sidescan record. The series of images in Figure 7 displays examples of these as they appear on the sidescan record. The raw unprocessed images are shown, as during processing some of the detail may be lost. The data for all these images was obtained at the maximum range of 200 m per side and at towing speeds averaging over 6 knots. Low returns are shown as a light tone, darkening as the backscattered signal strengthens. The typical resolution of these files is 1 to 2m in the along track direction and 0.1 to 0.2m in the across track, depending on speed.

Seagrass meadows are distinguished on the sidescan record by a characteristic coarse irregular texture with a strong return (Figure 7a). It is thought that the gas filled cavities of seagrass are partly responsible for this (McCarthy, 1997). The uniform texture and robust return of rhodolith beds are also easily distinguished on the sidescan record. Rhodolith beds formed by aggregations of ball shaped autonomous calcareous red algae are evident as the darker areas in Figure 7b and stand out clearly from the surrounding sand. The smooth surface of the sand provides poor backscatter and most of the incident sonic pulse is reflected away from the transducers. This provides a stark contrast to the hard textured surface of the rhodoliths which provide a strong backscatter return. Isolated bommies, reefs and edges of islands appear clearly on the sidescan record (Figure 7c). Note that shadows (shown as light areas) are formed behind features of high relief due to the angle of acoustic illumination and areas of steep slope are characterised by low return. Sand ripples of various wavelengths are also identifiable, although is this dependant on their wavelength and amplitude as well as the resolution of the data and the sea condition. The area magnified in the inset on Figure 7d shows sand ripples of approximately 2 to 4 m wavelength. The texture of rippled surfaces can serve as a good reflector for the acoustic beam. On images that have been recorded or processed at lower resolutions, regions that have been rippled by physical effects often appear darker than adjacent similar sediments with a smooth surface (Figure 7e).

The marine habitats of coastal Western Australia are formed by complex and dynamic combinations of substrate and community types and are often not easy classified. An example of this is found in the low limestone reef pavements which are commonly inundated by sand. Areas such as these can be populated by a variety of organisms and communities including sponges, ascidians, bryozoans and macroalgae which are typically dependent on a hard substrate. Seagrasses, especially *Halophila spp.* are also often found on reefs with a more permanent inundation. This poses a considerable problem for both classification and identification of the sidescan record. Although we can now identify the different characteristic texture and transitions onto areas of these low reefs from the acoustic return from the benthos, the need for validation of both the habitats and communities is much greater. Penrose & Siwabessy (2001) and Cochrane and Lafferty (2001) also report this as being an issue.

The images in Figure 8 illustrate the process of classifying an area from the sidescan mosaic, raw sidescan data and geo-referenced video. The fully processed mosaic (Figure 8a) represents 16 hours of sidescan tow over approximately 60 square km of an area surrounding the Woody Island group in the Recherche Archipelago, Western Australia. Tracks shown in red are those for which towed video has been obtained and the

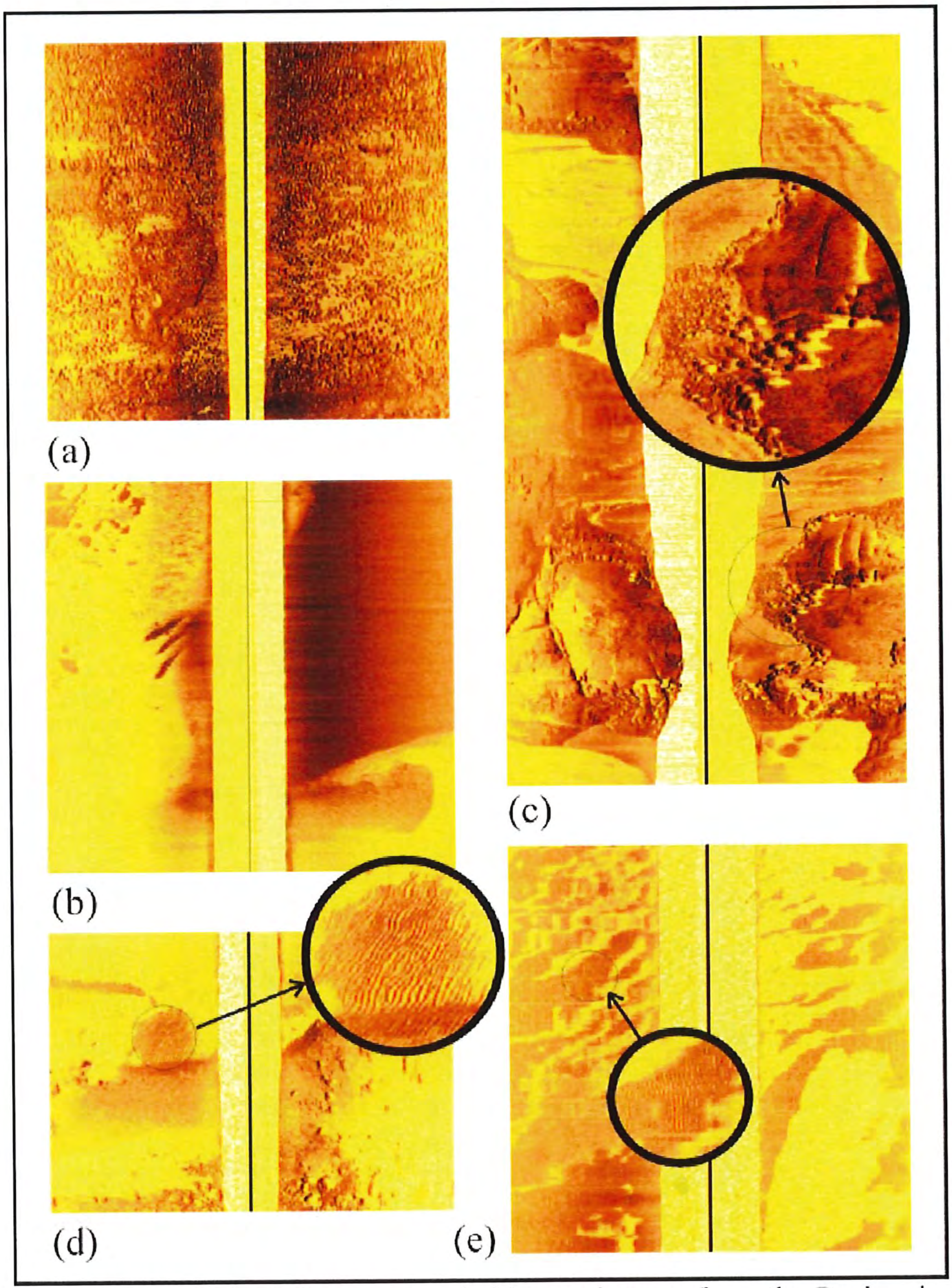


Figure 7: Examples of unprocessed sidescan images from the Recherche Archipelago taken at 100 kHz showing examples of different biota and habitats. a) Seagrass; b) Rhodoliths; c) Reef; d) Sand ripples; e) Sand ripples.

points in blue are drop video locations from a previous survey. The raw sidescan for the area marked A on the mosaic is illustrated in Figure 8b. An example of a classified video track named w16, collected over the transitions shown in area marked B is shown in detail in Figure 8c. This has been classified as being seagrass, low profile reef or sand by analysis of the video. A still image (Figure 8d) illustrates the low profile reef at point 125 of this track. Both the positional references (track name and point number) are shown together with the depth of 32.7 m on the second line down of the text overlay. The classification of habitats along the video track supports the labeling of distinguishable regions in the raw sidescan image. At this point the other data sets available for the area were considered including those shown in Figure 9. The collection and merging into a common platform of available information is a vital step in the classification process. Examination of all the available information with reference to the sidescan and video data in this way, allows broad classification of the area into a habitat map (Figure 8e).

This map shows a draft classification of the area in terms of broad habitat/community types. Classes were chosen on the basis of those easily distinguishable from the sidescan record. These classifications are very coarse, but with further processing of the video and sidescan, a map can be produced, identifying in more detail the biota and physical attributes of areas.

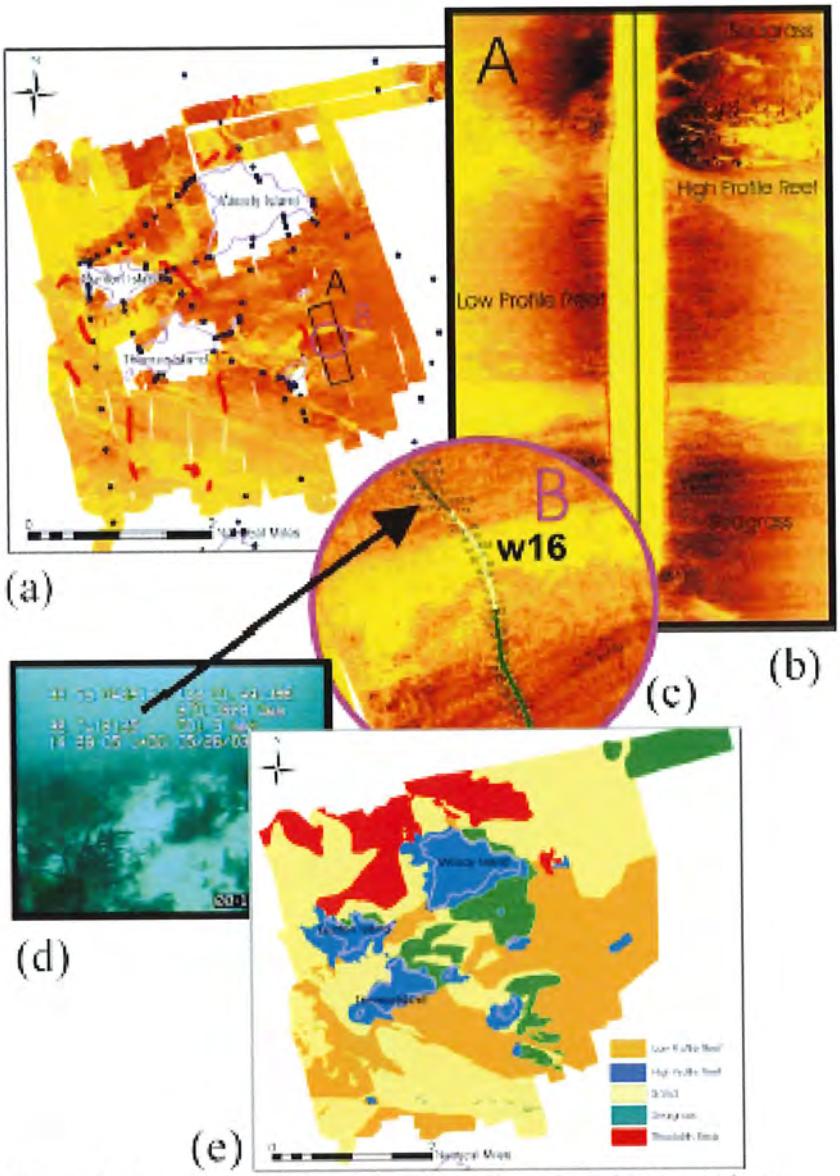


Figure 8: An example of the stages of creation of a habitat map from sidescan and video data. a) Sidescan mosaic; b) Raw sidescan data; c) Section of sidescan mosaic with overlaid classified video track; d) Frame of video showing text overlay; e) Classified habitat map.

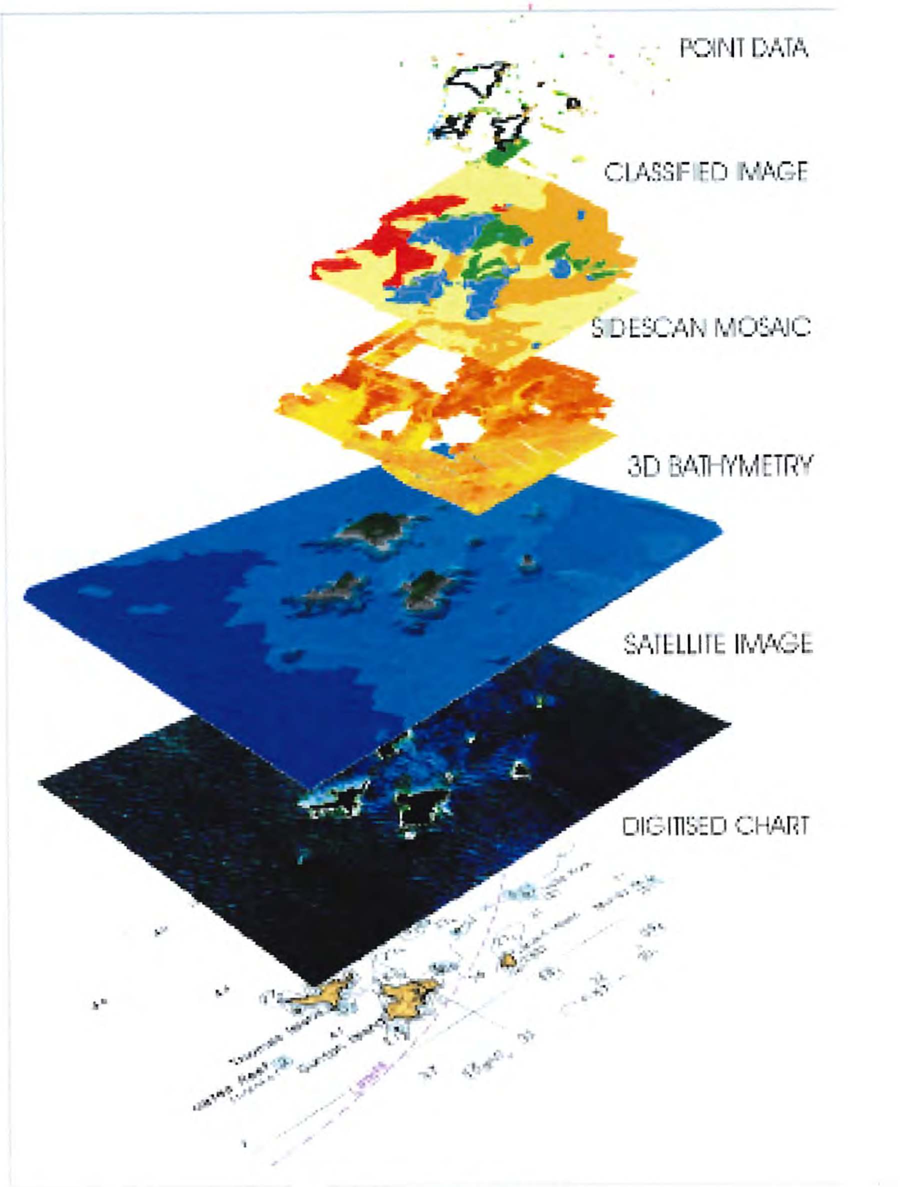


Figure 9: Data sets used in the creation of the habitat map.

Discussion

The combined package of sidescan sonar, towed video and real-time DGPS linked through GIS and other acquisition software has proved to be an efficient method of performing shallow water habitat mapping in the coastal environments of Western Australia. The availability of accurate GPS positioning and cost effective desktop computer based acquisition and processing equipment means older and lower end sidescan equipment can be used to provide accurate maps of the seabed at resolutions adequate to differentiate marine habitats and communities. The results shown here were obtained from twenty year old equipment fitted with new transducers and electronics costing approximately $AUD 15,000. A minimum capital investment of $AUD 100,000 would be expected for new equipment and software with similar capabilities to that described here. Although this is an order of magnitude less than for a multibeam sounder system comparisons are difficult as sidescan systems only record depth below the vessel and the quality of backscatter obtained from multibeam systems is continuously improving. Survey rates for sidescan are dependant on depth and the quality of data that is required, but, based on experience, an average of 4 square km per hour can be achieved in waters of 20 m and over.

The addition of a towing point behind and above the propeller enables surveys to be carried out with vessels as small as 7 m, and the ability to run the equipment at 12 volts has also improved system versatility. The quality of the sidescan image is affected by the movement of the vessel however, and becomes unusable in poor weather conditions in smaller vessels.

Despite the increase in availability, versatility and resolution of sidescan systems, direct sampling to support image interpretation is still critical to the success and accuracy of any survey. The video system described here has a number of benefits. Operationally the requirement for space on small vessels is relieved as it uses the same above surface hardware as the sidescan system and the low camera weight means that it can be deployed and retrieved by hand. Survey speeds are however limited by the amount of cable deployed, and although depths over 60 m can be achieved, the drag on the cable and the effort required to retrieve the system are effectively limiting. The availability of the vessel's position live over a backdrop of the sidescan record or chart has been found to be of great benefit in accurately targeting areas of interest. Numerical referencing of the video image with respect to the vessels track log has also proved to be invaluable in post processing and classification of the video and sidescan data. GPS time can also be used to reference points along the video track.

Classification of the surveyed area requires analysis of the texture of the sidescan record at a number of scales. The raw sidescan image is the highest resolution record available and although the easiest to interpret, is not correctly spatially processed. Processing and mosaicking the sidescan tracks produces a composite spatially correct image, but typically there will be some loss of detail due to reduction in resolution. The resolution of the mosaicked image output can be controlled, but the exponential increase in image size can be limiting. Here, the mosaicked images were used to generate the position of boundaries and transitions, using the raw images to accurately identify the habitat or community types.

Although the sidescan record was segmented and classified visually with reference to validation by video data in a style similar to McRea, et al., (1999), there are a number of commercially available packages designed to perform automated supervised or unsupervised classification on images. A wealth of literature is available pertaining to the segmentation and classification of generic and sidescan images (Jain, 1989). A discussion of this is considered outside the scope of this paper, but the author is currently working on a system of automated textural classification to be tested on both the raw and processed sidescan data. This will initially be based around the most commonly reported method of textural analysis using Grey Level Co-occurrence Matrices, but will extend to an investigation into more complex methods (Haralick, 1973; Shokr, 1991).

Although the equipment and methods described here are based around known and proven technology, their accuracy and usefulness has been augmented by being combined with GPS, and modern desktop based GIS systems in both the acquisition and processing phases. The system described has been found to be very successful in shallow water habitat mapping in Western Australia. Much of this success can be attributed to its portability and ease of support.

Here we have only considered using the sidescan sonar to obtain 'full coverage' of areas. Broad scale information about the area can be used to target areas for sidescan survey, just as the sidescan record itself, is used to target areas for higher resolution video sampling. Analysis of charts, oceanography, topography or bathymetry together with satellite or aerial photography can assist in the identification of boundaries of habitats for survey. For instance, in the areas of study in Western Australia, the water clarity is such that boundaries of rhodolith beds that have been identified by sidescan and video survey have been similarly identified by satellite imagery in greater than 30 m of water. It is proposed that sidescan sonar can be used as a validation tool for information relating to habitat extent obtained on a broader scale and that performing widely spaced transects may increase survey efficiency. Work is continuing in this area.

Acknowledgements

The field work for this paper was carried out as part of the Fisheries Research Development Council project 'Characterising the Fish Habitats of the Recherche Archipelago, 2001/060'. The author would also like to thank the Esperance Community for their support in this research. In addition I would like to thank my supervisor Dr. Gary Kendrick for his objective guidance in writing this paper and my colleague Katrina Baxter for her assistance in the field. Much credit is also due to Alan Cameron of

GSE rentals (UK), Chuck Harding of Edgetech (USA) and John Gann of Chesapeake Technologies (USA) for their excellent technical support.

References

Blondel, P., & Murton, B. J. 1997. *Handbook of Seafloor Sonar Imagery*. John Wiley and Sons, Chichester, 314pp.

Clarke, E. d. C., & Tarlton, P. 1952. *Physiography and other notes on a part of the south coast of Western Australia.*

Cochrane, G. R., & Lafferty, K. D. 2001. Use of acoustic classification of sidescan sonar data for mapping benthic habitat in the Northern Channel Islands, California. *Continental Shelf Research* 22(5): 683-690.

Davies, J., Foster-Smith, R., & Sotheran, I. S. 1997. Marine Biological Mapping for Environment Mapping Using Ground Discrimination Systems and Geographic Information Systems. *Journal of the Society for Underwater Technology* 22(4): 167-172.

Fish, J. P., & Carr, A. H. 1991. *Sound Underwater Images: A guide to the generation and interpretations of sidescan sonar images*. American Underwater Search and Survey Ltd., Lower Cape Publishing, 189pp.

Greene, H. G., Yoklavich, M. M., Starr, R. M., O'Connell, V. M., Wakefield, W. W., Sullivan, D. E., McRea Jr, J. E., & Cailliet, G. M. 1999. A classification scheme for deep seafloor habitats. *Oceanologica Acta* 22(6): 663-678.

Haralick, R. M., Shanmugam, K., & Dinstein, R. 1973. Textural features for image classifications. *IEEE Transactions Systems, Man and Cybernetics,* vol SMC-3: 610-621.

IMCRA. 1998. Interim Marine and Coastal Regionalisation for Australia: an ecosystem based classification for marine and coastal environments. Version 3.3. *Interim Marine and Coastal Regionalisation for Australia,*

Technical Group, Environment Australia, Commonwealth Department of the Environment. Canberra, Australia

Jain, A. 1989. *Fundamentals of Digital Image Processing.* Prentice-Hall, New York, 410pp.

Kvitek, R., Iampietro, P., Sandoval, E., Castleton, M., Bretz, C., Manouki, T., & Green, A. 1999. *Final Report, Early Implementation of Near shore Ecosystem Database Project.* SIVA Resource Center, Monterey Bay, California.

McCarthy, E. 1997. Acoustic Characterization of Submerged Aquatic Vegetation. *Proceedings of the High Frequency Acoustics in Shallow Water Conference, 1997,* 363-369

McRea (Jr), J. E., Greene, H. G., O'Connell, V. M., & Wakefield, W. W. 1999. Mapping marine habitats with high resolution sonar. *Oceanologica Acta* 22(6): 679-686.

Myers, J. S. 1990. Western Gneiss Terrane. *Geological Survey, Western Australian Memoirs, Geology and Mineral Resources of Western Australia* (3): 13-32.

Penrose, J. D., & Siwabessy, P. J. W. 2001. *Acoustic Techniques for Seabed Classification: Report prepared for the Marine Conservation Branch of the Western Australian Department of Conservation and Land Management (2001-36).* Curtin University of Technology, Perth.

Shokr, M. E. 1991. Evaluation of Second Order Texture Parameters for Sea Ice Classification From Radar Images. *Journal of Geophysical Research* 96(C6), 10: 625 - 610,640.

Stanbury, K. B., & Starr, R. M. 1999. Applications of Geographic Information Systems (GIS) to habitat assessment and marine resource management. *Oceanologica Acta* 22(6): 699-703.

Vincenty, T. 1975. Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. *Survey Review* 22(176): 88-93.

APPENDIX 8.3: Soft substrate macrofaunal communities in the western archipelago.

Simon Grove[1]

[1] School of Plant Biology (M090), Faculty of Natural and Agricultural Science, University of Western Australia, 35 Stirling Highway, Crawley 6009, Western Australia.

INTRODUCTION

The benthic macrofauna of soft substrates play important roles in ecosystem processes, such as nutrient cycling (eg dispersion and burial), secondary production (allowing trophic transfer back into the water column), pollutant metabolism, filtration of the water column, and the alteration of sediment stability and transport (Snelgrove 1998). They also have direct relationships with other benthic components such as micro- and meio-benthos.

Marine habitat diversity is regarded as a useful surrogate for species level biodiversity (Ward *et al.* 1999) and continuous data from large areas can be relatively rapidly collected using remote visual and acoustic techniques. There is a need for knowledge of relationships between measures of biodiversity and different levels of environmental variability (Ellingsen 2002).

Underwater video surveying indicated a wide variety of soft substrate environments ranging from fine sands to coarse gravels. The topography ranges from flat through fine to coarse ripples. There are also varying degrees of vegetative cover, by seagrasses and macroalgae including rhodoliths. The formation of rhodoliths themselves is controlled by water movement, light and sedimentation- water movement high enough to prevent burial by sedimentation, but not so high or unidirectional to cause mechanical destruction or transport out of favourable growing conditions (Foster 2001).

Soft substrate habitats are further modified by sessile invertebrates such as sponges, ascidians, bryozoans and tube worms. Mixed hard-soft substrate environments with sand-inundated low-profile reefs are also common in the Recherche Archipelago.

This study provides an initial characterisation of benthic macrofaunal communities associated with a selection of deeper (between 25 and 45m) soft substrate habitats located in inshore areas of the Western Archipelago. Studies of shallower (<20m) soft substrate habitats have been undertaken as part of the 12th International Marine Biology Workshop (February 2003).

METHODS

FIELD AND LABORATORY METHODS

Selection of sampling sites was made from GPS referenced video footage collected as part of drop and towed video surveys conducted between April and May 2002 (see Figure 2). The Macrobenthos of soft substrates at 11 sites around Woody Island (W1-W5) Esperance Bay (E1, E2) and the Remark (R1-R4) group of islands was sampled using a Van Veen Grab, with open jaw dimensions of 0.1 m2. (refer map, Figure 1) Initial sampling was made at sites W1, W2 and W3 during May 2002, and 9-10 replicate grabs were made at each location. Further sampling at the 8 remaining sites was made in November 2002. Five replicate grabs were made at each of these sites. All samples were sieved on board, using a 1mm mesh sieve, the contents of which were transferred into containers, and bulk preserved in a10% buffered formalin in seawater solution. After fixation the macrofauna was sorted in the laboratory from the remaining sediment by a combination of elutriation and hand picking. Rose Bengal stain was added to the samples to aid in sorting. Macrofauna was then sorted under a microscope to taxonomic levels determined by available expertise and condition of the specimens. Any macroalgae and seagrass found in the samples was blotted dry and weighed (formalin preserved wet weight). Rhodolith content of the samples was also scored (0=absent, 1=few, 2=many).

Additional grab samples were made for the analysis of sediments at each site. These samples were subsampled, and organic content was determined by the weight loss of dried sediment after ignition in a muffle furnace at 550 degrees C for 4 hours.

The other subsample was treated in 10% hydrogen peroxide solution until reaction had ceased, to remove organic matter, then dry sieved at phi intervals to characterise the grain size distribution.

Analytical methods

Multivariate and univariate analyses of macrobenthic community structure were made using PRIMER (Plymouth Marine Laboratory). Any macrofauna identified beyond the taxonomic level of Family were aggregated to that level for these analyses.

Diversity measures included total abundance, number of taxa, richness (Margalef's d) and Shannon-Wiener diversity index (H' ($\log_e$)). Sample by taxon abundance data were square-root transformed, and a triangular matrix of similarities calculated using the Bray-Curtis similarity measure. This was subject to clustering analysis (group-average hierarchical agglomerative clustering) and ordination (non-metric multidimensional scaling).

The contribution of taxa responsible for the groupings observed were examined using the similarity percentages (SIMPER) procedure (Clarke 1993). The combination of measured environmental variables that correlated best with the patterns of macrofauna was determined using the BIOENV method (Clarke and Ainsworth 1993).

Macrofaunal families were placed into feeding guilds: deposit feeders; suspension feeders; herbivores; carnivores/scavengers; carnivore/herbivores by consulting (Fauchald and Jumars 1979) and (Beesley, Ross *et al.* 2000)(polychaetes), (Beesley, Ross *et al.* 1998) (molluscs), (Holditch and Jones 1983) (Hale 1927-1929) (Jones and Morgan 1994) (crustaceans), (Edgar 2000) (Young 1962; Barnes 1980) (Shepherd and Thomas 1982; Shepherd and Thomas 1989; Shepherd and Davies 1997) (other groups).

Correlations between sample characteristics were made using the Pearson Product Moment Correlation coefficient. Where factors for individual grab samples were not available (eg sediment characteristics and depth) site averages for the other factors were used. Correlations with *p* values less than 0.05 were considered significant.

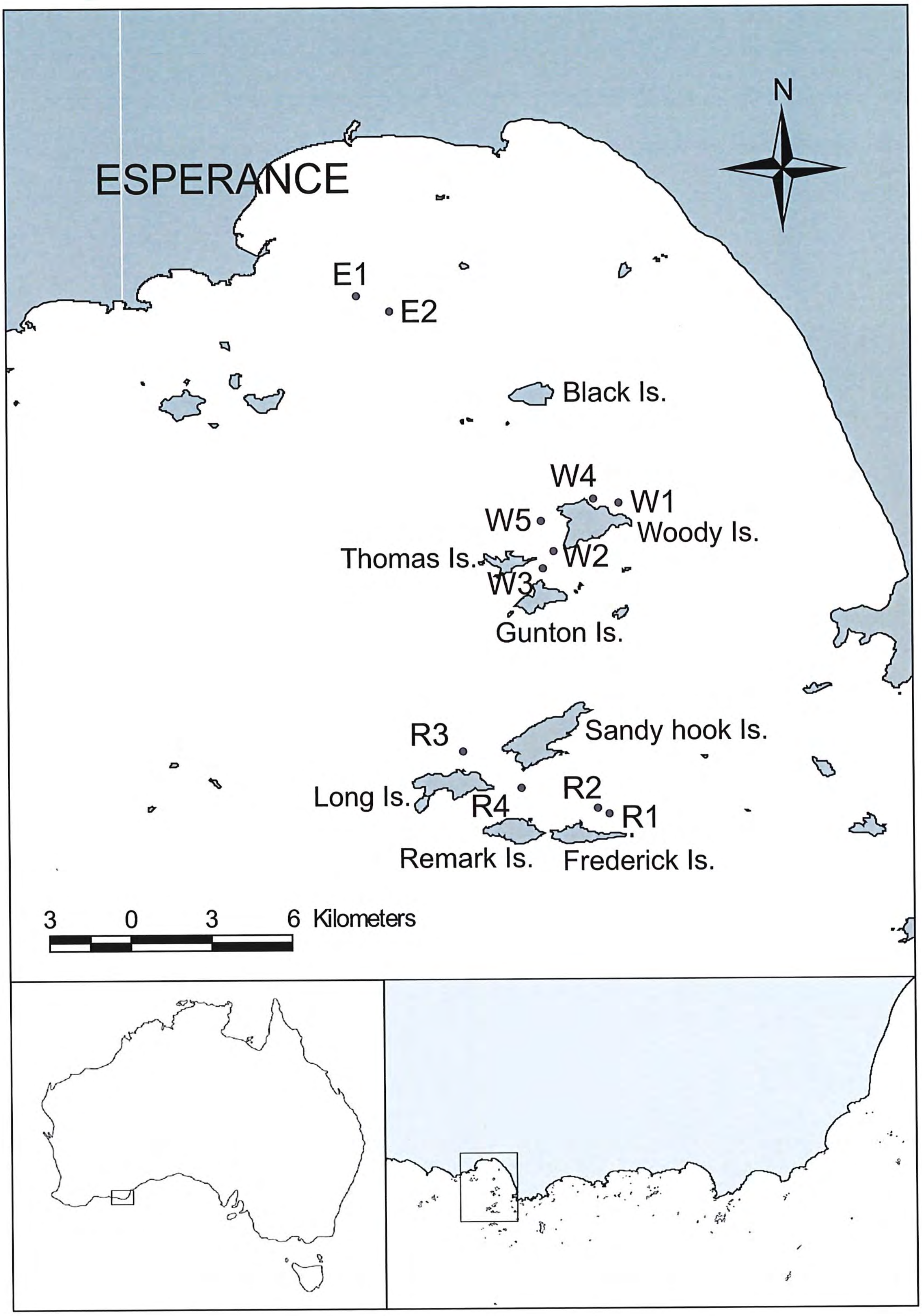
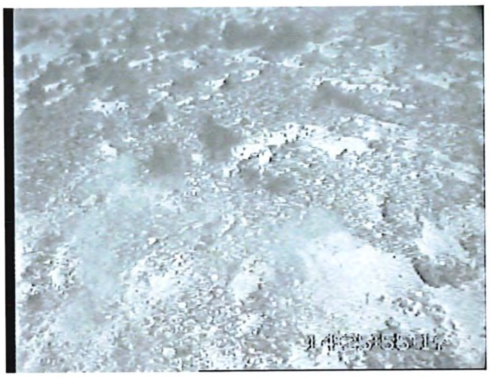


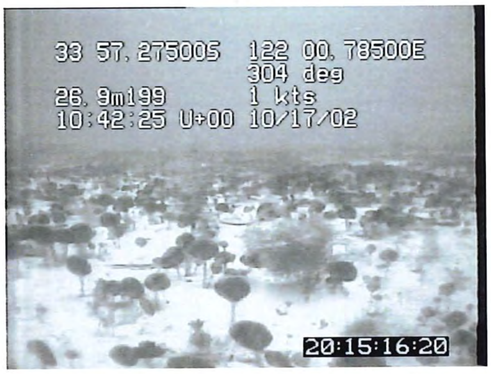
Figure 1: Site locations.

Site W1



Site W2

Site W3



Site W4

Site W5

Site E1

Site E2

Site R1

Figure 2: Stills from video footage at each site.

Site R2

Site R3

Site R4

Figure 2 continued.

Table 1: Site positions, video and sediment characterisation. NA= not available

Site ID	Data base ID	Depth (m)	longitude latitud (decimal degrees)	Habitat description (based on video footage)	Sediment characterisation	median Grain size (Phi units)	sorting	% sand	% mud	% gravel	Organics (%)
Inner Bay											
E1	hb155	35	121.93509 -33.88717	Very sparse seagrass (Posidonia) on sand substrate	slightly gravelly sand	2.4	moderately	99.7	0.2	0.1	1.3
E2	hb560	38	121.94624 -33.89257	Rhodolith bed, sparse macroalgae	NA	NA	NA	NA	NA	NA	NA
Woody Island group											
W1	2902	26	122.02193 -33.95565	Bare sand. Very sparse macroalgal cover, obvious bioturbation	slightly gravelly sand	3.1	moderately	90.0	9.6	0.4	3.5
W2	7166	30	122.0001 -33.97173	Rhodolith bed,sparse macroalgae	gravelly sand	0.7	poorly	84.9	0.1	15.0	5.1
W3	7149	29	121.997 -33.97755	Sparse Seagrass (Halophila, Posidonia) on sandy substrate	slightly gravelly sand	1.5	very well	99.7	0.0	0.3	2.1
W4	m199	27	122.01308 -33.95458	Sand, Bryozoan (Lanceopora) and sparse algae	slightly gravelly sand	2.4	poorly	94.1	4.2	1.7	4.2
W5	f254	41	121.99605 -33.96135	Bare sand , ripples, debris in troughs	slightly gravelly sand	0.5	moderately	98.5	0.0	1.5	3.1
Remark Island group											
R1	ri82	26	122.014065 34.05719	Rhodolith bed, sparse macroalgae	sandy gravel	-0.7	very poorly	37.5	1.4	61.1	7.8

R2	ri192	28	122.01759 -34.05882	Bare sand. Very sparse algal cover	slightly gravelly sand	2.3	moderately	99.1	0.3	0.7	3.3
R3	rd200	26	121.969299 -34.03828	Sand, sparse algal cover, dense tube worms burrows (Trichobranchidae)	slightly gravelly sand	0.4	moderately	95.3	0.0	4.6	2.4
R4	279	41	121.98898 -34.05022	Sand-inundated flat reef, with associated sessile invertebrates and macroalgae	sandy gravel	-0.8	poorly	64.8	0.1	35.2	4.9

RESULTS

Site position and sediment characterisation results are summarised in Table 1. Sediments ranged from sand to sandy gravel, with very little mud content (<63 microns. Three sites (E2, W2 and R1) were located within rhodolith beds. Site W1 was bare sand location, of flat topography, while site W5 was located in a coarse rippled bare sand environment. Sites E1 and R2 were sparsely vegetated (seagrass and macroalgae) sand environments located in close proximity to, but outside rhodolith beds. Acoustic surveying revealed sharply delineated transitions between bare sand and rhodolith beds are common (refer acoustic survey report). Site W3 was in an area of denser seagrass vegetation. The last three sites were in areas where sessile invertebrates were visually prominent: bryozoans in the case of site W4, tube worm borrows at site R3 while site R4 was located in an area of sand-inundated low profile reef.

The macrofauna were numerically dominated by crustaceans (49%) followed by polychaetes (28%), echinoderms (10%) then molluscs (7%). Within the Crustacea, amphipods numerically dominated (54%) followed by tanaids (19%) then decapods (11%) and isopods (8%). Bivalves numerically dominated the molluscs, then gastropods (18%) and chitons (13%). Ophiuroids dominated the echinoderms (84%), then echinoids (13%).

Macrofaunal abundance per grab sample ($0.1m^2$) ranged from 18 to 696 individuals (at site E1 and site R1 respectively). Average abundances for each site, along with other diversity measures, and representation among feeding guilds are listed in Table 2.

Significant correlations between various environmental and biological factors are listed in Table 3 (significant correlations between sediment factors are not included). MDS ordination of the samples (Figure 3) shows that the sites sampled provide a continuous distribution of macrofaunal assemblages rather than highly-structured, discrete communities. The samples from site R3, for example can be seen as intermediate between the rhodolith Sites (W2, R1 & E2) and the bare sand site, W3. There is a gradation from poorly sorted to well-sorted sediments running approximately left to right across the 2D representation (Figure 3).

Most replicate samples from each site are well grouped. The Exceptions include two samples from site W2. Both these samples were found to contain little or no rhodoliths (Video footage shows that rhodolith cover can be patchy). Two samples from site R4 (sand-inundated reef) were also outliers, possibly reflecting the limitations of the grab in sampling that environment. A three dimensional ordination shows that the spread of samples from sites W5 and W3 depicted in the 2 dimensional ordination is somewhat of a distortion, however variability in the macrofaunal composition between samples is definitely highest at site W3.

Results from the BIOENV Procedure are shown in Table 4, with sediment sorting being the highest correlated single environmental parameter to the patterns of similarities based on faunal composition.

Table 2: **Mean summary statistics for macrofaunal diversity and feeding guilds (standard errors in parentheses).**

Site	Database I.D. code	number of samples	Number of Taxa	Number of individuals	Richness (d)	Diversity (H'(loge))	Carnivores/ Scavengers (%)	Deposit feeders (%)	Herbivores (%)	Herbivore/Carnivore (%)	Suspension feeders (%)
E1	Hb155	5	18.4 (2.8)	46.2 (7.4)	4.51 (0.57)	2.39 (0.19)	44.2 (1.3)	44.8 (1.2)	0	1.8 (0.9)	8.9 (1.1)
E2	Hb560	5	38.0 (3.6)	188.2 (44.6)	7.15 (0.39)	2.74 (0.09)	61.7 (4.1)	11.6 (1.5)	1.1 (0.3)	11.8 (2.5)	13.8 (2.5)
W1	2902	10	29.2 (1.4)	239.0 (12.3)	5.15 (0.22)	2.35 (0.07)	42.1 (3.9)	50.5 (3.3)	0	1.2 (0.4)	6.2 (1.0)
W2	7166	9	49.2 (6.3)	335.4 (66.8)	8.39 (0.77)	2.86 (0.10)	56.0 (2.8)	23.2 (3.0)	2.5 (0.9)	14.4 (1.9)	3.8 (0.7)
W3	7149	9	16.0 (0.8)	45.7 (3.1)	3.94 (0.17)	2.01 (0.07)	69.7 (3.3)	18.7 (3.3)	1.0 (0.4)	4.1 (1.3)	6.5 (2.9)
W4	M199	4	41.5 (3.2)	292.8 (71.5)	7.23 (0.27)	2.72 (0.13)	43.4 (2.2)	21.8 (4.6)	0.4 (0.3)	9.4 (1.1)	25.0 (5.2)
W5	F254	5	24.4 (2.6)	90.2 (16.9)	5.23 (0.47)	2.49 (0.12)	34.1 (5.2)	55.3 (5.4)	0.3 (0.3)	7.3 (2.6)	3.0 (1.5)
R1	Ri82	5	61.8 (2.0)	487.0 (60.5)	9.88 (0.28)	3.26 (0.06)	54.0 (3.1)	24.2 (3.0)	1.5 (0.6)	12.0 (1.2)	8.2 (0.9)
R2	Ri192	5	29.6 (2.5)	95.2 (10.6)	6.27 (0.42)	2.80 (0.09)	42.9 (2.3)	33.7 (3.5)	0.4 (0.4)	9.8 (1.5)	13.0 (1.3)
R3	Rd200	5	51.8 (4.4)	290.8 (54.2)	9.01 (0.61)	2.83 (0.11)	27.0 (2.0)	49.4 (2.1)	0.4 (0.3)	8.3 (0.6)	14.9 (0.7)
R4	279	5	46.2 (9.3)	157.4 (40.3)	8.93 (1.37)	3.05 (0.18)	57.2 (4.1)	17.1 (4.5)	0.3 (0.2)	6.0 (1.0)	19.3 (2.8)

Table 3: Significant correlations ($p<0.05$) between biological and sediment factors in Esperance Bay.

Pearson correlation coefficients are shown. Bold type denotes $p<0.01$.

	Rhodoliths	algae	Number of taxa	Number of individuals	Taxa richness	Shannon diversity	%Carnivores	%Deposit feeders
Rhodoliths			**0.595**	**0.476**	**0.597**	**0.550**	**0.367**	**-0.541**
Algae			**0.399**	**0.446**	**0.358**			**-0.302**
seagrass			**-0.314**	-0.275	-0.302	**-0.332**	0.274	
Median grain size	-0.679							
Sorting	**0.862**		**0.848**	**0.806**	**-0.827**	**-0.875**		
%Gravel	**0.828**		0.733	0.650	0.735	0.766		
%sand	**-0.804**		-0.735	-0.695	-0.716	-0.744		
Organic content	**0.829**		**0.786**	**0.804**	0.739	**0.779**		
%Deposit feeders	**-0.541**	-0.302	-0.261		-0.298		**-0.811**	
%Herbivores	**0.449**		0.285	0.242	0.280		0.243	-0.300
%Herbivore/carnivore	**0.544**	0.279	**0.512**	**0.413**	**0.526**	**0.576**		**-0.376**
%Suspension feeders		0.260			0.291	0.271		-0.304

Sediment sorting, rhodolith content and seagrass content provided the best combination of measured environmental factors which correlated highest with the distribution of animal taxa. Water depth, across the range sampled (26-41m) was not selected as a factor with the fauna composition patterns.

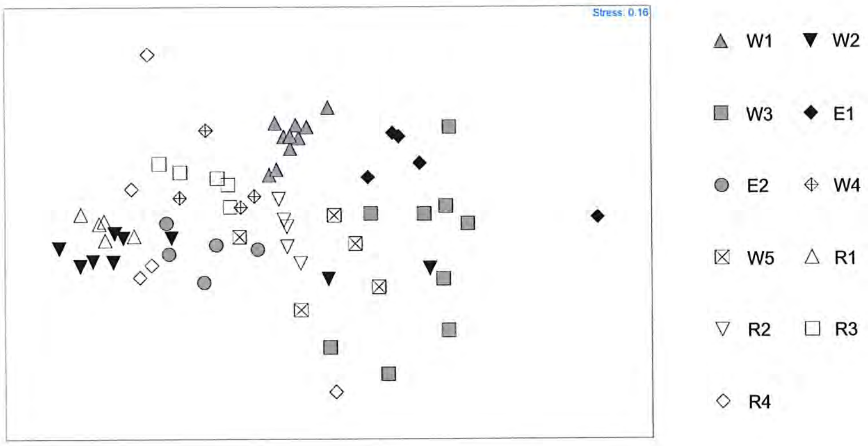
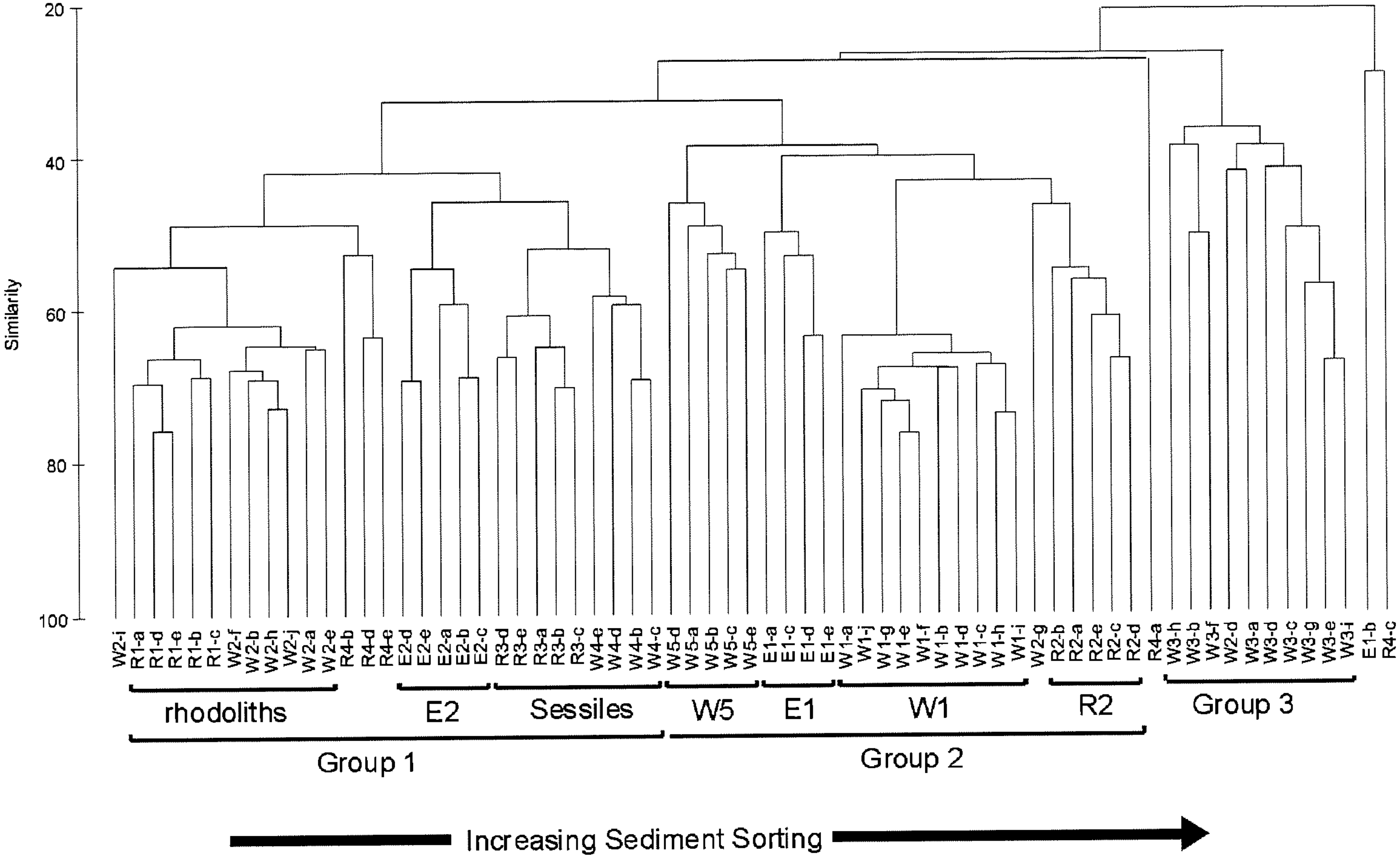


Figure 3: Non-metric MDS ordination of grab samples, based on square root transformed macrofaunal abundances, using the Bray-Curtis similarity measure. Refer to Figure 1 and Table 1 for site positions and descriptions.

Table 4: BIOENV analysis results: Pearson Product Moment correlation coefficients for between similarity matrices based on macrofaunal composition and other variables. Results for single variables and the best combination are listed:

Correlation co-efficient	Variable
0..494	Sediment sorting
0.390	%gravel
0.368	%sand
0.363	Rhodolith content
0.280	Median grain size
0.218	Depth
0.129	Seagrass content
0.096	Macroalgae content
0.044	%mud
0.524	Best combination (sorting, rhodolith content, seagrass content)

Figure 4: Dendrogram of samples clustered on basis of square-root transformed family abundance data.



The dendrogram (Figure 4) gives an alternative view of the relationships. Three large groups (groups1, 2 &3) are indicated here. The relationship of these groupings to sediment characteristics is clear. The first, comprising all samples from rhodolith beds, the reef area, and sites R3 and W4, had sediments that were very poorly to moderately sorted (Table 1). The group two contains samples from sites with moderately sorted bare sands. Group3 is comprised mostly of samples from site W3 where the sediments are well sorted.

Group 1 samples contained the highest abundances of macrofauna as well as number of taxa and diversity (Shannon diversity measure) (Refer Table 2). Group 2 samples were all lower in these measures, with the exception of those from site W1 which had relatively high total abundances.

Within the large groups 1 and 2, smaller groupings are indicated on the dendrogram such as rhodolith containing samples from sites W2 and R1 and samples from sites R3 and W4 ("sessiles"), These groups provide a useful way of examining the taxa responsible for the observed patterns.

Table 5 shows the characteristic taxa picked by the simper analysis for each of these groups. These are generally taxa which contribute most to the average similarity within the group (generally those with higher average abundance within the group) but also with consistent representation across the samples of the group. Those taxa that were picked to be good discriminators from other groups (using dissimilarity measures between the groups under similar criteria) are also indicated.

The rhodolith containing samples from sites W2 and R1, form a strong cluster ("rhodoliths"). Rhodolith content of the samples correlated positively with proportions of carnivores and herbivores/carnivores such as carnivorous or scavenging polychetes (*eg* Eunicids, Nereidids, Syllids, Polynoids, Dorvilleids, Hesionids and Euphronosids). Rhodolith content was also correlated with organic content and deposit feeding polychaetes such as Terebellidae, Spionidae and Flabelligeridae were also found to be characteristic of these samples. Samples from rhodoliths had high similarity to those from the sand inundated reef (site R4), and other characterising species such as Ophiuroids (*Ophoiotrix caespitosa*

Macrophiothrix spongicola Ophiactis tricolor & Ophiactis resiliiens), lobster krill (*Galathea australiensis*) and chitons were typically found associated with hard substrate sessile invertebrate communities in the area (author's personal observation). The other rhodolith site (E2) is somewhat separated. Grab samples taken at this site were unusual in that they contained almost no other sediment. Less fouling of the rhodolith thalli (*eg*. by other macroalgae, bryozoans) was also observed.

Samples from sites R3 and W4 are also grouped ("sessiles"). Sessile invertebrates were prominent in the video footage from these sites: the bryozoan *Lanceopora obliqua* in the case of site W4 and tube formations in the case of site R3. A fragment in one of the samples from this site indicated that the tubes belong to Chaetopterid polychaete worms, however, the grab penetration was not adequate to procure an intact specimen.

Group W1 is characterised by deposit feeding taxa, eg Appsuedid tanatids (*Saltipedis* sp.), Tellinid bivalves, Nematodes, Ophiuridae (*Ophiura kinbergi*) and heart urchins (Loveniidae: *Echinocardium cordatum*).

Group W3 (equivalent to Group 3 on the dendrogram) had a very well sorted sand environment, characterised by low diversity, richness, abundance and high variability between samples within the group. In comparison, Group E1, and W5 (moderately sorted sediments) had slightly higher diversity and richness, and higher proportions of deposit feeders. A higher proportion of suspension feeders (eg Venereidae and Sabellidae) distinguished site R2 from the other moderately sorted bare sand sites (W1, W5 and E1).

Samples from site W5 were quite spread on the ordination: ranging between similarity with the rhodolith site E2, to similarity with the well sorted sand site W3. Opportunistic scavengers and detritivores make up the distinguishing taxa: Appsuedes (*Appsuedes gallardoi*) Nereidid polychates, and Amphiuridae (*Amphiura* spp. & *Amphipholis squamata*).

Table 5: Characterising Taxa for the groups identified in the Cluster analysis. Taxa picked as good discriminators from other groups are indicated by an asterisk. Feeding modes are indicated: S, suspension feeder; D, Deposit feeder; C, carnivore/scavenger; H, herbivore; C/H, carnivore/herbivore.

Characterising Taxa		*Discriminating Taxa*							
	Average abundance per	W1	Rhodoliths	W3	E1	E2	sessiles	W5	R2
Group W1									
Amphipod- Gammaridea (C)	78.20	-							
Tanaid- Appsuedidae (D)	35.40	-	*	*	*	*			
Bivalve- Tellinidae (D)	24.70	-	*			*	*	*	
Nematode (D)	19.00	-		*	*	*	*	*	*
Ophiuroid- Ophiuridae (D)	11.50	-	*			*			
Polychaete- Spionidae (D)	7.20	-	*						
Cumacea (D)	9.70	-	*			*		*	
Ostracoda- Myodocarpa (C)	5.70	-		*					
Polychaete- Sabellidae (S)	4.50	-			*				
Ophiuroid- Amphiuridae (D)	3.50	-							
Polychaete- Ampharetidae (D)	2.70	-			*				
Echinoid- Loveniidae (D)	2.90	-							
Group rhodoliths									
Amphipod- Gammaridea (C)	115.75		-						
Ophiuroid- Ophiactidae (D)	29.92	*	-	*	*	*	*	*	*
Polychaete- Eunicidae (C/H)	18.83	*	-	*	*				
Polychaete- Nereididae (C/H)	18.00	*	-		*		*		
Polychaete- Syllidae (C)	18.42	*	-		*				
Polychaete- Terebellidae (D)	14.42	*	-	*	*				*
Polychaete- Polynoidae (C)	14.75		-	*	*		*		
Polychaete- Lumbrineridae (C)	16.42		-						
Galatheid- *Galathea australiensis* (C)	17.00		-	*	*				*
Ophiuroid- Amphiuridae (D)	9.42		-	*					
Nemerteans (C)	6.50		-		*			*	
Polychaete- Euphrosinidae (C)	12.75		-						
Isopod- Eurydicidae (C)	6.08		-	*				*	
Polychaete- Dorvilleidae (C)	4.42	*	-	*	*	*			*
Polychaete- Hesionidae (C)	2.83		-	*	*	*			*
Polychaete- Phyllodocidae (C)	4.42		-	*					
Chiton- Ischnochitonidae (H)	7.17		-						
Polychaete- Spionidae (D)	2.75		-	*		*		*	
Polychaete- Flabelligeridae (D)	3.08	*	-	*	*			*	
Neblacea (S)	4.25		-						
Gastropod- Trochidae (D)	3.08	*	-						

Group W3									
Amphipod- Gammaridea (C)	20.67			-					
Isopod- S.O.:Anthuridea (C)	1.22	*	*	-		*		*	
Ostracoda- Myodocarpa (C)	2.78			-					
Bivalve- Tellinidae (D)	1.00			-					
Polychaete- Nephtyidae (C)	0.89			-					
prawn- Processidae (C)	0.78			-					
Group E1									
Amphipod- Gammaridea (C)	13.75				-				
Polychaete- Spionidae (C)	9.25	*	*	*	-	*	*	*	*

Table 5 cont.

	Average abundance per	W1	Rhodoliths	W3	E1	E2	sessiles	W5	R2
Group E1 CONT.									
Bivalve- Tellinidae (D)	2.50		*		-	*	*	*	
Ophiuroid- Ophiuridae (D)	2.25		*		-	*			
Ostracoda- Myodocarpa (C)	2.00		*		-				
Ostracoda- Podocarpa (C)	1.75	*	*	*	-		*		*
Group E2									
Amphipod- Gammaridea (C)	64.80					-			
Neblacea (S)	9.60	*	*			-	*	*	
Polychaete- Sabellidae (S)	8.60				*	-		*	
Polychaete- Nereididae (H/C)	6.20				*	-	*		
Polychaete- Polynoidae (C)	5.20	*		*	*	-	*		
Polychaete- Syllidae (C)	7.40				*	-			
Echinoid- Temnopleuridae (H/C)	10.60	*				-			*
Polychaete- Terebellidae (D)	4.00	*		*	*	-			*
Tanaid- Appsuedidae (D)	5.00			*		-			
Ophiuroid- Amphiuridae (D)	4.40			*		-			*
Isopod-Stenetriidae (C)	3.00	*		*	*	-	*	*	*
Polychaete-Lumbrineridae(H/C)	2.20	*		*		-		*	*
Ostracoda-Myodocarpa (C)	2.60					-			
Nemerteans (C)	2.60				*	-			
<u>Group sessiles</u>									
Amphipod- Gammaridea (C)	53.56			*			-		
Tanaid- Appsuedidae (D)	64.67		*	*			-		
Polychaete- Sabellidae (S)	32.78				*		-	*	

Polychaete- Eunicidae (H/C)	10.33	*		*	*		-		
Polychaete- Syllidae (C)	6.22				*		-		
Polychaete- Capitellid (D)	4.89			*	*		-		
Polychaete- Terebellidae (D)	7.44						-		
Polychaete- Spionidae (D)	5.78						-		
Polychaete- Onuphidae (H/C)	4.11			*		*	-	*	
Isopod- S.O.:Anthuridea (C)	5.11						-		
Polychaete- Nereididae (H/C)	3.22			*	*		-		
Ostracoda- Myodocarpa (C)	3.11						-	*	
Amphipod- Caprellidae (C)	2.89	*		*	*	*	-	*	*
Bivalve- Veneridae (S)	6.11						-		
Bivalve- Mytilidae (S)	4.56	*	*	*	*		-	*	
Nemerteans (C)	3.11				*		-		
Polychaete- Polynoidae (C)	1.78	*		*	*	*	-	*	
Polychaete- Lumbrineridae (C)	2.11						-		
Polychaete- Dorvilleidae (C)	2.44						-		
Crab- Hymenosomatidae (C)	2.11						-		
Group W5									
Tanaid- Appsuedidae (D)	26.20		*	*	*	*		-	*
Amphipod- Gammaridea (C)	15.60							-	
Ophiuroid- Amphiuridae (D)	7.80			*				-	
Polychaete- Nereididae (C/H)	2.20			*				-	
Group R2									
Amphipod- Gammaridea (C)	23.40			*					-
Ophiuroid- Amphiuridae (D)	8.60	*		*					-
Polychaete- Sabellidae (S)	6.60				*			*	-
Ophiuroid- Ophiuridae (D)	2.80		*			*			-
Polychaete- Spionidae (D)	4.40								-
Polychaete- Polynoidae (C)	2.60	*		*	*				-
Nemerteans (C)	2.20			*				*	-
Polychaete- Nereididae (C/H)	3.20								-
Polychaete- Syllidae (C)	3.00								-
Bivalve- Veneridae (S)	1.40	*	*	*					-

DISCUSSION

The character and diversity of soft substrate macrofaunal assemblages were found to be related to the structural complexity of the bottom. This structural complexity was provided by either the sediment character, or by biogenic structures, including macroalgae, sessile invertebrates and rhodoliths. The ordinations show that in the western Archipelago, the assemblages bear a closer relationship to these structural factors, than to spatial distance between sites.

The relationship between sediment characteristics and benthic faunal composition is a well established concept. The very well sorted sediments were associated with low diversity and abundance. Lower sorting coefficients reflect the structural complexity of the sediment, and so diversity would be expected to increase (Gray 1974), as was the case here. The grain size and sorting are determined by characteristics of near-bed flow regimes (eg shear stress) (Nowell and Jumars 1984) which also directly affect the benthos through food and larval supply and particulate flux (Snelgrove and Butman 1994).

The highest diversities and species richness were found in the rhodolith beds (Sites W2, R1 & E2). This has been reported elsewhere, rhodoliths considered to be "habitat modifiers" providing structural complexity with natural spaces within the branches for cryptic fauna, and hard surfaces for the attachment of sessile invertebrates and other algae (Foster 2001; Stellar, Roismenn-Rodriguez *et al.* 2003).

The separation of site E2 from the other rhodolith sites may be related to water movement patterns – slight oscillatory movement and turning of the rhodolith thalli maintains plant integrity and prevents fouling (Steller and Foster 1995). Fouling of the rhodolith thalli was lower at this site, and oceanographic modelling data suggests higher bed velocities at this site compared with the others (see Oceanography Report, appendix 3). Discriminating taxa between this site and the other rhodolith sites included the Neblaceans (suspension feeders)- more abundant at E2, with deposit feeders Ophiactid ophiuroids (*Ophiactis tricolor* & *resiliiens*) and spinonid polychaetes being more abundant at the other sites. This might suggest a more favourable environment for the suspension feeding mode.

Rhodolith beds are considered of high conservation value in Europe, because of thies vulnerability and the diverse communities associated with them. The rhodoliths are slow growing (Foster 2001) and sensitive to activities such as scallop dredging (Hall-Spencer and Moore 2000).

Diversity and species richness at site R3 were at the level of the rhodolith/sand innundated reef sites. Dense aggregations of chaetopterid polychaetes have been found to stabilise otherwise shifting sediments forming mounds which support diverse assemblages of invertebrates (Bailey-Brock 1979). Diversity at site W4 was lower, however these were grouped with R3 in the multivariate analysis. It is not known whether the bryozoan *Lanceopora obliqua* can serve a similar sediment stabilising function. The rootlets were observed to coalesce the sand grains to a very small extent. *Lanceopora obliqua* can colonise areas of mobile sediment, being able to grow upwards to survive inundation in shifting sand environment (Shephard 1983). Sediments at both sites were poorly sorted: the extent to which this is due to hydrodynamic conditions which allow the colonisation of these sessile invertebrates or to the presence of the organisms themselves is unknown.

Increased proportions of suspension feeders have been associated with increasing stability of the sediments, and high abundances of suspension feeders abundant in well-sorted fine grain deposits (Gray 1974). In this study, no significant correlation was found between the ratio of suspension to deposit feeders with the sediment factors measured. Site R2, for example, has a high proportion of suspension feeders compared with other sites with moderately sorted slightly gravelly sand (W1, E1, W5). These are mainly represented by sabellid polychaetes and venereid bivalves.

A significant negative correlation was found between deposit and suspension feeders. Theories such as trophic group amensalism (Rhoads and Young 1970) suggest that deposit feeders (especially protobranch molluscs) reworking the sediments inhibit suspension feeders, by mechanisms such as interfering with their larval settlement, clogging their filtering structures and limiting the ability of sessile epifauna to maintain a firm connection with the sustrate. This might be supported at sites W1 and W5 but at site R3 there are relatively high abundances of both groups. The role of sediment stabilising organisms has been noted above whilst the concept of a simple dichotomy between suspension and deposit feeders is no longer considered valid (Snelgrove and Butman 1994).

As soft substrate benthic assemblages are related to the structural complexity of the substrate, classification of habitats within this environment require assessment of the sediment character (eg grain size descriptions). Remote techniques such as video can give a good assessment of biogenic structures (such as rhodoliths, worm tubes etc) and a crude idea of sediment character. However, in order to characterise these habitats fully, remote techniques would need to be supplemented by physical sampling and characterisation of the sediment.

Acknowledgments

We would like to thank the following people for species identifications: Loisette Marsh (Echinoderms), Roger Bamber (pycnogonids, tanaids). We would also like to thank Marcus Grey for supplying a vessel and skippers to do the van veen grabs from and for help in the field Andy Bickers, James Butler, Emma Kitson, Katrina Baxter and Dave Abdo.

REFERENCES.

Bailey-Brock, J. H. (1979). "Sediment trapping by Chaetopterid polychaetes on a Hawaiian fringing reef." Journal of Marine Research **37**: 643-657.

Barnes, R. D. (1980). Invertebrate zoology. Philadelphia, Saunders College.

Beesley, P. L., G. B. H. Ross, *et al.*, Eds. (1998). Mollusca: The Southern Synthesis. Fauna of Australia. Melbourne, CSIRO Publishing.

Beesley, P. L., G. J. B. Ross, *et al.*, Eds. (2000). Polychaetes & Allies: The Southern Synthesis. Fauna of Australia. Melbourne, CSIRO Publishing.

Clarke, K. R. (1993). "Non-parametric multivariate analyses of changes in community structure." Australian Journal of Ecology **18**: 117-143.

Clarke, K. R. and M. Ainsworth (1993). "A method of linking multivariate community structure to environmental variables." Marine Ecology Progress Series **92**: 205-219.

Edgar, G. J. (2000). Australian Marine Life: the plants and animals of temperate waters. Sydney, Reed New Holland.

Ellingsen, K. E. (2002). "Soft -sediment benthic biodiversity on the continental shelf in relation to environmental variability." Marine Ecology Progress Series **232**: 15-27.

Fauchald, J. and P. A. Jumars (1979). "The diet of worms: A study of polychaete feeding guilds." Oceanography and Marine Biology: An Annual Review **17**: 193-284.

Foster, M. S. (2001). "Rhodoliths: Between rocks and soft places." Journal of Phycology **37**(5): 659-66.

Gray, J. S. (1974). "Animal-sediment relationships." Oceanography and Marine Biology: an annual review **12**: 223-261.

Hale, H. M. (1927-1929). The Crustaceans of Australia, Parts I and II. Adelaide, Government Printer.

Hall-Spencer, J. M. and P. G. Moore (2000). "Scallop Dredging has profound long-term impacts on maerl habitats." ICES Journal of Marine Sciences **57**: 1407-1415.

Holditch, D. M. and J. A. Jones (1983). Tanaids. Cambridge, Cambridge University Press.

Jones, D. S. and G. J. Morgan (1994). A Field Guide to the Crustaceans of Australian Waters. Sydney, Reed.

Nowell, A. R. M. and P. A. Jumars (1984). "Flow environments of aquatic benthos." Annual Review of Ecology and Systematics **15**: 303-328.

Rhoads, D. C. and D. K. Young (1970). "The influence of deposit-feeding organisms on sediment stability and community trophic structure." Journal of Marine Research **28**: 150-178.

Shephard, S. A. (1983). "The epifauna of megaripples: species' adaptions and population responses to disturbance." Australian Journal of Ecology **8**: 3-8.

Shepherd, S. A. and M. Davies, Eds. (1997). Marine Invertebrates of Southern Australia Part III. Handbook of the Flora and Fauna of South Australia. Adelaide, South Australian Research and Development Institute.

Shepherd, S. A. and I. M. Thomas, Eds. (1982). Marine Invertebrates of Southern Australia Part I. Handbook of the Flora and Fauna of South Australia. Adelaide, South Australian Government Printing Division.

Shepherd, S. A. and I. M. Thomas, Eds. (1989). Marine Invertebrates of Southern Australia Part II. Handbook of the Flora and Fauna of South Australia. Adelaide, South Australian Government Printing Division.

Snelgrove, P. V. R. (1998). "The biodiversity of macrofaunal organisms in marine sediments." Biodiversity and Conservation **7**(9): 1123-1132.

Snelgrove, P. V. R. and C. A. Butman (1994). "Animal-sediment relationsships revisited: Cause versus effect." Oceanography and Marine biology Annual Review **32**: 111-177.

Steller, D. L., R. Roismenn-Rodriguez, *et al.* (2003). "Rhodolith bed diversity in the Gulf of California: the importance of rhodolith structure and consequences of disturbance." Aquatic Conservation: Marine and Freshwater Ecosystems **13**: S5-S20.

Steller, D. L. and M. S. Foster (1995). "Environmental factors influencing distribution and morphology of rhodoliths in Bahia Concepcion, B.C.S., Mexico." Journal of Experimental Marine Biology and Ecology **194**(2): 201-212.

Ward, T. J., M. A. Vanderklift, *et al.* (1999). "Selecting marine reserves using habitats and species assemblages as surrogates for biological diversity." Ecological Applications **9**(2): 691-698.

Young, J. Z. (1962). The life of vertebrates. New york & Oxford, Oxford University Press.

Appendix 8.4.1 The effect of bait on the discrimination of benthic marine fish assemblages sampled with underwater video stations.

Euan Harvey [1], Mike Cappo [2], James Butler[1], Gary Kendrick[1].

[1] School of Plant Biology (Botany M090), University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009.
[2] Australian Institute of Marine Science, PMB 3, Townsville MC, Queensland 4810.

INTRODUCTION

The composition, density and distribution of marine fish assemblages in topographically complex habitats are difficult to assess comprehensively, due to the heterogeneity of their habitats, variability in their patterns of behaviour and abundance, and sampling bias. Numerous comparative studies have documented bias and selectivity amongst sampling methods (eg Harmelin-Vivien and Francour 1992; Hickford and Schiel, 1995; Cappo and Brown 1996). The coefficients of variation for some extractive techniques, such as fish trapping, can be so high that the power to detect large changes in sample means is weak, requiring levels of replication that would be unacceptable in areas such as marine parks (Williams *et al.* 1997). The best approaches involve a suite of sampling techniques, calibrated against direct counts made with underwater visual surveys (see Willis and Babcock 2000, Willis *et al.* 2000).

Underwater visual census made by SCUBA divers in shallow waters, and by observers from submersibles in deeper waters have enabled precise and accurate density estimates to be made for a variety of species in a range of habitats (eg Yoklavich *et al.* 2000; Gaudian *et al.* 1995; Samoilys and Carlos 2000). However, these surveys can be seriously biased for some "shy" or cryptic species (Kulbicki 1998; Watson *et al.* 1995; Willis and Babcock 2000; Stewart and Beukers 2000).

More recently, remotely operated video stations have been used to avoid the biases introduced by the presence of SCUBA divers (Willis *et al.* 2000; Willis and Babcock 2000; Westera *et al.* 2003) and to avoid the gear selectivity inherent in baited trapping and hook-and-line surveys (Ellis and DeMartini 1995; Yau *et al.* 2001; Cappo *et al.* 2004). Video-based techniques are proving particularly useful in assessing the effects of marine protected areas because they are non-destructive, cost-effective and not limited by depth or time of day (see Cappo *et al.* 2003 for review; Denny and Babcock 2004).

Over recent years the image quality of video has dramatically improved, whilst its price has plummeted in some forms (see Harvey and Cappo 2001 for review). It is now feasible for researchers to deploy fleets of multiple video stations, which greatly increases the replication and spatial coverage of sampling with simultaneous sets of numerous underwater video stations (UVS) (Cappo *et al.* 2004). Remote video sampling is non-extractive and, unlike research trawling does not affect the seabed, allowing information on protected species and "charismatic megafauna", such as very large fish, sharks and rays, to be repeatedly gathered in an acceptable manner. Underwater video stations can be dropped with pin-point accuracy into very rugose habitats, such as boulder fields, coral and limestone reefs and kelp and seagrass beds.

Bait has been used as an attractant in all the studies mentioned above. Stationary baited UVS sample the large (>5 cm) mobile fishes attracted into, residing in, or passing through the field of view of the UVS. The timing of arrival and the maximum number of fish sighted within single periods have generally been used as estimators of relative abundance, following the development of models relating density of abyssal scavengers to bait plume travel by Priede *et al.* (1990, 1994), Priede and Merritt (1996) and Sainte-Marie and Hargrave (1987). None of these studies explicitly tested the effect of the bait on the conclusions about species diversity and abundance, yet herbivores (siganids, acanthurids) were caught mainly in unbaited fish traps whilst predatory serranids, lutjanids and lethrinids predominated in the catches of baited traps (see Cappo and Brown 1996 for review). It could be argued that baited UVS might preferentially sample predatory or scavenging species to the exclusion of herbivorous or omnivorous species. Whilst this has been desirable for video-based studies of the fate of discarded by-catch (Hill and Wassenberg 2000), such dynamics would severely bias discrimination of fish assemblages amongst vegetated and un-vegetated habitats in temperate and tropical biodiversity surveys.

In this report we compare the performance of baited and unbaited UVS in discriminating between demersal fish assemblages inhabiting distinctive benthic habitats in the temperate marine shelf waters in the Recherche Archipelago. We compare the diversity (*Nsp*) and abundance (*MaxN*) of different functional groups sampled by baited or unbaited UVS.

METHODS AND MATERIALS

Four baited and unbaited UVS were deployed in each of six habitats (a total of 48 samples) within Esperance Bay, South Western Australia in September of 2002. The locations of deployments within each habitat were predetermined from a habitat map of the area. The six habitats sampled were Seagrass (SG), Ecklonia (Eck), Other Macrophytes (O_M), Deep Reef (DR), Rhodoliths (Rhod) and Sand (S). The Seagrass habitat was characterised by a 60-100% cover of *Posidonia* sp between depths of 10 and 16m. The Ecklonia and Other Macrophyte habitats consisted of sloping granite reefs with a 60% cover or greater of *Ecklonia radiata* or *Sargassum* sp and *Cystophora* sp. Deep Reefs consisted of granite reefs at depths greater than 30m and were characterised by a sparse cover of macro algae or sponges. Rhodolith and Sand habitats had low relief with 80% or greater cover of rhodoliths or sand, and were always deeper than 30m.

Within each habitat, four one-hour recordings were made for both baited and unbaited UVS. At a site unbaited and baited UVS were sample sequentially with unbaited UVS being deployed prior to baited. We allowed 20 minutes to elapse between unbaited and baited deployments at the same site. Sampling was completed between 8.30 am and 3.30 pm to avoid crepuscular changes in behaviour. With up to four UVS deployed at any one time it was particularly important for baited UVS to ensure we maintained a distance of at least 500m between samples to minimise the attraction of fish from one site to another. Recordings were made using four stereo-video systems (see Harvey and Shortis, 1996, 1998 and Harvey *et al.* 2002 for design and measurement procedures) using either Sony TRV900E or TRV15 digital camcorders contained within waterproof housings.

Analysis of video tapes

When we reviewed the tapes we recorded the time the UVS settled on the seabed and for each species the time of first sighting (*TFAP*), time of first feeding at the bait (*TFF*), the maximum number of a species seen together in any one time on the whole tape (*MaxN*), time at which *MaxN* occurred and the intraspecific and interspecific behaviour.

We used *MaxN* as we were concerned that individual fish could be counted repeatedly when leaving and then entering the field of view during tape interrogation. The n_{peak} of Priede *et al.* (1994), the *MAXNO* of Ellis and DeMartini (1995), the *MAX* of Willis and Babcock (2000) and the *MaxN* of our study are all homologous. This statistic under-estimates the true abundance of fish visiting the bait bag or passing through the field of view of the camera. The occurrence of separate visits by different individuals of the same species is recorded as *MaxN*=1 and only a portion of a partially visible fish school contributes to *MaxN*. This usage results in conservative estimates of abundance in high-density areas and therefore differences detected between areas of high and low abundance (eg inside and outside marine protected areas) are also likely to be more conservative (Willis *et al.* 2000; Cappo *et al.* 2003).

The video recordings were broken into 60 one-minute time intervals from the time the video cameras came to rest on the seafloor. The maximum number of species *i* at any time *t* ($MaxN_{i,t}$) was recorded during each minute, but the final measure of relative abundance used in analyses was the highest $MaxN_{it}$ over the whole tape record.

Functional Groups

All species of fishes and elasmobranchs sighted on video tapes were assigned to one of ten functional groups, based on their feeding habits and functional morphology. This information was derived from "FishBase" (Froese and Pauly, 2004), Allen and Swainston (1988), Gloerfelt-Tarp and Kailola (1984), Kuiter (1993), Randall *et al.* (1990), Russell (1990), and Sainsbury *et al.* (1985). The groups were classified by the predominance of prey types into herbivores (1), corallivores (2), zooplanktivores (3), piscivores (4), and invertebrate carnivores (5). Further groupings were recognised by the predominance of prey mixtures into algae/invertebrates (6), invertebrates/algae (7), and sponges/invertebrates (8). Carnivores were also classified by the size and range of items eaten. Macro-invertebrate carnivores (9), like larger rays, eat large items such as cepahalopods, molluscs and crustaceans. Generalist carnivores (10) were recognised on the basis of a wide range of fishes and invertebrates taken from various positions in the water column.

Data analysis

Multivariate Analyses

Data was entered into a site by species matrix which was then used to create a triangular similarity matrix, based on the Bray-Curtis similarity coefficient. Given the conservative nature of *MaxN*$_i$, no data transformations were made. Data for *Pseudocaranx dentex, a* schooling trevally were removed from the analysis because the very high numbers of individuals which were periodically recorded dominated the analysis.

One-way analyses of similarities (ANOSIM) were used to analyse differences between habitats for both baited and unbaited data sets. Two-dimensional ordinations were created by non-metric multidimensional scaling (MDS), so that the rank order of distances between samples reflected the rank order of the matching similarities taken from the underlying triangular similarity matrix. All analysis was undertaken in PRIMER (Plymouth Routines in Multivariate Ecology) V5 (Clarke and Gorley, 2001).

Univariate Analyses

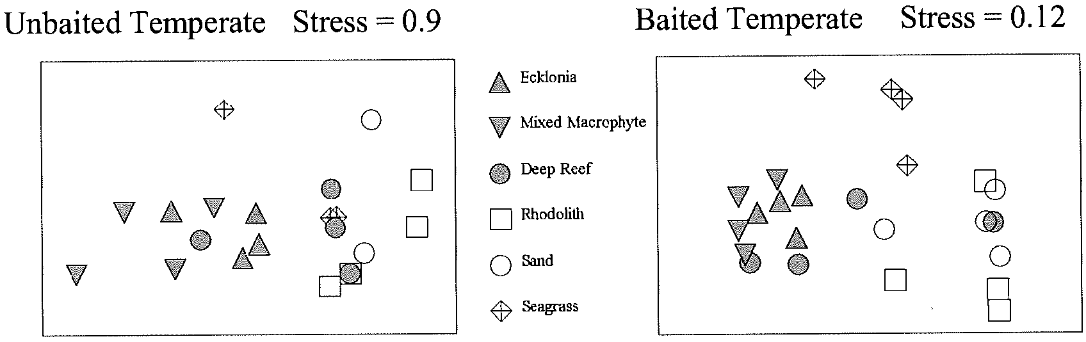
One way Analysis of Variance (ANOVA) was used to test for the effects of bait on *MaxN*$_i$ and species diversity (*Nsp*) within each habitat. Statistical analyses were conducted using Minitab (Version 13). Homogeneity of variances were examined using Cochran's test (1991). Many of the variances were heterogeneous ($P<0.05$) so data was fourth root transformed for all data. Analyses were performed if data remained heterogenous following transformation, as ANOVA is generally robust for heterogenous data (Underwood, 1997).

A two way ANOVA with Treatment and Habitat as factors was undertaken on Functional group data.

RESULTS

Multivariate Analysis

One way ANOSIM revealed distinct fish assemblages between habitats in both the unbaited and baited samples (Global R = 0.363 for unbaited and 0.599 for baited video). However, baited video samples provided a clearer visual separation on the MDS plot (Figure 1).


Unbaited Temperate Stress = 0.9

Baited Temperate Stress = 0.12

Figure 1: Multidimensional Scaling of fish assemblages in six temperate habitats using baited and unbaited remote underwater video. N=4 with 35 permutations.

Pair-wise comparisons between the habitats for the unbaited and baited samples showed that the use of bait results in higher R values and greater fish assemblage discrimination than is seen in the unbaited comparisons (Table 1).

Table 1: Pairwise comparisons from temperate habitats. ANOSIM based on 4 samples per habitat with a maximum of 35 permutations.

	Unbaited video stations		Baited video stations	
Habitat	R Value	Significance %	R value	Significance
Ecklonia vs Seagrass	0.49	2.9	0.917	2.9
Ecklonia vs Sand	0.708	2.9	0.849	2.9
Ecklonia vs Rhodoliths	0.792	2.9	0.865	2.9
Ecklonia vs Deep reef	0.328	14.3	0.323	2.9
Ecklonia vs Mixed Macrophytes	0.177	14.3	0.438	2.9
Mixed Macropyhtes vs Seagrass	0.792	2.9	0.958	2.9
Mixed macrophytes vs Sand	0.917	2.9	0.953	2.9
Mixed macrophytes vs Rhodoliths	0.99	2.9	0.979	2.9
Mixed macrophytes vs Deep reef	0.594	5.7	0.255	8.6
Deep reef vs Seagrass	-0.156	85.7	0.599	2.9
Deep reef vs Sand	-0.042	71.4	0.354	8.6
Deep reef vs Rhodoliths	0.12	25.7	0.474	5.7
Rhodoliths vs Seagrass	0.172	20.	0.766	2.9
Rhodoliths vs Sand	-0.042	45.7	-0.057	51.4
Seagrass vs Sand	0.099	17.1	0.719	2.9

Univariate analysis

Plots of the mean $MaxN_i$ and *Nsp* (Figure 2) recorded for each habitat revealed that in every case there were higher mean numbers of individuals and species recorded for baited video camera samples.

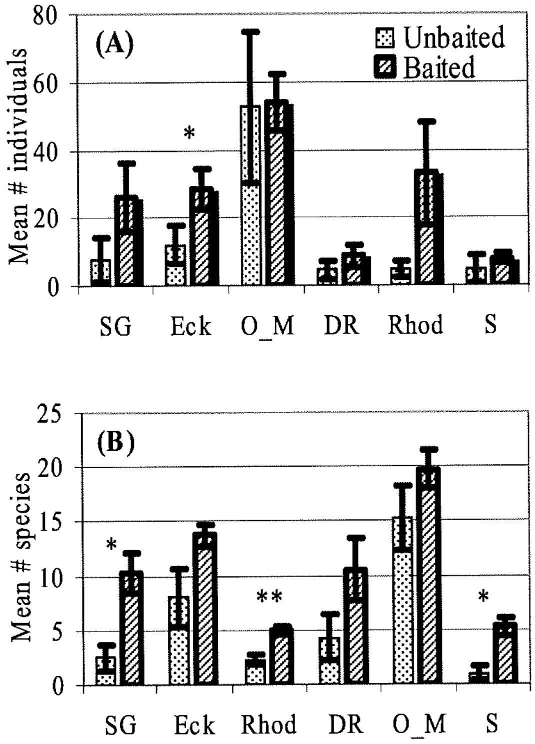


Figure 2: Mean $MaxN_i$ (A) and *Nsp* (B) for both unbaited and baited video stations in six benthic habitats. N=4. SG = Seagrass. Eck = Ecklonia, O_M = Other Macrophytes, DR = Deep reef, Rhod = Rhodoliths, S = Sand. Error bars = ± 1 SE. * indicates the level of significance for a one way ANOVA; * = $P<0.05$, ** = $P<0.01$, *** $P<0.001$.

One way ANOVA found statistically significant differences in one of the six habitats (Eck) for $MaxN_i$ and three for *Nsp* (SG, Rhod, S, See Figure 2).

Functional group analysis

When the relative abundance data is reclassified into functional groups plots of $MaxN_i$ (Figure 3a) and *Nsp* (Figure 3b) reveal higher mean values for baited UVS.

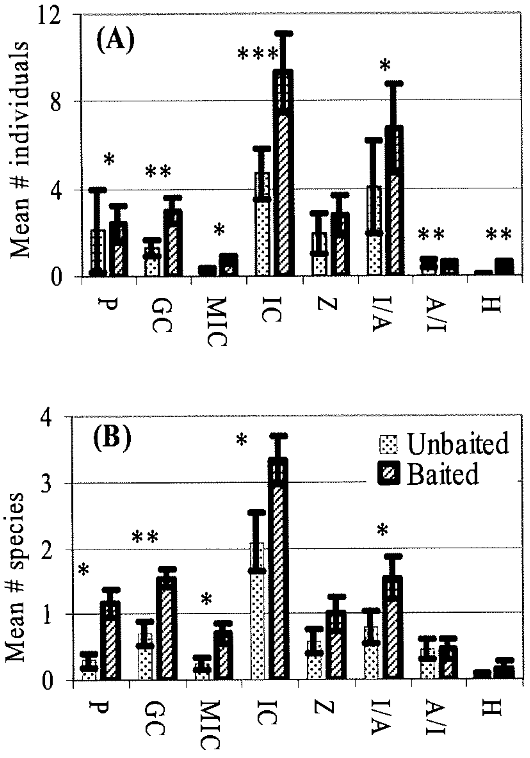


Figure 3: Mean $MaxN_i$ (A) and Nsp (B) counted for both unbaited and baited video in each of eight functional groups for six temperate benthic habitats. N=24. P=Piscivore, GC = Generalist Carnivore, MIC = Macroinvertebrate Carnivore, IC = Invertebrate Carnivore, Z = Zooplankton. I/A = Invertebrates/Algae, A/I = Algae/Invertebrates, H = Herbivores Error bars = ± 1 SE. * indicates the level of significance for treatment (baited vs unbaited) for a two one way ANOVA; * = $P<0.05$, ** = $P<0.01$, *** = $P<0.001$.

Number of Individuals (MaxNi)

There were significant statistical differences (Two way ANOVA) between treatments (baited vs. unbaited UVS) in the mean *MaxNi* for Piscivores, Generalist Carnivores, Macroinvertebrate Carnivores, Invertebrate Carnivores, Invertebrates/Algae but not for Zooplanktivores, Algae/Invertebrates and Herbivore groups (Table 2). There were also significant differences between habitats for all functional groups with the exception of Piscivores and Macroinvertebrate Carnivores. These differences between habitats are analysed in more detail in another part of this report and will not be analysed further here.

A significant Treatment * Habitat interaction was recorded for *MaxNi* for Herbivores which was caused by higher numbers of Herbivores being sampled in Baited * Seagrass in comparison to other combinations of habitat and treatment.

Table 2: Two way ANOVA tests for differences in *MaxNi*(a-h) and *Nsp* (i-p) between baited and unbaited UVS (treatments) for functional groups. N=48.

Source	*df*	(a) Piscivore *MaxNi*			(b) Generalist Carnivore *MaxNi*			(c) Macroinvertebrate Carnivore *MaxNi*			(d) Invertebrate Carnivore *MaxNi*		
		MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
T	1	2.885	6.77	***0.013***	3.845	16.91	**0.000**	1.233	4.98	***0.032***	3.270	14.71	**0.000**
H	5	0.843	1.98	0.105	0.735	3.24	***0.016***	0.334	1.35	0.266	1.461	6.57	**0.000**
T*H	6	0.093	0.22	0.952	0.299	1.32	0.279	0.236	0.95	0.460	0.045	0.20	0.960
Residual	36	0.426			0.227			0.248			0.222		
Total	47	22.987			17.201			12.995			18.803		
Source	*df*	(e) Zooplanktivore *MaxNi*			(f) Invertebrates /Algae *MaxNi*			(g) Algae/Invertebrates *MaxNi*			(h) Herbivores *MaxNi*		
		MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
T	1	0.731	2.46	0.126	1.811	4.22	***0.047***	0.0097	0.35	0.555	0.1764	2.93	0.095
H	5	2.325	7.83	**0.000**	3.823	8.92	**0.000**	2.3932	87.08	**0.000**	0.3067	5.10	**0.001**
T*H	6	0.400	1.35	0.267	0.361	0.84	0.530	0.0149	0.54	0.743	0.3718	6.18	**0.000**
Residual	36	0.297			0.429			0.0275			0.0601		
Total	47	25.051			38.164			13.0393			5.7339		
Source	*df*	(i) Piscivore *Nsp*			(j) Generalist Carnivore *Nsp*			(k) Macro invertebrate Carnivore *Nsp*			(l) Invertebrate Carnivore *Nsp*		
		MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
T	1	2.559	9.28	**0.004**	2.946	20.70	**0.000**	1.254	5.31	***0.027***	1.800	13.84	**0.001**
H	5	0.474	1.72	0.156	0.625	4.39	**0.003**	0.315	1.33	0.273	0.667	5.12	**0.001**
T*H	6	0.038	0.14	0.982	0.270	1.90	0.119	0.239	1.01	0.425	0.118	0.91	0.486
Residual	36	0.276			0.142			0.236			0.130		
Total	47	15.042			12.545			12.525			10.407		
Source	*df*	(m) Zooplanktivore *Nsp*			(n) Invertebrates /Algae *Nsp*			(o) Algae/Invertebrates *Nsp*			(p) Herbivores *Nsp*		
		MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
T	1	0.482	2.88	0.098	0.792	4.56	***0.040***	0.0137	0.53	0.470	0.0998	2.22	0.145
H	5	1.571	9.38	**0.000**	2.219	12.79	**0.000**	2.2681	88.26	**0.000**	0.2062	4.58	**0.002**
T*H	6	0.193	1.15	0.352	0.130	0.75	0.592	0.0137	0.53	0.750	0.2593	5.76	**0.001**
Residual	36	0.167			0.174			0.0257			0.0450		
Total	47	15.332			18.787			12.3477			4.0486		

Number of Species (Nsp)

For *Nsp* there were significant differences between treatments (baited vs. unbaited UVS) for Piscivores, Generalist Carnivores, Macroinvertebrate Carnivores, Invertebrate Carnivores and Invertebrates/Algae. Habitat differences were detected for all functional groups with the exception of Macroinvertebrate Carnivores. Again a significant Treatment * Habitat interaction was recorded for Herbivores. Bait * Seagrass had higher numbers of Herbivores than in any other combination of habitat and treatment.

DISCUSSION

Baited "video-fishing" techniques have been used to count juvenile fishes (Ellis and DeMartini 1995), to identify the scavengers of prawn (shrimp) trawl discards (Hill and Wassenberg 2000), to measure the performance of marine protected areas (Willis and Babcock 2000, Willis *et al.* 2000), and to measure abundance of abyssal scavengers (Priede and Merrett 1996) and other deep-water species (Gledhill *et al.* 1996, Yau *et al.* 2001). Such video techniques have been used because they offer a "hybrid" of the sampling advantages offered by Underwater Visual Census and extractive fishing techniques, whilst avoiding some of the selectivity associated with these methods. In these instances baited UVS have been used to sample a limited range of carnivorous or scavenging species. When the goal of a survey is to sample and compare the diversity of a range of habitats and determine the differences in fish assemblages between habitats, the advantages or disadvantages of using bait have not been examined.

In this study we found that baited UVS stations sampled more individuals and more species in every habitat (greater mean values) than unbaited UVS, although some of these differences weren't statistically significant. The same pattern was observed in the analysis of functional groups with baited UVS sampling more individuals and species of the Piscivore, Generalist Carnivore, Macroinvertebrate Carnivore, Invertebrate Carnivore and Zooplankton groups than unbaited UVS.

One of the important questions is whether the use of bait affects the numbers of individuals and species of herbivorous and algae affiliated fishes recorded. A logical prediction of the outcome using baited UVS would be that the additional predators being attracted to the UVS may scare away herbivorous and algae affiliated species, reducing the number of individuals and species recorded in these functional groups. Of great interest in this study is that baited UVS sampled slightly more individuals and a higher species diversity of the Herbivorous, Invertebrate/Algae and Algae/Invertebrate functional groups than the unbaited UVS. This was an important finding that contradicted the inferences about bait attractants made from fish trapping studies (see Cappo and Brown 1996 for review). Observations of fish behaviour during the tape analysis showed that herbivorous species did not readily approach the camera or the bait bag, but tended to be visible in the far field of view grazing or swimming by.

Baited UVS recorded species of fish which were; a) attracted to the bait plume or the structure of the UVS, b) species attracted by the activity of other fish feeding and aggregating around the UVS, c) species occupying territories within the field of view of the camera, d) and species indifferent to the station but present in or passing through the field of view during the deployment. The results presented here show that the use of bait in the field of view facilitates greater discrimination of fish assemblages between habitats. Used to investigate the effects of marine protected areas, it is likely that baited UVS will detect changes in the relative abundances of individual species, or assemblages fish inside and outside a protected area with greater staistical power and fewer samples than unbaited UVS.

Sampling more individuals of a single species has several advantages. Firstly, the variances of individual species sampled within a habitat with baited UVS was lower than for unbaited UVS samples. This was particularly important for the large Generalist Carnivores, Macroinvertebrate Carnivores and Piscivores which are mobile, but have relatively low densities and patchy distributions. As *MaxN* is conservative estimate of relative abundance (Willis and Babcock, 2000), the number of fish that are actually available to be measured in comparison to the number of individuals of a species that are seen during the analysis of a recording are vastly different. The use of bait increases the number of length measurements that can be made of an individual species and the chance of having a sufficient number of measurements to be able to make a statistically valid analysis.

CONCLUSION

The use of baited UVS resulted in higher relative abundances and a greater diversity of species being sampled in comparison to unbaited UVS. Sampling a greater proportion of fishes from a population has advantages for statistically discriminating between populations and for measuring changes in the length frequency of key species. The use of bait does not appear to negatively affect the relative abundances of herbivorous or algae affiliated fishes. Contrary to predictions baited UVS sampled more species individuals within these functional groups than unbaited UVS.

The question remains of how accurate an indication of the fish assemblage, species diversity and relative abundances do baited underwater cameras provide? This is a question that applies to all fish sampling techniques, all of which have biases. The only way to address this question is compare one technique with another to investigate the strengths and deficiencies. While baited UVS eliminate many biases associated with other sampling techniques they are also likely to introduce others. The only ways to discern the biases associated with baited UVS are to compare it with Underwater Visual Census by divers (eg Francour *et al.* 1999) and common extractive techniques, such as trawling and trapping. In this regard, Cappo *et al.* (2004) found that a prawn trawl and baited, remote, underwater video stations (BRUVS) recorded significantly different components of the fish fauna on soft-bottom inter-reef habitats. Trawls caught mainly small (<=300 mm), sedentary or cryptic, demersal species – such as flatfishes, apogonids, saurids, triglids and callionymids. The BRUVS recorded more larger, mobile species from a much wider size range of families, including large elasmobranchs, more pelagic species (such as carangids and scombrids), and numerous eels. The BRUVS performed best in the day, and trawls caught more species at night. Multivariate analyses showed that both techniques indicated the presence of very similar patterns of grouping of fish species assemblages, despite sampling quite different components of the fauna. That study concluded that BRUVS would complement trawls in comprehensive biodiversity assessments, but also noted that non-destructive baited video techniques were the only ones that could be used in the multi-species assemblages inhabiting rugose topography of a marine park. Similarly, Watson *et al.* (In press) compared baited and unbaited underwater stereo-video systems with a diver operated stereo-video system recording transects. They found that baited cameras recorded more species with lower variances than either of the other two techniques but that the baited and unbaited cameras did not samples some of the cave dwelling *Pempheridae* species which were not attracted to the bait and ventured out into the open at dusk. Perhaps the more important question if the goal of sampling is to detect spatial and temporal changes in the species diversity or relative abundance of demersal fishes is which technique provides the greatest consistency across a broad range of species? Watson *et al.* (In press) showed that baited underwater stereo-video systems had a greater statistical power to detect changes than samples recorded from unbaited underwater stereo-video systems and a diver operated stereo-video system due to reduced variance between samples.

Three major challenges remain in applying baited UVS to estimating relative abundances of fish and convert them to density estimates. 1) Separating repeated visits of the same fish from new arrivals within video tapes to get a better *MaxN*, 2) estimating the sampling area of each station, and 3) addressing the notion that *MaxN* is related more to the prevailing feeding opportunities in a habitat rather than fish abundance. These topics will require calibrations with other sampling techniques, better, ground-truthed models of bait plume dynamics, and closer attention to the species replacements and dynamics of fish visits and interactions within single tapes.

ACKNOWLEDGEMENTS

The authors acknowledge grants and financial aid from the Fisheries Research and Development Corporation (FRDC 2001/060) and the Coastal and Estuary Waterway Management Cooperative Research Centre. The authors are grateful to D. Gull who assisted with field work.

REFERENCES

Allen, G.R, Swainston, R., 1988. The marine fishes of north-western Australia. A guide for anglers and divers. Western Australian Museum, Perth, Australia. 201 pp.

Cappo, M., & I. Brown. 1996. Evaluation of sampling methods for reef fish populations of commercial and recreational interest, CRC Reef Research Centre, Technical Report No. 6, Townsville, CRC Reef Research Centre, 72 pp.

Cappo, M., Harvey, E., Malcolm, H. & P. Speare. 2003. Potential of video techniques to monitor diversity, abundance and size of fish in studies of Marine Protected Areas. In: "Aquatic Protected Areas - what works best and how do we know?", (Eds Beumer, J.P., Grant, A., and Smith, D.C.) World Congress on Aquatic Protected Areas proceedings, Cairns, Australia, August 2002. p 455-464.

Cappo, M., Speare, P. & G. D'eath. 2004. Comparison of Baited Remote Underwater Video Stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. Journal of Experimental Marine Biology and Ecology 302(2),123-152.

Clarke, K. R. & R. N. Gorley. 2001. "Primer v5: User Manual/Tutorial." (Primer-E Ltd.: Plymouth, UK.)

Denny, C.M. & R.C. Babcock. 2004. Do partial marine reserves protect reef fish assemblages? Biological Conservation 116: 119-129.

Ellis, D.M. & E.E. DeMartini. 1995. Evaluation of a video camera technique for indexing the abundances of juvenile pink snapper, *Pristipomoides filamentosus*, and other Hawaiian insular shelf fishes, Fishery Bulletin 93(1), 67-77.

Francour, P., Liret, C. & E.S. Harvey. 1999. Comparison of fish abundance estimates made by remote underwater video and visual census, Naturalista Siciliana, XXIII (Suppl), 155-168.

Froese, R. & D. Pauly. 2004 (Eds) Fishbase World Wide Web electronic publication. www.fishbase.org

Gaudian, G., Medley, P.A.H. & R.F.G. Ormond. 1995. Estimation of the size of a coral reef fish population. Marine Ecology Progress Series 122(1-3), 107-113.

Gledhill, C.T., Lyczkowski-Shultz, J., Rademacher, K., Kargard, E., Crist, G. & M.A. Grace. 1996. Evaluation of video and acoustic index methods for assessing reef-fish populations, Fisheries and Plankton Acoustics. Proceedings of an ICES International Symposium held in Aberdeen, Scotland, 12-16 June 1995, ICES Journal of Marine Science 53(2), 483-485.

Gloerfelt-Tarp, T. & P.J. Kailola. 1984. Trawled fishes of southern Indonesia and northwestern Australia. Australian Development Assistance Bureau; Directorate General of Fisheries, Indonesia; German Agency for Technical Cooperation, 406 pp.

Harmelin-Vivien, M.L. & P. Francour. 1992. Trawling or Visual Censuses - Methodological Bias in the Assessment of Fish Populations in Seagrass Beds. Marine Ecology-Pubblicazioni Della Stazione Zoologica Di Napoli I 13: 41-51.

Harvey, E.S. & M. Cappo. 2001. Direct sensing of the size frequency and abundance of target and non-target fauna in Australian Fisheries - a national workshop, 4-7 September 2000, Rottnest Island, Western Australia FRDC Project 2000/187 187 pp. ISBN 1 74052 057 2. http://wwwaimsgovau/pages/research/video-sensing/indexhtml

Harvey, E.S. & M.R. Shortis. 1996. A system for stereo-video measurement of sub-tidal organisms. Marine Technology Society Journal 29(4), 10-22

Harvey, E.S. & M.R. Shortis. 1998. Calibration stability of an underwater stereo-video system: Implications for measurement accuracy and precision. Marine Technology Society Journal 32(2), 3-17.

Harvey, E.S., Shortis, M., Stadler, M. & M. Cappo. 2002. A comparison of the accuracy and precision of measurements from single and stereo-video systems. Marine Technology Society Journal 36(2), 38-49.

Hickford, M.J.H. & D.R. Schiel. 1995. Catch Vs Count - Effects of Gill-Netting On Reef Fish Populations in Southern New-Zealand. Journal of Experimental Marine Biology and Ecology 188: 215-232.

Hill, B.J. & T.J. Wassenberg. 2000. The probable fate of discards from prawn trawlers fishing near coral reefs; A study in the northern Great Barrier Reef, Australia. Fisheries Research 48, 277-86

Kulbicki, M. 1998. How the acquired behaviour of commercial reef fishes may influence the results obtained from visual censuses. Journal of Experimental Marine Biology and Ecology 222, 11-30.

Kuiter, R.H. (1993) Coastal fishes of South-eastern Australia. Crawford House Press, Bathurst, New South Wales, Australia, 437 pp.

Priede, I.G. & N.R. Merrett. 1996. Estimation of abundance of abyssal demersal fishes; a comparison of data from trawls and baited cameras. Journal of Fish Biology 49 (SupplA), 207-216.

Priede, I.G., Smith, K.L. & J.D. Armstrong. 1990. Foraging behaviour of abyssal grenadier fish: inferences from acoustic tagging and tracking in the North Pacific Ocean. Deep-Sea Research 37(1), 81-101.

Priede. I.G., Bagley, P.M., Smith, A., Creasey, S. & N.R. Merrett. 1994. Scavenging deep demersal fishes of the Porcupine Seabight, north-east Atlantic: observations by baited camera, trap and trawl. Journal of the Marine Biological Association of the United Kingdom 74, 481-498.

Randall, J. R., Allen G. R. & R.C. Steene. 1990. The complete diver's and fishermen's guide to Fishes of the Great Barrier Reef and Coral Sea. Crawford House Press, Bathurst, New South Wales, Australia, 507pp.

Russell, B.C. 1990. Volume 12. Nemipterid fishes of the world (Threadfin breams, Whiptail breams, Monocle breams, Dwarf monocle breams and Coral breams). Family Nemipteridae. An annotated and illustrated catalogue of nemipterid species known to date. FAO Fisheries Synopsis. No. 125, Volume 12. FAO Rome, 149 pp.

Sainsbury, K.J., Kailola, P.J. & G.G. Leyland. 1985. Continental shelf fishes of northern and north-western Australia. An illustrated guide. CSIRO Division of Fisheries Research; Clouston and Hall and Peter Pownall Fisheries Information Service, Canberra, Australia. 375 pp.

Sainte-Marie, B. & B.T. Hargrave. 1987. Estimation of scavenger abundance and distance of attraction to bait. Marine Biology. 94, 431-433.

Samoilys, M.A. & G. Carlos. 2000. Determining methods of underwater visual census for estimating the abundance of coral reef fishes. Environmental Biology of Fishes 57(3), 289-304.

Stewart, B.D. & J.S. Beukers. 2000. Baited technique improves censuses of cryptic fish in complex habitats. Marine Ecology-Progress Series 197: 259-272.

Underwood, A.J. 1997. Experiments in Ecology. Their Logical Design and Interpretation Using Analysis of Variance. Cambridge University Press, Cambridge, UK.

Watson, D. L., Harvey, E. S., Anderson, M. J. & G.A. Kendrick. (in press). A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques. Marine Biology (accepted July 2005).

Watson, R.A., Carlos, G.M. & M.A. Samoilys. 1995. Bias introduced by the non-random movement of fish in visual transect surveys. Ecological Modelling 77, 205-214.

Westera, M., Lavery, P. & G. Hyndes. 2003. Differences in recreationally targeted fishes between protected and fished areas of a coral reef marine park. Journal of Experimental Marine Biology and Ecology 294: 145-168.

Williams, D.McB., Fowler, A.J. & S.J. Newman. 1997. Development of trap and drop-line sampling techniques for reef fishes: a report to Great Barrier Reef Marine Park Authority, 54 pp, Research Publication No 43 Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia.

Willis, T.J. & R.C. Babcock. 2000. A baited underwater video system for the determination of relative density of carnivorous reef fish. Marine and Freshwater Research 51, 755-763.

Willis, T.J., Millar, R.B. & R.C. Babcock. 2000. Detection of spatial variability in relative density of fishes: comparison of visual census, angling and baited underwater video. Marine Ecology Progress Series. 198, 249-260.

Winer, B., Brown, D.R. & K.M Michels. 1991. Statistical Principals in Experimental Design. McGraw-Hill, New York, USA.

Yau, C., Collins, M.A., Bagley, P.M., Everson, I., Nolan, C.P. & I.G. Priede. 2001. Estimating the abundance of Patagonian toothfish *Dissostichus eleginoides* using baited cameras: a preliminary study. Fisheries Research 51, 403-412.

Yoklavich, M.M., Greene, H.G., Cailliet, G.M., Sullivan, D.E., Lea, R.N. & M.S. Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fishery Bulletin 98: 625-641.

APPENDIX 1.1: Species recorded by unbaited and baited underwater video stations. U = unbaited, B = baited, SG = Seagrass. Eck = Ecklonia, O_M = Other Macrophytes, DR = Deep reef, Rhod = Rhodoliths, S = Sand.

Habitat Species	SG B	Eck B	O_M B	DR B	Rhod B	S B	SG U	Eck U	O_M U	DR U	Rhod U	S U
Acanthaluteres spilomelanurus	X		X				X					
Acanthistius serratus			X									
Achoerodus gouldii		X	X					X	X		X	
Arripis georgianus	X		X	X		X	X					
Aulopus purpurissatus		X		X	X							
Bodianus frenchii		X						X	X			
Caesioperca rasor		X	X	X					X	X		
Centroberyx lineatus		X	X	X				X	X			
Cheilodactylus nigripes		X	X					X	X			
Chelidonichthys kumu				X								
Chelmonops curiosus			X	X					X			
Chromis klunzingeri		X	X	X					X			
Contusus brevicaudus	X									X		
Coris auricularis		X	X	X					X	X		
Dactylophora nigricans									X	X		
Dasyatis brevicaudatus		X			X	X						
Dinolestes lewini			X	X				X	X			
Dotalabrus aurantiacus	X		X	X								
Enoplosus armatus								X				
Epinephelides armatus	X											
Eupetrichthys angustipes				X								
Galeorhinus galeus		X	X		X	X			X			
Girella tephraeops		X						X				
Heterodontus portusjacksoni		X										
Kyphosus sydneyanus									X			
Meuschenia flavolineata		X		X				X				
Meuschenia freycineti	X											
Meuschenia galii		X	X					X	X			
Meuschenia hippocrepis		X	X									
Myliobatis australis	X		X	X	X	X				X		
Neatypus obliquus		X	X	X					X			
Nelusetta ayraudi					X						X	
Nemadactylus valenciennesi		X	X	X				X	X	X		

Neoodax balteatus	X											
Pseudolabrus parilus	X	X	X	X		X	X	X	X	X		
Odax cyanomelas		X	X					X	X			
Opthalmolepis lineolatus	X	X	X	X	X		X	X	X	X	X	
Othos dentex		X	X									
Paraplesiops meleagris			X									
Parequula melbournensis	X			X	X	X				X	X	X
Parma mccullochi			X					X	X			
Parma victoriae			X						X			
Pelsartia humeralis	X											
Pempheris multiradiata			X	X					X			
Penicipelta vittiger	X											
Pictilabrus laticlavius	X		X					X				
Platycephalus longispinis	X											
Platycephalus speculator					X	X				X		
Pristiophorus cirratus					X	X						
Pseudocaranx dentex	X	X	X	X	X	X	X		X	X	X	X
Pseudolabrus biserialis		X	X	X		X		X	X	X		
Scobinichthys granulatus	X		X				X					
Scorpis aequipinnis		X	X	X				X	X	X		
Scorpis georgianus		X	X					X	X			
Seriola hippos		X		X						X		
Sillago bassensis						X						
Sphyraena novaehollandiae	X	X					X					
Tilodon sexfasciatum		X	X	X					X			
Trachurus novaezelandiae	X											
Trygonorrhina fasciata					X							
Upeneichthys vlamingii	X			X		X	X	X	X	X		X
Urolophus mucosus		X		X								
Urolophus paucimaculatus				X								
Total number of species	**20**	**29**	**33**	**27**	**11**	**12**	**8**	**19**	**27**	**15**	**5**	**3**

Appendix 8.4.2

The effect of white and red illumination on temperate water fish assemblages sampled at night with baited underwater video stations.

Euan Harvey [1], James Butler[1].

[1] School of Plant Biology (Botany M090), University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009.

INTRODUCTION

Fish assemblages often have strong affiliations with particular benthic habitats (Demestre *et al.* 2000, Harman *et al.* 2003, Anderson and Millar 2004). However, it has also been shown that some species of fish exhibit diurnal and nocturnal movements between habitats (Lowry and Suthers 1998, Platell and Potter 1999). These diurnal and nocturnal movements may be the result of feeding (eg. The Deep Scattering Layer) or reproductive behaviour (Lowry and Suthers 1998, Platell and Potter 1999).

Hobson *et al.* (1981) propose that trophic relationships are the major force in shaping activity patterns in the nocturnal and diurnal fishes with fish that feed nocturnally undergoing major evolutionary visual adaptations (Hobson *et al.* 1981, Partridge 1990, Bowmaker 1995). Fish that feed nocturnally often have a different eye structure to those that are most active during daylight hours (Shand *et al.* 2001). The majority of coastal fish species studied in the past have two kinds of photoreceptors within the retinae of their eyes. The two photoreceptors are referred to as either rods or cones depending on their shape. The maximum sensitivity of the photoreceptors depends on the maximum sensitivity/absorption (λ_{max}) of the visual pigments contained within these specialised cells. All teleosts possess rod photoreceptors in the retinae and the majority of diurnal marine teleosts have short-wave ('blue sensitive') single cones, and double cones that are sensitive to medium ('green') or long ('red') wavelengths (Shand *et al.* 2001). In coastal fish, the λ_{max} for the single cones generally range between 440 and 470 nm, whereas λ_{max} for the double cones ranges between 520 and 540 nm (Bowmaker, 1995).

It is believed that fish photoreceptors are most sensitive to light within the spectral range of wavelengths available in the fish's habitat. As maximum sensitivity is determined by the maximum transmission properties of the pigments within the rod and cone receptors it would be expected that fish would possess visual pigments with maximum sensitivities close to the maximum transmission wavelengths of the water they live in.

A study performed on 12 species of Lutjanids (the snappers) on the Great Barrier Reef used visual pigments as an indication of the maximum visual sensitivities of these fishes (Lythgoe and Patridge 1991, Lythgoe *et al.* 1994). The λ_{max} was found for the pigments of the rods, the single cones and the double cones. The rod λ_{max} for all twelve species was between 489-502 nm. The single cones λ_{max} for all ranged between 420-450 nm. These wavelengths being in the blue-green region of the spectrum typical of the maximum transmission of coastal waters. The double cones generally have a higher λ_{max} ranging from 487-575 nm. The lowest double cone pigment λ_{max} (487nm) was recorded from an outer reef species (*L. kasmira*) whereas the highest pigment λ_{max} (575nm) was recorded from an estuarine species (*L. argentimaculatus*), where you would expect maximum transmission wavelengths to be longer (Lythgoe *et al.* 1994).

Although Lythgoe *et al.* (1994) showed a correlation between the λ_{max} of the visual pigments of specific fish to the underwater photic conditions it must be expected that the shallower a body of water is, the broader the spectral range is (Partridge *et al.* 1988, 1989). Hence, the variation of visual pigments and therefore the spectral sensitivities of fish in shallow water exhibit great variation. For example larval stages of West Australian Dhufish show marked variation in visual sensitivity (Shand *et al.*, 2001). The production of rod photoreceptors earlier in dhufish development than when compared to other species indicated that dhufish are able to feed in lower light levels than other species at similar stages of development. Visual sensitivity maximums have been shown to be higher in larval stages than juvenile stages of development indicating that larvae are restricted to brighter surface waters (Evans *et* *al.* 1993). This demonstrates the evolutionary trend for visual systems in fish to evolve to the specific photic environment they inhabit.

The implications of visual sensitivity in sampling of fish assemblages at night using underwater video stations.

Although remote underwater photography (Priede at al. 1994, Priede and Merrett 1996) and unbaited (Francour *et al.* 1999) and baited underwater video stations (BUVS) (Ellis and DeMartini 1995, Cappo and Brown 1996, Willis *et al.* 2000) have become an increasingly popular method of sampling fish populations, only one study (Cappo *et al.* 2004) has used underwater video stations to sample nocturnal populations of fish. The use of BUVS to sample fish assemblages at night has its inherent problems, such as the need to provide illumination for the field of view of the video cameras. Anecdotal evidence suggests that many nocturnal species of fish are sensitive to and disturbed by white light. If we assume that coastal benthic fish lack visual sensitivity to 'red' wavelengths, in theory a red or red illumination source, with emissions in 600+ nm range could be used at night to illuminate fish, without the fish being able to detect it or be disturbed by it. Therefore, if we sampled nocturnal fish assemblages with BUVS illuminated by red and white light we would expect to sample different species of fish at different relative abundances.

This research aims to answer three questions:

1. Are there differences in nocturnal fish assemblages sampled by BUVS illuminated by red or white light?;
2. Are there differences in nocturnal and diurnal fish assemblages sampled by BUVS within six coastal habitats?;
3. Are diurnal fish assemblage habitat associations maintained by nocturnal fishes?

METHODS

Between the 5th and 13th November 2002 data on nocturnal fish assemblage were collected using baited UVS from four sites within each of six habitats located in Esperance Bay, South Western Australia. Different patches of a habitat were sampled with each of the four baited underwater videos being placed at least 500 metres apart. We chose to use baited UVS (BUVS) rather than unbaited as it has been shown that the use of bait results in more species and individuals being sampled and increases the statistical ability to discriminate between treatments (See Harvey *et al.* this volume). Diurnal data was collected from the same sites between the 12th and 13th of November 2002. Nocturnal sampling was restricted to between 8.00 pm and 3.30 am while diurnal sampling to between 8.30 am and 3.30 pm to avoid the dusk-dawn interface and crepuscular behaviour.

Nocturnal sampling used both white and red light (630 nm Light Emitting Device (LEDs)) to illuminate the field of view in front of the BUVS. The collection of data from a site with red and white light was usually sequential with a minimum of twenty minutes elapsing between deployments. The BUVS were left to record for one hour.

The six habitats sampled were Seagrass (SG), Ecklonia (Eck), Other Macrophytes (O_M), Deep Reef (DR), Rhodoliths (Rhod) and Sand (S). The Seagrass habitat was characterised by a 60-100% cover of *Posidonia* sp between depths of 10 and 16m. The Ecklonia and Other Macrophyte habitats consisted of sloping granite reefs with a 60% cover or greater of *Ecklonia radiata* or *Sargassum* sp and *Cystophora* sp. Deep Reefs consisted of granite reefs at depths greater than 30m and were characterised by a sparse cover of macro algae or sponges. Rhodolith and Sand habitats had low relief with 80% or greater cover of rhodoliths or sand, and were always deeper than 30m.

Equipment

Recordings were made using four stereo-video systems (see Harvey and Shortis, 1996, 1998 and Harvey *et al.* 2002a for design and measurement procedures) using either Sony TRV900E or TRV15 digital camcorders contained within waterproof housings. Vision Measurement System (VMS) (Shortis and Robson 2004) software was used to measure the fork lengths of fishes from the stereo-video recordings (Harvey *et al.* 2001a, b, 2002a, b). VMS was also used to standardise the distance at which were included in the sample. Using white light cameras could detect fish at a distance of 7 metres while with the red light we could only differentiate fish at 3.5 metres from the camera. The distance at which fish could be detected in diurnal samples ranged from 7 to 10 metres. For purposes of this comparison only fish within a distance of 3.5 metres of the stereo-video, as measured with VMS were included in the data set. For nocturnal sampling light sources were attached to the BUVS frame and a flashing light on a surface buoy was attached to aid in the relocation of the BUVS. Two BUVS were rigged with white light and two with redlights. The white illumination unit consisted of a galvanised steel battery housing containing a rechargeable 12V battery. The battery housing was attached under the camera crossbar. A single white quartz halogen (12V, 50 W) light in a waterproof housing was attached at the top and front of the BUVS frame. A bulb with a 60° reflector was used to ensure even lighting in the field of view for the two video cameras. The red illumination units consisted of a waterproof housing containing a rechargeable battery unit and three red lights. Each red light contained a bank of twenty five 630 nm LEDs which were attached to the BUVS frame, one in the centre, and the other two to the extreme right and left of the top crossbar. Video cameras were focussed on infinity and the Night-Shot function switched on to allow the greatest amount of light possible to be captured by the cameras.

Analysis of video tapes

When we reviewed the tapes we recorded the time the BUVS settled on the seabed and, for each species, the time of first sighting *(TFAP),* time of first feeding at the bait (*TFF*), the maximum number seen together in any one time on the whole tape (*MaxN*), time at which *MaxN* occurred, and the intraspecific and interspecific behaviour.

We used *MaxN* as we were concerned that individual fish could be counted repeatedly when leaving and then entering the field of view during tape interrogation. The n_{peak} of Priede *et al.* (1994), the *MAXNO* of Ellis and DeMartini (1995), the *MAX* of Willis and Babcock (2000) and the *MaxN* of our study are all homologous. This statistic under-estimates the true abundance of fish visiting the bait bag, or passing through the field of view. The occurrence of separate visits by different individuals of the same species is recorded as *MaxN*=1. The use of *MaxN* results in conservative estimates of abundance in high-density areas, and therefore differences detected between areas of high and low abundance (eg inside and outside marine protected areas) are also likely to be more conservative (Willis *et al.* 2000, Cappo *et al.* 2003).

The video recordings were broken into 60 one-minute time intervals from the time the BUVS came to rest on the seafloor. The maximum number of species *i* at any time *t*

($MaxN_{i,t}$) was recorded during each minute, but the final measure of relative abundance used in analyses was the highest $MaxN_{it}$ over the whole tape record.

Data Analysis

Univariate analysis

For each habitat the mean number individuals ($MaxN_i$) and species (*Nsp*) sampled per habitat for diurnal and nocturnal (both red and white light) BUVS were plotted (Figure 1). Initially a two way analysis of variance (ANOVA) was used to test the differences in $MaxN_i$ and *Nsp* between and amongst habitats and treatments. However, because we were most interested in the differences in treatments (diurnal and nocturnal red and white light) within, rather than between habitats we analysed $MaxN_i$ and *Nsp* for each habitat using a one way ANOVA. The use of ANOVA, like many statistical procedures, is based on the assumption that samples from different populations have the same variance. The distribution of the residuals usually were strongly skewed to the right, therefore the data required transformation to eliminate the problems associated with having large outliers and unusual observations (Rotchell *et al.* 2001). Homogeneity of variances were examined using Cochran's test (Winer 1991). Variances were heterogeneous ($P<0.05$) so all data was fourth root transformed.

Multivariate analysis

All multivariate analyses were undertaken in PRIMER (Plymouth Routines in Multivariate Ecology) V5 (Clarke and Gorley, 2001). Data were entered into a site by species matrix which was then used to create a triangular similarity matrix, based on the Bray-Curtis similarity coefficient. Given the conservative nature of $MaxN_i$, no data transformations were made. *Pseudocaranx dentex* was recorded in very high numbers of individuals (10s -100) within some samples and dominated the analysis disproportionately. Rather than eliminating the species from analysis we used a dispersion weighting technique (R. Clarke pers comm.). One-way analyses of similarities (ANOSIM) were used to analyse differences between habitats for both diurnal and nocturnal comparsions and white versus red light comparisons. Two-dimensional ordinations were created by non-metric multidimensional scaling (MDS). As some BUVS recorded no fish we have added a "dummy" species. Adding the "dummy" species, and a constant value to all samples does not affect the similarity or dissimilarity matrices, but does allow a balanced design to be maintained and sufficient permutations to compare treatments within habitats (R. Clarke pers comm). Similarity of Percentages (SIMPER) analysis was undertaken to identify key species that might be contributing to differences between red and white light and nocturnal and diurnal assemblages within a habitat.

RESULTS

Species richness (Nsp)

Diurnal BUVS recorded fifty six species while nocturnal BUVS using red and white illumination recorded a total of twenty five species, nineteen species for each type of illumination (Table 1). Thirty five of the fifty six species seen in diurnal samples were only observed during the daytime. Six species which were observed at BUVS illuminated by red light were not observed at BUVS illuminated by white light. Conversely, five species that were observed at BUVS illuminated by white light were not observed at red illuminated BUVS (Table 1).

Table 1: Fish species recorded on BUVS at day and night time periods (using white and red illumination).

Taxa	**Day**	**Night (white)**	**Night (Red)**
Acanthaluteres brownii	X		
Acanthaluteres pilomelanurus	X		
Achoerodus gouldii	X		
Arripis georgianus	X	X	
Aulopus purpurissatus		X	
Bodianus frenchii	X		
Caesoiperca razor	X		
Centroberyx gerradi	X	X	
Centroberyx lineatus	X	X	X
Cheilodactylus nigripes	X		
Chromis klunzingeri	X		
Conger wilsoni		X	X
Contusus brevicaudus	X	X	X
Coris auricularis	X		

Dactylophora nigricans	X		
Dasyatis brevicaudata	X		X
Dinolestes lewini	X	X	X
Dotalabrus aurantiacus	X		
Enoplosus armatus	X		
Epinephelus armatus	X		
Galeorhinus galeus	X	X	X
Girella tephraeops	X		
Heterodontus portjacksoni	X	X	X
Kyphosus sydneyanus	X		
Meuschenia galii	X		
Meuschenia flavolineata	X		
Meuschenia freycineti	X		
Meuschenia hippocrepis	X		
Myliobatus australis	X	X	X
Neatypus obliquus	X		
Nelusetta ayraudi	X		
Nemadactylus valenciennesi	X		
Notolabrus parilus	X	X	X
Odax acropitlus	X		
Odax cyanomelas	X		
Opthalmolepis lineolatus	X	X	
Othos dentex	X		
Parascyllium ferrugineum	X		X
Parequula melbournensis	X	X	X
Parma victoriae	X		
Pelsartia humeralis	X	X	X
Pempheris multiradiata	X	X	X
Penicipelta vittiger	X		
Phyllopteryx taeniolatus		X	
Pictilabrus laticlavus	X		
Platycephalus speculator	X	X	X
Pseudocaranx dentex	X		X
Pseudolabrus biserialis	X		
Scobinichthys granulatus	X		X
Scorpis aequipinnis	X		
Scorpis georgianus	X		
Seriola hippos	X		

Sillago bassensis	X	X	X
Sphyraena novaehollandiae	X		X
Threpterius maculosus	X		X
Tilodon sexfasciatum	X		
Trachurus novaezelandiae	X	X	X
Trygonorrhina fasciata	X		
Upeneichthys vlamingii	X		
Total	56	19	19

The mean number of species recorded per drop was higher during the day in all habitats (Figure 1a). A two way ANOVA on *Nsp* with Treatment and Habitat as factors showed that both main effects were significant and that there was a significant interaction (Treatment * Habitat $_{(10, 71)}$, MS = 0.2662, F = 7.07, p = 0.000).

One way ANOVA on each habitat detected significant differences between treatments within all six habitats (See Figure 1a for significance levels). Tukeys pair-wise comparisons showed that samples for Eck, O_M and DR nocturnal red (Red) and nocturnal white (White) illuminated BUVS were similar, but that diurnal (Day) BUVS were significantly different to both. For Rhod the only significant difference was between Day and Red. For SG and S Day and White were similar while Red was significantly different to Day and White.

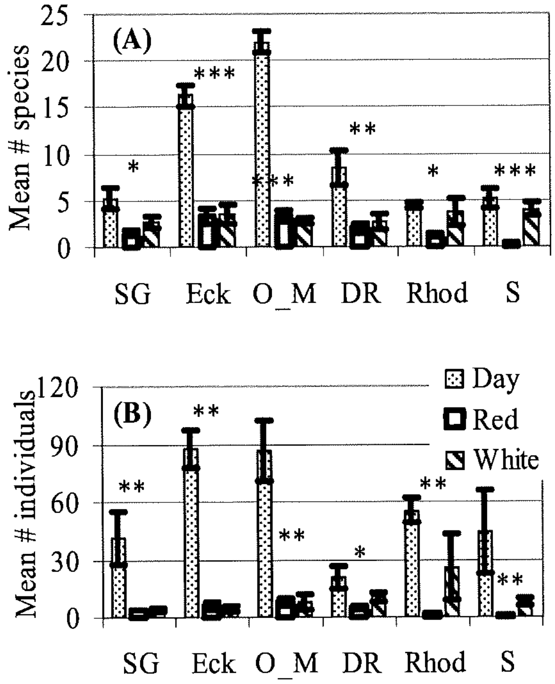


Figure 1: Mean *Nsp* (A) and $MaxN_i$ (B) for both diurnal (Day) and nocturnal red (Red) and white (White) illuminated underwater video stations in six benthic habitats. N=4. SG = Seagrass. Eck = Ecklonia, O_M = Other Macrophytes, DR = Deep Reef, Rhod = Rhodoliths, S = Sand. Error bars = ± 1 SE. * indicates the level of significance for a one way ANOVA; * = P<0.05, ** = P<0.01, *** P<0.001.

Number of individuals (MaxNi)

The mean number of individuals ($MaxN_i$) sampled was higher in all Day samples in each habitat in comparison to samples collect nocturnally with Red and White illumination (Figure 1b). A two way ANOVA on $MaxN_i$ with Treatment and Habitat as factors showed that both main effects were significant and that there was a significant interaction (Treatment * Habitat $_{(10, 71)}$, MS = 0.558, F = 4.08, p = 0.000). One way ANOVA on each habitat detected significant differences between treatments within all six habitats (See Figure 1b for significance levels). Tukeys pair-wise comparisons for SG, Eck and O_M showed that Red and White were similar, but that Day was significantly different to both. For DR and Rhod, Day and White were similar, Red and White were similar but Day and Red were significantly different. For S, Day and White were similar while Red was significantly different to Day and White.

Multivariate analysis

A two way crossed ANOSIM showed there were significant differences between Day, Red and White samples across all habitats (Global R=0.560, p=0.000, 5000 permutations) and between habitats across all treatments (Day, Red, White) (Global R=0.614, p<0.000, 5000 permutations). Pair-wise comparisons showed that Day was significantly different to Red and White which were similar (Table 2).

Table 2: Pair-wise tests of differences between the reef fish assemblages sampled with BUVS at day and at night using red and white illumination. 5000 permutations.

Treatment	R Value	Significance %
Day vs. Red	0.818	0
Day vs. White	0.594	0
Red vs. White	0.141	6.5

We created MDS plots for Day, Red and White (Figure 2) to visualise whether data recorded diurnally, or nocturnally with red and white illumination portrayed similar clustering patterns within, and between habitats.

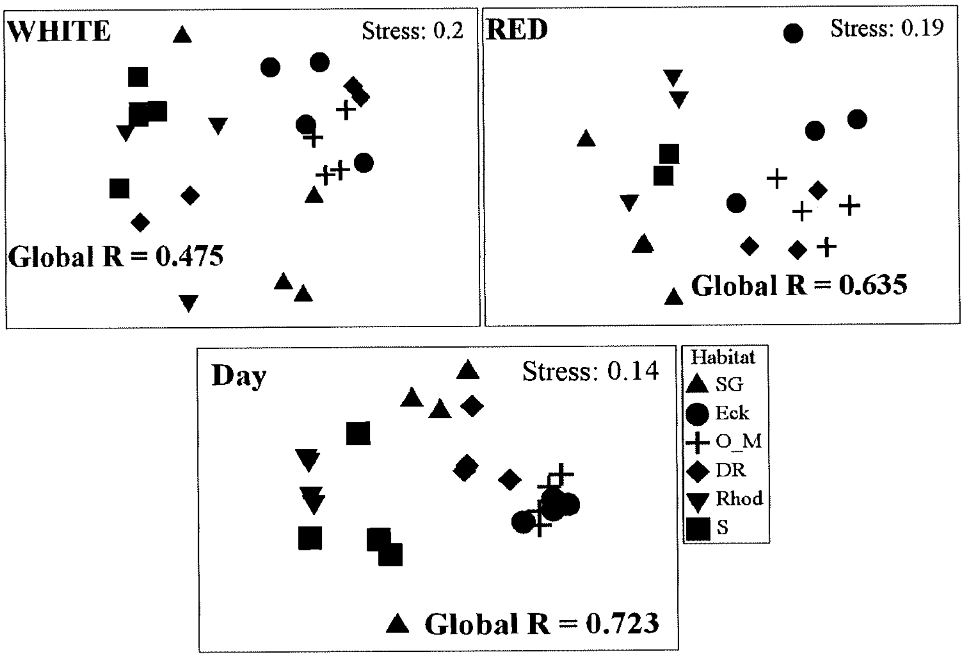


Figure 2: MDS plots for Day, Red and White for samples collected from six habitats. N=4. SG = Seagrass. Eck = Ecklonia, O_M = Other Macrophytes, DR = Deep Reef, Rhod = Rhodoliths.

In all MDS plots there is a separation of reef samples in the right of the plots with Rhodolith and Sand samples located on the left of the plots. The general patterns are quite similar with some exceptions. In the Day MDS samples from the same habitat tended to cluster more closely together with distinct separation of habitats, with the exception of Eck and O_M which appear to form a separate group. In Red the clustering is less defined, but there is still clear separation between habitats. Notably Eck and O_M are now less tightly clustered together. In White DR, Rhod, and Sand samples are mixed, but Eck and O_M are forming separate clusters. To test the observed patterns we performed a one way ANOSIM for Day, Red and White (Table 3).

Table 3: Pairwise comparisons amongst six habitats for data from Diurnal and Nocturnal BUVS. ANOSIM based on 4 samples per habitat with a maximum of 35 permutations. SG = Seagrass. Eck = Ecklonia, O_M = Other Macrophytes, DR = Deep Reef, Rhod = Rhodoliths, S = Sand.

Habitat	Day BUVS		Red BUVS		White BUVS	
	R Value	Sig. %	R value	Sig. %	R value	Sig. %
SG vs. Eck	0.615	2.9	0.781	2.9	0.5	5.7
SG vs. O_M	0.563	2.9	0.813	2.9	0.771	2.9
SG vs. DR	0.479	2.9	0.667	2.9	0.281	8.6
SG vs. Rhod	0.625	2.9	0.542	2.9	0.479	5.7
SG vs. S	0.5	5.7	0.5	2.9	0.74	2.9
Eck vs. O_M	0.396	5.7	0.146	25.7	0.208	20
Eck vs. DR	0.885	2.9	0.083	40	0	45.7
Eck vs. Rhod	1	2.9	0.542	5.7	0.688	2.9
Eck vs. S	0.958	2.9	0.792	2.9	0.771	2.9
O_M vs. DR	0.698	2.9	-0.271	94.3	-0.021	48.6
O_M vs. Rhod	1	2.9	0.99	2.9	0.823	2.9
O_M vs. S	0.927	2.9	1	2.9	0.969	2.9
DR vs. Rhod	1	2.9	0.948	2.9	0.135	25.7
DR vs. S	0.76	2.9	1	2.9	0.344	11.4
Rhod vs. S	0.385	8.6	0.5	14.3	0.01	40

Some notable differences between the treatments where the inability samples recorded with White light to discriminate between SG and Eck, SG and DR and S and

DR habitats. Samples recorded with either Red or White could not differentiate between Eck and DR and Eck and O_M habitats.

Comparisons of diurnal and nocturnal (Red and White Illumination) BUVS within habitats

To test whether there were differences in the fish assemblages recorded by BUVS within a habitat diurnally using natural light and nocturnally using artificial red and white illumination we performed a one way ANOSIM. MDS plots for each habitat assist with visualisation of the relationships between samples (Figure 3). We also performed SIMPER analysis to determine which species were contributing to any differences detected.

Seagrass

There were no statistically significant differences (Global R=0.098, p=21.7%, 5000 permutations) between samples collected during the day, or at night with red or white illumination (Table 4). An MDS plot (Figure 3A) shows a tendency for diurnal samples to be displaced from the nocturnal samples. *Pseudolabrus parilus, Pelsartia humeralis* and *Scobinichthys granulatus* all had higher relative abundances in diurnal samples in comparison to nocturnal.

Ecklonia

Statistically significant differences existed between Day, Red and White (Global R=0.588, p=0.5%, 5000 permutations) with significant pair-wise differences between Day and Red and Day and White. Red and White were similar (Table 4). This is reflected in the MDS (Figure 3B). Differences between diurnal and nocturnal samples were largely attributable to species sampled diurnally not being sampled nocturnally. Most notably these include *Achoerodus gouldii*, *Caesioperca razor*, *Dinolestes lewini*, *Kyphosus sydneyanus*, *Meuschenia galii*, *Meuschenia hippocrepis*, *Nemadactylus valenciennesi*, *Opthalmolepis lineolatus*, *Pseudocaranx dentex*, *Pseudolabrus biserialis*, and *Scorpis aequipinnis*. *Pempheris multiradiata* and *Conger wilsoni* were recorded in both nocturnal treatments but not diurnally.

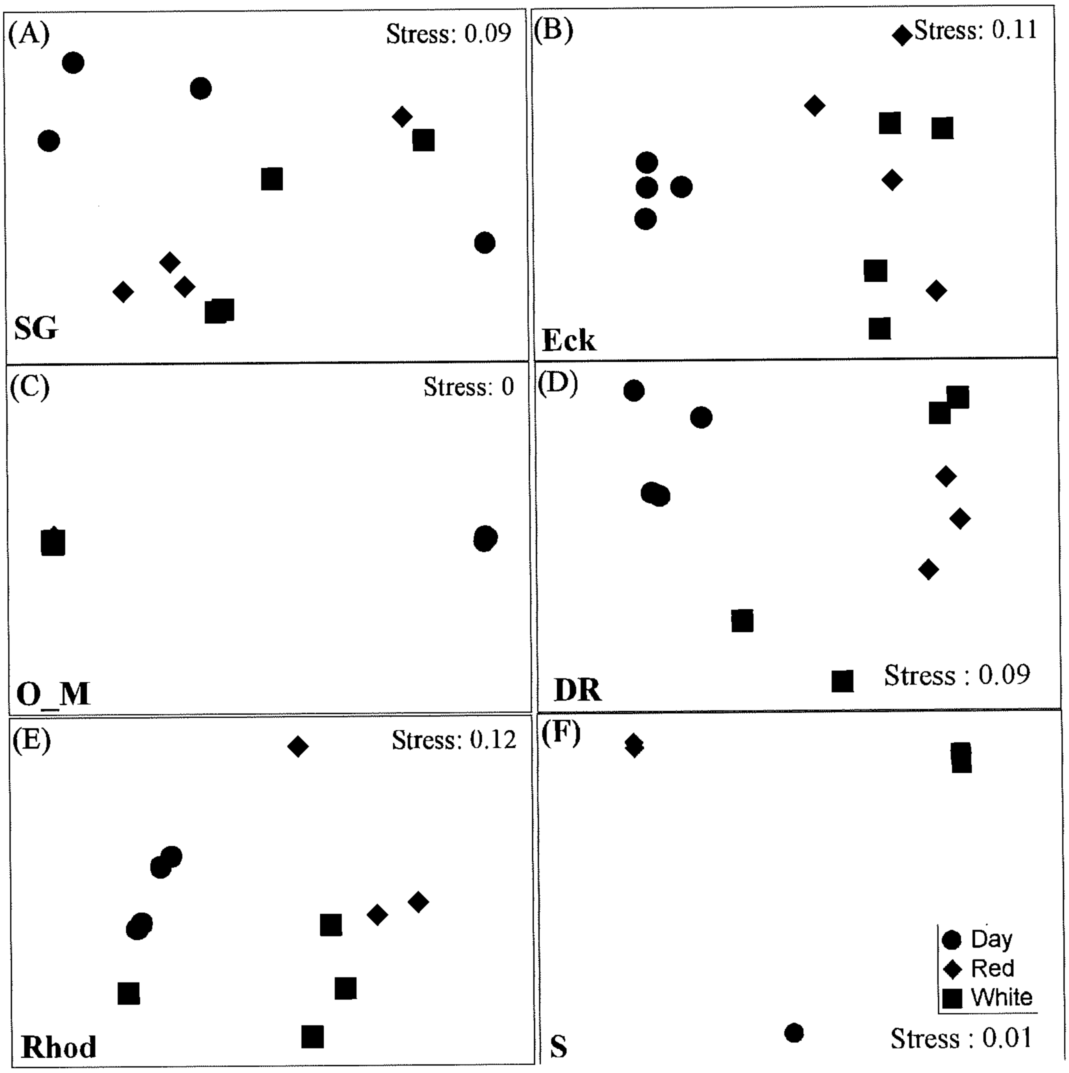


Figure 3: MDS plots for six habitats comparing Day, Red and White for samples within habitat. N=4. SG = Seagrass. Eck = Ecklonia, O_M = Other Macrophytes, DR = Deep Reef, Rhod = Rhodoliths.

Table 4: Pair-wise comparisons for data from Diurnal and Nocturval BUVS within six benthic habitats. ANOSIM based on 4 samples per habitat with a maximum of 35 permutations. SG = Seagrass. Eck = Ecklonia, O_M = Other Macrophytes, DR = Deep Reef, Rhod = Rhodoliths, S = Sand.

Habitat	Day vs. Red		Day vs. White		Red vs. White	
	R value	Sig. %	R value	Sig. %	R value	Sig. %
SG	0.219	20	0.188	22.9	-0.89	62.9
Eck	0.875	2.9	0.969	2.9	-0.281	91.4
O_M	1	2.9	1	2.9	-0.156	83.9
DR	1	2.9	0.719	2.9	-0.021	57.1
Rhod	0.813	2.9	0.531	5.7	0.396	2.9
S	1	2.9	0.156	14.3	1	2.9

Other Macrophytes

Statistically significant differences existed between Day, Red and White (Global R=0.676, p=0.6%, 5000 permutations) with significant pair-wise differences (Table 4) between Day and Red and Day and White while Red and White were similar (Figure 3C).

Differences between diurnal and nocturnal samples were caused by many species sampled diurnally not being present in nocturnal samples. With the exception of *Scorpis aequipinnis*, all of the species sampled diurnally in the Ecklonia habitat were sampled in diurnal in the Other Macrophyte habitat. Another eleven species were recorded in diurnal samples which were not present nocturnally. These included *Coris auricularis*, *Chromis klunzingeri*, *Girella tephraeops*, *Meuschenia flavolineata*, *Pseudolabrus parilus*, *Odax cyanomelas*, *Othos dentex*, *Scorpis georgianus*, *Seriola hippos*, *Tilodon sexfasciatum* and *Upeneichthys vlamingii.*

Both Red and White samples were clustered very closely showing high similarity. In both Red and White samples *Centroberyx lineatus* and *Pempheris multiradiata* were recorded at higher relative abundances than in Day samples.

Deep Reef

Statistically significant differences were found between Day, Red and Night (Global R=0.627, p=0.6%, 5000 permutations) with significant pair-wise differences (Table 4). Red and White samples were similar but both were different to Day (Figure 3D). *Acanthaluteres spilomelanurus*, *Coris auricularis*, *Opthalmolepis lineolatus*, *Pseudolabrus parilus*, *Penicipelta vittiger*, *Pseudolabrus biserialis*, *Scobinichthys granulatus* and *Upeneichthys vlamingii* were all present in diurnal samples but not in nocturnal samples. *Pempheris multiradiata* dominated nocturnal samples.

Rhodolith

There were statistically significant differences between Day, Red and Night (Global R=0.567, p=0.2%, 5000 permutations) with significant pair-wise differences (Table 4). Red was different to White and Day which were similar (Figure 3E).

Dasyatis brevicaudata and *Nelusetta ayraudi* were present in Day samples but not in Red and White. *Trachurus novaezelandiae* was present in higher relative abundances in Day in comparison to White and not present in Red. *Parequula melbournensis* and *Platycephalus speculator* had higher relative abundances in Day than in either White or Red samples. Conversely, *Heterodontus portjacksoni* was present in nocturnal samples, but not in diurnal.

Sand

There were statistically significant differences between Day, Red and Night (Global R=0.806, p=0.0%, 5000 permutations) and significant pair-wise differences (Table 4). Similar to Rhod, samples recorded with red illumination at night were different to White and Day which were different to one another (Figure 3F).

Heterodontus portjacksoni, Myliobatis australis, Parequula melbournensis and *Platycephalus speculator* had higher relative abundances in Day samples in comparison to White samples but were not present in Red. *Pseudocaranx dentex* was present in diurnal samples only.

DISCUSSION.

Differences in nocturnal fish assemblages sampled BUVS using red or white illumination

Contrary to our expectations white and red light sampled very similar fish assemblages with only two of six habitats recording significant differences between red and white lighting. The differences in these two habitats (Rhodoliths and Sand) were due to more species and more individuals being sampled by BUVS with white light. Notably, two of the species observed in higher relative abundances in white illuminated BUVS, *Pempheris multiradiata* and *Trachurus novaezelandiae* were observed feeding on zooplankton attracted to the BUVS by the white light which sometimes obscured the field of view. Far less zooplankton was attracted to the red lights and consequently lower numbers of *Pempheris multiradiata* and *Trachurus novaezelandiae*.

Differences in nocturnal and diurnal fish assemblages within six coastal habitats

We found significant differences in nocturnal and diurnal fish assemblages sampled by BUVS. More species and individuals were sampled by diurnal BUVS in comparison to red and white illuminated BUVS combined. Sixty two percent of the total species recorded were only sampled during the day. Only three of the fifty nine species recorded (*Aulopus purpurissatus*, *Conger wilsoni*, and *Phyllopteryx taeniolatus*) were only sampled nocturnally. *Conger wilsoni* is thought to be only active at night when it will actively swim over reefs in search of food (Hutchins and Swainston, 1986). *Phyllopteryx taeniolatus* is often seen by SCUBA divers during the day, but is most commonly encountered at night. It has also been recorded in other nocturnal BUVS surveys (Stadler, 2000). The species recorded in nocturnal surveys were either generalist carnivores, macro invertebrate carnivores or zooplanktivores. Species which were either herbivorous, or had a diet dominated by algae such as *Girella tephraeops*, *Odax cyanomelas*, *Kyphosus sydneyanus* and omnivorous species such as *Odax acroptilus*, *Dactylophora nigricans* and *Cheilodactylus nigripes* (Froese ands Pauly 2004) were only observed during the day.

Pempheris multiradiata was observed in Deep Reef, Seagrass and Rhodolith habitats at night but was only observed in the "Other_Macrophyte" habitat during diurnal samples. *Pempheris multiradiata* is common on shallow reefs diurnally and is normally seen in caves, crevices and overhangs (Harman *et al.* 2003). As dusk approaches they migrate out onto the reef (personal observations) and may move to sand based areas such as Seagrass, Rhodolith, Deep Reef and Sand habitats to feed at night (Platell and Potter, 1999).

Heterodontus portjacksonii also appeared to shift habitat nocturnally. At night it was commonly sampled on rhodolith beds, but was only sampled in reef habitats during this research. It is often seen by SCUBA divers resting in caves and under ledges during the day time. It is known to feed on crustaceans, including crabs and prawns, and zoobenthos such as gastropods and polychaetes (Froese ands Pauly 2004). Rhodolith beds have a high diversity of zoobenthos and crustaceans (see Grove this volume).

Diurnal and nocturnal differences in the composition, abundance and distribution of fish assemblages have been reported in several studies on reef fish assemblages (Colton and Alevizon 1981, Helfman *et al.* 1982; Robblee and Zieman, 1984).

Newman and Williams (1995) found nocturnal diurnal differences using fish traps on the Great Barrier Reef. *Lutjanid* sp. dominated the nocturnal catches whereas the diurnal catches were dominated by *Lethrinid* sp. Newman and Williams (2001) suggested that piscivores were more active during the day, whereas species active at night were more likely to be those feeding on benthic invertebrates. Herbivorous and omnivorous fish are active mainly during the day (Hobson 1965).

Are diurnal fish assemblage habitat associations maintained nocturnally?

Strong fish assemblage and habitat associations were recorded for twelve of the fifteen habiat comparisons made for samples collected diurnally. For the nocturnal samples fish assemblage habitat associations weakened with ten of the fifteen possible comparisons being significant for red illuminated BUVS, and only six of fifteen for data collected by white illuminated BUVS. Global R values displayed the same pattern and to be less strong for data collected by red illuminated BUVS and weaker again for white illuminated BUVS. Conversely stress values in MDS plots increased following the same pattern. Lower Global R Values and higher stress values in the MDS plots could have been caused by less species and fewer individuals being sampled. Alternatively, nocturnal diurnal migrations by some species might explain the higher stress values lower global Global R values. Given that less species and numbers of individuals are recorded at night than during the day the effect of a species dispersing from one habitat, where it shelters over the day, out over several different habitats at night to feed will result in multiple fish/habitat associations for a small range of species. This is supported by the more disperse clustering of samples in the MDS plot of nocturnal samples (Figure 2).

CONCLUSION

In this study there were distinctive nocturnal and diurnal fish assemblages in temperate coastal habiats in South Western Australia. Nocturnal fish assemblages were less speciose, and had fewer individuals than the diurnal assemblages but were distinctive. Additionally, fish habitat associations that existed during the day were less strong at night. Samples collected with red light maintained more of these fish habiat associations than samples collected by white light. Nocturnal fish assemblages are important and need habitat requirements and use need to be incorporated into biodiversity management plans. While we have shown that it is possible to sample these fish assemblages in a non-destructive manner using BUVS and artificial illumination, further comparative studies (eg Cappo *et al.* 2004) are required. While red lighting appears to be the logical choice for illumination one of the major challenges is going to be in the construction of a remote red lighting system with the ability to be able to illuminate sufficiently large areas in front of the BUVS for long periods of time. Design break throughs in this area will also facilitate the deployment of BUVS in deepwater habitats where there is insufficient light.

ACKNOWLEDGEMENTS

The authors acknowledge grants and financial aid from the Fisheries Research and Development Corporation (FRDC 2001/060) and the Coastal and Estuary Waterway Management Cooperative Research Centre. The authors are grateful to David Gull who assisted with field work. We also acknowledge access to accommodation and workshop facilities from the Department of Conservation and Land Management, Esperance.

REFERENCES

Anderson, M.J. & R.B. Millar. (2004). Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand. Journal of Experimental Marine Biology and Ecology 305: 191-221.

Bowmaker, J.K. (1995). The visual pigments of fish. Progress in Retinal and Eye Research 15: 1-31.

Cappo, M. & I. Brown. (1996). Evaluation of sampling methods for reef fish populations of commercial and recreational interest, CRC Reef Research Centre, Technical Report No. 6, Townsville, CRC Reef Research Centre, 72 pp.

Cappo, M., Harvey, E., Malcolm, H. & P. Speare. (2003). Potential of video techniques to monitor diversity, abundance and size of fish in studies of Marine Protected Areas. In: “Aquatic Protected Areas - what works best and how do we know?", (Eds Beumer, J.P., Grant, A., and Smith, D.C.) World Congress on Aquatic Protected Areas proceedings, Cairns, Australia, August 2002. p 455-464.

Cappo, M., P. Speare & G. De'ath. (2004). Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. Journal of Experimental Marine Biology and Ecology 302: 123-152.

Clarke, K. R. & R.N. Gorley. (2001). "Primer v5: User Manual/Tutorial." (Primer-E Ltd.: Plymouth, UK.)

Colton, D.E. and W.S. Alevizon (1981) Diurnal variability in a fish assemblage of a Bahamian coral reef. Environmental Biology of Fish 6: 341-345.

Demestre, M., P. Sanchez & P. Abello. (2000). Demersal fish assemblages and habitat characteristics on the continental shelf and upper slope of the north-western Mediterranean. Journal of the Marine Biological Association of the United Kingdom 80: 981-988.

Ellis, D.M. & E.E. Demartini. (1995). Evaluation of a Video Camera Technique For Indexing Abundances of Juvenile Pink Snapper, *Pristipomoides-Filamentosus*, and Other Hawaiian Insular Shelf Fishes. Fishery Bulletin 93: 67-77.

Evans, B.I., Harosi, F.I. & R.D. Fernald. (1993). Photoreceptor Spectral Absorbency in Larval and Adult Winter Flounder (*Pseudopleuronectes-Americanus*). Visual Neuroscience 10: 1065-1071.

Francour, P., Liret, C. and E.S. Harvey. (1999). Comparison of fish abundance estimates made by remote underwater video and visual census. Naturalista Siciliana XXIII (Suppl), 155-168.

Froese, R. & D. Pauly. 2004 (Eds) Fishbase World Wide Web electronic publication. www.fishbase.org

Harman, N., Harvey, E.S. & G.A. Kendrick. (2003). Differences in fish assemblages from different reef habitats at Hamelin Bay, south-western Australia. Marine and Freshwater Research 54: 177-184.

Harvey, E. & M. Shortis. 1996. A system for stereo-video measurement of sub-tidal organisms. Marine Technology Society Journal 29: 10-22.

Harvey, E.S. & M.R. Shortis. (1998). Calibration stability of an underwater stereo-video system: Implications for measurement accuracy and precision. Marine Technology Society Journal 32(2), 3-17.

Harvey, E., Fletcher, D. & M. Shortis. (2001a). A comparison of the precision and accuracy of estimates of reef-fish lengths determined visually by divers with estimates produced by a stereo-video system. Fishery Bulletin 99: 63-71.

Harvey, E., Fletcher, D. & M. Shortis. (2001b). Improving the statistical power of length estimates of reef fish: a comparison of estimates determined visually by divers with estimates produced by a stereo-video system. Fishery Bulletin 99: 72-80.

Harvey, E., Fletcher, D. & M. Shortis. (2002a). Estimation of reef fish length by divers and by stereo-video - A first comparison of the accuracy and precision in the field on living fish under operational conditions. Fisheries Research 57: 255-265.

Harvey, E., Shortis, M., Stadler, M. & M. Cappo. (2002b). A comparison of the accuracy and precision of measurements from single and stereo-video systems. Marine Technology Society Journal 36: 38-49.

Helfman G.S., Meyer, J.L., & W.N. McFarland. (1982). The ontogeny of twilight migration patterns in grunts (Pisces: Haemulidae). Animal Behaviour 30: 317-326

Hobson, E.S. (1965). Diurnal – nocturnal activity of some inshore fishes in the Gulf of Caliafornia. Copeia 3: 291-302.

Hobson, E.S., McFarland, W.N. & J.R. Chess. (1981). Crepuscular and nocturnal activities of Caliafornian nearshore fishes, with consideration to scotopic visual pigments and photic environment. Fishery Bulletin **53**: 181-188.

Hutchins, B. & R. Swainston. (1986). Sea fishes of Southern Australia: Complete field guide for anglers and divers. Swainston Publishing, Perth. 180 pp.

Lowry, M.B. & I.M. Suthers. (1998). Home range, activity and distribution patterns of a temperate rocky-reef fish, *Cheilodactylus fuscus*. Marine Biology 132: 569-578.

Lythgoe, J.N., Muntz, W.R.A., Partridge, J.C., Shand, J. & D.M. Williams. (1994). The Ecology of the Visual Pigments of Snappers (Lutjanidae) On the Great-Barrier-Reef. Journal of Comparative Physiology a-Sensory Neural and Behavioral Physiology 174: 461-467.

Lythgoe, J.N. & J.C. Partridge. (1991). The Modeling of Optimal Visual Pigments of Dichromatic Teleosts in Green Coastal Waters. Vision Research 31: 361-371.

Newman, S.J. & D.M. Williams. (2001). Spatial and temporal variation in assemblages of Lutjanidae, Lethrinidae and associated fish species among mid-continental shelf reefs in the central Great Barrier Reef. Marine and Freshwater Research 52: 843-851.

Newman, S.J. & D.M. Williams. (1995). Mesh size selection and diel variability in catch of fish traps on the central great-barrier-reef, Australia - a preliminary investigation. Fisheries Research 23 (3-4): 237-253.

Partridge, J.C., Archer, S.N. & J.N. Lythgoe. (1988). Visual Pigments in the Individual Rods of Deep-Sea Fishes. Journal of Comparative Physiology a-Sensory Neural and Behavioral Physiology 162: 543-550.

Platell, M.E. & I.C. Potter. (1999). Partitioning of habitat and prey by abundant and similar-sized species of the Triglidae and Pempherididae (Teleostei) in coastal waters. Estuarine Coastal and Shelf Science 48 (2): 235-252.

Priede, I.G., Bagley, P.M., Smith, A., Creasey, S. & N.R. Merrett. (1994). Scavenging Deep Demersal Fishes of the Porcupine Seabight, Northeast Atlantic - Observations By Baited Camera, Trap and Trawl. Journal of the Marine Biological Association of the United Kingdom 74: 481-498.

Priede, I.G. & N.R. Merrett. (1996). Community studies .2. Estimation of abundance of abyssal demersal fishes; A comparison of data from trawls and baited cameras. Journal of Fish Biology 49: 207-216.

Robblee, M.B. & J.C. Zieman. (1984). Diel variation in the fish fauna of a tropical seagrass feeding ground. Bulletin of Marine Science. **34:** 335-345.

Rotchell, J.M., Clarke, K.R., Newton, L.C. & D.J. Bird. (2001). Hepatic metallothionein as a biomarker for metal contamination: age effects and seasonal variation in European flounders

(*Pleuronectes flesus*) from the Severn Estuary and Bristol Channel. Marine Environmental Research 52: 151-171.

Shand, J., Archer, A.M., Thomas, N. & J. Cleary. (2001). Retinal development of west Australian dhufish, *Glaucosoma hebraicum*. Visual Neuroscience 18: 711-724.

Shortis, M. R., & S. Robson. 2004. VMS Reference and User Guide. http://www.geomsoft.com.au

Stadler, M. (2000) "An Evaluation of Underwater Stereo-video: A Non-destructive Technique to Census Reef Fish". Marine Biology Honours Thesis. The University of Western Australia, Perth.

Willis, R., Millar, R.B. & R. Babcock. (2000). Detection of spatial variability in relative density of fishes of fishes: comparison of visual censuses, angling and baited underwater video. Marine Ecology Progress Series 198: 249-260.

Willis, T.J. & R.C. Babcock. (2000). A baited underwater video system for the determination of relative density of carnivorous reef fish. Marine and Freshwater Research 51: 755-763.

Winer, B., Brown, D.R. and K.M Michels. (1991). Statistical Principals in Experimental Design. McGraw-Hill, New York, USA.

APPENDIX 8.5.1 Linking contemporary patterns to historical events: A comparison of macroalgal diversity within the Recherche Archipelago, Western Australia, and with the south coast of Australia.

N.A. Goldberg, G.A. Kendrick

[1] School of Plant Biology (M090), Faculty of Natural and Agricultural Science, University of Western Australia, 35 Stirling Highway, Crawley 6009, Western Australia.

ABSTRACT

Shared biogeographical history has contributed to the similarity in subtidal macroalgal flora and endemism across the 5500 km of south coast of Australia. Species richness in the Recherche Archipelago, located west of the Great Australian Bight, was compared to that of the south coast to evaluate if modern-day or historical processes control local diversity. Subtidal macroalgal diversity was compared among three island groups and two exposures (sheltered and exposed to southwesterly wind and swell). Macroalgae from 0.25 m^2 quadrats were collected from 3 islands within each island group, from sheltered and exposed sides of each island Macroalgae were sorted, wet-weighed, and identified to lowest taxonomic level. Multivariate tests and regressions were used to quantify differences among assemblages at the local and regional scales. The macroalgal flora from the archipelago clearly belonged to that of the southern coast of Australia, indicating that the flora was continental in origin and not a unique island flora. Assemblages in the archipelago were more different between exposures (Clarke's R = 0.45, $P = 0.001$) than among island groups (Clarke's R = 0.29, $P = 0.001$). Assemblages in the archipelago with high biomass generally had low species richness per 0.25 m^2, with a few overstory species contributing to over 90% of biomass. The remaining 140 to 170 species recorded in the archipelago were not limited by exposure or island group. The species pool and coexistence hypotheses were raised as possible explanations for the high species richness in temperate Australia and the high species turnover at the smallest spatial scale in the Recherche Archipelago.

INTRODUCTION

The south coast of temperate Australia provides an excellent system to evaluate the effect of shared biogeographical history on contemporary subtidal macroalgal diversity. The south coast marine flora of Australia is one of the richest floras in the world (Bolton 1994) due, in large part, to shared geologic history (Phillips 2001). Over 1100 macroalgal species are found along the south coast, consisting of tropical, temperate, and cold-water constituents. The south coast extends 5,500 km, from 35° to 40° latitude, with surface seawater temperatures ranging between 8 to 20°C, and a plethora of rocky substrata for macroalgae to attach (Womersley 1990; Phillips 2001). To understand the roles of shared history and contemporary factors on maintenance of subtidal macroalgal diversity, we compared diversity between local and regional scales.

In this study, contemporary macroalgal diversity within a region is the product of processes that have affected subtidal macroalgae for the past 160 million years (Phillips 2001). A region is an area in which species are able to disperse to a portion of the area (local scale) over a period of time that is less than the rate of speciation (Srivastava 1999; Hillebrand and Blenckner 2002). Assemblages in a region are affected by similar colonization history, biogeography (Cornell and Lawton 1992), large-scale disturbance events, random colonization, and extinction events (Palmer *et al.* 1996; Caley and Schluter 1997). For example, Edinger *et al.* (2000) concluded that a regional species pool rich with pandemic, Indian Ocean, Pacific Ocean, and endemic coral species contributed to the significant species richness found in eastern Indonesian reefs (local area).

To evaluate the contributions of contemporary and historical factors at the local scale, macroalgal diversity was characterized among island groups in the Recherche Archipelago, Western Australia. The local area comprises numerous habitats (e.g. depth, exposure) and processes (i.e. competition, Dayton 1971; trophic cascades, Paine 1966) that can affect diversity in subtidal macroalgal assemblages (Schiel and Foster 1986, Goldberg and Kendrick 2004). Where local diversity is disjunct from regional diversity then local-scale processes predominate: species-level interactions (Srivastava 1999), limited dispersal, spatio-temporal heterogeneity and patch-level disturbances (Palmer *et al.* 1996).

However, if physical conditions are relatively stable over thousands of years, then processes contributing to the maintenance of diversity may be similar at the local and regional scales. One paradigm that relates historical and contemporary influences on diversity is the species pool hypothesis (Taylor *et al.* 1990). This hypothesis links regional-scale processes (speciation, migration, and dispersal) with local-scale processes (interactions with physical and biotic factors) (Zobel 1997). The species pool hypothesis predicts greater richness in habitats that are most abundant (Taylor *et al.* 1990). The more common the habitat the greater the opportunity for speciation and adaptation (Zobel 1997). Richness may be depressed in relatively uncommon habitats subjected to extreme physical conditions (e.g. exposure, insolation) simply because fewer species have evolved mechanisms to survive such conditions. Support for this hypothesis is illustrated by productivity-richness unimodal curves in terrestrial environments (Grace 1999; Schamp *et al.* 2002).

We evaluated whether the macroalgal diversity in the Recherche Archipelago was a consequence of shared history along the south coast or local-scale contemporary processes. The archipelago marine flora was compared to that of the south coast region. If macroalgal flora in the archipelago was similar to the south coast, then historical factors most likely define present-day distributions. If macroalgal richness is different, then either the archipelago flora was unique, sampling was inadequate, or contemporary factors (i.e. species invasions, local changes in nutrient loading and turbidity) have contributed to disparity between local (archipelago) and regional (south coast) areas. Secondly, we tested whether macroalgal diversity was similar among island groups in the archipelago to explore whether diversity was maintained within islands or among islands. If macroalgal assemblages were similar among island groups, then biological and physical factors affecting species diversity are similar across the archipelago and potentially similar to that of the south coast, in general. If diversity is different among island groups, then environmental parameters (i.e. currents, gradients in exposure to wave energy, turbidity) differ across the archipelago, thereby contributing to changes in present-day diversity.

MATERIALS AND METHODS

Comparison between the floras of the Recherche Archipelago and south coast

Richness was compared among biogeographic zones across temperate Australia to determine if the flora of the Recherche Archipelago (RA) was similar to that of the southern coast. Subtidal macroalgal species lists were compiled from surveys of 11 islands in October of 2002 and 2003 (n = 372- 0.25 m^2 quadrats). CONCOM regions (regions proposed at the Second Council of Nature Conservation Ministers Technical Workshop in February, 1985) were designated Lower West Coast (LWC), South West Coast (SWC) of Western Australia, South Gulfs Coast (SGC) and the Great Australian Bight (GAB) in South Australia, Bass Strait (BS) of Victoria, Tasmania Coast (TC), Lower East Coast (LEC) and Central East Coast (CEC) of New South Wales (Fig. 1a). Species richness per CONCOM region was compiled from Sanderson (1997), and Womersley (1984, 1987, 1994, 1996, 1998, and 2003). The latter texts were also used for species identifications from the RA samples. Although a more recent system of marine zones has been designated (IMCRA) in Australia, it is based on fish distributions and not on benthic communities, and therefore not used. Non-metric, two-dimensional unconstrained plots were used to compare similarity in species richness among regions (PRIMER ver. 5, Plymouth; Clarke and Gorley 2001). Regression analysis was used to compare CONCOM coastline (km) to richness.

Comparison of diversity among island groups in the Recherche Archipelago

To determine if macroalgal assemblages differed among islands groups within and outside Esperance Bay, subtidal macroalgae were collected from three island groups: inshore (Black, Woody, and Thomas), offshore (Remark, Frederick, and Long), and eastern (Mart, Twin Peaks, and Middle, Fig. 1b). Inshore and offshore islands were sampled in October 2002 (Goldberg and Kendrick, 2004) and the eastern islands were sampled in October 2003. At each island, macroalgae were sampled from 0.25 m^2 quadrats (n = 6 replicates) at sites sheltered and exposed to southwesterly waves and in three depth strata: <10, 10-20, and >20 m (depth-related results are not included in this work). Macroalgae were sorted, identified to lowest taxonomic level, and wet-weighed. Overstory taxa (> 30 cm in length) were reported for each island group. Voucher specimens were deposited in the University of Western Australia herbarium, designated with a UWARA prefix.

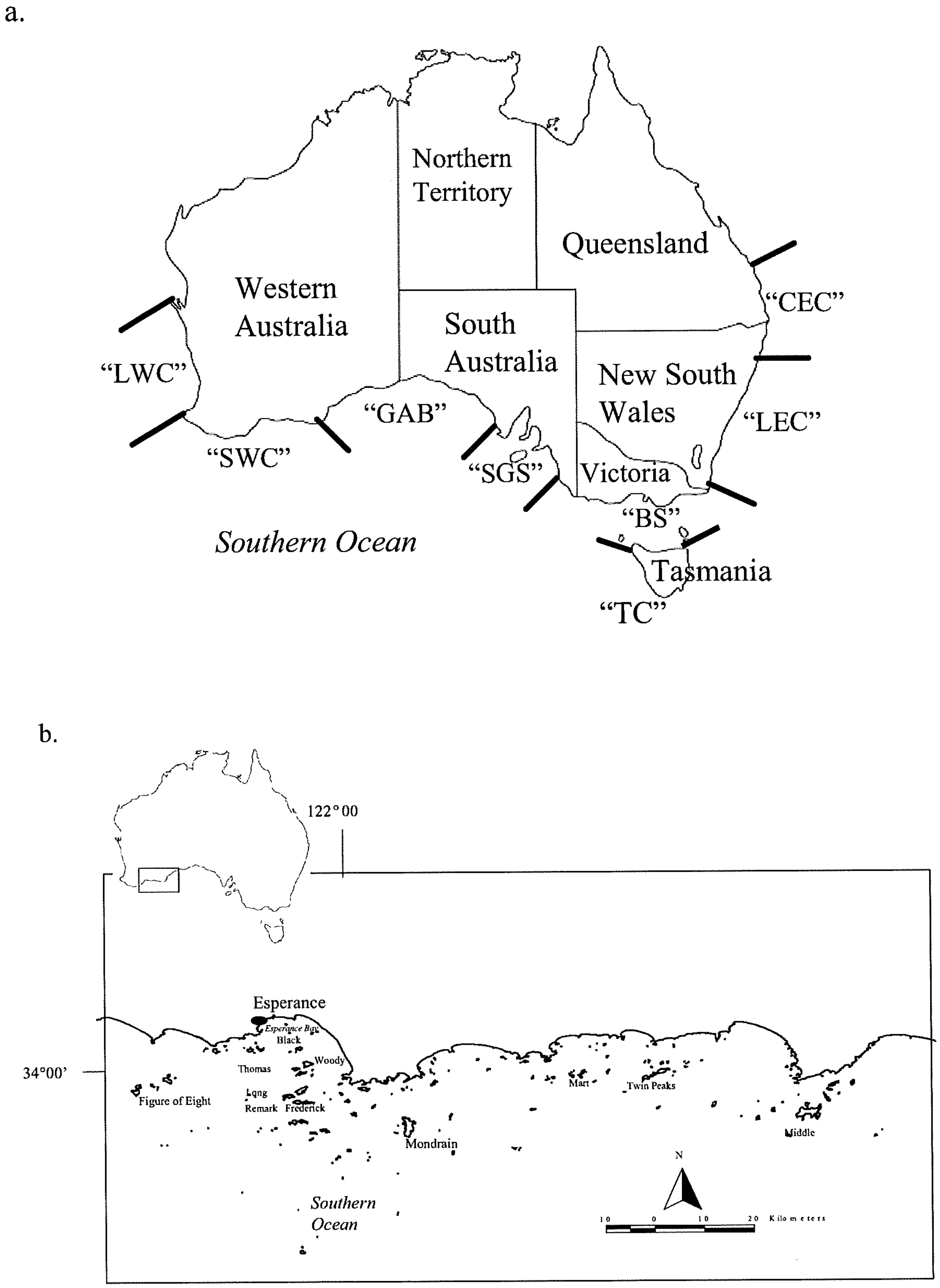


Figure 1: a. Map of Australia depicting temperate CONCOM regions: "LWC" = Lower West Coast, "SWC" = South West Coast, "GAB" = Great Australian Bight, "SGS" = South Gulfs Coast, "BS" = Bass Strait, "TC" = Tasmanian Coast, "LEC" = Lower East Coast, and

"CEC" = Central East Coast. b. Islands sampled in the Recherche Archipelago, Western Australia.

Differences among assemblages were quantified using analysis of similarity (ANOSIM; factors: island groups and exposure; PRIMER ver. 5, Plymouth) and illustrated with constrained plots (CAP, Auckland; Anderson 2002). Wet-weight data were fourth-root transformed to minimize the effects of more abundant species, and then similarities between pairs of assemblages were calculated with a Bray-Curtis similarity index (Bray and Curtis 1957). To determine if assemblages differed with the main factors exposure and island group, a two-way analysis of similarity was performed on the similarity matrix, generating a Clarke's R test statistic. If the Clarke's R (based on rank similarities) statistic is between 0.50 and 1.0, then assemblages are different. If the R statistic is less than 0.25, then the assemblages are similar (Clarke 1993).

RESULTS

Comparison between the floras of the Recherche Archipelago and south coast

The flora of the Recherche Archipelago was more similar to CONCOM regions along the south coast, than with the lower east coast (LEC) and the central east coast (CEC) (Fig. 2). Similarities among CONCOM regions roughly followed the contours of the south coast of Australia, indicating a gradual change in the flora (Fig. 2). LEC and CEC flora were distinct from the other CONCOM regions and the Recherche Archipelago (33% similar in the Chlorophyta, 26% similar in the Rhodophyta, and 31% in the Phaeophyceae). Our surveys recorded 257 species in the RA, and 64% of the species were recorded in the southwest coast (SWC). Of the 67 species found in RA but not in the SWC, 26 were found in LWC (lower west coast), 28 were found in the GAB (Great Australian Bight), and 19 were found east of the GAB. The Chlorophyta and Rhodophyta flora of RA were relatively distinct from other CONCOM regions (Fig 2a-b), but the Phaeophyceae flora was most similar to the LWC and SWC flora (Fig. 2c). An increase in species richness was observed with an increase in coastline (Fig. 3), indicating that differences in species richness among regions may also be a function of different lengths of sampled coastline.

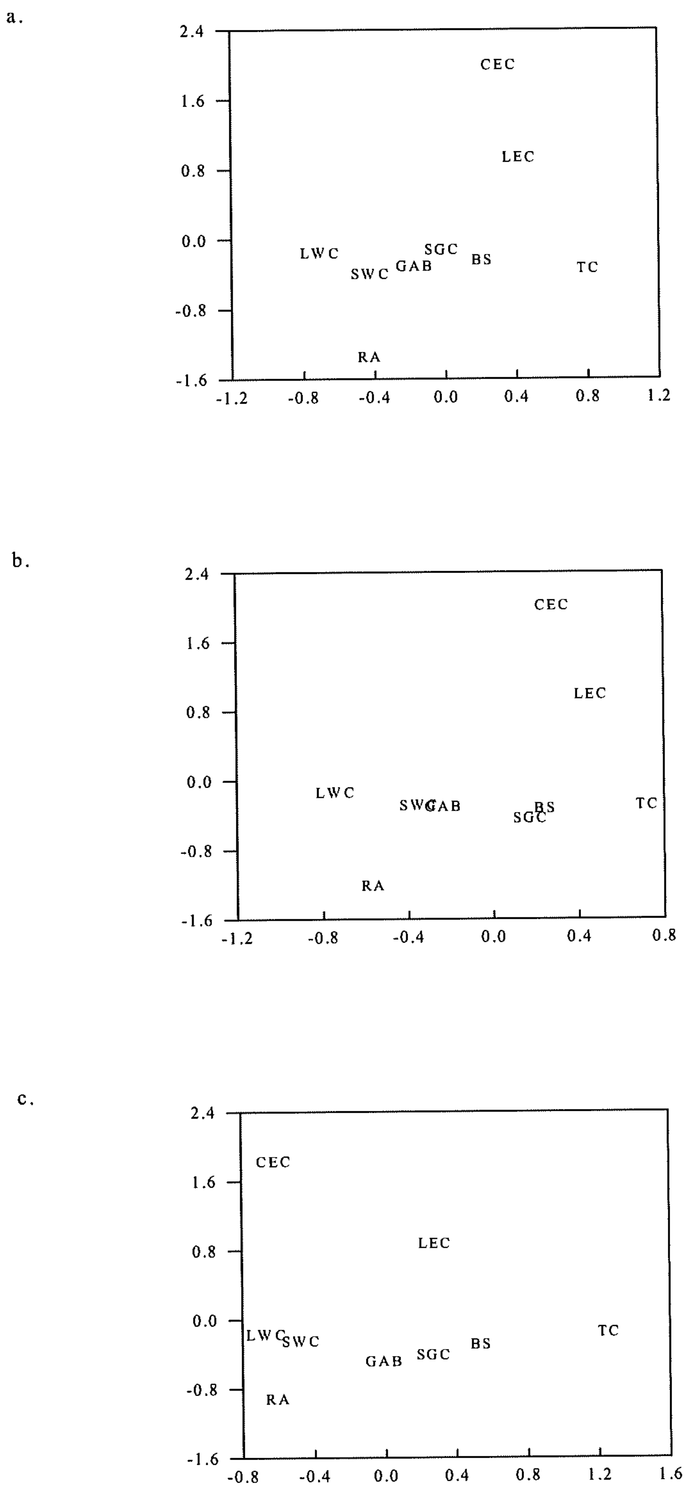


Figure 2: Non-metric two-dimensional plot depicting relationship of subtidal macroalgal species richness among CONCOM regions and with the Recherche Archipelago (RA). a. Chlorophyta, b. Rhodophyta, and c. Phaeophyceae. Stress = 0.01. Abbreviations: LWC = Lower West Coast, SWC = South West Coast, GAB = Great Australian Bight, SGS = South Gulfs Coast, BS = Bass Strait, TC = Tasmanian Coast, LEC = Lower East Coast, and CEC = Central East Coast.

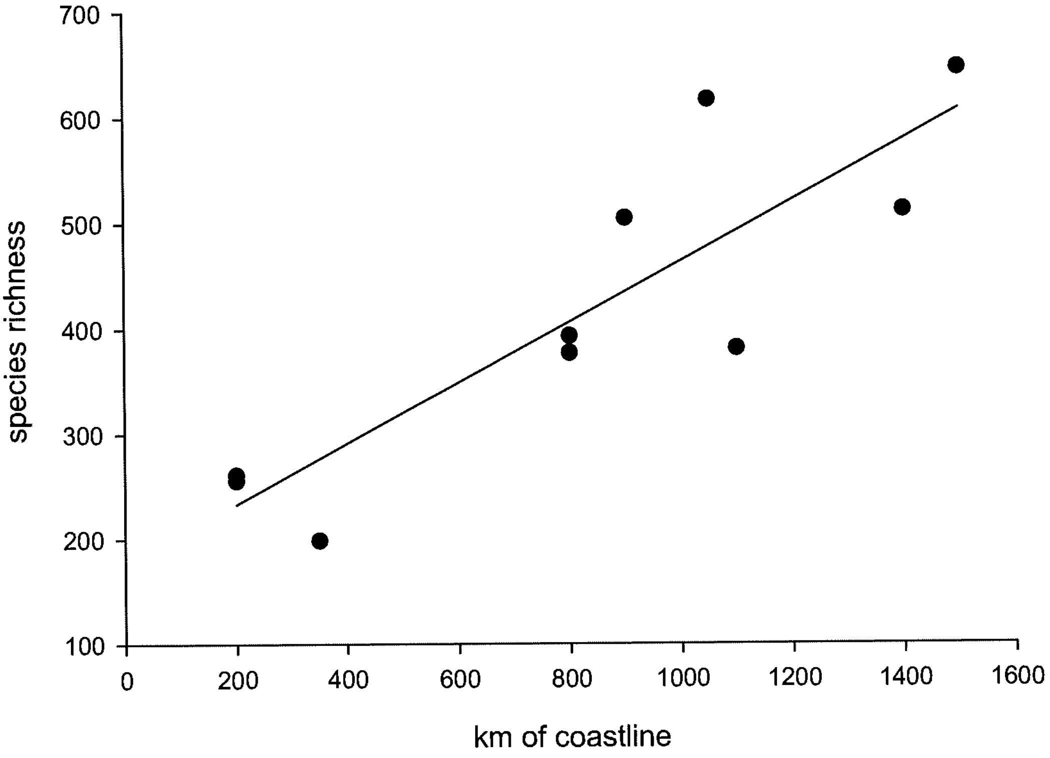


Figure 3: Relationship between length of coastline and species richness recorded in temperate Australia. $Y = 0.28x + 176$, $R^2 = 0.76$.

Comparison of diversity among island groups in the Recherche Archipelago

Subtidal assemblages were similar among island groups in the Recherche Archipelago. Richness per island group was 174 species at inshore islands, 178 species at offshore islands, and 181 species at eastern islands. Richness of species that contribute <5 g per 0.25 m^2 was 151 species at inshore islands, 150 species at offshore islands, and 163 species at eastern islands. Assemblages were more different between wave exposures (Clarke's R = 0.45, $P = 0.001$) than among island groups (R = 0.29, $P = 0.001$).

Assemblages from wave-sheltered inshore and offshore sites were similar (Clarke's R = 0.14, $P = 0.001$). Differences between eastern islands and either inshore or offshore islands (Clarke's R = 0.29 and 0.26, respectively, $P = 0.001$; Fig. 4a) was slightly greater. *Osmundaria prolifera*, *Sargassum sonderi*, *S. spinuligerum*, and *Botryocladia* *sonderi* contributed 50% of within island-group similarity between inshore and offshore, sheltered sites.

In contrast, assemblages from wave-exposed offshore and eastern islands were more similar (Clarke's R = 0.10, P = 0.001) than between inshore and either eastern or offshore islands (Clarke's R = 0.57 and 0.40, respectively, P = 0.001; Fig. 4a). *Scytothalia doryocarpa*, *Ecklonia radiata*, and *Sargassum fallax* contributed over 50% similarity at offshore and eastern island assemblages. Inshore island, wave-exposed assemblages were characterized with a more diverse overstory than elsewhere in the archipelago (Table 1).

Where macroalgal species richness per 0.25 m^2 was lowest, biomass estimates were relatively high, particularly at exposed sites (Fig. 5). Richness ranged between 1 and 44 species per 0.25 m^2 at exposed sites, and between 3 and 34 species per 0.25 m^2 at sheltered sites. Range in biomass at exposed sites was greater (41 to 3973 g per 0.25 m^2) than at sheltered sites (176 to 2567 g per 0.25 m^2). Samples with greater than 2 kg biomass were collected from exposed sites at Twin Peaks (*Ecklonia radiata* and *Scytothalia doryocarpa* contributed 86 to 100% of total biomass), Middle (*E. radiata* and *S. doryocarpa* contributed 91 to 100% of total biomass), Frederick (*Cystophora pectinata*, *C. racemosa*, and *E. radiata* contributed 73 to 95% total biomass), and Long Island (*E. radiata* and *S. doryocarpa* contributed 100% total biomass).

Table 1: Overstory species per island group (54-0.25 m^2 quadrats per island group) from exposed sites.

Species	Inshore	Offshore	Eastern
Acrocarpia robusta	*	*	
Caulocystis uvifera	*		
Cystophora brownii	*		*
C. expansa	*		
C. gracilis	*	*	
C. monilifera	*	*	*
C. pectinata	*	*	*
C. racemosa	*	*	*
C. retorta	*	*	*
C. subfarcinata	*	*	*
Ecklonia radiata	*	*	*
Sargassum fallax	*	*	*
S. heteromorphum	*		
S. laceriforlium	*		
S. linearifolium	*	*	*
S. paradoxum	*		
S. sonderi	*	*	*
S. spinuligerum	*	*	*
S. tristichum			
S. varians	*	*	*
S. verruculosum	*	*	*
Scytothalia dorycarpa	*	*	*
Total	21	15	14

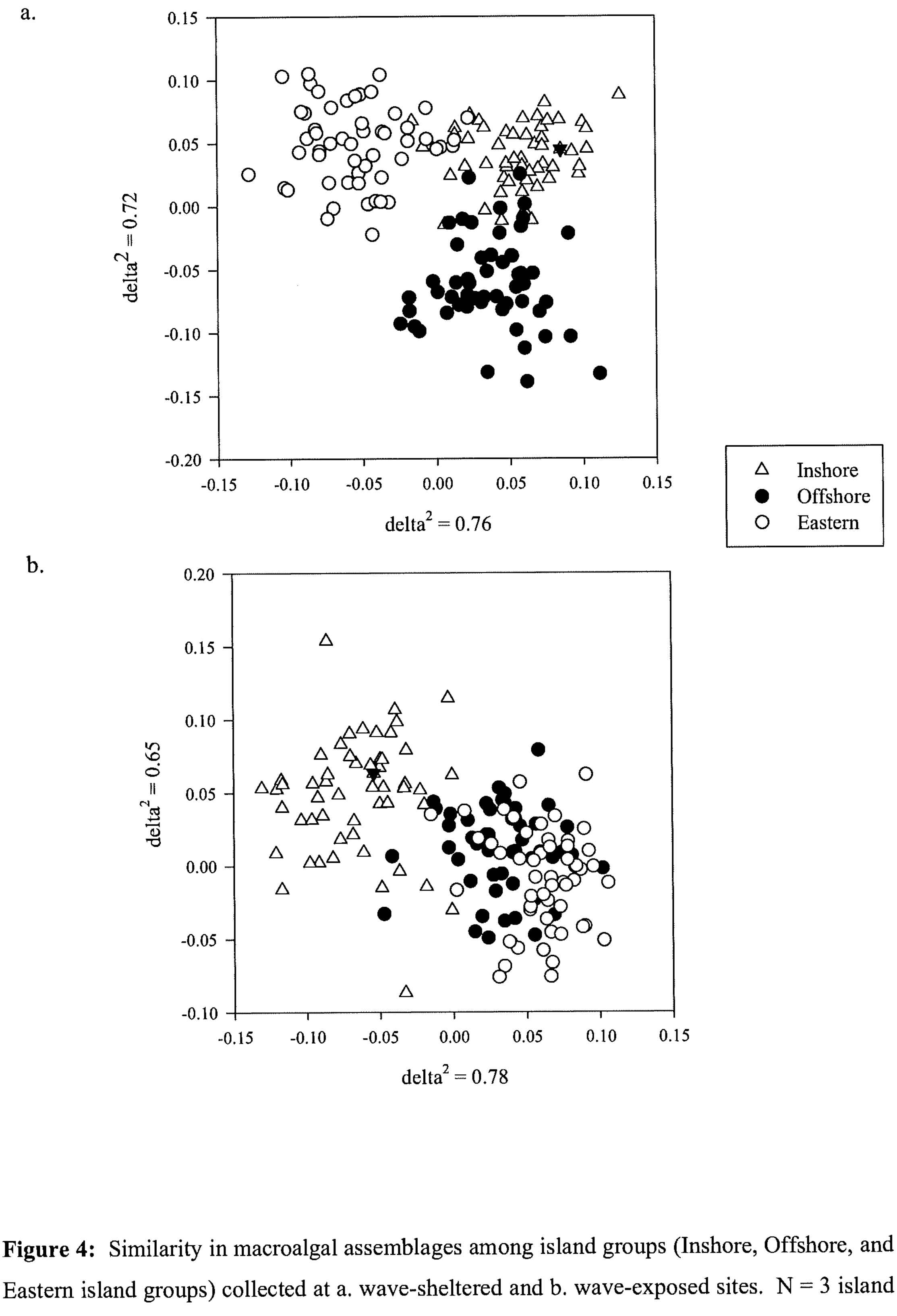


Figure 4: Similarity in macroalgal assemblages among island groups (Inshore, Offshore, and Eastern island groups) collected at a. wave-sheltered and b. wave-exposed sites. N = 3 island per island group. 54- 0.25 m^2 quadrats per exposure and island group combination. Biomass data were ln(x+1) transformed and similarities based on a Bray-Curtis dissimilarity index (CAP, Anderson 1999).

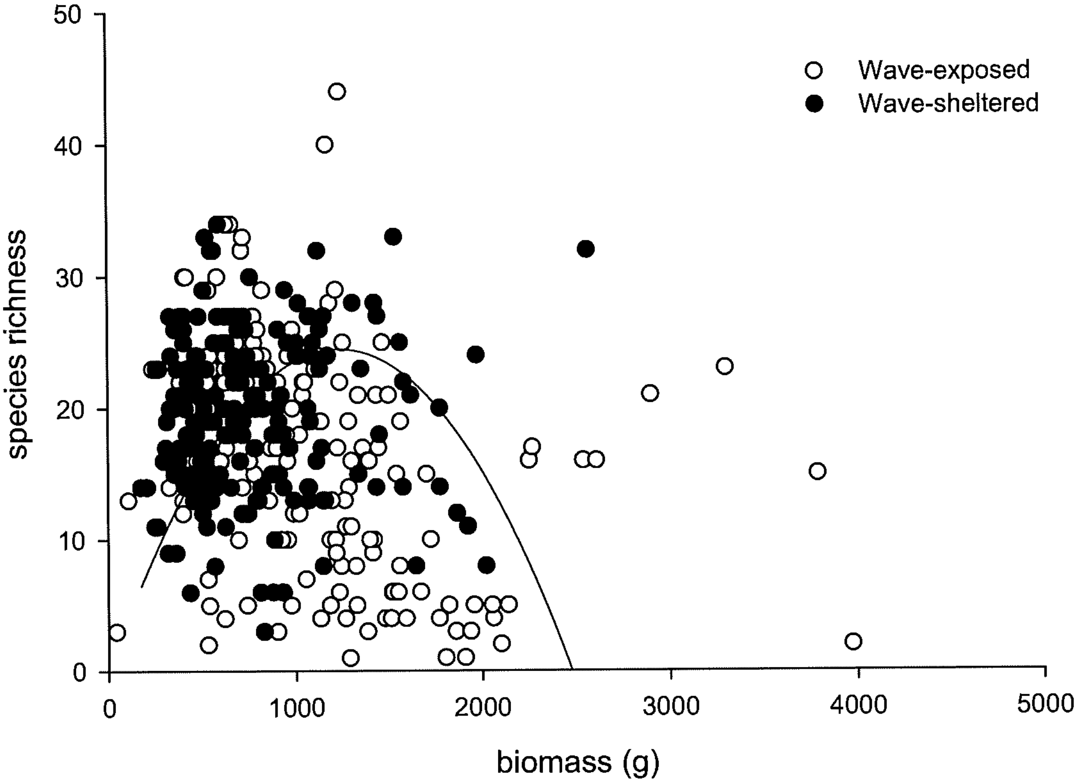


Figure 5: Unimodal relationship between macroalgal biomass per 0.25 m^2 and species richness. Assemblage data were collected from wave-exposed and sheltered sites at 11 islands in the Recherche Archipelago (186- 0.25 m^2 quadrats). $Y = (19*10^{-6})x^2 + 0.03x$, $R^2 = 0.81$).

DISCUSSION

Shared history along the south coast

Our data suggest that subtidal marine flora in the Recherche Archipelago was continental in origin and not a unique island flora (e.g. islands of New Zealand; Nelson 1994). Any differences between the Recherche Archipelago and temperate southern Australia were most likely due to sampling effort and a smaller coastline sampled in the archipelago compared to other temperate Australian, marine zones. Similarities in the flora found in the Recherche Archipelago and elsewhere along the south coast of Australia can be attributed to shared geologic history and relatively pristine conditions due to the absence of industrial centers and associated anthropogenic disturbances, particularly between the Great Australian Bight and the southwest corner of Australia.

As proposed by Womersley (1990) and Phillips (2001), species richness along the south coast of Australia has remained relatively high due to geographical isolation and benign conditions over the millenia. Separation of the south coast of Australia from Antarctica began approximately 90 million years ago and ended 30 million years ago with oceanic water flowing between the two continents (in Poore 1994). The southern Australian marine flora is assumed to have originated from the tropical Tethys Sea which was disrupted in the latter part of the Miocene (20 to 5 million years ago; McKenzie 1991). During the period of breakup between Australia and Antarctica, flora in the shared waters between the two separating continents was presumably Tethyan in origin (Phillips 2001), but species radiation may have contributed to present-day endemism along the south coast. Clayton (1994) speculated that prior to sheet-ice formation, Antarctic macroalgal species richness was similar to that of temperate southern Australia, particularly with respect to species in the Phaeophycean order Fucales. The south coast subtidal system has remained relatively stable with few extinction events, unchanging sea levels for the past six thousand years (Veevers 1991), benign coastal sea temperatures as the continent moved with the northerly drift of the Australian plate (Phillips 2001), and lack of volcanic activity and uplift as has affected the islands of New Zealand (Nelson 1994).

Maintenance of macroalgal diversity along the south coast of Australia

Maintenance of macroalgal diversity in temperate Australia may be a function of similarly adapted species to the most common habitats. Shared biogeographical history and substantial rocky reef systems across the southern coast of Australia encourage high species richness and endemism (Phillips 2001), but this richness may not extend to the most inhospitable and potentially uncommon habitats. Of the hundreds of species found in the Recherche Archipelago, few were at the most exposed sites. Instead, average biomass consisted predominantly of *Ecklonia radiata*, *Scytothalia doryocarpa*, and two *Cystophora* species, suggesting that these species have appropriate traits (tough thallus, holdfast strength, tolerance to surge) to survive benthic surge from Southern Ocean storm-generated swells. *Scytothalia doryocarpa* and *E. radiata* are indicators of extreme wave exposure in algal assemblages east of the Great Australian Bight (Collings and Cheshire 1998).

Should this relationship of low macroalgal richness and high biomass with more extreme exposure to waves and swells, as shown in this study, be consistent across the southern coast of Australia, then the species pool hypothesis may provide a framework towards understanding maintenance of macroalgal diversity in temperate Australia: the species pool hypothesis predicts that most species have not adapted to relatively uncommon habitats such as subtidal reefs exposed to extreme wave energy (Schamp *et al.* 2002). If the species pool hypothesis is shown to be true, then maintenance of diversity across temperate southern Australia is less a function of modern-day biological and physical interactions but a continuance of processes that have changed similarly over the millennia.

Maintenance of macroalgal diversity in the Recherche Archipelago

Generally the distributions of dominant species and similarities among island groups were delimited by exposure to wave energy. At either wave-exposed or sheltered sites, three to four species (*Osmundaria prolifera*, *Botryocladia sonderi*, *Scytothalia doryocarpa*, *Ecklonia radiata*, *Sargassum spp.*, and *Cystophora* spp.) were consistently present. Distributions of the remaining approximately 140 to 170 species were not limited by exposure or island group in this study (see also Goldberg and Kendrick 2004), a pattern also observed at Southern Australian islands (Baker and Edyvane 2003).

Coexistence (species adapted for and, thus, share similar habitats, *sensu* Aarssen 1983) of numerous species with niche overlap, rather than competitive exclusion contributes to the maintenance of species diversity in the Recherche Archipelago. Should species share competitive abilities, then their distributions may not be a function of predictable competitive exclusion hierarchies, but a result of stochastic dispersal/recruitment events (Aarssen 1983; Palmer *et al.* 1996). For example, overstory assemblages commonly consisted of >10 species, indicating that competitive combining abilities and not competitive exclusion predominate, despite narrow dispersal ranges (Kendrick and Walker 1995; Goldberg and Kendrick 2004).

Shepherd and Womersley (1981) also observed that competitive exclusion was not apparent in dominant overstory assemblages in South Australia.

How do rare macroalgal species manage to coexist without competitive exclusion? Alternate trait combinations (Schamp *et al.* 2002) such as morphological plasticity and tolerance to a range in settlement substrata (algal, rock, sponge) would permit species with niche overlap to coexist. For example, thalli of some *Laurencia* species were elongated and growing on other macroalgae, while others were more robust and growing on hard substratum. Small changes to the thallus morphology would allow for resource partitioning (i.e. adequate irradiance, nutrients, and space for recruitment and growth), as demonstrated in seagrass communities (Duarte 2000). Alternatively, spatial heterogeneity and high species turnover due to physical disturbance (frequency and intensity) may prevent competitive advantages but would encourage high species richness (Connell 1978; Aarssen 1983; Taylor *et al.* 1990; Grace 1999; Kendrick *et al.* 2004).

In summary, subtidal macroalgal flora in the Recherche Archipelago was comparable to the recorded flora along the south coast of Australia. Species richness in the archipelago may be maintained via flexible competitive combining abilities and successful dispersal events that link island-reef populations. Overstory taxa were characterized by coexistence of numerous species in a stand, particularly at the inshore islands. At more exposed sites, two to three overstory taxa dominated, supporting the species pool hypothesis that most species were found in more common habitats (sheltered to moderately exposed sites). Processes maintaining subtidal macroalgal diversity across the archipelago and the south coast were presumed to have remained comparable over the millennia.

ACKNOWLEDGEMENTS

We are thankful to the community of Esperance, Department of Conservation and Land Management, Captain P. Hudson and crew of the "Southern Image", and the Mackenzie family for use of their vessel "Sea Urchin". We gratefully acknowledge the macroalgal collectors and sorters: J. Heine, A. Kendrick, N. Harman, E. Harvey, S.L. Grove, D. Abdo, and D. Gull. HBS Womersley kindly confirmed species identifications. The manuscript was improved with the comments of J. Heine and D.I.

Walker. N.A.G. was supported by a University of Western Australia International Postgraduate Research Scholarship. The study was funded by a Strategic Research Fund for the Marine Environment and School of Plant Biology, University of Western Australia, grants to N.A.G. and a Fisheries Research and Development Corporation grant (2001/060) to G.A.K.

REFERENCES

Aarssen, L.W. (1983). Ecological combining ability and competitive combining ability in plants: toward a general evolutionary theory of coexistence in systems of competition. American Naturalist 122: 707-731.

Anderson, M.J. (2002). CAP: canonical analysis of principle coordinates. Department of Statistics, University of Auckland, Auckland.

Baker, J.L. & K.S. Edyvane. (2003). Subtidal macrofloral survey of St Francis and Fenelon Islands, South Australia. Transactions of the Royal Society of South Australia 127: 177-187.

Bolton, J.J. (1994). Global seaweed diversity: patterns and anomalies. Botanica Marina 37: 241-245.

Bray, J.R. & J.T. Curtis (1957). An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs 7: 325-349.

Caley, M.J. & D. Schluter (1997). The relationship between local and regional diversity. Ecology 78: 70-80.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18: 117-143.

Clarke, K.R. & R.N. Gorley. (2001). Primer v5: user manual/tutorial. PRIMER-E, Plymouth, United Kingdom.

Clayton, M.N. (1994). Evolution of the Antarctic marine benthic algal flora. Journal of Phycology 30: 897-904.

Collings, G.J. & A.C. Cheshire. (1998). Composition of subtidal macroalgal communities of the lower gulf waters of South Australia, with reference to water movement and geographical separation. Australian Journal of Botany 46: 657-669.

Connell, J.H. (1978). Diversity in tropical rain forests and coral reefs. Science 199: 1302-1310.

Cornell, H.V. & J.H. Lawton. (1992). Species interactions, local and regional processes, and limits to the richness of ecological communities: a theoretical perspective. Journal of Animal Ecology 61: 1-12.

Dayton, P.K. (1971). Competition, disturbance and community organisation: the provision and subsequent utilization of space in a rocky intertidal community. Ecological Monographs 41: 351-389.

Duarte, C.M. (2000). Marine biodiversity and ecosystem services: an elusive link. Journal of Experimental Marine Biology and Ecology 250: 117-131

Edinger, E.N., Kolasa, J. & M.J. Risk. (2000). Biogeographic variation in coral species diversity on coral reefs in three regions of Indonesia. Diversity and Distributions 6: 113-127.

Goldberg, N.A. & G.A. Kendrick. (2004). Effects of island groups, depth, and exposure to ocean waves on subtidal macroalgal assemblages in the Recherche Archipelago, Western Australia. Journal of Phycology, in press.

Grace, J.B. (1999). The factors controlling species density in herbaceous plant communities: an assessment. Perspectives in Plant Ecology, Evolution and Systematics 2/1: 1-28.

Hillebrand, H. & T. Blenckner. (2002). Regional and local impact on species diversity- from pattern to process. Oecologia 1321: 479-491.

Kendrick, G.A., Harvey, E.S., Wernberg, T., Harman, N. & N. Goldberg. (2004). The role of disturbance in maintaining diversity of benthic macroalgal assemblages in southwestern Australia. Japanese Journal of Phycology 51: 5-9.

Kendrick, G.A. & D.I. Walker. (1995). Dispersal of propagules of *Sargassum* spp (Sargassaceae, Phaeophyta) - observations of local patterns of dispersal and consequences for recruitment and population structure. Journal of Experimental Marine Biology and Ecology 192: 273-288.

McKenzie, K.G. (1991). Implications of shallow Tethys and the origin of modern oceans. Australian Systematic Botany 4: 37-40

Nelson, W.A. (1994). Distribution of macroalgae in New Zealand- an archipelago in space and time. Botanica Marina 37: 221-223.

Paine, R.T. (1966). Food web complexity and species diversity. American Naturalist 100: 65-75.

Palmer, M.A., Allan, J.D. & C.A. Butman. (1996) Dispersal as a regional process affecting the local dynamics of marine and stream benthic invertebrates. Tree 11: 322-326.

Phillips, J.A. (2001). Marine macroalgal biodiversity hotspots: why is there high species richness and endemism in southern Australian marine benthic flora? Biodiversity and Conservation 10: 1555-1577.

Poore, G.C.B. (1994). Marine biogeography of Australia. In: Hammond LS, Synnot RN (eds) Marine Biology. Longman Cheshire, Melbourne, pp 189-213

Sanderson, J.C. (1997). Subtidal macroalgal assemblages in temperate Australian coastal waters. Department of the Environment, Canberra.

Schamp, B.S., Laird, R.A. & L.W. Aarssen. (2002). Fewer species because of uncommon habitat? Testing the species pool hypothesis for low plant species richness in highly productive habitats. Oikos 97: 145-152.

Schiel, D.R. & M.S. Foster. (1986) The structure of subtidal algal stands in temperate waters. Oceanography and Marine Biology Annual Review 24: 265-307.

Shepherd, S.A. & H.B.S Womersley. (1981). The algal and seagrass ecology of Waterloo Bay, South Australia. Aqatic Botany 11: 305-371.

Srivastava, D.S. (1999). Using local-regional richness plots for species saturation: pitfalls and potential. Journal of Animal Ecology 68: 1-16.

Taylor, D.R., Aarssen, L.W. & C. Loehle. (1990). On the relationship between r/K selection and environmental carrying capacity: a new habitat templet for plant life history strategies. Oikos 58: 239-250.

Veevers, J.J. (1991). Phanerozoic Australia in the changing configuration of Proto-Pangea through Gondwanaland and Pangea to the present dispersed continents. Australian Systematic Botany 4: 1-11.

Womersley, H.B.S. (1984). The marine benthic flora of Southern Australia. South Australian Government Printing Division, Adelaide.

Womersley, H.B.S. (1987). The marine benthic flora of Southern Australia. South Australian Government Printing Division, Adelaide.

Womersley, H.B.S. (1990). Biogeography of Australasian marine macroalgae. In: Clayton MN, King RJ (eds) Biology of marine plants. Longman Cheshire Pty Limited, Melbourne, pp 368-381.

Womersley, H.B.S. (1994). The marine benthic flora of Southern Australia. Australian Biological Resources Study, Canberra.

Womersley, H.B.S. (1996). The marine benthic flora of Southern Australia. Australian Biological Resources Study, Canberra.

Womersley, H.B.S. (1998). The marine benthic flora of Southern Australia. State Herbarium of South Australia, Adelaide.

Womersley, H.B.S. (2003). The marine benthic flora of Southern Australia. Australian Biological Resources Study, Canberra.

Zobel, M. (1997). The relative role of species pools in determining plant species richness: an alternative explanation of species coexistence? Tree 12: 266-269.

Appendix 8.5.2 - A catalogue of the marine macroalgae found in the western islands of the Recherche Archipelago (Western Australia, Australia), with notes on their distribution in relation to island location, depth, and exposure to wave energy.

N.A. Goldberg[1] and G.A. Kendrick[1].

[1] School of Plant Biology (M090), Faculty of Natural and Agricultural Science, University of Western Australia, 35 Stirling Highway, Crawley 6009, Western Australia.

(In press as: Goldberg, N.I. & G.A. Kendrick. 2005. A catalogue of the marine macroalgae found in the western islands of the Recherche Archipelago (Western Australia, Australia), with notes on their distribution in relation to island location, depth, and exposure to wave energy. In: Wells, F.E., Kendrick, G. A. and Walker, D.I. (Ed.) *Proc. 12th International Marine Biological Workshop: The marine flora and fauna of the Archipelago of the Recherche, Western Australia.* W.A. Museum, Perth, (Accepted April 2004).

ABSTRACT

The distribution of subtidal macroalgae was assessed in the western islands of the Recherche Archipelago, Western Australia. Nine islands (four islands located inside and five islands located outside Esperance Bay) were sampled in three depth zones (<10, 10-20, and >20 m) and two exposures (sheltered and exposed to southwesterly wind and swell). In addition, one rhodolith bed was sampled within two nautical miles of Esperance harbour, in Esperance Bay, to identify the species making up individual rhodoliths and epiphytes. Of the 242 species recorded, there were 148 Rhodophyta, 65 Phaeophycaeae, and 29 Chlorophyta. Thirty-seven species had reported range extensions and two were presumably new species. Encrusting coralline species were not identified to species but represented three to five genera.

INTRODUCTION

Macroalgal assemblages in temperate Western Australia consist of an Australian endemic component, a widely distributed temperate component, a tropical component, and a polar component (Phillips, 2001). The subtidal flora in the Recherche Archipelago is affected by the seasonal Leeuwin Current (Cresswell, 1991), local currents created by seasonal wind patterns, and moderate to strong south-westerly swells. The distribution of macroalgae along the south-western and western coasts of Western Australia and east of the Great Australian Bight has been described through various collections (Womersley, 1953; Huisman and Walker 1990; Huisman, 1997; Harman *et al.*, 2003a,b; Wernberg *et al.*, 2003). The compilation of Australian algal lists has been published through proceedings of previous International Marine Biological Workshops (Huisman and Walker, 1990; Huisman, 1993, 1997), various ecological papers, and the algal taxonomic treatises published by H.B.S. Womersley (1984, 1987, 1994, 1996, 1998, 2003). The flora of the Recherche Archipelago had not received much attention. The first published species list was an algal collection (mainly from drift) by Willis, from an Australian Geographical Society expedition in 1950, and consisted of 53 species (Womersley, 1953).

Often field excursions investigated ecological questions and thus, collections were sampled within a known area, stratified by depth, exposure, and substratum, resulting in quantitative diversity estimates. Macroalgae are highly influenced by light, sedimentation, and wave energy in Australia (Shepherd and Womersley, 1970; Choat and Schiel, 1982; Collings and Cheshire, 1998; Kendrick *et al.*, 1999; O'Hara, 2001; Wernberg *et al.*, 2003) and elsewhere in the world (Dayton *et al.*, 1984; reviewed in Schiel, 1994; Foster and Vanblaricom, 2001). To test the generality of such differences in the Recherche Archipelago, we stratified our sampling design by depth and exposure at different inshore and offshore islands. The following species compilation is an attempt to further our knowledge of diversity and distribution of subtidal macroalgae found along the southern Australian coast.

MATERIALS AND METHODS

Site Description

The islands of the Recherche Archipelago span more than 200 km and are different to other islands found along the coastline of Western Australia. The islands are granitic, not limestone, and rise from a sand-inundated seafloor. The intertidal is steeply-sloping with a narrow band of filamentous macroalgae and invertebrates (pers. obs.). Subtidal reefs descend from the intertidal to the seafloor as gently sloping platforms, broken boulders (tens of m^2 in scale) with platforms, vertical walls, and rubble.

Islands and rhodolith beds sampled

In October 2002, macroalgae were collected from 8 islands: Black Island, Woody Island, Thomas Island, Remark Island, Frederick Island, Long Island, Figure of Eight Island, and Mondrain Island (Figure 1). Macroalgae were sampled from the sheltered and exposed reefs of each island. Exposed sites faced southwesterly wind and swell. At Figure of Eight Island and Mondrain Island, macroalgae were collected from platforms and walls on the sheltered and exposed sides of the island ($n = 2$ sites per exposure), in depths of 10 to 20 m ($n = 6$; 0.25 m^2 areas per substratum orientation per site).

At Black, Woody, Thomas, Remark, Long, and Frederick Island, macroalgae were collected from one exposed site and one sheltered site per island. Within each site, a gently-sloping, low-relief reef was stratified into three depth categories: less than 10 m, 10 to 20 m, and 21 to 28 m. Six quadrats (0.25 m^2) were placed randomly and all macroalgae were cleared by hand. Further collections were made at Black and Woody Island in April 2003.

In addition, we sampled the macroalgae that had recruited on settlement plates (sanded PVC plates) that were deployed at Lion Island in 10-20 m (September-April, 2003; Goldberg *et al.* 2004).

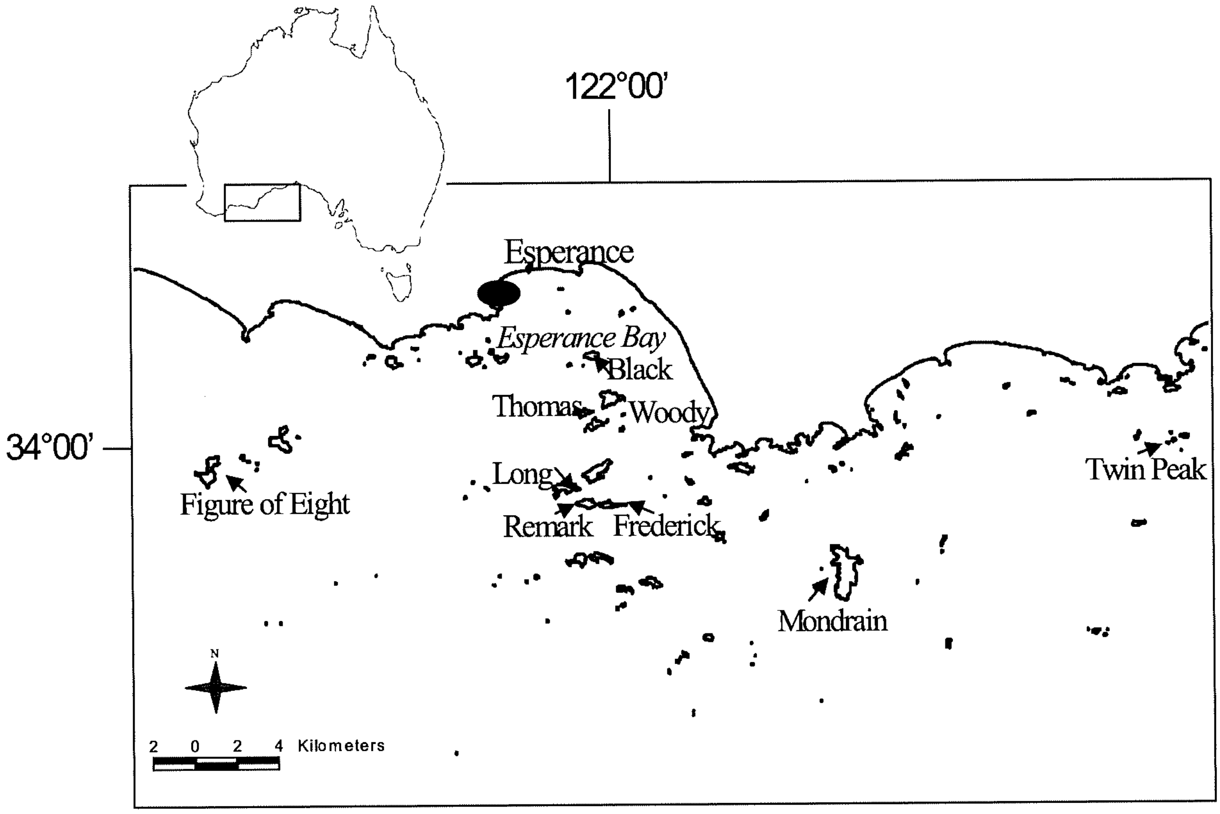


Figure 1 Inshore islands (Black, Woody, Thomas, and Lion Island), located in Esperance Bay, and offshore islands (Long, Remark, Frederick, Figure of Eight, and Mondrain Island) that were sampled for macroalgae in the Recherche Archipelago, Western Australia.

Algae were sorted to species after each collection. We used, for the most part, the keys and algal taxonomic descriptions provided in Womersley (1984, 1987, 1994, 1996, 1998, 2003), Huisman (2000), and Lucas and Perrin (1947) to identify specimens to lowest taxonomic level. H.B.S. Womersley confirmed species identifications in August 2003. Those species that were not reproductive but had appropriate vegetative characteristics were described with an *f.* preceding the name.

In February 2003, a rhodolith bed near Esperance Harbour was sampled. A Van Veen grab was used to collected rhodoliths in depths of 38 m. Rhodoliths were identified with the help of A. Harvey (Dept. of Botany, La Trobe University) using the specimen preparation protocol described in Harvey *et al.* (2002). Rhodoliths were listed separately in the catalogue. In general, rhodoliths that were sectioned had either buried conceptacles or were not reproductive, but adequate vegetative traits from which to identify to genera. Likewise, epiphytes associated with the rhodolith bed were listed separately.

Specimens have been deposited in the School of Plant Biology herbarium at the University of Western Australia. The collection will be completed by 2006.

Catalogue description

Each species description that was listed in the catalogue is divided into five parts. The '*References*' section provided a selection of literature that describes the species. The '*Type locality*' section described where the type specimen had been collected. The '*Distribution*' section noted countries located in the Indian Ocean where the species had been recorded (Silva *et al.*, 1996), with the 'Australia' subsection documenting where the species was located within the country (Womersley, 1984, 1987, 1994, 1996, 1998, 2003; Huisman, 1997, 2000). The '*Specimen*' section noted existing herbarium specimens and location collected (island, exposure, substratum orientation, and depth). '*Collection locations*' section described where the species was found, but no voucher collected, in the Recherche Archipelago (island, exposure, substratum orientation, and depth) that were either collected in 2002 or from previously published accounts.

RESULTS

Over 240 species were recorded in the Recherche Archipelago, with 148 species of Rhodophyta, 65 species of Phaeophyceae, and 29 species of Chlorophyta. Range extensions were recorded for 37 species (Table 1). Collected *Herposiphoniella plurisegmenta* specimens were tetrasporic and the first record of reproductive material for this genus (see Goldberg and Huisman, this volume). One *Sargassum* and one Rhodophyta have not been described previously (Womersley, pers. comm.). Individuals of *Laurencia* species varied in morphology, depending on the type of substratum to which they were attached. For example, *Laurencia elata* and *Laurencia filiformis* were found growing epiphytically on overstory species in addition to growing attached to the reef. Epiphytic individuals were more branched than the epilithic individuals that had robust main axes.

The number of nongeniculate coralline species in the rhodolith bed was not determined due to inadequate specimens, but may consist of at least three genera in the families Melobesioideae (*Lithothamnion*), Mastophoroideae (*Hydrolithon*) and

Sporolithaceae (*Sporolithon*). Rhodolith morphology ranged from lumpy, fruticose, to warty. Centres of rhodoliths consisted of encrusting coralline algae and not a pebble or shell. Size ranges of rhodoliths were <5 to 60 mm along the longest axis. Rhodolith densities were greater in the middle of the bed than along the offshore and inshore margins. Fifty-two species were found epiphytic on rhodoliths (Table 2)

Table 1: Macroalgae with range extensions, that were collected in the western islands of the Recherche Archipelago.

Division/Class	Species
Chlorophyta	*Caulerpa hedleyi* Weber-van Bosse
	Caulerpa longifolia C. Agardh
	Caulerpa remotifolia Sonder
	Rhipiliopsis multiplex Kraft
	Rhipiliopsis robusta Womersley
Phaeophyceae	*Bellotia eriophorum* Harvey
	Chlanidophora microphylla (Harvey) J. Agardh
	Dictyota fenestrata J. Agardh
	Dictyopteris gracilis Womersley
	Dictyopteris plagiogramma (Montagne) Vickers
	Dilophus marginatus J. Agardh
	Myriodesma harveyanum Nizamuddin and Womersley
	Myriodesma tuberosum J. Agardh
	Scoresbyella profunda Womersley
	Sargassum decurrens (R. Brown *ex* Turner) C. Agardh
	Sargassum lacerifolium (Turner) C. Agardh
	Sporochnus apodus Harvey
	Zonaria angustata (Kützing) Papenfuss
Rhodophyta	*Callophycus dorsiferus* (C. Agardh) Silva
	Callithamnion obstipum (Cowling, Kraft and West) Womersley
	Ceramium excellens J. Agardh
	Codiophyllum flabelliforme (Sonder) Schmitz
	Coelarthrum cliftonii (Harvey) Kylin
	Crouania shepleyana Wollaston
	Cryptonemia kallymenioides (Harvey) Kraft
	f. Dasya scopulifera Harvey

	Delisea hypneoides Harvey
	Doxodasya lenormandiana (J. Agardh) Schmitz
	f. Gloiocladia polycarpa (Harvey) Womersley
	Gloiophloea scinaioides J. Agardh
	Hirsutithallia mucronata Wollaston and Womersley
	Peyssonnelia foliosa Womersley
	Peyssonnelia inamoena Pilger
	Rhodopeltis borealis Yamada
	f. Rhodymenia leptophylla J. Agardh
	f. Rhodymenia prolificans Zanardini
	Tsengia comosa (Harvey) Womersley and Kraft

Table 2: Foliose and filamentous macroalgal epiphyte species attached to rhodoliths. Data taken from 0.09 m^3 Van Veen Grabs (n = 20) and 7 Dredges. * denotes range extension.

Division/Class	Species
Chlorophyta	_Cladophora_ unknown sp.
	Struvea plumosa Sonder
	*_Caulerpa longifolia_ C. Agardh
	*_Caulerpa remotifolia_ Sonder
	Polyphysa peniculus (R. Brown _ex_ Turner) C. Agardh
	*_Rhipiliopsis multiplex_ Kraft
Phaeophyceae	_Austronereia australis_ (Harvey) Womersley
	*_Bellotia eriophorum_ Harvey
	Colpomenia sinuosa (Mertens ex Roth) Derbes and Solier
	*_Dictyopteris gracilis_ Womersley
	Dictyopteris muelleri (Sonder) Reinbold
	Dictyopteris sp.
	Dictyota dichotoma (Hudson) Lamouroux
	Dictyota dichotoma var _intricata_ (C. Agardh) Greville
	Dictyota furcellata (C. Agardh) J. Agardh
	Dictyota naevosa (Suhr) J. Agardh
	Dictyota prolifera Lamouroux
	Dilophus robustus (J. Agardh) Womersley
	Lobophora variegata (Lamouroux) Womersley
	*_Myriodesma tuberosum_ J. Agardh
	*_Sporochnus apodus_ Harvey

	Sporochnus comosus C. Agardh
	Zonaria crenata J. Agardh
Rhodophyta	*Amphiroa anceps* (Lamark) Decaisne
	Botryocladia sonderi Silva
	**Callithamnion obstipum* (Cowling, Kraft and West) Womersley
	Carpothamnion gunnianum (Harvey) Kützing
	**Ceramium excellens* J. Agardh
	Champia affinis (J. Hooker and Harvey) J. Agardh
	Champia parvula (C. Agardh) Harvey
	Champia zostericola (Harvey) Reedman and Womersley
	**Crouania shepleyana* Wollaston
	Dasya extensa Sonder ex Kützing
	Dasya villosa Harvey
	Dictyomenia sonderi Harvey
	Dictyomenia tridens (Mertens ex Turner) Greville
	Erythroclonium sonderi Harvey
	Gloiocladia halymenioides (Harvey) Norris
	**Gloiophloea scinaioides* J. Agardh
	Gloiosaccion brownii Harvey
	Griffithsia teges Harvey
	Gymnothamnion elegans (Schousboe ex C. Agardh) J. Agardh
	Heterosiphonia gunniana (Harvey) Reinbold
	Hypnea ramentacea (C. Agardh) J. Agardh
	Hypnea valentiae (Turner) Montagne
	Hypoglossum dendroides (Harvey) J. Agardh
	Laurencia filiformis (C. Agardh) Montagne
Division/Class	Species
Rhodophyta	*Lenormandia latifolia* Harvey and Greville
	Mychodea disticha Harvey
	Osmundaria prolifera Lamouroux
	Vidalia spiralis (Lamouroux) Lamouroux *ex* J. Agardh
	Protokuetzingia australasica (Montagne) Falkenberg in Schmitz and Falkenberg

DISCUSSION

In general, macrophyte assemblages on rocky reefs consisted of a fucoid-dominated canopy with a diverse epiphytic and understory assemblage, epiphytes on seagrasses (Goldberg and Kendrick, 2004), and rhodolith beds. Dominance of one species was rarely observed. Of the 53 species recorded in Womersley's list (1953), 34 were found in this study. The rhodolith beds were an interesting discovery as local fishers and scientists had not previously recorded beds in the area. In addition, the beds in the Recherche Archipelago are unusual in that they may consist of several coralline taxa (pers. comm. M.S. Foster).

ACKNOWLEDGEMENTS

We thank the community of Esperance, Western Australia, the Department of Conservation and Land Management, and the following individuals for providing field assistance: Captains Peter Hudson and Marcus Gray and their crew, and J. Heine, N. Harman, E.S. Harvey, S.L. Grove, D. Gull, D. Abdo, S. Coote, and C. and E. Siemer. We extend a generous thank-you to H.B.S. Womersley for confirmation of *Specimen* identifications, and to A. Harvey and Wm. Woelkerling for help in identifying the taxa making up the rhodoliths and for use of their laboratory. This paper was improved through the editorial comments of J. Huisman, D.I. Walker, and J. Heine. N.A.G. was supported by an International Postgraduate Research Scholarship, University of Western Australia. N.A.G. would like to thank the Australian Marine Sciences Association for sponsorship to attend the International Marine Biological Workshop. The study was funded by FRDC grant 2001/060 to G.A.K. and a WA Government-CSIRO SRFME grant to N.A.G. and G.A.K.

Appendix 8.5.3

A catalogue of marine plants from the Recherche Archipelago

Division Chlorophyta (Green Algae)

Order Bryopsidales

Family Bryopsidaceae

***Bryopsis* sp.**

f. ***B. plumosa*** (Hudson) C. Agardh 1823: 448.

References: Womersley 1984: 282, figures 96C, 97A; Richardson 1982: 177; Womersley, 1956: 364; MacRaild 1974: 158; Kylin 1949: 66, figure 64; Harvey 1846: pl. 3.

Type locality: Exmouth, England.

Distribution: Widespread in temperate waters throughout the world.

Australia: Southern Australia.

Specimen: Black Island- Sheltered: 10-20 m, April (UWARA-240).

Collection locations: Black Island (Sheltered: 10-20 m, April).

Order Caulerpales

Family Caulerpaceaea

Avrainvillea clavatiramea Gepp and Gepp 1911: 33.

References: Womersley 1984: 253, figures 83E, 85I-K.

Type locality: Corio Bay, Victoria.

Distribution: Australia: Rottnest Island, Western Australia, to Port Phillip Bay, Victoria.

Specimen: Woody Island- Sheltered: 20+ m (UWARA-53).

Collection locations: Woody Island (Exposed: 10-20 m; Sheltered: 20+ m and 10-20 m; April).

Caulerpa brownii (C. Agardh) Endlicher 1843: 16.

References: Womersley 1984: 264, figures 88D-E, 89D; Womersley 1956: 365; Lucas 1936: 42, figures. 23-24; Weber-van Bosse 1898: 306, pl. 25, figure 3.

Type locality: Kent Islands, Bass Strait, Australia.

Distribution: Australia and New Zealand.

Australia: Whitfords Beach, Perth, Western Australia around southern Australia to Walkerville, Victoria; Tasmania.

Specimen: Mondrain Island- Sheltered: site 1- platform (UWARA-213).

Collection locations: Black Island (Exposed: <10 m; Sheltered: 10-20 m), Figure of Eight Island (Exposed/Sheltered: 10-20 m), Frederick Island (Exposed: <10 m; Sheltered: <10 m, 20+ m), Long Island (Exposed: <10 m), Mondrain Island (Sheltered: site 1- platform and wall), Remark Island (Exposed: <10 m; Sheltered: <10-20 m), Thomas Island (Exposed: <10 m), and Woody Island (Exposed/Sheltered: <10 m).

Caulerpa cactoides (Turner) C. Agardh 1817: XXIII.

References: Womersley 1984: 269, figures 91A, 92C; Fuhrer *et al.* 1981: 96, pls 161-162.

Type locality: Southern coast of Australia.

Distribution: Australia, Bangladesh, Indonesia (Sumba).

Australia: Dampier, Western Australia, to the Richmond River mouth, New South Wales.

Specimen: Mondrain Island- Exposed (UWARA-213).

Collection locations: Black Island (Exposed: 10-20 m) and Figure of Eight Island (Sheltered: site 1- platform), and Mondrain Island (Exposed).

Caulerpa sedoides C. Agardh *f.* ***geminata*** (Harvey) Weber-van Bosse 1898: 387.

References: Womersley 1984: 266, figures 89G, 90A (as *Caulerpa geminata)*; Fuhrer *et al.* 1981: 95, pl. 159 (as *C. geminata*).

Type locality: Rottnest Island, Western Australia.

Distribution: Australia: Geraldton, Western Australia, to Collaroy, New South Wales.

Specimen: Woody Island- Exposed: 20+ m (UWARA-54).

Collection locations: Black Island (Exposed: 10-20+ m), Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site1- platform and site 2 platform and wall), Frederick Island (Sheltered: 20+ m), Long Island (Exposed: <10 m), Mondrain Island (Exposed: site 2- platform and wall; Sheltered: site 1- wall and site 2-platform and wall), and Woody Island (Exposed: 10-20+ m).

Caulerpa hedleyi Weber-van Bosse 1910: 1, pl. 1, figures 1-4.

References: Womersley 1984: 268, figures 88H, 89H.

Type locality: "Off Kangaroo Island", South Australia.

Distribution: Australia: Rottnest Island, Western Australia; Isles of St. Francis, Pearson Island and Investigator Strait.

Specimen: Woody Island- Exposed: 20+ m (UWARA-51 and 55).

Collection locations: Black Island (Sheltered: 20+ m), Figure of Eight Island (Exposed/Sheltered: sites 1 and 2- platform), Frederick Island (Sheltered- 20+ m), Mondrain Island (Exposed: site 2- platform), Remark Island (Sheltered: 10-20+ m), and Woody Island (Exposed: 20+ m).

Notes: Range extension.

Caulerpa obscura Sonder 1845: 50.

References: Womersley 1984: 265, figures 88F, 89F; Fuhrer *et al.* 1981: 99, pl. 167.

Type locality: Western Australia.

Distribution: Australia: Houtman Abrolhos, Western Australia, to Walkerville, Victoria.

Specimen: Mondrain Island- Sheltered: site 1- platform (UWARA-213 and 244).

Collection locations: Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and wall), and Mondrain Island (Sheltered: site 1- platform and wall).

Caulerpa papillosa *J. Agardh 1873: 42.*

References: Womersley 1984: 270, figures 91C, 92E; Lucas 1936: 48.

Type locality: Queenscliff, Victoria.

Distribution: Australia: Middle Island, Recherche Archipelago, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Black Island- Sheltered: <10 m, April (UWARA-230).

Collection locations: Black Island (Sheltered: <10 m, April).

Caulerpa racemosa (Forsskål) J. Agardh var. [***laetevirens***] *f.* ***cylindracea*** (Sonder) Weber-van Bosse 1898: 366.

References: Womersley 1984:270, figures 91B, 92D; 1956:368.

Type locality: Suez, Egypt.

Distribution: Aldabra Islands, Andaman Islands, Australia, Bangladesh, Burma (Coco Group and Diamond Island), Djibouti, India, Indonesia, Kenya, Laccadive Islands, Madagascar, Malaysia, Maldives, Mauritius, Mozambique, Nicobar Islands, Pakistan, Réunion, Seychelles (including Mahé Island), Singapore, Somalia, South Africa, Sri Lanka, Tanzania, Yemen.

Collection locations: Black Island (Exposed: <10 m).

Caulerpa scalpelliformis (R. Brown *ex* Turner) C. Agardh 1817: XXII.

References: Womersley 1984: 258, figures 86D, E, 87D-E.

Type locality: Southern coast of Australia.

Distribution: Aldabra Islands, Australia, India, Kenya, Madagascar, Mauritius, Mozambique, Oman, Pakistan, South Africa, Sri Lanka, Tanzania, Yemen.

Australia: Whitfords, Western Australia, to Jervis Bay, New South Wales; Tasmania.

Specimen: Black Island- Sheltered: 10-20 m, April (UWARA-241).

Collection locations: Black Island (Exposed: <10 m; Sheltered: 10-20 m, April) and Figure of Eight Island (Exposed: site 2- platform and wall; Sheltered: site 2- platform).

Caulerpa trifaria Harvey 1863: pl. 261.

References: Womersley 1984: 264, figures 88C, 89C; Womersley 1956: 371; Lucas 1936: 39, figure 20; Weber van Bosse 1898: 229.

Type locality: Port Phillip Heads, Victoria, Australia.

Distribution: Australia: Cottesloe, Western Australia, to Western Port, Victoria; Tasmania.

Collection locations: Figure of Eight Island (Exposed: site 1- wall), Frederick Island (Sheltered: 20+ m), and Mondrain Island (Exposed: site 1- platform).

Caulerpa vesiculifera Harvey 1863: lvi.

References: Womersley 1984: 272, figures 91D, 92F; Womersley 1956: 371; Lucas 1936: 47.

Type locality: Western Port, Victoria.

Distribution: Australia: Shark Bay, Western Australia, to Phillip Island, Victoria; Tasmania.

Specimen: Figure of Eight Island- Sheltered: site 1- wall (UWARA-156 and 248).
Collection locations: Figure of Eight Island (Sheltered: site 1- wall).

Family Halimedaceae

Halimeda cuneata Hering *in* Krauss 1846: 214.
References: Millar and Kraft 1994: 435; Womersley 1984: 244, figures 81C, 82E-G; Hillis-Colinvaux 1980: 124-126, figures 36, 61.
Type locality: Durban, South Africa.
Distribution: Andaman Islands, Australia, Chagos Archipelago, India, Indonesia, Kenya, Madagascar, Mozambique, Nicobar Islands, Pakistan, Réunion, Somalia, South Africa, Tanzania.
Australia: Western Australian coast from the tropics to Middle Island, Recherche Archipelago.
Collection locations: Black Island (Exposed/Sheltered: <10 m), Frederick Island (Exposed: <10 m; Sheltered: 10-20+ m), and Mondrain Island (Sheltered: site 2- wall).

Family Udoteaceae

Rhipiliopsis robusta Womersley 1971a: 117, figures 9, 13.
References: Womersley 1984: 251, figures 83D, 85F-H.
Type locality: Tiparra Reef, Spencer Gulf, South Australia.
Distribution: Australia: Tiparra Reef and Pearson Island, South Australia.
Specimen: Figure of Eight Island- Exposed: site 1- platform (UWARA-193).
Collection locations: Figure of Eight Island (Exposed: site 1- platform).
Notes: Range extension.

Order Cladophorales

f. ***Apjohnia laetevirens*** Harvey 1855a: 335.

References: Womersley 1984: 182, figures 58A, 59A, B; Fuhrer *et al.* 1981: 93, pl. 156.

Type locality: Phillip Island, Victoria, Australia.

Distribution: Australia: Green Head, Western Australia, to Collaroy New South Wales; Bass Strait.

Specimen: Black Island- Sheltered: 10-20 m, April (UWARA-180).

Collection locations: Mondrain Island (Sheltered: site 2- platform) and Black Island (Sheltered: <10-20 m; April).

Notes: Could be a young *Struvea plumosa* (Womersley, pers. comm.).

Order Codiales

Family Codeaceae

Codium harveyi P. Silva *in* P. Silva and Womersley 1956: 277-278.

References: Womersley 1984: 2236, figures 79A, 80A.

Type locality: Vivonne Bay, Kangaroo Island, South Australia.

Distribution: Australia and New Zealand.

Australia: Shark Bay, Western Australia, and along southern Australia; Tasmania; Lake Macquarie, New South Wales.

Collection locations: Remark Island (Sheltered: 20+ m).

Codium lucasii Setchell *in* Lucas 1935: 200.

References: Womersley 1984: 227, figures 75C-D.

Type locality: Bondi, New South Wales.

Distribution: Port Denison, Western Australia to southern and eastern Australia, to Redcliffe, Queensland; Tasmania.

Specimen: Figure of Eight Island- Sheltered, wall (UWARA-155).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall) and Woody Island (Sheltered: 10-20 m, April).

Codium muelleri *Kützing 1856: pl. 95, figure 2.*

References: Womersley 1984: 236, figures 79B, 80B.

Type locality: Lefevre Peninsula, South Australia.

Distribution: Australia: Dongara, Western Australia, to Walkerville, Victoria.

Specimen: Black Island- Exposed: <10 m, April (UWARA-183).

Collection locations: Black Island (Exposed: <10 m; April).

Codium spongiosum Harvey 1855b: 565.

References: Womersley 1984: 228, figures 75E, 76F; Fuhrer *et al.* 1981: 105, pl. 180.

Type locality: King George's Sound, Western Australia.

Distribution: Australia, South Africa, Mauritius, New Caledonia, Hawaii, Brazil. Australia: Point Cloates, Western Australia, to Apollo Bay, Victoria; Lord Howe Island, New South Wales; Queensland; Tasmania.

Specimen: Figure of Eight Island- Sheltered: site 1- wall (UWARA-155, 170, and 217).

Collection locations: Figure of Eight Island (Sheltered: site 1- platform and wall and site 2- wall) and Long Island (Exposed: <10 m).

Codium mamillosum Harvey 1855b: 565.

References: Womersley 1984: 230, figures 77A, 78A; Silva and Womersley 1956: 269, figure 6; Lucas 1936: 53.

Type locality: Swan River, Western Australia.

Distribution: Australia, Japan, Tanzania.

Australia: Dongara, Western Australia, to Warrnambool, Victoria.

Collection locations: Black Island (Exposed/Sheltered: <10-20+ m), Figure of Eight (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform and site 2- wall); Frederick Island (Exposed: <10-20 m; Sheltered: 10-20 m), Long Island (Exposed: <10 m; Sheltered: <10-20 m); Mondrain Island (Exposed: site 2- platform; Sheltered: site 1- platform and site 2- platform and wall), Remark Island (Exposed: 10- 20+ m; Sheltered: <10-20 m), Thomas Island (Exposed: 10-20+ m; Sheltered: <10-20+ m), and Woody Island (Exposed/Sheltered: <10-20+ m).

Codium pomoides J. Agardh 1894: 100.

References: Womersley 1984: 232, figures 77B, 78B.

Type locality: Port Phillip Heads, Victoria, Australia.

Distribution: Australia: Rottnest Island, Western Australia, to Walkerville, Victoria.

Collection locations: Figure of Eight Island (Sheltered: site 1- platform and wall and site 2- wall), Frederick Island (Sheltered: <10 m), Long Island (Sheltered: <10 m), Remark Island (Sheltered: <10 m), Thomas Island (Exposed: 10-20+ m; Sheltered: <10-20+ m), and Woody Island (Exposed: 10-20 m).

Order Siphonocladales

Family Valoniaceae

Dictyosphaeria sericea Harvey 1855b: 565.

References: Womersley 1984: 223, pl. 13, figure 3, figure 74G-J; Fuhrer *et al.* 1981: 106, pl. 181.

Type locality: Rottnest Island, Western Australia

Distribution: Australia: Southern and south-west Australia.

Specimen: Black Island- Exposed: 10-20 m (UWARA-52).

Collection locations: Black Island (< 10-20 m), Long Island (Exposed: < 10 m and 20+ m), and Woody Island (Sheltered: 20+ m).

Struvea plumosa Sonder 1845: 50.

References: Kraft and Wynne 1996: 129; Womersley: 1984: 218, figure 73B-C.

Type locality: Western Australia.

Distribution: Australia: Houtman Abrolhos, Western Australia; around southern Australia to Encounter Bay, South Australia.

Specimen: Woody Island- Sheltered: 10-20 m, April (UWARA-172).

Collection locations: Figure of Eight Island (Sheltered: site 2- platform) and Woody Island (Sheltered: 10-20 m, April).

Division Heterokontophyta

Class Phaeophyceae (Brown Algae)

Order Cutleriales

Family Cutleriaceae

Cutleria multifida (Smith) Greville 1830: 60.

References: Womersley 1987: 260, figures 94A, 95.

Type locality: Yarmouth, England.

Distribution: Australia: Cockburn Sound, Western Australia, to Burraneer, Sydney, New South Wales; Tasmania.

Collection locations: Remark Island (Sheltered: <10 m).

Order Dictyotales

Family Dictyotaceae

Dictyota dichotoma (Hudson) Lamouroux 1809: 42.

References: Womersley 1987: 194, figures 64H-M, 65A-B.

Type locality: England; lecto*Type locality*: Port Phillip, Victoria, Australia.

Distribution: Aldabra Islands, Amirante Islands, Andaman Islands, Australia, Bangladesh, Burma, (Coco Group), Christmas Island, India, Indonesia, Kenya, Laccadive Islands, Madagascar, Malaysia, Maldives, Mauritius, Mozambique, Nicobar Islands, Pakistan, Réunion, Rodriguez Island, Seychelles (including Mahé Island), South Africa, Sri Lanka, Tanzania, Thailand, Yemen.

Specimen: Frederick Island- Exposed: 20+ m and Thomas Island- Exposed: <10 m (UWARA-43 and 44).

Collection locations: Frederick Island (Exposed: <10 m; Sheltered: 20+ m), Mondrain Island (Exposed: site 1- wall; Sheltered: site 2- wall), and Woody Island (Exposed: 20+ m).

Dictyota dichotoma (Hudson) Lamouroux *var.* ***intricata*** (C. Agardh) Greville 1830: 58.

References: Huisman 1997: 187; Womersley: 1987: 194-196, figure 65B.

Type locality: Cádiz, Spain.

Distribution: Australia, India, Kenya, Pakistan, Saudi Arabia, South Africa.

Australia: Venus Bay to Kangaroo Island, South Australia.

Specimen: Woody Island- Exposed: 20+ m (UWARA-36).

Collection locations: Woody Island (Exposed: 20+ m).

Notes: Range extension.

Dictyota fenestrata J. Agardh 1894: 73.

References: Womersley: 1987: 198, figures 65E, 66F-G.

Type locality: Port Phillip, Victoria.

Distribution: Australia: Port Phillip and Portland, Victoria, Tasmania.

Specimen: Remark Island- Sheltered: 10-20 m (UWARA-37).

Collection locations: Remark Island (Sheltered: 10-20 m).

Notes: Range extension.

Dictyota furcellata (C. Agardh) Greville 1830: xliii.

References: Womersley 1987: 194, figures 65C, 66A-C.

Type locality: Shark Bay, Western Australia.

Distribution: Australia, Mauritius.

Australia: Shark Bay, Western Australia, to Western Port, Victoria.

Specimen: Woody Island- Exposed: 20+ m (UWARA-24 and 36).

Collection locations: Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: sites 1and 2- platform), Frederick Island (Exposed: 10-20 m; Sheltered: <10-20+ m), Long Island (Exposed/Sheltered: <10 m), Mondrain Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- wall, and site 2- platform and wall), Remark Island (Sheltered: 10-20+ m), Thomas Island (Exposed: <10 m; Sheltered: 20+ m), and Woody Island (Exposed: <10-20+ m; Sheltered: 10-20 m).

Dictyota radicans Harvey 1855b: 536; 1859a: pl. 119.

References: de Clerck 1998: pl. 39A; Womersley 1987: 190, figures 63A, 64A-D.

Type locality: "New Holland"; Lecto*Type locality*: Rottnest Island, Western Australia.

Distribution: Australia: Rottnest Island, Western Australia, to Walkerville, Victoria.

Specimen: Remark Island- Sheltered: 10-20 m (UWARA-23, 49, and 245).

Collection locations: Black Island (Sheltered: 10-20+ m), Figure of Eight Island (Sheltered: sites1 and site 2- platform and wall), Frederick Island (Exposed: < 10 m; Sheltered: 10-20+ m), Mondrain Island (Exposed/Sheltered: site 2- platform and wall), Remark Island (Sheltered: 10-20 m), Thomas Island (Exposed: < 10 m; Sheltered: 10-20+ m), and Woody Island (Exposed/Sheltered: 10-20+ m).

Dictyopteris muelleri *(Sonder) Reinbold 1899: 43.*

References: Womersley 1987: 227, pl. 1, figures 78B, 79E-J; Fuhrer *et al.* 1981: 71, pls 112-113; Harvey 1860: pl. 180.

Type locality: Lefevre Peninsula, South Australia.

Distribution: Australia: North of Geraldton, Western Australia, to Port Jackson, New South Wales; Tasmania.

Specimen: Remark Island- Sheltered: 10-20 m (UWARA-35).

Collection locations: Figure of Eight Island (Exposed: site 1- platform and site 2-wall; Sheltered: sites 1 and 2- platform), Mondrain Island (Sheltered: site 1-platform), Remark Island (Sheltered: 10-20 m), Thomas Island (Exposed: <10 m; Sheltered: 20+ m), and Woody Island (Exposed: 20+ m).

Dictyopteris plagiogramma (Montagne) Vickers 1905: 58.

References: Phillips 2000: 282-323, figures 9A-K and 10A-F; Allender and Kraft 1983: 103-104, figures 17A-B; Huisman and Walker 1990: 375.

Type locality: La Habana, Cuba.

Distribution: Australia, Japan, Hawaiian Islands, Madagascar, New Zealand, and Seychelles.

Australia: Houtman Albrolhos to Albany, Western Australia; Lord Howe Island and Norfolk Islands.

Specimen: Thomas Island- Sheltered: 10-20 m (UWARA-30).

Collection locations: Frederick Island (Sheltered: <10 m), Long Island (Sheltered: 10-20 m), and Thomas Island (Sheltered: <10 m).

Notes: Range extension.

Dilophus fastigiatus *(Sonder) J. Agardh 1882: 107.*

References: Womersley 1987: 206-207, figures 70D-I; Phillips 1992: 666-671.

Type locality: Western Australia.

Distribution: Australia: Houtman Abrolhos Islands, Western Australia, to Wilson's Promontory, Victoria.

Specimen: Black Island- Sheltered: 10-20 m; Figure of Eight Island- Sheltered: site 1-platform; Thomas Island- Sheltered: 10-20 m (WARA-28, 46, 157, and 157).

Collection locations: Black Island (Exposed/Sheltered: 10-20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Exposed/Sheltered: 10-20 m), Mondrain Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: sites 1 and 2- platform and wall), Remark Island (Sheltered: 10-20 m), Thomas Island (Exposed/Sheltered: 10-20+ m), and Woody Island (Exposed: <10-20 m; Sheltered: <10-20+ m).

Dilophus marginatus *J. Agardh 1894: 91*

References: Phillips 1992: 657, figure 15B; Womersley 1987: 202, figures 67D, 68E-G; Allender and Kraft 1983: 118, figures 26F-H, 27; Womersley 1967: 212.

Type locality: Port Phillip, Victoria.

Distribution: Australia: Port Stanvac, South Australia around south-eastern Australia; Tasmania; Lord Howe Island.

Specimen: Black Island- Sheltered: 10-20 m, April (UWARA-158).

Collection locations: Black Island (Sheltered: 10-20 m; April).

Notes: Range extension.

Dilophus robustus *(J. Agardh) Womersley 1967: 213.*

References: Phillips 1992: 689-691, figures 19-21; Womersley 1987: 202, figures 67A, 68A-B.

Type locality: Port Phillip Heads, Victoria, Australia.

Distribution: Australia: Houtman Abrolhos Islands, Western Australia, to Port Phillip Heads, Victoria.

Specimen: Black Island- Exposed: 10-20 m (April 03); Remark Island- Sheltered: 10-20 m (UWARA-38 and 266).

Collection locations: Black Island (Exposed: 10-20 m; April 2003), Figure of Eight Island (Sheltered: site 1- platform), Frederick Island (Exposed: <10-20+ m; Sheltered: 10-20 m), Long Island (Exposed: <10 m; Sheltered: <10-20 m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and wall and site 2- wall), Remark Island (Exposed: <10-20 m; Sheltered: 10-20+ m), Thomas Island (Exposed: 10-20 m; Sheltered: <10 m), and Woody Island (20+ m).

Glossophora nigricans (J. Agardh) Womersley 1967: 214-215.

References: Womersley 1987: 199, figures 66H-K, 67A.

Type locality: Orford, Tasmania.

Distribution: Australia: Dongara, Western Australia to Walkerville, Victoria: Tasmania.

Specimen: Woody Island- Exposed: <10 m (UWARA-50 and 252).

Collection locations: Figure of Eight Island (Sheltered: site 2- wall), Frederick Island (Exposed: 10-20 m), Remark Island (Exposed: <10 m; Sheltered: 10-20 m), and Woody Island (Exposed: <10-20 m).

Lobospira bicuspidata Areschoug 1854: 364.

References: Womersley 1987: 214, figures 72K-L, 73A-B; Fuhrer *et al.* 1981: 69, pl. 109; Harvey 1858: pl. 34.

Type locality: Port Adelaide, South Australia.

Distribution: Australia: Nickol Bay, Western Australia, to Eden, New South Wales; Tasmania.

Specimen: Lion Island- Sheltered: 10 m (UWARA-276).

Collection locations: Black Island (Exposed: <10-20+ m; Sheltered: 20+ m), Figure of Eight Island (Exposed: site 2- platform and wall; Sheltered: sites 1 and 2- platform and wall), Frederick Island (Sheltered: 10-20 m), Long Island (Exposed/Sheltered: <10 m), Remark Island (Sheltered: 10-20 m), and Woody Island (Exposed: <10-20+ m; Sheltered: 20+ m).

Pachydictyon paniculatum (J. Agardh) J. Agardh 1894: 84.

References: Womersley 1987: 211, figures 71D, 72F-J; Fuhrer *et al.* 1981: 70, pl. 110.

Type locality: Picton [Bunbury], Western Australia.

Distribution: Australia: Geraldton and Abrolhos Islands, Western Australia, to Sydney, New South Wales; Tasmania.

Specimen: Frederick Island- Sheltered: <10 m (UWARA-31, 41, and 214).

Collection locations: Frederick Island (Sheltered: <10 m), Long Island (Sheltered: 10-20 m), Mondrain Island (Sheltered: site 2- wall), and Thomas Island (Sheltered: <10 m).

Family Scoresbyellaceae

Scoresbyella profunda Womersley 1987: 257-259.

References: Womersley 1987: 257-259, pl. 2, figure 2, figures 92B, 93.

Type locality: Egg Island, Isles of St Francis, South Australia.

Distribution: Australia: Rottnest Island, Western Australia, and Investigator Strait, Yorke Peninsula.

Specimen: Remark Island- Sheltered: 20+ m (UWARA-40).

Collection locations: Remark Island (Sheltered: 20+ m).

Notes: Range extension.

Family Zonarieae

Chlanidophora microphylla *(Harvey) J. Agardh 1894: 18, pl. 1 figs 3-5.*

References: Womersley 1987: 229, figures 80A, 81A-D; Levring 1940: 2, figure 1.

Type locality: Port Fairy, Victoria.

Distribution: Isles of St Francis, South Australia, to Inverloch, Victoria.

Specimen: Woody Island- Sheltered: <10 m, April (UWARA-178).

Collection locations: same locations as for *Distromium multifidum.*

Notes: Range extension.

Distromium flabellatum Womersley 1967: 218-220.

References: Womersley 1987: 230, figures 80B, 81E-I.

Type locality: Port Willunga, South Australia.

Distribution: Australia: Houtman Abrolhos Islands, Western Australia, to Port Phillip, Victoria.

Specimen: Frederick Island- Sheltered: 10-20 m (UWARA-27).

Collection locations: Black Island (Exposed/Sheltered: <10-20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Exposed: <10-20+ m; Sheltered: <10-20+ m), Long Island (Exposed: <10 m, 20+ m; Sheltered: <10-20+ m), Mondrain Island (Exposed: sites 1 and 2- platform; Sheltered: site 1- wall and site 2- platform and wall), Remark Island (Exposed: <10-20 m; Sheltered: <10-20+ m), Thomas Island (Exposed/Sheltered: <10-20+ m), and Woody Island (Exposed/Sheltered: <10-20+ m).

Distromium multifidum Womersley 1967: 220.

References: Womersley 1987: 232, figures 80C, 83A-D.

Type locality: Victor Harbor, South Australia.

Distribution: Australia: Hopetoun, West Austalia to Phillip Island, Victoria and Deal Island, Bass Straits.

Specimen: Black Island- Exposed: 10-20 m; Lion Island- Sheltered: 10-20 m (UWARA-22 and 272).

Collection locations: Black Island (Exposed/Sheltered: <10-20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 2- platform and wall), Frederick Island (Exposed: 10-20 m; Sheltered: <10-20+ m), Long Island (Sheltered: <10-20+ m), Mondrain Island (Exposed: site 1- platform; Sheltered: site 2- platform and wall), Thomas Island (Exposed/Sheltered: <10-20+ m), and Woody Island (Exposed/Sheltered: <10-20+ m).

Homoeostrichus sinclairii *(J. Hooker and Harvey) J. Agardh 1894: 15.*

References: Womersley 1987: 242, figures 85B, 86.

Type locality: Bay of Islands, New Zealand

Distribution: Australia: Head of the Great Australian Bight, South Australia to Newcastle, New South Wales; Bass Strait Islands.

Specimen: Woody Island- Exposed: 20+ m (UWARA-42).

Collection locations: Figure of Eight Island (Exposed: site 2- wall; Sheltered: site 2- platform), Frederick Island (Exposed/Sheltered: 10-20 m), Long Island (Sheltered: <10 m), Thomas Island (Exposed: 10-20 m), and Woody Island (Exposed: 20+ m).

Lobophora variegata (Lamouroux) Womersley *ex* Oliveira 1977: 221.

References: Womersley 1987: 255, figures 91F, G, 92A; Allender and Kraft 1983: 81, figures 4G-H, 5A-B.

Type locality: Antilles.

Distribution: South Africa, Australia. Tropical to temperate coasts in most seas. Australia: Western Australia to Aldinga, South Australia.

Specimen: Thomas Island- Sheltered: <10 m (UWARA-29).

Collection locations: Black Island (Exposed/Sheltered: 10-20+ m), Figure of Eight Island (Exposed: site 1- platform and wall; Sheltered: site 1- wall and site 2- platform and wall), Frederick Island (Exposed/Sheltered: <10-20 m), Long Island (Exposed: <10 m), Remark Island (Sheltered: 10-20 m), Thomas Island (Exposed: 20+ m, Sheltered: <10-20+ m), and Woody Island (Exposed: 10-20+ m, Sheltered: <10-20+ m).

Zonaria angustata *(Kützing) Papenfuss 1952: 170.*

References: Womersley 1987: 248, figures 88A, 89A-F; Womersley 1967: 224.

Type locality: Gulf St. Vincent, South Australia.

Distribution: Australia: Elliston, South Australia to Eden, New South Wales; Tasmania.

Specimen: Thomas Island- Sheltered: 10-20 m (UWARA-33).

Collection locations: Frederick Island (Sheltered: <10-20 m), Remark Island (Exposed: 10-20 m), Thomas Island (Sheltered: 10-20+ m), and Woody Island (Exposed: <10-20+ m).

Notes: Range extension.

Zonaria crenata J. Agardh 1873: 48-49.

References: Womersley 1987: 250, figures 88B, 89G-I; Womersley 1967: 226.

Type locality: Fremantle, Western Australia.

Distribution: Australia, India, Indonesia (Roti and Timor).

Australia: Fremantle, Western Australia to Southport, Queensland.

Specimen: Black Island- Exposed: 10-20 m (UWARA-25).

Collection locations: Black Island (Exposed/Sheltered: <10-20+ m), Figure of Eight Island (Exposed: site 1- platform and wall and site 2- wall; Sheltered: site 1- platform and site 2- wall), Frederick Island (Exposed: 10-20+ m; Sheltered: 20+ m), Long Island (Sheltered: <10-20+ m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Remark Island (Sheltered: <10-20 m), Thomas Island (Exposed: 10-20+; Sheltered: 10-20+ m), and Woody Island (Exposed: <10-20+ m; Sheltered: 10-20 m).

Zonaria spiralis (J. Agardh) Papenfuss 1944: 341.

References: Womersley 1987: 250, figures 90A, 91A-C, Fuhrer *et al.* 1981: 72, pl. 115.

Type locality: Eucla, Western Australia.

Distribution: Australia: Rottnest Island, Western Australia, to Flinders, Victoria.

Specimen: Black Island- Sheltered: 20+ m (UWARA-26 and 175).

Collection locations: Black Island (Exposed: 10-20 m; Sheltered: < 10 and 20+ m), Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Exposed/Sheltered: <10-20 m), Long Island (Sheltered: <10-20 m), Mondrain Island (Exposed/Sheltered: sites 1 and 2- platform and wall), Remark Island (Exposed: <10-20+ m, Sheltered: <10 m), Thomas Island (Exposed: <10-20+ m; Sheltered: 10-20 m), and Woody Island (Exposed: <10-20+ m, Sheltered: <10 m).

Zonaria turneriana J. Agardh 1870: 438.

References: Womersley 1987: 252, figures 90B, 91-E.

Type locality: Warrington, Otago, New Zealand.

Distribution: Australia: Houtman Abrolhos, Western Australia, to Port Phillip Heads, Victoria; New Zealand.

Specimen: Black Island- Sheltered: 10-20 m, April; Frederick Island- Exposed: 20+ m and Woody Island- Exposed: 20+ m (UWARA-32, 45, and 237).

Collection locations: Figure of Eight (Exposed/Sheltered: sites 1 and 2- platform and wall), Frederick Island (Exposed: <10-20+ m; Sheltered: <10-20 m), Long Island (Sheltered: 10-20 m), Mondrain Island (Exposed: site 2- platform and wall; Sheltered: site 1- platform and wall), Remark Island (Exposed: 20+ m), Thomas Island (Exposed: 10-20+ m; Sheltered: 20+ m), and Woody Island (Exposed: 20+ m).

Order Fucales

Family Cystoseiraceae

Acrocarpia robusta (J. Agardh) Womersley 1964: 99-100.

References: Womersley 1987: 364, figures 130B, 132E-G.

Type locality: Israelite Bay, Western Australia.

Distribution: Australia: Cape Naturaliste to Israelite Bay, Western Australia.

Specimen: Lion Island- Sheltered: 10 m (UWARA-281).

Collection locations: Black Island (Exposed: <10-20 m; Sheltered: <10 m), Figure of Eight (Exposed: sites 1- platform and site 2- wall), Frederick Island (Exposed: <10 m; Sheltered: 10-20 m), Long Island (Sheltered: <10 m), Lion Island (Sheltered: 10-20 m), Mondrain Island (Exposed/Sheltered: site 2- platform), Thomas Island (Exposed: <10-20 m; Sheltered: <10 and 20 m), and Woody Island (Exposed: <10-20 m; Sheltered: <10 m).

Caulocystis uvifera (C. Agardh) Areschoug 1854: 335.

References: Womersley 1987: 359, figure 129A; Fuhrer *et al.* 1981: 81, pl. 133; Womersley 1964: 101, figure 45, pl. 15.

Type locality: Shark Bay, Western Australia.

Distribution: Australia: Shark Bay, Western Australia, to Coogee (Sydney), New South Wales; Norfolk Island.

Specimen: Black Island- Sheltered: 10-20 m (UWARA-93 and 247).

Collection locations: Black Island (Sheltered: 10-20 m), Figure of Eight Island (Exposed/Sheltered: site 2- platform), Frederick Island (Sheltered: 10-20 m), Long Island (Sheltered: 10-20 m), Mondrain Island (Sheltered: site 2- platform); Thomas Island (Exposed: <10 m; Sheltered: 10-20 m), and Woody Island (Exposed: 10-20 m; Sheltered: 10-20+ m).

Cystophora brownii (Turner) J. Agardh 1848: 241.

References: Womersley 1964: 78, figure 18, pl. 6; 1987: 386, figures 142A, 145A.

Type locality: King George's Sound, Western Australia.

Distribution: Australia: Port Denison, Western Australia, to Kangaroo Island, Victor Harbour and Glenelg, South Australia; north-east Tasmania.

Specimen: Remark Island- Sheltered: <10 m (UWARA-78).

Collection locations: Black Island (Exposed: <10-20 m; Sheltered: <10 and 20+ m), Frederick Island (Sheltered: <10 m), Long Island (Sheltered: <10 m), Remark Island (Sheltered: <10 m), Thomas Island (Sheltered: <10 m), and Woody Island (Sheltered: <10 m).

Cystophora expansa (Areschoug) Womersley 1964: 77-78.

References: Womersley 1987: 382, figures 140A, 141D-F.

Type locality: Port Phillip, Victoria, Australia.

Distribution: Australia: Yallingup, West Australia, to Long Bay, New South Wales; Tasmania.

Collection locations: Black Island (Exposed: 10-20 m; Sheltered: <10 m), Frederick Island (Sheltered: <10 m), Long Island (Sheltered: <10 m), Remark Island (Sheltered: <10 m), Thomas Island (Exposed/Sheltered: <10 m), and Woody Island (Exposed/Sheltered: <10 m).

Cystophora gracilis Womersley 1964: 79.

References: Womersley 1987: 388, figures 142B, 145B-C.

Type locality: Vivonne Bay, Kangaroo Island, South Australia.

Distribution: Australia: Cowaramup Bay, West Australia, to Wanna, South Australia; Kangaroo Island, South Australia.

Specimen: Thomas Island- Exposed: <10 m (UWARA-76, 81, and 253).

Collection locations: Black Island (Exposed: <10 m), Frederick Island (Exposed/Sheltered: <10 m), Long Island (Sheltered: <10 m), Thomas Island (Exposed/Sheltered: <10 m), and Woody Island (Sheltered: <10 m).

Cystophora monilifera J. Agardh 1848: 241-242.

References: Womersley 1964: 74, figures 12-14, pl. 5, figure1; 1987: 382, figures 138B, 141A-C.

Type locality: Western Australia.

Distribution: Australia: Nickol Bay, Western Australia, to Long Bay, New South Wales; northern Tasmania.

Specimen: Woody Island- Sheltered: 20+ m (UWARA-79).

Collection locations: Black Island (Exposed: 10-20+ m; Sheltered: <10 and 20+ m), Figure of Eight Island (Exposed: sites 1 and 2- platform and site 2- wall; Sheltered: sites 1 and 2- platform and wall), Frederick Island (Exposed/Sheltered: 10-20 m), Long Island (Sheltered: <10-20+ m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: sites 1 and 2- platform and site 2- wall), Remark Island (Sheltered: 10-20 m), Thomas Island (Exposed: <10-20+ m; Sheltered: <10 m), and Woody Island (Exposed: <10 and 20+ m; Sheltered: <10-20+ m).

Cystophora pectinata (Greville and C. Agardh *ex* Sonder) J. Agardh 1848: 244-245.

References: Womersley 1987: 376, figures 135B, 139A-B; Womersley 1964: 81, figure 21, pl. 7.

Type locality: Southern Australia.

Distribution: Australia: Waterman Bay, Western Australia, to Gulf of St. Vincent and Kangaroo Island, South Australia; Walkerville, Victoria.

Specimen: Frederick Island- Exposed: 20+ m; Lion Island- Sheltered: 10 m (UWARA-75 and 283).

Collection locations: Black Island (Exposed: 20+ m), Figure of Eight Island (Sheltered: site 1- platform), Frederick Island (Exposed: <10-20+ m), Lion Island (Sheltered: 10 m), Long Island (Sheltered: 10-20 m), Mondrain Island (Sheltered: site 1- wall), Thomas Island (Exposed: <10-20 m; Sheltered: <10 m), and Woody Island (Exposed: <10 m).

Cystophora polycystidea *Areschoug* ex *J. Agardh 1848: 240.*

References: Womersley 1987: 380, figures 138A, 139G-H; Nizamuddin 1964: 42-63; Womersley 1964: 73, figures 10, 11 pl. 4, figure 2.

Type locality: Port Phillip, Victoria.

Distribution: Australia: Albany, Western Australia, to Long Bay, New South Wales; Tasmania.

Specimen: Woody Island- Sheltered: <10 m, April (UWARA-160 and 259).

Collection locations: Woody Island (Sheltered: <10 m, April).

Notes: Could be *C. gracilis*.

Cystophora racemosa (Harvey *ex* Kützing) J. Agardh 1870: 441-442.

References: Womersley 1987: 378, figures 137A, 139C-D; Womersley 1964: 83, figures 24-25, pl. 8.

Type locality: Cape Riche, Western Australia.

Distribution: Australia: Geographe Bay, Western Australia, to Kangaroo Island, South Australia; Queenscliff, Victoria.

Specimen: Lion Island- Sheltered: 10-20 m (UWARA-282).

Collection locations: Frederick Island (Exposed: <10-20 m), Long Island (Exposed: <10-20 m), Lion Island (Sheltered: 10-20 m), Mondrain Island (Exposed: site 2-

platform; Sheltered: site 1- wall), Remark Island (Exposed: <10-20+ m), and Thomas Island (Exposed: <10-20+ m).

Cystophora retorta (Mertens) J. Agardh 1848: 243.

References: Womersley 1987: 392, figures 144A, 145F-G; Nizamuddin 1964: 42-63; Womersley 1964: 92, figures 34, 35, pl. 11.

Type locality: "New Holland".

Distribution: Australia: Nickol Bay, Western Australia, to Wilsons Promontory, Victoria; Tasmania.

Specimen: Frederick Island- Exposed: <10 m; New Island- Sheltered: 10-20 m (UWARA-80 and 277).

Collection locations: Black Island (Exposed: <10 m), Frederick Island (Exposed: <10 m), and New Island (Sheltered: 10-20 m, Feb 2003).

Cystophora subfarcinata (Mertens) J. Agardh 1848: 240-241.

References: Womersley 1987: 400, figures 147B, 149E-G; Nizamuddin 1964: 42-63; Womersley 1964: 95, figures 38-40, pl. 13.

Type locality: Tasmania, Australia.

Distribution: Australia: Nickol Bay, Western Australia, to Wilsons Promontory, Victoria; Tasmania.

Specimen: Thomas Island- Exposed: <10 m (UWARA-77).

Collection locations: Black Island (Exposed: <10 m), Frederick Island (Exposed/Sheltered: <10 m), Long Island (Sheltered: <10 m), Remark Island (Sheltered: <10 m), Thomas Island (Exposed: <10 m), and Woody Island (Exposed/Sheltered: <10 m).

Myriodesma harveyanum *Nizamuddin and Womersley 1967: 377.*

References: Womersley 1987: 414, figures 153A-B.

Type locality: Kangaroo Island, South Australia.

Distribution: Australia: Isles of St. Francis to Kangaroo Island, South Australia.

Specimen: Thomas Island- Sheltered: 20+ m (UWARA-34).

Collection locations: Black Island (Sheltered: 20+ m), Long Island (Sheltered: 10-20 m), Mondrain Island (Sheltered: site 2- platform), Remark Island (Exposed: 10-20 m), and Thomas Island (Sheltered: 20+ m).
Notes: Range extension.

Myriodesma integrifolium Harvey 1859b: 286.
References: Womersley 1987: 412, figures 152, 155E; Nizamuddin and Womersley 1967: 376, figure 3, pl. 70A.
Type locality: Georgetown, Tasmania.
Distribution: Australia: Cottesloe, Western Australia, to Western Port, Victoria; northern Tasmania.
Specimen: Remark Island- Sheltered: 10-20 m (UWARA-47).
Collection locations: Black Island (Sheltered: 20+ m), Remark Island (Sheltered: 10-20+ m), Thomas Island (Sheltered: 20+ m), and Woody Island (Sheltered: 20+ m).

Platythalia quercifolia (R. Brown *ex* Turner) Sonder 1845: 51.
References: Womersley 1987: 404, figures 148B, 155A.
Type locality: King George's Sound, Western Australia *fide* Womersley, 1987: 404.
Distribution: Australia: Geraldton to the Recherche Archipelago, Western Australia.
Specimen: Remark Island- Exposed: 10-20 m (UWARA-39).
Collection locations: Figure of Eight Island (Sheltered: site 2- wall), Long Island (Exposed: <10 m), and Remark Island (Exposed: 10-20+ m).

Scaberia agardhii Greville 1830: 36.
References: Womersley 1987: 354, pl. 6, figure 3, pl. 7; Fuhrer *et al.* 1981: 87, pl. 144; Lucas 1936: 76, figure 44.
Type locality: Swan River Settlement, Western Australia *fide* Womersley, 1987: 404.
Distribution: Australia, South Africa.
Australia: Houtman Abrolhos Islands, Western Australia, to Bondi, New South Wales; northern Tasmania.
Specimen: Lion Island- Sheltered: 10 m (UWARA-279).
Collection locations: Black Island (Sheltered: <10-20+ m), Frederick Island (Sheltered: <10 m), Lion Island (Sheltered: 10 m), Mondrain Island (Sheltered: site 2- platform), and Thomas Island (Sheltered: 10-20+ m).

Family Sargassaceae

Sargassum decurrens (R. Brown *ex* Turner) C. Agardh 1820: 42.

References: Womersley 1954: 343, pl. 2, figure 1; 1987: 421, figures 157A, 160A; Harvey 1860: pl. 145.

Type locality: "North Shores of New Holland".

Distribution: Australia, Bahrain, Kuwait, New Caledonia, Qatar, Saudi Arabia. Australia: Rottnest Island, Western Australia, around northern Australia to Keppel Bay (Rockhampton) Queensland, with an isolated occurrence at Wallaroo, South Australia.

Specimen: Woody Island- Sheltered: 10-20 m (UWARA-85 and 257).

Collection locations: Woody Island (Sheltered: <10-20 m).

Notes: Range extension.

Sargassum distichum Sonder 1845: 51.

References: Womersley and Scott 1987: 444, figures 167, 168F.

Type locality: Western Australia.

Distribution: Australia: Houtman Abrolhos Islands, Western Australia, to Port Phillip, Victoria.

Specimen: Frederick Island- Sheltered: 10-20 m (UWARA-97).

Collection locations: Figure of Eight Island (Sheltered: site 2- wall and platform), Frederick Island (Sheltered: <10-20+ m), Mondrain Island (Sheltered: site 2- wall and platform), and Remark Island (Sheltered: 10-20+ m).

Notes: Could be *S. podacanthum*

Sargassum fallax Sonder 1845: 52.

References: Womersley 1987: 432, pl. 8, figure 4, 161B, 162A, 164C-E; J. Agardh 1889: 68, pl. 20, figures 1-7.

Type locality: Western Australia.

Distribution: Australia: Abrolhos Islands, Western Australia, to Ballina, New South Wales.

Specimen: Frederick Island- Exposed: 20+ m; Woody Island- Sheltered: 20+ m (UWARA-87, 98, and 99).

Collection locations: Black Island (Exposed: 20+ m), Frederick Island (Exposed: <10-20+ m), Long Island (Exposed: <10 m; Sheltered: 20+ m), Mondrain Island (Exposed: Exposed: sites 1 and 2- platform; Sheltered: sites 1 and 2 platform), Remark Island (Sheltered: 10-20+ m), Thomas Island (Exposed: <10 m; Sheltered: 20+ m), and Woody Island (Sheltered: 20+ m).

Sargassum heteromorphum J. Agardh 1873: 60.

References: Womersley 1987: 421, figures 157B, 160B.

Type locality: Georgetown, Tasmania.

Distribution: Australia: Rottnest Island, Western Australia, to San Remo, Victoria; northern Tasmania.

Specimen: Woody Island- Sheltered: 10-20 m (April) and 20+ m (UWARA-90 and 211).

Collection locations: Black Island (Exposed: 10-20 m; Sheltered: <10 m), Figure of Eight Island (Sheltered: site 2- platform), Frederick Island (Sheltered: <10-20+ m), Mondrain Island (Exposed: site 2- platform and wall), Long Island (Sheltered: <10-20 m), and Woody Island (Exposed: 20+ m; Sheltered: <10-20+ m).

Sargassum lacerifolium (Turner) C. Agardh 1820: 15.

References: Womersley 1987: 438, figures 163B, 168A.

Type locality: Port Dalrymple, Tasmania.

Distribution: Australia: Pearson Island, South Australia, to Pebbly Beach, New South Wales; Tasmania.

Specimen: Black Island- Exposed: <10 m, April 2003; Woody Island- Exposed: 20+ m; Sheltered: 20+ m (UWARA-82, 83 and 284).

Collection locations: Black Island (Exposed: <10 m, April 2003), Figure of Eight Island (Exposed: site 2- wall), Frederick Island (Sheltered: 20+ m), Long Island (Sheltered: 10-20+ m), Mondrain Island (Exposed: site 2- platform; Sheltered: site 1- platform), Remark Island (Sheltered: 20+ m), and Woody Island (Exposed: 20+ m).

Notes: Range extension.

Sargassum linearifolium (Turner) C. Agardh 1820: 24.

References: Womersley and Scott 1987: 440, figures 165, 168B; J. Agardh 1889: 45, pl. 14(III), figures 3-7; Kützing 1861: 11, pl. 18.

Type locality: "Western coast of New Holland".

Distribution: Australia, India, Mauritius.

Australia: Houtman Abrolhos, Western Australia, to Rockingham Bay, Queensland.

Specimen: Woody Island- Exposed: 20+ m (UWARA-88).

Collection locations: Black Island (Exposed: <10 m; Sheltered: <10 m and 20+ m), Frederick Island: (Sheltered: <10 m), Long Island (Exposed: <10 m), Mondrain Island (Exposed: site 1- wall/platform; Sheltered: site 2- platform), Remark Island (Sheltered: <10 m), Thomas Island (Exposed: <10 m; Sheltered: 10-20+ m), and Woody Island (Exposed: 20+ m).

Sargassum paradoxum *(R. Brown* ex *Turner) J. Hooker and Harvey 1847 [1847-1849]: 413.*

References: Womersley 1987: 430, figures 161A, 164A-B; Grunow 1915: 358; Harvey 1860: 282; Sonder 1855: 512; J. Agardh 1889: 68.

Type locality: Tasmania or Kent Islands, Bass Strait.

Distribution: Australia: Arno Bay, South Australia, to Westernport Bay, Victoria; Tasmania.

Collection locations: Black Island (Exposed: 10-20 m), Figure of Eight Island (Exposed/Sheltered: site 2- wall), and Mondrain Island (Sheltered: site 1- platform and site 2- platform and wall).

Sargassum podacanthum Sonder 1845: 51.

References: Womersley 1987: 444, figures 166B, 168E; Grunow 1915: 377; De Toni 1895: 97; J. Agardh 1848: 323.

Type locality: Western Australia.

Distribution: Australia: Point Peron, Western Australia, to Port Noarlunga, South Australia.

Specimen: Black Island- Sheltered: 10-20 m (UWARA-96).

Collection locations: Black Island (Sheltered: 10-20 m), Frederick Island (Sheltered: <10 m), Long Island (Sheltered: <10 and 20+ m), Remark Island (Sheltered: 10-20 m), Thomas Island (Sheltered: <10 m), and Woody Island (Sheltered: 20+ m).

Sargassum sonderi (J. Agardh) J. Agardh 1873: 59-60.

References: Womersley 1987: 424, figures 158B, 160D; Womersley 1954: 346, figure 1D, pl.3; Grunow 1915: 332.

Type locality: Western Australia.

Distribution: Australia: Cowaramup Bay, Western Australia, to Wilsons Promontory, Victoria; Tasmania.

Specimen: Remark Island- Sheltered: 20+ m and Thomas Island- Sheltered: <10 m (UWARA-91).

Collection locations: Long Island (Sheltered: <10 m), Remark Island (Sheltered: 20+ m), and Thomas Island (Sheltered: <10 m).

Sargassum spinuligerum Sonder 1845: 51.

References: Womersley and Scott 1987: 442, figures 166A, 168D; J. Agardh 1889: 117, pl. 31, figures 1-7.

Type locality: Western Australia.

Distribution: Australia: Houtman Abrohos, Western Australia, to Western Port, Victoria.

Specimen: Woody Island- Exposed: 20+ m (UWARA-89 and 246).

Collection locations: Black Island (Exposed: 20+ m; Sheltered: <10-20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Sheltered: <10-20+ m), Long Island (Exposed: <10 m; Sheltered: <10-20+ m), Mondrain Island (Exposed: site 2- platform and wall; Sheltered: sites 1 and 2: platform and wall), Remark Island (Sheltered: <10-20+ m), Thomas Island (Exposed: <10-20 m; Sheltered: <10-20+ m), and Woody Island (Exposed: <10 m; Sheltered: <10-20+ m).

Sargassum varians Sonder 1845: 51.

References: Womersley 1987: 426, figures 159A, 160E; Womersley 1954: 349, figure 1G-H, pl. 4, figure 2; J. Agardh 1889: 49, pl. 16, figures 1-8.

Type locality: Western Australia.

Distribution: Australia: Cottesloe, Western Australia, to Wilsons Promontory, Victoria; Tasmania.

Specimen: Woody Island- Sheltered: <10 m (UWARA-94).

Collection locations: Black Island (Exposed: 10-20+ m; Sheltered: <10-20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- wall; Sheltered: site 1-

platform), Frederick Island (Exposed: <10 m; Sheltered: <10-20+ m), Long Island (Sheltered: <10-20+ m), Mondrain Island (Exposed: site 1- platform and wall and site 2- platform; Sheltered: sites 1 and 2: platform and wall), Remark Island (Sheltered: <10-20+ m), Thomas Island (Exposed: 10-20 m; Sheltered: <10-20+ m), and Woody Island (Exposed: 10-20+; Sheltered: <10-20+ m).

Sargassum verruculosum C. Agardh 1820: 26.

References: Womersley 1987: 426, figures 159B, 160F; Womersley 1954: 350, figure 1I, J, pl. 5; Lindauer *et al.* 1961: 314, pl. 78, right: Grunow 1915: 336; J. Agardh 1889: 53, pl. 18, figures 1-6.

Type locality: Western Australia.

Distribution: Australia and New Zealand.

Australia: South-western Western Australia, to Maroubra, New South Wales; Tasmania.

Specimen: Black Island- Exposed: 20+ m and Lion Island- Sheltered: 10 m (UWARA-95 and 280).

Collection locations: Black Island (Exposed: 10-20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform), Frederick Island (Exposed: 10-20+ m; Sheltered: <10-20 m), Lion Island (Sheltered: 10 m), Long Island (Sheltered: <10-20 m), Mondrain Island (Exposed: site 2- platform and wall; Sheltered: site 1- platform), Remark Island (Sheltered: <10 and 20+ m), Thomas Island (Exposed: 10-20 m; Sheltered: <10 and 20+ m), and Woody Island (Exposed: <10-20+ m; Sheltered: <10 m).

Family Seirococcaceae

Scytothalia dorycarpa (Turner) Greville 1830: xxxiv.

References: Womersley 1987: 351, figures 126, 127I, Lucas 1936: 69, figure 42.

Type locality: King George's Sound, Western Australia

Distribution: Australia: Dongara, Western Australia, to Bondi, New South Wales; northern Tasmania.

Specimen: Lion Island- Sheltered: 9 m (UWARA-278).

Collection locations: Black Island (Exposed: 20+ m), Figure of Eight Island (Exposed: site 1- platform), Frederick Island (Exposed: 10-20+ m), Long Island (Exposed: 10-20+ m; Sheltered: 20+ m), Lion Island (Sheltered: 10 m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and wall), Remark Island (Exposed: <10-20+ m; Sheltered: 10-20 m), and Thomas Island (Exposed: 10-20+ m).

Order Lamniariales

Family Alariaceae

Ecklonia radiata (C. Agardh) J. Agardh 1848: 146.

References: Womersley 1987: 332, pl. 4, figure 2, 120, 121I-K; Fuhrer *et al.* 1981: 74, pls 118-119; Lucas 1936: 95, figure 52.

Type locality: Port Jackson, New South Wales.

Distribution: Australia, Madagascar, New Zealand, Oman, South Africa.

Australia: Kalbarri, Western Australia, to Caloundra, Queensland; Tasmania; Lord Howe Island.

Collection locations: Black Island (Exposed: 20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall), Frederick Island (Exposed: <10-20+ m), Long Island (Exposed: 10-20+ m; Sheltered: 20+ m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform), Remark Island (Exposed: <10-20+ m; Sheltered: <10 m), Thomas Island (Exposed: 10-20+ m), and Woody Island (Exposed: <10 m).

Order Scytosiphonales

Family Scytosiphonaceae

Colpomenia sinuosa (Mertens *ex* Roth) Derbès and Solier *in* Castagne 1851: 95.
References: Womersley 1987: 297, figures 107A, 108E-F; Fuhrer *et al.* 1981: 64, pl. 99.
Type locality: Cádiz, Spain.
Distribution: Andaman Islands, Australia, Bahrain, Bangladesh, India, Indonesia (Java and Sumba), Iran, Kenya, Kuwait, Laccadive Islands, Madagascar, Malaysia, Mauritius, Mozambique, Pakistan, Réunion, Rodriguez Island, Saudi Arabia, Seychelles (including Mahé Island), Singapore, Somalia, South Africa, Sri Lanka, Tanzania, Yemen. Australia: cosmopolitan.
Australia: Widespread.
Collection locations: Figure of Eight Island (Sheltered: site 2- platform), Long Island (Exposed: <10 m), Remark Island (Sheltered: <10 m), and Thomas Island (Exposed: <10 m).

Hydroclathrus clathratus (C. Agardh) Howe 1920: 590.
References: Womersley 1987: 300, figures 109A, 110A, B; Fuhrer *et al.* 1981: pl. 100.
Type locality: Uncertain
Distribution: Aldabra Islands, Andaman Islands, Australia, Bahrain, Bangladesh, Diego Garcia Atoll, India, Indonesia, Kenya, Kuwait, Laccadive Islands, Madagascar, Malaysia, Maldives, Mauritius, Mozambique, Nicobar, slands, Pakistan, Réunion, Rodriguez Island, Saudi Arabia, Seychelles, Singapore, Somalia, South Africa, Sri Lanka, Tanzania. Australia: Cosmopolitan.
Collection locations: Black Island (Exposed: <10), Figure of Eight Island, (Sheltered: site 1- wall, site 2- platform and wall), Long Island (Exposed: <10), and Thomas Island (Exposed: <10).

Order Sporochnales

Family Sporochnaceae

Encyothalia cliftonii Harvey 1859a: pl. 62.

References: Womersley 1987: 289, figures 104C, 105G-I; Lucas 1936: 99, figure 55.

Type locality: Fremantle, Western Australia.

Distribution: Australia: Kalbarri, Western Australia, to Guichen Bay, South Australia; Walkerville, Victoria.

Specimen: Long Island- Exposed: <10 m; Woody Island- Sheltered: 10-20 m; April (UWARA-48 and 236).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall and site 2- platform), Long Island (Exposed: <10 m; Sheltered: 10-20+ m), Mondrain Island, and Thomas Island (Exposed: <10 m).

Sporochnus comosus *C. Agardh 1824: 259.*

References: Womersley 1987: 280-282, figures 99D, 101F-J, 102A.

Type locality: "New Holland".

Distribution: Australia: Houtman Abrolhos, Western Australia, around southern Australia and Tasmania, to the Calliope River, Queensland.

Specimen: Woody Island- Sheltered: <10 m, April (UWARA-234).

Collection locations: Woody Island (Sheltered: <10-20 m; April).

Sporochnus radiciformis *(Turner) C. Agardh 1817: 12.*

References: Womersley 1987: 284, figures 102C, D, 103D-I; Fuhrer *et al.* 1981: 66, pl. 102; Harvey 1862: pl. 226 (as *S. scoparius).*

Type locality: "New Holland".

Distribution: Australia and Japan.

Australia: Rottnest Island, Western Australia, to Botany Bay, New South Wales.

Specimen: Figure of Eight Island- Sheltered: site 1- wall and Woody Island- Sheltered: 10-20 m, April (UWARA-189, 212, and 235).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall) and Woody Island (Sheltered: 10-20 m, April).

Division Rhodophyta (Red Algae)

Class Florideophyceae

Order Bonnemaisonales

Family Bonnemaisoniaceae

Asparagopsis armata *Harvey 1855b: 544.*

References: Lucas and Perrin 1947: 224, figure 107; Levring 1953: 528; Harvey 1862: pl. 192.

Type locality: Garden Island and King George's Sound, Western Australia.

Distribution: Australia, Burma, India, South Africa.

Australia: Yanchep, Western Australia, around southern Australia to Port Stephens, New South Wales; Tasmania.

Specimen: Mondrain Island- Sheltered: site 1- wall (UWARA-201).

Collection locations: Figure of Eight Island (Sheltered: site 2- platform), Mondrain Island (Sheltered: sites 1 and 2- platform and wall), and Thomas Island (Sheltered: <10 m).

Bonnemaisonia australis Levring 1953: 515.

References: Womersley 1996: 333-334, figure 149.

Type locality: Port Phillip Heads, Victoria.

Distribution: Whyalla to Brighton, South Australia; Port Phillip, Victoria; Low Head, Tasmania.

Specimen: Frederick Island- Sheltered: 20+ m (UWARA-268).

Collection locations: Frederick Island (Sheltered: 20+ m).

Notes: Range extension.

Delisea hypneoides Harvey 1859b: 305.

References: Womersley 1996: 340, fig 153; Lucas and Perrin 1947: 241, figure 103; Levring 1953: 520, figures 49-51.

Type locality: Georgetown, Tasmania.

Distribution: Australia: Point Peron, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Mondrain Island- Sheltered: site 2- wall (UWARA-208).

Collection locations: Figure of Eight Island (Exposed/Sheltered: site 2- wall), Frederick Island (Sheltered), and Mondrain Island (Sheltered: site 2- wall).

Delisea pulchra (Greville) Montagne 1844: 158.
References: Womerlsey 1996: 342, figure 154; Bonin and Hawkes 1988: 627, figures 29-31; Fuhrer *et al.* 1981: 39, pls 51, 42; Levring 1953: 521, figures 52-55B; Lucas and Perrin 1947: 241, figures 105-106; Harvey 1847 [1847-1849]: 89, figure 18, 1858: pl. 16.
Type locality: "New Holland".
Distribution: Australia: Rottnest Island, Western Australia, southern Australia; Kermadec Island, New Zealand; Macquarie Island; Antarctic Peninsula; South Georgia; Kerguelen Island; Heard Island.
Specimen: Remark Island- Exposed: 10-20 m (UWARA-71).
Collection locations: Black Island (Exposed: 20+ m), Figure of Eight Island (Exposed: site 1- wall; Sheltered: site 1- platform), Frederick Island (Exposed: <10-20+ m), Long Island (Sheltered: 20+ m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and site 2- wall), Remark Island (Exposed: <10-20+ m; Sheltered: 10-20 m), and Thomas Island (Exposed: 10-20 m).

Order Ceramiales

Family Ceramiaceae

Antithamnion armatum (J.Agardh) De Toni 1903: 1398.
References: Wollaston and Womersley *in* Womersley 1998: 104, figures 41D-F, 43D-G; Wollaston 1968: 290, figures 16, 18A-J.
Type locality: "New Holland".
Distribution: Australia: Rottnest Island, Western Australia, to Port Phillip Heads, Victoria; Renie, Trial Harbour; west coast of Tasmania.
Collection locations: Figure of Eight Island (Exposed: site 2- wall; Sheltered: sites 1 and 2- wall) and Mondrain Island (Sheltered: site 2- platform).

Antithamnion hanovioides (Sonder) De Toni 1903: 1398.

References: Wollaston and Womersley *in* Womersley 1998: 110, figure 45C-E, 46; Wollaston 1968: 295, figure 19.

Type locality: St. Vincent's Gulf, South Australia.

Distribution: Australia: Houtman Abrolhos, Western Australia to Wilson's Promontory, Victoria; Tasmania.

Collection locations: Figure of Eight Island (Exposed: site 1- platform) and Frederick Island (Exposed: <10 m).

Ceramium tasmanicum (Kützing) Womersley 1978: 226.

References: Womersley 1998: 400-402, figures 182E, 184.

Type locality: Tasmania.

Distribution: Australia: Western Australia, to Western Port, Victoria; Tasmania.

Specimen: Thomas Island- Sheltered: <10 m (UWARA-263).

Collection locations: Thomas Island (Sheltered: <10 m).

Dasyphila preissii *Sonder 1845: 53.*

References: Wollaston and Womersley *in* Womersley 1998: 68, figures 25A, 26; Wollaston 1977: 443, figures 1-16.

Type locality: Western Australia

Distribution: Australia: Houtman Abrolhos Islands, Western Australia, to Wilson's Promontory, Victoria; northern Tasmania.

Specimen: Figure of Eight Island- Sheltered: site 1- wall (UWARA-164).

Collection locations: Figure of Eight Island (Sheltered: sites 1 and 2- wall) and Mondrain Island (Sheltered: site 1- platform).

Euptilota articulata *(J. Agardh) Schmitz 1896: 7.*

References: Womersley 1998: 355, figures 141E, 164-465; Fuhrer *et al.* 1981: 54, pls 81, 82.1; Lucas and Perrin 1947: 338, figure 164.

Type locality: "New Holland".

Distribution: Australia, India, Japan.

Australia: Western Australia to Queensland.

Specimen: Lion Island- Sheltered: 10m; Mondrain Island- Exposed (UWARA-186 and 271).

Collection locations: Lion Island (Sheltered: 10 m) and Mondrain Island (Exposed).

Griffithsia teges Harvey 1855b: 559.

References: Baldock *in* Womersley 1998: 322, figures 151A-B, 152A-D. Baldock 1976: 541, figures 40-43, 83, 85.

Type locality: Fremantle, Western Australia.

Distribution: Australia: Fremantle, Western Australia, to Wilson's Promontory, Victoria.

Specimen: Remark Island- Exposed: <10 m (UWARA-61).

Collection locations: Mondrain Island (Exposed: site 1- platform), Remark Island (Exposed: <10 m), and Woody Island (Sheltered: 20+ m).

Haloplegma preissii (Harvey) Montagne 1845: 149.

References: Womersley and Wollatson *in* Womersley 1998: 284, figures 134, 141D; Fuhrer *et al.* 1981: 51, pl. 75; Lucas and Perrin 1947: 336, figure 163; Harvey 1859a: pl. 79.

Type locality: Swan River Colony [Perth], Western Australia.

Distribution: Australia: Western and southern coasts of Australia; Tasmania.

Specimen: Thomas Island- Sheltered: 20+ m (UWARA-141).

Collection locations: Black Island (Sheltered: 20+ m), Mondrain Island (Exposed: site 2- wall; Sheltered: site 2- platform), Remark Island (Exposed: 10-20 m), and Thomas Island (Sheltered: 20+ m).

Hirsutithallia mucronata *Wollaston and Womersley* in *Womersley 1998: 253*

References: Womersley and Wollatson *in* Womersley 1998: 253, figures 118, 121A-D.

Type locality: Kangaroo Island, South Australia.

Distribution: Australia: Elliston, South Australia, to Inverloch, Victoria; Tasmania.

Specimen: Long Island- Exposed: <10 m (UWARA-64).

Collection locations: Long Island (Exposed: <10 m).

Notes: Range extension.

Ptilocladia australis (Harvey) Wollaston 1968: 265.

References: Wollaston and Womersley *in* Womersley 1998: 61, figures 20A, 22A-F; Huisman *et al.* 1990: 96; Kendrick *et al.* 1988: 204.

Type locality: King George's Sound, Western Australia.

Distribution: Australia: Shark Bay, Western Australia, to Walkerville, Victoria.

Collection locations: Figure of Eight Island (Sheltered: site 1- wall).

Ptilocladia pulchra Sonder 1845: 53.

References: Wollaston and Womersley *in* Womersley 1998: 57, figure 18C, 21A-C; Silva *et al.* 1996: 422.

Type locality: "New Holland".

Distribution: Australia: Fremantle, Western Australia, to Queencliff, Victoria; Tasmania.

Specimen: Thomas Island- Exposed: <10 m (UWARA-105).

Collection locations: Figure of Eight Island (Exposed: site 1- platform; Sheltered: sites 1 and 2- platform), Frederick Island (Exposed: <10 m; Sheltered: 10-20+ m), Long Island (Exposed: <10 m), and Thomas Island (Exposed: <10 m).

Ptilocladia vestita (Harvey) Wollaston 1968: 263.

References: Wollaston and Womersley *in* Womersley 1998: 60, figs 18D-F, 21F-I; Kendrick *et al.* 1988: 52.

Type locality: Rottnest Island, Western Australia.

Distribution: Australia: Exmouth, Western Australia, to Glenelg River mouth, Victoria; Tasmania.

Specimen: Woody Island- Sheltered: 10-20, April (UWARA-168 and 190).

Collection locations: Woody Island (Sheltered: 10-20 m, April).

Spyridia dasyoides Sonder 1853: 680-681.

References: Womersley 1998: 379, figures 173J-K

Type locality: Holdfast Bay [Gulf St. Vincent], South Australia.

Distribution: Australia: Widespread.

Specimen: Woody Island- Exposed: 20+ m (UWARA-111 and 117).

Collection locations: Black Island (Exposed: 20+ m; Sheltered: 10-20+ m), Figure of Eight Island (Exposed: site 2- wall; Sheltered: site 1- platform), Frederick Island

(Exposed: 10-20+; Sheltered: 10-20 m), Long Island (Sheltered: 10-20 m), Mondrain Island (Exposed: sites 1 and 2- platform; Sheltered: sites 1 and 2- platform and wall), Remark Island (Exposed: 10-20 m; Sheltered: 20+ m), Thomas Island (Exposed: 10-20+ m), and Woody Island (Exposed: <10-20+ m; Sheltered: 20+ m).

Wollastoniella myriophylloides (Harvey) E. Gordon 1972: 91.
References: Womersley 1998: 81, figures 30B. 31E-F, 32; Harvey 1862: pl. 224.
Type locality: Rottnest Island, Western Australia.
Distribution: Australia: Port Denison, Western Australia, to Port Phillip Bay, Victoria.
Specimen: Woody Island- Sheltered: 10-20 m, April (UWARA-112, 163, and 173).
Collection locations: Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: sites 1 and 2- platform), Mondrain Island (Sheltered: site 1- platform), and Thomas Island (Sheltered: 10-20+ m).

Wrangelia plumosa Harvey 1844b: 450.
References: Womersley 1998: 27, figures 5A-B, 6; Gordon 1972: 21, figures 4-5, 10G, H, J, 51.
Type locality: Georgetown, Tasmania.
Distribution: Australia: Houtman Abrolhos, Western Australia, to Port Stephens, New South Wales.
Specimen: Long Island- Exposed: <10 m (UWARA-68).
Collection locations: Long Island (Exposed: <10 m).

Family Dasyaceae

***Dasya* spp.**
Notes: Unreproductive *Specimen*s characterized by vegetative traits.

Dasya baldockii Parsons and Womersley *in* Womersley 1998: 436.
References: Parsons and Womersley *in* Womersley 1998: 436, figure 198.
Type locality: Althorpe Island, South Australia.
Distribution: Australia: Rottnest Island, Western Australia, to West Island, South Australia.

Specimen: Long Island- Exposed: <10 m (UWARA-68).

Collection locations: Long Island (Exposed: <10 m; Sheltered: 20+ m).

f. **Dasya clavigera** *(Womersley) Parsons 1975: 585, figs 7-9A-B, 40B.*

References*:* *Parsons and Womersley* in *Womersley 1998: 459, figures 209-210; Shepherd and Womersley 1976: 190.*

Type locality: Kangaroo Island, South Australia.

Distribution: Australia: Hopetoun, Western Australia, to Westernport Bay, Victoria; Tasmania.

Specimen: Woody Island- Sheltered: 10-20 m, April (UWARA-169).

Collection locations: Woody Island (Sheltered: 10-20 m, April).

f. ***Dasya cliftonii*** Harvey 1855b: 542.

References: Parsons and Womersley *in* Womersley 1998: 448, figure 204; Lucas and Perrin 1947: 312, figure 149; Harvey 1858, pl. 3.

Type locality: Fremantle Harbour, Western Australia.

Distribution: Australia: Western and southern Australia.

Specimen: Long Island- Exposed: <10 m and Thomas Island- Sheltered: <10 m (UWARA-68 and 137).

Collection locations: Long Island (Exposed: <10 m) and Thomas Island (Sheltered: <10 m).

f. ***Dasya kraftii*** Parsons and Womersley 1998: 433-436.

References: Parsons and Womersley *in* Womersley 1998: 433-436.

Type locality: Third Beach, Esperance, Western Australia.

Distribution: Australia: Rottnest Island, Western Australia, to Cape Thomas, South Australia; Montagu, Tasmania.

> *Specimen*: Third Beach, Esperance (Parsons, 21.xi.1968; AD A33349; isotype CHR, 315367).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall) and Mondrain Island (Exposed: site 2- wall).

f. ***Dasya scopulifera*** Harvey 1863: pl. xxiv.

References: Parsons and Womersley *in* Womersley 1998: 446, figure 203; Lucas 1912: 157.

Type locality: Bunbury, Western Australia.

Distribution: Australia: Port Denison to Bunbury, Western Australia.

Specimen: Woody Island- Exposed: 20+ m (UWARA-136).

Collection locations: Woody Island (Exposed: 20+ m).

Notes: Range extension.

Dasya villosa Harvey 1844b: 433.

References: Parsons and Womersley *in* Womersley 1998: 427, figure 194; Lucas and Perrin 1947: 312.

Type locality: Georgetown, Tasmania.

Distribution: Australia: Esperance, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Esperance (Firman, Dec. 1951; AD, A18891).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall) and Long Island (Exposed: <10 m).

Heterosiphonia gunniana (Harvey) Reinbold 1899: 49.

References: Parsons and Womersley *in* Womersley 1998: 496, figures 228-229.

Type locality: Georgetown, Tasmania.

Distribution: Australia: Fremantle, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Woody Island- Exposed: 20+ m (UWARA-128).

Collection locations: Frederick Island (Exposed- 10-20 m), Remark Island (Sheltered: 20+ m), and Woody Island (Exposed: 20+ m).

Heterosiphonia muelleri (Sonder) De Toni 1903: 1237.

References: Parsons and Womersley *in* Womersley 1998: 465, figures 212-213; Lucas and Perrin 1947: 313.

Type locality: Georgetown, Tasmania.

Distribution: Australia, Sri Lanka.

Australia: Albany, Western Australia, to Kiama, New South Wales; Tasmania.

Specimen: Mondrain Island- Sheltered: site 1- platform (UWARA-165).

Collection locations: Mondrain Island (Sheltered: site 1- platform).

Thuretia quercifolia Decaisne 1844: 236

References: Parsons and Womersley *in* Womersley 1998: 502, figures 231-233A-B; De Toni 1903: 1175.

Type locality: Australia.

Distribution: Australia: Dongara, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Black Island- Sheltered: 10-20 m, April (UWARA-159).

Collection locations: Black Island (Sheltered: 10-20 m; April).

Family Delesseriaceae

Apoglossum spathulatum (Sonder) Womersley and Shepley 1982: 329.

References: Womersley 2003: 37, figures 6E, 12-13; Huisman and Walker 1990: 429.

Type locality: Georgetown, Tasmania.

Distribution: Australia, Indonesia, India, and South Africa.

Australia: Rottnest Island, Western Australia, to Gabo Island, Victoria; Tasmania; Lord Howe Island.

Collection locations: Remark and Thomas Islands (Exposed- >20 m).

Claudea elegans Lamouroux 1813: 122.

References: Womersley 2003: 16, figures 1,2, 6A-B; Norris 1987: 311, figures 1-6; Harvey 1844a: 408, pl. xx.

Type locality: "New Holland"

Distribution: Australia, India, Malaysia, Pakistan, South Africa.

Australia: Houtman Abrolhos, Western Australia; southern Australia.

Specimen: Black Island- Sheltered: 20+ m (UWARA-70).

Collection locations: Black Island (Sheltered: 20+ m) and Woody Island (Sheltered: 10-20 m).

Hypoglossum dendroides (Harvey) J. Agardh 1898: 186.

References: Womersley 2003: 56, figures 16G-H and 21; Huisman and Walker 1990: 430.

Type locality: Fremantle, Western Australia.

Distribution: Fremantle and Rottnest Island, Western Australia, to Point Avoid, Eyre Peninsula, South Australia.

Collection locations: Black Island (Sheltered: >20 m).

Hypoglossum revolutum (Harvey) J. Agardh 1898: 188.

References: Womersley 2003: 43, figures 14 and 16A; Huisman and Walker 1990: 430.

Type locality: King George's Sound, Western Australia.

Distribution: Houtman Abrolhos, Western Australia, to Portland Bay, Victoria.

Collection locations: Figure of Eight Island (Sheltered: site 1- wall).

Martensia australis *Harvey 1855b: 537.*

References: Womersley 2003: 95, figures 42-43; Millar 1990: 416-417, figures 52A-C.

Type locality: King George's Sound, Western Australia.

Distribution: Australia: Western, southern, and eastern Australia.

Specimen: Figure of Eight Island- Sheltered: site 1- wall (UWARA-166).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall) and Mondrain Island (Sheltered: site 1- platform).

Family Rhodomelaceae

Acanthophora dendroides Harvey 1855b: 538.

References: Womersley 2003: 409, figures 177 A-B; Kraft 1979: Figure 7.

Type locality: Rottnest Island, Western Australia.

Distribution: Aldabra Islands, Andaman Islands, Australia, Bahrain, Bangladesh, Burma (Boronga).

Australia: Western Australia; Queensland; New South Wales.

Specimen: Figure of Eight Island- Sheltered: site 1- platform; Woody Island: Exposed- 10-20 m (UWARA-198).

Collection locations: Figure of Eight Island (Sheltered: site 1- platform).

Amansia pinnatifida *Harvey 1862: pl. 222.*

References: Womersley 2003: 392, figure 170B-I.

Type locality: King George's Sound, Western Australia.

Distribution: Australia: King George's Sound, Western Australia, to Robe, South Australia.

Specimen: Thomas Island- Sheltered: 20+ m (UWARA-260).

Collection locations: Thomas Island (Sheltered: 20+ m).

Amansia serrata (Harvey) Womersley 2003: 394.

References: Womersley 2003: 394, figure 171.

Type locality: Rottnest Island, Western Australia.

Distribution: Australia: Western and southern Australia.

Specimen: Remark Island- Sheltered: 10-20 m (UWARA-116).

Collection locations: Black Island (Sheltered: 20+ m), Thomas Island (Sheltered: 10-20+ m), and Woody Island (Exposed: 20+ m).

Brongniartella australis (C. Agardh) Schmitz 1893: 218.

References: Womersley 2003: Figure 100; Adams 1994: 311, pl. 104; De Toni 1903: 1010.

Type locality: "New Holland".

Distribution: Australia: Whitfords Beach, Western Australia, to Bemm Reef, Victoria; Tasmania.

Collection locations: Lion Island (settlement plates- 10-20 m).

Chiracanthia arborea (Harvey) Falkenberg *in* Schmitz and Falkenberg 1897: 441.

References: Womersley 2003: 233, figure 99; Lucas and Perrin 1947: 277.

Type locality: Georgetown, Tasmania.

Distribution: Australia: Geographe Bay, Western Australia, to Port Phillip, Victoria; Tasmania.

Specimen: Thomas Island- Sheltered: 20+ m (UWARA-261).

Collection locations: Thomas Island (Sheltered: 20+ m).

Cladurus elatus *(Sonder) Falkenberg* in *Schmitz and Falkenberg 1897: 435.*

References: Womersley 2003: 419, figure 182.

Type locality: Lefevre Peninsula, South Australia.

Distribution: Australia: Cliff Head, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Mondrain Island- Sheltered: site 2- platform (UWARA-161 and 215).

Collection locations: Black Island (Sheltered: 10-20+ m), Frederick Island (Sheltered: 20+ m), Mondrain Island (Sheltered: site 2- platform), Remark Island (Sheltered: 10-20+ m), Thomas Island (Exposed: <10 m; Sheltered: <10-20+ m), and Woody Island (Exposed: 10-20+ m; Sheltered: 10-20+ m).

Cliftonaea pectinata Harvey 1859a: pl. 100.

References: Womersley 2003: 325, figures 142-143; Lucas and Perrin 1947: 289, figure 135.

Type locality: Garden Island, Western Australia.

Distribution: Australia: Western Australia.

Specimen: Black Island- Sheltered: 20+ m (UWARA-69).

Collection locations: Black Island (Sheltered: 20+), Frederick Island (Sheltered: 20+), Long Island (Sheltered: 10-20+ m), Mondrain Island (Sheltered: site 2- wall), and Remark Island (Sheltered: 10-20+ m).

Coeloclonium verticillatum (Harvey) J. Agardh 1876: 640.

References: Womersley 2003: 415, figure 181.

Type locality: Garden Island, Western Australia.

Distribution: Australia: Rottnest Island, Western Australia, to Port Phillip Heads, Victoria; Tasmania.

Specimen: Figure of Eight Island- Sheltered: site 2- platform (UWARA-199).

Collection locations: Figure of Eight Island (Sheltered: site 2- platform).

Echinosporangium semipennatum ***(Lamouroux*** ex ***Poiret) Kylin 1956: 537.***

References: Womersley 2003: 329, figures 144-145.

Type locality: "New Holland".

Distribution: Eyre, Western Australia, to Port Elliot, South Australia.

Specimen: Remark Island- Sheltered: 20+ m (UWARA-144).

Collection locations: Remark Island (Sheltered: 20+ m).

Dictyomenia harveyana Sonder 1853: 698.

References: Womersley 2003: 349, figure 152; Lucas and Perrin 1947: 282, figure 129; De Toni 1903: 983.

Type locality: "New Holland".

Distribution: Australia: Houtman Albrolhos, Western Australia, to San Remo, Victoria; Bass Strait; Twofold Bay, New South Wales.

Collection locations: Thomas Island (Sheltered: 20+ m).

Dictyomenia sonderi Harvey 1858: pl. 21.

References: Womersley 2003: 347, figure 151A-G; Lucas and Perrin 1947: 280, figure 127; Falkenberg 1901: 285, pl. 19, figures 13-16.

Type locality: Garden Island, Western Australia.

Distribution: Australia: North of Dongara, Western Australia, to Backstairs Passage, South Australia.

Collection locations: Thomas Island (Sheltered: 10-20+ m).

Doxodasya bolbochaete *(Harvey) Falkenberg 1901: 538.*

References: Womersley 2003: 264, figures 113, 114A-B, 115; Parsons 1975: 659, figures 30-31, 46A.

Type locality: Georgetown, Tasmania.

Distribution: Australia: Houtman Abrolhos Islands, Western Australia, to Western Port, Victoria; northern Tasmania.

Collection locations: Long Island (Sheltered: 10-20 m).

Doxodasya lenormandiana (J. Agardh) Schmitz 1893: 220.

References: Womersley 2003: 270, figure 117; May 1965: 378; De Toni 1903: 1022.

Type locality: Glenelg River mouth, Victoria.

Distribution: Australia: Seal Bay, Kangaroo Island, to Glenelg River mouth, Victoria.

Specimen: Black Island- Sheltered: 20+ m (UWARA-238).

Collection locations: Black Island (sheltered: 20+ m).

Notes: Range extension.

Echinothamnion hystrix (J. Hooker and Harvey) Kylin 1956: 506.

References: Womersley, 2003: 222: Figure 94; Huisman 2000: 165; Silva *et al.* 1996: 492; Shepherd and Womersley: 1981: 367.

Type locality: Georgetown, Tasmania.

Distribution: Australia: Nichol Bay, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Black Island- Sheltered: 10-20 m, April 2003 (UWARA-264).

Collection locations: Black Island (Sheltered: 10-20+ m, April 2003: 10-20 m).

Herposiphoniella plurisegmenta *Womersley 2003: 299*

References: Womersley 2003: 299, figure 131.

Type locality: Althorpe Island, South Australia.

Distribution: Fremantle, Western Australia, to Cape Northumberland, South Australia.

Specimen: Mondrain Island- Exposed: 10-20 m, wall (UWARA-269).

Collection locations: Mondrain Island (Exposed: site 2- wall).

Notes: First record of a reproductive *Specimen* (tetrasporic).

Kuetzingia canaliculata (Greville) Sonder 1845: 54.

References: Womersley 2003: 378, figure 1632; Silva *et al.* 1996: 503; Harvey 1847 [1847-1849]: 23, pl. 9, figure 15.

Type locality: Swan River Settlement, Western Australia.

Distribution: Australia: Western Australia.

Specimen: Black Island- Sheltered: 20+ m (UWARA-142).

Collection locations: Black Island (Sheltered: 20+ m), Mondrain Island (Exposed: site 2- platform), Remark Island (Exposed: <10 m), Thomas Island (Exposed: 20+ m), and Woody Island (Sheltered: 20+ m).

Laurencia arbuscula Sonder 1845: 55.

References: Womersley 2003: 466, figures 205F, 208; Saito and Womersley 1974: 828, figures 3A, 11-12.

Type locality: Western Australia.

Distribution: Australia: Rottnest Island, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Thomas Island- Exposed: <10 m and Sheltered: 10-20 m (UWARA 133 and 135).

Collection locations: Thomas Island (Exposed: <10, Sheltered: 10-20 m).

Laurencia brongniartii J. Agardh 1841: 20-21.

References: Womersley 2003: 477, figures 214G, 215; Saito and Womersley 1974: 839, figures 4C, D, 20-21.

Type locality: Martinique, West Indies.

Distribution: Australia, Indonesia (Flores), Japan, Madagascar, New Caledonia, South Africa, Sri Lanka, West Indies.

Australia: Point Peron, Western Australia, around northern Australia to Mossy Point and Lord Howe Island, New South Wales; isolated records in South Australia.

Specimen: Mondrain Island- Sheltered: site 1- platform (UWARA-203).

Collection locations: Black Island (Exposed: <10-20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform), Frederick Island (Exposed: <10-20 m; Sheltered: <10-20+ m), Long Island (Sheltered: <10-20+ m), Mondrain Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform and wall and site 2- wall), Remark Island (Exposed: <10-20+ m; Sheltered: <10-20 m), Thomas Island (Exposed: <10-20+ m), and Woody Island (Exposed: <10-20+ m; Sheltered: <10 m).

Laurencia clavata Sonder 1853: 694-695.

References: Womersley 2003: 462, figures 205D, 206; Saito and Womersley 1974: 825, figures 2A-B, 9.

Type locality: Lefevre Peninsula, South Australia.

Distribution: Australia: Port Denison, Western Australia, to Phillip Island, Victoria.

Collection locations: Black Island (Exposed: <10-20 m; Sheltered: <10-20+ m), Figure of Eight Island (Exposed: site 2- wall; Sheltered: site 1- platform), Frederick Island (Sheltered: 20+ m), Long Island (Sheltered: <10 and 20+ m), Mondrain Island (Sheltered: site 1- platform and site 2- platform and wall), Remark Island (Exposed: <10-20 m), Thomas Island (Exposed/Sheltered: <10-20+ m), and Woody Island (Exposed/Sheltered: <10-20+ m).

Laurencia elata (C. Agardh) J. Hooker and Harvey 1847[1847-1849]: 401.

References: Womersley 2003: 475, figures 213, 214E; Saito and Womersley 1974: 837, figures 3E, 18-19; Fuhrer *et al.* 1981: 56, pl. 85; Lucas and Perrin 1947: 249, figure 110.

Type locality: King Island, Bass Strait, Australia.

Distribution: Australia, New Zealand, South Africa, Tanzania, Yemen.

Australia: Port Denison, Western Australia, to Mossy Point, New South Wales; Tasmania.

Specimen: Thomas Island- Exposed: 20+ m (UWARA- 143).

Collection locations: Black Island (Exposed: <10-20+ m; Sheltered: <10 m), Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1: platform and wall), Frederick Island (Exposed: <10 and 20+ m), Long Island (Exposed: <10 and 20+ m; Sheltered: 20+ m), Remark Island (Exposed: <10 and 20+ m; Sheltered: < 10 m), Thomas Island (Exposed: <10 and 20+ m; Sheltered: <10 m), and Woody Island (Exposed: 20+ m; Sheltered: <10 m).

Laurencia filiformis (C. Agardh) Montagne 1845: 125.

References: Womersley 2003: 469, figures 201-211, 214B-C; Fuhrer *et al.* 1981: 57, pl. 87; Saito and Womersley 1974: 832, figures 3C-D, 14-16.

Type locality: Western Australia.

Distribution: Australia, Indonesia (Java and Sumatra), New Zealand, Pakistan, Sri Lanka.

Australia: Houtman Abrolhos, Western Australia, to Tilba, New South Wales; Tasmania.

Specimen: Figure of Eight Island- Sheltered: site 1- wall; Mondrain Island- Sheltered: site 1- platform; Woody Island- Sheltered: 10-20 m, April (UWARA-134, 149, 154, 204, and 219).

Collection locations: Black/Remark/Thomas/Woody Islands (Exposed/Sheltered: <10-20+ m), Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: sites 1 and 2- platform), Frederick Island (Exposed: <10-20 m; Sheltered: <10-20+ m), Long Island (Exposed: <10; Sheltered: <10-20 m), and Mondrain Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall).

Notes: Dendritic forms present.

Laurencia majuscula (Harvey) Lucas 1935: 223.

References: Womersley 2003: 457, figures 202, 205A; Saito and Womersley 1974: 819, figures 1A, 6.

Type locality: Rottnest Island, Western Australia.

Distribution: Australia, India, Indonesia (Sumba), Iran, Kenya, Maldives, Seychelles (Mahé Island), Sri Lanka.

Australia: Widespread.

Specimen: Long Island- Exposed: <10 m (UWARA-60).

Collection locations: Black Island (Exposed: 10-20 m; Sheltered: <10 m); Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: sites 1 and 2- platform and wall), Frederick Island (Exposed: 10-20 m; Sheltered: <10-20+ m), Long Island (Exposed: <10 m; Sheltered: <10-20+ m), Mondrain Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: sites 1 and 2- platform), Remark Island (Exposed: <10 m; Sheltered: <10-20 m), Thomas Island (Exposed: 10-20+ m; Sheltered: <10-20 m), and Woody Island (Exposed: <10-20 m).

Lenormandia latifolia Harvey and Greville *in* Harvey 1847 [1847-1849]: 19.
References: Womersley 2003: 389, figure 169.
Type locality: Swan River Colony [Perth], Western Australia.
Distribution: Australia: Yanchep, Western Australia, to Cape Northumberland, South Australia.
Specimen: Thomas Island- Sheltered: 20+ m (UWARA-63).
Collection locations: Thomas Island (Sheltered: 20+ m) and Woody Island (Exposed: 20+ m).

Lophothalieae Schmitz and Falkenberg 1897: 445.
Specimen: Figure of Eight Island- Sheltered: site 1- wall (UWARA-195).
Collection locations: Figure of Eight Island (Sheltered: site 1- wall).
Notes: *Specimen* undescribed, but most likely in this tribe (pers. comm., Womersley).

Osmundaria prolifera Lamouroux 1813: 23.
References: Womersley 2003: 404, figure 176; Silva *et al.* 1996: 532; Norris 1991a; Lucas and Perrin 1947: 299, figure. 141.
Type locality: Western Australia.
Distribution: Australia: Rottnest Island and southwestern Australia to Kangaroo Island, South Australia.
Specimen: Woody Island- Sheltered: <10 m, April 2003 (UWARA-273).
Collection locations: Black Island (Exposed/Sheltered: 10-20+ m), Figure of Eight Island (Exposed: site 1- platform), Frederick Island (Sheltered: 10-20+ m), Long Island ((Sheltered: 10-20+ m), Mondrain Island (Exposed: site 2- platform and wall; Sheltered: site 2- platform), Remark Island (Sheltered: 10-20+ m), Thomas Island

(Exposed: 20+ m; Sheltered: 10-20+ m), and Woody Island (Exposed/Sheltered: <10-20+ m).

Pollexfenia pedicellata *(Harvey) Papenfuss 1942: 448.*

References: Womersley 2003: 352, figure 153; Fuhrer *et al.* 1981: 31, pl. 35 (as *Jeannerettia pedicellata*); Harvey 1844b: 431-432.

Type locality: Georgetown, Tasmania.

Distribution: Australia: Houtman Abrolhos, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Woody Island- Sheltered: 10-20 m, April (UWARA-181).

Collection locations: Woody Island (Sheltered: 10-20 m, April).

Polysiphonia decipiens Montagne 1842: 5.

References: Womersley 2003: 207, figure 88; 1979: 499-502, figure 12.

Type locality: Auckland Island, New Zealand.

Distribution: Australia, New Zealand, and Tierro del Fuego.

Australia: Houtman Abrolhos, Western Australia, to Newcastle, New South Wales; Tasmania.

Specimen: Thomas Island- Sheltered: 20+ m and Woody Island- Sheltered: 10-20 m, April (UWARA-74, 179, 191, and 218).

Collection locations: Frederick Island (Sheltered: 20+ m), Thomas Island (Sheltered: 20+ m), and Woody Island (Sheltered: <10-20 m, April).

Protokuetzingia australasica (Montagne) Falkenberg *in* Schmitz and Falkenberg 1897: 469.

References: Womersley 2003: 374, figure 162; Lucas and Perrin 1947: 295, figure 139; Harvey 1858: pl. 27 (as *Rytiphloea australasica*).

Type locality: Storm Bay, Tasmania.

Distribution: Australia: Port Denison, Western Australia, to San Remo, Victoria; Tasmania.

Specimen: Thomas Island- Sheltered: 20+ m (UWARA-267).

Collection locations: Black Island, Thomas Island, and Woody Island (Sheltered: 20+ m).

Vidalia spiralis (Lamouroux) Lamouroux *ex* J. Agardh 1863 [1851-1863]: 1126.

References: Womersley 2003: 397, figure 173; Huisman and Walker 1990: 440; Harvey 1847 [1847-1849]: 25, pl. 9, figures 1-6 (as *Epineuron spirale*).

Type locality: "New Holland".

Distribution: Australia: Houtman Abrolhos, Western Australia, to Kangaroo Island and Lacepede Bay, South Australia.

Specimen: Black Island- Exposed: 10-20 m, April 2003; Thomas Island- Exposed: 20+ m; Woody Island- Sheltered: 10-20 m, April (UWARA-118, 121, and 265).

Collection locations: Black Island (Exposed: 10-20 m; Sheltered: 10-20 m), Mondrain Island (Exposed: sites 1 and 2- platform), Remark Island (Sheltered: 10-20 m), Thomas Island (Exposed/Sheltered: 20+ m), and Woody Island (Exposed: 10-20 m; Sheltered: 10-20+ m).

Family Sarcomeniaceae

Sarcomenia delesserioides Sonder 1845: 56.

References: Womersley 2003: 165, figures 75E, 76; Womersley and Shepley 1959: 171-176, figures 1-19, pl. 1, figure 1.

Type locality: Western Australia.

Distribution: Australia: Houtman Abrolhos, Western Australia, to Western Port, Victoria.

Specimen: Black Island- Exposed: <10 m (UWARA-184).

Collection locations: Remark, Long, and Thomas Islands (Exposed: <10 m).

Sarcotrichia tenera *(Harvey) Womersley and Shepley 1959: 209.*

References: Womersley 2003: 155, figures 71E-H, 72A-E; Wynne 1996: 181.

Type locality: Fremantle, Western Australia.

Distribution: Australia: Fremantle, Western Australia, to Westernport, Victoria; Tasmania.

Specimen: Long Island- Exposed: <10 m (UWARA-262) and Woody Island- Sheltered: <10 m, April (UWARA-176).

Collection locations: Long Island (Exposed: <10 m) and Woody Island (Sheltered: <10 m; April).

Order Corallinales

Family Amphiroideae

Amphiroa anceps (Lamarck) Decaisne 1842: 125.
References: Womersley and Johansen *in* Womersley 1996: 285, figure 130; Millar 1990: 315-317, figures 9A-H; Harvey 1847 [1847-1849]: 98, pl. 37.
Type locality: Swan River, Western Australia.
Distribution: Andaman Islands, Australia, Comoro Islands, India, Indonesia, Kenya, Madagascar, Mauritius, Nicobar Islands, Oman, Pakistan, Singapore, Somalia, South Africa, Sri Lanka, Tanzania, Yemen.
Australia: Widespread.
Collection locations: Figure of Eight Island (Sheltered: site 1- platform and wall), Frederick Island (Exposed: <10 m), Long Island (Exposed: <10 and 20+ m; Sheltered 20+ m), Mondrain Island (Exposed/Sheltered: site 1- platform and wall), Remark Island (Exposed: <10 and 20+ m), Thomas Island (Exposed: <10-20+ m; Shletered: <10 and 20+ m), and Woody Island (Exposed: 20+ m).

Amphiroa gracilis Harvey 1855b: 547.
References: Womersley and Johansen *in* Womersley 1996: 286, figure 131; Harvey 1862: pl. 231.
Type locality: Fremantle, Western Australia.
Distribution: Australia, Madagascar.
Australia: Widespread.
Collection locations: Black Island (Exposed: <10-20+ m; Sheltered: 10-20+ m), Figure of Eight Island (Exposed: site 2- wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Exposed: <10-20+ m), Long Island (Exposed: <10-20 m; Sheltered: 10-20+ m), Mondrain Island (Exposed/Sheltered: sites 1 and 2- platform and wall), Remark Island (Exposed: 10-20+ m; Sheltered: 10-20+ m), Thomas Island (Exposed: <10 and 20+ m; Sheltered: <10 and 20+ m), and Woody Island (Exposed: <10 and 20+ m).

Family Corallinoideae

Corallina officinalis Linnaeus 1758: 805.

References: Womersley and Johansen *in* Womersley 1996: 291, figure 132.

Type locality: Europe.

Distribution: Australia, India, Pakistan, South Africa.

Australia: Widespread.

Collection locations: Frederick Island (Exposed: 10-20 m), Long Island (Exposed: <10 and 20+ m; Sheltered: 20+ m), Remark Island (Exposed: <10-20+ m; Sheltered: 10-20 m), Mondrain Island (Exposed: site 1- wall and site 2- platform; Sheltered: site 1- wall and site 2- platform), and Thomas Island (Exposed: <10-20+ m, Sheltered: 20+ m).

Haliptilon roseum (Lamarck) Garbary and Johansen 1982: 218.

References: Womersley and Johansen *in* Womersley 1996: 310, figure 141; Johansen and Womersley 1986: 551, figures 1-6.

Type locality: "Les mers Australes".

Distribution: Australia, Kenya, Madagascar, Mauritius. Mozambique, New Zealand, South Africa, Tanzania.

Australia: Shark Bay, Western Australia, around southern Australia to Port Denison, Queensland.

Collection locations: Black Island (Sheltered: <5-20 m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 2- platform and wall), Frederick Island (Sheltered: <10 and 20+ m), Long Island (Sheltered: 20+ m), Mondrain Island (Sheltered: site 1- wall), Thomas Island (Exposed: <10 m; Sheltered: 10-20+ m), and Woody Island (Exposed: <10-20+ m; Sheltered: <10-20 m).

Jania micrarthrodia Lamouroux 1816: 271.

References: Johansen and Womersley *in* Womersley 1996: 299, figure 136.

Type locality: Western Australia [mouth of Swan River].

Distribution: Australia, Christmas Island, Mauritius, New Zealand, Sri Lanka, Tanzania.

Australia: Geraldton, Western Australia, to Walkerville, Victoria; Tasmania; New South Wales.

Collection locations: Figure of Eight Island (Exposed- site 1- platform; Sheltered: site 2- platform), Frederick Island (Sheltered: 10-20 m), Remark Island (Sheltered: 20+ m), Thomas Island (Exposed: <10; Sheltered: 10-20+ m), and Woody Island (Exposed: 20+ m; Sheltered: 10-20 m).

Jania pulchella (Harvey) Johansen and Womersley 1994: 619-622.

References: Johansen and Womersley *in* Womersley 1996: 309, figure 140; Johansen and Womersley 1994: 619-623, figures 19-20, 41-42.

Type locality: Rottnest Island, Western Australia.

Distribution: Australia, Sri Lanka.

Australia: Houtman Abrolhos, Western Australia, to Portland, Victoria.

Specimen: Black Island- Exposed: 10-20 m, April (UWARA-239).

Collection locations: Black Island (Exposed: 10-20 m, April), Figure of Eight Island (Exposed: site 1- platform and wall and site 2- wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Exposed: 10-20 m; Sheltered: 10-20+ m), Long Island (Exposed: <10-20+ m; Sheltered: 10-20+ m), Mondrain Island (Exposed: site 1- wall; Sheltered: site 1- wall and site 2- platform and wall), Remark Island (Exposed: <10-20+ m; Sheltered: 10-20+ m), Thomas Island (Exposed: <10 m; Sheltered: 20+ m), and Woody Island (Exposed: 20+ m).

Family Mastophoroideae

Metagoniolithon radiatum (Lamarck) Ducker 1979: 85.

References: Womersley and Johansen *in* Womerlsey 1996: 319, figures 143, 144A-C; Ducker 1979: 85-88, figures 4-8.

Type locality: "Habite les mers de la Nouvelle-Hollande".

Distribution: Australia: Port Denison, Western Australia, to Cape Paterson, Victoria, King Island, and northern Tasmania.

Collection locations: Black Island (Exposed: <10 m), Figure of Eight Island (Exposed: site 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Exposed: <10 m; Sheltered: <10 and 20+ m), Long Island (Exposed: <10 m), Mondrain Island (Sheltered: site 2- platform), Remark Island (Sheltered: <10 m), Thomas Island (Exposed: <10-20 m; Sheltered: <10-20+ m), and Woody Island (Exposed: <10 m; Sheltered: <10-20+ m).

Metagoniolithon stelliferum (Lamarck) Ducker 1979: 83.
References: Womersley and Johansen *in* Womerlsey 1996: 320, figures 143, 144A-C; Fuhrer *et al.* 1981: 19, pl. 11; Ducker 1979: 83, figures 1-3.
Type locality: "Habite les mers de la Nouvelle-Hollande".
Distribution: Australia, Seychelles.
Australia: Houtman Abrolhos, Western Australia, to Refuge Cove, east of Wilsons Promontory, Victoria; King and Flinders Island; Tasmania.
Collection locations: Frederick Island (Sheltered: <10 m).

Metamastophora flabellata (Sonder) Setchell 1943: 131.
References: Woelkerling *in* Womersley 1996: 243, figure 108-110; Woelkerling 1980: 201, figures 1-33.
Type locality: Mouth of Swan River, Western Australia.
Distribution: Australia, Mozambique, South Africa.
Australia: Kalbarri, Western Australia, to Waterloo Bay, Victoria; Tasmania.
Specimen: Black Island- Exposed: 20+ m (UWARA-56).
Collection locations: Black Island (Exposed: 20+ m), Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and site 2- wall), Frederick Island (Exposed: <10-20+ m, Sheltered: 10-20+ m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and wall and site 2- wall), Remark Island (Exposed: <10 and 20+ m; Sheltered: 10-20+ m), Thomas Island (<10-20+ m; Sheltered: 20+ m), and Woody Island (Exposed: <10-20+ m).

Order Gelidiales

Family Gelidiaceae

Pterocladia lucida (R. Brown *ex* Turner) J. Agardh 1851 [1851-1863]: 483-484.

References: Womersley 1994: 137, figures 40A-B, 41A-E; Lucas and Perrin 1947: 144, figure 19; Fuhrer *et al.* 1981: 34, pl. 41; Harvey 1863: pl. 248.

Type locality: South coast of "New Holland".

Distribution: Australia, Indonesia (Java), New Zealand, Sri Lanka.

Australia: Kalbarri, Western Australia, to Coffs Harbour, New South Wales.

Specimen: Woody Island- Exposed: 20+ m (UWARA-109).

Collection locations: Woody Island (Exposed: 20+ m).

Order Gigartinales

Family Acrotylaceae

Carpopeltis elata (Harvey) Schmitz 1895: 168.

References: Womersley and Lewis *in* Womerlsey 1994: 366, figures 48B, 49D-F, 50C.

Type locality: Rottnest Island, Western Australia.

Distribution: Australia: Geraldton to Recherche Archipelago, Western Australia.

Specimen: Long Island- Sheltered: 20+ m (UWARA-187).

Collection locations: Figure of Eight Island (Exposed: site 1- wall; Sheltered: site 2- wall), Frederick Island (Exposed: 10-20 m), Long Island (Exposed: 20+ m), Mondrain Island (Exposed: site 1- platform and wall and site 2- platform; Sheltered: site 1- platform), and Remark Island (Sheltered: 10-20 m).

Carpopeltis phyllophora *(J. Hooker and Harvey) Schmitz 1895: 168.*

References: Womersley and Lewis *in* Womerlsey 1994: 169-170, figures 48A, 49A-C, 50A-B; De Toni 1905: 1604.

Type locality: Port Arthur, Tasmania.

Distribution: Geraldton, Western Australia, to Phillip Island, Victoria; Tasmania.

Specimen: Black Island- Exposed: 20+ m (UWARA-125) and Long Island- Exposed: 20+ m (UWARA-58 224).

Collection locations: Black Island (Exposed/Sheltered: 10-20+ m), Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: sites 1 and 2- platform and wall and site 2- platform), Frederick Island (Exposed: 20+ m; Sheltered: 10-20+ m), Long Island (Exposed: <10-20+ m; Sheltered: 10-20+ m), Mondrain Island (Exposed/Sheltered: sites 1 and 2- platform and wall), Remark Island (Exposed: <10-20+ m; Sheltered: <10-20 m), Thomas Island (Exposed/Sheltered: 10-20+ m), and Woody Island (Exposed: <10-20+ m; Sheltered: <10 and 20+ m).

Hennedya crispa Harvey 1855b: 552.

References: Kraft and Womersley *in* Womersley 1996: 368, figures 120C-D, 121H-M; Kraft 1977a: 113, figures 5-6, 14. Harvey 1859a: pl. 75.

Type locality: Garden or Rottnest Island, Western Australia.

Distribution: Australia: Houtman Abrolhos, Western Australia, to Pearson Island, South Australia.

Specimen: Long Island- Exposed: 20+ m (UWARA-66).

Collection locations: Black Island (Exposed: 20+ m), Frederick Island (Exposed: <10 m, Sheltered: 10-20 m), Long Island (Exposed: <10 and 20+ m), Remark Island (Exposed: 10-20 m; Sheltered: 20+ m), Thomas Island (Exposed: <10 and 20+ m; Sheltered: 20+ m), and Woody Island (Exposed: 20+ m).

Family Cystocloniaceae

Craspedocarpus ***sp.***

f. **Craspedocarpus blephicarpus** *(Harvey) Min-Thein and Womersley 1976: 106.*

References: Womersley 1994: 421, figures 145A-B, 146A-E.

Type locality: Garden and Rottnest Island, Western Australia.

Distribution: Geraldton, Western Australia, to Phillip Island, Victoria; Bass Strait.

Specimen: Woody Island- Sheltered: 10-20 m, April (UWARA-174).

Collection locations: Woody Island (Sheltered: 10-20 m, April).

Rhodophyllis volans Harvey 1855b: 553.

References: Womersley 1994: 417, figures E, F, 144; Lucas and Perrin 1947: 165, figure 37A-F.

Type locality: Rottnest Island, Western Australia.

Distribution: Champion Bay, Western Australia, to Walkerville, Victoria; Tasmania.

Collection locations: Figure of Eight Island (Exposed: site 1- platform).

Family Dicranemataceae

Tylotus obtusatus (Sonder) J. Agardh 1876: 429.

References: Womersley 1994: 324, figures 106H-N, 107A-C; Kraft 1977b: 245, figures 10-11, 19-20; Harvey 1862: pl. 210 (*Curdiea obtusata*).

Type locality: Geographe Bay, Western Australia.

Distribution: Australia and South Africa.

Australia: Houtman Abrolhos Islands, Western Australia, to Western Port, Victoria.

Specimen: Woody Island- Exposed: 20+ m (UWARA-104).

Collection locations: Black Island (Sheltered: 10-20 m), Figure of Eight Island (Sheltered: site 1- platform), and Woody Island (Sheltered: 10-20 m).

Family Dumontiaceae

Gibsmithia womerlseyi Kraft and Ricker *ex* Kraft 1986: 441.

References: Womersley 1994: 228, figures 68F, 71H-K.

Type locality: Esperance, Western Australia.

Distribution: Esperance and Hopetoun, Western Australia; Waterloo Bay, South Australia.

Specimen: Figure of Eight Island- Sheltered: site 1- wall (UWARA-209, 223, and 251) and Esperance (Kraft *et al.*, 20.xii.1980; MELU, K7654).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall).

Rhodopeltis australis Harvey 1863: 264.

References: Womersley 1994: 166, figures 42E-H, 44F; Nozawa 1963: 35, figure 12C-H; De Toni 1905: 1671.

Type locality: Rottnest Island, Western Australia.

Distribution: Australia: Cottesloe and Rottnest Island, Western Australia, to Point Roadknight, Victoria.

Specimen: Black Island- Exposed: 10-20 m, April 2003 (UWARA-274).

Collection locations: Black Island (Exposed: 10-20 m; April 2003).

Rhodopeltis borealis Yamada 1931: 75-76.

References: Huisman 2000: 90; Nozawa 1970: 102-107, figures 1A-C, 2-3.

Syn*Type locality*: Ryukyuretto, Japan; Ryusensui, Kotosho, Taiwan.

Distribution: Australia, Japan, Philippines, Taiwan.

Australia: Houtman Abrolhos and Rottnest Island, Western Australia.

Specimen: Figure of Eight Island- Sheltered: site 2- wall (UWARA-194).

Collection locations: Figure of Eight Island (Sheltered: site 2- wall).

Notes: Range extension.

Family Hypneaceae

Hypnea ramentacea (C. Agardh) J. Agardh 1876: 561.

References: Womersley 1994: 40, figures 153D-G, 154C, 155A-B.

Type locality: "New Holland".

Distribution: Australia: Port Denison, Western Australia, around southern Australia to Walkerville, Victoria; north coast of Tasmania.

Specimen: Mondrain Island- Sheltered: site 2; Remark Island- Exposed: 10-20 m; Woody Island- Sheltered: <10 m, April (UWARA-62 and 232).

Collection locations: Figure of Eight Island (Exposed: site 2- wall; Sheltered: site 1- wall), Mondrain Island (Sheltered: site 2), Remark Island (Exposed: 10-20 m), and Thomas Island (Exposed: <10 m; Sheltered: 10-20+ m).

Family Kallymeniaceae

*Specimen*s too young to be identified to species were combined as *Austrophyllis/Callophyllis* sp. or just *Callophyllis* sp. (pers com. HBS Womersley)

Austrophyllis **Womersley and Norris/*Callophyllis*** **Kutzing**

References: Womersley 1994: 249-259.

Specimen: Woody Island, Sheltered: 10-20 m (UWARA-243).

Collection locations: Woody Island (Sheltered: 10-20 m).

Callophyllis **sp. Kutzing**

References: Womersley 1994: 252-259.

Specimen: Mondrain Island- Sheltered: site 1- wall and site 2- platform (UWARA-227 and 249).

Collection locations: Figure of Eight Island (Sheltered: site 2- wall) and Mondrain Island (Exposed: site 1- platform and wall; Sheltered: site 2- platform).

Callophyllis lambertii (Turner) J. Agardh 1851 [1851-1863]: 300.

References: Womersley 1994: 255, figures 80C and 81C-G.

Type locality: "New Holland".

Distribution: Australia and New Zealand.

Australia: Head of the Great Australian Bight, South Australia, to Walkerville, Victoria; Tasmania.

Specimen: Black Island- Sheltered: 10-20 m, April (UWARA-243).

Notes: Range extension.

Kallymenia cribrosa Harvey 1855b: 555.

References: Womersley 1994: 233, figures 72A, 73A-E; Womersley and Norris 1971: 4, figures 1-5, 77; Lucas and Perrin 1947: 161, figures 33, 35.

Type locality: Fremantle, Western Australia.

Distribution: Australia: Abrolhos Islands, Western Australia, to Flinders Victoria; Tasmania.

Specimen: Mondrain Island- Exposed: site 1- wall (UWARA-206).

Collection locations: Frederick Island (Sheltered: 20+ m) and Mondrain Island (Exposed and Sheltered: site 1- wall).

Family Mychodeaceae

Mychodea aciculare *(J. Agardh) Kraft 1978: 555.*

References: Womersley 1994: 462, figures 163B-C, 164E-J.

Type locality: "New Holland".

Distribution: Australia: Cape Riche, Western Australia, to Walkerville, Victoria; Tasmania.

Collection locations: Mondrain Island (Sheltered: site 2- platform) and Remark Island (Sheltered: <10 m).

f. **Mychodea ramulosa** *J. Agardh 1897: 50.*

References: Womersley 1996: 456, figures 160G-L, 161A-B; Kraft 1978: 538, figures 10-11, 35; Kylin 1932: 63, figure 19, pl. 26, figure 64.

Type locality: "New Holland".

Distribution: Australia: King George's Sound, Western Australia, to Portland, Victoria.

Specimen: Remark Island- Sheltered: 10-20 m; Black Island- Sheltered: 20+ m (UWARA-107 and 124).

Collection locations: Black Island (Sheltered: 20+ m), Figure of Eight Island (Exposed: site 2- wall), Long Island (Exposed: <10 m), Mondrain Island (Sheltered: site 2- platform), Remark Island (Exposed: <10 m; Sheltered: 10-20+ m), and Thomas Island (Exposed: <10 m; Sheltered: 20+ m).

Family Nemastomataceae

Adelophycus corneus *(J. Agardh) Kraft* in *Womersley 1994: 272.*

References: Kraft *in* Womersley 1994: 272, figures 85D-F, 86A-E.

Type locality: Port Elliot, South Australia.

Distribution: Australia: Cockburn Sound, Western Australia, to Point Lonsdale, Victoria.

Specimen: Black Island- Exposed: 10-20 m, April 2003 (UWARA-274).

Collection locations: Black Island (Exposed: 10-20 m, April 2003)

Tsengia comosa (Harvey) Womersley and Kraft *in* Womersley 1994: 278.

References: Womersley and Kraft *in* Womersley 1994: 278: Figures 87E, 88E-G.

Type locality: Phillip Island, Victoria.

Distribution: Australia: Elliston, South Australia, to Phillip Island, Victoria.

Specimen: Figure of Eight Island (UWARA-205).

Collection locations: Figure of Eight Island (UWARA-205).

Notes: Range extension.

Family Peyssonneliaceae

Peyssonnelia capensis Montagne 1847: 177.

References: Womersley 1994: 155, figures 44B, 45D-F; Denizot 1968: 123, figures 105, 107.

Type locality: Port Natal, South Africa.

Distribution: Australia, Angola, Indonesia (Java), Japan, Madagascar, Maldives, Mozambique, Réunion, Seychelles, Solomon Islands, South Africa, Tanzania.

Australia: Western, southern, and eastern Australia.

Collection locations: Black Island (Exposed: 20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Exposed: <10-20 m), Long Island (Sheltered: 10-20+ m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and wall), Remark Island (Exposed: 10-20+ m), Thomas Island (Exposed/Sheltered: 20+ m), and Woody Island (Exposed: 20+ m).

Peyssonnelia foliosa *Womersley.*

References: Womersley 1994: 158-159, figures 44D, 46A-B.

Type locality: "The Hotspot", West of Flinders Island, South Australia.

Distribution: Australia: Islands off the west coast of Eyre Peninsula and Kangaroo Island, South Australia.

Specimen: Thomas Island- Exposed: 20+ m (UWARA-115).

Collection locations: Thomas Island (Exposed: 20+ m).

Notes: Range extension.

Peyssonnelia inamoena Pilger 1911: 311, figures 24-25.

References: Womersley 1994: 164, figures 47I-O.

Type locality: Gross-Batanga, Cameroon, West Africa.

Distribution: Widely distributed in tropical to temperate waters.

Australia: Head of the Great Australia Bight, South Australia; D'Entrecasteaux Channel, Tasmania.

Collection locations: Frederick Island (Sheltered: 20+ m).

Notes: Range extension

Peyssonnelia novae-hollandiae Kützing 1847: 33.

References: Womersley 1994: 157, figures 44C, 45G-I; Denizot 1968: 107, figure 92.

Type locality: South Australia.

Distribution: Australia: Perth region, Western Australia, to northern New South Wales.

Specimen: Woody Island- Exposed: 20+ m (UWARA-103).

Collection locations: Black Island (Exposed: 10-20 m), Figure of Eight Island (Exposed: site 2- platform and wall; Sheltered: site 2- wall), Frederick Island (Exposed: 20+ m; Sheltered: 10-20+ m), Long Island (Sheltered: 20+ m), Mondrain Island (exposed: site 1- platform and site 2- wall), Remark Island (Exposed: 10-20+ m; Sheltered: 10-20 m), Thomas Island (Exposed: 10-20+ m), and Woody Island (Exposed: 20+ m).

Family Solieriaceae

Areschougia congesta (Turner) J. Agardh 1872: 26.

References: Womersley 1994: 356, figures 117A, 118A-F, 119F; Min-Thein and Womersley 1976: 55, figures 18-19, 57.

Type locality: Kent Island, Bass Strait.

Distribution: Australia: Hamelin Bay, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Woody Island- Sheltered: 10-20 m (UWARA-220 and 228).

Collection locations: Black Island (Sheltered: 20+ m), Figure of Eight Island (Exposed: site 2- platform; Sheltered: site 1- platform), Frederick Island (Sheltered: 20+ m), Thomas Island (Sheltered: 10-20+ m), and Woody Island (Exposed: 20+ m; Sheltered: 10-20+ m).

Callophycus dorsiferus *(C. Agardh) Silva 1957: 143.*

References: Womersley 1994: 333, figures 108A, 109E-I; Min-Thein and Womersley 1976: 15, figures 3-4, 50.

Type locality: "New Holland".

Distribution: Australia: Port Denison to Hamelin Bay, Western Australia.

Specimen: Thomas Island- Exposed: 20+ m (UWARA- 131 and 138).

Collection locations: Thomas Island (Exposed: 20+ m).

Notes: Range extension.

Callophycus harveyanus (J. Agardh) Silva 1957: 143.

References: Womersley 1994: 337, figures 108C, 110F-G; Min-Thein and Womersley 1976: 27, figures 9-10, 52B; Kraft 1984: Figure 53.

Type locality: Fremantle, Western Australia *fide* Min-Thein and Womersley, 1976: 27.

Distribution: Australia: Houtman Albrolhos to Eucla, Western Australia.

Specimen: Thomas Island- Exposed: 20+ m (UWARA-131).

Collection locations: Black Island (Exposed: 10-20 m), Figure of Eight Island (Exposed: site 1- platform), Frederick Island (Exposed: <10-20 m), Mondrain Island (Exposed: site 1- platform and wall; Sheltered: site 2- wall), Remark Island (Exposed: <10-20+ m), and Thomas Island (Exposed: <10- 20 m).

Callophycus oppositifolius (C. Agardh) Silva 1957: 143.

References: Womersley 1994: 335, figures 108B, 110A-E; Kraft 1984: Figure 51; Min-Thein and Womersley 1976: 23, figures 7-8, 51B, 52A.

Type locality: Swan River, Western Australia.

Distribution: Australia: Houtman Abrolhos and Geraldton, Western Australia, to Kangaroo Island and Yorke Peninsula, South Australia; Lacepede and Guichen Bays, South Australia.

Specimen: Remark Island- Exposed: 20+ m (UWARA-73).

Collection locations: Black Island (Exposed: 20+ m; Sheltered: <10 m), Frederick Island (Exposed: 10-20 m), Long Island (Exposed: 20+ m), Mondrain Island (Exposed: sites 1 and 2- platform), Remark Island (Exposed: 10-20+ m), and Thomas Island (Exposed: 10-20 m).

Erythroclonium muelleri *Sonder 1853: 692.*

References: Womersley 1994: 351, figures 115A, 116A-E; Min-Thein and Womersley 1976: 75, figures 27-28, 59B; Fuhrer *et al.* 1981: 45, pl. 64; Lucas and Perrin 1947: 170, figure 41.

Type locality: Lefevre Peninsula, South Australia.

Distribution: Australia: Rottnest Island, Western Australia, eastward to Port Phillip Bay, Victoria; Georgetown, Tasmania.

Specimen: Remark Island- Sheltered: 10-20 m; Thomas Island- Sheltered: 20+ m (UWARA-139, 148, and 171).

Collection locations: Black Island (Sheltered: 20+ m), Mondrain Island (Sheltered: site 2- platform), Remark Island (Exposed: 20+ m; Sheltered: 10-20+ m), Thomas Island (Sheltered: 10-20+ m), and Woody Island (Sheltered: 10-20; April).

Rhabdonia coccinea (Harvey) Harvey *in* J. Hooker and Harvey 1847: 408.

References: Womersley 1994: 345, figures 113A, 114A-G; Lucas and Perrin 1947: 171, figure 42A-F; Harvey 1858: pl. 54.

Type locality: Garden Island, Western Australia *fide* Kylin, 1932: 36.

Distribution: Australia: Champion Bay, Western Australia, to Snowy River mouth, Victoria; Tasmania.

Specimen: Thomas Island- Sheltered: 20+ m (UWARA-120).

Collection locations: Black and Thomas Islands (Sheltered: 20+ m).

Solieria robusta (Greville) Kylin 1932: 18.

References: Womersley 1994: 340, figures 11A, 112A-G; Min-Thein and Womersley 1976: 7, figures 1-2, 49; Fuhrer *et al.* 1981: 45, pl. 63.

Type locality: Near Fremantle, Western Australia.

Distribution: Australia, India, Kenya, Kuwait, Madagascar, Mauritius, Pakistan, Singapore, South Africa, Sri Lanka, Tanzania, Yemen.

Australia: Houtman Abrolhos, Western Australia, to Port Phillip Bay, Victoria; Tamar Estuary, Tasmania; Lord Howe Island, New South Wales.

Specimen: Thomas Island- Sheltered: 20+ m (UWARA-119).

Collection locations: Black, Thomas, and Woody Islands (Sheltered: 20+ m).

Order Gracilariales

Family Gracilariaceae

Curdiea obesa (Harvey) Kylin 1932: 61.

References: Womersley 1996: 42, figure 13; Harvey 1862: pl. 217 (as *Sarcocladia obesa*).

Type locality: Rottnest Island, Western Australia.

Distribution: Australia: Geraldton, Western Australia, to Nora Creina, South Australia.

Specimen: Woody Island- Exposed: 20+ m (UWARA-152).

Collection locations: Figure of Eight Island (Exposed: site 2- platform and wall; Sheltered: site 2- wall), Mondrain Island (Exposed: site 1- platform and site 2- platform and wall; Sheltered: site 1- platform), Thomas Island (Exposed: 10-20+ m), and Woody Island (Exposed: <10 and 20+ m).

Gracilaria *sp. Greville 1830: liv, 121.*

References: Womersley 1996: 15-28.

Specimen: Black Island- Sheltered: 20+ m (UWARA-140).

Collection locations: Black Island (Sheltered: 10-20+ m), Remark Island (Sheltered: 10-20 m), and Woody Island (Exposed: 10-20 m; Sheltered: 10-20+ m).

Order Halymeniales

Family Halymeniaceae

Codiophyllum flabelliforme *(Sonder) Schmitz 1895: 146.*

References: Womersley and Lewis *in* Womersley 1994: 216, figures 65G-H, 67; De Toni 1905: 1603.

Type locality: Western Australia.

Distribution: Australia: Dongara to King George's Sound, Western Australia.

Specimen: Mondrain Island- Sheltered: site 2- wall (UWARA-167).

Collection locations: Figure of Eight Island (Exposed: site 1- platform) and Mondrain Island (Sheltered: site 2- wall).

Notes: Range extension.

Cryptonemia kallymenioides (Harvey) Kraft *in* Scott *et al.* 1982: 246.

References: Womersley and Lewis *in* Womersley 1994: 185, figures 53C, 54D-E; Scott *et al.* 1982: 246, figures 2-25.

Type locality: Fremantle, Western Australia.

Distribution: Australia: Houtman Abrolhos Islands to Hamelin Bay, Western Australia.

Specimen: Mondrain Island- Exposed: site 1- wall (UWARA-256).

Collection locations: Mondrain Island (Exposed: site 1- wall).

Notes: Range extension.

Cryptonemia undulata Sonder 1855: 516.

References: Womersley and Lewis *in* Womersley 1994: 182, figures 53A-B, 54A-C; Scott *et al.* 1982: 249, figures 27-35. Lucas and Perrin 1947: 380, figure 191.

Type locality: Port Phillip, Victoria, Australia.

Distribution: Australia, India, Kenya, Tanzania.

Australia: Port Denison, Western Australia, to Port Phillip Bay, Victoria.

Specimen: Frederick Island- Sheltered: 20+ m and Woody Island- Sheltered: 10-20 m, April (UWARA-57 and 177).

Collection locations: Black Island (Sheltered: 10-20 m; April) and Frederick Island (Sheltered: 20+ m).

Epiphloea bullosa (Harvey) De Toni 1905: 1578.

References: Huisman 2000: 101; Harvey 1863: pl. 277 (as *Schizymenia bullosa*).

Type locality: Fremantle, Western Australia.

Distribution: Australia: Western and southern Australia.

Specimen: Figure of Eight Island- Sheltered: site 2- wall (UWARA-192).

Collection locations: Figure of Eight Island (Sheltered: site 2- wall) and Long Island (Sheltered: 10-20 m).

Gelinaria ulvoidea *Sonder 1845: 55.*

References: Huisman 2000: 102; Womersley and Lewis *in* Womersley 1994: 206, figures 62A-C, 63A-C; Lucas and Perrin 1947: 163, figure 36.

Type locality: Western Australia.

Distribution: Australia: Yanchep, Western Australia, to Walkerville, Victoria; Tasmania..

Specimen: Woody Island- Sheltered: 10-20 m, April (UWARA-222).

Collection locations: Woody Island (Sheltered: 10-20 m, April).

Halymenia floresia (Clemente y Rubio) C. Agardh 1817: XIX.

References: Womersley and Lewis *in* Womersley 1994: 189-191, figure 56A.

Type locality: Sanlúcar de Barrameda, Cádiz, Spain.

Distribution: Australia, Bangladesh, Comoro Islands, India, Singapore, Sri Lanka, Tanzania, Yemen.

Australia: Widespread.

Specimen: Frederick Island- Sheltered: 10-20 m (UWARA-150).

Collection locations: Figure of Eight Island (Exposed: site 2- platform), Frederick Island (Sheltered: 10-20 m), and Remark Island (Sheltered: 10-20 m).

Thamnoclonium dichotomum (J. Agardh) J. Agardh 1876: 168.

References: Womersley and Lewis *in* Womersley 1994: 214, fig 65D-F, 66; DeToni 1905: 1615.

Type locality: "New Holland".

Distribution: Australia, South Africa.

Australia: Nichol Bay, Western Australia, to Richmond River mouth, New South Wales; Tasmania.

Specimen: Mondrain Island- Sheltered: site 2- wall; Thomas Island- Sheltered: 10-20 m (UWARA-101 and 229).

Collection locations: Frederick Island (Sheltered: 10-20+ m), Mondrain Island (Exposed: site 1- wall and site 2- platform; Sheltered: sites 1 and 2- wall), Remark Island (Exposed: 20+ m; Sheltered: <10-20+ m), Thomas Island (Exposed: 10-20+ m; Sheltered: 10-20 m), and Woody Island (Exposed: 20+ m).

Order Nemaliales

Family Galaxauraceae

Galaxaura marginata (Ellis and Solander) Lamouroux 1816: 264.

References: Huisman and Womersley *in* Womersley 1994: 113, figures 32A-F, 33B-D; Huisman and Borowitzka 1990: 157, figures 14-27; Papenfuss *et al.* 1982: 411, figures 7-9, 24, 36-37; Harvey 1860: pl. 136.

Type locality: Bahama Islands West Indies.

Distribution: Amirante Islands, Andaman Islands, southeast Arabian coast, Australia, Comoro Islands, Djibouti, India, Indonesia (Flores and Java), Kenya, Laccadive Islands, Madagascar, Maldives (Addu Atoll), Mauritius, Mozambique, Nicobar Islands, Oman, Réunion, Seychelles, Somalia, South Africa, Sri Lanka, Tanzania, Yemen.

Australia: Temperate waters of southern Australia.

Collection locations: Figure of Eight Island (Exposed/Sheltered: site1- platform), Frederick Island (Exposed: <10-20 m), Mondrain Island (Exposed: site 1- platform and site 2- wall), Long Island (Exposed: 20+ m), and Thomas Island (Exposed: 20+ m).

Order Plocamiales

Family Plocamiaceae

Plocamium angustum (J. Agardh) J. Hooker and Harvey 1847: 404.

References: Womersley 1994: 378, figure 125; Fuhrer *et al.* 1981: 36, pl. 45; Womersley 1971b: 11, figures 2-6; Lucas and Perrin 1947: 211, figure 76.

Type locality: "New Holland".

Distribution: Australia: Rottnest Island, Western Australia, to Tuggerah Lakes, New South Wales.

Specimen: Black Island- Exposed: 10-20 m (UWARA-127).

Collection locations: Black Island (Exposed: 10-20+ m), Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform), Frederick Island (Exposed: 10-20+ m; Sheltered: <10 m), Long Island (Exposed: <10 m), Mondrain Island (Exposed: site 1- platform and site 2- wall), Remark Island (Exposed: <10-20+ m; Sheltered: <10 m), Thomas Island (Exposed: <10-20+ m), and Woody Island (Exposed: 20+ m).

Plocamium cartilagineum (Linnaeus) Dixon 1967: 58.

References: Womersley 1994: 389, figure 131A-D; Womersley 1971b: 22, figures 36-39.

Type locality: Northern Europe.

Distribution: Widespread in temperate and cold waters in both hemispheres.

Australia: Rottnest Island, Western Australia, to Newcastle, New South Wales; Tasmania.

Specimen: Remark Island- Sheltered: 20+ m (UWARA-122).

Collection locations: Figure of Eight Island (Exposed: site 1- platform and site 2- platform and wall), Frederick Island (Exposed: <10-20+ m; Sheltered: 10-20+ m), Long Island (Exposed: <10 m; Sheltered: <10-20 m), Mondrain Island (Exposed: site 1- wall and site 2- platform and wall; Sheltered: site 1- platform and site 2- wall), Remark Island (Exposed: <10-20+ m; Sheltered: 10-20+ m), Thomas Island (Exposed: <10-20+ m), and Woody Island (Exposed: <10-20+ m).

Plocamium costatum *(C. Agardh) J. Hooker and Harvey 1847: 404.*

References: Womersley 1994: 381, figure 126; Lucas and Perrin: 1947: 212, figure 77.

Type locality: "New Holland".

Distribution: Australia and New Zealand.

Australia: Eyre Peninsula, South Australia, to Point Dromeday, New South Wales; Tasmania.

Collection locations: Thomas Island (Exposed: 10-20 m).

Notes: Range extension.

Plocamium leptophyllum *Kützing 1849: 885.*

References: Womersley 1994: 391: Figure 131E-G; De Toni 1900: 589; Reinbold 1897: 52.

Type locality: Georgetown, Tasmania.

Distribution: Australia and New Zealand.

Australia: Waldegrave Island, South Australia, to Green Cape, New South Wales; Tasmania.

Specimen: Woody Island- Exposed: 20+ m (UWARA-102).

Collection locations: Frederick Island (Sheltered: 10-20 m) and Woody Island (Exposed: 20+ m).

Notes: Range extension.

Plocamium mertensii (Greville) Harvey 1849 [1847-1849]: 122.

References: Womersley 1994: 383, figure 128; Fuhrer *et al.* 1981: 37, pl. 48; Womersley 1971b: 15, figures 17-23; Lucas and Perrin 1947: 215, figure 80.

Type locality: "New Holland".

Distribution: Australia: Nichol Bay, Western Australia, to San Remo, Victoria; Tasmania.

Specimen: Thomas Island- Exposed: 20+ m (UWARA-126).

Collection locations: Black Island (Exposed: 10-20+ m; Sheltered: <10 m), Figure of Eight Island (Exposed: sites 1 and 2: platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Frederick Island (Exposed/Sheltered: 10-20 m), Long Island (Exposed: <10 m; Sheltered: 10-20+ m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and wall and site 2- wall), Remark Island (Exposed: <10-20+ m; Sheltered: 10-20+ m), Thomas Island (Exposed: 10-20+ m; Sheltered: 20+ m), and Woody Island (Exposed: <10-20+ m).

Plocamium preissianum Sonder 1845: 54-55.

References: Womersley 1994: 387, figure 130; Womersley 1971b: 20, figures 29-35; Lucas and Perrin 1947: 211, figure 75.

Type locality: Western Australia.

Distribution: Australia: Houtman Albrolhos Islands, Western Australia, to Wilsons Promontory, Victoria.

Specimen: Black Island- Exposed: 20+ m (UWARA-123).

Collection locations: Black Island (Exposed: 20+ m), Figure of Eight Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform), Frederick Island (Exposed: <10-20+ m), Mondrain Island (Exposed: sites 1 and 2- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), Thomas Island (Exposed: <10-20+ m), and Woody Island (Exposed: 20+ m).

Order Rhodymeniales

Family Champiaceae

Champia parvula (C. Agardh) Harvey 1853: 76.

References: Womersley 1996: 129, figure 54A-C; Price and Scott 1992: 55-57, figure 14A-E.

Type locality: Cádiz, Spain.

Distribution: Australia, Aldabra Islands, Bangladesh, Burma, Diego Garcia Atoll, India, Indonesia (Flores; Java; Sumatra), Iran, Kenya, Kuwait, Laccadive Islands, Madagascar, Malaysia, Maldives, Mauritius, Pakistan, Réunion, (including Mahé Island), Somalia, South Africa, Sri Lanka, Tanzania, Yemen, Seychelles.

Collection locations: Black, Frederick, and Long Islands (Sheltered: 10-20+ m), Figure of Eight Island (Sheltered: site 1- wall and site 2- platform), and Mondrain Island (Sheltered: sites 1 and 2- platform).

Champia zostericola (Harvey) Reedman and Womersley 1976: 87.

References: Womersley 1996: 127, figures 52D-F, 53A-G; Huisman and Walker 1990: 415..

Type locality: Rottnest Island, Western Australia.

Distribution: Australia: Houtman Abrolhos Island, Western Australia, to Kiama, New South Wales; Tasmania.

Specimen: Woody Island- Sheltered: 10-20 m (UWARA-129).

Collection locations: Black Island (Exposed: <10 m), Figure of Eight Island (Sheltered: site 1- wall and site 2- platform), Frederick Island (Sheltered: 10-20+ m), Long Island (Sheltered: 10-20+ m), Mondrain Island (Sheltered: sites 1 and 2- platform), and Woody Island (Sheltered: 10-20 m).

Family Rhodymeniaceae

Asteromenia peltata (Taylor) Huisman and Millar 1996: 139.

References: Huisman 2000: 112; Huisman and Millar 1996; Schneider and Searles 1991: 345, figures 406-407; Schneider 1975: 133-134, figures 2, 5-6 (as *Weberella peltata*); Taylor 1960: 477, pl. 54, figures 5-7 (as *Fauchea peltata*).

Type locality: Isla Tortuga, Venezuela.

Distribution: Australia, Bermuda, Brazil, Cuba, Iran, Jamaica, Maldives, Venezuela. Australia: Houtman Abrolhos Islands, Western Australia.

Specimen: Figure of Eight Island- Sheltered: site 1- wall (UWARA-196 and 226).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall).

Notes: Range extension.

Botryocladia sonderi Silva *et al.* 1996: 355.

References: Womersley 1996: 48: Figure 15; Fuhrer *et al.* 1981: 46, pl. 66; Lucas and Perrin 1947: 203: Figure 67 (as *Chrysymenia obovata*).

Type locality: "Swan River", Western Australia.

Distribution: Australia: Temperate Australia.

Specimen: Thomas Island- Sheltered: <10 m (UWARA-147).

Collection locations: Black Island (Sheltered: 10-20+ m), Frederick Island (Exposed: 10-20 m; Sheltered: 10-20+ m), Long Island (Sheltered: <10-20+ m), Remark Island (Sheltered: <10-20+ m), Thomas Island (Sheltered: <10-20+ m), and Woody Island (Exposed/Sheltered: <10-20+ m).

Coelarthrum cliftonii *(Harvey) Kylin 1931: 15.*

References: Huisman 1996: 96, figures 1-15; Womersley 1996: 57, figure 19; Norris 1986: 537, figures 6-8; Harvey 1858: pl. 57 (as *Chylocladia cliftoni*).

Type locality: Fremantle, Western Australia.

Distribution: Australia, Canary Islands, Mauritius, South Africa, West Indies. Australia: The Montebello Islands, to Fremantle, Western Australia.

Specimen: Mondrain Island- Exposed (UWARA-188).

Collection locations: Black Island (Exposed/Sheltered: 10-20+ m), Frederick Island (Sheltered: 20+ m), Long Island (Sheltered: 10-20 m), Mondrain Island (Exposed: site1- platform and wall; Sheltered: site 1- platform and site 2- platform and wall), and Woody Island (Sheltered: 10-20+ m).

Notes: Range extension.

Coelarthrum opuntia (Endlicher) Børgesen 1937: 333.

References: Womersley 1996: 55, figure 18; Huisman 1996: 100, figures 16-25.

Type locality: Indian Ocean.

Distribution: Australia, India, Kenya, Pakistan, Sri Lanka, Yemen.

Australia: Darwin, Northern Territory; Western Australia; southern Australia to Walkerville, Victoria; Tasmania.

Collection locations: Figure of Eight Island (Sheltered: site 1- wall).

Erythrymenia minuta Kylin 1931: 13.

References: Womersley 1996: 67, figures 23, 30B; Womersley 1950: 175; Kylin 1931: 13, pl. 4, figure 10.

Type locality: Port Phillip Heads, Victoria, Australia.

Distribution: Australia: Sorrento, Western Australia, to Portsea, Victoria; Tasmania.

Collection locations: Figure of Eight Island (Sheltered: site 1- wall) and Remark Island (Exposed: <10 m).

Gloiocladia spp.

f. ***Gloiocladia australe*** (J. Agardh) Norris 1991b: 592.

References: Womersley 1996: 98, figures 37C, 39.

Type locality: "New Holland".

Distribution: Point Peron, Western Australia, to Walkerville, Victoria; Tasmania.

Specimen: Mondrain Island- Sheltered: site 1- platform (UWARA-200).

Collection locations: Mondrain Island (Sheltered: site 1- platform).

f. **Gloiocladia halymenioides** *(Harvey) Norris 1991b: 592.*

References: Womersley 1996: 101, figures 37D, 40; Huisman 1993: 17; Lucas and Perrin 1947: 194, figure 61.

Type locality: Fremantle, Western Australia.

Distribution: Australia: Fremantle, Western Australia, to Walkerville, Victoria; Tasmania

Specimen: Mondrain Island- Sheltered (UWARA-200).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall and site 2- platform and wall).

f. **Gloiocladia polycarpa** *(Harvey) Womersley 1996: 97.*

References: Womersley 1996: 97, figure 38.

Type locality: East coast, Tasmania.

Distribution: Australia: Port Fairy to Western Port, Victoria; Tasmania.

Collection locations: Figure of Eight Island (Exposed: site 1- platform).

Notes: Range extension.

Gloiosaccion brownii Harvey 1859a: pl. 83.

References: Womersley 1996: 53, figure 17; Fuhrer *et al.* 1981: 47, pl. 67 (as *Botryocladia brownii*); Lucas and Perrin 1947: 202, figure 66.

Type locality: Fremantle, Western Australia.

Distribution: Australia and New Zealand.

Australia: Geraldton, Western Australia; to Jervis Bay, New South Wales; Tasmania.

Specimen: Thomas Island: Exposed- <10 m (UWARA-146).

Collection locations: Black Island (Exposed: <10 m), Frederick Island (Exposed: <10 m), Long Island (Exposed: <10 m; Sheltered: 10-20 m), Remark Island (Exposed: <10-20 m), and Thomas Island (Exposed: <10 m; Sheltered: 20+ m).

Hymenocladia usnea (R. Brown *ex* Turner) J. Agardh 1852 [1851-1863]: 772.

References: Womersley 1996: 107, figure 43.

Type locality: Kent Island, Bass Strait.

Distribution: Australia: Port Denison, Western Australia, to Walkerville, Victoria; Kent Island, Bass Strait.

Specimen: Long Island- Exposed: <10 m; Mondrain Island- Sheltered: platform; Remark Island- Exposed: <10 m (UWARA-59, 65, and 162).

Collection locations: Black Island (Exposed: <10 m; Sheltered: 10-20+ m), Figure of Eight Island (Exposed: site 1- platform and site 2- wall; Sheltered: site 1- wall and site 2- platform and wall; Sheltered: site 1- wall and site 2- platform and wall), Frederick Island (Sheltered: 20+ m), Long Island (Exposed: <10 m), Remark Island (Exposed: <10 m), Thomas Island (Sheltered: 10-20+ m), and Woody Island (Sheltered: 10-20 m).

Rhodymenia spp.

f. **Rhodymenia leptophylla** *J. Agardh 1877: 20.*

References: Womersley 1996: 73, figure 25; Adams 1994: 231, pl. 83; Millar 1990: 368-369, figure 27C.

Type locality: Bay of Islands, New Zealand.

Distribution: Australia and New Zealand.

Australia: West Island, South Australia, to Westernport Bay, Victoria; New South Wales; Queensland; Tasmania.

Specimen: Remark Island- Sheltered: 20+ m (UWARA-110).

Collection locations: Black Island (Sheltered: 10-20 m), Figure of Eight Island (Exposed: site 1- platform and site 2- wall; Sheltered: site 1- wall and site 2- platform), Frederick Island (Sheltered: 10-20 m), Remark Island (Sheltered: 10-20+ m), Thomas Island (Sheltered: 10-20+ m), and Woody Island (Exposed: 20+ m).

Notes: Range extension.

Rhodymenia prolificans *Zanardini 1874: 499.*

References: Womersley 1996: 82, figures 29-30E; Lucas and Perrin 1947: 201.

Type locality: Georgetown, Tasmania.

Distribution: Lawrence Rock, Portland, and Gabo Island, Victoria; Tasmania

Specimen: Black Island- Sheltered: 10-20 m, April and Woody Island- Exposed: 20+ m (UWARA-106, 113, 221, 223, and 238).

Collection locations: Figure of Eight Island (Sheltered: site 2- platform), Frederick Island (Sheltered: 10-20 m), Mondrain Island (Exposed: site 1- platform), Remark Island (Sheltered: 10-20+ m), Thomas Island (Sheltered: 10-20+ m), and Woody Island (Exposed: 20+ m; Sheltered: 10-20 m).

Notes: Range extension.

Webervanbossea splachnoides (Harvey) De Toni f. 1936: 6.

References: Womersley 1996: 61, figure 20; Huisman 1995: 368.

Type locality: Garden Island, Western Australia.

Distribution: Andaman Islands, Australia, India, Indonesia (Lombok), Yemen.

Australia: Houtman Abrolhos Islands, Western Australia, around southern Australia, to Port Phillip Heads, Victoria; north-eastern Tasmania.

Specimen: Figure of Eight Island- Sheltered: site 1- wall (UWARA-225).

Collection locations: Figure of Eight Island (Sheltered: site 1- wall) and Mondrain Island (Sheltered: site 2- platform).

Rhodoliths

Family Corallinaceae

Hydrolithon munitum (Foslie and Howe) Penrose *in* Womersley 1996; 263.

References: Penrose *in* Womersley 1996: 263, figure 120.

Type locality: Cave Cayes, Exuma Chain, Bahamas.

Distribution: Australia, Bahamas, Jamaica, tropical and subtropical Western Atlantic. Australia: Tropical Western Australia, Lucky Bay, Cape Le Grande, Western Australia, to Point Westall, South Australia.

Specimen: Rhodolith bed off Esperance Harbour and Lucky Bay, Cape Le Grand, Western Australia- <3 m (Woelkerling, Platt, and Jones 9.ii.1984; La Trobe University, 14351).

Collection locations: Rhodolith bed off Esperance Harbour: depth of 38 m.

Lithothamnion sp. Heydrich 1897b: 412.

Specimen: Rhodolith bed off Esperance Harbour

Collection locations: Rhodolith bed off Esperance Harbour: depth of 38 m.

Mesophyllum sp. Lemoine 1928: 251.

Specimen: Rhodolith bed off Esperance Harbour

Collection locations: Rhodolith bed off Esperance Harbour: depth of 38 m.

Synarthrophyton sp. Townsend 1979: 252.

Specimen: Rhodolith bed off Esperance Harbour

Collection locations: Rhodolith bed off Esperance Harbour: depth of 38 m.

Family Sporolithaceae

Sporolithon sp.Heydrich 1897a: 66.

Collection locations: Rhodolith bed off Esperance Harbour: depth of 38 m.

REFERENCES

Adams, N. M. (1994). Seaweeds of New Zealand. Canterbury University Press, Christchurch.

Agardh, C. A. (1817). Synopsis algarum Scandinaviae. Lund.

Agardh, C. A. (1820). Species algarum Vol. 1, part 1, Fucoideae. Lund, 1–168.

Agardh, C. A. (1823). Species algarum Vol. 1, part 2. Lund, 399-531.

Agardh, C. A. (1824). Systema algarum. Literis Berlingianis, Lund.

Agardh, J.G. (1841). In historiam algarum sybolae. Linnaea 15: 150, 443-457.

Agardh, J.G. (1848). Species, genera et ordines algarum. Volumen primum: algas fucoideas complectens. Volume 1, Gleerup, Lund.

Agardh, J.G. (1851-1863). Species, genera et ordines algarum. Volumen primum: algas fucoideas complectens. Volume 2, Gleerup, Lund.

Agardh, J.G. (1870). Om Chatham-oarnes Alger. Ofversigt af Forhandligar: Kongl. Svenska Vetenskaps-Akademien 27: pages 435-456.

Agardh, J.G. (1872). Bidrag till Florideernes systematic. Lunds Universitets Årsskrift, Afdelningen for Mathematik och Naturvetenskap 8: 1-60.

Agardh, J.G. (1873). Till algernes systematik, Nya bidrag. Lunds Universitets Årsskrift, Afdelningen för Mathematik och Naturvetenskap 9: 1–71.

Agardh, J.G. (1876). Species, genera et ordines algarum. Volume 3, Weigel, Leipzig.

Agardh, J.G. (1877-8). De algis Novae Zealandiae marinis. Lunds Universitets Arsskrift, Afdelningen for Mathematik och Naturvetenskap 14: 1-32.

Agardh, J.G. (1882). Till algernes systematik. Nya bidrag. (Andra afdelningen.). Lunds Universitets Årsskrift, Afdelningen för Mathematik och Naturvetenskap 17: 1–134, pls 1-3.

Agardh, J.G. (1889). Species Sargassorum Australiae. Kongliga Svenska Vetenskaps-Akademiens Handlingar 23:1-133, pls 1-31.

Agardh, J.G. (1894). Analecta algologica. Continuatio I. Lunds Universitets Arsskrift, Andra Afdelningen, Kongliga Fysiografiska Sallskapets I Lund Handlingar 29: 1-144, pls 1-2.

Agardh, J.G. (1897). Analecta algologica. Continuatio IV. Lunds Universitets Arsskrift, Andra Afdelningen, Kongliga Fysiografiska Sallskapets I Lund Handlingar 33: 1-106, pls 1-2.

Agardh, J.G. (1898). Species, genera et ordines algarum. Vol. 3, part 3 – De dispositione Delesseriearum. Gleerup, Lund.

Allender, B. M. and Kraft, G. T. (1983). The marine algae of Lord Howe Island (New South Wales): the Dictyotales and Cutleriales (Phaeophyta). Brunonia 6: 73–130.

Areschoug, J. E. (1854). Phyceae novae et minus cognitae in maribus extraeuropaeis collectae ... Nova Acta Regiae Societatis Scientiarum Upsaliensis, ser. 3, 1: 329–372.

Baldock, R. N. (1976). The Griffithsieae group of the Ceramiaceae (Rhodophyta) and its southern Australian representatives. Australian Journal of Botany 24: 509–593.

Bonin, D.R. & M.W. Hawkes. (1988). Systematics and life histories of New Zealand Bonnemaisoniaceae (Bonnemaisoniales, Rhodophyta): II. The genus Delisea. New Zealand Journal of Botany 26: 619-632.

Børgesen, F. (1937). Contributions to a south Indian marine algal flora – II. Journal of the Indian Botanical Society 16: 311–357.

Castagne, L. (1851). Supplément au catalogue des plantes qui croissent naturellement aux environs de Marseille. Aix, 125 pp., pls. VIII–XI.

Choat, J.H. & D.R. Schiel. (1982). Patterns of distribution and abundance of large brown algae and invertebrate herbivores in subtidal regions of northern New Zealand. Journal of Experimental Marine Biology and Ecology 60: 129-162.

Collings, G.J. & A.C. Cheshire. (1998). Composition of subtidal macroalgal communities of the lower gulf waters of South Australia, with reference to water movement and geographical separation. Australian Journal of Botany 46: 657-669.

Cresswell, G.R. (1991). The Leeuwin Current- observations and recent models. Journal of the Royal Society of Western Australia 71: 1-14.

Dayton, P.K., Currie, V., Gerrodette, T., Keller, B.D., Rosenthal, R. & D. Ven Tresca. (1984). Patch dynamics and stability of some California kelp communities. Ecological monographs 54: 253-289.

Decaisne, M. J. (1842). Mémoire sur les corallines ou polypiers calcifères. Annales des Sciences Naturelles, Botanique ser. 2, 18: 96–128.

Decaisne, M. J. (1844). Note sur quelques algues a fronds reticules. Annales Sciences Naturales 2: 233-236.

De Clerck, O. (1998). A revision of the genus Dictyota Lamouroux (Phaeophyta) in the Indian Ocean. Ph. D., Universiteit Gent, Faculteit der Wetenschappen Academiejaar 1998-1999. pages 356 + appendices.

Denizot, M. (1968). Les Algues Floridées encroutantes (à l' exclusion des Corallinacées). Paris.

De Toni, J. filius (1936). Noterelle di nomenclatura algological. VII. Primo elenco di Floridee omonime. Brescia 14:1-8.

De Toni, J.B. (1895). Phyceae japonicae novae addita enumeratione algarum in ditione maritime Japnoiae hucusque collectarum. Memorie del Real Istituto Veneto di Scienze, Lettere ed Arti 25: 1-78.

De Toni, J.B. (1900). Sylloge Algarum Omnium Hucusque Cognitarum. Padua section 2: 387-775.

De Toni, J.B. (1903). Sylloge Algarum Omnium Hucusque Cognitarum. Padua section 3: 775-1525.

De Toni, J.B. (1905). Sylloge Algarum Omnium Hucusque Cognitarum. Padua section 4: 1523-1973.

Dixon, P.S. (1967). The typification of Fucus cartilagineus L. and Fucus corneus Huds. Blumea 15: 55-62.

Ducker, S.C. (1979). The genus Metagoniolithon Weber-van Bosse (Corallinaceae, Rhodophyta). Australian Journal of Botany 27: 67-101.

Endlicher, S. L. (1843). Mantissa botanica altera. Sistens generum plantarum supplementarum tertium. Vindobonae [Wien].

Falkenberg, P. (1901). Die Rhodomelaceen des Golfes von Neapel und der angrenzenden Meeres-Abschnitte. Fauna und Flora des Golfes von Neapel, Monographie 26: xvi + 754pp.

Foster, M.S. & G.R. Vanblaricom. (2001). Spatial variation in kelp forest communities along the Big Sur coast of central California, USA. Cryptogamie Algologie 22: 173-186.

Fuhrer, B., Christianson, I. G., Clayton, M. N. & B.M. Allender. (1981). Seaweeds of Australia. Reed, Sydney.

Garbary, D.J. & H.W. Johansen. (1982). Scanning electron microscopy of Corallina and Haliptilon (Corallinaceae, Rhodophyta): surface features and their taxonomic implications. Journal of Phycology 18: 211–219.

Gepp, A. & E.S. Gepp. (1911). The Codiaceae of the Siboga expedition, including a monograph of Flabellarieae and Udoteae. Siboga-Expeditie Monographie 62: 1–150.

Goldberg, N.A. & G.A. Kendrick. (2004). Effects of island groups, depth, and exposure to ocean waves on subtidal macroalgal assemblages in the Recherche Archipelago, Western Australia. Journal of Phycology, in press.

Goldberg, N., Kendrick, G. & J. Heine. (2004). Highway or country road: Algal recruitment with distance from an island reef. Journal of the Marine Biological Association of the United Kingdom, in press.

Gordon, E.M. (1972). Comparative morphology and taxonomy of the Wrangelieae, Sphondylothamnieae and Spermothamnieae (Ceramiaceae, Rhodophyta). Australian Journal of Botany, Supplement 4: 1-180.

Greville, R.K. (1830). Algae Britannicae. Maclachlan and Stewart, Edinburgh.

Grunow, A. (1915). Additamenta ad cognitionem Sargassorum. Verhandlungen der Kaiserlich-Königlichen Zoologisch-Botanischen Gesellschaft in Wien 65: 329-448.

Harman, N., Harvey, E.S. & G.A. Kendrick. (2003a). Differences in fish assemblages from different reef habitats at Hamelin Bay, south-western Australia. Marine and Freshwater Research 54:1-8.

Harman, N., Kendrick, G.A., Harvey, E.S., Vanderklift, M.A. & D.I. Walker. (2003b). Use of surrogates for the rapid assessment of marine biodiversity. Proceedings of the World Congress on Aquatic Protected Areas: 465-476 Cairns, Australia.

Harvey, S.H., Woelkerling, W.J. & A.J.K. Millark. (2002). The sporolithaceaea (Corallinales, Rhodophyta) in south-eastern Australia: taxonomy and 18sRNA phylogeny. Phycologia 41: 207-227.

Harvey, W.H. (1844a). A few remarks on Claudea elegans. London Journal of Botany 3: 408-411, pl. 20.

Harvey, W.H. (1844b). Algae of Tasmania. London Journal of Botany 3: 42-454.

Harvey, W.H. (1846). Phycologia Britannica. Reeve, London.

Harvey, W.H. (1847-1849). Nereis Australis or Algae of the Southern Ocean. Reeve, London.

Harvey, W.H. (1853). Nereis boreali-americana ... Part II. Rhodospermeae. Smithsonian Contributions to Knowledge. 5: 1–258.

Harvey, W.H. (1855a). Short characters of some new genera and species of algae discovered on the coast of the colony of Victoria, Australia. Annals and Magazine of Natural History including zoology, botany and geology, series 2, 15: 332-336.

Harvey, W.H. (1855b). Some account of the marine botany of the colony of Western Australia. Transactions of the Royal Irish Academy 22: 525–566.

Harvey, W.H. (1858). Phycologia Australica Vol. 1. Reeve, London.

Harvey, W.H. (1859a). Phycologia Australica Vol. 2. Reeve, London.

Harvey, W.H. (1859b). Algae. In Hooker, J.D., The Botany of the Antarctic Voyage III. Flora Tasmaniae, 2: 282-343. Reeve, London.

Harvey, W.H. (1860). Phycologia Australica Vol. 3. Reeve, London.

Harvey, W. H. (1862). Phycologia Australica Vol. 4. Reeve, London.

Harvey, W. H. (1863). Phycologia Australica Vol. 5. Reeve, London.

Heydrich, F. (1897a). Corallinaceae, inbesondere Melobesieae. Berichte der Deutschen Botanischen Gesellschaft 15: 34-71, Plate 3.

Heydrich, F. (1897b). Melobesiaea. Berichte der Deutschen Botanischen Gesellschaft 15: 403-420, Plate 20.

Hillis-Colinvaux, L. (1980). Ecology and taxonomy of Halimeda: Primary producer of coral reefs. Advances in Marine Biology 17: 1–327.

Hooker, J.D. & W.H. Harvey. (1847). Algae Tasmanicae: being a catalogue of the species of algae collected on the shores of Tasmania by Ronald Gunn, esq., Dr. Jeannerett, Mrs. Smith, Dr. Lyall, and J.D. Hooker; with characters of the new species. London Journal of Botany 6: 397-417.

Howe, M.A. (1920). Algae. Pp. 553–618. In: Britton, N. L. and Millspaugh, C. F. The Bahama Flora. New York.

Huisman, J.M. (1993). Supplement to the catologue of the marine plants recorded from Rottnest Island. In Wells, F.E., Walker, D.I., Kirkman, H. and R. Lethbridge (eds), The marine flora and fauna of Rottnest Island, Western Australia, 2: 11-18. Western Australian Museum, Perth.

Huisman, J.M. (1995). The morphology and taxonomy of Webervanbossea De Toni f. (Rhodymeniales, Rhodophyta). Cryptogamic Botany 5: 367-374.

Huisman, J.M. (1996). The red algal genus Coelarthrum Børgesen (Rhodymeniaceae, Rhodymeniales) in Australian seas, including the description of Chamaebotrys gen. nov. Phycologia 35: 95–112.

Huisman, J.M. (1997). Marine Benthic Algae of the Houtman Abrolhos Islands, Western Australia. Pp. 177–237. In: Wells, F. E. (ed.) The Marine Flora and Fauna of the Houtman Abrolhos Islands, Western Australia. Western Australian Museum, Perth.

Huisman, J. M. (2000). Marine Plants of Australia. University of Western Australia Press, Nedlands.

Huisman, J.M. & M.A. Borowitzka. (1990). A revision of the Australian species of Galaxaura (Rhodophyta Galaxauraceae), with a description of Tricleocarpa gen. nov. Phycologia 29: 150–172.

Huisman, J.M., Kendrick, G.A., Walker, D.I. & A. Coute. (1990). The marine algae of Shark Bay, Western Australia. Research in Shark bay. Report of the France'Australe Bicentenary Expedition Committee, pp. 89-100.

Huisman, J. M. & A.J.K. Millar. (1996). Asteromenia (Rhodymeniacae, Rhodymeniales), a new red algal genus based on Fauchea peltata. Journal of Phycology 32: 138–145.

Huisman, J.M. & D.I. Walker. (1990). A catalogue of the marine plants of Rottnest Island, Western Australia, with Notes on their Distribution and biogeography. Kingia 1:349-459.

Huisman, J.M. & H.B.S. Womersley. (1994). In Womersley, H.B.S. (ed.), The Marine Benthic Flora of Southern Australia. Part IIID: 99-118. Government Printer, South Australia. Australian Biological Resources Study, Canberra.

Johansen, W. H. & H.B.S. Womersley. (1986). Haliptilon roseum (Corallinaceae, Rhodophyta) in southern Australia. Australian Journal of Botany 34: 551–567.

Johansen, W. H. & H.B.S. Womersley. (1994). Jania (Corallinales, Rhodophyta) in Southern Australia. Australian Systematic Botany 7: 605-625.

Kendrick, G.A., Lavery, P.S. & J.A. Phillips. (1999). Influence of Ecklonia radiata kelp canopy on structure of macro-algal assemblages in Marmion Lagoon, Western Australia. Hydrobiologia 398/399: 275-283.

Kendrick, G.A., Walker, D.I. & A.J. McComb. (1988). Changes in the distribution of macro-algal epiphytes on stems of the seagrass Amphibolis antarctica along a salinity gradient in Shark Bay, Western Australia. Phycologia 27: 201-208.

Kraft, G.T. (1977a). Studies of marine algae in lesser-known families of the Gigartinales (Rhodophyta). I. The Acrotylaceae. Australian Journal of Botany 25: 97-140.

Kraft, G.T. (1977b). Studies of marine algae in lesser-known families of the Gigartinales (Rhodophyta). II. The Dicranemataceae. Australian Journal of Botany 25: 219-267.

Kraft, G.T. (1978). Studies of marine algae in the lesser-known families of the Gigartinales (Rhodophyta). III. The Mychodeaceae and Mychodeophyllaceae. Australian Journal of Botany 26: 515-610.

Kraft, G.T. (1979). Transfer of the Hawaiian red alga Cladhymenia pacifica to the genus Acanthophora (Rhodomelaceae, Ceramiales). Japanese Journal of Phycology 27: 123–135.

Kraft, G.T. (1984). Taxonomic and morphological studies of tropical and subtropical species of Callophycus (Solieriaceae, Rhodophyta). Phycologia 23: 53-71.

Kraft, G. T. (1986). The genus Gibsmithia (Dumontiaceae, Rhodophyta) in Australia. Phycologia 25: 423–447.

Kraft, G.T. & H.B.S. Womersley. (1994). Family Acrotylaceae. In H.B.S. Womersley (ed.), The marine benthic flora of southern Australia Vol IIIA: 363-376. Australian Biological Resources Study: Canberra.

Kraft, G.T. & M.J. Wynne. (1996). Delineation of the genera Struvea Sonder and Phyllodictyon J.E. Gray (Cladophorales, Chlorophyta). Phycological Research 44: pages 129-142.

Krauss, F. (1846). Pflanzen des Cap- und Natal-Landes, gesammelt und zusammengestellt von Dr. Ferdinand Krauss. (Schluss). Flora 29: 209–219.

Kützing, F. T. (1847). Diagnosen und Bemerkungen zu neuen oder kritischen Algen. Botanische Zeitung 5: 1–5, 22–25, 33–38, 52–55, 164–167, 177–180, 193–198, 219–223.

Kützing, F. T. (1856). Tabulae phycologicae ... Vol. 6. Kohne: Nordhausen.

Kützing, F. T. (1861). Tabulae phycologicae ... Vol. 11. Kohne: Nordhausen.

Kylin, H. (1931). Die Florideenordnung Rhodymeniales. Lunds Universtets Årsskrift. Ny Följd, Andra Afdelningen 27: 1–48.

Kylin, H. (1932). Die florideenordnung Gigartinales. Lunds Universitets Årsskrift, Ny Följd, Andra Afdelningen 28(8): 1–88.

Kylin, H. (1949). Die Chlorophyceen der Swedischen Westkuste. Lunds Universitets Årsskrift, Ny Följd, Andra Afdelningen 45: 1-79.

Kylin, H. (1956). Die Gattungen Der Rhodophyceen. Gleerups, Lund.

Lamouroux, J. V. F. (1809). Exposition des caractères au genre Dictyota (1) et tableau des espèces qu'il renferme. Journal de Botanique [Desvaux] 2: 38–44.

Lamouroux, J. V. F. (1813). Essai sur les genres de la famille des thalassiophytes non articulées. Annales du Muséum d'Histoire Naturelle [Paris] 20: 21–47, 115–139, 267–293, pls. 7–13.

Lamouroux, J. V. F. (1816). Histoire Des Polypiers Coralligènes Flexibles, Vulgairement Nommés Zoophytes... F. Poisson, Caen.

Lemoine, M. (1928). Un nouveau genre de Melobesiee: Mesophyllum. Bull. Soc. bot. Fr. 75: 251-254.

Levring, T. (1940). Die Phaeophyceengattungen Chlanidophora, Distromium und Syringoderma. Kung. Fysiografiska Sällskapets i Lund Förhandlingar 10: 1-11.

Levring, T. (1953). The marine algae of Australia. I. Rhodophyta: Goniotrichales, Bangiales and Nemalionales. Arkiv for Botanik, series 2, 2: 457-530.

Lindauer, V.W., Chapman, V.J. & M. Aiken. (1961). The marine algae of New Zealand II. Phaeophyceae. Nova Hedwigia 3: 129-350.

Linnaeus, C. (1758). Systema naturae per regna tria naturae...Editio decima...Vol. 1. Holmiae [Stockholm]. pp. [I–IV+][1]–823 [824=errata].

Lucas, A.H.S. (1912). Supplementary list of the marine algae of Australia. Proceedings of the Linnaeus Society, New South Wales 37: 157-171.

Lucas, A.H.S. (1935). The marine algae of Lord Howe Island. Proceedings of the Linnaeus Society, New South Wales 60: 194-232.

Lucas, A.H.S. (1936). The Seaweeds of South Australia. Part I. Introduction and the Green and Brown seaweeds. Government Printer, Adelaide.

Lucas, A.H.S. and Perrin, F. (1947). The Seaweeds of South Australia. Part II. The Red Seaweeds. Government Printer, Adelaide.

MacRaild, G.N. (1974). The taxonomy, life history and cytology of Bryopsis and related genera from southern Australia. Thesis, University of Melbourne.

May, V. (1965). A census and key to the species of Rhodophyceae (red algae) recorded from Australia. Contributions from the New South Wales National Herbarium 3: 349-429.

Millar, A.J.K. (1990). Marine red algae of the Coffs Harbour region, northern New South Wales. Australian Systematic Botany 3: 293–593.

Millar, A.J.K. & G.T. Kraft. (1994). Catalogue of marine benthic green algae (Chlorophyta) of New South Wales, including Lord Howe Island, south-western Pacific. Australian Systematic Botany 7: pages 419-453.

Min-Thein, U. & H.B.S. Womersley. (1976). Studies on southern Australian taxa of Solieriaceae, Rhabdoniaceae and Rhodophyllidaceae (Rhodophyta). Australian Journal of Botany 24: 1-166.

Montagne, C. (1842). Prodromus generum specierumque phycearum novarum, in itinere ad polum antarticum... collectarum. Paris.

Montagne, C. (1844). Quelques observations touchant la structure et la fructification des genres Ctenodes, Delisea et Lenormandia, de la famille des floridees. Annales des Sciences Naturelles, Botanique 1: 151-161, pl. 10-11.

Montagne, C. (1845). Voyage at Pole Sud et dans l'oceanie. Plants Cellulaires. Paris, 21–43, 145–168.

Montagne, C. (1847). Enumeratio fungorum quos a cl. Drège in Africa meridionali collectos et in herbario Miqueliano servatos descriptionibus nonnullis illustravit ... Annales des Sciences Naturelles, Botanique, ser. 3, 7: 166–181.

Nizamuddin, M. (1964). The anatomy and life history of Cystophora, Acrocarpia and Caulocystis (Fucales). Botanica Marina 7: 42-63.

Nizamuddin, M. & H.B.S. Womersley. (1967). The morphology and taxonomy of Myriodesma (Fucales). Nova Hedwegia 12: 373-383, pls 69-73.

Norris, R. E. (1986). Coelarthrum (Rhodymeniaceae, Rhodophyceae), a genus new to southern Africa. South African Journal of Botany 52: 537–540.

Norris, R.E. (1987). Claudea elegans (Delesseriaceae, Rhodophyceae) in Natal, its first record in the western Indian Ocean and Africa. Journal of Botany 53: 311-315.

Norris, R. E. (1991a). The structure, reproduction and taxonomy of Vidalia and Osmundaria (Rhodophyta, Rhodomelaceae). Botanical Journal of the Linnean Society 106: 1–40.

Norris, R.E. (1991b). Some unusual marine red algae (Rhodophyta) from South Africa. Phycologia 30: 582-596.

Nozawa, Y. (1963). Systematic anatomy of the genus Rhodopeltis. Mem. Junshin Jun. Coll. 5: 1-48.

Nozawa, Y. (1970). Systematic anatomy of the red algal genus Rhodopeltis. Pacific Science 24: 99-133.

O'Hara, T.D. (2001). Consistency of faunal and floral assemblages within temperate subtidal rocky reef habitats. Marine and Freshwater Research 52:853-863.

Oliveira, E. C. de (1977). Algas marinhas bentônicas do Brasil. São Paulo, Brazil: Universidade de São Paulo, Instituto de Biociências. [IV +] 407 pp. [Thesis.]

Papenfuss, G.F. (1942). Notes on algal nomenclature. I. Pollexfenia, Jeannerettia and Mesotrema. Proceedings of the National Academy of Sciences of the United States of America 28: 446-451.

Papenfuss, G.F. (1944). Notes on algal nomenclature. III. Miscellaneous species of Chlorophyceae, Phaeophyceae and Rhodophyceae. Farlowia 1: 337-346.

Papenfuss, G.F. (1952). Notes on South African marine algae. III. Journal of South African Botany 17: 167-188.

Papenfuss, G.F., Mshigeni, K.E. and Chiang, Y.M. (1982). Revision of the red algal genus Galaxaura with special reference to the species occurring in the western Indian Ocean. Botanica Marina 25: 401-444.

Parsons, M.J. (1975). Morphology and taxonomy of the Dasyaceae and the Lophothalieae (Rhodomelaceae) of the Rhodophyta. Australian Systematic Botany 23: 549-713.

Parsons, M.J. and Womersley, H.B.S. (1998). Dasyaceae. In Womersley, H.B.S. The Marine Benthic Flora of Southern Australia. Part IIIC. Pp. 422-510. State Herbarium of South Australia, Adelaide.

Phillips, J.A. (1992). Taxonomy and reproduction in Australian species of Dilophus (Dictyotales, Phaeophyta). Australian Systematic Botany 5: 657-694.

Phillips, J.A. (2000). Systematics of the Australian species of Dictyopteris (Dictyotales, Phaeophyta). Australian Systematic Botany 13: 283-323.

Phillips, J.A. (2001). Marine macroalgal biodiversity hotspots: why is there high species richness and endemism in southern Australian marine benthic flora? Biodiversity and Conservation 10: 1555-1577.

Pilger, R. (1911). Die Meeresalgen von Kamerun. Nach der Sammlung von C. Ledermann. In Engler, A., Beitrage zur Flora von Africa 39. Botanische Jahrbucher fur Systematik, Pflanzengeschichte und Pflanzengeographie 46: 294-323.

Price, I. R. and Scott, F. J. (1992). The Turf Algal Flora of the Great Barrier Reef Part 1. Rhodophyta. James Cook University of North Queensland, Townsville.

Reedman, D.J. and Womersley, H.B.S. (1976). Southern Australian spcies of Champia and Chylocladia (Rhodymeniales, Rhodophyta). Transactions of the Royal Society of South Australia 100: 75-104.

Richardson, J.P. (1982). Life history of Bryopsis plumosa (Hudson) Agardh (Chlorophyceae) in North Carolina, U.S.A. Botanica Marina 25: 177-183.

Reinbold, T. (1897). Die Algen der Lacepede und Guichen Bay und deren näherer Umgebung (Süd Australien), gesammelt von Dr. A. Engelhart-Kingston. II. Nuova Notarisia 8: 41-62.

Reinbold, T. (1899). Meeresalgen von Investigator Street (Süd Australien), gesammelt von Miss Nellie Davey (Waltham, Honitan). Hedwegia 38: 39-51.

Saito, Y. and Womersley, H.B.S. (1974). The southern Australian species of Laurencia (Ceramiales, Rhodophyta). Australian Journal of Botany 22: 815–874.

Schiel, D.R. (1994). Kelp communities. In L.S. Hammond and R.N. Synnot (eds), Marine Biology, 134-361. Longman Cheshire Pty Limited, Melbourne.

Schmitz, F. (1893). Die gattun Lopothalia. Journal Ag. Berichte der Deutschen Botanischen Gesellschaft 11: 212-232.

Schmitz, F. (1895). Marine Florideen von Deutsch-Ostafrika. Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzengeographie 21: 137-177

Schmitz, F. (1896). Kleinere beitrage zur kentniss der Florideen VI. Nuova Notarisia 7: 1-32.

Schmitz, F. and Falkenberg, P. (1897). Rhodomelaceae. Pp. 421–480 In: Engler, A. and Prantl, K. (Eds) Die Natürlichen Pflanzenfamilien. 1 Teil, Abt. 2. Engelmann, Leipzig.

Schneider, C.W. (1975). North Carolina Marine Algae. V. Additions to the flora of Onslow Bay, including the reassignment of Fauchea peltata Taylor to Weberella Schmitz. British Journal of Phycology 10: 129-138.

Schneider, C.W. & R.B. Searles. (1991). Seaweeds of the southeastern United States: Cape Hatteras to Cape Canaveral. Duke University Press, Durham.

Scott, F.J., Wetherbee, R. and Kraft, G.T. (1982). The morphology and development of some prominently stalked southern Australian Halymeniaceae (Cryptomeniales, Rhodophyta). I. Cryptonemia kallymenioides (Harvey) Kraft comb. nov. and C. undulata Sonder. Journal of Phycology 20: 286-295.

Setchell, W.A. (1943). Mastophora and the Mastophoreae: genus and subfamily of Corallinaceae. Proceedings of the National Academy of Sciences of the United States of America 29: 127-135.

Shepherd, S.A. & H.B.S. Womersley. (1970). The sublittoral ecology of West Island, South Australia. I. Environmental features and the algal ecology. Transactions of the Royal Society of South Australia 94: 105-138.

Shepherd, S.A. & H.B.S. Womersley. (1976). The subtidal algal and seagrass ecology of St. Francis Island, South Australia. Transactions of the Royal Society of South Australia 100: 177-191.

Shepherd, S.A. & H.B.S. Womersley. (1981). The algal and seagrass ecology of Waterloo Bay, South Australia. Aquatic Botany 11: 305-371.

Silva, P.C. (1957). Remarks on algal nomenclature. Taxon 6: 141-145.

Silva, P. C., Basson, P. W. & R.L. Moe. (1996). Catalogue of benthic marine algae of the Indian Ocean. University of California Publications in Botany 79: 1-1279.

Silva, P.C. & H.B.S. Womersley. (1956). The genus Codium (Chlorophyta) in southern Australia. Australian Journal of Botany 4: 261-289.

Sonder, O. G. (1845). Nova algarum genera et species, quas in itinere ad oras occidentales Novae Hollandiae, collegit L. Preiss, Ph.Dr. Botanische Zeitung 3: 49–57.

Sonder, O. G. (1853). Plantae Muellerianae: Algae. Linnaea 25: 657–703.

Sonder, O. G. (1855). Algae annis 1852 et 1853 collectae. Linnaea 26: 506-528.

Taylor, W. R. (1960). Marine Algae of the Eastern Tropical and Subtropical Coasts of the Americas. University of Michigan Press, Ann Arbor.

Townsend, R. A. (1979). Synarthrophyton, a new genus of Corallinaceae (Cryptonemiales, Rhodophyta) from the southern Hemisphere. Journal of Phycology 15: 251-259.

Vickers, A. (1905). Liste des algues marines de la Barbade. Annales des sciences Naturelles, Botanique, ser. 9, 1: 45-66.

Weber-van Bosse, A. (1898). Monographie des Caulerpes. Annales de Jardin Botanique Buitenzorg 15: 243-401, pls 20-34.

Weber-van Bosse, A. (1910). Note sur les Caulerpa de l'ile Taiti et sur un nouveae Caulerpa de la Nouvelle Hollande. Annales de l'institut Oceanographie 2: 1-8.

Wernberg, T, Kendrick, G.A. & J.C. Phillips. (2003). Regional differences in kelp-associated algal assemblages on temperate limestone reefs in south-western Australia. Diversity and Distributions 9: 427-441.

Woelkerling, W. J. (1980). Studies on Metamastophora (Corallinaceae, Rhodophyta) II Systematics and Distribution. British Phycological Journal 15: 227-245.

Woelkerling, W.J. (1996). Mastophoroideae. In H.B.S. Womersley (ed.), The Marine Benthic Flora of Southern Australia. Part IIIB: 237-255. Canberra, Australian Biological Resources Survey.

Wollaston, E.M. (1968). Morphology and taxonomy of southern Australian genera of Crouanieae Schmitz (Ceramiaceae, Rhodophyta). Australian Journal of Botany 16: 217-417.

Wollaston, E.M. (1977). Morphology and life history of Dasyphila preissii Sonder with notes on the taxonomic position of Muellerena wattsii (Harvey) Schmitz (Rhodophyta, Ceramiaceae). Phycologia 16: 443-450.

Wollaston, E.M. and Womersley, H.B.S. (1998). Tribe Antithamnieae Hommersand 1963:330. In H.B.S. Womersley (ed.), The marine benthic flora of southern Australia Vol. IIIC: 98-127. Adelaide, State Herbarium of South Australia.

Womersley, H.B.S. (1950). The marine algae of Kangaroo Island. III. List of Species 1. Transactions of the Royal Society of South Australia 73: 137-197.

Womersley, H.B.S. (1953). The Archipelago of the Recherche. 3b. Marine Alage. Australian Geographic Society Report 3b:36-38.

Womersley, H.B.S. (1954). Australian species of Sargassum, subgenus Phyllotrichia. Australian Journal of Botany 2: 337–354.

Womersley, H.B.S. (1956). A critical survey of the marine algae of southern Australia. I. Chlorophyta. Australian Journal of Marine and Freshwater Research 7: 343-383.

Womersley, H.B.S. (1964). The morphology and taxonomy of Cystophora and related genera (Phaeophyta). Australian Journal of Marine and Freshwater Research 7: 53-110.

Womersley, H.B.S. (1967). A critical survey of the marine algae of southern Australia. II. Phaeophyta. Australian Journal of Botany 15: 189-270.

Womersley, H.B.S. (1971a). New records and taxa of marine Chlorophyta in southern Australia. Transactions of the Royal Society of South Australia 95: 113-120.

Womersley, H.B.S. (1971b). The genus Plocamium (Rhodophyta). Transactions of the Royal Society of South Australia 95: 9-27.

Womersley, H. B. S. (1978). Southern Australian species of Ceramium Roth (Rhodophyta). Australian Journal of Marine and Freshwater Research 29: 205–257.

Womersley, H. B. S. (1979). Southern Australian species of Polysiphonia Greville (Rhodophyta). Australian Journal of Botany 27: 459–528.

Womersley, H.B.S. (1984). The Marine Benthic Flora of Southern Australia. Part 1. Government Printer, South Australia.

Womersley, H.B.S. (1987). The Marine Benthic Flora of Southern Australia. Part II. Government Printer, South Australia.

Womersley, H.B.S. (1994). The Marine Benthic Flora of Southern Australia. Part IIIA. Australian Biological Resources Study, Canberra.

Womersley, H. B. S. (1996). The Marine Benthic Flora of Southern Australia. Part IIIB. Australian Biological Resources Survey, Canberra.

Womersley, H. B. S. (1998). The Marine Benthic Flora of Southern Australia. Part IIIC. State Herbarium of South Australia, Adelaide.

Womersley, H. B. S. (2003). The Marine Benthic Flora of Southern Australia. Part IIID. Australian Biological Resources Survey, Canberra.

Womersley, H.B.S. & H.W. Johnasen. (1987) Subfamily Corallinoideae (Areschoug) Foslie 1908:19. In Womersley, H.B.S. (ed.), The Marine Benthic

Flora of Southern Australia. Part II: 288-293, 317-323. Government Printer, South Australia.

Womersley, H.B.S. & J.A. Lewis. (1994). Family Halymeniaceae Bory 1828: 158. In H.B.S. Womersley (ed.), The Marine Benthic Flora of Southern Australia. Part IIIA: 167-218. Australian Biological Resources Study, Canberra.

Womersley, H.B.S. & R.E. Norris. (1971). The morphology and taxonomy of Australian Kallymeniaceae (Rhodophyta). Australian Journal of Botany, Supplement 2: 1-62.

Womersley, H.B.S. & L.A. Scott. (1987). Subgenus Sargassum. In Womersley, H.B.S. The Marine Benthic Flora of Southern Australia. Part II: 440-447. Government Printer, South Australia.

Womersley, H.B.S. & E.A. Shepley. (1959). Studies on the Sarcomenia group of the Rhodophyta. Australian Journal of Botany 7: 168-223.

Womersley, H.B.S. & E.A. Shepley. (1982). Southern Australian species of Hypoglossum (Delesseriaceae, Rhodophyta). Australian Journal of Botany 30: 321-346.

Wynne, M.J. (1996). A revised key to genera of the red algal family Delesseriaceae. Nova Hedwigia 112: 171-190.

Yamada, Y. (1931). Notes on some Japanese algae II. Journal of the Faculty of Science, Hokkaido Imperial University, Series 5, Botany 1: 65-76.

Zanardini, G. (1874). Phyceae Australicae novae vel minus cognitae. Flora 57: 486-490, 497-505.

Zanardini, G. (1878). Phyceae Papuanae novae vel minus cognitae a cl. Beccari in itinere ad Novam Guineam annis 1872–75 collectae. Nuovo Giornale Botanico Italiano 10: 34–40.

APPENDIX 8.6: Sponge and Ascidian Communities

Dr Justin I. McDonald[1] & Dr Jane Fromont[2]

[1] School of Plant Biology, Faculty of Natural & Agricultural Sciences, University of Western Australia, 35 Stirling Highway, Crawley 6009 Western Australia
[2] Department of Aquatic Zoology, Western Australian Museum, Francis Street, Perth 6000 Western Australia

Introduction

Currently in Australia there are few quantitative published accounts of the structure and function of temperate benthic invertebrate assemblages, and none from Western Australia. The southwestern region of Western Australia is a relatively pristine environment of great diversity, with high levels of endemism reported in some groups of crustaceans and molluscs (Morgan & Wells, 1991). The major benthic habitat forming organisms, such as sponges and ascidians, are an important and integral component of the marine system. They provide shelter, food and recruitment structures for many organisms including commercial fish, crustacean and mollusc species. Sponges and ascidians are filter-feeding invertebrates that are predominantly marine, and can be found in almost every aquatic habitat from upper intertidal to depths of over 8000m. Sponges are reported to be particularly diverse in the southwest of Western Australia (Hooper & Levi, 1994), yet for the Esperance area this temperate fauna remains unknown. It is widely acknowledged that areas of study such as sponge taxonomy and patterns of sponge distributions are major gaps in our knowledge of coastal systems. Hooper and Levi (1994) estimated that at least 60 % of the Australian sponge fauna is undescribed, with the Demosponge fauna of temperate southwestern Western Australia being the most poorly known of all. Presently our knowledge of the sponge fauna of the southwest is from a limited number of papers, most of which were published more than half a century ago (*e.g.* Bowerbank, 1876). None of these studies examined the fauna in the Esperance region and many of the publications only document fauna as far south as Albany, with most of the historical collections conducted from metropolitan waters (Cockburn Sound, Fremantle, Cottesloe and Rottnest Island).

A recent 'biological survey of the major benthic habitats of the south coast' conducted by Colman (1997) in the Fitzgerald Biosphere reserve identified 102 different sponges, yet of this number only one was identified to species level. This lack of taxonomic detail illustrates the importance of this study. There is an urgent need to correctly describe and quantify the organisms that comprise these benthic habitats.

FRDC 2001/060

In October and November 2002 a FRDC funded field trip was undertaken to examine the sessile benthic sponge and ascidian communities of the Recherche Archipelago. During this trip samples were collected from Black, Thomas, Woody, Long, Frederick, Remarck and Mondrain Islands. The objective of the survey was to characterise the benthic invertebrate assemblages across a range of spatial scales, from large scale differences between islands of the Recherche Archipelago (10's km) to smaller scale differences between exposed and sheltered sites (100's metres), and between vertical and sloping substratum (metres). To our knowledge this study is the first in the southern hemisphere to provide quantitative taxonomic data on distributions of animals from six phyla across a range of spatial scales. (Note: only two phyla are discussed in this report as identifications are still underway for the others).

In January 2003 a funding application by Kendrick, Fromont and McDonald was successful in obtaining three years funding from the CSIRO's Strategic Research Fund for the Marine Environment (SRFME) to conduct research on sessile benthic communities of the Recherche Archipelago. This funding allowed an expansion of the initial FRDC collection, and allowed for preliminary taxonomic processing of specimens collected on the FRDC trip as well as a subsequent October 2003 SRFME field programme.

METHODS

SAMPLING DESIGN

FRDC field trip - October to November 2002

The objective of this study was to characterise the benthic invertebrate assemblages across a range of spatial scales. Initially this was to investigate large scale patterns between islands of the Recherche Archipelago (10's km) as well as smaller scale differences between exposed and sheltered sites (100's metres).

Benthic invertebrate fauna were collected from horizontal substrata at eight islands: Black, Thomas, Woody, Remarck[1]*, Frederick, Long, Figure of Eight and Mondrain. Invertebrate habitats were sampled at sheltered and exposed sites within an island, and at a range of depths: waters 0-10m, 10-20 m, and waters 20-25 m depth, with equal numbers of quadrats taken from each exposure and depth.

The sampling design had three levels:

Islands	(kms apart, e.g. individual Islands within a group)
Exposure	(100's m apart, sheltered or exposed)
Depth	(Three depth ranges 5-10; 10-20; 20 – 25 m)

This partially hierarchical sampling strategy was developed to test the following:

- that there are differences in benthic invertebrate assemblages between islands
- that there are differences in benthic invertebrate assemblages between sheltered and exposed sites
- that there are differences in benthic invertebrate assemblages at different depths

Substratum orientation

As a result of the first collections during the 2002 sampling, the design was modified to capture habitats associated with vertical substrata in addition to the horizontal substrata. Vertical substrata are defined as those habitats with a vertical orientation of between 80 and 90° relative to the ocean floor. Horizontal substrata are defined as those habitats with a horizontal orientation of between 0 and 20° relative to the ocean floor. Observations of these habitats indicated that their inclusion would provide a valuable new component to the study. However, the addition of vertical substrata to the design effectively doubled the sampling and processing effort, and it was therefore decided that sampling would only occur at a single depth (10-20 m (15 m). The 15 m depth was chosen as observations indicated that species diversity and numbers were greatest at this depth. This new sampling regime commenced at Figure of Eight and Mondrain Islands. By adding this component to the experimental design we hoped to determine if there was variation in species structure, composition & abundance between vertical and horizontal strata.

The new sampling design had three levels:

Islands	(kms apart)
Exposure	(100's m apart, sheltered or exposed)
Substrata orientation	(metres apart, horizontal and vertical substrata at a single depth)

This modified sampling strategy now tests the following:

- that there are differences in benthic invertebrate assemblages between islands
- that there are differences in benthic invertebrate assemblages between sheltered and exposed sites
- that there are differences in benthic invertebrate assemblages between horizontal and vertically orientated substrata

SFRME field trip - October 2003

In October 2003 the final field work for this study was undertaken by McDonald, Fromont and Dr Jan Watson who sampled hydroids. During this trip we sampled some of the more remote islands within the Archipelago. The islands sampled were the Mart Group, Twin Peaks and Middle Island. All sampling conducted in this trip used the substratum orientation sampling protocol (below).

Islands	(kms apart)
Exposure	(100's m apart, sheltered or exposed)
Substrata orientation	(metres apart, horizontal and vertical substrata at a single depth)

IN-SITU COLLECTION AND RECORDING

All sampling was conducted by a team of three divers on SCUBA. The first diver haphazardly placed a 30 x 30 cm quadrat over an area of substratum. The quadrat was photographed using a high-resolution digital camera in an underwater housing to record valuable taxonomic and spatial information. Divers 2 and 3 would then collect and bag all benthic invertebrates within the quadrat. This process was repeated for five replicate quadrats at three depths for both sheltered and exposed sites on each island.

Photographic recording of specimens

The morphology of many of these invertebrates is extremely variable, and is influenced by physical and biotic factors, such as substratum shape and stability, water movement, light penetration or spatial competition. Photographic information records valuable data such as colour (many sponges and ascidians change colour once disturbed), gross morphological characteristics such as surface texture (*e.g.* conulose – regular bumps on surface) and shape.

Field processing of samples

Once all collecting was completed bagged samples were returned to the boat where further processing occurred. This involved re-photographing all specimens against a scale to illustrate size and colour. They were then placed into bags with labels identifying collection date, site, depth, exposure and pertinent taxonomic information.

Ascidia fixation

Correct taxonomic identification of ascidia requires fixation according to a specific protocol. Ascidians are contractile and this affects the shape of both colonial and solitary species, the appearance and consistency of the test, the number and appearance of muscle bands and obscures the morphology of many of the internal organs, especially that of small colonial zooids. Colour is also lost following removal from the substrate and placement in fixative and preservative.

Specimens were narcotised with menthol crystals for up to three hours in sufficient water to just cover the specimen and with all air removed from the bag. Specimens were deemed sufficiently narcotised if the siphons did not respond to stimulation.

All specimens collected were preserved in 70 % ethanol.

TAXONOMIC IDENTIFICATION OF SPECIMENS

This study examines six different taxa: Porifera; Ascidiacea; Hydrozoa; Echinodermata; Coelenterata; and Bryozoa. As many of the identifications are ongoing, results will concentrate on the dominant taxon, the Porifera (sponges). Sponges constitute the vast majority of the benthic fauna collected (see results Figure 1). Where possible identifications of all fauna collected were made to the species level. However, due to funding and time constraints, for most specimens this will not be possible, and identification to the lowest taxonomic unit (LTU) was conducted. The preparation of specimens for taxonomic identification involves dissections, spicule preparations, SEM analysis, tissue sectioning and skeletal analysis. These procedures are all very time consuming.

We have provided preliminary identifications (Order, Family level) for approximately 90% of the samples collected from the 2002 FRDC trip.

Sponges

Taxonomic classification in this phylum is based upon the composition of the skeletal elements, the size and shape of the structures (fibres, megascleres or microscleres), the number of branches and branching forms of fibres, the rays or axes of the spicules and their shape and distribution in the sponge body. Most Demospongiae produce rigid skeletons composed of siliceous spicules (mainly megascleres that are monaxonid, triaxonid or tetraxonid), and/or spongin fibres, to support the soft tissue, although a few have no rigid skeleton at all.

Traditionally, spicules are classed as: (1) megascleres, which are involved in main skeletal architecture; and (2) microscleres, which are highly variable in shape (Bavestrello, 2000) which are thought to support membranes enabling them to remain contractile. Both the mega- and microscleres have a diverse geometry and it is their relative size and functional morphology that differentiate the two. Similarly, the distribution of spicules within the skeleton - the skeletal structure - varies between taxa.

Spicule preparations were made by boiling small pieces of sponge, including ectosome and choanosome, in concentrated nitric acid. The solution was centrifuged through distilled water then absolute alcohol twice. Spicule extracts were air dried then mounted on glass slides and examined using light microscopy. Spicule dimensions (length and width) were measured and measurements were based upon examination of fully developed spicules from different individuals.

Ascidians

The characters useful for classifying ascidians include the position of the gut loop, the position and type of gonads, the morphology of the branchial tentacles, the number of branchial (pharyngeal) folds and the shape of the perforations (stigmata), the condition of the stomach wall and the nature of gut diverticulae (liver), the presence of a kidney and the colonial organisation.

Large solitary specimens were opened around the ventral mid line, either by opening the whole body including the test, or by removing the body from the test before making the incision. The cut was made from siphon to siphon the long way around (around the endostyle) with sharp scissors. The specimen was pinned out, and the branchial sac examined before gently removing it from the body wall by severing the connectives, so that the gut and gonads and other structures embedded in the pallial body wall could be observed.

(Solitary ascidia of the Recherche Archipelago - McDonald 2004 - accepted IMBW)

(The invasive pest species Ciona intestinalis (Linnaeus, 1767) reported in a harbour in southern Western Australia – McDonald 2004 – Marine Pollution Bulletin, 49: 868-870)

Bryozoans & Hydroids

Bryozoans and Hydroids require specialist identifications. Bryozoan identification is being done by Dr Josh Mackie and hydroid identifications by Dr Jan Watson. Some of these identifications are presented in this report.

Corals

The scleractinea, gorgonians and soft corals are being processed by myself, Dr Jane Fromont and Loisette Marsh (Western Australian Museum). These identifications are ongoing and no data is presented for this group (other than total number collected).

Sea stars

Sea-star identification was done by Loisette Marsh (Western Australian Museum) and this data is presented in this report.

(Asteroidea from shallow waters of the Archipelago of the Recherche - McDonald & Marsh 2004 – accepted IMBW)

STATISTICAL METHODOLOGIES

Analysis of all invertebrate groups

Multivariate analysis of all invertebrate data was analysed using ANOSIM (Analysis of SIMilarities) and where necessary presented as MDS (Multi-Dimensional Scaling) plots in PRIMER 6 (Beta version).

Diversity measures such as total abundance, number of individuals, richness (Margalef's d), evenness (Pilou's J') and Shannon Weiner diversity index (H' (log e)) of all invertebrate data were conducted using DIVERSE in PRIMER 6 (Beta version) and where necessary are presented as graphical plots.

Ecological diversity is considered a function of the number of different classes (richness) and the relative distribution of individual elements among these classes (evenness). Various indices have been proposed as measures of diversity that incorporate both aspects richness and evenness. Shannon-Weiner index weighs individual classes by their relative abundances. It can be understood as an estimator of the degree of uncertainty attached to the identity of any individual randomly selected from a community, which increases with richness as well as with evenness.

Analysis of sponge orders

As many of the identifications are still ongoing, the majority of the following results section will concentrate on the dominant taxa, the Porifera (sponges). Sponges constitute the vast majority of the benthic fauna collected (see results Figure 1).

Univariate analyses were used to test for significant differences of total sponges (order and family level) and individual sponge orders and their relationship to exposure, depth and orientation were conducted using Chi^2 analyses.

Analysis of sponge morphologies

As taxonomic groupings may be limiting when discussing organism distributions in an ecological context, sponges were also analysed based on their morphology. Sponges were divided into the following morphological types for analyses;

Encrusting; Branching; Massive, and Stalked. Multivariate analysis of sponge morphology were conducted using the same protocols outlined earlier in this report. Univariate analyses to test for significant differences in sponge morphologies associated with exposure, depth and orientation were conducted using Chi^2 analyses.

Results

ALL INVERTEBRATES

Of the six phyla examined in this study, the sponges and the bryozoans were the dominant taxa. Sponges represented approximately 72% of all fauna collected, bryozoans 10%, ascidians and sea-stars 7%, and hydroids and corals both 2% (Figure 1). Sponges were consistently the most abundant organisms recorded for each island (Table 1) (see *Appendix.* for species lists).

An MDS plot of the benthic faunal structure for each island showed differences among islands (low stress value: 0.05) at km scales not regional differences (10-100 km)(Figure 2). ANOSIM results revealed patterns in benthic faunal composition among islands (global R value: 0.259) but no patterns with exposure (sheltered/exposed) (global R value: 0.053). The absence of invertebrate fauna, except sponges, at Frederick and Long Islands may account for the lack of significant patterns among islands.

Total abundances of benthic invertebrates for each island ranged from 15 at Long Island to 181 at Middle Island (Table 2). Thomas (3 depths), Mondrain (2 strata) and Middle Island (2 strata) had the highest species richness (Figure 3) and diversity (Figure 4) of all sites examined (Table 2).

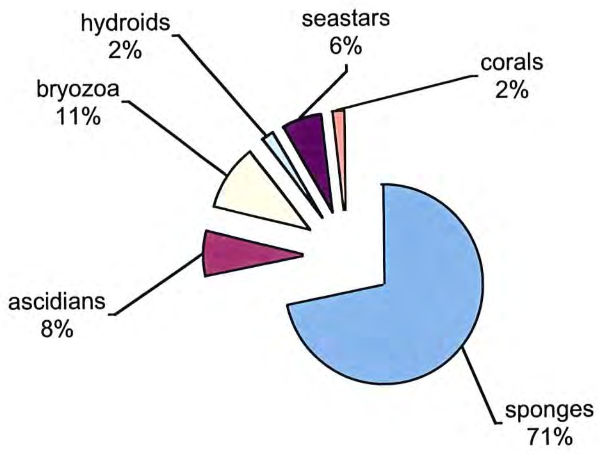


Figure 1: Fauna per taxa as a percentage (%) of total fauna collected.

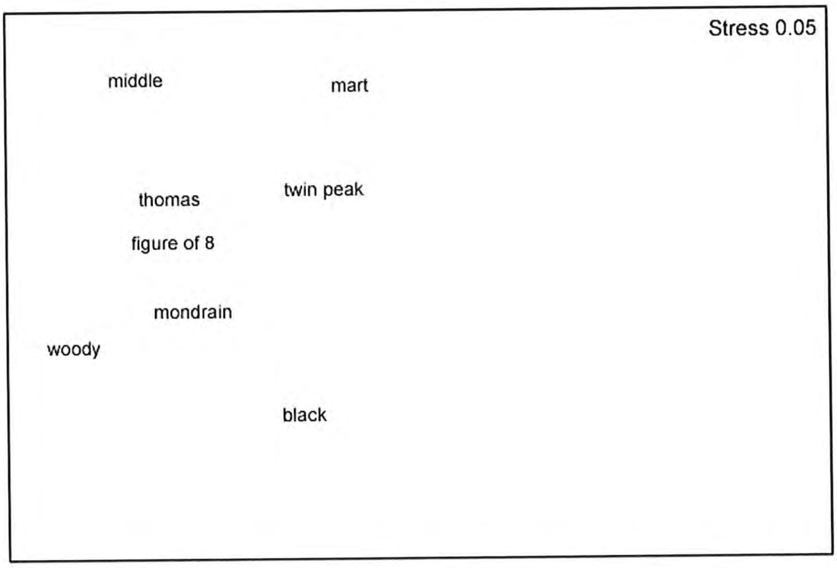


Figure 2: An nMDS plot showing the relationship among islands relating to benthic invertebrate community composition.

Table 1: Number of invertebrates (abundance) recorded for each island sampled (n/a indicates that samples still have to be processed).

	sponges	ascidians	bryozoans	hydroids	sea-stars	corals
Black	27	2	4	-	-	1
Thomas	55	7	15	1	10	3
Woody	48	23	22	2	-	3
Frederick	13	-	-	-	-	-
Long	7	-	-	2	6	-
Fig 8	100	3	9	1	6	6
Mondrain	67	10	31	8	14	2
Mart	43	4	n/a	-	6	n/a
Twin peak	37	5	n/a	-	2	n/a
Middle	166	3	n/a	2	10	n/a

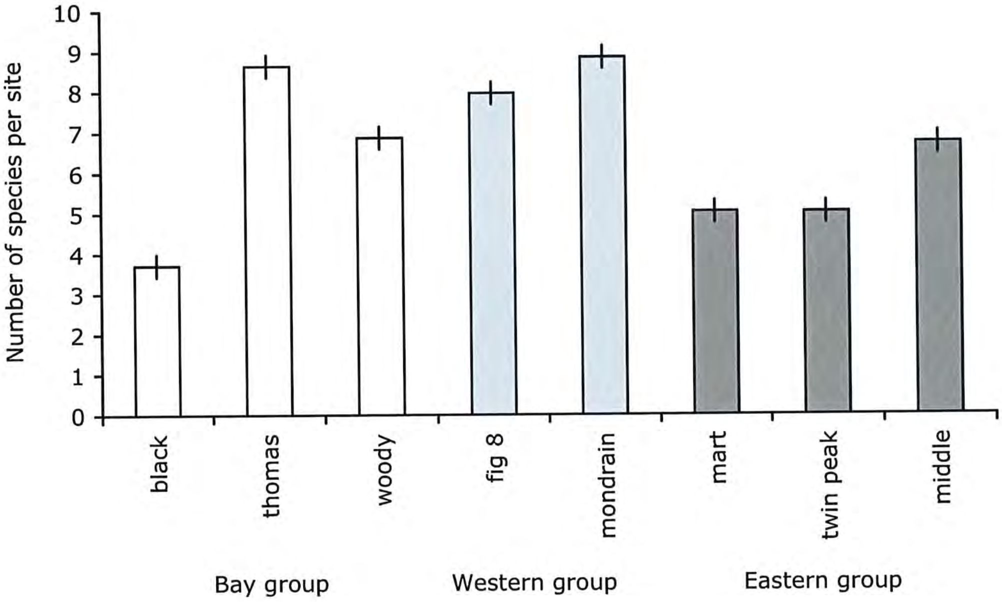


Figure 3: Average richness of all benthic invertebrates collected for each island sampled (n=310 quadrats).

Table 2: Summary statistics for benthic invertebrate fauna for each island.

	Number of taxa (s)	Number individuals (N)	of Richness (d)	Diversity H' (log e)
Black	14	33	3.717995678	2.44683
Thomas	43	129	8.642308901	3.37691
Woody	32	91	6.872304481	3.11668
Frederick	9	13	3.118969962	2.0579
Long	13	15	4.431232477	2.52321
Figure of 8	39	118	7.965313784	3.39998
Mondrain	40	82	8.850121329	3.31254
Mart	21	53	5.037412975	2.58708
Twin peak	20	44	5.020890029	2.60611
Middle	36	181	6.732715204	3.03164

THE SPONGES

A total of 644 individual Demosponges were collected from 250 quadrats at 10 sites along the Recherche Archipelago. Middle Island had the greatest number of sponges (Figure 4). Plots of sponge richness (Figure 5) show that despite Middle Island having the greatest number of sponges, richness was higher at Black and diversity was higher at Thomas, Figure of 8 and Mondrain (Table 3).

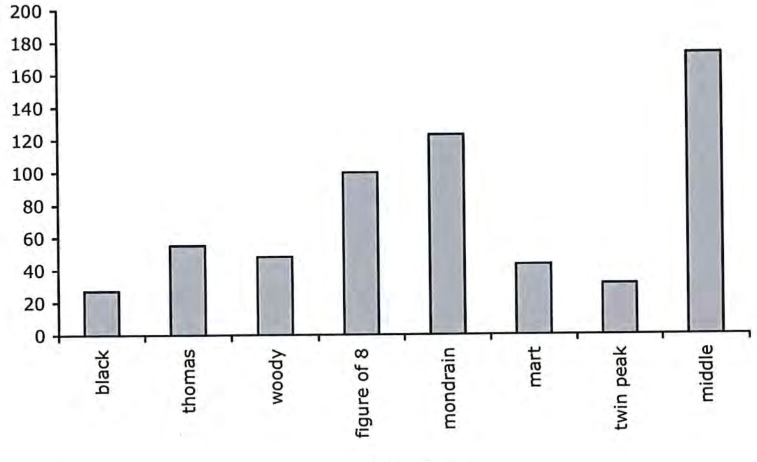


Figure 4: Number of individual sponges recorded for each island sampled (n=310 quadrats sampled).

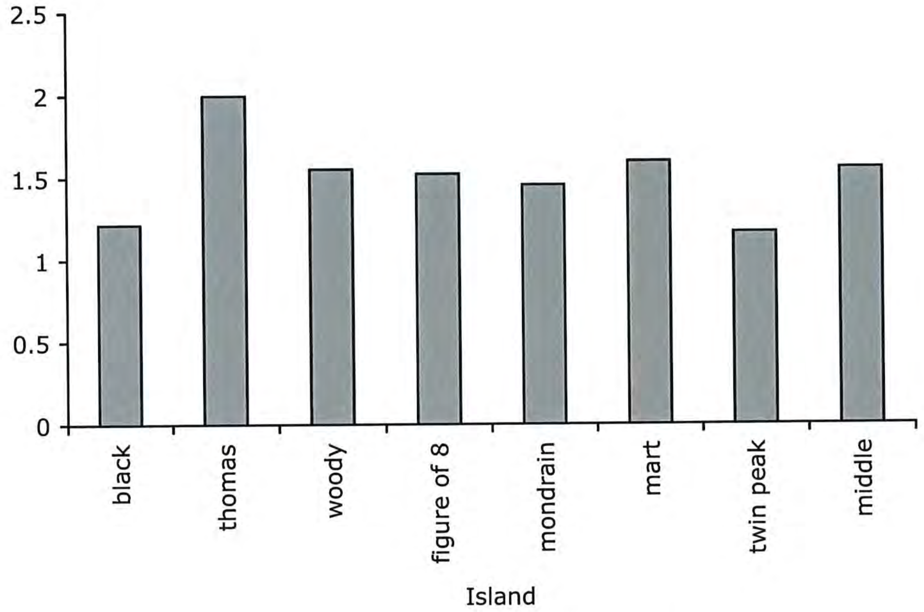


Figure 5: Sponge richness for each island sampled (based on order level data)(n=310 quadrats).

Table 3: Summary statistics of sponge diversity per island (based on order level data).

	Number of orders	Number of individuals	Richness (d)	Evenness (j)	Diversity H' (loge)
Black	5	27	1.213652	0.926105	1.490509
Thomas	9	55	1.99634	0.804075	1.766732
Woody	7	48	1.549907	0.873945	1.700618
Frederick	6	13	1.949356	0.947523	1.697734
Long	5	7	2.055593	0.962961	1.549826
Fig 8	8	100	1.520031	0.858149	1.784471
Mondrain	8	123	1.454641	0.827692	1.721137
Mart	7	43	1.595236	0.653992	1.272609
Twin peak	5	31	1.164827	0.661738	1.065026
Middle	9	173	1.552406	0.723864	1.590491

ANOSIM results indicated similarity in sponge order composition among islands (global R value: 0.165) and between sheltered and exposed sites (global R value: 0.036). There was no clear pattern of sponge order distribution associated with island or exposure, and the results suggested a fragmented distribution of sponge orders across all sites sampled.

Analysis of the data into those islands sampled at three depths and those sampled at two strata orientations also revealed no pattern in sponge assemblages using order level data (Table 4).

Table 4: ANOSIM results examining patterns in sponge community patterns (based on order level data) with islands, exposures and orientation. (* indicates significant result).

Family level analyses	ANOSIM test	Global R
All islands	Island similarities	0.165*
	Exposure similarities	0.036
Islands 3 depths sampled	Island similarities	0.004
	Exposure similarities	0.046
	Depth similarities	0.018
Islands 2 strata orientations	Island similarities	0.073
	Exposure similarities	0.146
	Orientation similarities	0.009

Sponge orders

Individuals from 11 of the 15 orders of Demospongiae currently recognised were collected during sampling along the Recherche Archipelago. Sponge orders were dominated by the Poecilosclerida and the Dictyoceratida, which in combination made up approximately 60% of the sponges identified to date (Figure 6).

No patterns in sponge community composition (based on order level data) were associated with any of the factors tested (exposure, depth or substrata orientation). There were no significant differences in the number of sponges collected among exposures, depths or substratum orientation for the Chondrosidae, Dictyoceratida, Hadromerida or the Halichondrida (Table 7). The Astrophorida had significantly more individuals in exposed sites (Table 7, Figure 7 a) and significantly more on vertical substrata (Table 7, Figure 7 b). The Dendroceratida also had significantly more individuals on vertical than on horizontal substrata (Table 7, Figure 8). The Haplosclerida showed significant differences associated with increasing depth, with significantly more individuals at 20^{+} m depth (Table 7, Figure 9). The Poecilosclerida had significantly more individuals with decreasing depth, with more individuals in <10 m depth (Figure 10 a). The Poecilosclerida also had had significantly more individuals in exposed than sheltered sites (Figure 10 b).

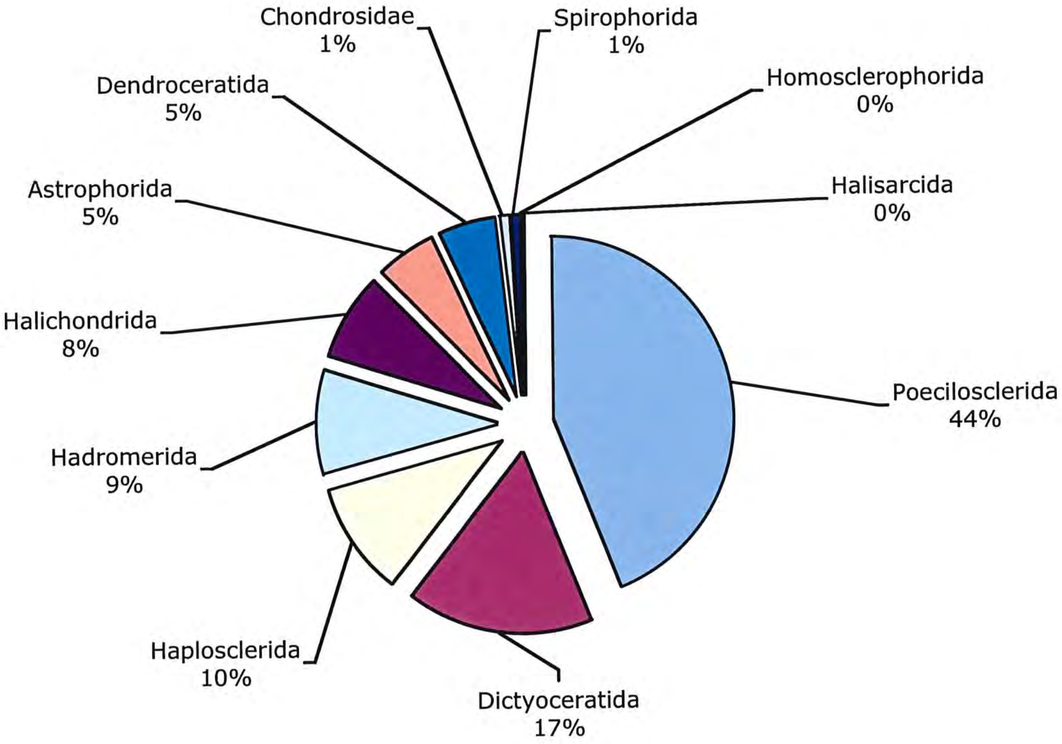


Figure 6: Sponges per order as a percentage of the total sponges collected.

Table 7: Summary of Chi^2 analyses testing differences in all orders, then individual orders by exposure, depth and orientation (values in bold indicate significant differences).

	By exposure (Chi^2 critical 3.841 @ 0.05)	By depth (Chi^2 critical 5.991 @ 0.05)	By orientation (Chi^2 critical 3.841 @ 0.05)
All orders	**Chi^2: 6.59**	Chi^2 : 1.92	Chi^2 : 3.18
Astrophorida	**Chi^2 : 9.52**	Chi^2 : 3.8	**Chi^2 : 9.53**
Chondrosidae	Chi^2 : 0.2	Chi^2 : 1	Chi^2 : 0.33
Dendroceratida	Chi^2 :0.31	Chi^2 : 2	**Chi^2 : 11.56**
Dictyoceratida	Chi^2 : 0.34	Chi^2 : 0.32	Chi^2 : 0.11
Hadromerida	Chi^2 : 0.6	Chi^2 : 3.92	Chi^2 : 0.25
Halichondrida	Chi^2 : 0.72	Chi^2 : 4.62	Chi^2 : 0.02
Haplosclerida	Chi^2 : 1.56	**Chi^2 : 6.4**	Chi^2 : 1.28
Poecilosclerida	**Chi^2 : 10.01**	**Chi^2 : 24.5**	Chi^2 : 0.00
Spirophorida	Chi^2 : 1.8	Chi^2 : 4	Chi^2 : 1.8

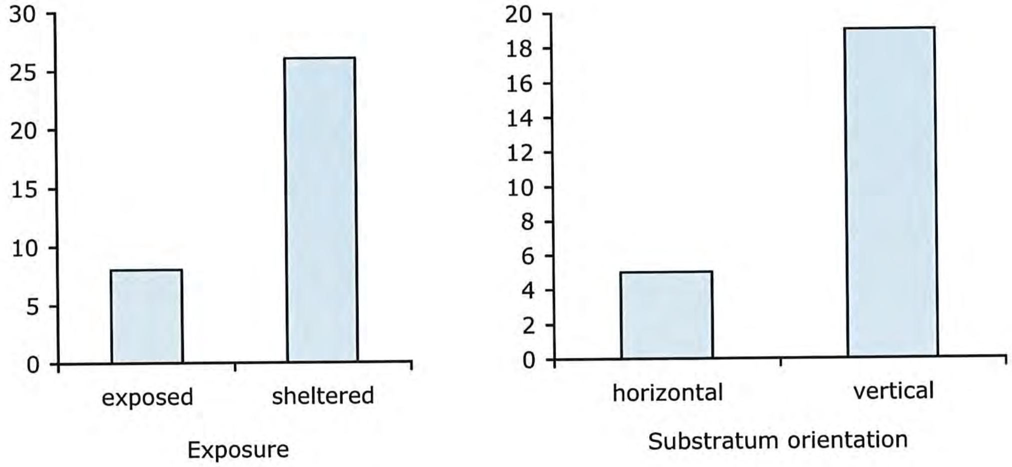


Figure 7: Number of Astrophorida individuals (*Y axis*) recorded from (a) exposed and sheltered sites (all islands (n=310 quadrats); and (b) horizontal and vertical substratum (Figure of 8, Mondrain, Mart, Twin Peak and Middle Islands)(n=160 quadrats).

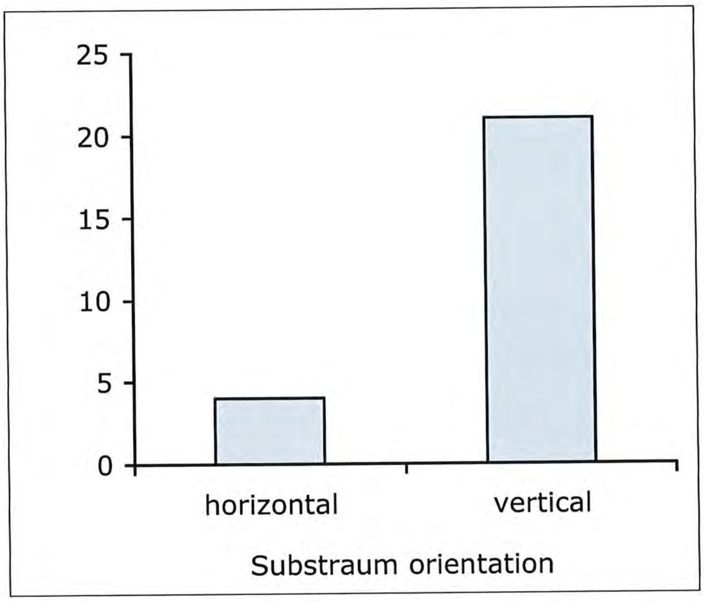


Figure 8: Number of Dendroceratida individuals (*Y axis*) recorded from horizontal and vertical substratum (Figure of 8, Mondrain, Mart, Twin Peak and Middle Islands)(n=160 quadrats).

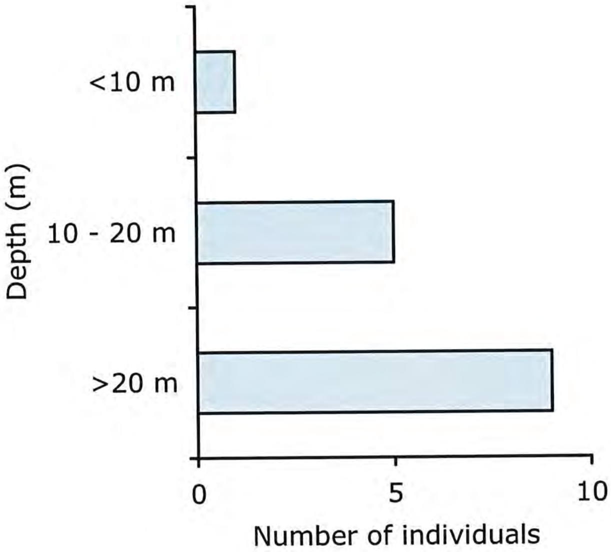


Figure 9: Number of Haplosclerida individuals (*Y axis*) recorded at each depth regime sampled for Black, Thomas, Frederick, Long and Woody islands (n=150 quadrats).

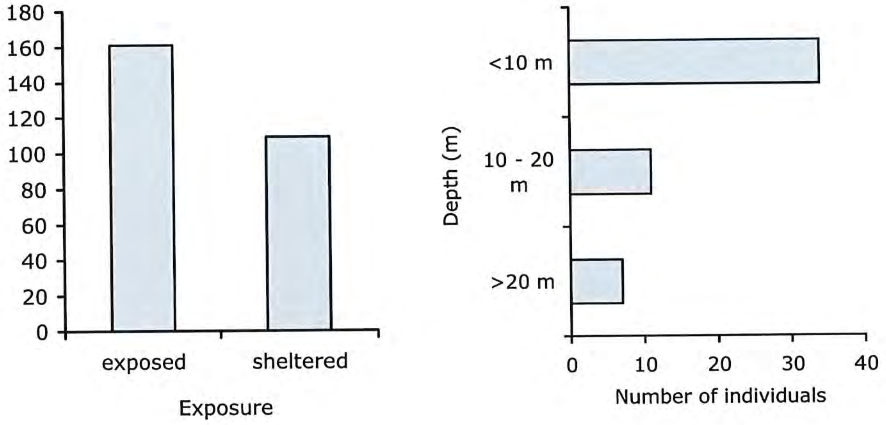


Figure 10: Number of Poecilosclerida individuals (*Y axis*) recorded from (a) exposed and sheltered sites (all islands; n=310 quadrats); and (b) at each depth regime sampled (Islands: Black, Thomas, Frederick, Long and Woody (n=150 quadrats).

Morphological analyses

Massive and stalked morphologies were the most abundant (Figure 11). There was little differentiation in sponge form with exposure (Figure 11). Stalked forms dominated at Figure of 8 and Mondrain (Figure 12). For those islands where sampling of two strata occurred, only Figure of 8 and Mondrain Island are used in the following morphological analyses. The remaining islands from the SRFME 2003 trip (Mart, Twin Peak and Middle) require further processing for this morphological data to be available.

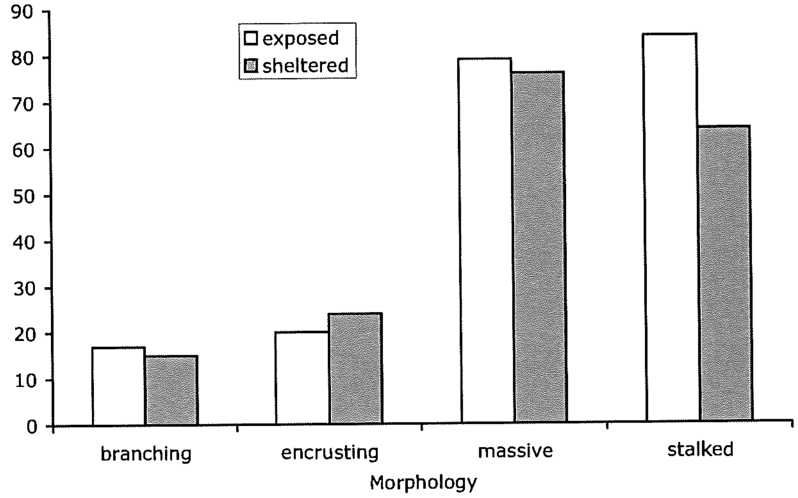


Figure 11: Number of sponges (*Y axis*) from four morphological types collected from sheltered and exposed habitats (n=230 quadrats).

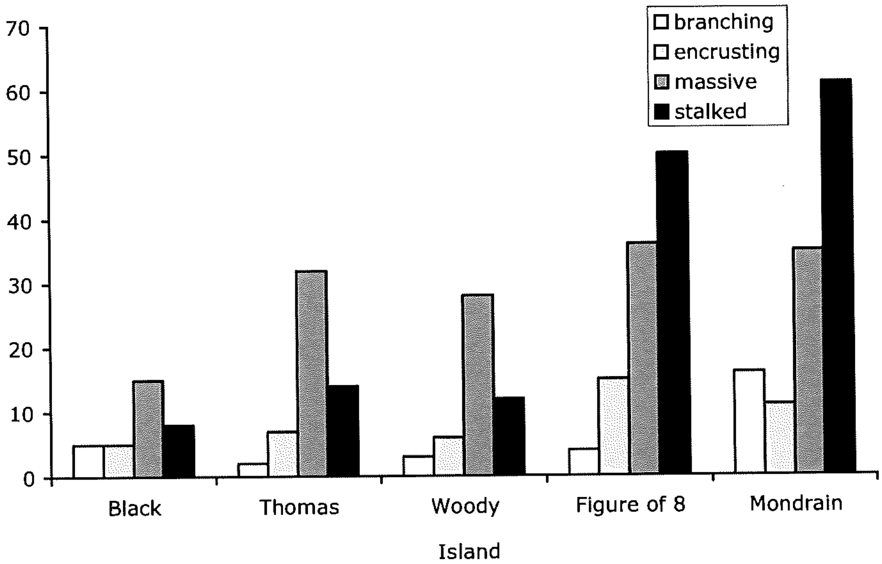


Figure 12: Numbers of sponges (*Y axis*) from four morphological types collected from seven of the ten islands sampled (n=230 quadrats).

Black Island had the greatest richness (Figure 13) and diversity in sponge morphology (Figure 16) of seven islands assessed to date (Table 5).

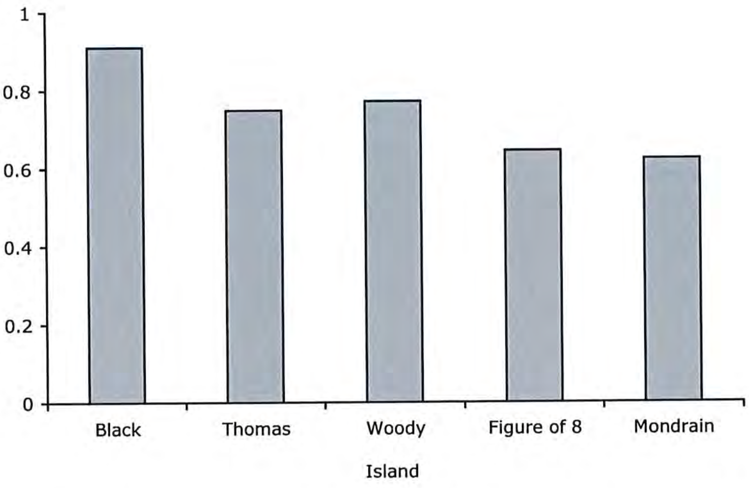


Figure 13: Sponge morphological richness (d) (*Y axis*) for seven of the ten islands assessed to date (n=190 quadrats).

Table 5: Summary statistics of sponge diversity for seven of the ten islands assessed to date.

	Number of morphologies	Number of individuals	Richness (d)	Diversity H' (log e)
Black	4	27	0.910239	1.32466
Thomas	4	55	0.748628	1.046278
Woody	4	49	0.770848	1.092494
Frederick	3	13	0.779742	0.925129
Long	2	7	0.513898	0.59827
Figure of 8	4	105	0.644612	1.122782
Mondrain	4	123	0.623418	1.186666

Morphological types of sponges varied for the seven islands examined to date (low stress value of 0.09) (Figure 14). An ANOSIM testing for patterns in sponge morphology among islands revealed significant patterns (global R value: 0.378) (Table 6).

There was a clear pattern in morphological structure associated with substratum orientation for Figure of 8 and Mondrain Island (low stress value of 0.04) (Figure 15). An ANOSIM testing similarities in sponge morphology between substrata showed significant differences between horizontal and vertical substratum (global R value: 0.771)(Table 6). Massive sponges were more abundant on vertical compared to horizontal habitats (Figure 16).

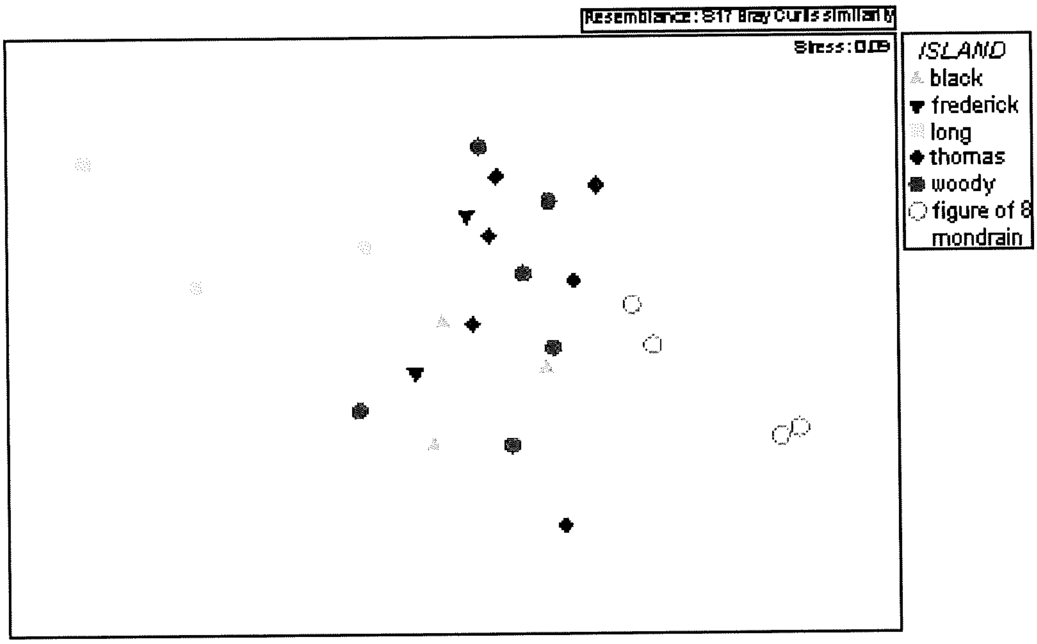


Figure 14: An nMDS plot showing the relationship between sponge morphology and island.

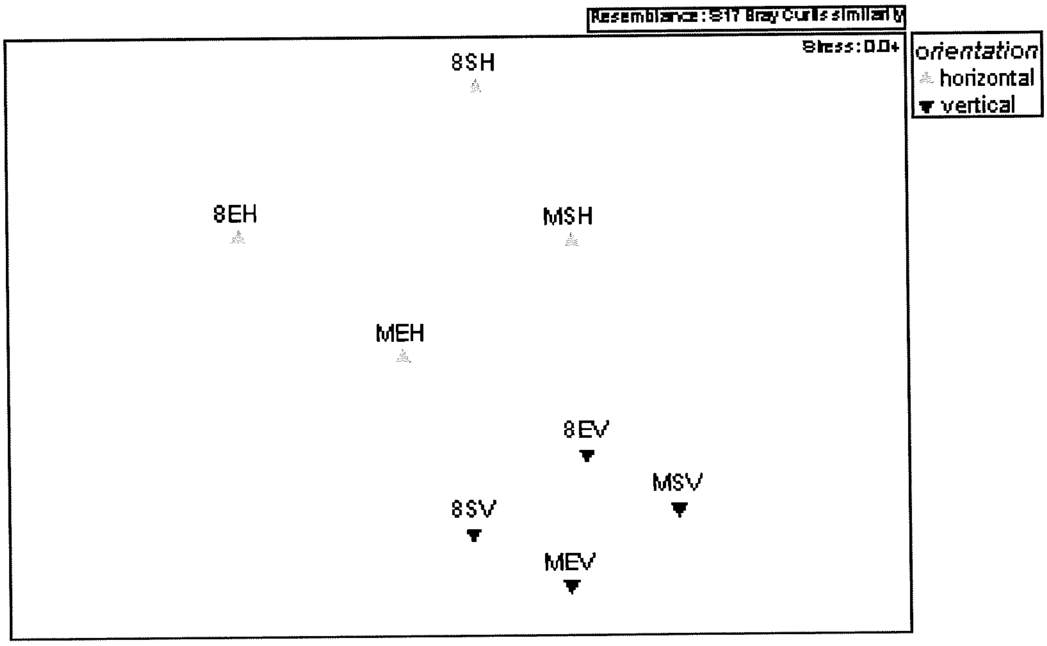


Figure 15: An nMDS plot of Figure of 8 and Mondrain Islands showing groupings of sponge morphology by substratum orientation.

Table 6: ANOSIM results examining patterns in sponge morphology (based on order level data) with islands, exposures and orientation. (All islands = Black, Thomas, Woody, Frederick, Long, Figure of Eight and Mondrain; Islands with 3 depths = Black, Thomas, Woody, Frederick, Long; Islands with 2 strata = Figure of Eight and Mondrain)(* indicates significant).

Morphological data	ANOSIM test	Global R
All islands	***Island similarities***	0.378*
	Exposure similarities	-0.05
Islands with 3 depths	Island similarities	0.183
	Exposure similarities	-0.004
	Orientation similarities	-0.085
Islands with 2 strata	Island similarities	-0.141
	Exposure similarities	0.771*
	Orientation similarities	-0.182

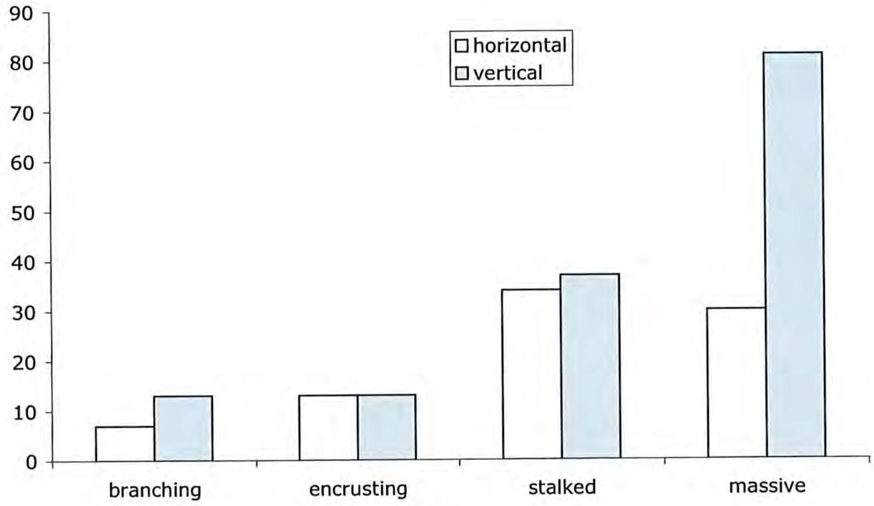


Figure 16: Number of individuals (*Y axis*) in four sponge morphological groups pooled for Figure of 8 and Mondrain islands, highlighting variation in abundance with substrata (n=80quadrats).

ASCIDIANS

Ascidian fauna was dominated by solitary species such as *Herdmania* sp and *Clavelina ostrearium* (Figure 17). The undescribed ascidian fauna consisted mainly of colonial species, the majority of which are likely to be Didemnid species. The introduced pest *Ciona intestinalis* was not observed at any of the sites examined but was found in Bandy Creek Harbour.

Table 7. Percentage of each ascidian species recorded in each depth sampled.

	<10 m	10 to 20 m	> 20 m
Ciona intestinalis	100	0	0
Clavelina ostrearium	0	57	43
Herdmania grandis	35	65	0
Pyura spinifera	0	50	50
Pyura australis	0	0	100
Pyura gibbosa draschii	20	60	20

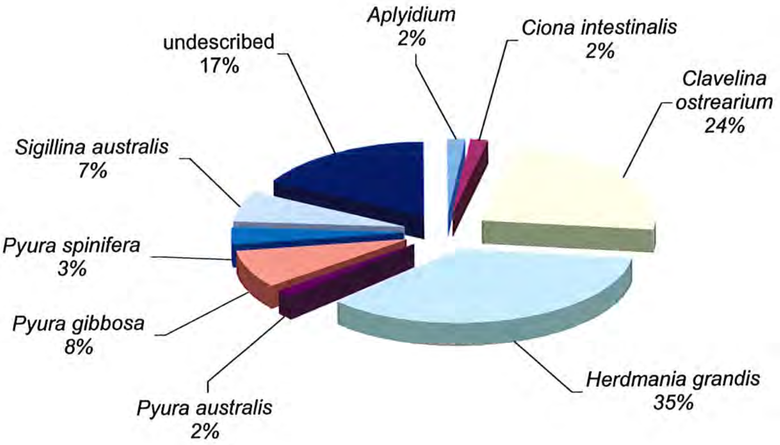


Figure 17: Ascidian species identified as a percentage of total ascidians collected in 2002.

Discussion

The objectives of this study were to investigate the sessile benthic sponge and ascidian communities of the Recherche Archipelago. Within this objective there was a specific aim to determine if there was any pattern in benthic invertebrate assemblages associated with islands, exposure, depth, or substratum orientation. Of the ecological studies that have examined benthic invertebrates and their distributions, most have been conducted in the tropics. Very few have been conducted in temperate environments and none in southern Western Australia. Of the temperate studies, most have described large-scale geographical patterns, often for single species only. Small-scale patterns associated with factors such as exposure and substratum orientation are rarely, if ever addressed. For much of Western Australia, we have no basic knowledge of the species present, or of how they are influenced by abiotic factors. Furthermore the information we have on these groups is largely qualitative.

ALL INVERTEBRATES

This study indicates that the Recherche Archipelago region is highly diverse for all invertebrates. Invertebrate richness varied among islands, however there was no relationship between richness and the number of individuals recorded at any island. Benthic faunal structure differed among islands, with more variability in faunal structure among islands than within an island. The pattern of invertebrate distribution indicates that rather than a continuous distribution of organisms across all islands, there were some islands that lacked the fauna that were present at other islands. For example, Frederick and Long Islands were the only islands lacking both ascidians and bryozoans, clearly highlighted in the MDS plot (Figure 2), showing both Long and Frederick Islands as outlying sites.

There were no patterns in benthic faunal assemblages with exposure (sheltered/exposed), suggesting that there was greater variation within each of the exposures than between exposures. This is likely due to different groups of invertebrates having distinct habitat preferences.

This masking of differences between exposures may be due to the level of taxonomic resolution to which many of the organisms have been processed. As some groups are only to order level, if investigated further (family, genus level) more distinct patterns associated with exposure may be observed.

THE SPONGES

Sponges were highly diverse and were recorded from every island, at sheltered and exposed sites, all depths examined and on both horizontal and vertical substrata. A total of 644 individual sponges from 11 out of 15 recognised orders of Demospongiae were recorded in this study. As with the 'total invertebrate' analyses, there was variation in the richness among islands and no relationship was evident between richness and the number of sponges recorded at any island.

Sponge composition using order level data differed with islands examined. Thomas and Middle Islands had individuals from nine orders, while Black, Long and Twin Peak had only five orders present. There was, however, no difference in sponge composition between exposures indicating that orders were not exposure specific and occurred at both sheltered and exposed sites.

The lack of differences in sponge orders among exposures, depths or substratum orientation indicated that orders were not specific to these categories. This was evident in orders such as the Poecilosclerida, which occurred at every island, exposure, depth and orientation. The absence of pattern may however, be related to the use of high taxonomic (order) level data masking any lower taxonomic variation present at family or genus levels. For groups such as sponges it may be that lower taxonomic level species data, and hence further time and funding, is required to identify any patterns that may exist.

Univariate examination of individual orders revealed that the sponges were dominated by the orders Poecilosclerida and the Dictyoceratida, which combined made up approximately 60% of the sponges identified to date. The Poecilosclerida are one of the most species rich orders in the Demospongiae (akin to the Phaeophyta in the algal realm) and consequently it is not surprising that they were recorded in every island, exposure, depth and orientation, dominating the sponge fauna of the Recherche Archipelago. Despite the cosmopolitan nature of this order, they exhibited distinct preferences for exposure and depth, with significantly more individuals recorded from exposed sites and shallow depths (< 10 m). Several other sponge orders such as the Astrophorida, Haplosclerida and Dendroceratida had significant differences in abundance associated with exposure, depth or substratum orientation indicating a distinct preference in these orders for a particular habitat.

SPONGE MORPHOLOGIES

Sponge morphology was important in the habitat preferences exhibited by the sponges. Sponge morphology is often stated as being influenced by abiotic factors, such as exposure, and as such may be more ecologically relevant for describing patterns observed in sponge communities.

Massive and stalked forms were the most abundant sponge forms recorded. This result was not unexpected as massive and stalked forms are generally more robust, and consequently may not be considered to be habitat specific. That is, these forms may be expected to occur in any habitat sampled, where as delicate branching forms may be unlikely to occur in exposed habitats.

Sponge morphological richness was similar among sites, indicating that all sites had the full complement of sponge forms. The exception was Long Island, which lacked both branching and encrusting species. Absence of branching and encrusting morphologies at Long Island is unexpected given that these forms are highly adaptable, *ie.* not limited by habitat, and are generally found in most habitats regardless of exposure or depth. The absence of these forms may have been an artefact of the sampling used (haphazard quadrat placement missing these forms).

Sponge morphology differed among islands, suggesting that rather than a continuous distribution of morphologies across all islands, there were some islands that possessed more individuals of a particular morphology than others. The observed pattern is likely to have been the result of Long Island lacking both branching and encrusting forms.

There was no difference in sponge morphology between exposures. There was however a clear pattern in sponge morphology associated with substratum orientation. Branching, encrusting, and stalked forms occurred in relatively equal numbers on horizontal and vertical substrata, however massive forms were significantly more abundant on vertical compared to horizontal habitats. The vertical substrata sampled may be subjected to greater water flow. Vertical substrata often lacked the buffering presence of an algal over-storey associated with many of the horizontal habitats. The massive sponge form may persist in exposed habitats as it has greater tolerance in higher energy environments.

The vertical substrata contained more individuals within a defined area than their horizontal counterparts. The absence of algae on many of the vertical surfaces may provide greater available space for sponge colonisation and hence the higher numbers.

ASCIDIANS

The ascidian fauna identified to date was dominated by six species of solitary ascidia belonging to three families, the Cionidae, the Clavelinidae and the Pyuridae. Many samples are still to be identified and consist mainly of colonial ascidians belonging to the family Didemnidae. The species described in this study are common throughout much of Australia's southern temperate waters. See McDonald 2004 in *Appendix 2a* for more details of this group.

This study also identified a population of the introduced pest species *Ciona intestinalis* in Bandy Creek Harbour (see McDonald 2004 – *Appendix 2b* for more details). *Ciona intestinalis* (Linnaeus 1767) has been recorded in most harbours throughout the world (Kott, 1997). Introduced pests such as *Ciona intestinalis* are known to rapidly cover the substratum, smothering and eventually excluding native species (Lambert & Lambert, 1998). Due to the small size of Bandy Creek Harbour, which receives only local traffic, it is hypothesised that the original point of *C. intestinalis* introduction was likely to be the larger port of Esperance that receives both national and international traffic. Once established in a new region, non-native species such as *C. intestinalis* often invade new areas adjacent to the occupied area by natural dispersal e.g. via transport in water currents. This dispersal increases the risk that habitats of high conservation and/or economic value (marine parks, aquaculture sites) will be impacted. The numerical dominance of many invasive organisms has been blamed for the collapse of coastal fisheries worth millions of dollars annually (Bax *et al.,* 2003). The Esperance region has a large tourism and diving industry that has been identified as a key location for many new aquaculture facilities, including proposed abalone and oyster facilities. The potential for *C. intestinalis* to smother and displace native or aquaculture species is well documented (Kang *et al.*, 1978; Cayer *et al.,* 1999) and indicates that if left unmanaged *C. intestinalis* could pose a significant ecological and economic threat to the Esperance region.

CONCLUSIONS

The benthic invertebrate fauna of the Recherche Archipelago is highly diverse. Sponges were by far the most dominant organisms found, with 11 out of 15 orders of Demospongiae recorded in this study. Diversity and richness varied among islands when the distribution of invertebrates was assessed for all fauna, for sponge orders and also for sponge morphology.

At the island level all analyses (all fauna grouped, sponge order and sponge morphology) showed a similar pattern with variation occurring among islands. This pattern suggests that there was no broad uniform Archipelago wide pattern, rather some islands possessed their own suite of fauna, sponge orders or sponge morphologies. Each island was not different to every other, but rather some islands had more of a particular type (order or morphology) than others. The island differences observed in sponge morphology are believed to be due to the absence of two morphological types at Long Island.

There were no patterns in the combined benthic invertebrate distribution, nor sponge order with exposure. The exception was the sponge orders Astrophorida and Poecilosclerida for those islands sampled across two substrata (Figure of 8 and Mondrain) in which there was greater variation between each exposure than within. This may be due to the greater numbers of Astrophorida in sheltered sites, and Poecilosclerida in exposed sites.

There were no global patterns in sponge distribution evident with depth (ie all orders or morphological level). When orders where analysed individually however, the

Haplosclerida had significantly more individuals in waters >20 m deep, while the Poecilosclerida had significantly more individuals in waters <10 m deep, indicating clear habitat preferences for these two orders.

There were no patterns in all fauna or sponge orders associated with substratum orientation. Morphology was the only global factor to show a significant difference with substratum orientation, with massive forms clearly more abundant on vertical than horizontal substrata. The Astrophorida and the Dendroceratida were the only sponge orders to display orientation differences, with significantly more individuals on vertical than horizontal substrata.

The data in this report provides baseline data on the distribution of benthic invertebrates within the Recherche Archipelago. Furthermore it provides data on the distribution patterns in these fauna and sponge morphologies across a range of spatial scales. Sponges were the most dominant benthic fauna present. These animals provide shelter, food and recruitment structures for many organisms including commercial fish, crustacean and mollusc species. The dominance of sponges in the communities investigated was an indication of their capacity to withstand variable and often stressful environmental conditions associated with these regions.

REFERENCES

Bavestrello, G. (2000). Skeletal development in two species of *Tethya* (Porifera, Demospongiae). Italian Journal of Zoology, **67**: 241-244

Bax N., Williamson, A., Aguero, M., Gonzalez, E. & W. Geeves. (2003). Marine invasive alien species: a threat to global biodiversity. Marine Policy. 27: 313-323.

Bowerbank, J.S. (1876). Contributions to a general history of the Spongiadae. Part viii. Proceedings of the Zoological Society, London 1876: 768-775

Cayer, D., MacNeil, M. & A.G. Bagnall. (1999). Tunicate fouling in Nova Scotia aquaculture: A new development. Journal of Shellfish Research, **18** (1), 327.

Colman, J.G. (1997). Biological survey of the major benthic habitats of the south coast (Starvation boat harbour – Groper Bluff): 7-21 March 1997. Data report: MRIP/SC/F – 11/1997

Hooper, J.N.A. & C. Lévi. (1994). Biogeography of Indo-west Pacific sponges, *Microcionidae*, *Raspailiidae*, *Axinellida*e. *In* Soest, R.W.M. van, Kempen, T.M.G. van and Braekman, J.C. (eds), Sponges in time and space, Balkema. Rotterdam :191-212

Kang, P.A., Bae, P.A. & C.K. Pyen. (1978). Studies on the suspended culture of oyster, *Crassostrea gigas* in Korean coastal waters. 5. On the fouling organisms associated with culturing oysters at the oyster culture farms in Chungmu. Bulletin of the Fisheries Research Developmental Agency, Busan, 20, 121-127.

Kott, P., 1997. The Tunicates. In: Marine Invertebrates of Southern Australia, Part I. Editors. S. A. Shepherd and I. M. Thomas, 1092 – 1255.

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**: 59-69

APPENDIX 8.6.2: Solitary Ascidiacea from shallow waters of the Recherche Archipelago, Western Australia

(accepted by: Wells, F.E., Kendrick, G. A. and Walker, D.I. (Ed.) Proceedings of 12th International Marine Biological Workshop: The marine flora and fauna of the Archipelago of the Recherche, Western Australia. W.A. Museum, Perth)

Abstract

This paper reports on the physical characteristics and habitats of six species of solitary ascidian belonging to three families, the Cionidae, the Clavelinidae (Aplousobranchia) and the Pyuridae (Stolidobranchia). These animals were recorded throughout extensive collections made in the Archipelago of the Recherche. These animals remove oxygen and food from the water column and thus must be suitably positioned to maximise any benefits of flow. Water flow however, has the potential to damage or dislodge sessile organisms. This paper discusses gross morphology adaptations such as body shape, presence or absence of stalk, and texture and toughness of the protective test that may confer advantages for each species within their habitat.

Introduction

Members of the Class Ascidiacea (Phylum Tunicata), commonly known as ascidians or sea squirts, are solitary or colonial organisms with a sessile adult and a tailed, free-swimming larva. The ascidia are a conspicuous component of the sessile filter feeding fauna. Australia's ascidian fauna has both temperate and tropical components with an indigenous Gondwanan component found from 35° longitude and 6° latitude (Kott, 1997). Gondwana species are also known from South Africa, New Zealand or have circumpolar distributions (Kott, 1997)

Ascidians have evolved along two main lines, the Aplousobranchia that have a mainly colonial habitat and vegetative replication, and the Stolidobranchia and Phlebobranchia that have enhanced various organs to increase the efficiency of solitary animals. These modifications include increases in branchial sac size and in filtering area by infolding of sac and/or coiling of stigmata, the development of a large digestive gland, an increase in gonad size, and an increase in adhesive qualities and toughness of the test (Kott, 1997). Ascidians in the sub-orders Aplousobranchia and the Stolidobranchia from Australian waters have been described in extensive detail by Kott (1985, 1990 and 1992).

The fauna described in this paper were collected as part of a larger study investigating the sponge and ascidian communities of the Recherche Archipelago, South Western Australia. The Archipelago extends for more than 200 km (approximately 34°S, 122°E) from Figure Eight Island in the west to Middle Island in the east (Figure 1) and represents one of the most southerly regions of WA. Furthermore it is the region where the influence of the relatively warm Leeuwin current that flows down the West coast of Australia declines and the cooler waters of the Southern Ocean have more influence. The islands are primarily granitic, exposed to moderate to high wave energy, and often descend steeply to the seafloor (average depth 50 m). None of the animals reported here have been previously recorded from this region. Many of them had been previously reported to have distributions from Albany, WA to Victoria however no collections had been made from this region to validate these distributions. The information provided in this paper provides valuable distribution records as well as new ecological data on these species.

Methods

The sampling protocol used a partially hierarchical design, which was further stratified by substratum orientation. Sampling within each depth was haphazard, with equal numbers of samples taken from each substratum orientation and depth.

Habitats were sampled at sheltered and exposed sites around an island, and at a range of depths: waters 0-10m, 10-20 m and 20-30m, with equal numbers of replicate samples taken from each location and stratum. A site was defined as sheltered if it was not directly in the path of the prevailing currents and swells; conversely an exposed site was directly influenced by currents and swells.

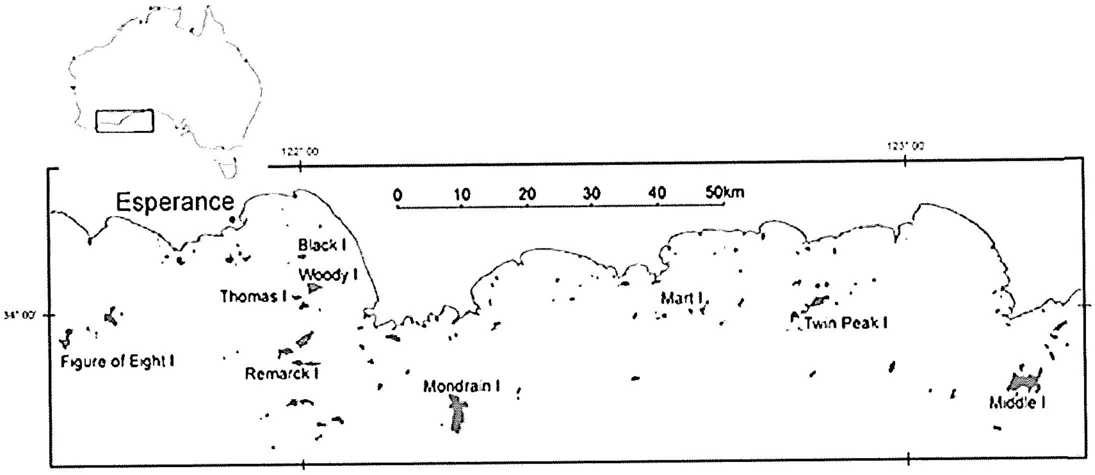


Figure 1: Map of Recherche Archipelago from western most sampling site (Figure of Eight Island) through to eastern extent of sampling (Middle Island).

COLLECTION

All samples were collected by the author on SCUBA. Prior to collection all samples were photographed in-situ to record valuable taxonomic information such as colour and form that can be lost or deteriorate after collection. All samples were placed into labelled calico bags to be processed upon returning to the boat.

Ascidia relaxation and preservation

All samples were relaxed in a menthol solution. The period of relaxation was often relative to the size of the specimen, with larger specimens taking longer to relax than their smaller counterparts. Once all samples reached a relaxed state where the muscles of the openings did not react to stimuli they were fixed in a 70% ethanol solution.

Material was identified using the keys in Kott (1985, 1990 and 1992).

The species recorded in this paper may currently exist in the Western Australian Museum (WAM) collections. However, to the authors knowledge there are no published records of these collections. As such, all discussion related to these species are based upon distributions and ecological recordings made in this study only. Voucher material of all species has been deposited in the Western Australian Museum where they have catalogue numbers WAM Z21256 to Z21261.

Results - Taxonomic descriptions

Systematics

Class Ascidiacea

Suborder Aplousobranchia Lahille, 1887

Family Cionidae Lahille, 1887

Genus *Ciona* Lahille, 1887

***Ciona intestinalis* (Linnaeus, 1767)**

Type species for *Ciona*: *Ascidia intestinalis* (Linnaeus, 1767)

References used for identification: Kott (1990)

WAM number: Z21256

Distribution

The genus *Ciona* is recorded in most harbours throughout the world (Kott, 1997). This species was only found in Bandy Creek Harbour Archipelago of the Recherche (Figure 2). The previously recorded range of this animal along southern Australia is from Cockburn Sound, Albany, Port Adelaide and Port Phillip Bay (Kott, 1990).

Description

Ciona intestinalis is a solitary form with a long cylindrical soft body up to 150 mm long. The body is enclosed in a thin, soft, gelatinous, translucent clear to greenish coloured tunic. The posterior end of the tunic has small projections, or holdfasts, which attach the animal to the substratum. Siphons are variable in length. The inhalant anterior opening into the gut is larger and terminal with 8 lobes. The atrial siphon is smaller and shorter with 6 lobes. Live colour was retained when frozen but lost upon preservation in alcohol (Figure 3a).

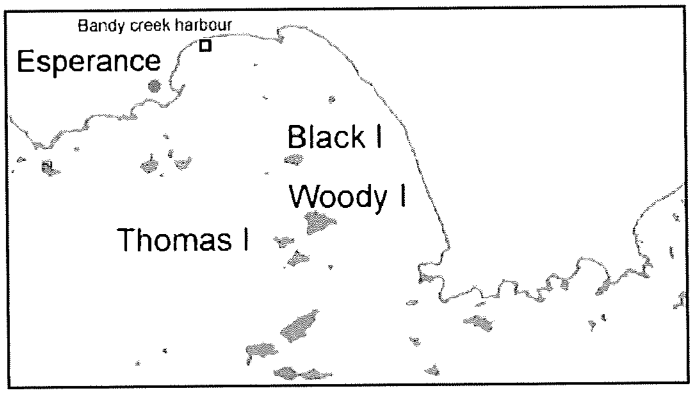


Figure 2. Distribution of *Ciona intestinalis* recorded within the Archipelago of the Recherche (sheltered site □, exposed site ■).

Ecology

Ciona intestinalis is a very common fouling organism in most of Australia's ports. Kott (1997) states that this species is disappearing from many of the locations in which it was once common, with records at that time only from Port Phillip Bay, Victoria. In this study *C. intestinalis* was only found in Bandy Creek Harbour. Animals were at approximately 3 m depth on pylons and the sandy to silty substratum. Individuals are always found crowded together in dense aggregations (approximately 12 animals per 0.25 m^2)(McDonald, 2004). Animals occasionally had epiphytes (alga and other invertebrates) present on the test.

Family Clavelinidae Forbes & Hanley, 1848

Genus *Clavelina* Savigny, 1816

Clavelina ostrearium (Michaelson, 1930)

Type species: *Podoclavella ostrearium* (Michaelsen, 1930)

References used for identification: Kott (1990)

WAM number: Z21257

Distribution

The genus *Clavelina* is well represented in southern Australian waters from Albany in WA to South Australia. This species occurs along the Southern coast of Australia only and has previously been recorded from Oyster Harbour, Albany across the Great Australiana Bight to Nuyts Archipelago in South Australia (Kott, 1990). This species was found throughout much of the shallow coastal waters of the Archipelago of the Recherche. Individuals were recorded at Black Island on exposed horizontal habitat 24 m deep; Thomas Island on sheltered horizontal habitat 20 m deep; Woody Island on exposed horizontal habitat 15 and 22 m deep and sheltered horizontal habitats 15 and 22 m deep; Mondrain Island on sheltered horizontal habitat 15 m deep and one individual at 15 m on vertical substratum; Mart Island on sheltered horizontal habitats 15 m deep (Figure 1).

Description

Clavelina ostrearium is a stalked solitary form. Animals had a short narrow stalk (up to 7 cm in length) and large thorax (up to 4 cm long). The thorax was very dark to translucent blue in colour with a blue stalk (Figure 3 b & c). Colour was retained when frozen. The thorax would retract when preserved giving a much darker colour beneath a clear test.

Ecology

Clavelina ostrearium was recorded in both sheltered and exposed sites in waters greater than 10 m deep. No individuals were recorded at depths shallower than 10 m. The habitat of this species has been reported as open, sandy or rocky substratum in places of slight water movement to a depth of 30m (Kott, 1997). *Clavelina ostrearium* individuals recorded in this study were from horizontal or gently sloping sandy regions overlying a hard granite substratum. Individuals inhabited areas of high algal density, predominantly low lying (<10 cm), red species. The short stature of the algae meant that the stalks of *C. ostrearium* individuals placed them above the algae and as such provided uninterrupted access to the prevailing water flow.

Suborder Stolidobranchia Lahille, 1887

Family Pyuridae Hartmeyer, 1908

Genus: *Herdmania* Lahille, 1888

***Herdmania grandis* (Heller, 1878)**

Type species for *Herdmania*: *Cynthia grandis* (Heller, 1878)

References used for identification: Kott (2002)

WAM number: Z21258

Distribution

The genus *Herdmania* is cosmopolitan, known from the Atlantic, Pacific and Indian Oceans. The species *Herdmania grandis* (Heller, 1878) has been recorded from Papua New Guinea (Monniot & Monniot, 2001) to Burnie, Tasmania (Kott, 2002). Previous records for Western Australia indicate that this species has been found from Port Hedland to Albany (Kott, 2002). This study extends the recorded range for this species along the south coast with collections from Black Island on exposed horizontal habitat 5 m deep; Thomas Island on sheltered horizontal habitat 5 and 15 m deep; Woody Island on exposed horizontal habitat 5 and 15 m deep and sheltered horizontal habitats 5 m deep; Mondrain Island on sheltered horizontal habitat 15 m deep and at 15 m on vertical substratum; Twin Peak Island on sheltered vertical habitat 15 m deep; and Middle Island on exposed vertical habitat 15 m deep (Figure 1).

Description

The species *Herdmania grandis* is the largest known species of the genus *Herdmania* (≥ 18 cm in maximum dimension). This species has a hemispherical to dome shaped robust form with short cylindrical siphons (Figure 3 d).

These animals had an extremely tough opaque leathery test that may contain sand or other small detrital material. It is this test structure that is one of the characters distinguishing *H. grandis* from others in the genera. Once all foreign algal and epiphytic material was removed the opaque test ranged from cream, pale orange to pink in colour. Colour was retained when frozen, but specimens lost their colour and became duller when preserved in alcohol.

Ecology

Herdmania individuals recorded in this study were from sheltered and exposed sites in waters shallower than 20 m. No individuals were recorded beyond this depth. The vast majority of animals were recorded on sponge dominated vertical granite substratum. These regions are often free of sediment and algae and as such represent clear regions for attachment. Unlike many other solitary ascidian *H. grandis* does not have a stalk to place it above algae and other benthos. This problem may be overcome by inhabiting vertical substratum with little or no algae. In addition the apical position of the apertures of the animal provides access to the prevailing water flow. The tests of *H. grandis* individuals were often covered by sponges or other colonial ascidians which may have been utilising these animals as a substratum also placing them into the prevailing water flow.

Genus: *Pyura* Molina, 1782

Pyura spinifera (Quoy & Gaimard, 1834)

Type species *Ascidia spinifera* (Quoy & Gaimard, 1834)

References used for identification: Kott (1985)

WAM number: Z21259

Distribution

This species has been recorded from Busselton WA to Port Jackson in NSW (Kott, 1985). In this study individuals of this species were recorded from Remarck Island on sheltered vertical habitat 20 m deep; and Mondrain Island on sheltered vertical granite habitats 15 m deep (Figure 1).

Description

This species was exclusively found as a stalked solitary form (Figure 3e). In this study animals were recorded up to 100 cm in height. Both inhalent and exhalent siphons are located on the dorsal side of the head, with the branchial aperture directed towards the substratum. This animal is highly conspicuous with a bright yellow to yellow fawn nodulose oval shaped head on a long stalk. The bright colouration of these animals is due to the sponge *Halisarca* encrusting the test and stalk. Individuals were predominantly yellow coloured sponge covering however pale purple/pink specimens have been observed.

The yellow colouration of the animal was retained when frozen, but specimens lost much of their colour becoming duller when preserved in alcohol.

Ecology

In this study *Pyura spinifera* was recorded in both sheltered and exposed sites, at ≤ 20 m depth. Previously it has only been recorded in waters greater than 20 m (Kott, 1985). Kott (1997) states that this species is generally found on sand and rubble substrata in regions of slight to moderate water movement. In the Archipelago of the Recherche however individuals were consistently found attached to the lower regions of vertical granitic rock walls. The height of these animals and their attachment to the base of vertical substratum allowed access to water flow without high currents, often associated with these walls in shallower depths. The height of these animals also placed them above any algae that may have restricted water flow.

Pyura australis **(Quoy & Gaimard, 1834)**

Type species *Ascidia spinifera* (Quoy & Gaimard, 1834)

References used for identification: Kott (1985)

WAM number: Z21260

Distribution

This species has a widespread distribution from Geraldton WA, along the southern coast of Australia, and Tasmania to Port Hacking NSW. Only one *Pyura australis* individual was recorded from Thomas Island on sheltered horizontal habitat 20 m deep (Figure 1).

Description

This species has an oval shaped, often laterally compressed head above a thin whip like stalk (up to 30 cm in height). Both apertures are on the dorsal side of the head. The branchial aperture faces the substratum away from the atrial aperture. *P. australis* was orange/red in colouration with tubercles and longitudinal ridges on the test giving a convoluted or nodulose appearance (Figure 3f). The posterior region of the head is often smooth and rounded. The anterior region of the head may taper gradually to a stalk or end abruptly. The stalk is tough and leathery tapering gently as it reaches the 'holdfast'.

The colouration was retained when frozen, but became less vibrant, often turning yellow to yellow brown when preserved in alcohol.

Ecology

The individual of *Pyura australis* was found in a sheltered site in waters 20 m deep. This species has been recorded in both sheltered and exposed habitats with a maximum recorded depth of 22m at Geraldton WA (Kott, 1985). In the Archipelago of the Recherche this species inhabited sand covered granite substratum with high algal cover dominated by *Ecklonia* and *Cystophera*. It is believed that *P. australis* individuals overcome any restricted water flow beneath the algal canopy by the long whip like stalk that places them above or in the upper regions of the canopy and therefore access to the prevailing water flow. The flexible stalk and tough test allows this animal to move with the algal canopy in response to the water flow without potential damage from algal scouring/abrasion.

***Pyura gibbosa* (Heller, 1878) *draschii* Kott, 1972**

Type species *Pyura pachydermatina* (Millar, 1966)

References used for identification: Kott (1985)

WAM number: Z21261

Distribution

Pyura gibbosa has two subspecies *P. gibbosa gibbosa* recorded from Tasmania north to Moreton Bay, Queensland and *P. gibbosa draschii* recorded from Cockburn Sound in WA to Bass Strait, Victoria. These subspecies differ in micro morphological characters (see Kott, 1985 for characters). In this study individuals of *P. gibbosa draschii* were recorded from Woody Island on sheltered horizontal habitats 5 & 20 m deep; Twin Peak Island on sheltered vertical habitat 15 m deep; and Mart Island on sheltered vertical habitat 15 m deep (Figure 1).

Description

This species resembles *Pyura australis* in that it also has an oval shaped head on a whip like stalk (up to 30 cm in length). Both apertures are on the dorsal side of the head. However it differs from *P. australis* in that the tubercle like structures are sharper and more pronounced. The head is more rectangular, narrowing abruptly to the stalk. The longitudinal ridges in the test of *P. gibbosa draschii* are also more pronounced than in *P. australis*. The test of this animal is also extremely robust and leathery providing protection to internal organs. Colouration was a reticulated orange to purple through to yellow and brown patterns (Figure 3 g & h). Colour was retained when frozen, but became less vibrant, often turning yellow to yellow brown when preserved in alcohol.

Ecology

Pyura gibbosa draschii individuals were recorded from sheltered sites only at all three-depth profiles sampled (<10m, 10 – 20m, > 20m deep). *P. gibbosa draschii* inhabited the same sand covered granite substratum with high algal cover as *P. australis*. It is proposed that *P. gibbosa draschii* also uses its flexible stalk to raise it into or above the algal canopy providing access to the prevailing water flow.

Discussion

Gross morphological characters such as body shape, presence or absence of stalk, and texture and toughness of the protective test have allowed the Ascidiacea to occupy almost every marine habitat. This paper records six species of solitary ascidian from extensive collections throughout the Archipelago of the Recherche. These species belong to three families, the Cionidae, the Clavelinidae and the Pyuridae and are common throughout much of Australia's southern temperate waters. These filter-feeding animals rely upon the surrounding water body to provide them with oxygen and food and thus they must be suitably positioned to maximise the benefits of this flow. Water flow however, has the potential to damage or dislodge sessile organisms, so animals must have adaptations that can overcome these detrimental effects of flow whilst still accessing food and oxygen.

Four of the six species recorded here are stalked individuals inhabiting algal dominated habitats. Clavelina ostrearium was found in both sheltered and exposed sites (60% & 40% distribution respectively), at depths greater than 10 m (Table 1) where they are less likely to be negatively influenced by wave action. Furthermore these animals are low lying (rarely greater than 10 cm in height) and occupy relatively sheltered microhabitats in the shadow of nearby boulders or near the base of vertical elevations. The sheltered microhabitats occupied by C. ostrearium are densely covered by algae but the algal communities are rarely greater than the height of the animal and as such did not appear to restrict water flow to these animals.

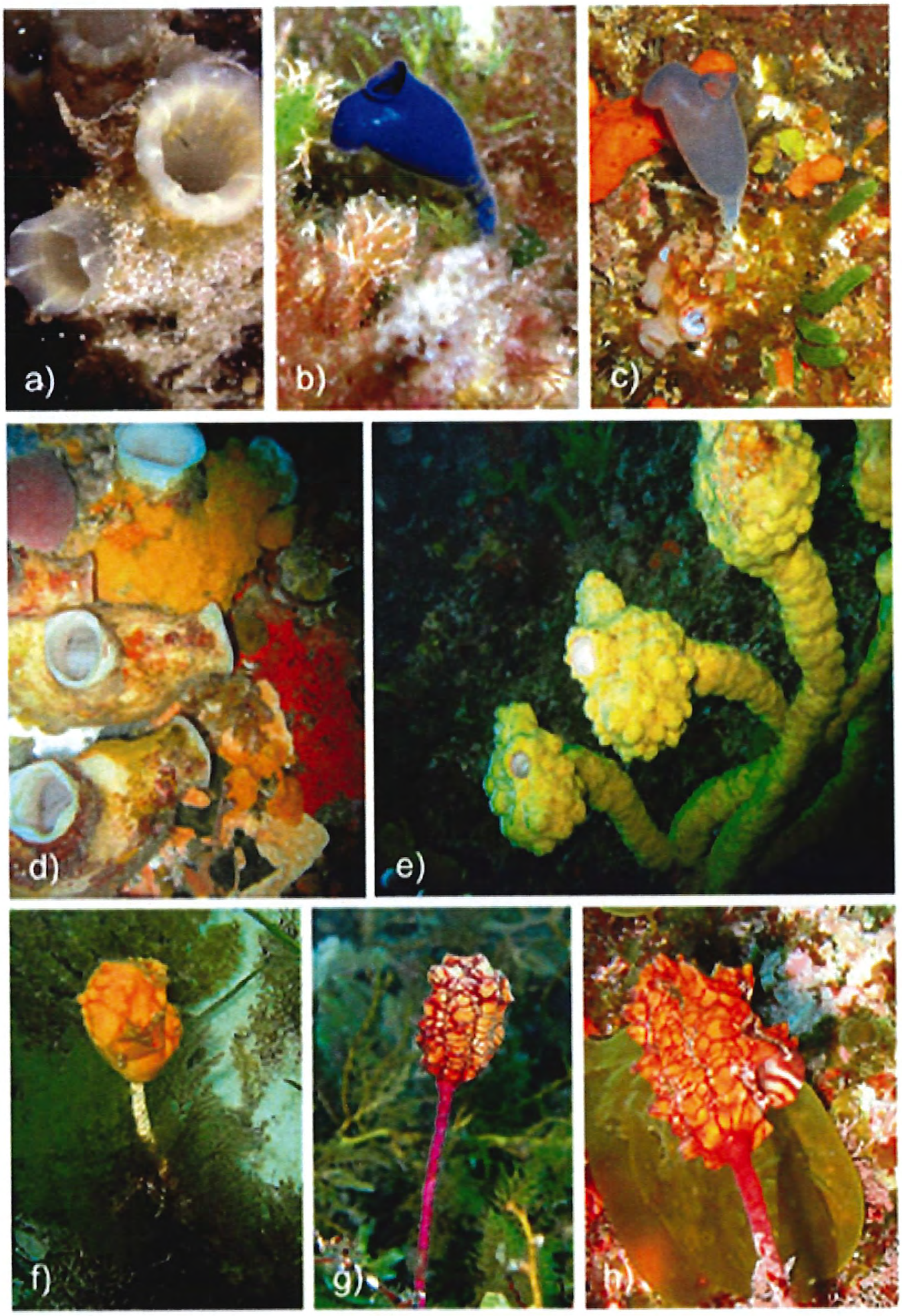


Figure 3. *In-situ* photographs of solitary ascidian species described in this study a) *Ciona intestinalis*; b & c) *Clavelina ostrearium*; d) *Herdmania grandis*; e) *Pyura spinifera*; f) *Pyura australis*; and, g & h) *Pyura gibbosa draschii*.

Table 1. Habitat data for each ascidian species recorded.

Species	Exposure	Depth (& % of individuals recorded at each depth)			Substratum orientation	Substratum type
		<10 m	10 to 20 m	> 20 m		
Ciona intestinalis (n=10)	sheltered	100	0	0	horizontal & vertical	metal pylons & sand
Clavelina ostrearium (n=14)	sheltered & exposed	0	57	43	horizontal & vertical	sand & granite
Herdmania grandis (n=21)	sheltered & exposed	35	65	0	horizontal & vertical	granite
Pyura spinifera (n=6)	sheltered	0	50	50	vertical	granite
Pyura australis (n=1)	sheltered	0	0	100	horizontal	sand covered granite
Pyura gibbosa draschii (n=8)	sheltered	20	60	20	horizontal & vertical	sand covered granite

All *Pyura spinifiera, P. australis* and 80 % of *P. gibbosa draschii* individuals were found in sheltered waters greater than 10 m depth (Table 1). This preference for deep sheltered habitats locates them in regions where they are less likely to be negatively influenced by wave action. Unlike the other two Pyurids *P. spinifera* were only located near the base of vertical substrata away from areas of high water flow and algal canopy. However *Pyura australis* and *P. gibbosa draschii* lived in regions of high algal cover. Potentially this dense algal cover could act as a baffle reducing water flow and a potentially reducing oxygen and food intake of these animals. The use of a long flexible stalk places the inhalant siphons of these animals above the algal baffle allowing access to food and oxygen. The flexible nature of the stalk allows the animals to move with the water flow reducing damage or dislodgement from the substratum. Orientation of inhalant and exhalent siphons on many of these species means that as the animal bends one way with the current its exhalent siphon is placed into the prevailing flow 'dragging' exhalent waste water away from the animal. As the flow changes direction the animal bends and the inhalant siphon is orientated for intake of 'fresh' oxygen and food laden water. The protective leathery test of many of these species provides protection from any abrasion that could occur as these animals move in the current, and prevents damage from algal scouring.

The exceptions to the above are the species *Ciona intestinalis* and *Herdmania grandis*. *Ciona intestinalis* was only recorded in a sheltered harbour location. Individuals were found on both vertical substratum (pylons) and a soft silty/shell horizontal bottom. Both horizontal and vertical substrata were relatively clear of other sessile benthos apart from small amounts of algae, consequently there was no algal canopy to influence water flow. The sheltered harbour also protects these animals from damage or dislodgement that may occur in more exposed locations.

Herdmania grandis was the most abundant species recorded in this study (Figure 4). *Herdmania grandis* lived in both sheltered and exposed sites (60% & 40% distribution respectively) and unlike the three pyurid species was not recorded at depths greater than 20 m (Table 1). This species also inhabited vertical rather than horizontal substratum. Vertical substrata were dominated by sponges and rarely had algae present. However the lack of an algal canopy makes this species more visible to predators and to potential damage from greater water flow. It is proposed that the robust leathery test of H. grandis protects the animal from predation or damage. The animals are also fixed strongly to the substratum and considerable force is required to remove them. In addition the hemispherical shape of these animals, without a stalk, reduces any potential drag they may incur from currents. The use of a stalk on these vertical habitats would confer no obvious advantages as algae were rarely present and there was no reduction in water flow that may limit growth of the animal.

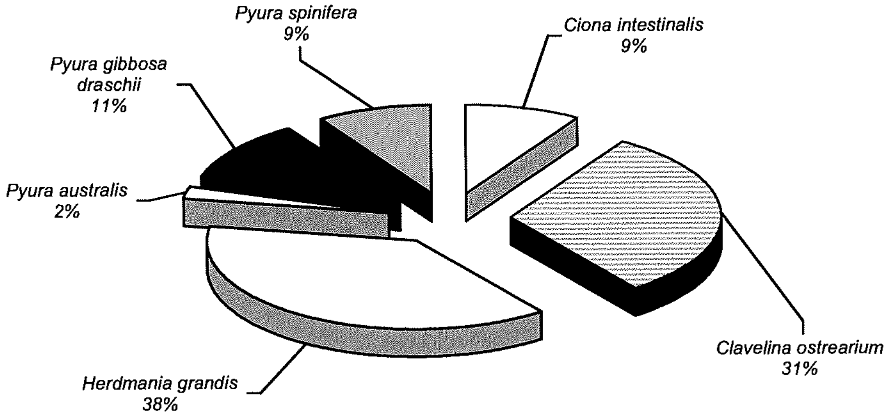


Figure 4. Graphical representation of solitary ascidian fauna collected (% indicate proportion of each species relative to total ascidian fauna recorded).

Acknowledgements

I would like to thank Drs Fred Wells and Gary Kendrick and Professor Di Walker for organising the 12th International Marine Biology Workshop. I also thank Dr Grey Coupland for her comments on this manuscript. This study was jointly funded by a CSIRO SRFME grant (Strategic Research Fund for the Marine Environment) grant awarded to Dr Justin McDonald, Dr Jane Fromont & Dr Gary Kendrick) and FRDC grant (Fisheries Research Development Council 2001/060).

References

Kott, P. 1985. The Australian Ascidiacea. Part 1, Phlebobranchia and Stolidobranchia. *Memoirs of the Queensland Museum* 23: 1-440

Kott, P. 1989. Form and function in the Ascidiacea. *Bulletin of Marine Science* 45 (2): 253-276.

Kott, P. 1990. The Australian Ascidiacea. Part 2, Aplousobranchia (1). *Memoirs of the Queensland Museum* 29 (1): 1-266

Kott, P. 1992. The Australian Ascidiacea. Part 3, Aplousobranchia (2). *Memoirs of the Queensland Museum* 32 (2): 375-620.

Kott, P. 1997. The Tunicates. In: *Marine Invertebrates of Southern Australia, Part I.* S. A.

Shepherd and I. M. Thomas (Eds.). Pp: 1092 – 1255

Kott, P. 2002. The genus *Herdmania* Lahille, 1888 (Tunicata, Ascidiacea) in Australian waters. *Zoological Journal of the Linnean Society* 134: 359 – 374

McDonald, J.I. 2004. The invasive pest species *Ciona intestinalis* (Linnaeus, 1767) reported in a harbour in southern Western Australia. *Marine Pollution Bulletin* 49: 868-870

Appendix 8.6.3 The invasive pest species Ciona intestinalis (Linnaeus, 1767) reported in a harbour in southern Western Australia

Marine Pollution Bulletin

Justin I. McDonald

School of Plant Biology (M090), University of Western Australia, 35 Stirling Highway Crawley, Western Australia, Australia 6009. Email: justinmc@cyllene.uwa.edu.au

Ciona intestinalis (Linnaeus 1767) is a solitary ascidian (Phylum Chordata, Subphylum Tunicata, Sub order Aplousobranchia) that has been recorded in most harbours throughout the world (Kott, 1997). It has been recorded on the coasts of the Mediterranean Sea, Black Sea, northern Europe, the Arctic, Greenland, and the Atlantic coast of North America south to Massachusetts (Kott, 1952). It has been introduced into most major ports including many in the southern hemisphere and has previously been identified as a common fouling organism in many of Australia's ports (Kott, 1990). The vast majority of these reports have, however, been from the eastern coast of Australia or from more westerly ports in Western Australia, such as Albany (Kott, 1990). Kott (1997) stated that *C. intestinalis* appears to be declining from many of the locations in which it was once common, with records at the time of her study only from Port Phillip Bay, Victoria. The reduction in distribution was also supported by later surveys of Hewitt *et al.* (2002). This paper is the first report of *C. intestinalis* in a West Australian harbour for almost ten years.

Marine pests are introduced by a diverse array of vectors along an intricate network of pathways. Shipping ballast water and hull fouling were ranked the highest risk vectors for both international and domestic introductions (APEC Marine Resource Conservation Working Group, 2002). At any given moment it is estimated that 10,000 different species are being transported between biogeographic regions in ballast tanks alone (Carlton 1999).

Introduced species may cause a decline in local biodiversity of species, which is a fundamental global concern. Introduced pests such as *Ciona intestinalis* are known to rapidly cover the substratum, smothering and eventually excluding native species (Lambert & Lambert, 1998). The south west region of Western Australia has previously been described as a relatively pristine environment of great diversity, with high levels of endemism (Morgan & Wells, 1991). Yet much of our knowledge of the southwest fauna is from a limited number of papers, most of which were published more than a century ago (*e.g.* Bowerbank, 1876). Consequently changes to the abundance and diversity of native species resulting from the impact of introduced species may go unnoticed.

The finding of *C. intestinalis* in Bandy Creek was part of a larger study currently being conducted by McDonald, Fromont and Kendrick investigating the sponge and ascidian communities of the Recherche Archipelago. The Recherche Archipelago extends for more than 200 km (approximately 34°S, 122°E) from Figure Eight Island in the west to Middle Island in the east, and represents one of the most southerly regions of WA.

The body of *Ciona intestinalis* was enclosed in a thin, soft, gelatinous, translucent, clear to greenish coloured tunic. Animals had a long cylindrical soft body up to 150 mm long. Similarly Jackson (2000) reported that *C. intestinalis* can grow up to 20 mm month^{-1} to a size of approximately 150 mm. Siphons were variable in length. The inhalant anterior opening into the gut was larger and terminal with eight lobes. The atrial siphon was smaller and shorter with six lobes (Figure 1). *C. intestinalis* is a permanent hermaphrodite with fertilisation occurring externally (Jackson, 2000). Eggs are negatively buoyant and released in mucus strings that tangle and attach to nearby adults, contributing to the dense aggregations of adults (MarLIN, 2004). The posterior end of the tunic had small projections, or holdfasts, which attached the animal to the substratum. In Bandy Creek the substratum for attachment was mainly the wooden and metal pylons of the boat jetty where tight aggregations of these animals were observed. Individuals were however also were observed covering small areas at the base of the pylons anchored to the sand.

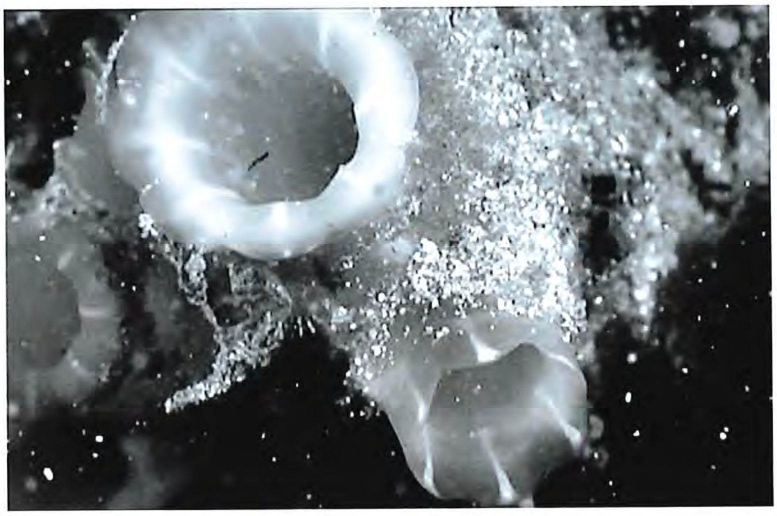


Figure 1: *Ciona intestinalis* photographed *in-situ* in Bandy Creek Harbour (Photograph courtesy of J.E. Watson).

Due to the small size of Bandy Creek Harbour, which receives only local traffic, it is hypothesised that the original point of introduction was likely to be the larger port of Esperance that receives both national and international traffic. The source of *C. intestinalis* inhabiting Bandy Creek Harbour is unknown. DNA comparisons with populations from Port Phillip Bay, Victoria, the last published report of this species in Australia, should be conducted to identify if the bay way the point of origin. It is predicted that *C. intestinalis* will be found at the larger port of Esperance and, given the frequency of boat traffic, may spread to other areas of the Western Australian coastline.

Introduced marine pests, such as *C. intestinalis,* can be significant stressors, often forcing changes in their new marine communities. *Ciona intestinalis* is well documented as a dominant, smothering species that rapidly covers the substratum, often to this exclusion of native species (Petersen & Riisgard, 1992; Riisgard *et al.,* 1998). In southern California, *Ciona intestinalis* has influenced the environment to such an extent that it dominates shallow water habitats and now much of the native fauna is completely absent or very rare (Lambert & Lambert, 1998). The aggregations of *Ciona intestinalis* recorded from Bandy Creek Harbour were few and scattered. The scattered nature of these animals may indicate that this 'invasion' has not been present for a long period of time and as such may have the potential to be controlled.

It is often stated that it is easier to prevent marine introductions rather than eliminating or controlling them. Once established in a new region, non-native species often invade new areas adjacent to the occupied area by natural dispersal e.g. via transport in water currents in the case of many seaweeds and phytoplankton. Increasing spread increases the risk that habitats of high conservation and/or economic value (marine parks, aquaculture sites) will be impacted. Hewitt *et al.*, (2002) identify that Australia is already known to host over 250 exotic marine species with 92 reported from WA. In most cases the threat posed by these exotic species is not known. The numerical dominance of invasive organisms has been blamed for the collapse of coastal fisheries worth millions of dollars annually (Bax *et al.*, 2003). The Esperance region has been identified as a key location for many new aquaculture facilities, including proposed abalone and oyster facilities. The potential for *C. intestinalis* to smother and displace native or aquaculture species is well documented (Kang *et al.*, 1978; Cayer *et al.*, 1999; Clarke & Castilla, 2000) and indicates that if left unmanaged *C. intestinalis* could pose a significant ecological and economic threat to the Esperance region.

ACKNOWLEDGEMENTS

I would like to thank Dr Grey Coupland for her comments on this manuscript. This research was made possible under the Fish Resources Management Act 1994, Section 7 (3) and the Wildlife Conservation Act 1950, Regulation 17. This work is part of a larger study examining the sponge and ascidian communities of the Recherche Archipelago and is funded by a CSIRO SRFME grant (Strategic Research Fund for the Marine Environment) awarded to Dr Justin McDonald, Dr Jane Fromont & Dr Gary Kendrick.

REFERENCES

APEC Marine Resource Conservation Working Group. (2002). Development of a regional risk management framework for APEC economies for use in the control and prevention of introduced marine species – Final report. Editors. Williamson, A.T., Bax, N.J., Williamson, A., Aguero, M., Gonzalez, E., & W. Geeves. 2003. Marine invasive alien species: a threat to global biodiversity. Marine Policy. 27: 313-323.

Bowerbank, J.S. (1876). Contributions to a general history of the Spongiadae. Part viii. Proceedings of the Zoological Society, London, 768-775

Carlton, J.T. (1999). The scale and ecological consequences of biological invasions in the world's oceans. In: Sandlund, O.T., Schei, P.J., Viken, A., Editors. Invasive species and biodiversity management. Dordrecht: Kluwer Academic Publishers, 195-212.

Cayer, D., MacNeil, M. & A.G. Bagnall. (1999). Tunicate fouling in Nova Scotia aquaculture: A new development. Journal of Shellfish Research, 18 (1), 327.

Hewitt C.L., Martin R.B., Sliwa C., McEnnulty, F.R., Murphy, N.E., Jones T. & S. Cooper. (2002). Editors. National Introduced Marine Pest Information System. Web publication <http://crimp.marine.csiro.au/nimpis>, Date of access: 27-May-2004.

Jackson, A. (2000). *Ciona intestinalis* a sea squirt. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [online]. Plymouth: Marine Biological Association of the United Kingdom. Web publication: <http://www.marlin.ac.uk>, Date of Access: 5/25/2004.

Kang, P.A., Bae, P.A. & C.K. Pyen. (1978). Studies on the suspended culture of oyster, *Crassostrea gigas* in Korean coastal waters. 5. On the fouling organisms associated with culturing oysters at the oyster culture farms in Chungmu. Bulletin of the Fisheries Research Developmental Agency, Busan, 20, 121-127.

Kott, P. (1953). The ascidians of Australia. Australian Journal of Marine and Freshwater Research, 3, 206-333.

Kott, P. (1990). The Australian Ascidiacea. Part 2: Aplousobranchia (1). Memoirs of the Queensland Museum, 29, 1-266.

Kott, P. (1997). The Tunicates. In: Marine Invertebrates of Southern Australia, Part I. Editors. S. A. Shepherd and I. M. Thomas, 1092 – 1255.

Lambert, C.C. & G. Lambert. (1998). Non-indigenous ascidians in southern California harbors and marinas. Marine Biology, 130, 675-688.

Morgan, G.J. & F.E. Wells. (1991). Zoogeographic provinces of the Humboldt, Benguela and Leeuwin current systems. Journal of the Royal Society of Western Australia, 74, 59-69.

Petersen, J.K. & H.U. Riisgard. (1992). Filtration capacity of the ascidian *Ciona intestinalis* and its grazing impact in a shallow fjord. Marine Ecology Progress Series, 88, 9-17.

Riisgard, H.U., Jensen, A.S. & C. Jurgensen. (1998). Hydrography, near-bottom currents, and grazing impact of the filter-feeding ascidian *Ciona intestinalis* in a Danish Fjord. Ophelia, 49 (1), 1-16.

APPENDIX 8.6.4: Asteroidea from shallow waters of the Recherche Archipelago

(accepted by: Wells, F.E., Kendrick, G. A. and Walker, D.I. (Ed.) Proceedings of 12th International Marine Biological Workshop: The marine flora and fauna of the Archipelago of the Recherche, Western Australia. W.A. Museum, Perth)

Justin I. McDonald[1*] & Loisette Marsh[2]

1* Corresponding author: School of Plant Biology (M090), Faculty of Natural & Agricultural Sciences, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009. Email: justinmc@cyllene.uwa.edu.au

2. Department of Aquatic Zoology, Western Australian Museum, Locked Bag 49, Welshpool, Western Australia 6986

ABSTRACT

This paper describes twelve species of sea star belonging to six families, the Asterinidae, Asteropseidae, Echinasteridae, Goniasteridae, Ophidiasteridae, Oreasteridae. Furthermore it presents valuable information on habitat and distribution of each species throughout the Recherche Archipelago.

Introduction

The asteroidea, commonly known as sea stars or starfish, are cosmopolitan animals occurring in all of the world's oceans and seas. It is estimated that there are more than 7000 species of Echinoderms, of which approximately 1500 are living species of Asteroidea (sea star) (Zeidler & Shepherd 1982). Within Australia's southern waters 34 species have been recorded in depths less than 30 m, with approximately 17 more species known to occur in deeper waters of the continental shelf (Zeidler & Shepherd 1982).

This paper presents ecological and geographical information on twelve species of sea star recorded from extensive collections throughout the Recherche Archipelago.

Many of the animals recorded in this study have been previously identified as having distributions from Albany to Victoria, however, no collections and therefore no validations of these statements have been made from this region. The fauna described in this paper were collected as part of a larger study investigating the sponge and ascidian communities of the Recherche Archipelago.

Study site

The Recherche Archipelago extends for more than 200 km (approximately 34°S, 122°E) from Figure Eight Island to Middle Island (Figure 1) and represents one of the most southerly points of Western Australia. Furthermore it is the region where the influence of the relatively warm Leeuwin currents declines and the effects of the cooler waters of the Southern Ocean predominate. The islands are primarily granitic, exposed to moderate to high wave energy, and often descend steeply to the seafloor (average depth 50 m).

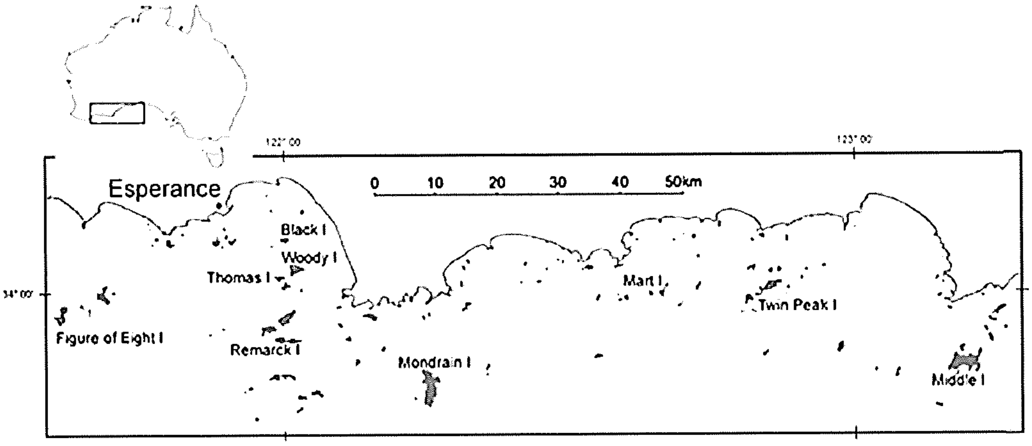


FIGURE 1: Map of Recherche Archipelago from western most sampling site (Figure of Eight Island) through to eastern extent of sampling (Middle Island).

Methods

Habitats were sampled at sheltered and exposed sites adjacent to an island, and at a range of depths: waters 0-10 m deep, 10-20 m deep and 20-30 m deep. A site was defined as sheltered if it was not directly in the path of the prevailing currents and swells. Conversely an exposed site was directly influenced by currents/swells.

COLLECTION

All sampling was conducted by a team of divers using SCUBA. All samples were photographed *in-situ* to record valuable taxonomic information such as colour that can be lost after preservation. Imagery was recorded using a high-resolution digital camera in an underwater housing.

All of the specimens discussed in this paper were identified from photographic imagery. All species were identified on the basis of their morphological features, colours, habitat, and postures, the characters commonly used by field researchers. All material was identified by the second author from the Western Australian Museum (WAM). All information relating to type species was obtained from Rowe & Gates (1995).

The species recorded in this paper may currently exist in the Western Australian Museum (WAM) collections. However, there are no published records of these collections from the Recherche Archipelago region. As such, all discussion related to these species are based upon distributions and ecological recordings made in this study and published data.

Abbreviations used in this paper: AM – Australian Museum, Sydney Australia; BMNH – Natural History Museum, London, England; MCZ – Museum of Comparative Zoology, Harvard University, Cambridge Massachusetts, USA; MNHP – Museum of Natural History Paris, France; SAMA - South Australian Museum Adelaide, Australia; WAM – Western Australian Museum, Perth Western Australia; ZMB – Museum für Naturkunde an der Universität, Humbolt zu Berlin, Berlin Germany.

Systematics

Class: Asteroidea

Family: Asterinidae Gray, 1840

Genus: *Pseudonepanthia* A.H. Clark, 1916

Pseudonepanthia troughtoni (Livingstone, 1934)

Type species for *Psuedonepanthia*: *Pseudonepanthia gotoi* H.L. Clark 1916

Species holotype catalogue number: AM J3978

Distribution

Pseudonepanthia troughtoni is a common sea star endemic to the southern Australian coastline (Zeidler & Shepherd, 1982) and comprised 8% of the sea stars recorded here. It has a recorded distribution of Green Head, WA (Rowe & Gates, 1995) to Wilsons Promontory, Victoria and King Island and the Kent Group in Tasmania (Zeidler & Shepherd, 1982). In this study, individuals of this species were recorded from New Island, sheltered habitat at 20 m; Mondrain Island, sheltered habitat at 15 m; Twin Peak Island, sheltered habitat at 15 m; Mart Island, sheltered habitat at 15 m; Middle Island, exposed habitat at 15 m and seagrass habitat at 15 m (Figure 1, Table 1).

Description

Pseudonepanthia troughtoni is a moderate to large species with a maximum recorded arm radius of 70 mm. Animals have five long, rounded and slightly tapering arms covered by small dorsal plates that are rhombic in shape without major gaps in the skeletal network. The majority of these plates have small spinelets, with spinelets on the underside of the plates arranged into tufts or fans (Zeidler & Shepherd, 1982). The dorsal surface is generally pale pink to orange in colour (Figure 2 a).

Ecology

Pseudonepanthia troughtoni is found on exposed reef habitats from 0 to 73 m in depth (Rowe & Gates, 1995). Individuals in this study were recorded from both sheltered and exposed habitats in waters 15 to 20 m deep. These habitats were generally dominated by encrusting coralline and filamentous red algae. Algae were always low lying (< 3 cm in height). Other invertebrates recorded in the same vicinity included species of bryozoan (*Orthoscuticella* sp.) and encrusting sponges, which were found in all regions occupied by this species. Individuals are often small and occupy cryptic habitats *eg*. under rocks or ledges during daylight. It is reported to feed on encrusting animals such as sponges (Edgar, 1997).

Class Asteroidea

Family Asteropseidae Hotchkiss and Clark, 1976

Genus *Petricia* Gray, 1847

Petricia vernicina (Lamarck, 1816)

Type species for *Petricia*: *Petricia punctata* Gray 1847

Species holotype catalogue number: MNHP

Distribution

This species has a large distribution from Houtman Abrolhos, WA to Caloundra, Qld, and around Tasmania (Zeidler & Shepherd, 1982). It has also been recorded at Lord Howe Island, Norfolk Island and the Kermadec Islands (Edgar, 1997). Individuals of this species comprised

3% of the sea stars recorded and were recorded from New Island, sheltered habitat at 15 m (Figure 1, Table 1).

Description

This species has a soft almost rubbery appearance due to its thick smooth skin. *Petricia vernicina* has a maximum recorded arm radius of 90 mm. It has small surface plates covered by a smooth, tough skin. The central disc of this sea star is large in comparison with the size of the arms (Zeidler & Shepherd, 1982). This species varies in colour from dull brown, orange to a vibrant red (Figure 2 b).

Ecology

Petricia vernicina is found on reef habitats from 0 to 60 m in depth (Zeidler & Shepherd, 1982). This species has been recorded on both sheltered and fully exposed reefs. In this study *P. vernicina* was recorded from sheltered sites within New Island. They were found on vertical walls and under ledges with very little or no algal cover. When algae were present, they were very sparse and low-lying (< 3 cm in height). However, encrusting coralline algae were often abundant. Sponges, both encrusting and massive forms were also present along with species of bryozoan (*Orthoscuticella* sp.) and colonial ascidia. *Petricia vernicina* is reported as feeding on encrusting invertebrates, particularly sponges, ascidians and bryozoans (Zeidler & Shepherd, 1982; Edgar, 1997).

Family Echinasteridae Verrill, 1867

Genus *Echinaster* Müller and Troschel, 1840

Echinaster arcystatus H.L. Clark, 1914

Type species for *Echinaster*: *Asterias seposita* Lamarck 1816

Species holotype catalogue number: WAM 4918

Distribution

This species has a large distribution from Shark Bay, WA, along the southern coast of Australia, the Kent Group, Tas to Montague Island, NSW (Edgar, 1997). Individuals of this species comprised 7% of the sea stars recorded and were from New Island, exposed habitat at 15 m; Thomas Island, sheltered habitat at 20 m; Mart Island, exposed algal dominated habitat at 20 m; Middle Island, exposed habitat at 15m (Figure 1, Table 1).

Description

This species has a mosaic like network of skeletal ridges bearing small light coloured spines highlighted against a darker background. *Echinaster arcystatus* has a maximum recorded radius of 180 mm (Zeidler & Shepherd, 1982). Dense papulae protrude from the meshes giving the animal a slippery feel when handled alive (Edgar, 1997). Colouration on the reticulated ridges ranged from dull yellow to dark red or brown (Figure 2 c).

Ecology

Echinaster arcystatus is found on exposed reef habitats from 0 to 46 m in depth (Rowe & Gates, 1995). In this study they were recorded from approximately 15 to 20 m in depth from islands near to the mainland and from those further offshore. They were found in both sheltered and exposed habitats that were dominated by large amounts of low-lying (< 3cm in height) algae. Algae were predominantly filamentous red species, however *Caulerpa scapelliformis* was also recorded. *Echinaster arcystatus* is reported to feed on encrusting sponges as well as molluscs and detritus (Zeidler & Shepherd, 1982). Encrusting sponges were often found under algae near the animals, however these sponges were neither abundant nor large in size.

Echinaster glomeratus H.L. Clark, 1916

Type species for *Echinaster*: *Asterias seposita* Lamarck 1816

Species holotype catalogue number: AM J1624

Distribution

This species has a distribution from the Houtman Abrolhos, WA, to Cape Jervis, SA (Zeidler & Shepherd, 1982). Individuals of this species comprised 3% of the sea stars recorded and were from Long Island, exposed habitat at 15 m; Mart Island, exposed habitat at 15 m (Figure 1, Table 1).

Description

Echinaster glomeratus is very similar to *E. arcystatus* however this species is distinguished by the clusters of small spines embedded in the skin of the dorsal surface (Zeidler & Shepherd, 1982). *Echinaster glomeratus* has a maximum recorded radius of 150 mm (Edgar, 1997). Colour varies from yellow to a dark red (Figure 2 d).

Ecology

Echinaster glomeratus is found on exposed reef habitats from 0 to 64 m in depth (Rowe & Gates, 1995). This sea star is reported to live in the open, but is rarely seen by most divers (Edgar, 1997). In this study they were recorded from two islands that are quite far apart geographically. At both Long and Mart Islands they were found on steeply sloping to vertical substratum in exposed habitats. The substratum consisted mainly of encrusted sand trapped in fine filamentous algae (<3 cm in height). Like many other species of sea star on subtidal rocky reefs, *Echinaster glomeratus* may also feed on sponges, ascidians and/or bryozoans, however this has yet to be documented.

Echinaster varicolor H.L. Clark, 1938

Type species for *Echinaster*: *Asterias seposita* Lamarck 1816

Species holotype catalogue number: MCZ 3339

Distribution

This species has been recorded from Broome to the Recherche Archipelago, WA (Edgar, 1997). Individuals of this species comprised 6% of the sea stars recorded and were from Thomas Island, sheltered habitat at 20 m; Remarck Island, sheltered habitat at 15 m; Mondrain Island, sheltered habitat at 15 m (Figure 1, Table 1).

Description

Echinaster varicolor is one of the largest and most conspicuous species along this region of coastline (Zeidler & Shepherd, 1982). It has a small disc with long arms to a maximum radius of 110 mm (Edgar, 1997). In southern waters its colour ranges from reddish to brown with black spots regularly arranged over the upper surface (Figure 2 e). On the north-west coast of Western Australia the colour ranges from orange with darker spots to grey with dark blue spots and it reaches 200 mm in arm radius.

Ecology

Although this sea star is reported to live in the open *E. varicolor* is not a common species, and is only occasionally seen by divers. It has previously been found on sheltered to moderately exposed reef and seagrass habitats from 1 to 50 m in depth (Edgar, 1997). In this study they were only found in sheltered habitats. However, the substratum type was varied. Animals were recorded on *Turbinaria* coral, sand encrusted boulders with filamentous algae, and on vertical substratum dominated by *Rhipiliopsis* sp., *Codium spongiosum* and *Tylotus obtusa. Echinaster varicolor* is expected to feed on sponges, ascidians and/or bryozoans, however this has yet to be documented.

Genus *Plectaster* Sladen, 1889

Plectaster decanus (Müller & Troschel, 1843)

Type species: *Echinaster decanus* Müller & Troschel, 1843

Species syntype catalogue numbers: ZMB 751-753

Distribution

This species has been recorded from Two Rocks, WA to Byron Bay, NSW (Zeidler & Shepherd, 1982), including the north coast of Tasmania (Rowe & Gates, 1995). Individuals of this species comprised 18% of the sea stars recorded here and were from New Island, sheltered habitat at 20 m; Thomas Island, sheltered habitat at 15 & 20 m and exposed habitat at 15 m; Long Island, sheltered habitat at 15 & 20 m; Figure of Eight Island, sheltered habitat at 20 m; Mondrain Island, sheltered habitat at 15 m and exposed habitat at 20 m; Twin Peak Island, sheltered habitat at 15 m; Middle Island, exposed at 15m and sheltered habitat at 15 m (Figure 1, Table 1).

Description

Plectaster decanus is a highly patterned species with rows of low granules forming a network mosaic of coloured ridges across the upper surface of the animal. It has a maximum recorded arm radius of 120 mm (Zeidler & Shepherd, 1982). Arms are long, tapering and cylindrical. Its Ridges are red to orange surrounding purple or red almost hexagonal shaped papule clusters (Figure 2 f).

Ecology

Plectaster decanus has previously been found on sheltered to moderately exposed reef habitats from 0 to 200 m in depth (Edgar, 1997). In this study they were recorded on steeply sloping, vertical walls and under ledges from both sheltered and exposed habitats. Substratum varied from 100 % cover of *Turbinaria* coral to areas dominated by encrusting coralline algae. As with many sea star species on subtidal rocky reefs, *Plectaster decanus* may feed on sponges, ascidians and/or bryozoans, however this has yet to be documented. However, in every record of these animals in this study they were always found in close proximity to the bryozoan genera *Orthoscuticella* and *Vittaticella*, both from the order Cheilostomata.

Family Goniasteridae Forbes, 1841
Genus *Tosia* Gray, 1840
Tosia australis (Gray, 1840)

Type species: *Tosia australis* Gray 1840
Species holotype catalogue number: BMNH 1843.3.10.26

Distribution

This species has been recorded from Kalbarri, WA (Rowe & Gates, 1995) to southern NSW (Zeidler & Shepherd, 1982) and around Tasmania (Edgar, 1997). Individuals of this species comprised only 1% of the sea stars recorded and were from Middle Island, sheltered seagrass habitat at 15 m (Figure 1, Table 1).

Description

Tosia australis is a firm bodied animal, with 6 (rarely 8) plates on margins of the upper body forming a pavement effect (Zeidler & Shepherd, 1982). It has shallow interbrachial arcs that give the body a distinct pentagonal shape. It has a maximum arm radius of 50 mm (Edgar, 1997). This species is often referred to as a biscuit star. Its colour varies from brown, pink, mauve to purple (Figure 2 g).

Ecology

Tosia australis is reported from sheltered and moderately exposed reef habitats from 0 to 40 m in depth (Edgar, 1997). It is often found on jetty piles. In more exposed regions the plates at the ends of the arms may be slightly more swollen (Zeidler & Shepherd, 1982). In this study it was recorded from a sheltered habitat dominated by the seagrass *Posidonia australis*.

Tosia australis feeds mainly on sponges, ascidians, bryozoans, detritus and algae (Zeidler & Shepherd, 1982), present within its seagrass habitat.

Genus *Pentagonaster* Gray, 1840

Pentagonaster dubeni Gray, 1847

Type species: *Pentagonaster pulchellus* Gray 1840
Species holotype catalogue number: BMNH 1846.6.7.27

Distribution

This species has been recorded from Shark Bay, WA to southern Qld and around Tasmania (Edgar, 1997). Individuals of this species comprised 13% of the sea stars recorded and were from Thomas Island, exposed habitat at 20 m; Long Island, sheltered habitat at 20 m; Remarck Island, exposed habitat at 15 m; Figure of Eight Island, sheltered & exposed habitats at 20 m; Sandy Hook Island, sheltered habitat at 20 m; Mondrain Island, sheltered habitat at 15 m; Mart Island, sheltered habitat at 15 m (Figure 1, Table 1).

Description

Pentagonaster dubeni is another firm-bodied animal, with highly visible plates on margins of the upper body. It has a distinct star shaped flattened body covered with smooth rounded plates. Interbrachial arcs have between 8 and 20 large, prominent marginal plates (Zeidler & Shepherd, 1982). Distal supero-marginal plates may be enlarged (Zeidler & Shepherd, 1982). It has a maximum arm radius of 75 mm, however the length of these arms can vary considerably between locations (Zeidler & Shepherd, 1982). This species, like *Tosia australis*, is often referred to as a biscuit star. It is easily recognised by its yellow, orange or red plates separated by thin white or yellow lines of granules (Figure 2 h).

Ecology

Pentagonaster dubeni is recorded on sheltered and moderately exposed reef habitats from 0 to 160 m in depth (Rowe & Gates, 1995). This species is most often observed in shallow sheltered bays. They were recorded from most islands within the Archipelago in both sheltered and exposed habitats. The majority of the animals were recorded on vertical substratum dominated by sponges, however one animal was found in the open on a sloping sandy substratum with the alga *Caulerpa cactoides*. *Pentagonaster dubeni* feeds mainly on sponges, ascidians, bryozoans and algae and was often found on, or directly adjacent to these animals (Zeidler & Shepherd, 1982).

Family Ophidiasteridae Verrill, 1867

Genus *Fromia* Gray, 1840

Fromia polypora H.L. Clark, 1916

Type species: *Asterias milleporella* Lamarck 1816

Species holotype catalogue number: AM E5018

Distribution

This species has been recorded from the Houtman Abrolhos WA to Sunshine Beach Queensland (Rowe & Gates, 1995), and around Tasmania (Edgar, 1997). Individuals of this species comprised 10% of the sea stars recorded and were from New Island, sheltered habitat at 20 m; Mondrain Island, sheltered habitat at 15 and 20m and exposed habitat at 15 m; Long Island, exposed habitat at 15 m; Sandy Hook Island, sheltered habitat at 10 m; Middle Island, sheltered seagrass habitat at 15 m (Figure 1, Table 1).

Description

Fromia polypora is an easily seen species. It has a maximum arm radius of 110 mm (Edgar, 1997). Arms are long, tapering and cylindrical, orange to yellow in colour and flecked with black papulae (Figure 2 i).

Ecology

Fromia polypora is a common species found on exposed reef habitats from 0 to 160 ms in depth (Edgar, 1997). They were found predominantly in sheltered habitats, with the exception of one individual recorded at an exposed site. Animals were easy to spot due to their colouration against the background, furthermore these animals tended to occur on more open areas of vertical rock walls. Substratum typically had low algal cover, and where algae were present they were filamentous reds, encrusting coralline or branching coralline such as *Amphiroa* sp. The vast majority of the habitats upon which these animals were recorded were covered in encrusting sponges. The diet of *Fromia polypora* is reported to consist mainly of sedentary invertebrates such as sponges and ascidians (Edgar, 1997).

Family Oreasteridae Fisher, 1911

Genus *Nectria* Gray, 1840

Nectria saoria Shepherd, 1967

Type species: *Asterias ocellifera* Lamarck 1816

Species holotype catalogue number: SAMA K670

Distribution

This species has been recorded from Fremantle, WA to Port Phillip Bay, Vic (Edgar, 1997). Individuals of this species comprised 4% of the sea stars recorded and were from Mart Island, exposed habitat at 15 m; Middle Island, sheltered and exposed habitats at 15m (Figure 1, Table 1).

Description

Nectria saoria has a body that is elevated relative to the arms. It is a distinct large five armed species with a maximum arm radius of 83 mm (Zeidler & Rowe, 1986), however the length of these arms can vary considerably between locations. It is easily distinguished by the prominent dorsal arm plates near the arm tip that may be as large as the tabulae on the disc (Zeidler & Shepherd, 1982). Arms are often rounded on the upper surface. Colouration is generally a bright orange to rose red with black papular areas (Figure 2 j).

Ecology

Nectria saoria is the most common of the *Nectria* species and is reported from exposed reef habitats ranging from 0 to 30 m in depth (Edgar, 1997). This species was recorded in both sheltered and exposed habitats. This species primarily occupied the base or lower regions of the granitic boulders that characterise much of this region. Substratum ranged from open regions of sand to areas of encrusting sand mixed with patchy gelatinous red algae. Small individuals of *Cystophora* sp. were also recorded near these animals. *Nectria saoria* is reported to feed on sponges, ascidians, bryozoans and algae (Zeidler & Shepherd, 1982).

Nectria wilsoni Shepherd & Hodgkin, 1965

Type species: *Asterias ocellifera* Lamarck 1816

Species holotype catalogue number: WAM 3-65

Distribution

This species has been recorded from Beagle Island, WA to Lakes Entrance, Vic (Edgar, 1997). Individuals of this species comprised 14% of the sea stars recorded and were from Mondrain Island, sheltered habitat at 10 and 15 m and exposed habitat at 20 m; Long Island, sheltered habitat at 20 m; Remarck Island, sheltered and exposed habitats at 15 m; Mart Island, exposed habitat at 15 m; Middle Island, sheltered habitat at 15m and sheltered seagrass habitat at 15 m (Figure 1, Table 1).

Description

Like other species in this family, *Nectria wilsoni* has a body that is elevated relative to the arms. It has a maximum recorded arm radius of 100 mm (Zeidler & Shepherd, 1982). *Nectria wilsoni* is distinguished from others in this family by central granules of the tabulae with convex upper surfaces, tabulae are fringed by irregular granules (Zeidler & Rowe, 1986). Tabulae are well separated from one another by gaps and are restricted to the disc and arm bases (Edgar, 1997). Colouration is deep orange to red (Figure 2 k).

Ecology

Nectria wilsoni inhabits regions from 0 to 45 m in depth and is generally reported from more sheltered habitats than other *Nectria* species (Edgar, 1997). In this study *N. wilsoni* were recorded on sheltered and exposed reef and sheltered seagrass habitats. Animals were always found on open horizontal substratum, never on vertical, cryptic habitats or under ledges. Substratum was predominantly bare coarse sand through to very coarse shell grit. Several animals were recorded directly on sponges that were in these open sandy regions. Animals often had a layer of sand over them, either from sand material dropping out of suspension or as a consequence of foraging in this substratum. *Nectria wilsoni* was also found on bare sand within a *Posidonia australis* seagrass meadow, it is expected to feed on sponges, ascidians, bryozoans, detritus and algae present within its habitat. However, this has yet to be documented.

Nectria macrobrachia H.L. Clark, 1923
Type species: *Asterias ocellifera* Lamarck 1816
Species holotype catalogue number: BMNH 1929.6.12.1

Distribution

This species has been recorded from Port Gregory, WA to Wilsons Promontory, Vic, and King Island (Edgar, 1997) and Flinders Island, Tas (Rowe & Gates, 1995). Individuals of this species comprised 13% of the sea stars recorded and were from New Island, sheltered habitat at 15 and 20 m; Thomas Island, exposed habitats at 10, 15 & 20 m; Mondrain Island, sheltered habitat at 15 and 20 m; Figure of Eight Island, sheltered habitat at 10 and 15 m and exposed habitat at 15 m (Figure 1, Table 1).

Description

Like other species in this family, *Nectria macrobrachia* has a body that is elevated relative to the arms. It is the smallest of the *Nectria* species with a maximum arm radius of 60 mm. *Nectria macrobrachia* has crowded tabulae with low flat central granules that are smaller than peripheral granules (Zeidler & Rowe, 1986). The peripheral granules that extend to the ends of the arms are raised above the central ones giving the tabulae a concave appearance (Zeidler & Shepherd, 1982). Colour is usually yellow, pale pink or orange, with darker purple, brown or greenish tips (Figure 2 l).

Ecology

Nectria macrobrachia is documented from exposed reef habitats 0 to 180 m in depth (Edgar, 1997). In this study *N. macrobrachia* was recorded in both sheltered and exposed habitats. Animals were always found on open vertical substratum, never on horizontal habitats. The substratum was predominantly filamentous red algae, branching calcareous alga (*Amphiroa* sp.) and both encrusting and massive sponges. Animals were regularly recorded on/or directly adjacent to sponges. *Nectria macrobrachia* is expected to feed on sponges, ascidians, and/or bryozoans. However, this has yet to be documented. The ecological data presented in this paper may add weight to this theory.

Figure 2. In-situ photographs of sea star species described in this study a) *Pseudonepanthia troughtoni*; b) *Petricia vernicina*; c) *Echinaster arcystatus*; d) *Echinaster glomeratus*; e) *Echinaster varicolor*; f) *Plectaster decanus*; g) *Tosia australis*; h) *Pentagonaster dubeni*; i) *Fromia polypora*; j) *Nectria saoria*; k) *Nectria wilsoni*; l) *Nectria macrobrachia.*

Discussion

The shallow water sea star fauna recorded in this study is representative of the subtidal southern coast of Western Australia. This study recorded 12 species of sea stars and goes further than most other records of asteroid distributions in that it provides information on the ecology and habitats of these animals. Habitats ranged from exposed vertical sponge dominated rock substratum to sheltered horizontal seagrass or algal dominated substratum.

Table 1. Presence or absence of sea star species for each island sampled (islands arranged geographically from west to east) (shaded areas indicate species present)

	Figure of 8	Thomas	Long	Sandy Hook	Remarck	New	Mondrain	Mart	Twin Peak	Middle
P. troughtoni						▨	▨			
P. vernicina						▨				
E. arcystatus		▨				▨		▨		▨
E. glomeratus			▨					▨		
E. varicolor		▨			▨		▨			
P. decanus	▨	▨	▨			▨	▨	▨	▨	▨
T. australis										▨
P.dubeni	▨	▨	▨	▨	▨		▨	▨		
F. polypora			▨	▨		▨	▨			▨
N. saoria								▨		▨
N. wilsoni			▨		▨		▨	▨		▨
N.macrobrachia	▨	▨				▨	▨			

Marsh (1991) in her study on the shallow water echinoderms of Albany recorded 25 species of sea stars. In the Albany study Marsh recorded all of the species identified in this paper, however *Fromia polypora* was recorded as *Austrofromia polypora. Fromia polypora* was the type of a new genus *Austrofromia* by H.L. Clark, (1921) however, this was referred back to *Fromia* by Rowe (1989). This paper also uses the revised names of genera of *Asterinidae.* The species formerly called *Nepanthia troughtoni* was referred to the new genus *Pseudonepanthia.* The Asterinidae were revised by O'Loughlan and Waters (2004) who erected five new genera and five new species to accommodate species removed from *Asterina* and *Patiriella.*

Acknowledgements

We would like to thank Drs Fred Wells, Di Walker and Gary Kendrick for organising the 12th International Marine Biology Workshop. We also thank Dr Grey Coupland for her comments on this manuscript.

This study was jointly funded by a CSIRO SRFME grant (Strategic Research Fund for the Marine Environment) awarded to Dr Justin McDonald, Dr Jane Fromont & Dr Gary Kendrick and an FRDC grant (Fisheries Research Development Council 2001/060)

References

Clark, H.L. (1921) The echinoderm fauna of Torres Strait. *Papers from the department of Marine Biology Carnegie Institution Washington*, **10**: 1-224.

Edgar, G.J. (1997) Class Asteroidea in *Australian Marine Life.* pp: 333 – 357 Reed Books, Victoria Australia.

Marsh, L.M. (1991) Shallow water echinoderms of the Albany region, south-western Australia. In: *The Marine Flora and Fauna of Albany, Western Australia* (Vol II). F. E. Wells, Walker, D. I., Kirkman, H., and Lethbridge, R. (Eds) Pp 439-482. Western Australian Museum, Perth.

O'Loughlan, P.M., & Waters, J.M. (2004) A molecular and morphological revision of genera of Asterinidae (Echinodermata: Asteroidea). Memoirs of Museum Victoria, **61** (1): 1-40.

Rowe, F.W.E., & Gates, J. (1995) Echinodermata. In Wells, A (Ed.) Zoological Catalogue of Australia, Vol 33. Pp 510. CSIRO Melbourne Australia.

Zeidler, W. & Shepherd, S. A. (1982) Sea stars (Class Asteroidea). In: *Marine Invertebrates of Southern Australia*, Part I. S. A. Shepherd and I. M. Thomas (Eds.) Pp: 400 – 418. South Australian Research and Development Institute in conjunction with the Flora and Fauna of South Australia Handbooks Committee.

Zeidler, W. & Rowe, F. W. E. (1986) A revision of the southern Australian starfish genus *Nectria* (Asteroidea: Oreasteridae) with the description of a new species. *Records of the South Australian Museum,* **19** (9): 117 – 138.