NORTH WEST SHELF
JOINT ENVIRONMENTAL
MANAGEMENT STUDY

Ecosystem characterisation of Australia's North West Shelf

NWSJEMS

TECHNICAL REPORT No. 12

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ACRONYMS

ACOM	Australian Community Ocean Model
AFMA	Australian Fisheries Management Authority
AFZ	Australian Fishing Zone
AGSO	Australian Geological Survey Organisation now Geoscience Australia
AHC	Australian Heritage Commission
AIMS	Australian Institute of Marine Science
AMSA	Australian Maritime Safety Authority
ANCA	Australian Nature Conservation Agency
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZLIC	Australian and New Zealand Land Information Council
APPEA	Australian Petroleum, Production and Exploration Association
AQIA	Australian Quarantine Inspection Service
ARMCANZ	Agricultural Resources Management council of Australia and New Zealand
ASIC	Australian Seafood Industry Council
ASDD	Australian Spatial Data Directory
CAAB	Codes for Australian Aquatic Biota
CAES	Catch and Effort Statistics
CALM	Department of Conservation and Land Management (WA Government)
CAMBA	China Australia Migratory Birds Agreement
CDF	Common data format
CITIES	Convention on International Trade in Endangered Species
CTD	conductivity-temperature-depth
CMAR	CSIRO Marine and Atmospheric Research
CMR	CSIRO Marine Research
COAG	Council of Australian Governments
ConnIe	Connectivity Interface
CPUE	Catch per unit effort
CSIRO	Commonwealth Science and Industrial Research Organisation
DCA	detrended correspondence analysis
DIC	Dissolved inorganic carbon
DISR	Department of Industry, Science and Resources (Commonwealth)
DEP	Department of Environmental Protection (WA Government)
DOM	Dissolved organic matter
DPIE	Department of Primary Industries and Energy
DRD	Department of Resources Development (WA Government)
EA	Environment Australia
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPP	Environmental Protection Policy
ENSO	El Nino Southern Oscillation
EQC	Environmental Quality Criteria (Western Australia)
EQO	Environmental Quality Objective (Western Australia)
ESD	Ecologically Sustainable Development
FRDC	Fisheries Research and Development Corporation
FRMA	Fish Resources Management Act
GA	Geoscience Australia formerly AGSO
GESAMP	Joint Group of Experts on Scientific Aspects of Environmental Protection
GIS	Geographic Information System
ICESD	Intergovernmental Committee on Ecologically Sustainable Development
ICS	International Chamber of Shipping
IOC	International Oceanographic Commission
IGAE	Intergovernmental Agreement on the Environment
ICOMOS	International Council for Monuments and Sites
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change

IUNC	International Union for Conservation of Nature and Natural Resources
IWC	International Whaling Commission
JAMBA	Japan Australian Migratory Birds Agreement
LNG	Liquified natural gas
MarLIN	Marine Laboratories Information Network
MARPOL	International Convention for the Prevention of Pollution from Ships
MECO	Model of Estuaries and Coastal Oceans
MOU	Memorandum of Understanding
MPAs	Marine Protected Areas
MEMS	Marine Environmental Management Study
MSE	Management Strategy Evaluation
NCEP - NCAR	National Centre for Environmental Prediction – National Centre for Atmospheric Research
NEPC	National Environmental Protection Council
NEPM	National Environment Protection Measures
NGOs	Non government organisations
NRSMPA	National Representative System of Marine Protected Areas
NWQMS	National Water Quality Management Strategy
NWS	North West Shelf
NWSJEMS	North West Shelf Joint Environmental Management Study
NWSMEMS	North West Shelf Marine Environmental Management Study
ICIMF	Oil Company International Marine Forum
OCS	Offshore Constitutional Settlement
PFW	Produced formation water
P(SL)A	Petroleum (Submerged Lands) Act
PSU	Practical salinity units
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SOI	Southern Oscillation Index
SMCWS	Southern Metropolitan Coastal Waters Study (Western Australia)
TBT	Tributyl Tin
UNCED	United Nations Conference on Environment and Development
UNCLOS	United Nations Convention of the Law of the Sea
UNEP	United Nations Environment Program
UNESCO	United Nations Environment, Social and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
WADEP	Western Australian Department of Environmental Protection
WADME	Western Australian Department of Minerals and Energy
WAEPA	Western Australian Environmental Protection Authority
WALIS	Western Australian Land Information System
WAPC	Western Australian Planning Commission
WHC	World Heritage Commission
WOD	World Ocean Database
www	world wide web

TECHNICAL SUMMARY

Habitats serve a variety of functions on the North West Shelf (NWS). They support the life history stages of a diverse suite of tropical species including commercially harvested ones. In addition to natural disturbance regimes, habitats are altered in response to the sectoral uses, which in turn affects the distribution and life histories of species. Habitats thus serve as the nexus linking species with uses and natural disturbance, and different habitats serve different purposes at various stages of the life history of a species. A detailed understanding of habitats, at least at the structural level, is thus a prerequisite for a more comprehensive understanding of ecological structure and functions on the North West Shelf.

This component of the North West Shelf Joint Environmental Management Study (NWSJEMS) aimed to collate and integrate data on habitats for the region of the North West Shelf extending from North West Cape to Port Hedland and from the coast to the 200 m isobath. The three main activities of the study were:

- Development of an integrated collection of information on habitats of the North West Shelf, including expert information;
- Application of the CSIRO Habitat Classification Framework to the data to determine the spatial nesting and structuring of habitat units on the North West Shelf; and
- Provision of the habitat structure classification for input into other models developed within NWSJEMS.

The main outputs presented in this report are in the form of maps and statistical descriptions of key ecosystems and habitats. These maps and descriptions of their component attributes were designed to assist the process modelling of the ecosystem and impacts of uses, as well as directly supporting planning and management by Western Australian agencies and industries. The maps were produced primarily from existing information, but survey fieldwork was also undertaken to fill in critical gaps in spatial coverage and missing components.

Disparate sources of information were integrated into a composite regional map describing the habitats of the North West Shelf at a variety of spatial scales. This strategy was developed around the application of a hierarchical habitat classification framework. This framework allowed information of different types (physical, biological, geological) to be recorded into the relevant spatial level so that an inventory of information describing habitats of various scales could progressively be built up.

The first phase of the approach involved a comprehensive collation of information to support the application of the CSIRO Hierarchical Habitat Classification Framework. Various information sources including published documents; digital and paper maps; imagery; statistical analysis, and expert information have been used to inform the process. The application of the framework has allowed for the development of mapping units for the three levels of the classification comprising:

- *Provinces*: the largest spatial scale of habitat structuring reflecting paleo-historic evolutionary processes;
- *Biomes*: represents habitat structures responding to the role of the largest environmental gradients – in this case reflected by depth as a primary surrogate

for a variety of biophysical processes. Substructure at this level reflect changes that are primarily orthogonal to the depth structures; and

- *Biogeomorphological units*: are habitat structures represented by "fields of features" or large geomorphic structures such as gulfs, bays or plateaus. Substructures within this level are morphologically related differences in the distribution of habitats.

In areas where the data was adequate, it has also been integrated for an initial assessment of a fourth level referred to as *primary biotopes*. However, considerable additional field sampling would be required to map to this level for the whole study region.

From the integration and analysis of available data, mapping layers containing relevant information for the various levels of the hierarchical classification were generated. The study region lies within the Level 1 North Western Province of the IMCRA (1988) classification, which extends from North West Cape, to Cape Leveque. At this scale, the North West Shelf is a unique benthic regional environment on the continental shelf of Australia. As such it is a bioregion of national significance.

The Level 2 biomic structure of the region contains three sub-units:

- *Level 2A* units consist of demersal shelf and coastal zone;
- *Level 2B* units identified are:
  - coastal, consisting of estuaries, lagoons and embayments at less than 10 m depth;
  - sub-tidal nearshore, covering the depth range 10 to 20 m;
  - further offshore are the inner shelf (20 to 70 m), mid shelf (70 to 120 m) and outer shelf biomes (120 to 200 m) (the precise boundaries are still subject to analysis); and
- *Level 2C* units along the coast consist of broad alongshore categorisation based on distinct basement structural features and their corresponding collection of biological attributes.

The most detailed level of classification obtained for the region was to Level 3. Data availability allowed mapping to three levels for the coastal zone, and one level for the offshore areas. Data used for the offshore analysis consisted of research trawl records for fish species. Existing geomorphic and topographic mapping, combined with aerial photography and imagery was used for the inshore mapping. Expert information also provided assistance for determining mapping units for Levels 2 and 3 of the classification.

1. INTRODUCTION

Characterising the distribution pattern of marine habitats on the North West Shelf was a prerequisite to understanding the relationships between human uses and natural disturbances, and therefore represented a key element in developing effective management of the North West Shelf environment. Habitat characterisation provides the underlying spatial framework for developing models of habitat dynamics, trophic interactions and impacts of human uses such as fishing and coastal development.

1.1 Regional setting

The study area covers the Pilbara region of Western Australia from North West Cape to Cape Keraudren (figure 1.1.1). The marine extent of the study region occurs within the western section of the Rowley Shelf, which covers the area from North West Cape to Melville Island in the Northern Territory (CALM, 1994). The offshore boundary of the Rowley Shelf was formed by tectonic subsidence, and has an average depth of 560 m. The inner waters of the shelf are subject to run-off from rivers and have relatively strong tidal flow resulting in turbid nearshore waters.

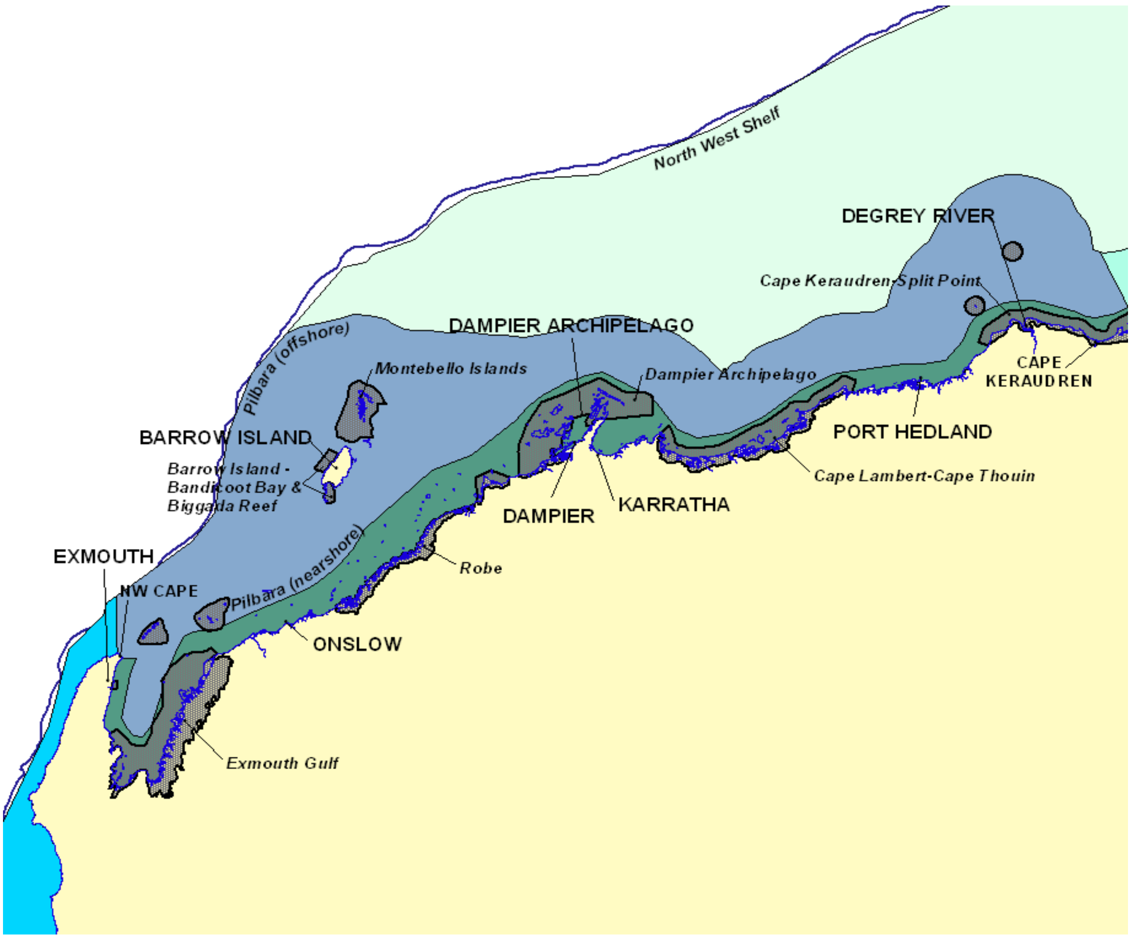


Figure 1.1.1: Study area showing IMCRA regions and *Wilson Report* units.

Nearshore and offshore community types can be distinguished based on physical influences. For much of the region, the shelf consists of gently inclined Pleistocene limestone extending to around 15 metres depth several kilometres offshore. This is broken locally by limestone reefs and small islands. Local biogenic accretion on the shelf results in sheets and mounds of corals, calcareous algae and bioclastic sand and gravel deposits. Bio-erosion, physical erosion and dispersion processes on the shelf result in a variable mosaic of geomorphic and sedimentary products ranging from residual upstanding limestone outcrops with sediment aprons, to winnowed sediment veneers on limestone pavements and sediment blankets.

The coastline of the Pilbara predominantly consists of systems of barrier islands and associated protected lagoons. The ridges were formed by the accumulation of aeolian shoreline calcareous sand ridges that are now limestone (Semeniuk, 1992). Conspicuous Pleistocene limestone units in the Pilbara region are often ridge-like and form shore parallel barriers. These limestone ridge units are important where they outcrop at or near the shore, as they play a part in determining coastal geomorphology and controlling Holocene sedimentary patterns (Semeniuk, 1992). Also regionally important for the marine environment, are areas where the Pleistocene limestones occur at depth and are sheet-like. While not important in the development of major coastal structures, these limestone pavements appear substantial in their extent over the region. Their interplay with local sedimentation, coastal features and hydrodynamics are an important factor in determining the coastal and nearshore habitats.

Sediment characteristics are also significant in differentiating habitats at a range of scales on the North West Shelf. Within the large-scale context of coastline types, a range of coastal features has been classified on the basis of sediment type, including sand ridges, tidal flat deposits, beaches, beach rock, and dunes (Semeniuk, 1992). The adjacent nearshore zone is characterised by muddy substrates with sediments predominantly of terrigenous origin. Deltas of the region locally contribute a halo of fluvial sand which blankets the delta periphery (Semeniuk, 1992). Further offshore, substrates are generally more sandy, with a gradual transition in deeper water to finer sands, muds and oozes mostly of biogenic origin (CALM, 1994). The boundary between the offshore and coastal environmental types is approximately the 10 m contour (Semeniuk, 1992).

1.2 Approach

This project was designed to collate and validate habitat information and develop a consistent hierarchical description of habitat distributions on the North West Shelf. The major components were:

(i) Sourcing of existing habitat and human use information from the North West Shelf including that identified in the recent review of existing information (Heyward et al. 2006) and through structured information gathering from experts.

(ii) Opportunistic field sampling in areas of poor data coverage.

(iii) Development of a comprehensive database system of habitat related information capable of storing and analysis of a wide range of data types (e.g. images, maps, tables and figures, descriptions and other textural information).

(iv) Production of maps of key ecosystems and habitats in the form of both hard-copy maps and digital GIS layers.

(v) Testing and refinement of habitat mappings using expert opinion.

(vi) Refinement and application of the CSIRO Hierarchical Classification Scheme to North West Shelf habitat distributions. This activity significantly extended the results of the *Wilson Report*, which had previously characterised many of the key coastal areas of Western Australia on the basis of geomorphology and marine floras and fauna (figure 1.1.1, CALM 1994).

The methodologies underlying components (i) to (v) are described in Chapter 2 and for component (vi) in Chapter 3. This is followed by the study results in Chapter 4, a summary in Chapter 5, and recommendations about further work in Chapter 6.

2. DATA COLLATION AND INTEGRATION

A major data collation program was undertaken to support development of a comprehensive set of habitat maps for the North West Shelf. The first stage of this process involved gathering information on the biology and geomorphology of the region from existing papers, reports and datasets. The second stage involved integrating this information into a single database linked to a GIS. The third stage involved collection of more targeted information from reports and regional experts in order to test the data and refine the regionalisation boundaries.

2.1 Sourcing existing data

Data was compiled on a diverse range of ecological and human uses (table 2.1.1) from both government agencies and private companies (table 2.1.2). Papers and reports identified in Heyward et al. (2006) or through discussions with regional experts were also compiled and relevant information extracted. Images, maps, tables and figures from the various sources were digitally scanned and stored in a database (described below) along with relevant textural information from papers and reports.

All data sets were tagged to clearly identifying their source and any available information on data quality was captured. This provided a useful resource for end users and some guidance for future data gathering activities. It also supported the creation of metadata, which has been fully documented in a metadata system (Brodie et al. 2006).

Table 2.1.1: Types of ecological and human use data.

Class	Data
Ecological	topography marine habitats terrestrial habitats satellite imagery aerial photography
Human use	infrastructure and developments contaminants inventory fisheries license areas petroleum license areas tenure conservation zones national parks and nature reserves recreational use satellite imagery aerial photography

Table 2.1.2: Government and industry suppliers of data.

Government/industry	Organisation
Western Australia Government	Conservation and Land Management Environmental Protection Minerals and Energy Land Administration Transport Resources Development Fisheries WA Ministry for Planning WA Museum Waters and Rivers Commission
Commonwealth Government	Geoscience Australia Environment Australia CSIRO AIMS Australian Maritime Safety Authority Royal Australian Navy Australian Survey and Land Information Group
Oil and gas industry	Apache Energy Woodside BHP Chevron
Mining industry	Hamersley Iron Dampier Salt

Papers and reports

Key references on North West Shelf habitats included the *Wilson Report* and a large number of reports on studies undertaken by oil and gas companies as part of the Public Environmental Review requirements for licence applications. Mapping data and existing environmental or habitat classifications were of key importance. However, even in the better studied sections of the coast, such as the West Pilbara and offshore islands, there was no systematic survey of the marine flora or fauna available (CALM, 1994).

Remote imagery

Remotely sensed imagery was available in the form of both *LandSat*™ satellite data and aerial photography. The satellite data provided a visual representation of the entire region at a relatively coarse scale. This was complemented by the aerial photography which was available at very fine scale (one metre resolution) over a more limited coastal region between Dampier Archipelago and the De Grey River. Time series aerial photography of Dampier Archipelago also provided some information on changes in land use and coastal habitats. Both data sets were particularly useful in defining boundaries between regions.

CSIRO trawl data

Existing trawl data from CSIRO research cruises included photographic observations and trawl catch composition data. The trawl information was from 451 research trawls undertaken in depths of 30 to 150 m. It consisted primarily of fish catch (species composition and abundance) integrated over trawl lengths of a few kilometres. The photographic data consisted of approximately 37350 still images. Each image showed a small-scale viewing area from which sessile (or limited mobility) invertebrates and bottom types could be identified, along with occasional sightings of more mobile fish.

Benthic samples

Data was also used from benthic invertebrate and sediment sampling replicated at four sites in 1982-83 by CSIRO.

2.2 Supplementary field sampling

Supporting ecosystem information was obtained through two field trips undertaken in conjunction with study collaborators and agencies operating in the region (Butler et al. 2002). These activities also provided a valuable opportunity for study participants to gain first-hand experience of the environment of the region. Field notes from these activities are provided in Appendices A and B.

Port Hedland (URS)

The first field trip focused on the key industrial area of Port Hedland, where the environmental consultancy company URS was undertaking sediment sampling in and around the harbour. Information gathered included general descriptions of the environment and human uses, detailed habitat information, and GPS fixes for georeferencing aerial photographs (see Appendix A).

Exmouth to Broome (Fisheries WA)

The second field trip involved participation in a Fisheries WA research voyage from Exmouth to Broome. Benthic habitat information was obtained using underwater video footage at 22 sites in previously poorly sampled regions (Appendix B). The video footage was archived and representative frames captured for use in the habitat database.

During the voyage, detailed fish catch information was also obtained and fish stomach contents were collected to assist in the understanding of trophic relationships in the region (Appendix B). This data helped define critical groups and interactions that have now been represented in models of the region (Bulman, 2006; Fulton et al. 2006b).

2.3 Development of the database and GIS

A database was created to store coordinates, descriptions and associated images for ready access using GIS or other packages capable of reading the spatial and textual information. The use of GIS allowed a wide variety of data formats, types and coordinate systems to be brought together in a single framework for mapping and analysis. The GIS used was ESRI *ArcView*, and *ArcInfo*. The standard data format for GIS layers was ESRI shapefiles, using the Map Grid of Australia (MGA), Zone 50 coordinate system.

Additional information was also stored in the database, including references to the reports that contained the information. A link was also created to the NWSJEMS bibliographic database using *Procite-ID* and the document title to allow reference back to the source information. The original data sources were maintained and attributes were added to integrated data sets to allow an audit trail for determining the lineage of any particular spatial component. This allowed all originating data sets to be identified directly through metadata.

2.4 Georeferencing data

Where site locations were not available as coordinates they were extracted from the most detailed location maps available in the reports. Scanned maps were geo-referenced using existing data or any coordinate information present on the maps. Data sets were converted to the standard coordinate system (MGA, Zone 50) and compared to a base data set to identify any issues of spatial inaccuracy. These inaccuracies may have occurred due to differences in projection, datum, and capture scale. Where required, data sets were transformed or reprojected to align most accurately with the base data sets. However, because of the fuzzy nature of the boundaries being mapped very high spatial accuracy was usually not critical. Once sites were geo-located in the GIS, descriptive data was entered and any available images taken at the sites were scanned. The information was then available to support the mapping of habitats.

2.5 Expert information and assessment

Experts experienced in field observations were approached to:

- capture local undocumented knowledge;
- identify additional sources of documented information not previously captured; and
- provide additional quality control on the previously captured data.

The consultation with experts took the forms of interviews (table 2.5.1), and an expert workshop in Perth in December 2000.The results were of varying scale and quality, but taken together provided a rich and invaluable compilation of information on the environment, ecology and uses of the North West Shelf. As examples, divers provided particularly useful information on habitat types in the coastal and near-shore environments, while the expert workshop provided an opportunity to critically test GIS layers from the database.

Table 2.5.1: Scientific experts interviewed.

Name	Organisation
Kelly Pendoley	Apache Energy, consultant and PhD student
Mike Ford	Bowman Bishaw Gorman, consultant
Eric Paling	Murdoch University, consultant
David Gordon	Consultant
Di Jones	WA Museum
Shirley Slack-Smith	WA Museum
Clay Bryce	WA Museum
Barry Hutchins	WA Museum
Chris Simpson	CALM - Marine Conservation Branch
Bob Prinz	CALM - Marine Conservation Branch
Di Walker	University of Western Australia

3. DEVELOPING A HABITAT CLASSIFICATION FRAMEWORK

Scientific description and practical management both require spatially explicit frameworks in which issues associated with resource utilisation, conservation, management and monitoring can be conducted at appropriate spatial and temporal scales. Such frameworks must be derived from a systematic scientifically-based ecological approach and be designed to address a range of management needs likely to arise from multiple uses of resources. The disparity in the scale and manner in which regions are typically demarcated reflects a lack of agreement or understanding of the scale-dependent nature of biodiversity.

3.1 A general hierarchical approach

The approach to regionalisation advocated here is a pragmatic strategy based on a hierarchical treatment of biodiversity. While a single classification scheme is unlikely to meet all needs, a conceptual classification framework that can be individually tailored to particular purposes (identifying information gaps, field sampling, modelling, monitoring, and resource management) could provide a useful starting point.

Tailoring the framework to a particular application requires consideration of:

- available information;
- habitat processes and elements under study; and
- scales at which decisions are made.

Ideally decisions are made at scales that are larger than the habitat processes, utilising information available at still smaller scales, however, this is often not feasible.

A key aspect of tailoring the hierarchy is the definitions of habitat elements and processes at each hierarchical level. These definitions link available information with the decision variables. One implication is that monitoring of surrogates and indicators is hierarchically dependent, so that different monitoring methods may be required at different levels. This is particularly pertinent to the monitoring of biodiversity.

The hierarchical framework developed here builds on existing approaches to regionalising the Australian marine environment (IMCRA, 1998) and is continuing to evolve as part of a more generic ecological classification framework (Last et al. 2006). The scheme recognises two parallel classifications based on habitat or ecological descriptions of marine biodiversity (figure 3.1.1). The key distinction made here is between the more spatially-based habitat description and the biologically-based ecological description of biodiversity. However, these two streams are interlinked through ecological processes and characteristics that maintain the integrity of the ecosystem. Since these processes can not usually be observed directly, they tend to be monitored via habitats or species related indicators.

Figure 3.1.1: Proposed hierarchical structuring of marine biodiversity using either habitat (left tree) or ecological (right tree) descriptors. The habitat levels are spatially-based while the ecological levels may traverse a number of habitat levels – depending on the ecological question(s) under investigation (the linkages in the middle). For example, a fish species may rely primarily upon a small number of biotopes (Level 4/5) within which it feeds, but larvae of that species may disperse over a much wider area characterised by a biome (Level 2). The habitat classification used here (left tree) is designated as the CSIRO Habitat Classification Version 1.2.

3.2 Application to the North West Shelf

A useful starting point in applying our hierarchical framework to the North West Shelf is provided by Semeniuk (1986). His study used a hierarchy of spatial scales to develop a nomenclature system for coastal geomorphic units of the North West Shelf coastal zone. The framework consists of a set of spatial units in decreasing scale with selection guidelines (table 3.2.1). It is proposed that this framework be extended beyond its geomorphological foundation to include other physical and biological descriptors. Descriptions of the proposed habitat units are given in table 3.2.2, while example components for Levels 2 and below (which are most relevant to the NWSJEMS) are shown in figure 3.2.1.

Within our proposed framework (table 3.2.2), Semeniuk’s (1986) regional and large scales (table 3.2.1) approximate Level 3A and 3B respectively, where the key characteristics can be adequately described in terms of geomorphic surrogates. However, at other levels, surrogacy alone does not provide sufficient discrimination. For example, Semeniuk’s (1986) medium scale is broadly consistent with Level 4 apart from terminology differences and the need to incorporate biological elements such as seagrasses and corals. Similarly, Semeniuk’s (1986) small and fine scales are subsets of the more generalised Level 5 and 6 units incorporating geomorphological, biological and physical descriptors. Further refinement at all levels can continue as new information becomes available (as illustrated by the subdivisions of Level 2 in table 3.2.2).

Table 3.2.1: Summary table of scale terms and their respective scales of reference (from Semeniuk, 1986, Table 1).

Scale terms	Frame of reference	Landscape element	Examples
Regional (megascale)	500 – 100 km^2	land region	ria shores, delta lands, beach/dune shores
Large (macroscale)	50 – 10 km^2	land facet	riverine channels, narrow embayments, broad embayments, sandy shores, islands, sub-tidal reaches
Medium (mesoscale)	5 – 1 km^2	site or land element	spits, cherniers, rocky headlands, tidal flats, tidal creeks, alluvial fans
Small (microscale)	500 – 10 m^2	site or land element or local scale	smooth salt-encrusted mud surface, smooth rippled sand surface, hummocky, burrow-mounded mud surface
Fine (leptoscale)	5 – 1 m^2	microrelief or microform	ripple marks, erosional rills, burrow mounds

Table 3.2.2: Levels, descriptions and relevant information for the CSIRO Habitat Classification Scheme (Version 1.2) as applied to the North West Shelf. An adequate description of each level requires the next level down so as to understand variability (except for micro communities already at the finest resolution) and the next level up in order to provide context and understand top-down constraints.

Level	Description	Relevant information
1.	Provincial units derived by CSIRO and comprise both pelagic and continental shelf demersal provinces, but attention here is restricted to the demersal province only for the NWS. The NWS continental shelf falls within one province (North Western Province from North West Cape to Cape Leveque)	Demersal and pelagic fish, tectonic plate age, fault zones locations, bathymetry, water properties.
2A.	Biomes divide the region into the neritic and oceanic zones with the boundary between the two at the continental shelf break (nominally the 200 m isobath) (Nybakken, 1997). The neritic zone has four primary biomes: estuarine, coastal marine, demersal shelf and pelagic shelf. The oceanic zone consists of: three primary demersal biomes (continental slope, abyssal, and hadal), and five pelagic biomes (epi-, meso-, bathy-, abysso- and hadopelagic biomes). The slope, and deeper regions are not included in this analysis.	Bathymetry, vertical profile of water properties, vertical distribution of fish and invertebrates (water depth related).
2B.	Subdivisions within the Level 2A biomic units which may be operationally more useful units at this level. In this study we identified three sub-biomic units from a cluster analysis of informative fish species, referred to as the inner, mid and outer shelf biomes.	Fish and invertebrate assemblage analysis, bathymetry, ocean water properties.
2C.	These are mesoscale units identified within each of the Level 2B units. For example, within the coastal marine biome are Exmouth Gulf and Dampier Archipelago. These sub-biomic units may contain a distinct collection of biotas. Note: The IMCRA-derived so-called “mesoscale regions” are regions derived for management purposes; they contain a mixture of biomes (Level 2) and geomorphological units (Level 3).	See text for derivation methodology.

Level	Description	Relevant information
3A, 3B.	Geomorphological units: within each biome there are major meso-scale biogeophysical subdivisions that can be easily identified and which usually have distinct biotas. These biotas can be mapped within levels above to provide a generalised geomorphological expression of a geographic area. On the continental shelf, typical units include (Shepard, 1959): glaciation structures, sandbanks and depressions, deltaic bottoms, submarine plains and valleys, seamounts, bioherms (“hills that owe their growth to some type of calcareous organism” Shepard, 1959), rocky banks and islands, coral atolls, and regions of strong current/bottom stress. In the coastal biome typical units include fringing reefs, beaches, tidal flats, mudflats, and shallow embayments (Note use of plural forms (e.g. beaches not beach) to denote a general category, not denying that there are various types within it and note also the need to incorporate at least two categories 3A and 3B to accommodate a generalised version of Semeniuk’s (1986) regional and large scales).	Detailed bathymetry combined with a geomorphic analysis of bathymetry structure, remote sensing information.
4.	Primary biotopes: within a geomorphological level, primary biotopes are hard, soft or mixed substrates (e.g. shelly/sandy regions within coral reefs) modified by hydrological variables such as wave exposure, turbidity, tidal effects and current speed. On the NWS, maps can be obtained to this level based on some targeted acoustic discrimination work (hardness/softness and roughness) and a desktop study.	Acoustic (sidescan + texture mapping) information, sediments, exposure analyses, turbidity, detailed ocean current modelling.
5.	Secondary biotopes: substructural units of the primary biotopes distinguished by the generalised types of biophysical substrate within the soft/hard/mixed types (e.g. igneous, calcareous, silts, sands, gravels, seagrasses, sponges).	Benthic survey using video (possibly high-resolution acoustics, photos, diving where possible and other high resolution viewing devices).
6.	Biological facies: within biotopes, these are identifiable biophysical units defined by a biological indicator, or suite of indicator species, that identify a biological assemblage used as surrogate for a biocoenosis or community. These include, for example, a particular species of seagrass, or group of corals, sponges, or other macro-fauna strongly adherent to the facies. It is not expected to go lower than the facies level in the North West Shelf project. Down to this level, the hierarchy is pseudo-spatial and involves a mix of biogeophysical definitions that reflect the primary scale-dependent biogeophysical processes and associations needed by biodiversity managers.	As per Level 5 but finer scale mapping.
7.	Micro communities: within facies there exist assemblages of species that depend on member species of the facies (e.g. isopods on seagrass strands). It is assumed that conservation of the facies will generally ensure conservation of associated micro-communities.	Yet to be determined.

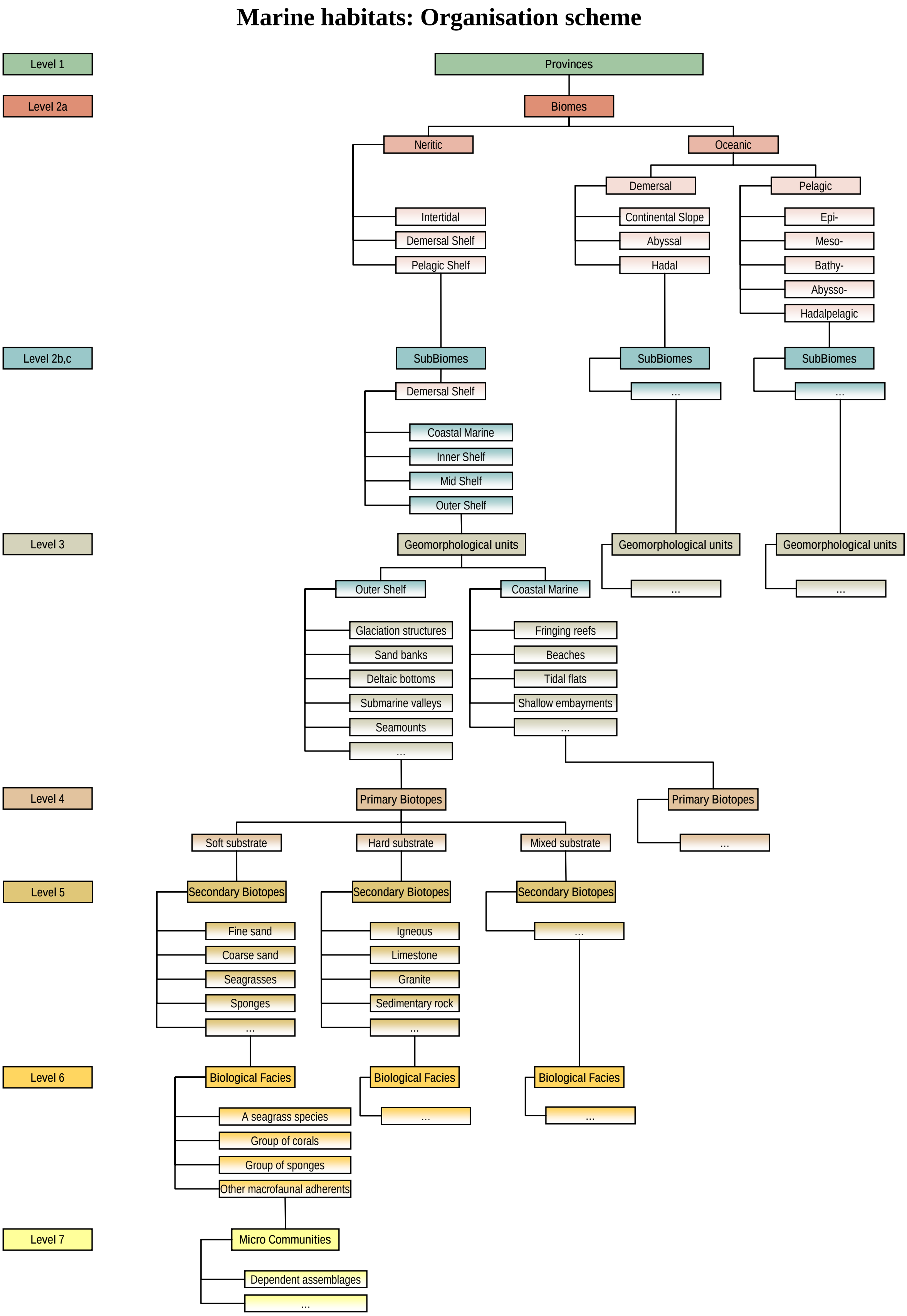


Figure 3.2.1: A partial "exploded view" of the proposed habitat classification showing example components at each of the habitat levels 2 to 7.

3.3 Integration of North West Shelf data

Spatial overlays were used to integrate existing classification layers (imported into the GIS at the appropriate hierarchical level) with the habitat data compiled in this study. Where existing data was integrated through direct spatial addition (GIS spatial data processing), all relevant available information was maintained including the information on the hierarchical structure. This consistent management of spatial scaling across the levels of the hierarchy was important in providing a stable base on which to establish data dependent decisions at a particular hierarchical level.

The use of overlapping spatial layers in the GIS will allow hierarchical classification at finer-scale levels of the scheme to be modified or enhanced in the future as updated data becomes available. Once underlying fine scale data are modified, the overlying hierarchy can be reapplied with minimal effort. The existing relationships to parent classes in the hierarchy can then be re-established. An example of this may be inclusion of new topographic data or habitat maps that form the basis for fine scale levels.

Level 2 – biomes

At Level 2, biomes have been primarily differentiated by depth-associated changes in habitats which may reflect changes in physical disturbance conditions such as tidal, wave and cyclone mixing, water property variations such as turbidity, nutrients, temperature and salinity, and substrate changes such as sediment composition. Biologically such changes manifest themselves in an integrated sense in the distribution and abundance of various taxa (biological surrogates). For this it was possible to draw upon the comprehensive trawl and photographic based observation set.

Since the species level information from the trawl and photographic data was not sufficient to differentiate biomes, an aggregate analysis was required that would capture changes in species composition with depth-associated environmental changes. As part of the national regionalisation project IMCRA (CSIRO, 1996), a pilot study was conducted of the CSIRO trawl data which suggested strong depth-oriented variations in fish species associations. There were marked alterations in the alongshore location of species groups, but strong constraints on their depth preferences. Drawing upon these observations, a range of correspondence analyses were undertaken including an innovative extension which accounts for environmental associations (B. Venables, pers. comm.). These analyses provide the underlying Level 2 biomic structure for the North West Shelf and the approach is described in Appendix C.

Level 3 – biogeomorphic units

In the nearshore coastal zone, depth and depth-related structures were used as surrogates for geomorphic features. Offshore depth-related features such as shoals, reefs, platforms, channels and embayments were developed to identify changes in the topography of the marine environment, and used as surrogates for geomorphological features in the absence of any detailed information describing them. This was particularly important for the north-eastern region of the study region where there is almost no actual habitat information available. Offshore, the amount of information available from photography and other imagery rapidly decreases, leaving insufficient data to resolve Level 3 units.

The Level 3 units identified over the Pilbara nearshore region approximate Semeniuk's (1986) classification (table 3.2.1) and extend the CSIRO Habitat Classification Scheme (table 3.2.2) by defining the nature of substructures (Levels 3B and 3C) and by enhancing the understanding of geomorphic influences on habitats:

- Level 3A: Regional scale – biogeomorphological regions of the Pilbara. These units contain a number of morphologically based units that characterise a particular region of the coastline. Components of each region may overlap as in the case of Exmouth Gulf which has components consistent with elements of the Onslow-Robe coastal section. Examples of Level 3A units are Dampier Archipelago and Exmouth Gulf.
- Level 3B: Large scale – major structural elements which make up the regions. These elements make up the major components of the regional scale units. Examples of Level 3B units are archipelago, beach/dune shore, river delta, barrier islands.
- Level 3C: Medium/small scale – finer scale elements or subcomponents of the major structural elements. Examples of Level 3C units are intertidal flats, mangal, beach, intertidal pavement. Units at this scale represent the most detailed level of mapping available and often identified from remotely sensed data sources such as satellite imagery and aerial photography.

Higher levels

Geomorphic units do not differentiate facies and so are independent of substrate type. Differentiation of biologically relevant facies occurs at Level 4 and was mostly beyond data available to the study. Where adequate data was available, Level 4 mappings were derived for localised regions.

4. RESULTS

The main outputs of the habitat characterisation project were:

1. a comprehensive database of collated information, including photographic and satellite images, maps, tables and figures, descriptions and other textural information;
2. mappings of habitats covering levels of the hierarchical classification scheme; and
3. some assessment of quality expressed in terms of data coverage.

Each of these is described in the sections of this chapter, although it should be recognised that the database itself represents the main form of project delivery.

4.1 Information exchange

4.1.1 Ground truth data

The database of attributes was populated with information extracted from papers, reports and existing datasets. It contains 254 individual ground truth locations within the study region and 117 images. The level of detail available in the reports varied from basic site descriptions, to extensive information about sediments, microphyte, coral species and cover, water depth, and additional community information.

A map of the locations of all sites recorded is shown in figure 4.1.1. Figure 4.1.2 shows more detail over Dampier Archipelago region where 87% or 221 of the 254 sample sites were situated. The information gathered may not be exhaustive, but does give a good indication of the density and coverage of available data over the region. A sample database record is shown in figure 4.1.3 and an associated image extracted from the database in figure 4.1.4.

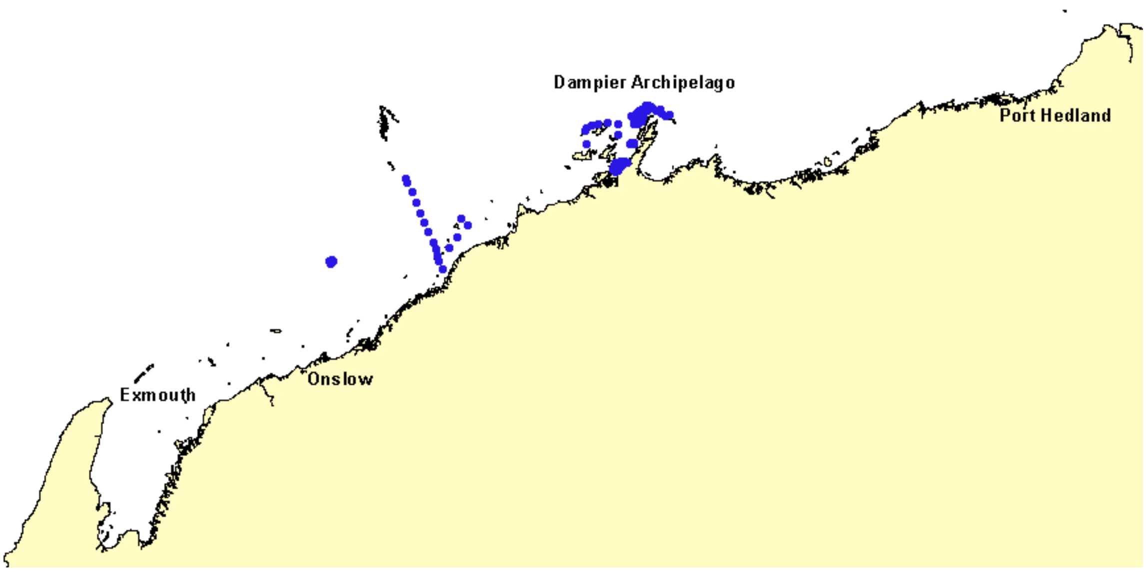


Figure 4.1.1: Locations of sites extracted from reports. Note the greater density of sites around the Dampier Archipelago.

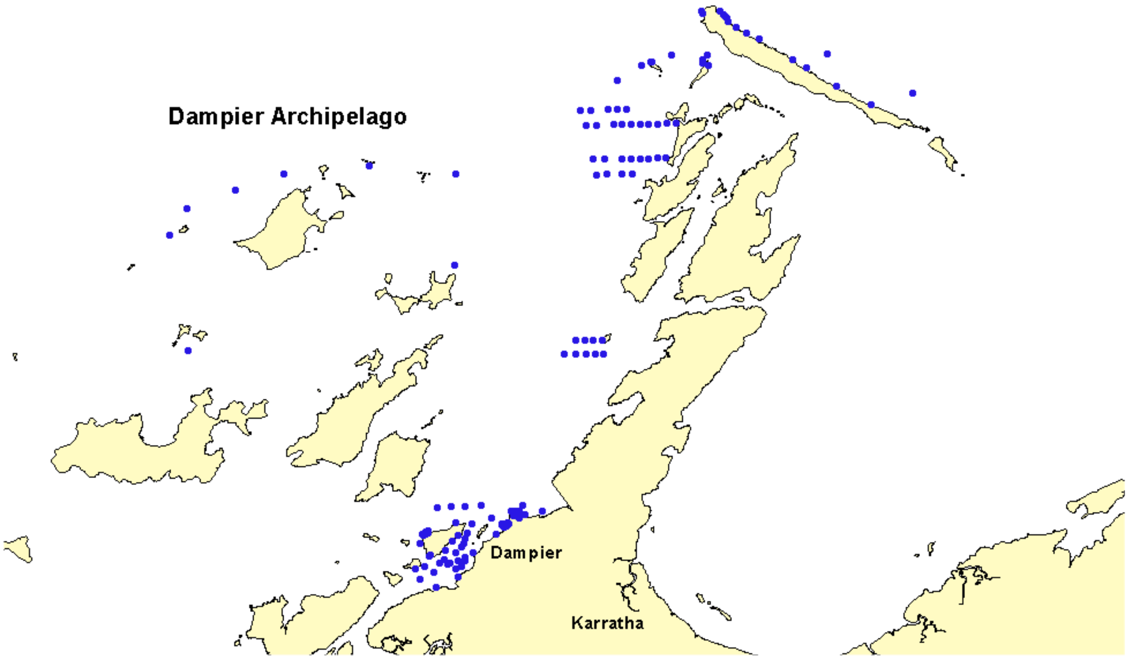


Figure 4.1.2: Sites identified over Dampier Archipelago.

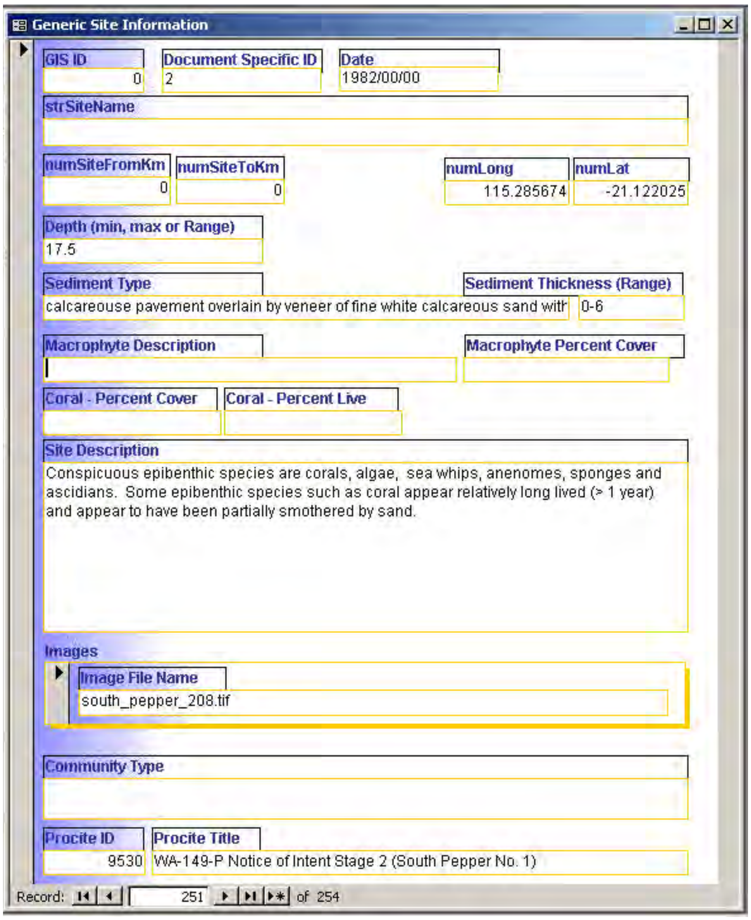


Figure 4.1.3: Sample site information from habitat database. Details were extracted from a Public Environmental Review document for the South Pepper No.1 oil well development.

Figure 4.1.4: Image associated with habitat record shown in figure 4.1.3 (image from south_pepper_208.tif).

4.1.2 Supplementary field sampling

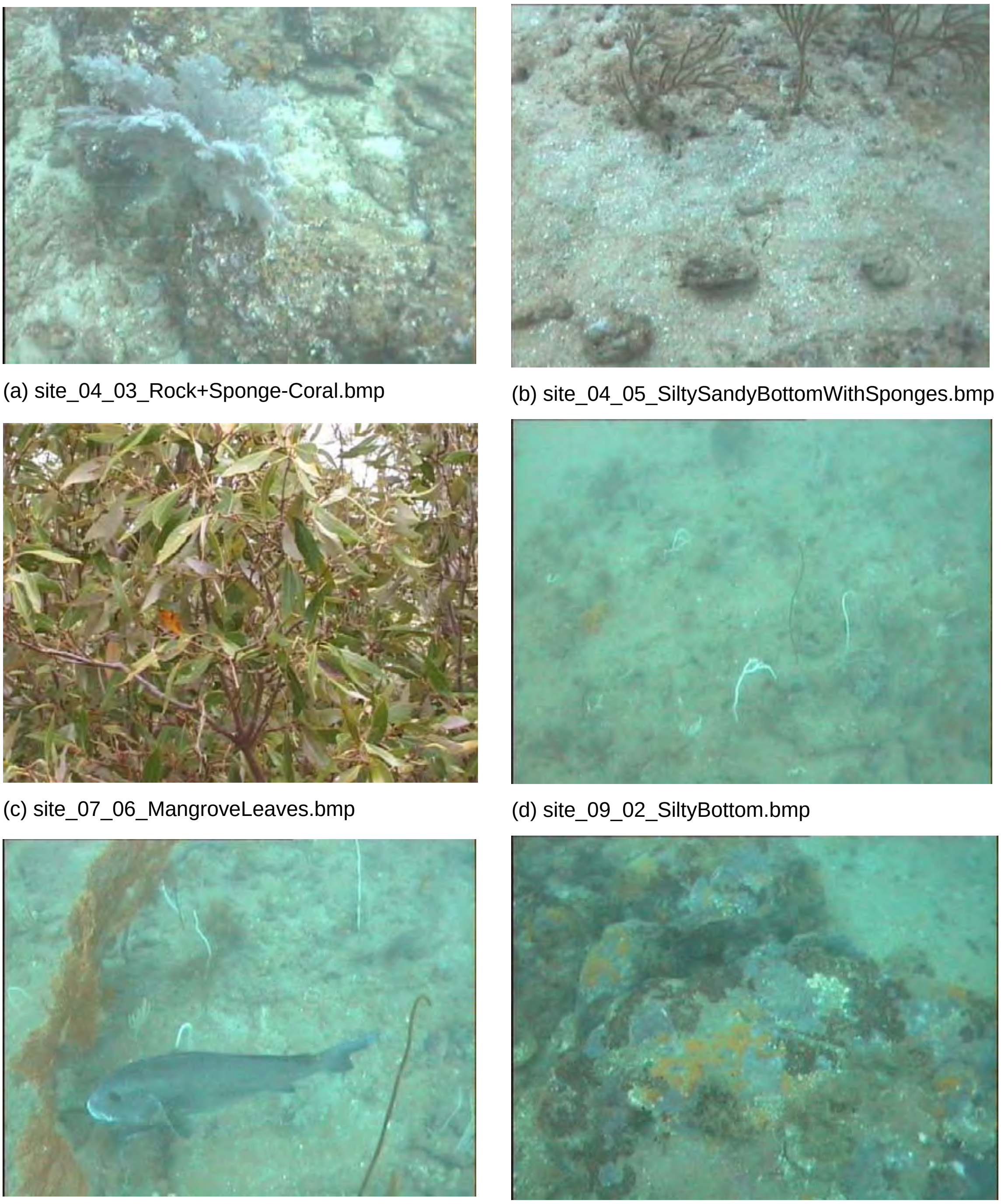
The ground truth data was supplemented by opportunistic sampling in areas of poor data coverage. Descriptions from the major industrial centre of Port Hedland are provided in Appendix A. Details of fish sampling and stomach content analysis over the broader shelf are given in Appendix B, with corresponding details of underwater video listed in Appendix C. Examples of frames captured from the video footage and incorporated into the database are shown in figure 4.1.5.

4.1.3 Mapping of coastal habitats and infrastructure developments

Aerial photography

Aerial photography was sourced to support both habitat characterisation and change induced by human impacts. It provided both up-to-date information and information on historic changes.

Water penetrating aerial photography was obtained from the WA State Land Information Capture Program (SLICP) through the WA Land Information System (WALIS) Marine Group. The imagery covered coastal and nearshore areas between the Dampier Archipelago and De Grey River (figure 4.1.6). The photography was undertaken during times of low sun angle, light winds and low tide so as to maximise water penetration. The photography capture scale was 1:40000 and negatives were scanned to provide a one metre pixel size (DOLA Job Numbers WA4610(C), WA4646(C), WA4647(C)).The resulting photographic dataset complements other flights in the area including similar photography flown by CALM to support marine park planning processes (figure 4.1.7).



(a) site_04_03_Rock+Sponge-Coral.bmp

(b) site_04_05_SiltySandyBottomWithSponges.bmp

(c) site_07_06_MangroveLeaves.bmp

(d) site_09_02_SiltyBottom.bmp

(e) site_09_04SiltyBottom+Sponge.bmp

(f) site_10_01_Rock+CorralineAlgae.bmp

Figure 4.1.5: Sample frames taken from video footage captured during the Fisheries WA voyage.

Figure 4.1.6: Aerial extent of SLICP imagery showing coverage from Cape Lambert to the De Grey River, and inset of detail from Point Samson.

Figure 4.1.7: Aerial photography over Dampier Archipelago obtained by CALM for marine park planning processes.

Historical aerial photography

Historical aerial photography was obtained over key areas in the Dampier Archipelago to provide time series snap-shots of development impacts on the marine and coastal environments. Hard copy prints of aerial photography from 7/5/1974, 5/6/1980 and 25/8/1994 were obtained. The area covered was Dampier town site to the Woodside LNG plant on the Burrup Peninsula and included pre and post facility images. This represented the best accessible colour aerial photography time series over the region. Prints were scanned and georeferenced using the 2001 SLICP imagery as a base to generate orthophoto mosaics for each time point. Additional oblique aerial photographs were available from 1983 and 1988 for the region from Cape Preston to Point Samson (figure 4.1.8).

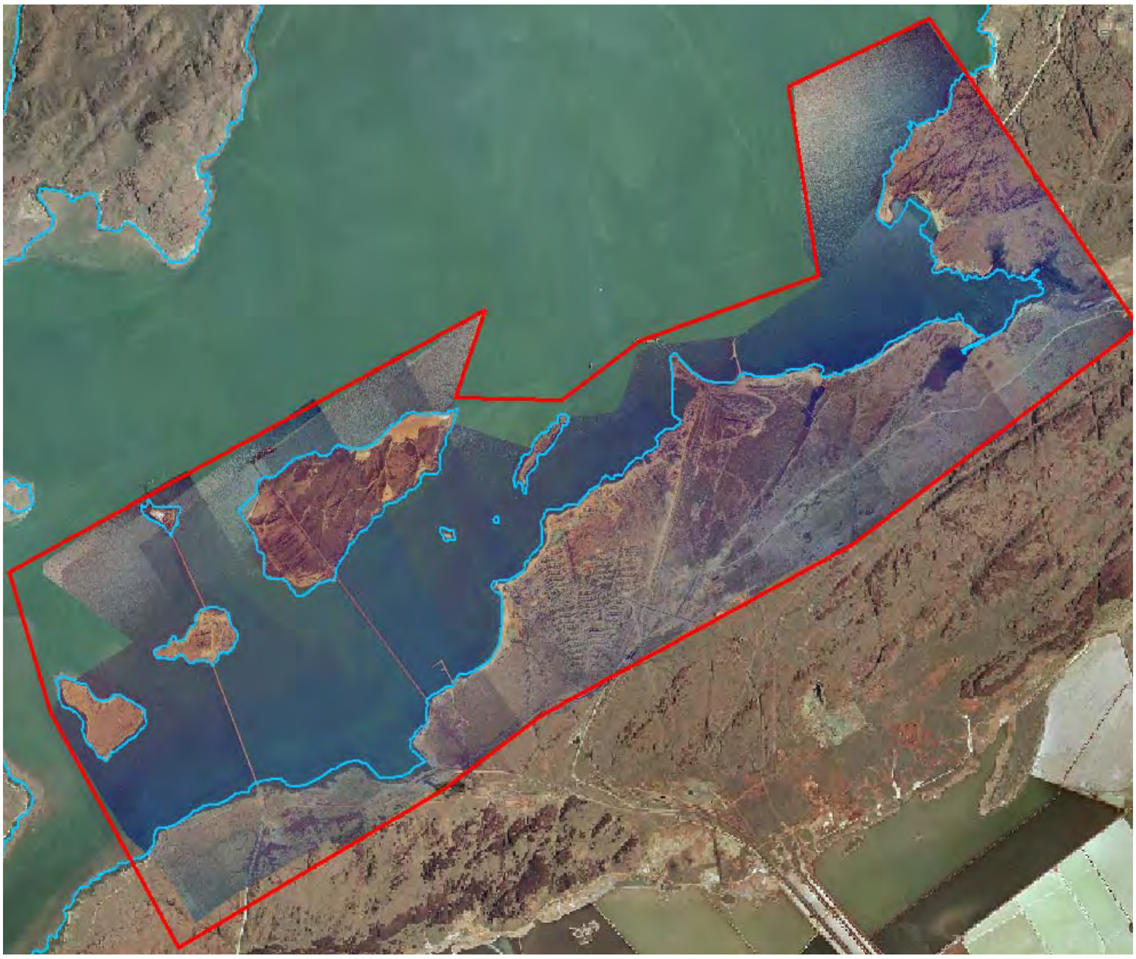


Figure 4.1.8: Historical imagery from 1983 over the Burrup Peninsula from Dampier to King Bay superimposed over the top of the 2002 CALM imagery. The 1983 image was taken prior to the Woodside King Bay development.

4.2 Hierarchical classification

The ecosystem characterisation produced two levels of classification for the study region. Level 2 Biomes were classified through statistical analyses of research trawl data on fish species associations. Details of the approach are provided in Appendix C. Level 2 units were generated for the majority of the offshore areas from De Grey River to just west of the Barrow-Monte Bello Islands. Level 3 units were classified using best available spatial data sets, and input from the regional experts. Units were derived for the coastal zone of the study region extending offshore to approximately 20 m depth.

4.2.1 Level 2 – biomes

Level 2 of the classification was differentiated to two levels: Offshore units at Level 2A were derived from statistical analyses of cruise information and coastal units were determined from analyses of existing published reports and the expert information. Level 2B units were derived from the same information sources, but at a finer scale.

Level 2A

IMCRA 3.3 defines three units at the biome level (Level 2A) comprising a nearshore zone (PIN: Pilbara – nearshore), an offshore zone (PIO: Pilbara – offshore) and an outer shelf unit (NWS: North West Shelf). PIN extends from North West Cape in a zone along the coast which approximately follows the 10 m isobath. PON extends offshore from PIN and occupies the remaining width of the shelf (to the 200 m isobath) west of Barrow Island and the Monte Bello Islands, then narrowing to the east to depths of 50 m or shallower. Offshore of this boundary out to the 200 m isobath is the North West Shelf unit.

The current classification at this same Level 2A differs significantly from IMCRA 3.3. It includes a coastal marine classification which closely follows PIN, except that its offshore boundary is tied to the 10 m isobath and there is a short north-eastward extension of the shallow habitats emanating from Exmouth Gulf at North West Cape. The 10 to 20 m range is another sub-biome (subtidal nearshore) which is unmapped at this stage. Further offshore are the inner shelf, mid shelf and outer shelf biomes (figure 4.2.1) – the precise boundaries are still subject to analysis but broadly range as:

- Inner Shelf: 20 to 70 m:
- Mid Shelf: 70 to 120 m; and
- Outer Shelf: 120 to 200 m.

The shelf area west and south-west of Barrow-Monte Bello is unmapped, along with the interior region (deeper than 10 m) of Exmouth Gulf.

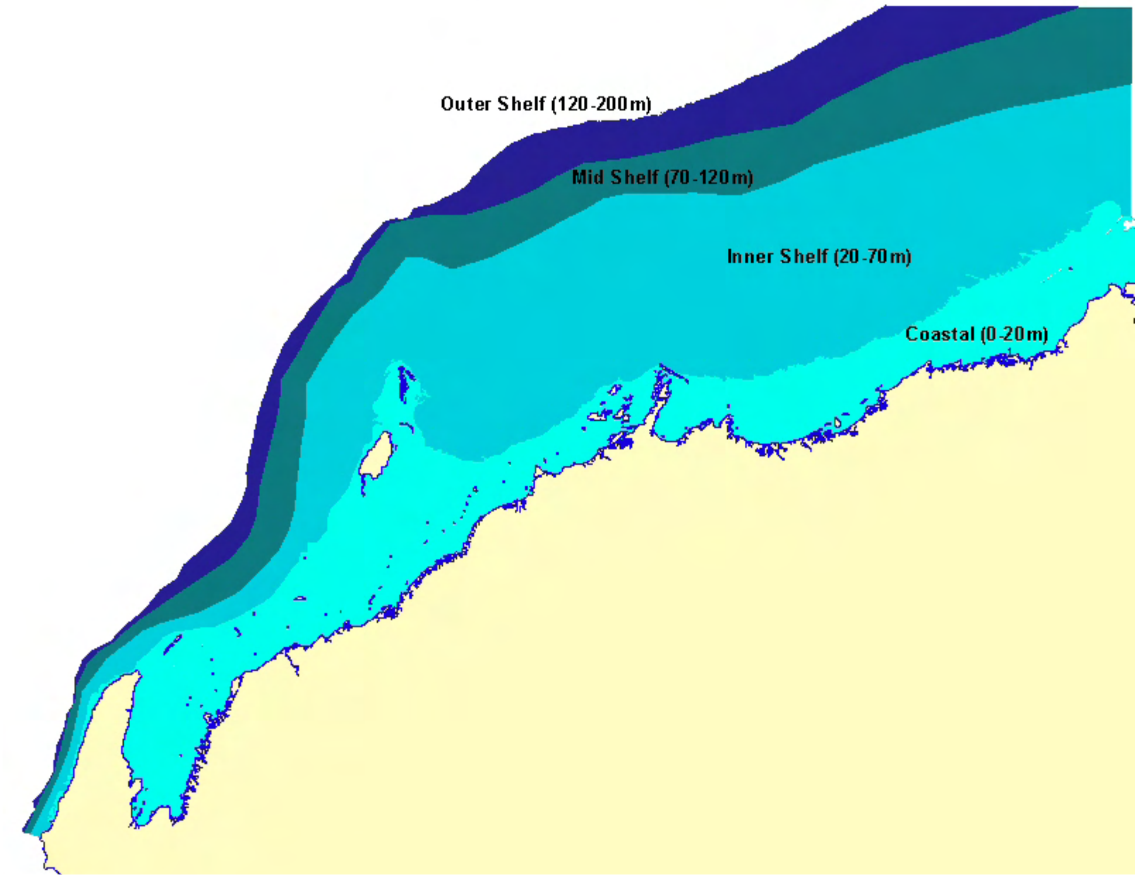


Figure 4.2.1: Level 2A Biome units for the whole study region.

Level 2B

Offshore Level 2B units were derived from additional analysis of the research trawl fish data. Within the Level 2A coastal biome a number of Level 2B units have been tentatively identified on the basis of descriptive accounts in the *Wilson Report* and from information supplied by regional experts (figure 4.2.2). These units are:

Exmouth Gulf

Area: Comprising a north-eastward extension emanating from North West Cape, a slight south-westward extension along Ningaloo, the eastern and western coastal marine banks of the Gulf up to Locker Point.

Characteristics: Distinguished as a major tropical gulf/embayment, one of the largest along the West Australian coast, with a relatively warm and hypersaline southern bay. Supports main commercial fisheries for prawn that rely upon its distinctive eastern and southern mangals, tidal flats and mudflats. The western shore comprises dune-backed beaches and supports hard corals south of North West Cape to the Bay of Rest. A diverse and rich suite of faunal elements (macroalgae, seagrasses, molluscs, sea whips/sea pens) are found along the north eastern extension of the Gulf which is included here as part of the Exmouth Gulf unit.

Onslow-Robe

Area: East of Locker Point to an eastern boundary which is just west of the Fortescue River delta. Includes the town of Onslow, and the delta systems of the Ashburton, Crane and Robe rivers, and a number of islands.

Characteristics: Distinguished as one of the longest coastline stretches containing a distinctive and diverse mangal habitat, differing in species composition and structure from those of Exmouth Gulf to the south-west and the Fortescue River to the north east (Wilson, 1994). Contains a number of inactive deltas, and numerous small low limestone islands some of which support corals.

Dampier

Area: From a western edge which encompasses the Fortescue River delta to just east of Picard Island.

Characteristics: An archipelago of regional significance containing numerous islands and reefs, and supporting a diverse range of corals, soft-substrate infauna and endemic molluscs. Cape Preston to the west and Cape Lambert to the east are included in this unit as secondary features associated with the main archipelago.

Depuch-Port Hedland

Area: From east of Picard Island to a boundary east of Port Hedland.

Characteristics: Primarily a long stretch of mangal coastline containing a number of active deltas and the unique beaches of Munda and Cowdrie. South-east of Munda Beach a string of islands, the largest of which is the rocky Depuch Island, spans the area offshore of the Bella Bella, Peewah and Yule rivers.

De Grey

Area: The De Grey delta east of Port Hedland up to Cape Keraudren.

Characteristics: Major delta system of De Grey comprising extensive mud and sandbanks of high turbidity, several bays and rocky shores with small beaches along the gently sloping coast.

Barrow-Monte Bello

The Barrow-Monte Bello's complex and associated limestone pavement forms a substructural unit within the inner shelf biome. The extent of its linkage with the surrounding inner shelf and nearshore biomes is unexplored at this stage.

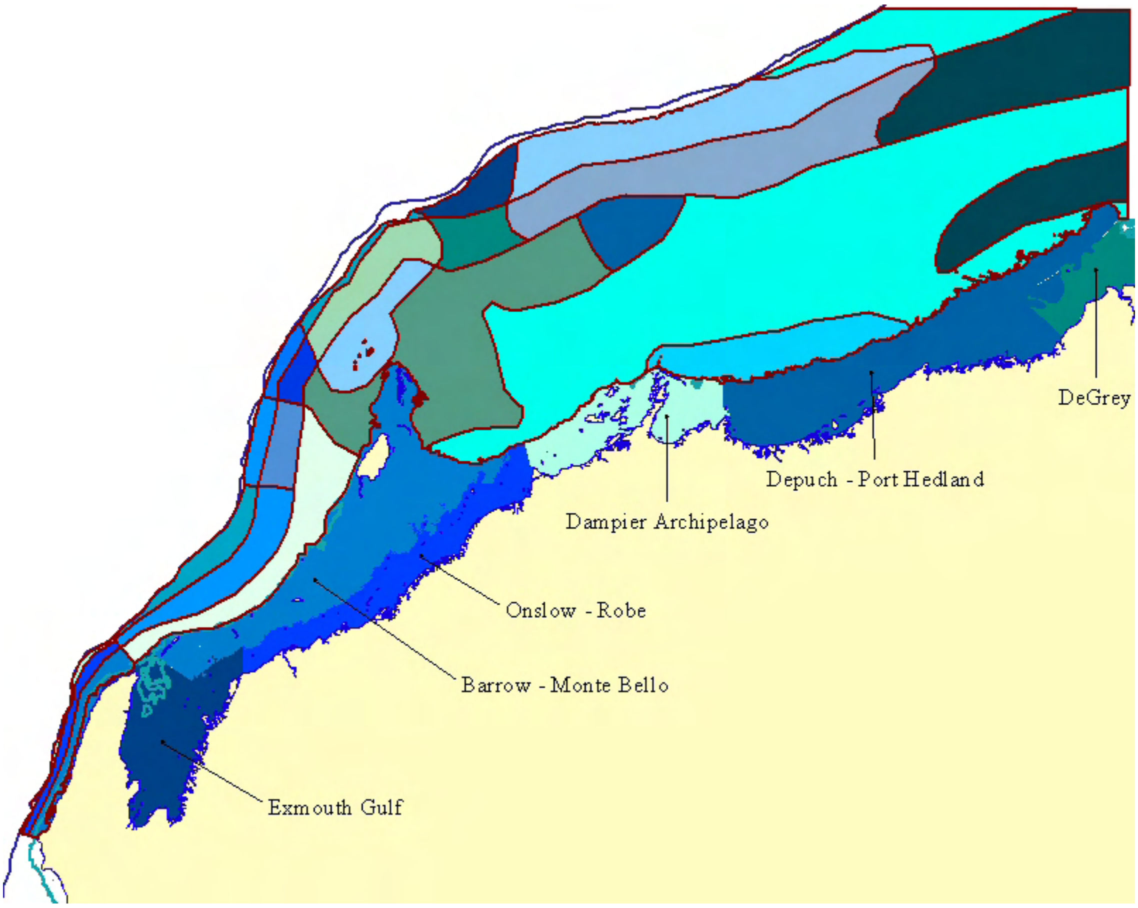


Figure 4.2.2: Map showing Level 2B Biome units for the whole study region. Offshore areas (outlined in red) have been derived from analysis of fisheries data and are not yet fully described. Inshore areas (<20 m) are implied and require additional data for verification.

4.2.2 Level 3 – biogeomorphic units

Level 3A

In applying the hierarchical classification, the Level 3A units form major structural sub-components of Level 2 biomes. A wide variety of information, including GIS layers, expert interviews and workshop, and existing integrated studies of the Pilbara region (CALM, 1994), were used to identify 18 biogeomorphic regions within the study region (figure 4.2.3). These units represent areas containing suites of geomorphic features (e.g. field of sandbanks) that are differentiated by environmental gradients, and major geomorphological units (e.g. a large embayment).

The Level 3A units are described for coastal waters of the region, extending offshore to the 20 metre bathymetric contour (table 4.2.1). Most existing descriptions of the area are for the coastal zone, with the 10 to 20 metre depth range for the eastern section of the study region remaining largely undescribed. The region was identified as a major information gap with no existing habitat mapping or marine surveys (Heyward et al. 2006) and regional experts could offer few additional insights.

The area between Dampier Archipelago and North West Cape is better described, and has been mapped by a number of different projects and groups. This area is covered extensively by petroleum leases, and contains significant island groups, both nearshore and offshore.

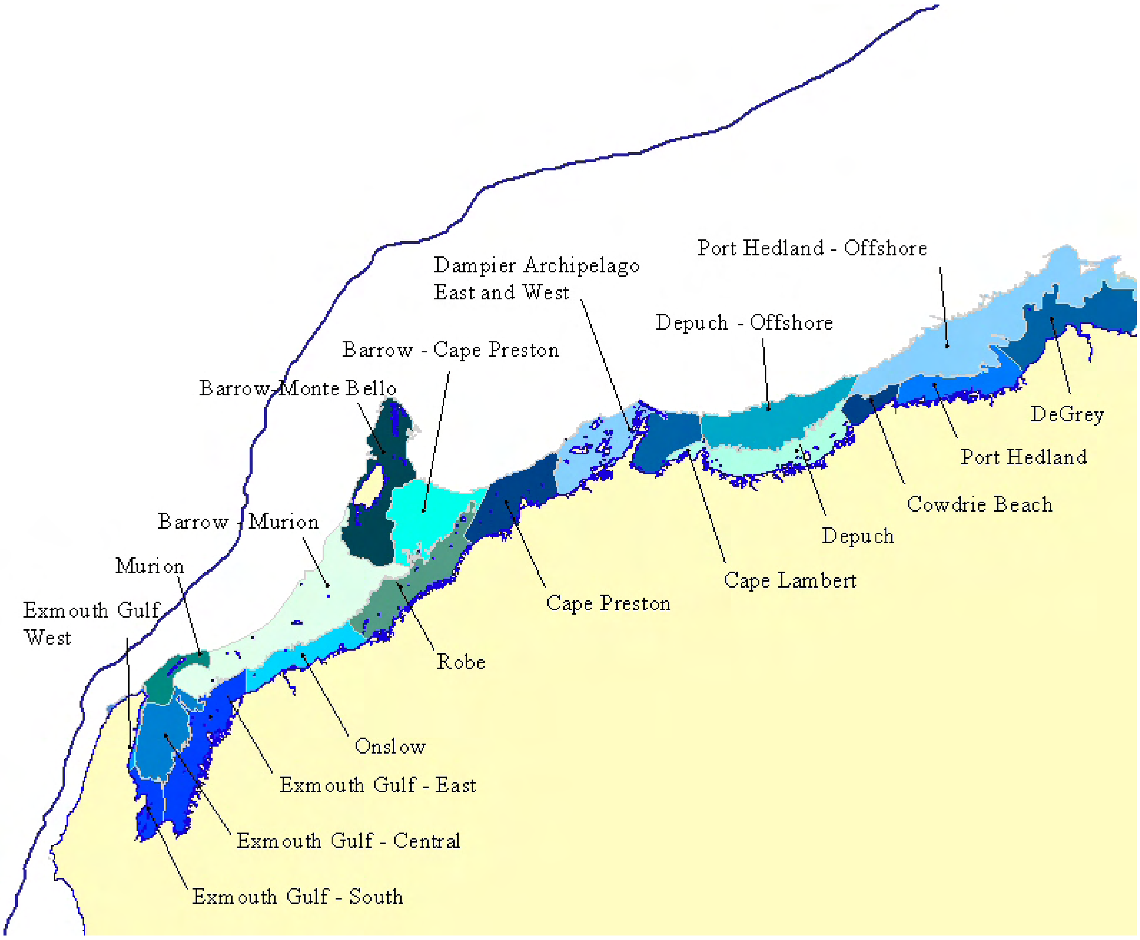


Figure 4.2.3: Coastal units at Level 3A for the study region.

Table 4.2.1: Level 3A units of the coast of the North West Shelf. Description of the major landmarks which bound the units, and depth ranges. Major community types are also indicated. Coastal units extend offshore to the 10 metre contour, unless otherwise indicated. Offshore units extend to the 20 metre contour. Descriptions have been drawn extensively from CALM (1994).

Unit Name	Description
West Exmouth Gulf	WAPET Jetty to North West Cape. Dune-backed beaches, hard corals, relatively sheltered with gradation from exposed North West Cape, diverse and rich suite of faunal elements (macroalgae, seagrasses, molluscs, sea whips/sea pens) are found along the northern part of this coast.
South Exmouth Gulf	WAPET Jetty to the western side of Sandalwood Peninsula. Hypersaline and warm coastal section comprising fine muddy sediments. Mangroves in Gales Bay.
East Exmouth Gulf	Locker Point to Giralia Bay/Sandalwood Peninsula. Extensive and distinctive mangals, supra-tidal flats supporting major prawn fisheries. Low limestone islands with muddy beaches and rock pavement shores. Intertidal pavements support extensive macroalgal beds and coral communities.
Central Exmouth Gulf	Waters of Exmouth Gulf greater than 10 metres deep. Extending approximately north between Exmouth Reef and South Murion Island to the Barrow-Murion unit. Exmouth Gulf is one of the largest embayments on the Western Australian coast (Wilson, 1994). It supports a major Prawn fishery.
Barrow – Murion	Waters between Barrow Island, Barrow Island Shoals and Murion Islands/ Exmouth Gulf. Bounded by the 20 metre contour offshore, and the 10 metre contour onshore. Major islands include Serrurier, Bessieres, Thevenard and Airlie Islands. Transition between coastal and marine waters. Strong tidal currents between North West Cape and South Murion Island.
Onslow	Locker Point to Cane River. Active and deltas, beaches and distinct mangroves, exposed coast subject to occasional terrestrial outflows, numerous small low limestone islands supporting corals.
Robe	Cane River, east to the Fortescue River. Extensive mangroves along with relatively dense array of offshore islands, shoals and deltas.
Cape Preston	Fortescue River, east to the western end of Regnard Bay. Western segment of Dampier Archipelago, numerous islands, shoals, reefs supporting soft substrate infauna and endemic molluscs.
Barrow – Monte Bello Islands group	Island group consisting of Barrow Island, Lowendal and Monte Bello Islands, extending inshore to the Barrow Shoals. The southern section bounded by the 10 metre contour, and the northern section by the 20 metre contour.
Barrow – Cape Preston	Waters between Barrow Island, Barrow Island Shoals and Cape Preston. Bounded by the 20 metre and 10 metre bathymetric contours. The south-western section split between the Barrow-Murion unit by shallow waters between Great Sandy Island and the Barrow Shoals. The eastern section separated from Cape Preston by the 10 metre contour extending close to the 20 metre contour at McLennan Bank. Transition between coastal and marine waters.
Murion Islands	Murion Islands, and waters between North West Cape and east to Peak Island. Transition between Exmouth Gulf and oceanic waters.

Unit Name	Description
Dampier Archipelago – West	Western side of Dampier Archipelago. Most prominent regional archipelago of NWS, larger islands, shoals and reefs providing diverse environment for infauna, molluscs.
Dampier Archipelago – East	Eastern side of Burrup Peninsula. Extending offshore to just east of Delambre Island, and onshore to Cleaverville Creek. Large shallow embayment of Nichol Bay.
Cape Lambert	Eastern end of Nichol Bay, from Cleaverville creek to the western side of Cape Lambert, and offshore to Bezout Island. Forms the boundary between Dampier Archipelago and the eastern section of the region.
Depuch	Cape Lambert to Cape Cossigny. Extensive stretch of mangal coastline, some active deltas, Depuch Island offshore.
Depuch – Offshore	Offshore waters between 10 and 20 metres deep from Cape Lambert to Cape Cossigny. Transition between coastal and oceanic waters. Bathymetry shows offshore reefs, however no islands are present in this section.
Port Hedland – Offshore	Offshore waters between 10 and 20 metres deep from Cape Cossigny to the De Grey River. Bathymetry shows offshore reefs. Turtle Island is present in the eastern end of the region, offshore from the De Grey River and is surrounded by a shallow reef.
Cowdrie Beach	Cape Cossigny to Cape Thouin. Munda and Cowdrie beaches are amongst expansive mangal coastline either side. Turtle nesting site.
Port Hedland	Cape Thouin to the western end of sandy coastline extending from Spit Point. Mangroves along shoreline east and west of Port Hedland.
De Grey	West of Spit Point to approximately Cape Keraudren. Major delta at mouth of De Grey River, extensive mud and sandbanks, high turbidity, several bays and rocky shores, small beaches, gently sloping coast.

With increasing distance offshore, the amount of information available to generate classification units becomes increasingly sparse. The level of confidence in the locations of boundaries becomes lower, and generally the size of units differentiated becomes larger. Typically, coastal units are well defined to the intertidal zone, and offshore to the limit of visibility in aerial photos or satellite imagery for defining boundaries. Available bathymetry was used to define the coastal units outside the shallow coastal area. Existing unit definition should be refined as better definitions of the geomorphology become available, or targeted field work is carried out.

Level 3B

The Level 3B units form distinct geomorphological features and the major landform type within the Level 3A regional scale units (table 4.2.2). From this perspective the 3A units consist of groupings dominated by a set of typically one to three 3B units. Level 3A units with similar groupings of 3B units would be identified as similar types. In the coastal zone of the North West Shelf Level 3B units (figure 4.2.4; table 4.2.2) follow the types identified by Semeniuk (1992) and later adopted by Wilson (CALM, 1994). The offshore units are primarily based on depth gradients, proximity to the mainland, and distinct subsurface features (table 4.2.2). The units currently map directly to the existing Level 3A units as there is no additional information available to map units consistently at this scale for the whole study region. Mapping has been done to approximately the five metre contour offshore, and landwards to the high tide line.

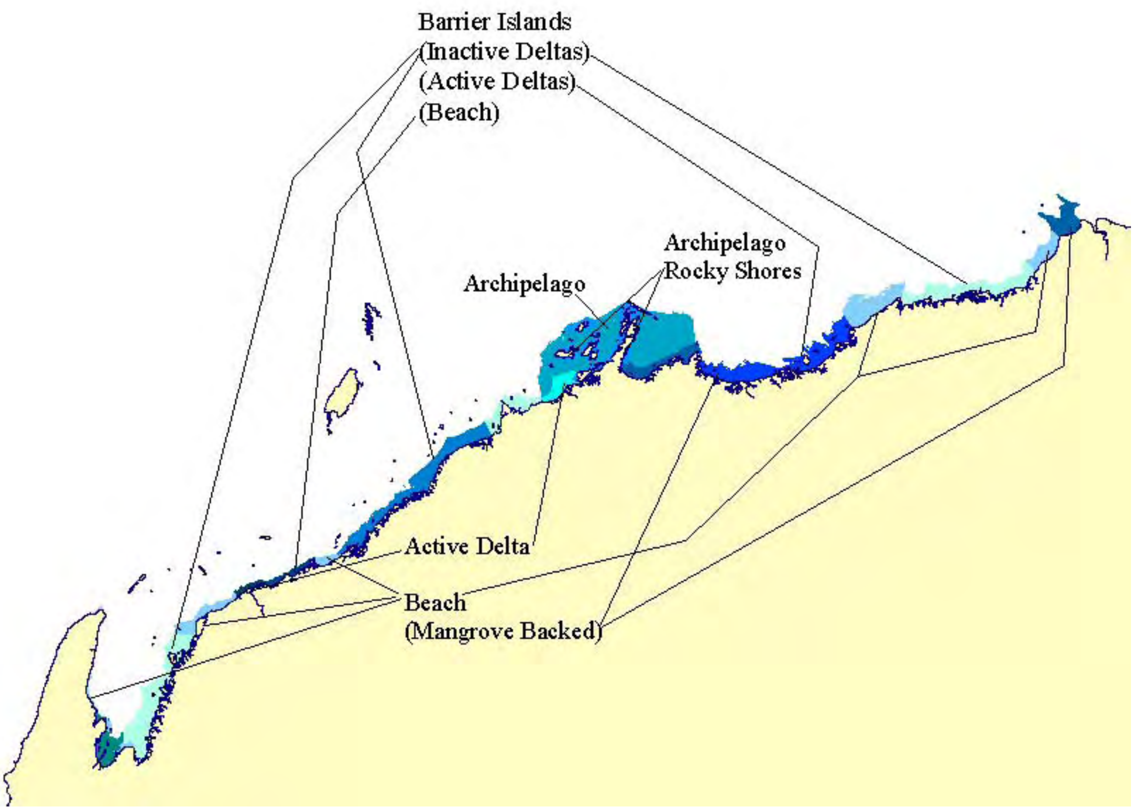


Figure 4.2.4: Level 3B units for the coastal zone of the study region. The main coastal units in the region are barrier complexes, and beaches. Sub types are also identified for these two groups.

Table 4.2.2: Level 3B of the North West Shelf.

	Geomorphic unit	North West Shelf Level 3B units identified
Coastal	Active deltas	De Grey River; Ashburton River; Sholl Creek; Maitland River
	Beach/dune shores	Urala; Yardi River; Coonga Creek; Cape Preston – East; Cape Thouin; Spit Point; Exmouth Gulf – Western Shore; Hooley Creek; Beadon Creek – East
	Inactive, eroding deltas and their Barriers	Robe River; Fortescue River
	Limestone Barrier Coasts	Port Hedland; Coolgara Point
	Bays and their associated limestone barriers	Mardie Creek; Exmouth Gulf – Eastern Shore; Nickol River; Depuch
	Archipelago/Ria coasts	Dampier Archipelago
Offshore	Nearshore island groups, in waters less than 10 metres	Robe – nearshore;
	Offshore island groups surrounded by waters greater than 10 metres	Onslow – Robe – offshore
	Non emergent offshore reef chains	Depuch – Port Hedland - offshore
	Shallow embayments	Shallow mangrove backed bays in the southern Exmouth Gulf. Gales Bay, and Bay of Rest. The Sandalwood Peninsula represents the transition between the Pilbara Coast and the Gascoyne Coast.

Level 3C

Level 3C units represent the major coastal and nearshore geomorphic units and are the best available mapping available across the entire study region at a similar scale. Units identified at this level were largely derived from existing mapping. The major data sources were topographic maps for the coastal units and bathymetry for the offshore units, the boundary between the two units being the intertidal zone. Intertidal units were based on the best available maps which were verified from aerial photography. The topographic data were a mixture of 1:50 000 and 1:100 000 scale mappings. The bathymetry was obtained from the Department of Transport, with additional information obtained from charts and industry data. The resulting units may be modified or refined as improved data become available.

Level 3C units identified for the North West Shelf are listed in table 4.2.3 with a brief description of each. A corresponding map of all units across the study region is shown in figure 4.2.5, with increasing levels of detail revealed in figures 4.2.6 to 4.2.12. Figures 4.2.9 to 4.2.12 best indicate the spatial scale of the mapping derived at this level in coastal regions. Offshore waters are classified in a single unit as there was inadequate information to map these areas at Level 3C.

Figures 4.2.13 to 4.2.15 show imagery used for classification. *LandSat* imagery (figure 4.2.13) was used where aerial photography was not available (figures 4.2.14 and 4.2.15).

Table 4.2.3: The mapping units identified at Level 3C of the hierarchy.

Geographic unit	Description
Land/island	Mainland, islands.
Beach – dune	Sandy beaches or dune shorelines above the mean water level. Does not differentiate sandy substrate in the marine environment.
Salt flats – tidal flats	Landward extent of tidal zone inundated only at high tide or during elevated tidal events such as cyclones.
Mud and tidal flats	Tidally inundated. Intertidal zone.
Mangroves	Occurrence of mangroves or mangals. Mangroves are recognised as a unique unit as a subset of the mud and tidal flats.
Embayment – subtidal zone	Shallow waters enclosed by an embayment which are not exposed at low tide.
Tidal channel (subtidal)	Tidal drainage channel/s which incise tidal flats and may extend inland to form tidal creeks through coastal tidal or mud flats.
Nearshore waters (<5 metres)	Undifferentiated shallow nearshore and coastal waters which are not tidally exposed.
Channel (<5 metres)	Channel in coastal waters separating islands less than 5 metres deep. Does not include extensions of coastal creeks.
Channel (5 to 10 metres)	Channel 5 to 10 metres deep separating islands or islands from mainland.
Channel (10 to 20 metres)	Channel 10 to 20 metres deep separating islands or islands from mainland.
Nearshore reef	Areas identified as reef, adjacent (connected either directly or adjacent to mudflats) to the mainland coastline or islands.
Offshore reef	Areas identified as reef not immediately adjacent to mainland coast or island. Generally in waters deeper than 5 metres.
Offshore waters (5 to 10 metres)	Offshore waters between 5 and 10 metres depth. Includes water surrounded by deeper waters (>10 metres).
Offshore waters (10 to 20 metres)	Waters between 10 and 20 metres depth.
Offshore waters (>20 metres)	Waters greater than 20 metres deep.
Shallow island fringe	Shallow waters adjacent to island which are intertidal. Less than 5 metres depth.
Offshore waters <5 metres (island, shoal)	Shallow water in areas deeper then 5 metres which are less than 5 metres depth. May be represented as shoals or reefs on navigation charts, or shallow waters in bathymetric charts. Not surrounding or adjacent to islands.
Offshore waters 5 to 10 metres (island, shoal)	Shallow water in areas of water deeper than 10 metres which are between five and 10 metres deep. May be represented as shoals or reefs on navigation charts.

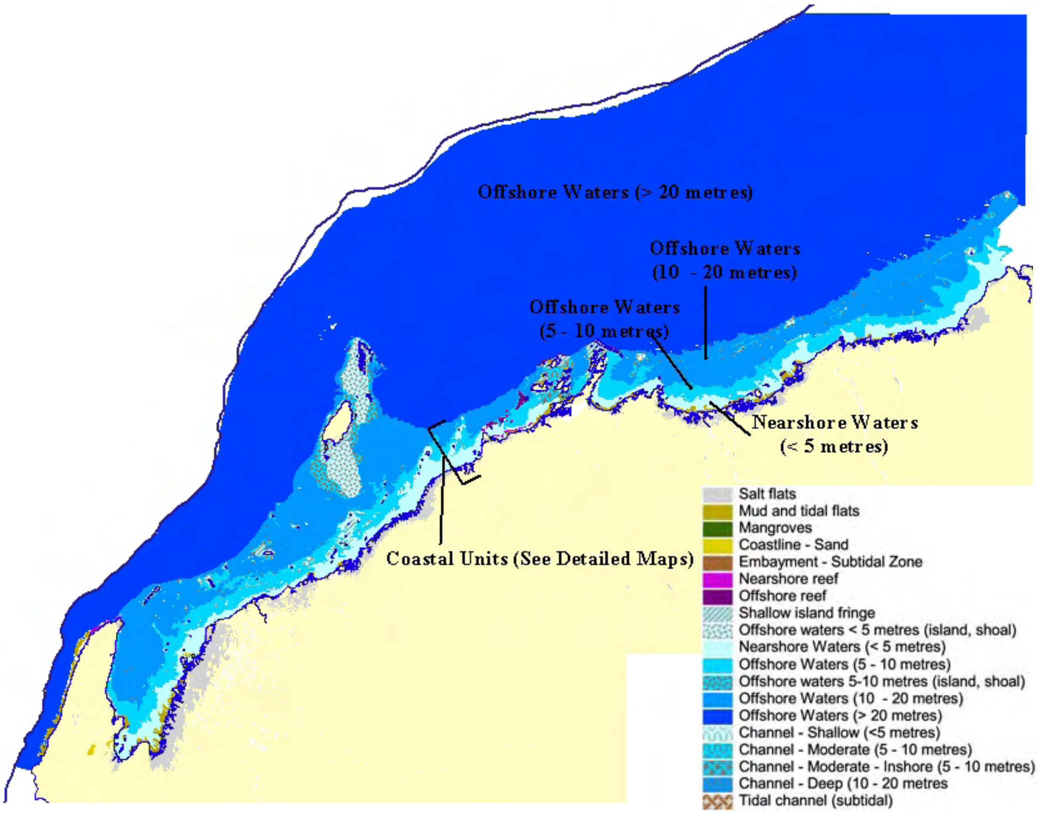


Figure 4.2.5: Level 3C units for the coastal zone of the study region. Details are shown in subsequent figures.

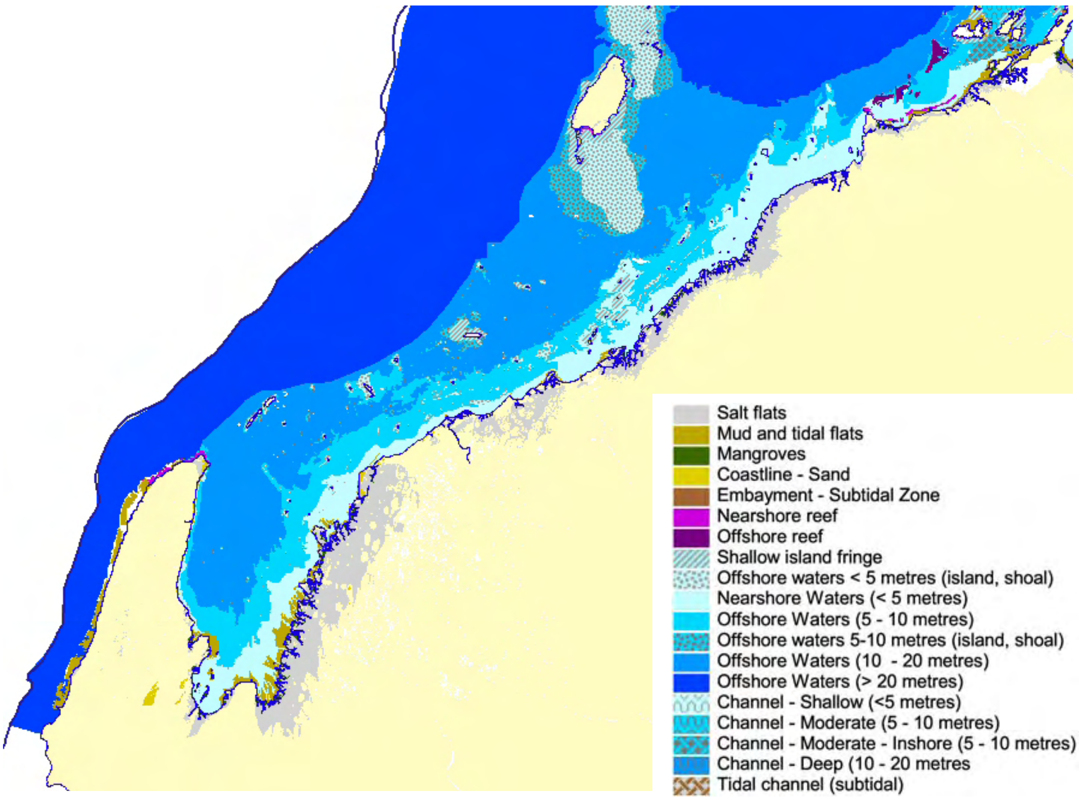


Figure 4.2.6: Level 3C units for the western section of the North West Shelf including Exmouth Gulf.

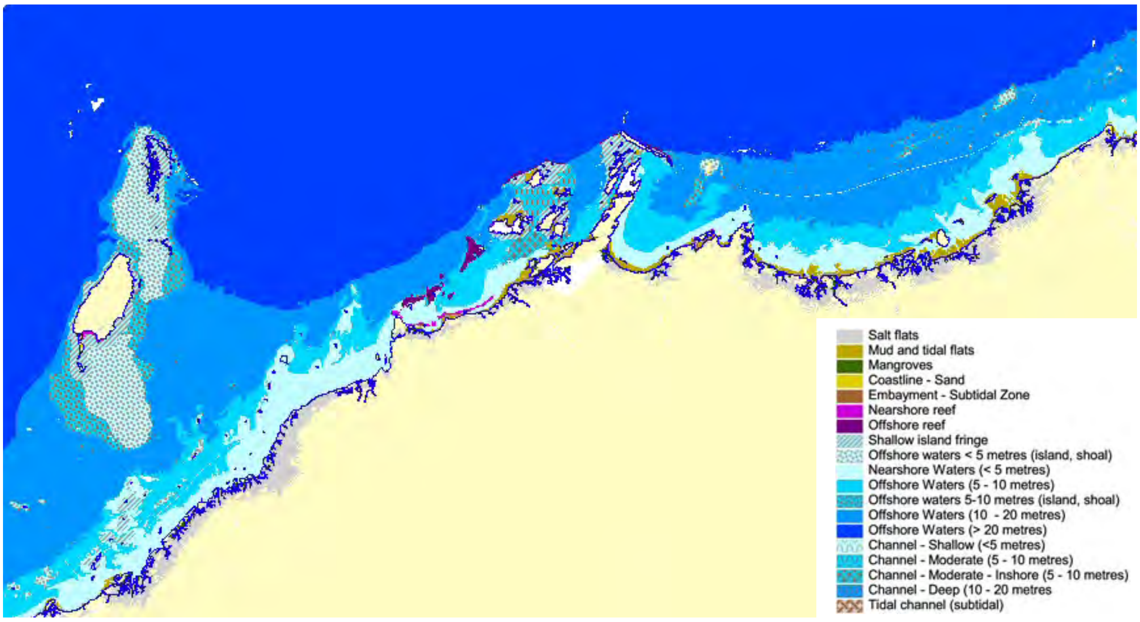


Figure 4.2.7: Level 3C units for the central section of the North West Shelf including Dampier Archipelago.

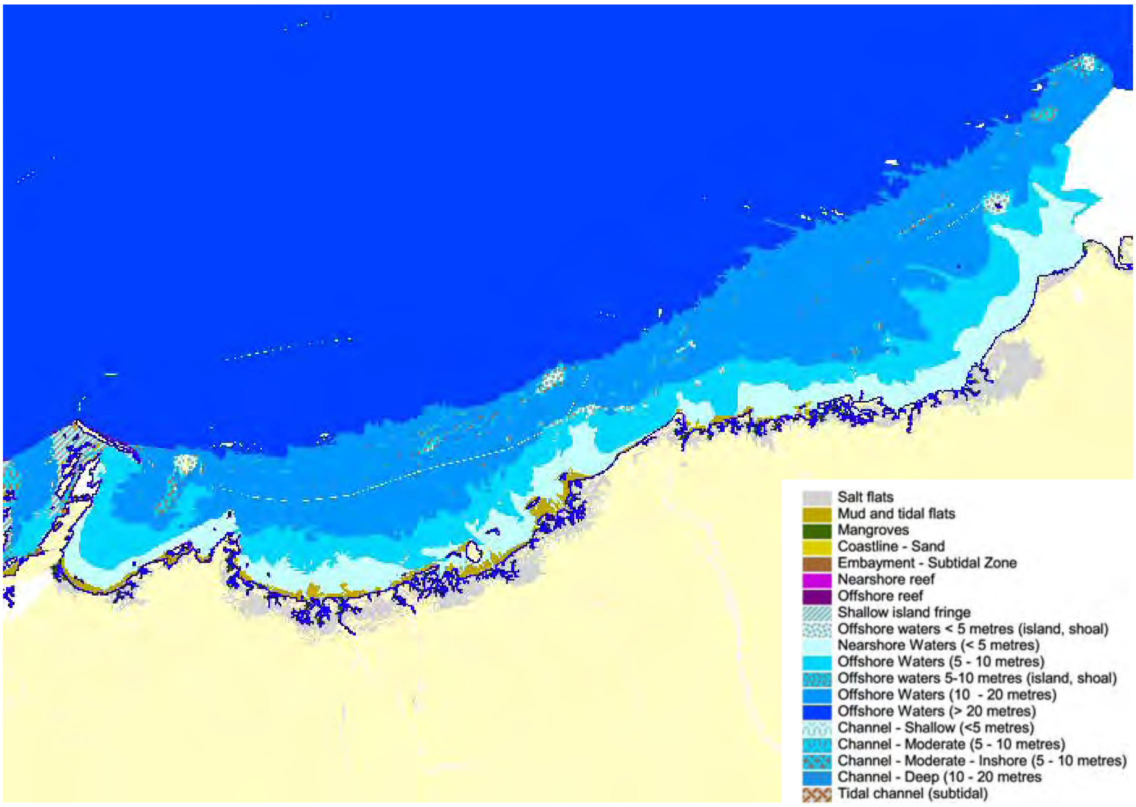


Figure 4.2.8: Level 3C units for the eastern section of the North West Shelf including Port Hedland.

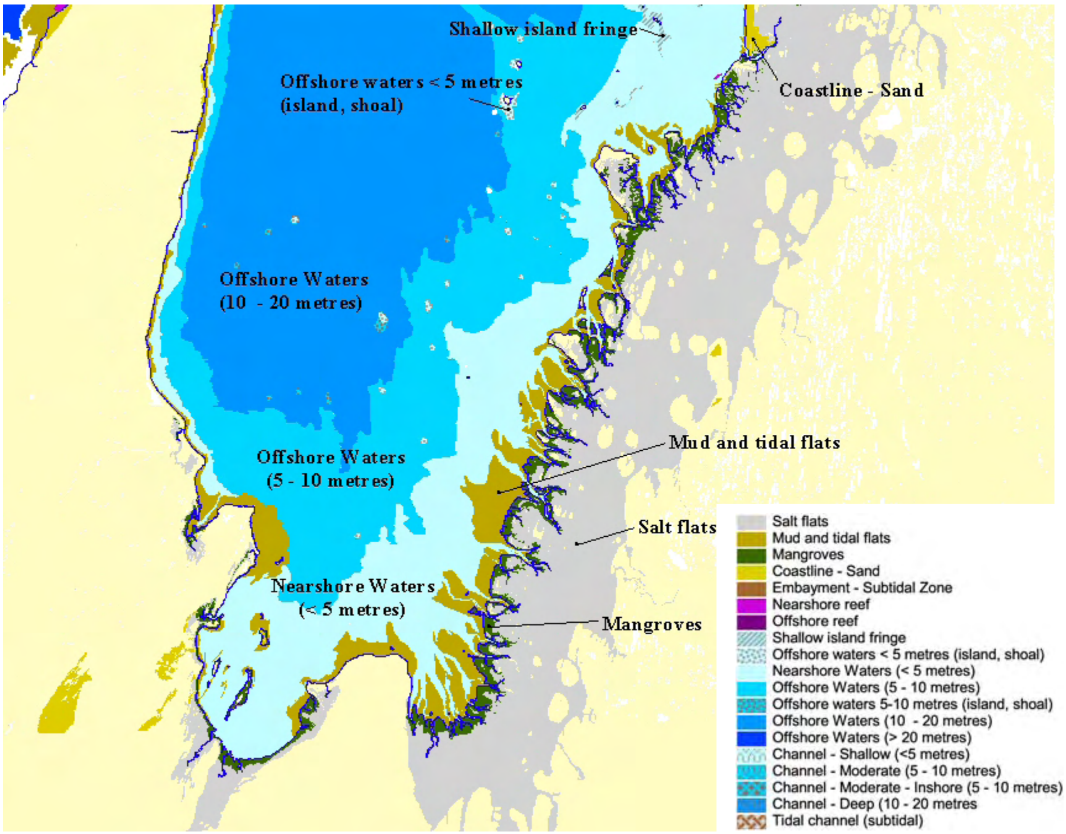


Figure 4.2.9: Examples of Level 3C units within Exmouth Gulf.

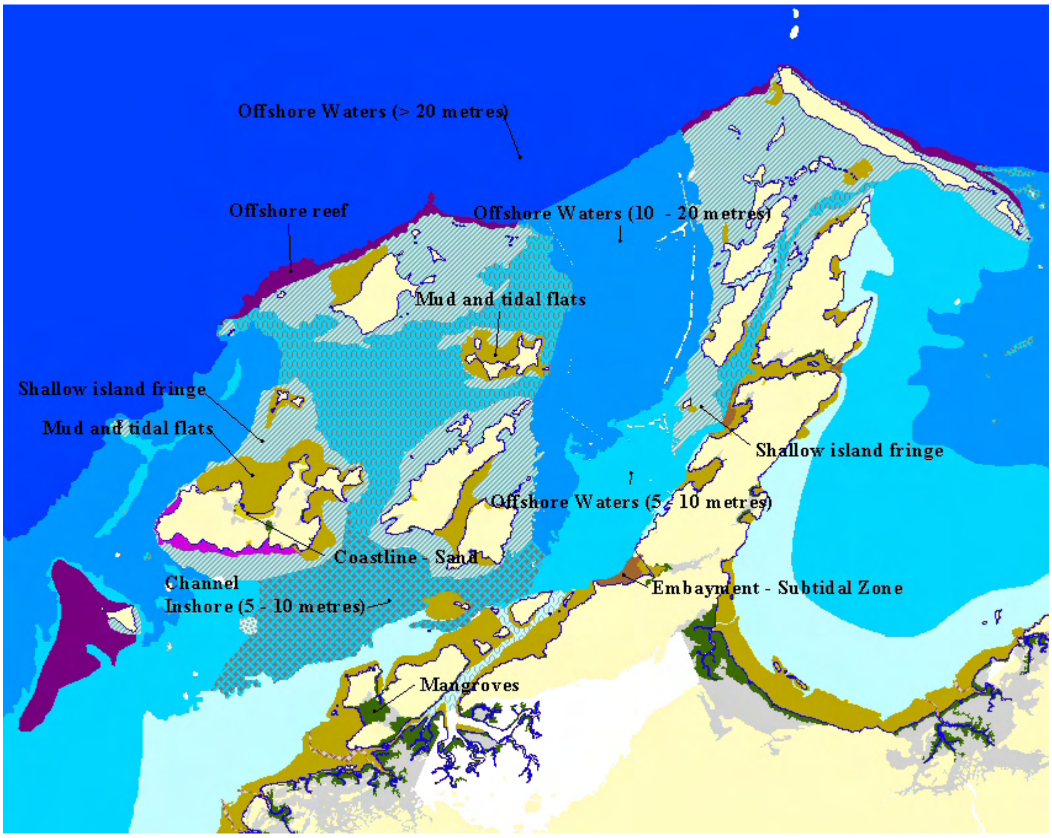


Figure 4.2.10: Examples of Level 3C units within Dampier Archipelago.

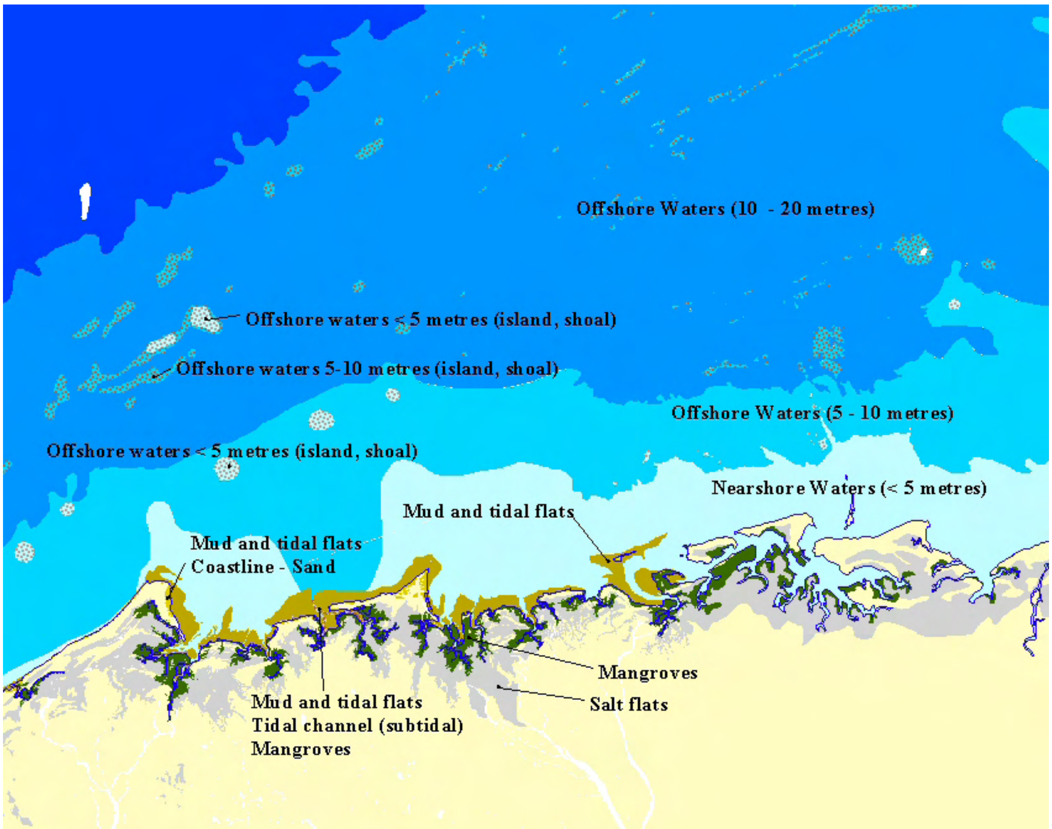


Figure 4.2.11: Examples of Level 3C units around Port Hedland.

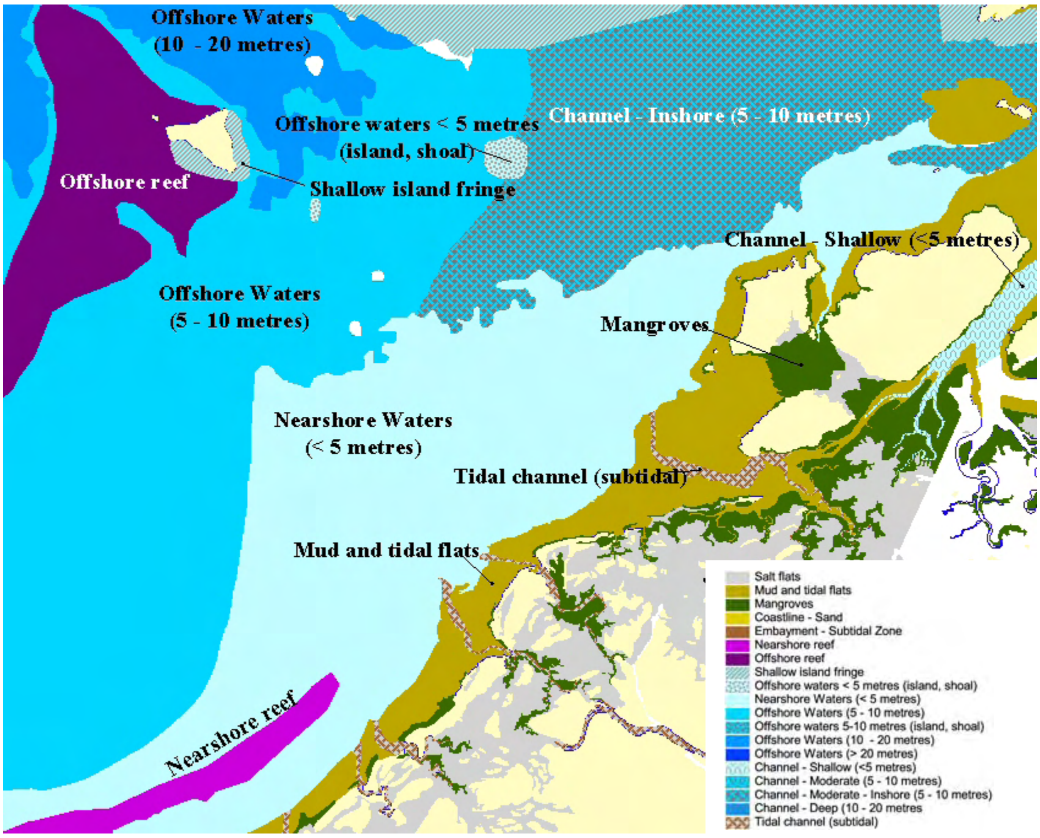


Figure 4.2.12: Additional detail of Level 3C units within Dampier Archipelago.

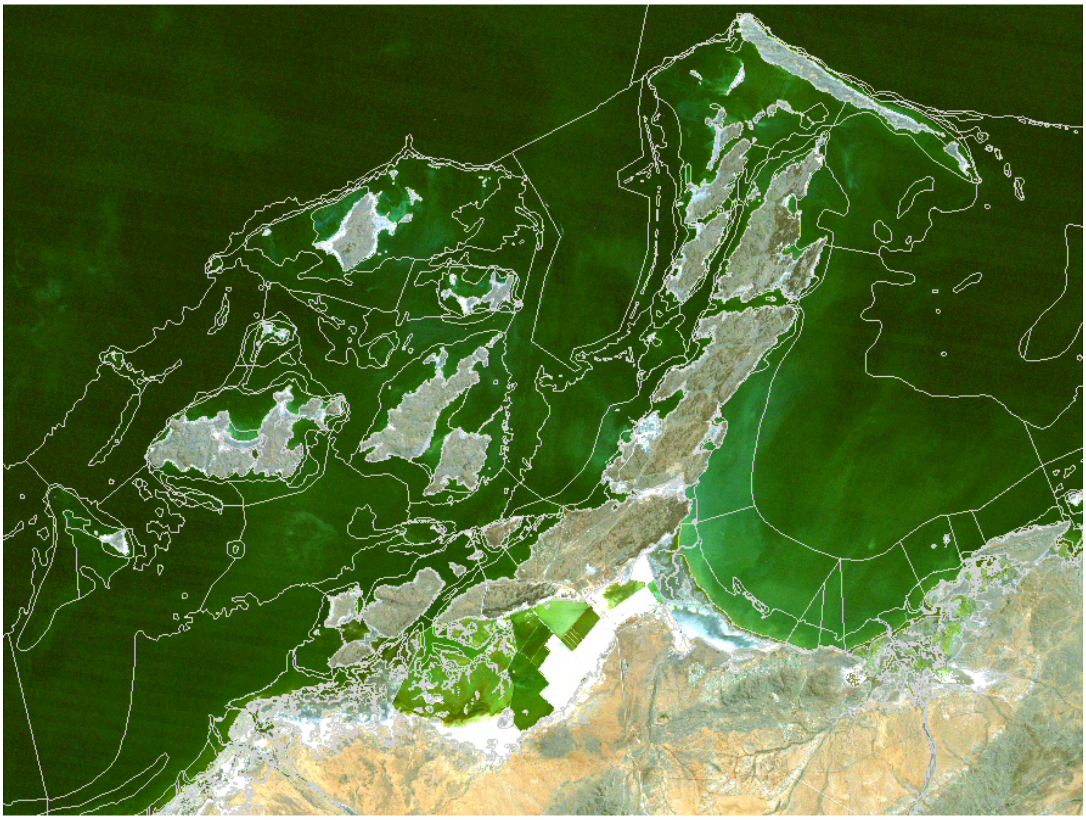


Figure 4.2.13: Sample of satellite imagery used to inform the classification process.

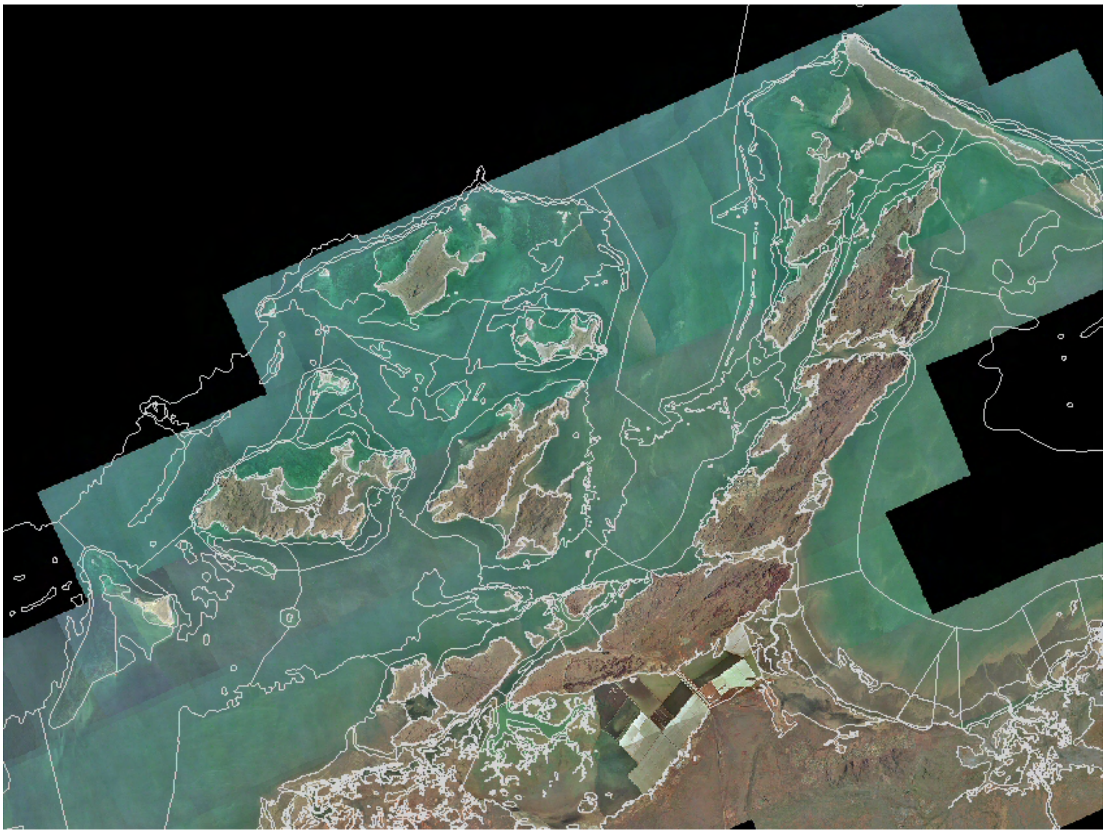


Figure 4.2.14: Sample of aerial photography used to inform the classification process. Approximate scale 1:250 000.

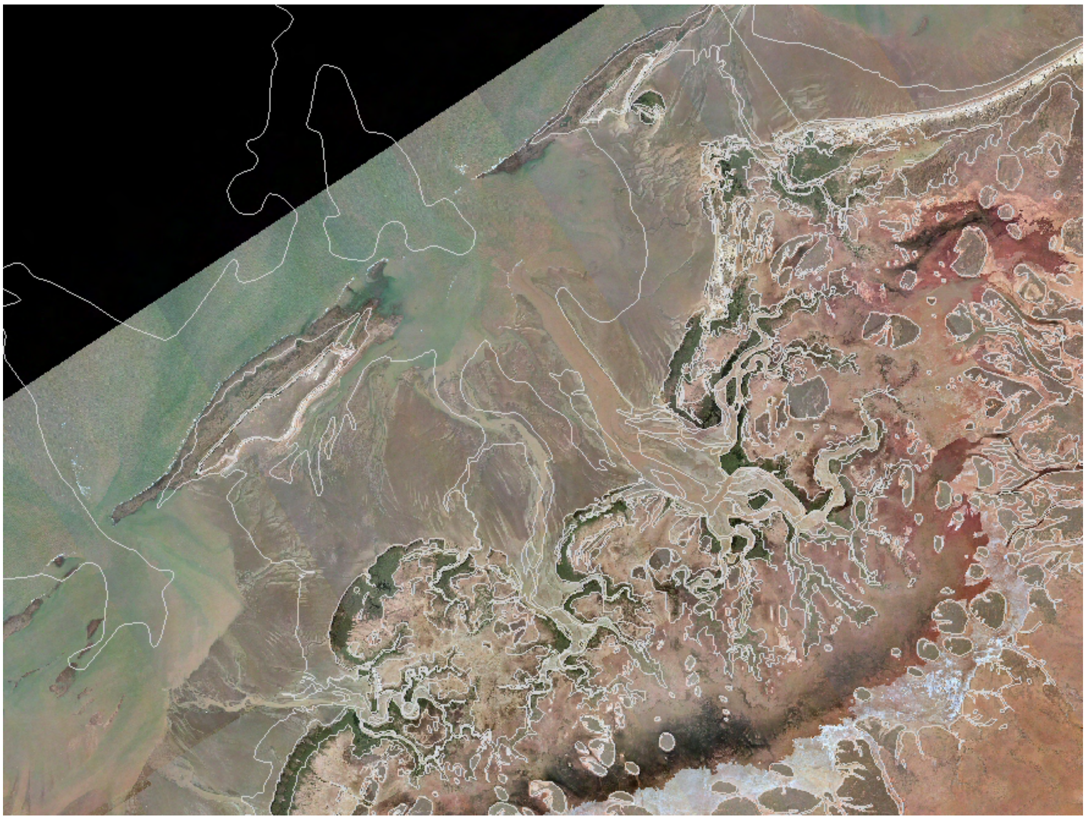


Figure 4.2.15: Sample of aerial photography used to inform the classification process. The image is from Dampier to De Grey River. Salt flats, mud flats, islands, mangroves and tidal channels can be clearly identified. Approximate scale 1:75 000.

4.2.3 Level 4 units – coastal and nearshore marine habitats

Additional information was obtained on marine habitats in some areas (particularly where it was required for modelling) which extended the application of the hierarchical classification to Level 4. This information was compiled from existing habitat mapping over the region, and inferred where data did not exist.

There are large areas that have not previously been mapped. Coastal and shallow water areas in the western section covered by the oil and gas industry were mapped in addition to areas around the shallow waters adjacent to the mainland, and surrounding islands. This is probably to compensate for the lack of mapping information at these locations from aerial photography and satellite imagery.

There is a high level of overlap between the Level 3C units derived for the areas adjacent to the coastline, as many of the existing data sources appear to be the same (probably this also applies to the DOLA topographic data). Additional mapping is also available for the marine environment from a number of sources.

CALM Marine Conservation Branch had previously merged all existing data to develop habitat maps for the marine park planning areas of the Barrow/Monte Bello Islands and Dampier Archipelago regions. The CALM data was used where available, and additional habitat gaps were filled from existing data, or from information extracted from reports and the expert interview process. The data at this level of detail represents the starting point for the development of Level 4 and 5 mapping units, and was integrated into the existing hierarchical classification.

Mosaic units were derived for areas where suitable data was not available to differentiate individual elements. This was required for waters deeper than 5 to 10 m where the available imagery (*LandSat* and aerial photography) did not provide relevant information. Existing information extracted from field surveys and reports was used to define the mosaics in these regions. Depth was used as the primary differentiation attribute between units in offshore waters.

A major issue with the habitat information for the North West Shelf is that fieldwork, conducted mainly for the oil and gas industry, has largely centred on islands and coral reefs. Hence, there is very little information available for the intervening areas, particularly in non coastal areas east of Dampier Archipelago.

The units derived for the Level 4 classification are listed in table 4.2.4. The classification was applied across the study area (figure 4.2.16) using information from Level 3C of the classification (figure 4.2.5). A detailed mapping of the units at Level 4 for Dampier Archipelago is presented in figure 4.2.17.

Table 4.2.4: Level 4 habitat units derived for the study region.

Habitat Type
Land
Beach (sand, supratidal)
Coral reef communities (intertidal or shallow/granite)
Coral reef communities (intertidal or shallow/limestone)
Coral reef communities (subtidal reef platform)
Coral reef communities (subtidal)
Coral reef communities (subtidal/lower seaward reef slope)
Intertidal and subtidal reef, muds and sands. Adjacent to coastline.
Intertidal Limestone pavements; reef flats; intertidal rubble deposits
Intertidal sand
Macroalgae (limestone reef)
Mangal
Mudflat
Salt marsh
Sand (subtidal)
Sand; Limestone pavement; macroalgae; seagrass; Occasional bommies
Silt (Subtidal)
Subtidal reef (low relief)
Subtidal reef (low relief) + Sand
Subtidal reef; Extensive filter feeder communities

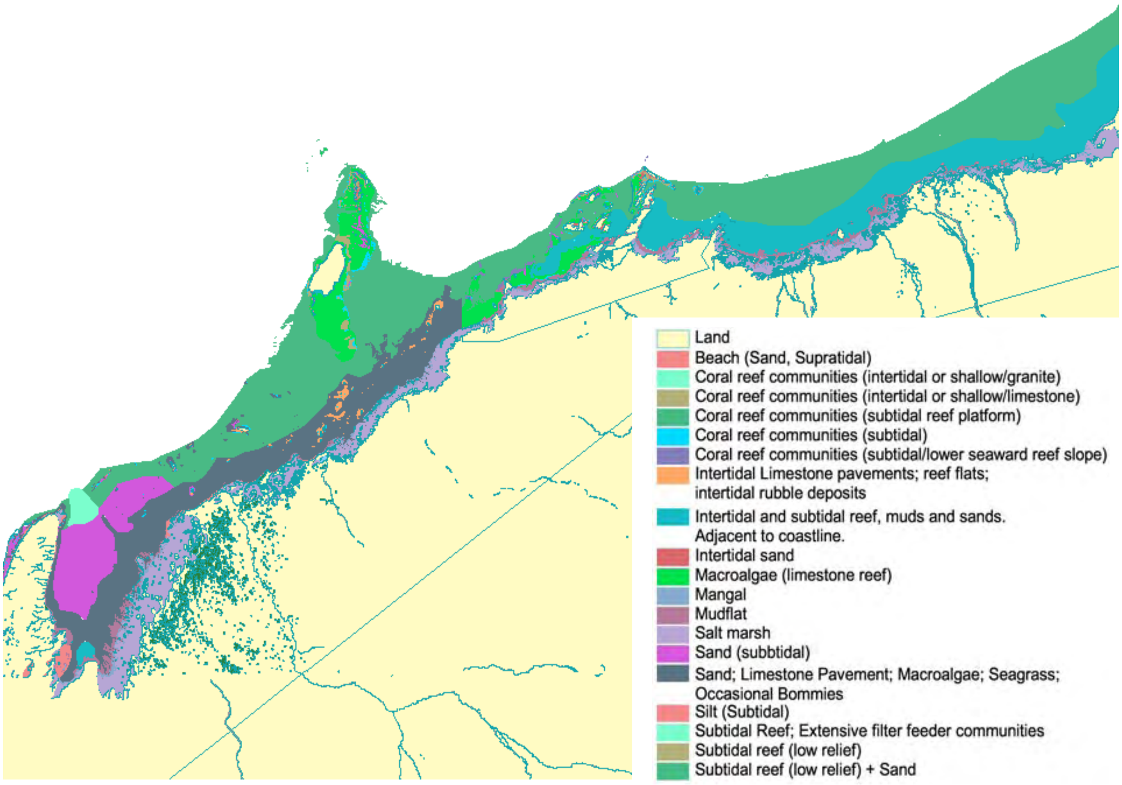


Figure 4.2.16: Map of the Level 4 habitats derived for the NWSJEMS region.

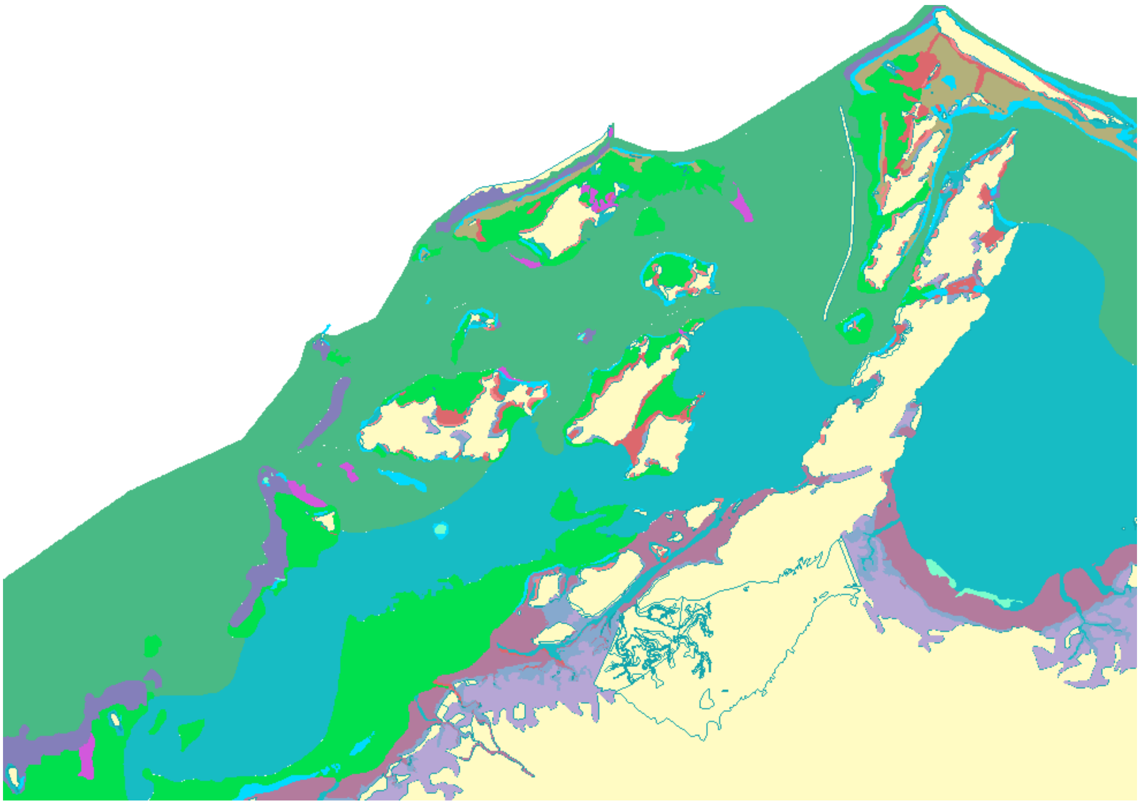


Figure 4.2.17: Map showing the level of detail of Level 4 habitats over the Dampier Archipelago. Colour legend as in figure 4.2.16.

4.3 Data coverage

So as to indicate the availability of habitat data over the study region, existing habitat data sets have been combined and presented. Figure 4.3.1 shows the coverage of existing habitat data sets compiled for the whole region. Coastal data sets obtained consist primarily of the Department of Land Administration topographic data (figure 4.3.2). This information appeared in a number of existing data sets obtained by the study. Coastal marine data exists primarily for the region between Point Samson (east of Dampier Archipelago) and Ningaloo reef. Dampier Archipelago is well covered, as are the islands between Dampier and Ningaloo reef. Almost all major islands in the region have been mapped to the expected depth limit of airborne imagery (around 10 m). This includes island fringes and adjacent intertidal platforms (figure 4.3.2).

Areas with poor data coverage are the inter-island regions, and all of the area east of Dampier Archipelago, beyond the De Grey River. Some basic mapping is available around the harbour of Port Hedland, and the islands north of the De Grey River mouth.

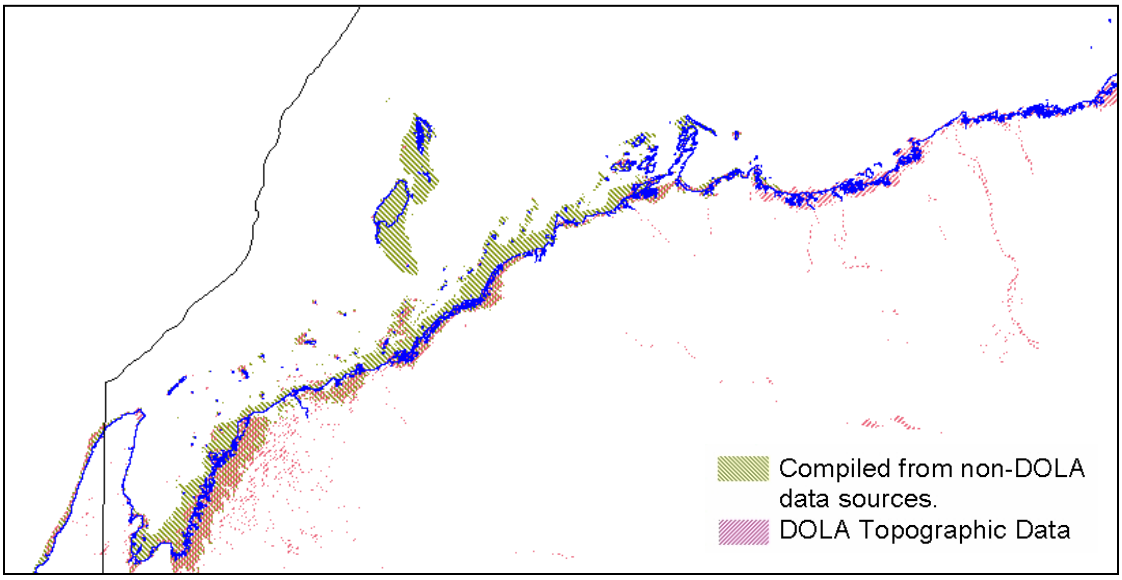


Figure 4.3.1: Map showing coverage of source habitat data over the study region.

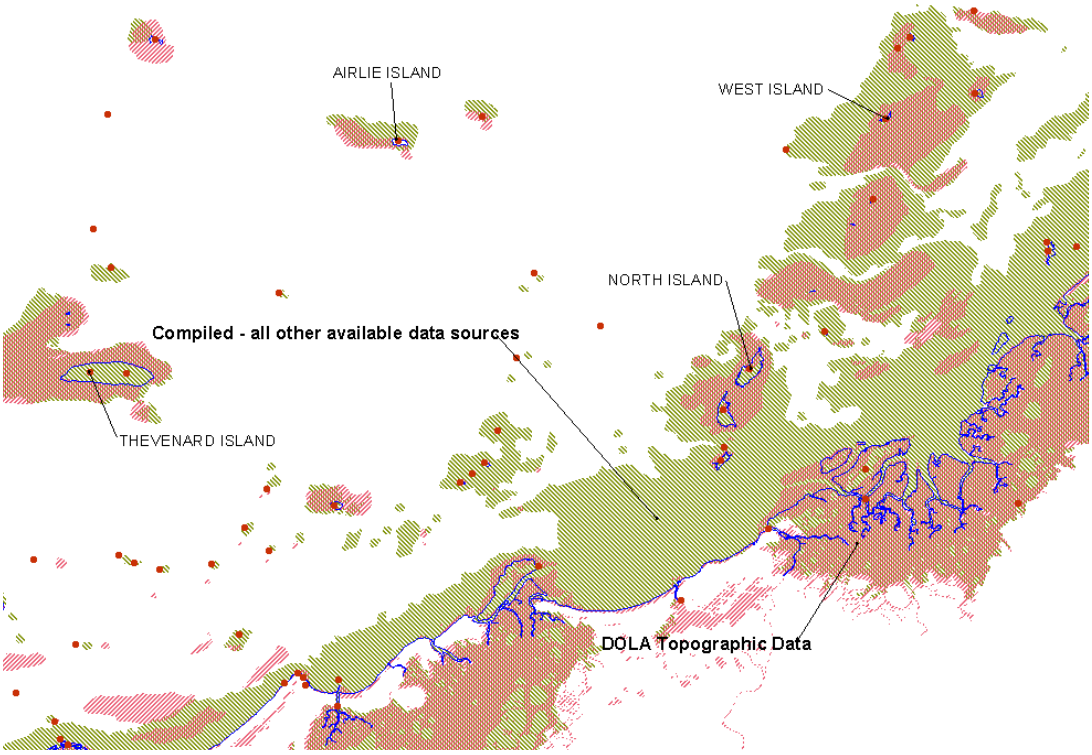


Figure 4.3.2: Detail of available data. DOLA topographic data for coastal areas and compiled data sources for coastal and marine areas.

5. SUMMARY

Biogeomorphic units were developed for the coastal region between North West Cape and the De Grey River. Three levels of differentiation were derived for the study region based on analyses of the existing information for the coastal geomorphology of the region:

- Level 3A covers broad regional suites of geomorphic units which were derived from the expert interview and delphic analysis processes;
- Level 3B covers geomorphic sub units, of which nine distinct types were identified. These units occur systematically across the Pilbara region;
- Level 3C units comprise the elemental structure of the Level 3B units. They occur across the landscape from landward to seaward in the variety of parent units.

A detailed analysis of the interaction between the three levels of geomorphic units would materially assist in deriving Level 4 and 5 units. This level of understanding would require significantly more ground truth data in order to derive the required amount of detail at these levels.

Existing habitat data obtained from a variety of sources was combined in a GIS to produce a composite data set for areas where data was available. Additional expert information was integrated with other available environmental information to generate habitat surrogates for the remainder of the study region. The habitat data were then integrated through the GIS using the existing hierarchical classification to provide the regional context and systematic incorporation of the available information. Data gaps have been identified as an indication of the accuracy of the mappings and as a guide to future sampling.

The data sets described in this report are available through the CSIRO Marine *Data Trawler* (Brodie & Fuller, 2006) with appropriate access requirements and licensing. Metadata is also available through the Australian Spatial Data Directory (ASDD) via the CSIRO Marine node and also through the CSIRO Marine metadata server *MarLIN* (Brodie & Fuller, 2006).

6. RECOMMENDATIONS

While a significant amount of information was obtained and applied to characterise the ecosystem over the study area, the majority of the region is still largely unmapped. Significant data gaps exist to the east of Dampier Archipelago, particularly the inner shelf region (low water mark to the 20 m isobath). Coastal regions have been covered by terrestrial mapping, and offshore regions by existing research. Offshore areas between Barrow Island and North West Cape are also largely undescribed, although increased petroleum exploration may change this in the future.

The application of the classification to Level 3 for the study area represents a major step forward in understanding of habitats and their distribution in the region. Integration of existing mapping information has been performed typically at Level 4 of the classification. Mapping, including ground truthing, has largely been undertaken on a by-project basis for small parts of the region. In order to characterise the region at this scale, significant ground truthing would be required. Understanding of the region would be significantly enhanced with the information obtained from further field studies, and it would greatly support the management of environmental resources.

Collaborative studies on the linkages between habitats and faunal communities would further enhance the understanding of the ecological interplays operating in the region. For example, the work undertaken for this study on habitat discrimination complements existing research by the WA Museum on faunal distributions on the Dampier Archipelago. A collaborative effort would provide an important resource for improving the understanding of the habitats and communities. Integration with other research would also further enhance any additional information gathered from ground-truthing.

The hierarchical classification has assisted modelling studies of habitat dynamics across a range of spatial scales (Fulton et al. 2006a). While the focus of these models was on Level 4 units, higher-order (larger) units need to be incorporated and linkages between these levels need to be examined.

Comparative studies of the CSIRO hierarchical classification and other international frameworks need to be examined in order to focus attention on a more structured approach to defining habitat units. The current study, reported here, clearly demonstrates the utility of the structured approach to what was, in the beginning, a region about which little was known of its habitats.

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APPENDIX A: REPORT ON PORT HEDLAND FIELDWORK WITH URS, 13 TO 17 MARCH 2002

Notes from Robin Thomson

A.1 Timetable of activities

13 March

Arrived in Port Hedland at 17:00.

14 March

Walked into town and made contact with Big Blue, a diving and fishing boat charter company contracted to help URS with their sediment sampling programme. Was told that URS were delayed in Port Lambert where they were sampling for another project and would not be in until later. Purchased new batteries for the GPS and contacted Mike Fuller to ask for instructions and to obtain a starting point for the GPS. Wandered about foreshore at Port Hedland taking photographs of industrial activities and attempting to speak to recreational anglers or other users of the marine environment but encountered very few people. Returned to hotel (on foot in 40 degree heat, nearly died) and worked on computer, spent some time in the later afternoon looking at the rock platform in front of the hotel.

Peter Smith arrived at about 19:30 and at around 20:00 collected me for the meeting at Big Blue which was attended by ourselves, Graham from Big Blue and a representative from BHP Billiton who has us all sign safety forms. Planned the following day's sampling which proved difficult given that tidal movements were important for launching and retrieving the boat and that various sites required various tidal heights for sediment sampling.

15 March

Met at Big Blue at 05:00, launched the smaller boat, Baby Blue, and went sampling near the harbour mouth. I took a GPS reading at each site and attempted to describe the habitat and biota at that site. Then took boat out to the easternmost control site where I took a GPS reading for Mike Fuller and continued my descriptions. Helped Peter with his sampling after having completed my own work. Returned to Big Blue at about 13:00 and launched the larger boat, Big Blue. Skipped lunch do to lack of time because of the tides. Took a number of grab samples in the harbour before proceeding to the westernmost regional site. The tide was receding very rapidly and we could not stay in the area for long nor could we get close to the shore in most places because of the long shallow tidal flats. Eventually took a reading on a small point on a headland to the east of the regional site for Mike Fuller. Took GPS and depth measurements in the harbour where the habitat and biota descriptions were rather limited and performed the usual descriptions at the regional site. Sampling continued until after sunset, returning to the harbour after the regional sampling in order to complete grab samples in the turn of the tide.

16 March

This was a rest day for the URS sampling. Took GPS reading and performed habitat and biota description in front of the hotel. Absence of recreational continued preventing interviews. Worked on computer.

17 March

Met at Big Blue at 07:30 to complete sampling programme in shallow creek area. Took usual readings and made descriptions. Departed Port Hedland 10:00.

A.2 Interviews

I was able to speak to a plant worker from the HBI plant (a BHP plant which smelts iron ore into iron briquettes). He did not fish himself but stated that nearly all the other workers at the HBI plant in South Hedland are recreational anglers. He did not show much interest in or knowledge of the marine environment in the area. Despite working at HBI for two to three weeks per month and therefore spending more time there than at his other home in Perth, he considers himself a resident of Perth, not of Port Hedland. He was brought to Port Hedland to help repair the HBI plant after recent damage to the plant.

The operators of Big Blue, Graham and Karin have lived in Port Hedland for 20 years and four years respectively. During Graham's 20 years there have been a number of changes to the marine infrastructure in the area. The wharf has been enlarged by dredging, a tug-boat harbour has been put in and the main wharf rebuilt. He does not believe that any of this effected the extent of the mangroves or marine populations generally. The only impact he has noticed was when sediment from harbour dredging was dumped onto an artificial reef formed by several sunken barges. This reef was used by anglers and divers and has now been lost. Sediments from dredging operations can only be dumped within a specified area approximately six miles off-shore but unfortunately this artificial reef was within that area. Karin mentioned a distant area called Rolly Shoal (Graham seemed reluctant to say where exactly this area was) which used to be a little known spot which was full of fish life. The Shoal was discovered by anglers and now a commercial operator comes to Port Hedland once a year, connects five or so small recreational vessels to his larger vessel and tows them out to Rolly Shoal to fish for perhaps a week at a time. All the large reef fish (such as potato cod) have been removed by this activity. No inspectors go out to the shoal as it is too far away.

Graham says that turtles are sometimes found dead in the harbour. It is though that they swallow plastic bags (jellyfish are natural prey).

Another impact that Graham has noted on the marine environment is from the salt works. Many years ago there used to be occasional fish kills in some of the creeks in the area (e.g. 4 mile creek) which were eventually tracked to the salt works. Brine is pumped into large pans where it is left to evaporate before being pumped into a different pan for further evaporation. The brine is moved from pan to pan , becoming more concentrated and precipitating out more salt as it goes along. The remaining water is finally pumped out into creeks. They are now regulated and are only permitted to use two creeks, one of which is 12-mile creek.

Until about three months ago a commercial licence was issued for developing a blue swimmer crab fishery. This took place in rocky reef area off Port Hedland where recreationals traditionally fish using dilly nets or drop nets or simply by hand. The commercial operation continued for about six months and appeared to fish the area out. The operator used a row of dilly nets.

This is only Peter Smith’s (URS) third trip to Port Hedland so he does not know the area well. However Ian Baxter also of URS has conducted surveys of the reef habitat for URS and reports of this work exist. They may not be in the public domain however. Anthony Bougher (URS) has conducted work on birds and mangroves in the area and might be able to provide reports or at least expert opinion should specific questions arise. The general phone number for URS is 9221 1630.

A taxi driver told me that Port Hedland used to be an island. A swampy area connected it to the mainland but this has been drained and filled.

URS always sample during a spring tide because of the wide range of water depths needed to sample their sites. Some are low and therefore need low water in order to be reached and some are high and need high tides in order to be able to get a boat up shallow creeks and across shallow mud flats to reach these sites. In order to launch the boat the tide must not be at its lowest because the boat ramp does not extend far enough down and becomes very slippery. The tidal range is several meters at these times and therefore the usual strong currents become much stronger. For these reasons recreational fishing and diving seldom occur a these times.

A recreational angler who has lived in Port Hedland for seven years says that the recreationals have needed to move further out from the harbour in order to get catches of large fish. However around this time of year some of them begin to turn up really close to the shore, presumably coming in to spawn. He fishes by following the harbour markers out. These go for 20 miles apparently but he doesn’t go that far. He looks for a reef and fishes that.

Another recreational angler who was setting off in a shi-boat with five others for a Sunday’s fishing said that they were planning to go out to the 25 mile marker and fish on reefs close to that. He said that closer reefs could be fished but that luck was better further out.

An engineer from BHP who has lived in Port Hedland for 25 years and has been a recreational angler says that he has seen large changes in the fish populations because 10 years ago Malaysian fishers overfished the area. He does not know whether the fish have come back as he no longer fishes much. I was not able to ask him more about this because I was called away. BHP workers find that there is good fishing at the Finnigans plant at one end of the tunnel that runs under the harbour. Salmon and rock code are caught there. Rock cod are sometimes taken by seine net.

A.3 General comments about the area

Port Hedland is a very small town and although recreational angling seems to be a popular past-time, its impact is likely to be limited by the relatively small number of people living in the area. Anglers seem to primarily fish by boat, they follow the channel markers that guide the ore carriers into and out of the port, using these as guides to find their favourite fishing spots. When following the channel markers the anglers seem to fish very far out, say 25 miles from shore. Some fish the inshore region, particularly in the creeks in the mangroves where Barramundi are to be found. Bait collecting occurs in the intertidal habitats, both rocky and muddy.

Those I spoke to did not seem to have any environmental concerns regarding the area although might reflect the makeup of the people who live there, nearly all of whom depend on the mine in some what for their livelihood, and their suspicion of outsiders. It might also reflect the lack of ownership that many people I encountered seemed to feel, none had been born in Port Hedland and few intended staying a long time. One recreational angler did state that fishers are having to move ever further from shore in pursuit of good catches but he did not seem concerned by this. Interestingly, he was the only person I spoke to who did not depend in any way on the mine, neither was he planning to stay in Port Hedland much longer.

Most people seem to own 4x4 vehicles and these are driven on the beaches in order to reach shore-based fishing spots. Quad bikes are also in evidence on the beaches although not is large numbers. There seem to be numerous bush tracks where these vehicles are normally taken.

The ore carriers are enormous vessels and there was daily movement during the time that I was there. These have a strong propeller wash capable of scouring the bottom of the harbour. A safe channel is kept dredged, out to several miles from shore, for these vessels. The harbour itself has, in part, been created by cutting away the sides of a rocky platform. A harbour has also been created for the tug vessels that service the ore carriers. Fishing seems to be a favourite pastime of the crew of the tankers, there always seemed to be at least one line dangling from the side of the carriers. Crew also fish at night for squid and use a small light for this purpose.

Dredging apparently occurs only once in two years but given the length of the shipping channel must be a very large scale affair. There is a specified site for the dumping of dredged material. The area has a very large tidal range and therefore strong currents so it may be that this material can be spread over quite a large area.

Iron ore dust from the BHP operations gets into the marine environment, which is why URS have been conducting sediment sampling. Their work will show to what extent this is occurring. The salt operation produces, as a waste product, highly saline water. This apparently kills fish and presumably invertebrates as well. They used to release this into a range of creeks, irregularly, but they are now limited to only two creeks.

Table A.1: Site locations with habitat and biota descriptions.

Site	Lat	Long	Date	Time	Description
1.	20º 19.570S	118º 34.536E	14/03/02	21:49 UTC	Mud substrate, no grit, approx 120 m from edge of mangrove area, some roots presumably mangrove roots sticking up out of mud. 1% low green plants (macroalgae?). A few mudskippers. 0.5% whelks (1 to 2 cm long). Crab holes (approx 1 cm in width) in mud 20 to 40 per m^2. Two leathery collars of moon snail eggs found. 5 to 10 waders (birds) in the area, silver gulls and terns moving through the area.
2A.	20º 19.626S	118º 34.563E	14/03/02		Muddy substrate with scattered pebbles covering 20% of the surface. The pebbles have 90% coverage of filter feeders, mainly barnacles of 0.5 cm or less. Some mussels and oysters never larger than 4 cm. 30 to 50 crab holes in mud per m^2. Closer to mangroves than previous fix.
2B.	20º 19.675S	118º 34.512E	14/03/02		Mud substrate, more crabs than at previous site: 40 to 80 holes per m^2. Closer to mangroves than previous fix.
3.	20º 19.685S	118º 34.483E	14/03/02		Soft muddy substrate next to edge of mangrove area, many mangrove roots visible. Audible cracking from fiddler crabs but none visible. Approx 100 crab holes per m^2. Some midges.
4.	20º 19.364S	118º 34.302E	14/03/02		Water's edge, soft mud with shell grit lying on top. Small barnacles (<4 mm wide) settled on larger shells at density of 50% aerial coverage. Some large tube worms visible, 1 to 3 m^2.
5.	20º 19.084S	118º 34.153E	14/03/02	22:28 UTC	Edge of a line of rocks. Large shoals of mullet in the shallow turbid water. 30% ascidian cover on the sides of the rocks and 10% sponge. On the rock surface 80% barnacle cover (up to 1.5 cm wide) and 20% tube worm cover. Below the rock line is soft mud sediment with approx 150 crab holes to the m^2. 3% oyster coverage on rocks. Two trickles of fresh water are flowing into the sea at this point.
6.	20º 18.499S	118º 34.105E	14/03/02	22:50 UTC	Edge of a pile of rocks forming one end of a large overhead conveyor belt (BHP). The rock pile is surrounded by sandy substrate, a little bit muddy. The water's edge is approx 30 m away; one large salmon (50 cm) was seen. The rocks have a thin layer of clayey mud on their surfaces with the usual cover of tubeworms and barnacles. 1% ascidian cover on the undersides of the rocks and 1% grazers (round snails, up to 2 cm wide. Very few small mussels (<=3 cm) and various whelks from a few mm to 1.5 cm long. 10% oyster coverage and a large coverage of v. small oysters in some patches. Closer to the boat the substrate is muddy sand with about 2 to 5 crab holes per m^2.

Site	Lat	Long	Date	Time	Description
					Several trickles of water running into the sea and no waders in sight but wader prints on the sand. Mangrove propagules seen.
7.	20º 17.195S	118º 45.200E	14/03/02	23:48 UTC	Water 5 m deep, bottom seems to have 20% sponge coverage, looks pristine and a great spot to snorkel. Water is relatively clear. Perhaps 10 m viz. Bottom is muddy sand. 60 cm green turtle seen apparently in good condition, also a school of batfish. A school of baitfish were being fed on by terns and salmon.
8.	20º 18.333S	118º 46.360E	14/03/02	1:05 UTC	Right next to a small creek at the URS sampling site RS20. Soft mud bank right at the edge of a mangrove forest. Covered in fiddler crabs and also a few other species, not as numerous. Mudskippers present. The mangroves were rhizophora with a narrow fringe of abyssinia. One nest of large ants found. The mud bank was clayey mud but on the opposite side of the creek (which was the inside of a bend in the creek) there was a sandbank. Barnacles grow on the trees right up to the high water mark (about 1 m above the then current level). The water in the creek that RS20 is sited on is very turbid, visibility is zero. There are some turtles in the water and waders on the banks. The banks are covered in mangroves, initially these are nearly all abyssinia with only 1% rhyzophora although there are occasional patches of the darker green of rhyzophora. At the sample site, RS20, this pattern has reversed with nearly all trees rhyzophora. The banks are a mass of crab holes, various species with male fiddlers most visible. Mudskippers are also common at the edge of the water. Many birds – kingfishers, Brahminy kite, small waders and herons.

Table A.2: Site locations of harbour grab sampling.

Site	Lat	Long	Date	Time	Description
9.	20º 19.308S	118º 34.561E	3:47 UTC	14/03/02	Depth 15.2 m, mud bottom. Water visibility zero.
10.	20º 19.232S	118º 35.042E	4:03 UTC	14/03/02	Close to edge of wharf. Depth 23.8 m, rocky bottom. Water visibility zero. A ship had just berthed which is presumably why the bottom was cleared of mud.
11.	20º 19.285S	118º 34.884E	4:20 UTC	14/03/02	Almost under wharf. Depth 23.8 m, red-brown coarse gravel bottom – looked like iron ore! Water visibility zero. Numerous other GPS fixes and associated depth readings were taken in the harbour, these can be obtained from me. On the whole the depth in that harbour varies from 14 to 24 m, mostly around 20 m. The water is extremely turbid and the bottom varies from a thick black silt, to coarse red-brown gravel that looks much like iron ore, to plain rock. The large ore tankers come and go daily and their wash scours the harbour bottom. A few jellyfish were seen in the water and ships crew fish for finfish and squid.
12.	20º 20.666S	118º 28.941E	7:37 UTC	14/03/02	Water <1 m deep and very turbid, light brown in colour. Mangroves and some rocks on the nearby muddy bank. Egrets on bank. A creek enters the sea at this point. The bottom is composed of muddy sand with shell grit overlay. Ridged clams approx 5 cm in length are embedded in the bottom. Crab holes are seen at a density of about 20 holes per m^2. Guitar fish and stingrays lie in the shallow water.
13.	20º 18.458S	118º 45.677E	8: 22 UTC	16/03/2002	Tip of a rocky headland (see “regional GPS fixes” above). Barnacles make up approx. 40% of the surface area of the reef, oysters sponges and corals together make up a further 5%.
14.	20º 18.425S	118º 36.435E	0: 08 UTC	15/03/2002	Flat rocky reef in front of suburb and fringed by a sandy beach which is a popular spot for walking dogs. The reef although rock appears to have been formed by perhaps tubeworms or corals or both. Very diverse area containing representatives of practically every marine taxonomic group. Large numbers of filter feeders – barnacles, mussels, ascidians, sponges, anemones, sea cucumbers. Also grazers – limpets; pleurobranchs; scavengers – large numbers of hermit crabs (in clumps) and two large blue swimmer crabs; predators – octopuses, various fish including mudskippers, polychaetes; and plants – macro-algae. Mangrove propagules were present at a rate of 3 to 4 to a metre wide strip perpendicular to the ocean. Wading birds were present at a density of about 1 to 100 m^2. A number of quadrants were taken and this information can be obtained from myself.

15.	20º 18.680S	118º 34.440E	22: 38 UTC	16/03/2002	Three storey jetty at edge of harbour, close to town. Light scattering of barnacles on jetty pylons.
16.	20º 19.309S	118º 34.971E	22: 53 UTC	16/03/2002	Patch of mud (about 5 m^2) of about 0.5 foot deep overlaying pebbles next to an artificial boat ramp in the harbour near the BHP operations. This boat ramp is seldom used now. Large crab holes (4 to 5 cm wide) about 3 per m^2 and smaller crab holes (<1 cm wide) about 40 per m^2. Very few pebbles on the surface but these all have small barnacles and tube worms on their surfaces. One piece of washed up seaweed.
17.	20º 19.586S	118º 34.903E	23: 21 UTC	16/03/2002	Water approx 1 m deep (this was close to low tide). The bottom is thickly covered with green vegetation, they seem concentrated on higher ground, which will presumably be uncovered at full low tide. One turtle was briefly glimpsed.
18.	20º 19.594S	118º 34.926E	23: 30 UTC	16/03/2002	Sandy area with shell grit. Sparse sponges of a wide range of shapes and sizes, some large seastars. Several large stingrays (30 cm wide). Water relatively clear.
19A.	20º 19.591S	118º 34.942E	23: 31 UTC	16/03/2002	Water turbid, can't see bottom even though water depth is <1 m. The shore is made up of sand, mud and pebbles, small groups of waders visible. Between the fix given above and:
19B	20º 19.591S	118º 34.942E	23: 40 UTC	16/03/2002	Two groups of 10 birds each were seen.
20.	20º 19.803S	118º 35.338E	23: 45 UTC	16/03/2002	URS site HS80. There is a trickle of water flowing from the nearby mangrove stand across the mud and shell grit bank to the sea. Sponges cover approx 2% of the area – some are very large (the largest was 10 cm wide by 30 cm long). Some sponges live relatively high above the shore because they are in the bed of the small creek/trickle. No to very few crab holes. The turbid water is full of stingrays. Several moonsnail egg collars visible. Closer to the mangroves crab holes become more numerous. Mangrove propagules wash down the small creek (about one propagule to 5 m).
21.	20º 19.785S	118º 35.486E	0: 00 UTC	16/03/2002	URS site HS70. At mouth of small creek. Relatively hard mud with grit. The banks close to the small creek are covered with very fine green threads forming a mossy-looking carpet. This follows the creek and the shoreline. They seem to be holding the mud together because they form raised areas. Clams are embedded in the mud (about 1.5cm in length) and crabs holes at a density of 50 to 60 m^2. Mangrove propagules are found in the creek at one per 5 m of creek. The nearby mangroves seem to be mostly rhyzophora. A fisherman in a tinny is fishing the creek.

APPENDIX B: RV NATURALISTE CRUISE REPORT, 21 FEBRUARY TO 17 MARCH 2002

WA Department of Fisheries voyage: 21 February to 17 March 2002

B.1 WA Fisheries

A Fisheries Research and Development Corporation funded project (FRDC Project 2000/132) examined seven representative sites from Exmouth to the top end of the Kimberley in the inshore region of north-western Australia in waters outward from the shoreline to depths of 30 metres. Both fish traps and trawls were used to determine the species distribution and the composition of the bottom fish resources. For further information contact Dr. Stephen Newman (snewman@fish.wa.gov.au), Department of Fisheries, Western Australia.

Inshore demersal fish stocks in Australia's north-west face increased exploitation pressure by an ever increasing number of recreational fishers in direct competition with an adjacent commercial fishing industry. There has therefore been a need to determine the species distribution and the composition of the bottom fish resources in the inshore region of north-western Australia in waters outward from the shoreline to depths of 30 metres, including the documentation of the abundance and diversity of any significant finfish by-catch of prawn trawlers operating within the region, as a basis for formulating rational management plans for the exploitation of the bottom fish resource among user-groups.

B.2 CSIRO

In consultation with WA Fisheries it was agreed that CSIRO staff would join the voyage to collect data for the NWSJEMS and fulfil the following objectives:

- Identify critical gaps in the coverage of maps of key ecological attributes and habitats, in terms of both missing components and of the spatial extent of mapped components;
- Design and conduct field surveys to fill priority gaps in the coverage of maps of key ecological attributes and habitats;
- Ground-truth data for coverages and, to the extent possible, for process parameters; and
- Produce and deliver final coverages (hard-copy maps and digital layers) of the key ecological attributes and habitats from analysis of the available existing and new survey data.

B.3 Itinerary

Leg 1: 21 February to 4 March 2002

Leg 2: 4 to 16 March 2002

B.4 Area of operation

Dampier to Broome.

B.5 Cruise objectives

Collect stomachs from a predefined list of species, bag and freeze for processing and analysis at the CSIRO Marine Labs, Hobart.

Collect footage of benthic habitat by deploying a drop video camera for analysis at the CSIRO Marine Labs, Hobart.

B.6 Cruise results

Stomach contents were collected from the targeted list (table B.3) and other abundant fish species for dietary analysis.

The data collected has not been used explicitly in the model parameterisation. However, it has been pivotal to the development of the conceptual model underlying the formal agent-based model (ABM) of the study area. The data collected helped to define critical groups, and the range of specific interactions and processes that needed to be included in the formulation of the biological components of the ABM.

Video footage was filmed of the benthic habitat (table B.5).

In order to assist with the bioregionalisation and habitat mapping project, benthic habitat information was obtained from drop-down video footage gathered at 22 selected sites during the cruise. The video footage was transferred from tape to PC and CD-ROM for distribution. Selected representative frames were captured from each video.

Mapping boundaries were derived from other data sources, including expert interviews, reports and existing mapping, as well as remotely sensed data from satellite imagery and aerial photography (SLICP imagery). The video and captured still frames provided important source of information for assisting the description of habitat types within mapping units, and for adding to the existing library of information gathered from external agencies and reports.

B.7 Cruise narrative

The daily routine for the “Naturaliste” trip was to set and haul traps from 6am to 8am and 5.45pm to 8.00pm. CSIRO staff did not collect samples from the traps.

Trawls shots of 15 minute were set during the day. Catches from these trawls were sorted, identified, counted and weighed. CSIRO staff collected a sample of identified species and stomachs. These were bagged, labelled, frozen and sent to Hobart CSIRO Laboratories for analysis.

During the day as the opportunity provided, a drop video camera was deployed when the ship was not steaming to take shots of the benthic environment.

CSIRO staff assisted WA Fisheries staff as required throughout the cruise.

B.8 CSIRO personnel

Leg 1 Melanie Martin

Leg 2 Helen Webb

B.9 Acknowledgments

WA Fisheries: Dr Stephen Newman
Skipper and crew of the research vessel "Naturaliste"
CSIRO: Cathy Bulman, Franzis Althaus, Vincent Lyne, Mike Fuller, Bruce Barker, Mark Lewis

Table B.2: Scientific and common names of fish encountered.

Scientific name	Common name
Pseudorhombus diplospilus	Flounder
Alectes indicus	Diamond trevally
Alepes sp.	Smallmouth scad
Carangoides malabaricus	Malabar trevally
C. talamperoides	White-tongued trevally
Selar crumenthalmops	Purse-eyed scad
Selaroides leptolepis	Smooth tailed trevally
Choerodon cauteroma	Blue-spotted tusky
C. cephalotes	Purple tuskfish
Leiognathus bindus (common Leiognathus species)	Orangetipped ponyfish
Lethrinus genivittatus	Threadfin emperor
L. laticaudis	Grass emperor
Lutjanus carponotatus	Stripey sea perch
L. malabaricus	Saddle-tailed sea perch
Paraupeneus chrysopleuron (common goatfish)	Yellow-striped goatfish
Nemipterus furcosus or whatever nemipterids are common	Rosy threadfin bream
Parapercis diplospilus	Double-spot grubfish
Sphyraena forsteri	Bigeye barracuda

Table B.3: Number of species and their CAAB number that had biological analysis done on their stomach contents.

Species	CAAB	ave FL (cm)	StdDev FL (cm)	No fish
Saurida undosquamis	37118001	16.5184211	2.509486562	76
Inegocia japonica	37296029	20.3333333	0.351188458	3
Sillago burrus	37330004	13.6222222	1.381826489	9
Carangoides fulvoguttatus	37337037	22.2	3.818376618	2
Lutjanus malabaricus	37346007	10.9		1
Nemipterus furcosus	37347005	20.2		1
Pentapodus porosus	37347007	15.7615385	2.29749027	26
Pentapodus vitta	37347022	18.7666667	1.761628035	3
Lethrinus genivittattus	37351002	9.66923077	2.33130349	65
Upeneus sp.	37355008	12.3428571	1.560965649	28
Upeneus lizonius	37355009	15.5625	1.133814674	8
Upeneus assymmetricus	37355010	10.5068182	1.125269524	44
*Pristiotis jerdoni (*aka *obtusirostris)*	37372001	6.61190476	0.913637165	42
Choerodon cauteroma	37384005	13.35	3.905978324	4
Choerodon vitta	37384006	12.1		1
Parapercis nebulosa	37390005	15.3986301	2.231248601	73
Siganus nebulosus	37438001	9.60588235	1.183968974	34
Rastrelliger kanagurta	37441012	14.5		1
Pseudorhombus jenynsii	37460002	21.4818182	2.214415581	11
Pseudorhombus arsius	37460009	22.3609756	3.42139431	41
Pseudorhombus argus	37460038	17.6756098	2.019254873	41
Grand Total				514

Table B.4: List of trawl stations on Fisheries WA cruise.

Date	Location	Ops no	Trawl no.	SLat	SLong	ELat	ELong	Start depth (m)	Finish depth (m)
trawl time 15 mins trawl speed 3 knots									
22/2/02	Locker Point (shallow)	2022201	1	21.6723	114.68258	21.66515	114.6909	12	
22/2/02	Locker Point (shallow)	2022202	2	21.687933	114.68178	21.676183	114.68565	11.3	
22/2/02	Locker Point (shallow)	2022203	3	21.6775	114.717	21.666417	114.71752	11.1	
23/2/02	Locker Point (deep)	2022301	1	21.463	114.81468	21.473167	114.81202	23.4	
23/2/02	Locker Point (deep)	2022302	2	21.483767	114.77545	21.4916	114.7647	28.5	
24/2/02	Locker Point (deep)	2022401	3	21.470083	114.79395	21.461233	114.80303	29.5	
24/2/02	Locker Point (deep)	2022402	4	21.460967	114.80368	21.4697	114.7938	28.9	
25/2/02	Locker Point (shallow)	2022501	4	21.550317	114.91603	21.5544	114.92862	13	
26/2/02	Steam to Cape Preston								
27/2/02	Cape Preston (deep)	2022701	1	20.7398	116.11475	20.736233	116.1284	22.3	
27/2/02	Cape Preston (deep)	2022702	2	20.735167	116.13092	20.738717	116.1174	19.1	
27/2/02	Cape Preston (deep)	2022703	3	20.73705	116.11233	20.7327	116.12565	23.8	
27/2/02	Cape Preston (deep)	2022704	4	20.73195	116.12582	20.73665	116.11278	23	
28/2/02	Trip ashore near Steamboat Island								
1/3/02	Cape Preston (shallow)	2030101	1	20.803633	116.20775	20.792467	116.21453	9.6	
1/3/02	Cape Preston (shallow)	2030102	2	20.789733	116.21672	20.801817	116.20833	11.6	
1/3/02	Cape Preston (shallow)	2030103	3	20.793517	116.2007	20.80315	116.18793	10.9	
1/3/02	Cape Preston (shallow)	2030104	4	20.802533	116.79435	20.189383	116.19993	11.9	
2/3/02	Trip ashore near Preston spit								
3/3/02	Steam to Port Hedland								
4/3/02	Port Hedland hand over for Leg 2								
5/3/02	Steam to Cape Keraudren								
6/3/02	North of Cape Keraudren	2030601	1	19.902367	119.73605	19.892117	119.72897	9.4	11
6/3/02	North of Cape Keraudren	2030602	2	19.889583	119.72695	19.90055	119.73465	11.6	10.1

Date	Location	Ops no	Trawl no.	SLat	SLong	ELat	ELong	Start depth (m)	Finish depth (m)
6/3/02	North of Cape Keraudren	2030603	3	19.906817	119.78292	19.904933	119.76955	7.1	7.8
6/3/02	North of Cape Keraudren	2030604	4	19.903717	119.76582	19.9059	119.77972	7.2	7.9
7/3/02	no trawls								
8/3/02	North of Cape Keraudren	2030801	1	19.742933	119.72108	19.744683	119.73418	21	
8/3/02	North of Cape Keraudren	2030802	2	19.74545	119.73988	19.74375	119.72592	18.1	20.6
8/3/02	North of Cape Keraudren	2030803	3	19.7432	119.75558	19.743283	119.74185	21.3	21
8/3/02	North of Cape Keraudren	2030804	4	19.741683	119.73317	19.74245	119.74868	21.3	21.8
10/3/02	Steam to Cape Bassut								
11/3/02	Cape Bassut (deep)	2031101	1	18.678567	121.45397	18.67455	121.4417	22.2	24.5
11/3/02	Cape Bassut (deep)	2031102	2	18.6716	121.44017	18.675467	121.45372	24.5	22.6
11/3/02	Cape Bassut (deep)	2031103	3	18.67365	121.46107	18.669333	121.44818	21	24.5
11/3/02	Steam to Cape Bassut	2031104	4	18.66635	121.44475	18.66965	121.45885	25.3	22.2
12/3/02	Cape Bassut (shallow)	2031201	1	18.637117	121.67408	18.637667	121.65998	6	7
12/3/02	Cape Bassut (shallow)	2031202	2	18.63345	121.65767	18.6332	121.67103	7.5	6.7
12/3/02	Cape Bassut (shallow)	2031203	3	18.6475	121.57072	18.633917	121.57162	15	13.8
12/3/02	Cape Bassut (shallow)	2031204	4	18.635667	121.5716	18.646483	121.57073	14.2	15
13/3/02	Cape Bassut (shallow)	2031301	1	18.647567	121.5707	18.634667	121.57135	15	13.7
13/3/02	Cape Bassut (shallow)	2031302	2	18.636367	121.57152	18.649317	121.57043	14.2	14.9
13/3/02	Cape Bassut (shallow)	2031303	3	18.632333	121.66095	18.632633	121.675	7.3	6.5
13/3/02	Cape Bassut (shallow)	2031304	4	18.63735	121.6741	18.6365	121.66072	6.5	6.8
14/3/02	Steam to Broome								

Table B.5: Underwater video filming stations, environmental conditions and comments.

Site Name	Date	Latitude	Longitude	Depth	Water clarity	Sea condition	Wind condition	Comments
Locker Point (1)	24/04/2002	-21.5465	114.7067	15.4	Clear	small swell	light	
Locker Point (2)	25/02/2002	-21.568	114.9175	11.2	Clear	Calm	None (< 5 knots)	
Cape Preston Deep	27/02/2002	-20.7382	116.1158	20.1	Clear	Calm	<5 knots	
Cape Preston	27/02/2002	-20.7388	116.1462	15.8	Clear	Calm	Light (<5 knots)	Soft coral, fan coral, edge of coral bommie? *Heniochus accuminatus* *Abudefdef bengalensis* *Antheas*? *Sphyraena barracuda* *Lutjanus lemniscatus* *Pomacanthus sp*. *Caestro teres*? Rubble, coral, some dead coral
Steamboat Island	28/02/2002	-20.8332	116.0792	5.2	Clear	Calm	Light	Flat bottom, some shells Area near Steamboat Island
	28/02/2002	-20.7523	116.1442	10.5	Clear	Calm	Light	Light garden, fan corals.
Cape Preston Shallow	1/03/2002	-20.8108	116.2027	11.9	Clear	Calm	Light	Medium to heavy garden bottom Fan coral, soft corals Basket sponge? Hard coral?
Cape Preston Area	2/03/2002	-20.7775	116.2508	8.7	Clear	Medium Swell	Medium	Drifted to 17:45. -20 46.72, 116 15.00 (7.7 m) Original timing: 32:54 to 42:00 (end)
Cape Lambert Area	3/03/2002	-20.3077	116.8523	29.8	Clear	Choppy	Medium, Strong	Golden trevally, Sea Whips Large fish near end of sequence, *Diagramma labiosum*
Cape Lambert	3/03/2002	-20.3067	116.8513	26	Clear	Choppy	Medium, Strong	Sea urchins, Sponges, Surgeon fish, Trevally,

Site Name	Date	Latitude	Longitude	Depth	Water clarity	Sea condition	Wind condition	Comments
								Pentapodus, *Sebae*? Finish at -20 18.43, 116 51.05, 27m
	5/03/2002	-19.7442	120.2333	22.8	Clear		Light	Sandy bottom, Pepples Rock???? Sponge Finish -19 44.82, 119 43.60, 22.8 m
Cape Keraudren, Shallow	6/03/2002	-19.9043	119.7368	9.2				Finish -19 54.32, 119 44.21, 9.0 m
North Cape Keraudren	6/03/2002	-19.7492	119.7278	22.7				Finish -19 44.96, 119 43.66, 21.9 m
	7/03/2002	-19.8197	119.687					Stationary, Shark turned up 8 foot tiger shark Flat sandy bottom
	7/03/2002	-19.8207	119.6817	15.2				Finish -19 49.26, 119 40.91, 15.8 m
	8/03/2002	-19.7438	119.7213	22.1				Video Lost, battery failed. Finish -19 44.56, 119 43.26, 23.0 m
	8/03/2002	-19.7022	119.6493	23				Finish, -19 42.20, 119 38.94, 20.6 m
	9/03/2002	-19.755	119.8122	15.3				
	8/03/2002	-19.7	119.6752	25.2				Stationary before??? Pille???
	11/03/2002	-18.675	121.4522	25.7				Stationary
	11/03/2002	-18.6423	121.4988	23.1				
	12/03/2002	-18.637	121.6733	10.5				
	13/03/2002	-18.6757	121.6063	10.3				

APPENDIX C: NOTES ON CORRESPONDENCE ANALYSIS OF CATCH DATA

Dr B. Venables explained the technique he developed in the following notes (edited from his original informal communications):

Detrended correspondence analysis argues as follows: In correspondence analysis the first component (or scaling) usually gives you a pretty good idea of the main gradient in the habitat but the second scaling is very often just a non-linear function of the first, in fact a quadratic function usually, and even though it achieves the maximum correlation with a linear function of the species variables (subject to the usual uncorrelatedness constraints) it does not tell you much more than the first about the habitat. To get over this the second scaling is often chosen to have maximum correlation not just under the constraint that it be uncorrelated with the first, but that it be uncorrelated with its square also. This clearly removes a "horseshoe" pattern when the first is plotted against the second, and what it is supposed to do is reach further down in the "sack of scalings" for something that genuinely adds a different dimension to the ordination.

Well, in our case, when the first is plotted against the second, it is not a graceful horseshoe but a broken-stick pattern, which can be captured fairly well by a quadratic in fact. It should be explained that sandbar sharks were removed from the data sets because of their unique and very unusual association with other species; which on later analysis of the original data showed that these sharks were caught from longlines rather than trawl nets (these different fishing devices have differing species catchabilities). With sandbar sharks included, the second scaling just picks out those stations where they were caught, largely because, it seems, they were more often caught alone (by longlines) than any other single species, as if their presence signalled the absence of just about everything else.

It turns out that a great deal more can be accomplished with the idea than this. If you have determining variables associated with (in our case) the stations you can ask for scalings that are uncorrelated with (or even functions of) these determining variables as much as you can with previous scalings. In fact the whole field of modelling with covariates opens up here and although someone must have noticed this before there appears to be no reference to it. A few pictures shown below illustrate in quick outline what can be done:

- The first scaling of stations is chosen to be orthogonal to a seasonal factor, reflecting the fact we are interested in features of the data with some sort of temporal permanency.
- The second scaling is chosen to be orthogonal to (that is, uncorrelated with) both the season factor and a spline term in depth with six degrees of freedom. This guarantees that the second scaling will not be any simple functions of the first, in particular no horseshoe. Hopefully it will give information on a different ordination variable than the first.

What happened? The first scaling was not so different from what it was without the seasonal adjustment and the correlation achieved with the species factor was hardly suppressed at all. It was clearly very closely related to depth. Figure C.1 shows a colour contour of the scores in the field overlaid with depth contours at 20, 40,…, 200 m levels (but with labels stripped off as they come out crowded). Clearly, the results show the first constrained scaling is just about totally to do with depth.

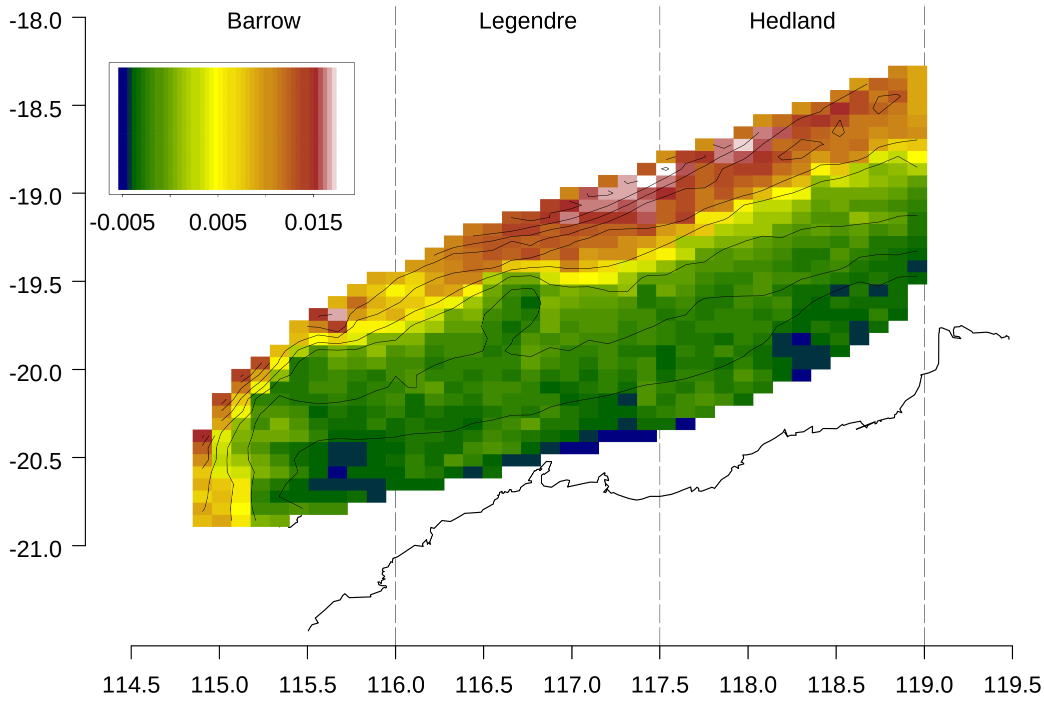

Figure C.1: Contour of first scaling, orthogonal to season, with depth contours overlaid.

The second contouring shown below (figure C.2) was constructed from a scaling of stations and interpolation constrained to be orthogonal to season and a 6 degree-of-freedom spline representation of depth. If you plot these scalings against the first, all trace of the horseshoe is gone and although they are not constrained to be uncorrelated, they very nearly are.

If there is anything non-depth related in the fish data regarding the habitats that can be discovered this way I think it is in this scaling. Looking at it with knowledge of the region, does it suggest anything even remotely profound? I suspect not as I think it is the combination of depth and this one that will ultimately give some information on habitat classification, and neither has the complete story in isolation.

Bottom temperature and depth are so closely linked that there is not much hope of treating them as separate variables for ordination or classification purposes (figure C.3). Perhaps on some levels, though, it could be important.

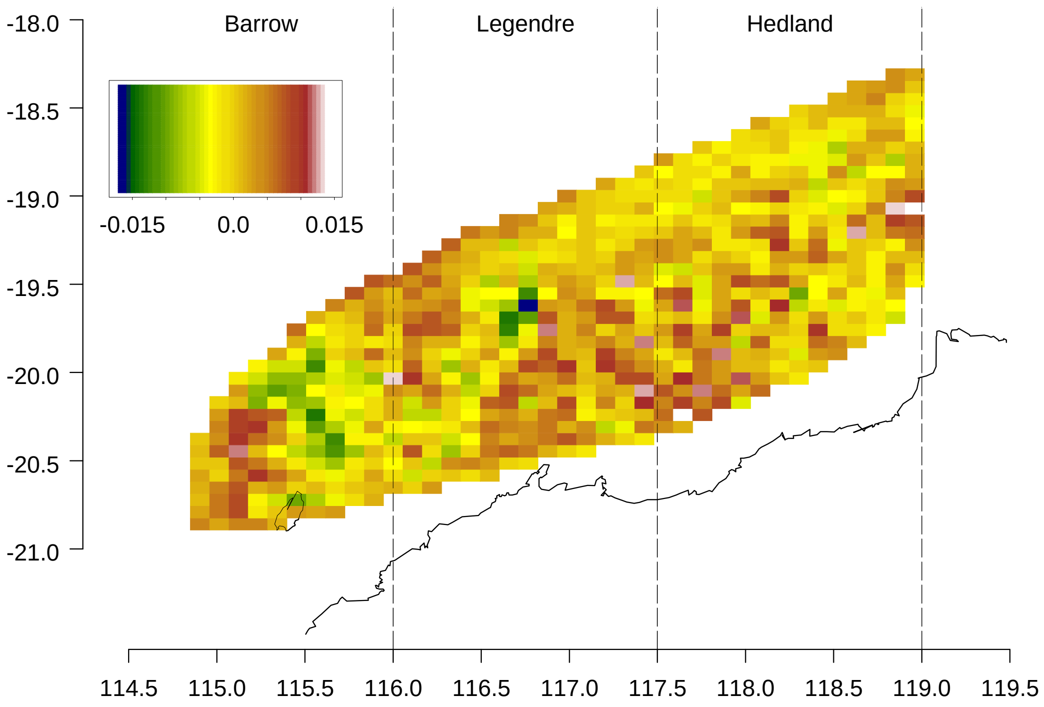

Figure C.2: Second scaling of stations, orthogonal to season and depth.

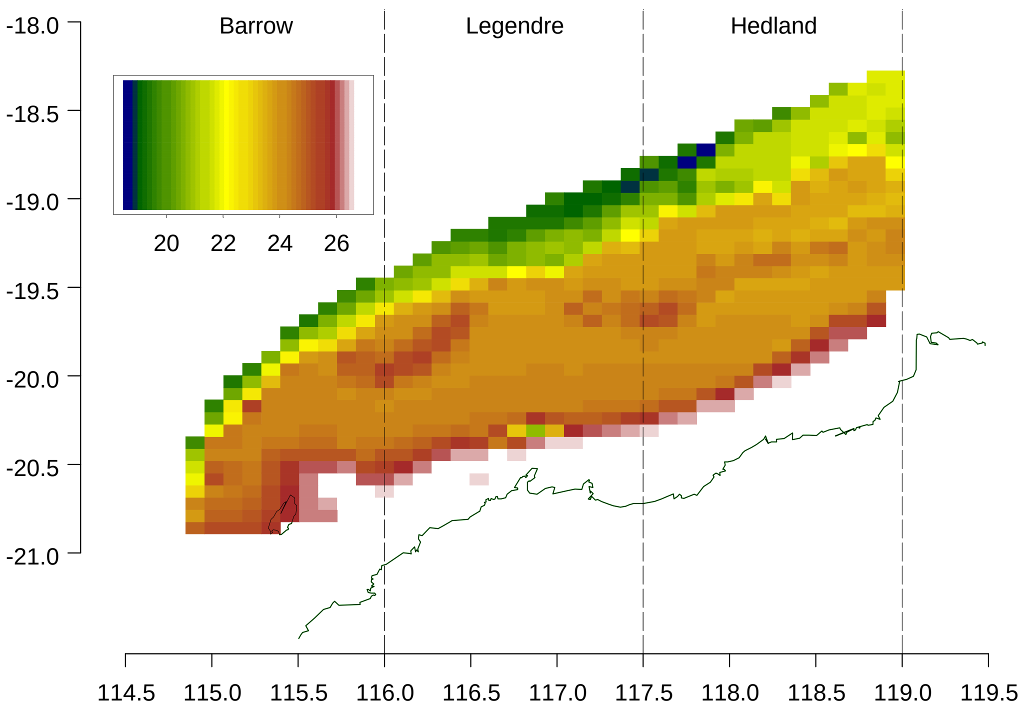

Figure C.3: Bottom temperature according to the temperature model.

Details of the results are contained in two series: BZ1, BZ2, BZ3, and WZ1, WZ2, WZ3 (figures C.4 to C.9). The "B" graphs are based on binary (presence/absence) reductions of the catch data, and the "W" series are based on a "weighted" version which was obtained as follows: Take the total catch for each species and scale the individual catches so that the total = the total number of times that species is caught. This means the "weighted" station x species matrix has the same column totals as the original "binary" version, but generally different row totals (and the entries are not integral, of course). The canonical correspondence idea carries forward for such matrices without any difficulty in principle, and I suspect this is about a good a use as we can make of the actual catch data without knowing anything more about relative sizes and importance of species, but the results are not very different for B or W so far.

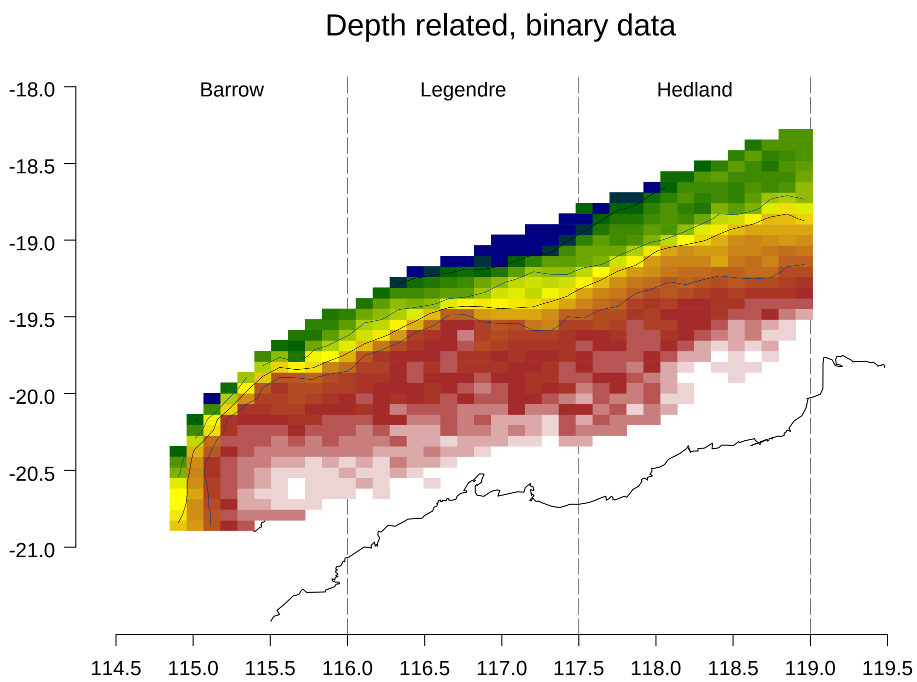

Figure C.4: Graph BZ1.

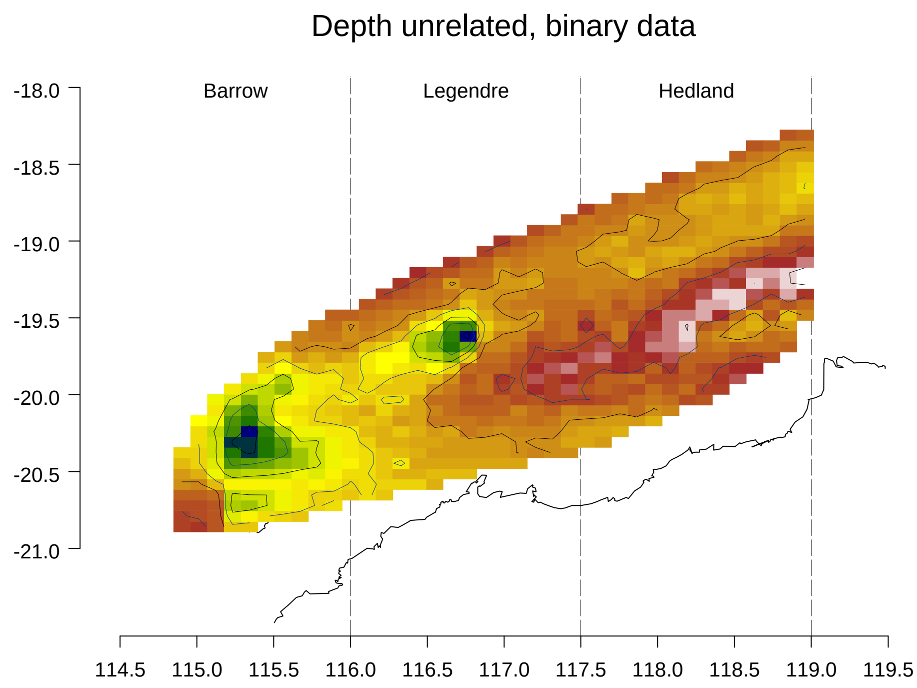

Figure C.5: Graph BZ2.

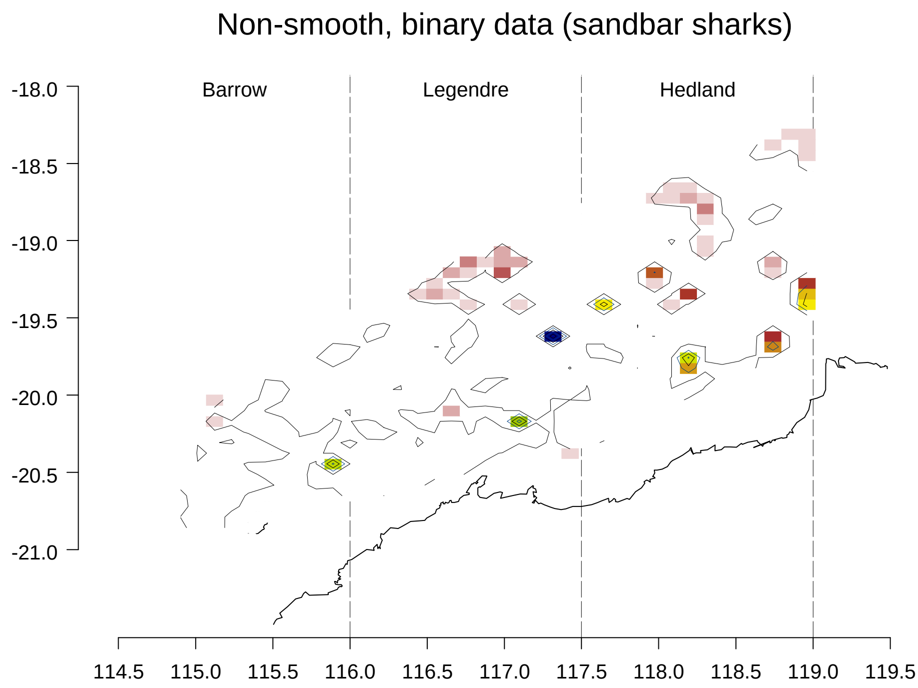

Figure C.6: Graph BZ3.

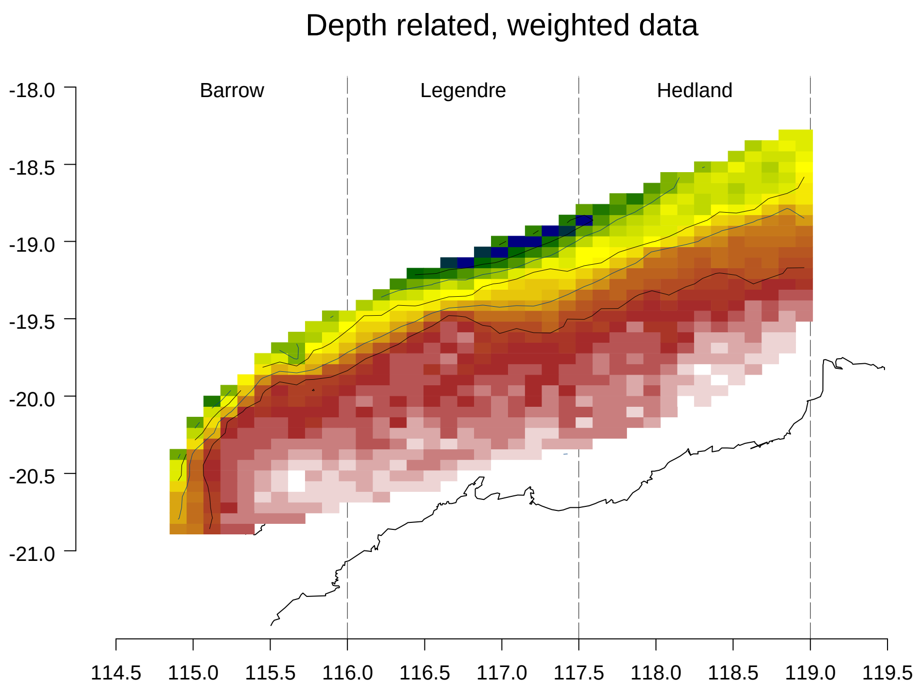

Figure C.7: Graph WZ1.

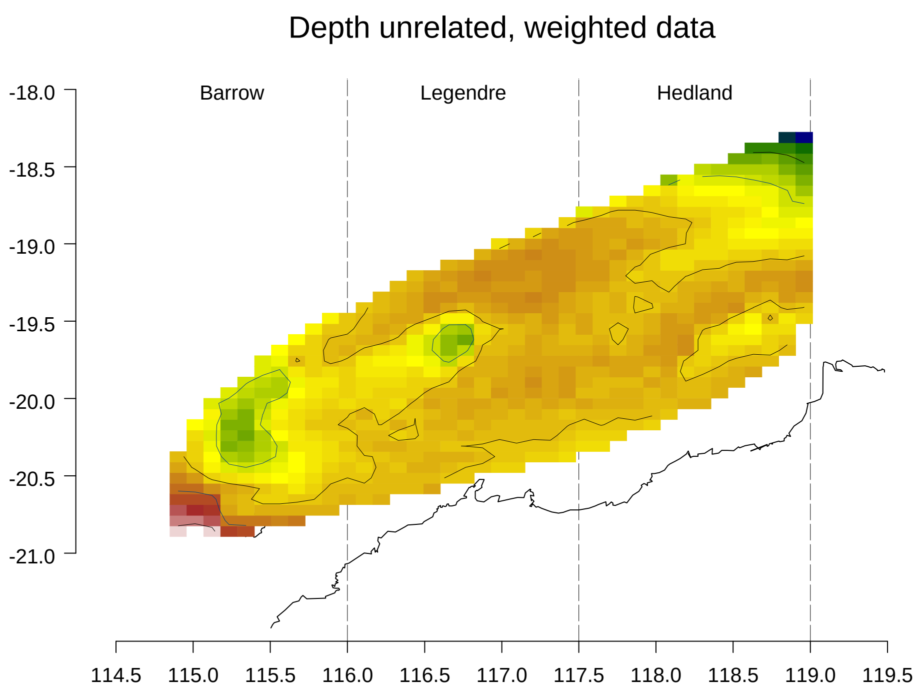

Figure C.8: Graph WZ2.

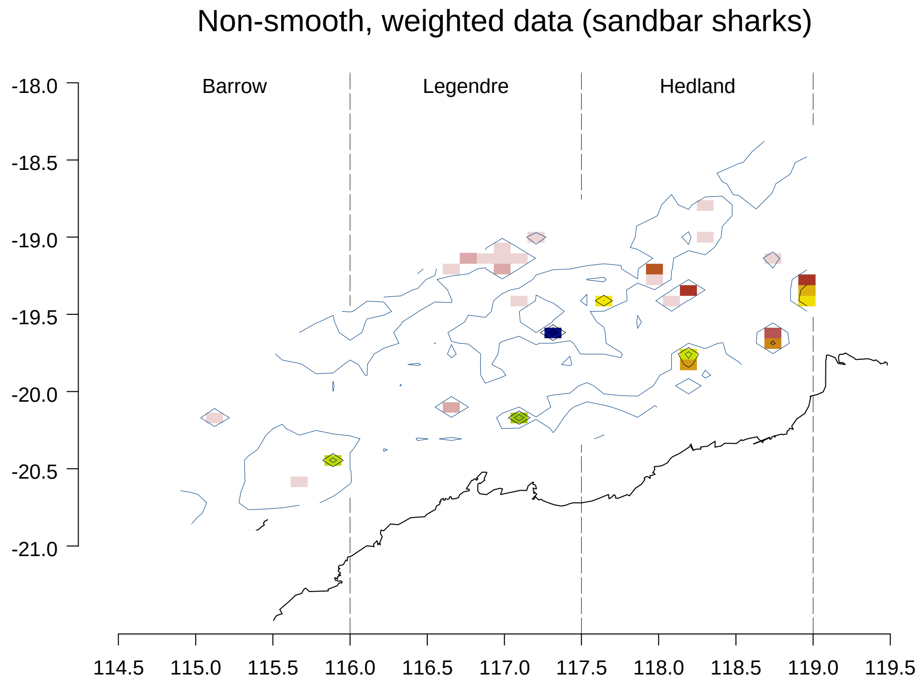

Figure C.9: Graph WZ3.

The graphs BZ1 and WZ1 show a contouring of the row scalings chosen so that:

1. They are orthogonal to a “Cruise” factor (so they are, as much as we can make them, not influenced by features that vary strongly with cruise), and
2. They are constrained to be a function of Depth. The reason being that if you do not constrain like this you get a scaling that is clearly dominated by Depth, so why not sharpen it up?

You get a scaling that of course points up how the fish gradient varies with depth. It seems not to move very much until it hits the shelf edge, it seems to me.

The second set of graphs BZ2 and WZ2 shows a constrained second row scaling chosen so that the components are:

1. Orthogonal to a Cruise factor + a spline basis in Depth with 5 knots (This effectively prevents the second scalings from being some disguised non-linear function of Depth).
2. Constrained to be a 4th degree polynomial in Latitude and Longitude. That is it can be a linear function of all powers of the form Latitude^a * Longitude^b where a+b < 5. There are ten such terms and it is necessary to include all of them to give the scalings a spatial affine invariance. Imposing this constraint in the first place is just a means of ensuring that the scalings do not vary too quickly (or discontinuously) in space. I would prefer to do this with penalties using something like a smoothing spline but that seems to be rather more trouble than it is worth.

3. The column scalings are simply made orthogonal to the first set of column scalings, as is usual.

The third set of graphs BZ3 and WZ3 is what you get if you make the row scalings orthogonal to Cruise factor + Depth spline basis + polynomial terms in Latitude and Longitude up to degree 4, i.e. it is strongly orthogonal to the first two scalings and effectively forced to be a highly volatile function of spatial location. Out pops the Sandbar sharks, of course! If you look at what's going on here you find that Sandbar sharks occur relatively uncommonly with other fish, so by putting just about all stations (and nearly all fish species) in one big blob in the centre you can adjust the relatively few remaining scalings so that they form a quite nice, tight straight line. Of course, though, they are scattered all over the place in actual spatial coordinates, which is why the constraint in 2, was necessary to bypass this triviality.

The results of the above analyses provide the underlying biomic structure (Level 2) for the shelf areas of the North West Shelf extending approximately from the 20 m isobath out to the shelf edge.

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