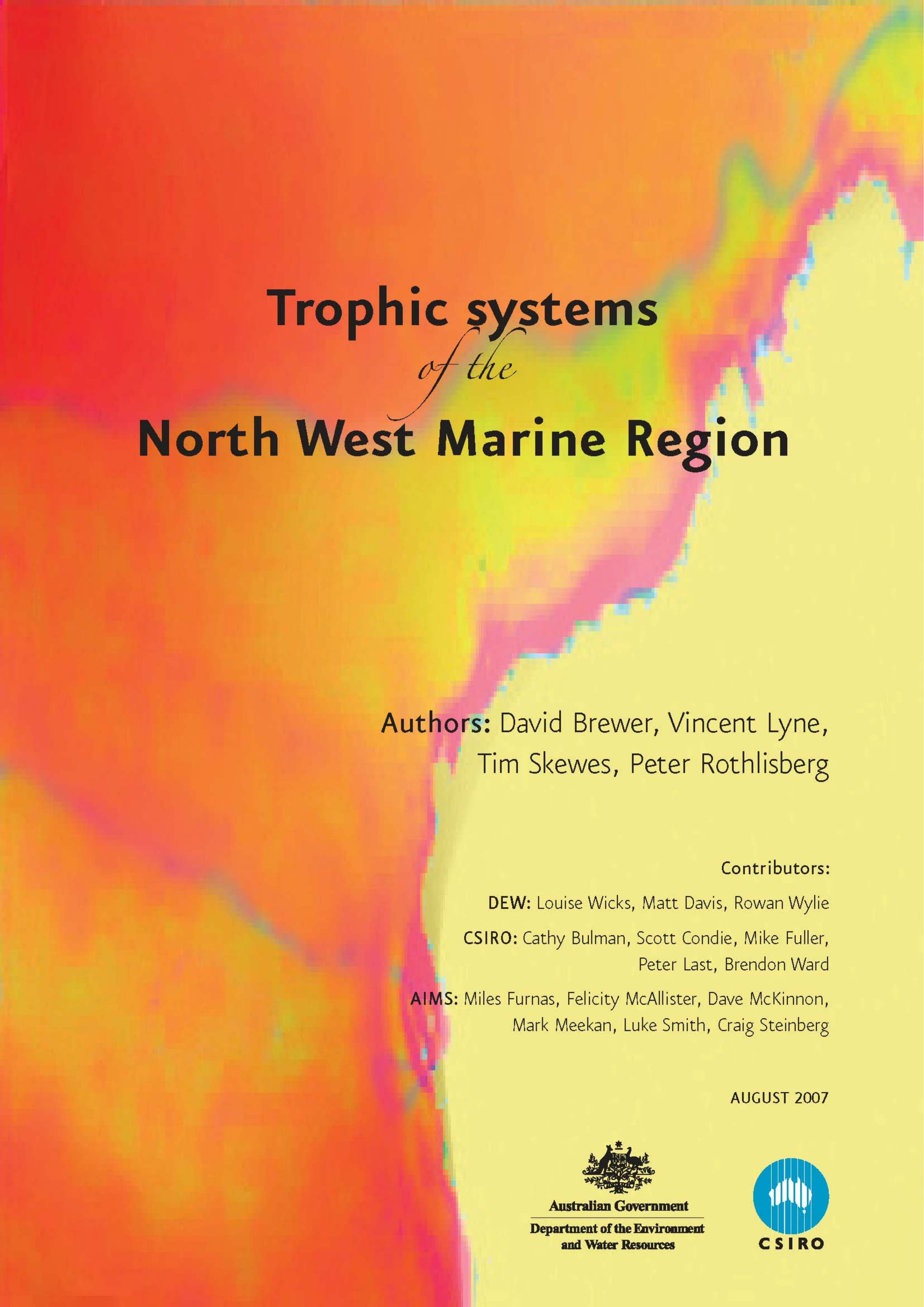

Trophic systems
of the
North West Marine Region

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1. EXECUTIVE SUMMARY

The Australian Government is in the process of preparing Marine Bioregional Plans for all Commonwealth waters. This report contributes to that process by gathering, reviewing and summarising the best available information to identify and describe the trophic systems, functional groups and relationships, links across systems and physical drivers of the North West Marine Region (NWMR) for use in the North-west Bioregional Profile.

Researchers at the CSIRO Marine and Atmospheric Research (CMAR), with input and review from scientists from The Australian Institute of Marine Science (AIMS), undertook an assessment of the trophic systems of the region to assist The Department of the Environment and Water Resources (DEW) in developing an understanding of the NWMR ecological systems. The restricted timeframe necessitated focussing only on existing information. Close collaboration with DEW staff assisted the process through the provision of literature reviews of physical drivers and species assemblages. The report was compiled with the intention of providing a broad overview of existing information to provide an integrated understanding of the trophic systems of the NWMR and its important features. This report, together with a number of others commissioned or written by DEW, in consultation with various experts and stakeholders, will subsequently be used by DEW in compiling the North West Bioregional Profile.

Our approach to the information compilation was systematic and selective but ultimately constrained by the available information and the time limits of this project. Thus some regions of the NWMR are described in greater detail than others. The information gaps are mostly noted in our descriptions so as to guide future data gathering efforts. The key guiding principle we developed to aid the information compilation was to focus on providing a “systems” view of the NWMR at a range of scales of interest to DEW. We began by developing a conceptual definition of a system and then progressively compiling the information required to implement this definition for the NWMR.

The systems approach we developed required defining firstly a broad set of regional systems that were differentiated by large scale oceanographic drivers. Within this regional set of systems, sub-regions were defined based primarily on differences in processes operating on the continental shelf, the continental slope and the abyssal plains. Important ecological features and specific trophic processes associated with those features provides the finest level of description attempted in this project.

We identified three major systems influencing the NWMR with a small element of a fourth system in the south. The fourth (southern-most) system resulted partly from alignment issues between the definition of the NWMR and natural boundaries of the Indian Ocean Central Watermass – a large high salinity gyre driven by evaporative forcing – that impinges on the NWMR up to about Shark Bay and is a key feature of the South West Marine Region.

The northern portion of the NWMR is driven largely by the oligotrophic Indo-Pacific Throughflow (ITF) which critically affects the productivity of the trophic systems down to about Broome. The deep overlying surface layer of oligotrophic water mass suppresses upwellings and a subsurface maximum in chlorophyll is formed where nutrients and light are sufficient for photosynthesis to proceed. South of this system is a massive oceanic transitional zone that spans almost the width of the Indian Ocean from the North West Shelf across to Africa. We further divided the area under the influence of the transitional zone into two major systems, based largely on the width of the shelf: one from Broome to North West Cape associated with the wide northern shelf and another from North West Cape down to just north of Shark Bay associated with the narrower shelf driven by its closeness to the deep ocean and the beginnings of the Leeuwin Current. Sub-regions and important features within these regional systems were subsequently identified and described to the extent possible in this project. Shelf, slope and abyssal areas are also major ecological determinants and were used to further compartmentalise the region into trophic system sub-regions.

In this report we have described the NWMR as a strongly physically forced system with several key drivers. Energetic physical processes control the delivery of deep nutrient to shallower depths so that the region as a whole is strongly constrained by the intensity and frequency of energetic events, and the intensity of the Indo-Pacific Throughflow. In other words, the dynamics of this region are strongly governed by temporal physical events.

The surface layers of the offshore regions rely upon picoplankton and microbial recycling, while larger diatoms, plankton and copepods rapidly regenerate to use any nutrients that upwell into the photic zone. The shelf regions are highly dependent on physical processes that transport nutrients from the offshore into the bottom of the water column and towards the coast. Coastal regions therefore rely upon recycling processes to support the standing crop of various trophic groups. Detritivores play a key role in the recycling process along with the microbial groups. Energetic events enhance productivity that is rapidly taken up by primary consumers including the important filter feeder groups. Bentho-pelagic groups play a key role in competing for productivity in both the pelagic and benthic sub-systems and in so doing also they facilitate the transfer of productivity between the sub-systems. The trophic systems of the NWMR are highly tuned to utilise productivity wherever it is injected into the photic zone from physical events. These events and background physical processes such as tides and seafloor mixing processes critically control the trophic systems of the region.

The NWMR can be distinguished from the other marine regions around Australia by its unique combination of features. These include a wide continental shelf, very high tidal regimes, very high cyclone incidence, unique current systems and its warm oligotrophic surface waters. It also has a range of unique features including the highly productive Ningaloo reef region, the expansive Exmouth Plateau slope region and offshore reefs. Although there is some connectivity with the North Marine Region (NMR) via larval advection within the Indo-Pacific throughflow, a large proportion of the demersal and benthic fauna in particular are relatively unique to the region. There is some overlap with the NMR in that the WJBG and western extents of the NMR show a high degree of similarity in habitats, communities, and hence their trophic systems. Similarly, the most southern sub-regions (Kalbarrri Shelf and Wallaby Saddle) are probably closer in character to the SWMR than the NWMR; to the extent that a slight manoeuvring of the boundary edges of these ‘edge’ regions may make more ecological sense. However, the majority of the NWMR is ecologically unique, as borne out in the limited number of studies that have assessed aspects of these communities in a broad context.

The resilience and vulnerability of trophic systems in the NWMR varies between different sub-regions and more locally between different trophic communities. Some environments are adapted to coping with environmental variability such as the shelf regions in the north of the NWMR, which are subject to highly variable coastal freshwater and nutrient input, highly variable tidal currents and/or sporadic major climate events such as cyclones. These environments are likely to be more resilient to other climatic variability such as variations in seasonal patterns, more frequent or more intense weather patterns. However, their tolerance to increased water temperatures is less certain, and their tolerance to anthropogenic pollution is likely to be low, as demonstrated in marine environments elsewhere.

Other trophic communities appear to be less tolerant of environmental change, such as the offshore coral reefs that are subject to bleaching and high mortality under slightly elevated sea temperatures; or the productive trophic system adjacent to Ningaloo Reef which relies on the seasonal flow of the Ningaloo Current. The continental slope sub-regions have relatively narrow physical tolerances but are adapted to some physical disturbance such as sediment slumping. The deeper communities survive in a relatively narrow range of tolerances. They are removed from many potential sources of impact, but are unlikely to be able to tolerate physical, chemical or environmental changes.

Although this report describes the trophic and ecological systems of the NWMR, it relies on expert knowledge and inference throughout many of the sub-regions. There is an urgent need for greatly improved understanding in many of the regions’ habitats in order to adequately manage and conserve its values. The least understood areas include the slope and abyssal sub-regions, and some of the shelf sub-regions. However, within these sub-regions many habitats – including bank and channels, canyons, shoals, islands and pinnacles – are highlighted in this report based on their high ecological value, but are poorly understood. They often have high biodiversity, limited spatial extent and are impacted by fishing or other industry, and as such, the communities and species supported by them may be at risk and require specific protection. The connectivity between habitats and species conservation is also poorly understood and requires further research to adequately protect the species and habitats within the NWMR.

Acknowledgements

Despite the limitations of the project, we have thoroughly enjoyed the scientific challenge presented to us by DEW and we wish to record our sincere appreciation and acknowledgement of the efforts of the DEW team in assisting beyond the call of duty with this project. We also acknowledge the wealth of information compiled by researchers who have worked in this region. While we are unable to fully acknowledge and include the work of these researchers, this project should be viewed as part of a coherent attempt at gaining an integrated understanding of the NWMR. We apologise in advance to those whose work we may have overlooked but trust that they will have the opportunity to provide substantive input in the NWMR planning efforts.

We also thank those who helped produce the report including Donna Bugden and Toni Cannard (project support, report compilation and formatting) and Louise Bell (front cover).

2. INTRODUCTION

The Australian Government is in the process of preparing Marine Bioregional Plans for Commonwealth waters. This is being separately compiled for the South East, South West, North, East and North West Marine Regions. The first step in the planning process involves gathering, reviewing and summarising the best available information for each Marine Region to broadly describe the key drivers, natural processes, habitats, species, heritage values, human uses and benefits of the region. This information will form the Bioregional Profile for that region.

To this end, The Department of the Environment and Water Resources (DEW) is undertaking in-house research and information collation by the NW team at DEW, Hobart, with contributions from a number of contracts to provide scientific expertise on specific aspects of the region. This report delivers information for the NWMR Bioregional Profile by providing an understanding of the trophic systems and the physical drivers of these systems. This includes identifying different trophic systems, their large scale physical drivers, functional groups and relationships, links across systems, resilience and vulnerability of each system, and information gaps.

The NWMR encompasses Commonwealth waters from Kalbarri in the south to the WA/NT border (Figure 3-1). The following sections of the report firstly describe our approach to characterising the trophic systems and the conceptual models and diagrams used throughout, followed by a general description of the NWMR and the drivers that influence and characterise the region. The region is compartmentalised into eleven trophic systems (sub-regions) (Figure 5-3). The key influences on the compartmentalisation process are described, followed by separate descriptions for each of the trophic systems (Sections 6.1-6.11; described as NWMR sub-regions) and a discussion of the general features of the region.

3. OBJECTIVE, KEY QUESTIONS AND ACTIVITIES

The objective of this project is to describe the trophic systems of the NWMR.
The key questions that the study was initially designed to address included:

1. What are the major trophic systems in the region? How do they differ across the region geographically?
2. What are the key physical drivers in the NWMR and how do they result in different trophic systems across the region?
3. How resilient are these systems to change?
4. What are the links between trophic systems within the NWMR?
5. What are the key features of the trophic systems in the NWMR and how do they differ from other marine regions in Australia?

Key activities have included:

1. Completion of a written report summarising the trophic systems for the NWMR, including a documention of gaps in knowledge.
2. Interact, where possible, with relevant experts in compiling the information.
3. Provide DEW with a list of datasets, GIS layers, maps and diagrams used in developing the trophic system descriptions.
4. Incorporate DEW's comments and reviews by selected experts on the draft report into a final report.

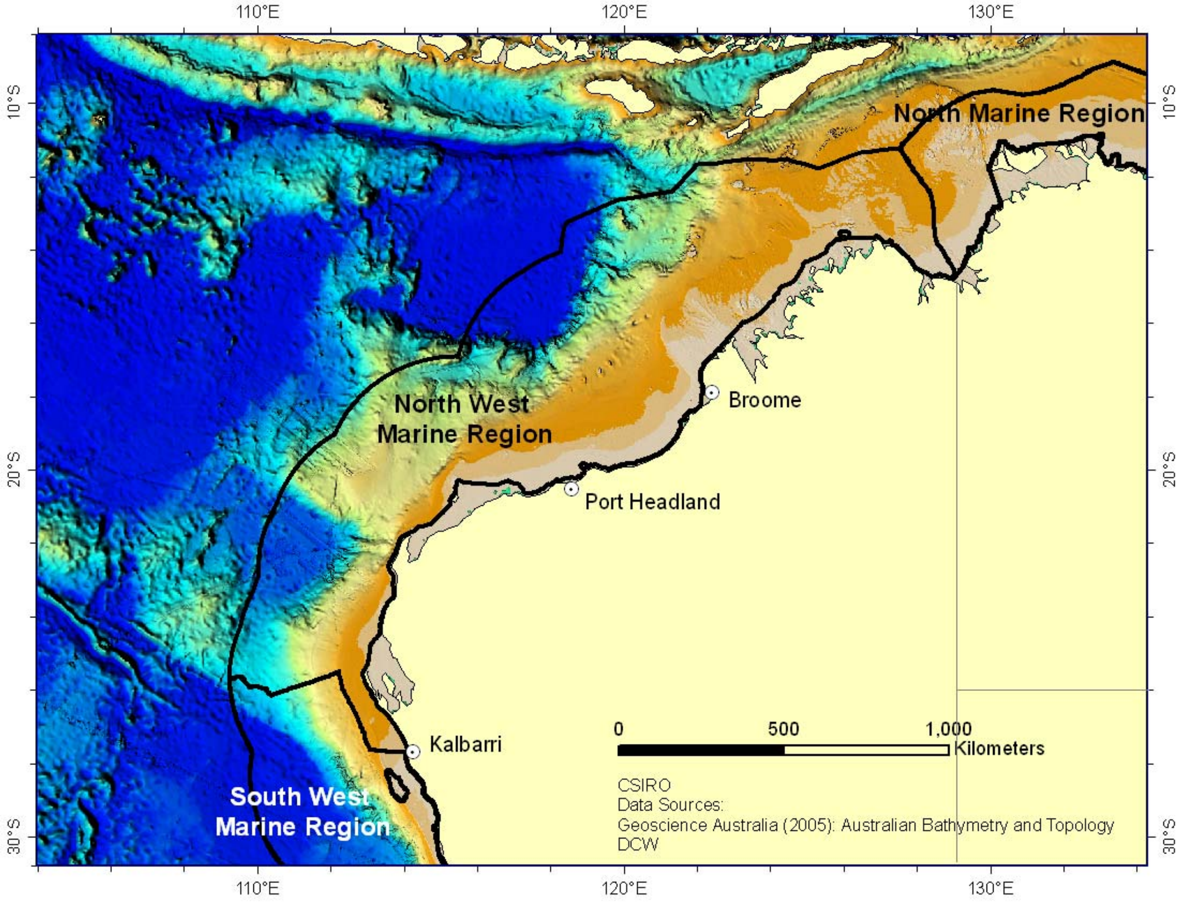

Figure 3-1 The North West Marine Region with the adjacent North and South West Marine Regions

4. APPROACH TO DESCRIBING TROPHIC SYSTEMS

The project methods for describing the trophic systems are outlined as a series of steps below:

4.1 Development of generic conceptual trophic system model

We reviewed the quantitative EcoPath/EcoSim trophic model developed by Bulman (2006) in the NWMR as part of the North West Shelf Joint Environmental Management Study project. Following on from this review, and in discussions with the author Dr Cathy Bulman, other CSIRO staff and DEW, a modified approach was developed that took into consideration the fact that EcoPath/EcoSim models are time consuming and focussed on fisheries applications; resource for the current project were very tight, and that our research focus was much broader. The key aspects of this new approach were the aggregation of biological trophic information to the functional group level, explicit incorporation of habitat information and key drivers, and identifying services provided by, or linkage interactions between, systems. This step involved identifying regional drivers, and using any existing quantitative models, data, publications and expert opinion to develop trophic models that were broadly representative of those in the NWMR. DEW assisted in this task by providing relevant references and expert compilations on the following components: invertebrates, large pelagics, cephalopods, whales, seasnakes, turtles, seabirds, commercial fisheries, geomorphology and oceanographic drivers.

4.2 SYSTEMS OF THE NWMR

The generic model developed above was implemented in the NWMR by identifying the broad regional differences in oceanographic forcing that would affect the trophic systems. Key considerations we took into account included:

- A review and qualitative assessment of drivers of the trophic systems in the NWMR (e.g. oceanography, sediments, geomorphology, productivity/nutrients, climate, habitats, species composition, terrestrial inputs) and how these might result in differences in broad trophic systems across the region;
- A description of how the trophic systems of the NWMR may differ from other marine regions around Australia because of their component species groups and/or habitats;
- Identification of important habitats and species in the NWMR based on their role in trophic systems;
- Information provided by DEW from their literature reviews and through their separate consultations with key experts.

Following on from this approach, we developed a generic conceptual representation of how the region, the sub-regions their trophic systems and important features, all relate to each other. A model of this concept is illustrated in Figure 4-1.

At the broadest level, the NWMR is defined by regional oceanographic, climatic, geophysical and biological drivers that are quite different to its neighbouring regions (identified in Figure 4-1 by the box on the right) such as the South West and Northern Marine Regions. The NWMR may provide services to the community, conservation, various industries and other uses, including services to neighbouring systems. It may also use services from neighbouring systems in the form of species, genes, population, nutrients and other water properties that are important to the trophic systems of the NWMR.

A sub-region contains a unique set of drivers that control its environment and variation at the larger timescales: for example, tidal, seasons, interannual and climatic. Drivers may provide, and alter, the input of biotic and abiotic elements that affect the productivity of the system and the services it provides. Drivers may also disturb and redistribute elements of the system.

Sub-regions may be responsible for elements of services provided by the regional system and they may also preferentially, or otherwise, use the services provided by neighbouring sub-regions. Thus each sub-region has a local set of drivers and services including exchanges with neighbouring sub-regions (Figure 4-1 and Figure 4-2). Within each sub-region there is a collection of trophic elements (denoted by "T" in Figure 4-1) which may comprise functional groups or biota that are of importance to the functioning of the sub-region and/or to the services it provides. The trophic elements are associated with a set of habitats (denoted by "H" in Figure 4-1).

Part of the exchange, or linkage, between sub-regions may be from a dependence of a set of trophic elements on habitats in more than one sub-region (denoted for example by the red dashed line in Figure 4-1 that crosses sub-regions 1 and 2). Features within sub-regions may comprise important trophic elements (denoted by "t" within the larger "T" trophic groups in Figure 4-1), which in turn are associated with one or more important sub-habitats (denoted by "s" within "H") that are part of the sub-region suite of habitats.

The issue of linkage between habitats and trophic elements is highlighted in Figure 4-1 as dashed lines which show the types of interactions that are possible. An important aim of the sub-region descriptions is to identify and characterise these linkages.

4.3 APPROACH, JUSTIFICATION AND CONTEXT

In characterising the trophic systems in the NWMR we used a combination of known scientific information and expert opinion. In particular, the compartmentalisation process used a hierarchical process beginning with the major physical drivers that form the foundations of habitats and determine the biogeochemical characteristics of the region. At the top level, we used the pelagic regionalisation by Lyne and Hayes (2005) (see Figure 5-9) as the primary basis for defining the systems of the NWMR. The Lyne and Hayes, (2005) classification used offshore information on water masses and was less accurate on the shelf. Therefore on the shelf and slope, the regionalisation based on fish by Last *et al* (2003) and the IMCRA demersal shelf regionalisation by Lyne and Last (1996) were used to assist the definition of the sub-regions.

The trophic systems, or sub-regions were described using maps, conceptual models, diagrams and a concise written narrative. The narratives have focussed on the species and species groups (e.g. trophic functional groups) that we believe might play significant ecological roles in the sub-regions being described. More comprehensive species lists may be available for some sub-regions and can be obtained by way of the literature cited in the document.

Much of the scientific information exists in either scientific papers or reports, although some of the information was summarised from existing data held by CSIRO and AIMS. The expert opinion was gathered during workshops held with scientists from CSIRO (Hobart – 28th-29th March), AIMS (22nd-23rd May, 1st-2nd August); and through emails and phone calls to individual experts (e.g. sea turtles – Colin Limpus, Qld NPWS).

Describing trophic systems of the scale of the NWMR is potentially a very large and difficult task. Defining the boundaries of individual sub-regions is complex. However, to provide an adequate, but useful level of information for the purpose of the Bioregional Profile we restricted the description to a relatively small number (eleven) of trophic systems. These were created and agreed upon through workshops and discussions using the conceptual approach described previously in conjunction with information on the main physical drivers and known ecological community boundaries (see Sections 4.3 and 5, below).

Please note: In instances where a comment is not referenced the authors have drawn conclusions about the trophic system based upon broad scientific theory and/or what can be inferred from other marine environments. The need for further research in these instances is often noted in the ‘data gaps’ sections.

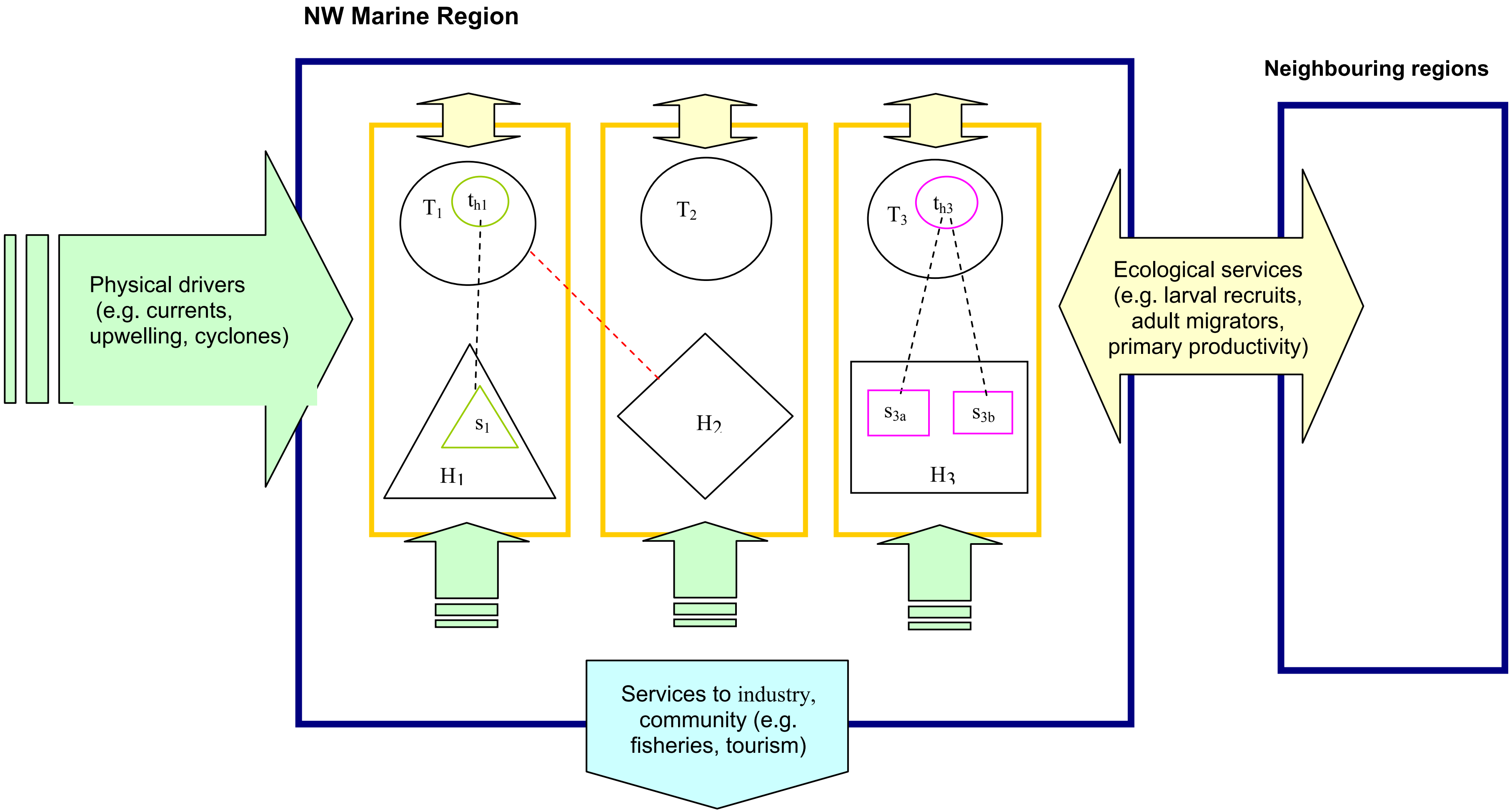

Figure 4-1 Conceptual regionalisation model – illustrating the relationship between (i) the NWMR and neighbouring regions and (ii) three sub-regions, each comprising a major habitat type (H) and associated trophic system (T). Key sub-habitats (s) and their associated trophic systems (t) are also shown. The influence of physical drivers and flow of ecological services is also shown at the regional and sub-regional level.

4.4 CONCEPTUAL MODELS AND DIAGRAMS

Schematic trophic models and habitat diagrams have been used to help describe the trophic systems within the NWMR. In combination these figures depict a range of characteristics for each trophic system, including:

- the main functional groups within each trophic system;
- examples of the species from each functional group;
- the main environments and other 'important habitats' in each sub-region;
- the main physical drivers impinging on each sub-region;
- the main services exported from and imported into each sub-region; and
- an indication of the level of certainty we have in each of the components.

The models of the trophic systems are designed to display the main functional groups in each sub-region and their links, providing a snapshot of the trophodynamics within the sub-region (see trophic sub-regional template - Figure 4-2). Most of the sub-regions trophic systems are simplifications (of the real world) designed to capture key aspects of the sub-region that are different from its neighbours or have an important ecological role in the sub-region.

The generic trophic sub-regional template (Figure 4-2) describes both pelagic and benthic environments. A thermocline is shown separating the surface layer within which pelagic primary production supplies resources to secondary and tertiary consumers. Detritus supplies resources to the benthic environment and is either directly consumed by detritivores (pelagic or benthic) or benthic producers. These supply resources to benthic primary and secondary consumers, which may include bentho-pelagic species groups. The bentho-pelagic groups may also provide the interface between the benthic and pelagic systems. Physical processes operate on both environments. Linkages with the neighbouring sub-regions are illustrated in the top right through exchanges of services or movement of migratory species.

Some sub-regions were either relatively uniform in their habitat features or had no other habitat type that we thought warranted highlighting as an 'important habitat'. Additional features and habitats (likely to have different trophic processes) are described in the narrative only. This helps to keep the models both informative but simple enough to be easily interpreted.

The 'important habitats' were selected based on having several or all of the following features:

- substantially different from the most common habitat and trophic system in the sub-region;
- relatively high species diversity and/or biomass;

- relatively unique in the NWMR.

Habitat diagrams complement the trophodynamic models by providing a visual impression of the sub-region including their depth profile, physical processes, water masses and other influences on the trophic systems. Together we hope that the trophic models and habitat diagrams provide the reader with relatively comprehensive visual depictions of the main components and influences in these trophic systems.

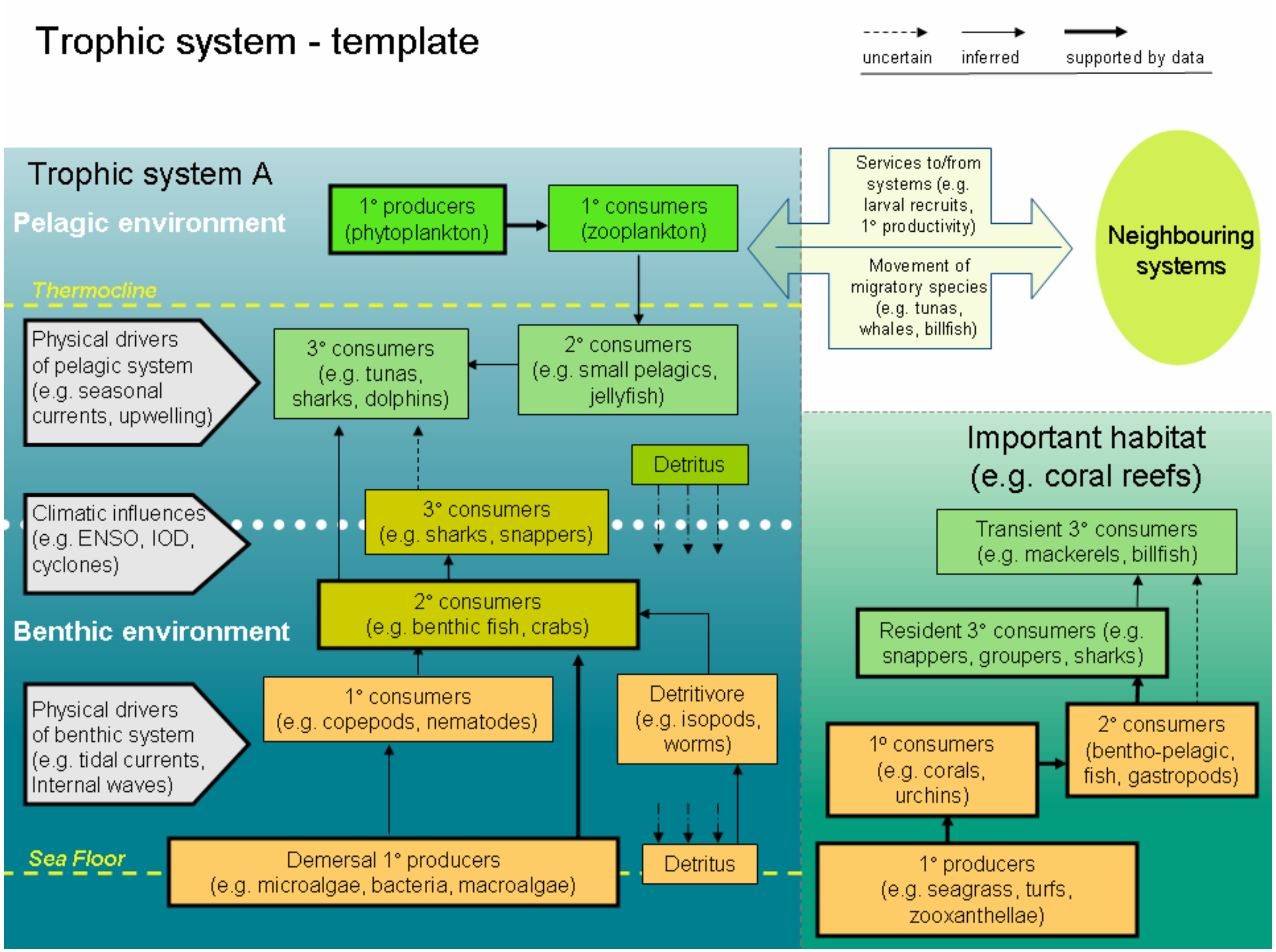

Figure 4-2 Template for schematics of the trophodynamics of each sub-region in the NWMR, showing the main functional groups, different environments, key ecological features of the system, physical drivers, and biological linkages and services between systems.

5. DESCRIPTION OF THE REGION AND IT'S MAJOR SYSTEMS

5.1 GENERAL DESCRIPTION OF NW MARINE REGION

This region covers more than 1.07 million square kilometres of water under Commonwealth jurisdiction from Kalbarri in the south (114° 10' E, 27° 41' S) to the WA/NT border (129° E, 14° 53' S) in the north (Figure 3-1). It extends from the state waters (3 nm from the coastal baseline) beyond the continental shelf and slopes out to the extent of Australia's EEZ, to about 700 km offshore at its widest extent.

5.2 DEFINING TROPHIC SYSTEMS

The top-down hierarchical approach meant that at each level of the hierarchy we attempted to differentiate drivers within the context of the level above. Thus, the regional drivers for the NWMR are conditional upon the basin-scale drivers operating at the scale of the Indian Ocean Basin. We loosely define drivers as processes which may comprise physical processes such as climate, weather/sunlight, ocean currents including upwellings and downwellings, mixing and convection, waves, tides, freshwater input, evaporation and other air-sea exchanges, as well as seafloor processes such as hydrothermal vents (e.g. Figure 5-6, Figure 5-8, Figure 5-4, Figure 5-5, Figure 5-8 and Table 5-2). These processes operate on the system to bring about change within the system and/or bring with them biogeochemical components that interact with and ultimately affect the productivity and ecological processes of the system. For example, upwellings may alter the temperature, salinity, oxygen and nutrient properties of the system environment but it may also upwell deep water communities and species into the system. Drivers in the form of ocean currents generally involve both inputs and outputs to the system and from considerations of simple mass conservation, the composition of the waters coming into the system may be quite different to those which are being "pushed" out of the system. We differentiate drivers from biological vagrants, such as whales or other cosmopolitan species that may transit through the system and use it as a source of resources.

One last point to note is that drivers generally operate through or along the boundaries of the system, apart from body forces such as gravity, magnetism and pressure. For example, in the North West Shelf, a southward flow from the Kimberley region enters the North West Shelf through its northern boundary. Likewise, winds blow across the top surface of the ocean causing air-sea exchanges, mixing and drift. Thus, the definition of drivers is dependent upon the definition of the system boundaries.

5.2.1 Hierarchy of drivers

For the purposes of this project we distinguish a number of levels for the drivers. For reference and illustration we show the pattern of winds and currents taken from the text by Tomczak and Godfrey (see Figure 5-1 and Figure 5-2).

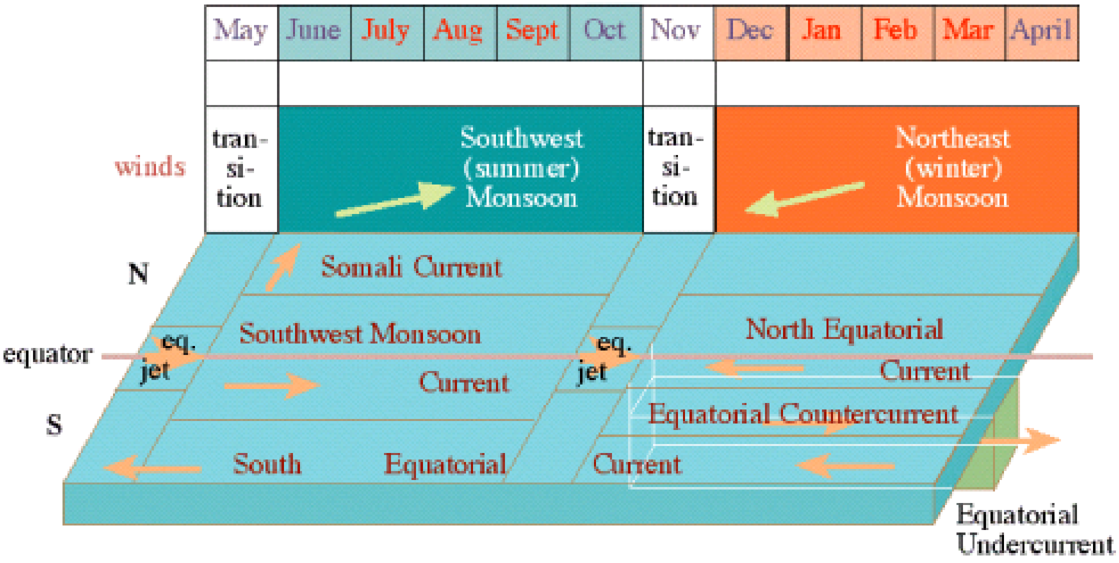

Figure 5-1 Tomczak and Godfrey's (2005) depiction of the monsoon system in the Indian Ocean. The top part indicates the wind cycle, the lower part shows the major currents that develop in response to the wind. (after Tomczak and Godfrey, 2005).

Level 1. Basin Scale: At the scale of the Indian Ocean Basin (defined roughly as the Indian Ocean bounded by the continents with an open-ended connection in the south with the Southern Ocean) the key drivers comprise the flux of waters entering and exiting the southern boundary, the throughflow of waters in the passages connecting the Indian and Pacific Oceans, the formation of water masses through air-sea exchanges, climate and weather disturbances, along with the associated set of waves and currents, seafloor venting processes and the inflow of freshwater and other runoff constituents from the continents. Specifically, the deep waters of the southern Indian Ocean enters from the south and from the dense high salinity evaporative waters from the marginal seas of the Red Sea and Persian Gulf (Fieux *et al.*, 2005). The South Equatorial Current originates in the western Pacific and has a generally westward flow, which is dispersed by New Guinea and north-eastern Australia (Wilson & Allen, 1987). Part of the flow becomes the East Australian Current and another part flows around the northern side of New Guinea and between the eastern islands of Indonesia and the Timor Sea to become the Indo-Pacific Throughflow (ITF) (also called Indonesian Throughflow). These waters determine the composition of the Indian Ocean component of the South Equatorial Current which is a major circulation feature during the south-west monsoon season. During the north-east monsoon, the South Equatorial Current loses strength and retreats south, whilst the Equatorial counter current (locally the Java Current) enters from the west. Just south of Java it is drawn into the South Equatorial Current, which flows in the opposite direction. Reportedly there is some upwelling at the interface between the two current systems which is of some importance to the productivity of this part of the ocean and has implications for example in the distribution of seabirds.

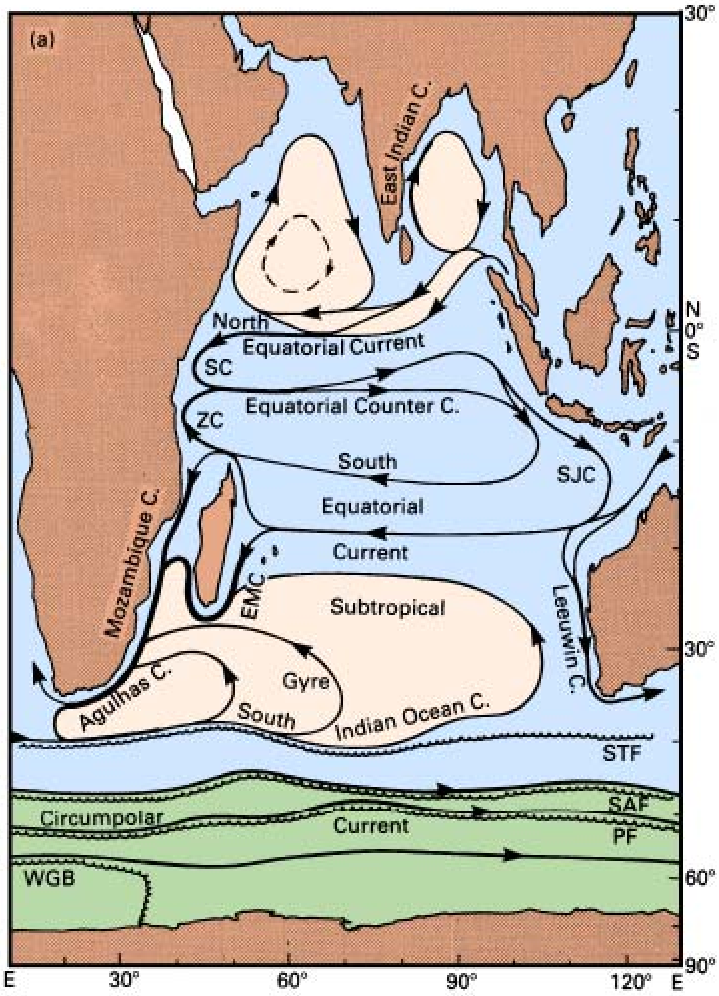

Figure 5-2 Tomczak and Godfrey's (2005) depiction of the surface currents in the Indian Ocean during the Northeast Monsoon (March-April) (after Tomczak and Godfrey, 2005)

Level 2. Sub-basin Scale: At this scale, the drivers at the Basin scale are differentially distributed in space, time and type (of driver) such that, for example, the north-east Indian Ocean is quite different from the north west. In the north east, the ITF and its monsoonal variation is a dominating influence while in the north west the reversing currents and the outflows form the Persian Gulf and Arabian Sea dominate. In the south east Indian Ocean, evaporative processes combined with a gyral circulation creates the high salinity waters of the Indian Ocean Central Water whose influence reaches the central and southern shores of Western Australia. Between the north east and south east regions, there is a major oceanic frontal zone whose northern limit is the southern front of the South Equatorial Current, and the southern limit is the northern extent of the Indian Ocean Central Water. For more information see the "Water mass descriptions" section below.

Level 3. Regional Scale: This is the scale of the NWMR – the subject of this study. The drivers here are variations of those that apply at the sub-basin scale. In the north of the region, the outflow of the ITF waters through the passages of Indonesia is evident and fluctuates at a variety of timescales. Seasonally, the maximum net relative transport into the Indian Ocean is 12 Sv[1] in August/September, while the amplitude and phase of the annual signal varies considerably within the Indonesian region (Meyers *et al.*, 1995). During the north east monsoon (November to March) the sea level difference is less than 10 cm and hence the flow is weaker (Cresswell *et al.*, 1993). Sub-tropical water temperatures throughout the region are largely derived from the influence of the ITF which also controls the depth of the thermocline.

At the sub-regional scale, the first order differentiation of systems (into sub-regions) is via depth (Hedgepeth, 1957). This is due to the dependence of a variety of processes, including mixing processes, the formation of the thermocline and depth-structured layering of the deep water masses (called stratification) on the continental slope and deep ocean (see Figure 5-3). Following the concepts embodied in the demersal regionalisation framework, the depth structures comprise three zones:

- The first is the shelf zone subject to various mixing processes which in turn is split into various depth bands as discovered by Lyne *et al.* (2006) for the North West Shelf.
- The second is the slope zone where Heyward *et al.* (2006) found seasonally repeated patterns of circulation and nutrient flux, with an apparent disjunction between inner and outer shelf water quality along the ~80 m isobath, and another change at the ~200 m isobath across which sub-tropical and tropical water move seasonally. Beyond this shelf-break isobath, Last *et al.* (2003) have documented the existence of a number of demersal biomes with transitions and Lyne and Hayes (2005) have also noted the existence of pelagic water mass layers. The base of the continental slope zone in this region is usually at about the 3000 m isobath.
- The third zone is the deep ocean - Abyss zone beyond the 3000 m isobath. Above the deep ocean abyssal zone the pelagic ocean is structured into distinct depth bands and interactions within the water column characterised by the rain of surface production and various intrusions of water masses laterally.

Level 4. Local scale: At the next level of differentiation, various types of processes and features of the environment are discriminated. Often features and processes are associated in an intimate way within each system. For example, canyons in the continental slope are repositories for various matter that may be deposited from the shelf and sides of the canyons. While at the same time the canyon interacts with boundary currents and other processes such as internal waves/tides leading to topographically forced currents at the canyon heads that support enhanced local and downstream productivity. This in turn attracts opportunistic deposit feeders and a variety of predators while supporting a rich and dynamic community within the sides and floor of the canyon. Within the North West Marine Region obvious large features of the environment (e.g. the Joseph Bonaparte Gulf; the unique Kimberley shelf and coast and the Exmouth/Ningaloo Shelf environment) are associated with particular functional groups at the sub-region scale and these are described in detail in Section 6.

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[1] Sv (Sverdrup) is the flow of water in units of $10^6 m^3$ per second.

Water mass descriptions

The water masses are described below and in Figure 5-3, Figure 5-4 and Figure 5-5, and named on the diagrams for each system (Section 6). These sections are from the work of Lyne and Hayes (2005) on the pelagic regionalisation of Australia. They illustrate the layered nature of offshore water masses and the latitudinal variation due to the presence of major system oceanographic drivers including the ITF in the northern most section (purplish water masses), the Indian Ocean Central Water gyre in the southern section (cyan waters, note also Leeuwin Current along the surface waters, inshore waters of the upper slope in deep blue) and the frontal waters in the middle illustration. See text for how these data were used to describe the NWMR sub-regions.

The water mass sections show classified water masses from the Lyne and Hayes (2006) pelagic classification which should be consulted for details on the classification procedures and definitions of the water masses. Note that the color scale is the water mass identification index/number, and so, does not represent any property such as temperature.

Section at -12^o S: Deep overlying layer of surface and midwater ITF down to about 300m.

Section at -15^o S: Similar to previous section but now there is some suggestion of subsurface upwelling of deepwater at the continental slope. In both sections, the water on the shelf is different to those in the deep water. An impressive mixed water mass appears at the continental shelf edge and the mixed waters appears to intrude well into the offshore water masses (at about 100m depth level) as a thin subsurface intrusion. This suggests that the shelf-break is an intense area of boundary mixing, where mixed waters are formed and subsequently intrude into the interior to enhance the flow of nutrients to support the so-called "Deep Chlorophyll Maximum" (discussed later) above the thermocline.

Section at -19^o S: Reinforces previous observation of shelf-break mixing but in this case the base of the mixed water mass at the shelf-break is much deeper and broader and the width of the offshore intrusion is also deeper. The shape of the shelf-break is smoother (less sharp) than the other sections.

Section at -22^o S: Less distinct boundary mixing signatures at the shelf edge, but still persistent.

Section at -24o S: Narrow surface Leeuwin Current apparent along the continental slope with the water mass signature of the current reaching down to deeper than 200m. Some subsurface interleaving/instability in the water mass profile is apparent at the edge of the Leeuwin Current.

Section at -25o S: The Leeuwin Current continues to become narrower while extending down about the same depth.

From the section at -19o S down to the -25o S, the deep water masses (off the continental slope) are rising to the east. In geostrophic balance, this suggests that the deep water is flowing northward.

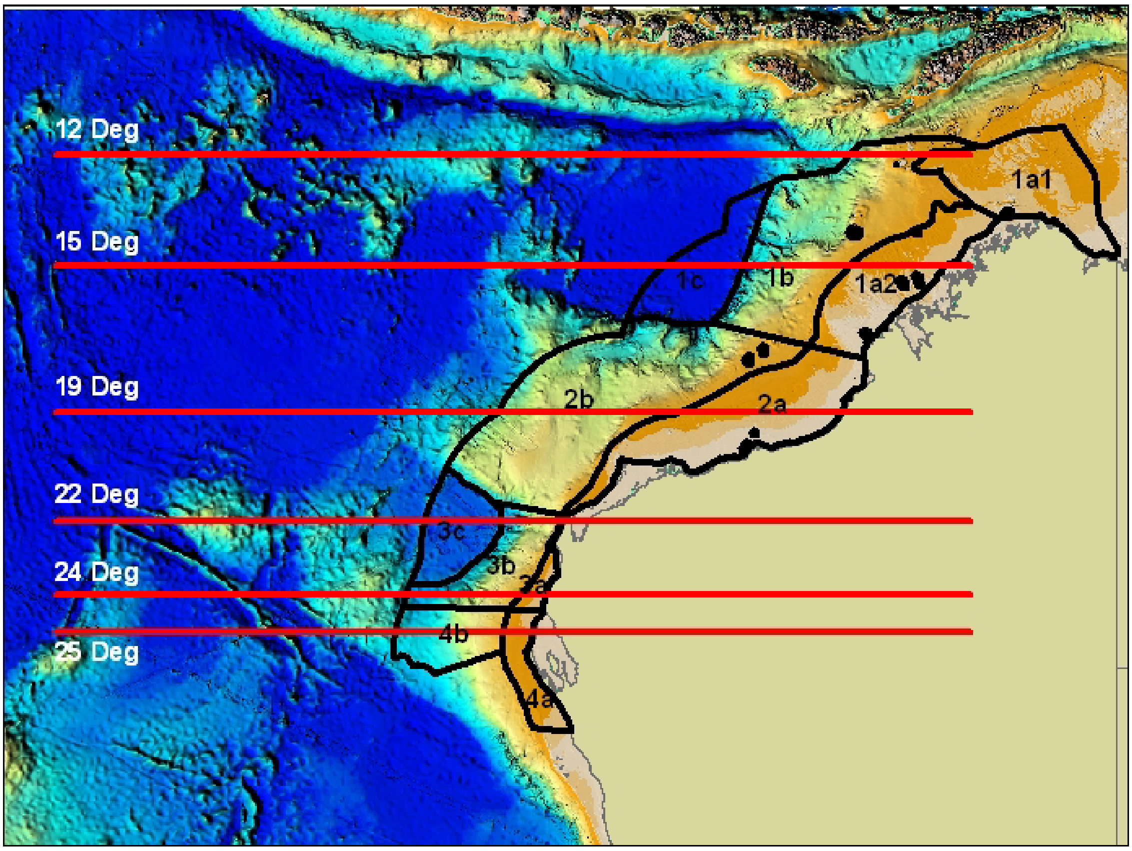


Figure 5-3 Water mass profile locations from six sections across the North West Marine Refgion. The water mass profiles are shown in Figure 5-4 and Figure 5-5.

5.2.2 Structure of the trophic systems

At each of the scales of the drivers, trophic systems can be determined and described that rely upon the environments at those scales. Naturally as we go to finer scales, greater details are required on the specialisation, adaptation and configuration of functional groups and their associated habitats. The definition of trophic systems was confirmed through the analysis of a wide range of available abiotic physical datasets (e.g. Figure 5-4, Figure 5-5, Figure 5-8, Table 5-2 and Appendix 1). This abiotic or physical information is useful for determining trophic systems because ecological communities are established and bounded in a large part by their tolerances to physical properties such as temperature, depth, salinity etc. It is also cheaper and easier to collect information on the physical properties of marine systems than the ecological aspects and hence, we have more information on the physical characteristics of the region. Differences in species community types are less well documented and were used as a secondary determinant of the system boundaries; partly because there was not a consistent level of good ecological or dietary information (from which trophic systems could be inferred) throughout the region. The differences in some of the key physical parameters of each region can be compared as in Figure 5-8.

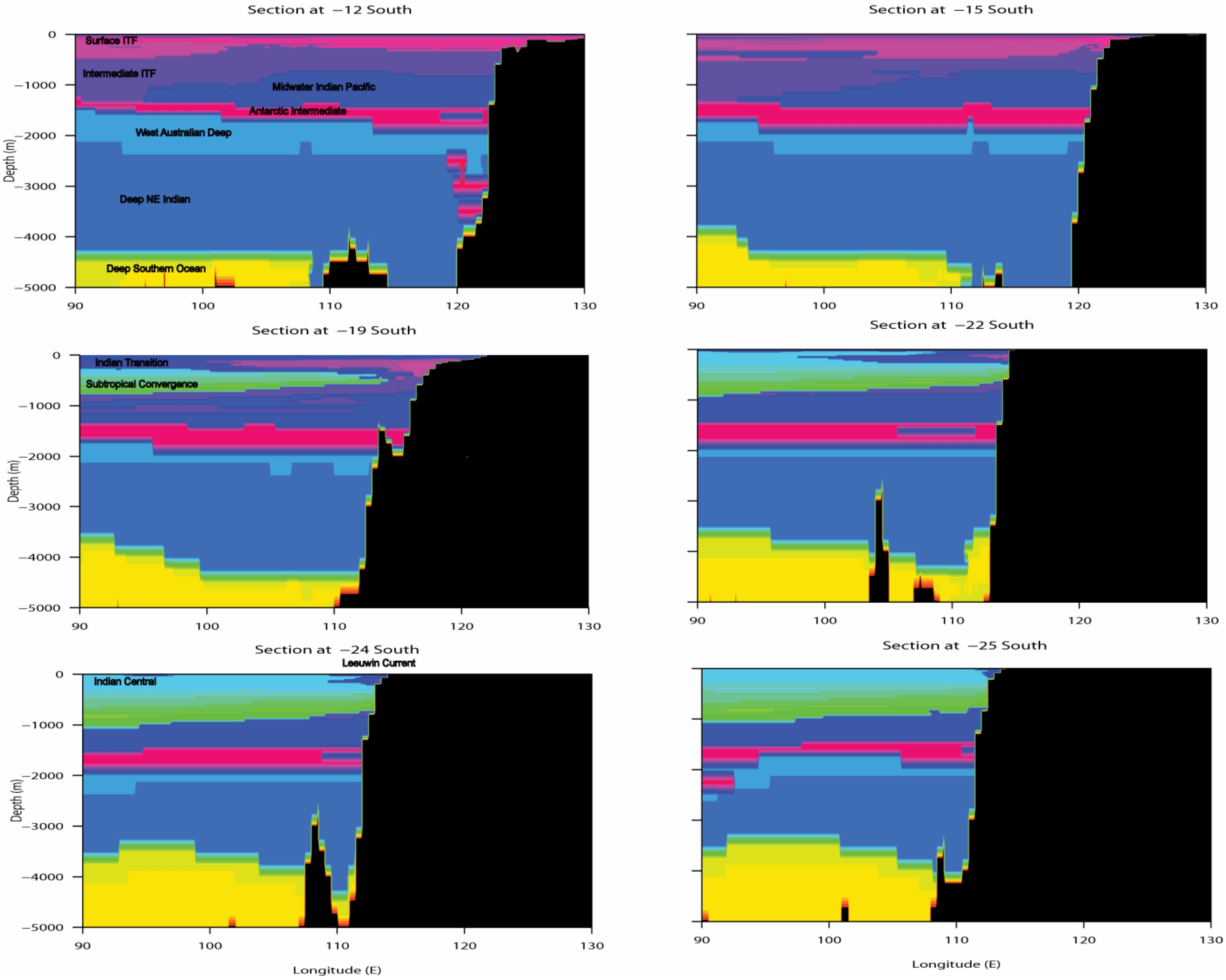


Figure 5-4 Water mass profiles from six sections across the NWMR to 5000 m depth. These were produced from data located at the cross-region transects shown in Figure 5-3. The unnamed water masses can be identified from the named water masses of the same colour and similar position.

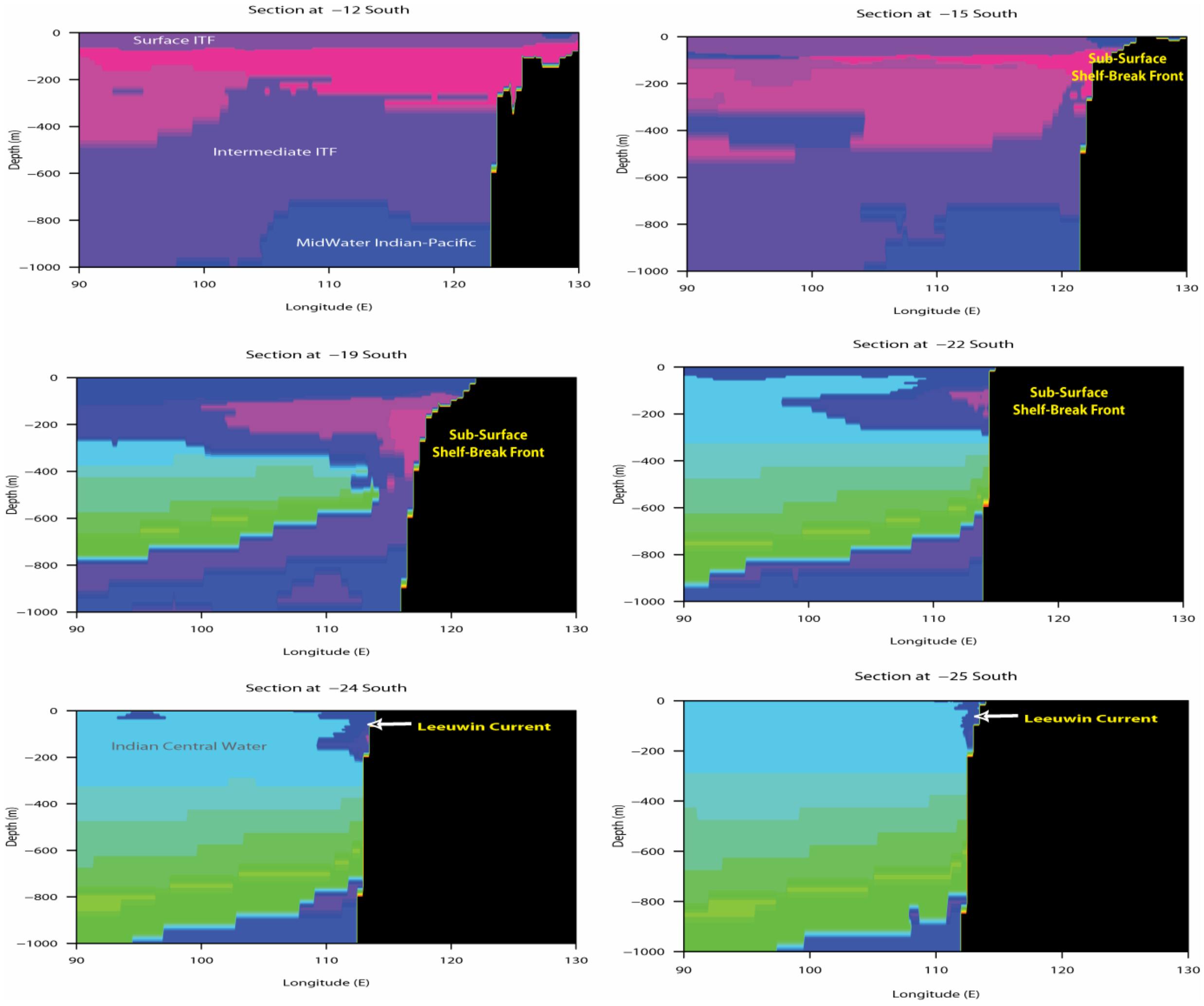


Figure 5-5 Water mass profiles from six sections across the NWMR to 1000 m depth. These were produced from data located at the cross-region transects shown in Figure 5-3. Water masses are labelled on Figure 5-4

Level 1. Basin scale trophic systems: At the scale of the Indian Ocean, the trophic system is constrained by the semi-enclosed nature of the Indian Ocean, which implies that much of the trophic elements are reproduced within the Indian Ocean, or are advected into the basin from the southern connection and from the ITF. The lack of deep water production also implies that production within the basin as a whole is constrained, ultimately by the upwellings of deepwater nutrients and it's replenishment from the south, outflows from the continents and from the ITF. The deep overlying oligotrophic waters of the ITF are a major barrier to convective mixing up of nutrients hence turbulent mixing from other processes such as equatorial currents, internal tidal mixing, boundary currents (Leeuwin Current) and eddy activity critically control the nature of productive processes at the local scale and collectively at the largest basin scale.

Monsoonal winds (Figure 5-6) and cyclones (Figure 5-7) also play a critical role and thus the trophic systems as a whole in the Indian Ocean are relatively deprived of deep ocean nutrients and much of that which does reach the near surface comes about from sporadic and energetic events. Our expectation is that communities, populations and species will be adapted to take advantage of these energetic events while being able to conserve resources for the next event. Overall, at the basin scale, nutrient enriched waters intrude from the south but subduct to depths below the photic zone. While in the north a deep overlying oligotrophic layer forces production to subsurface zones that can access the deepwater nutrients. Boundary and equatorial currents and the mixing along the continental margins provide for and sustain the major trophic systems of the Indian Ocean. Thus the physical processes strongly control the overall productivity of the Indian Ocean Basin.

Level 2. Sub-basin scale trophic systems: At this scale, the configuration of surface and deep water masses, their nearness to the surface and their location to large scale turbulent mixing processes will have a major influence on the spatial distribution of productivity and community composition. Likewise, gyral circulations and their entrainment of surrounding waters and retention of populations, communities and species create sub-regions in the Indian Ocean that contain trophic systems with relatively unique trophic characteristics. For the purposes of this project, we recognise the main sub-basin systems as comprising the ITF carrying with it Indo-Pacific communities, populations and species. Here, the pelagic components of the trophic system are dynamically driven by the ITF and monsoonal reversals in winds (Figure 5-6). High productivity along the margins of the continent and edges of the South Equatorial Current are utilised by highly mobile communities including seabirds, megafauna and large pelagics which rely upon the downstream evolution of plankton to larger prey. Despite its low nutrient status, the currents associated with the ITF bring about seasonal and sporadic high productivity (by affecting upwelling of deeper nutrient-rich water) along the Sahul Shelf and immediately offshore of the shelf under the ITF core current as seen in movies showing the evolution of SeaWifs chlorophyll (http://oceancolor.gsfc.nasa.gov/SeaWiFS/HTML/SeaWiFS.BiosphereAnimation.110E.html). Benthic communities are able to respond rapidly to these events. Current systems at depth and associated with the ITF flow are likely to be relatively strong and favour filter feeders located on a variety of substrates both on the shelf and the slope.

The warm salty and oligotrophic Indian Ocean Central Waters impinge upon the southern part of the study region and it is a major sub-basin system whose influence is only marginally felt in the study region. Likewise, the oceanic front between the ITF and the Indian Ocean Central Waters is a major system boundary which has the North West Shelf at its eastern edge. Thus, the study region is comprised of the ITF as a major component while the frontal region off the North West Shelf and the south experiences the boundary effects of large scale oceanic sub-systems. In such circumstances we would expect the trophic systems of the NW Shelf and the south to be adapted to boundary current processes and shelf-break processes while the on the shelf would have a strong reliance on resources from the offshore zones and alongshore advection. Filter feeders and benthic producers would be key components of such systems. Thus, shelf ecosystems of the Indian Ocean are strongly reliant upon offshore nutrient sources for their productivity while open ocean systems are reliant upon energetic currents and surface mixing. These sources in turn are controlled by physical processes which affect nutrient delivery.

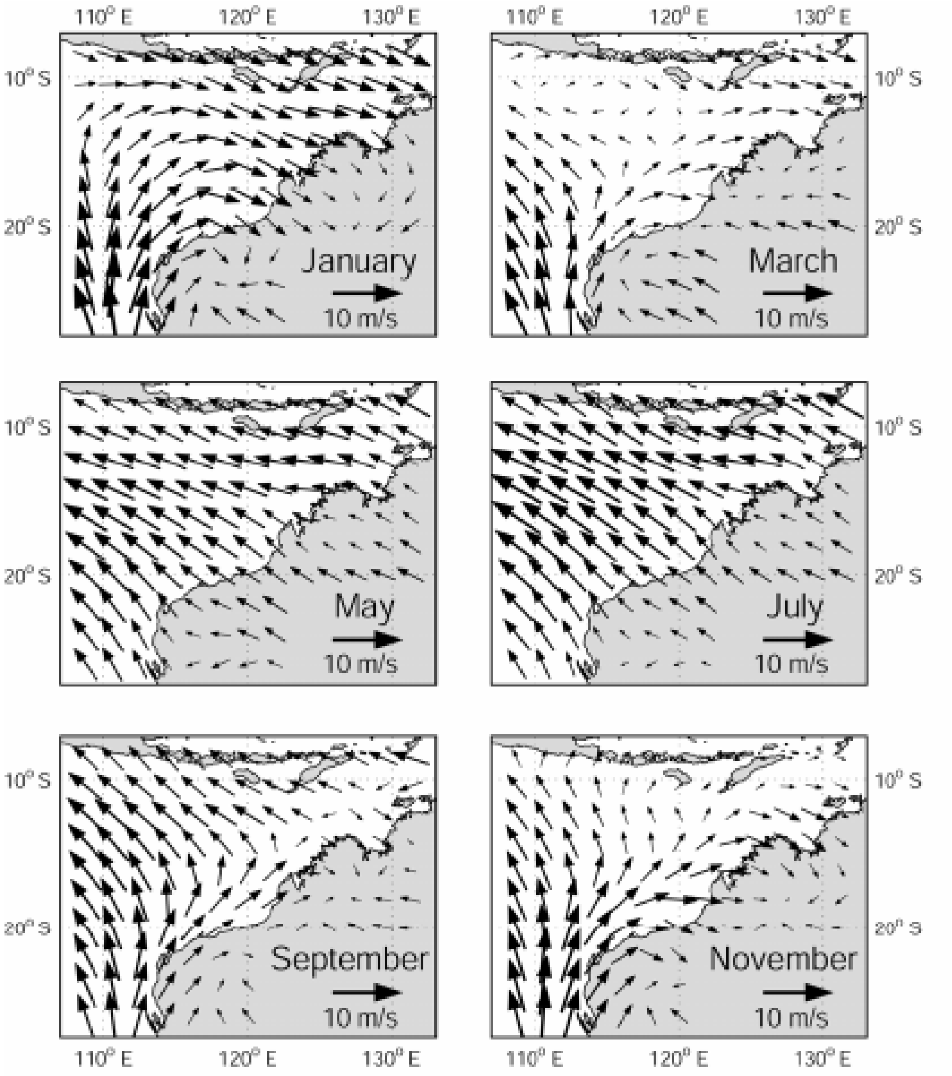


Figure 5-6 Seasonally averaged winds in the North West Marine Region at a height of 10 m above mean sea level during January, March, May, July, September, and November. These fields were calculated by vector averaging the 12 hourly outputs of the NCEP-NCAR re-analysis dataset across the years 1982 to 1999 (From Condie *et al*., 2006 – JEMS).

Level 3. Regional scale trophic systems of the NWMR

The spatial boundaries for the trophic systems were informed by the range and differences in the summary statistics for various physical drivers and ecological data (Table 5-2). However, they are by their nature, approximate boundaries and should not be seen as hard and fast system boundaries.

With the above consideration in mind, the compartmentalisation of the NWMR into trophic systems, referred to hereafter as sub-regions is described below. Initially into four major systems at the sub-basin scale (level 2, above), and within these, the sub-regions (level 3, above), which are described in detail in Section 6.

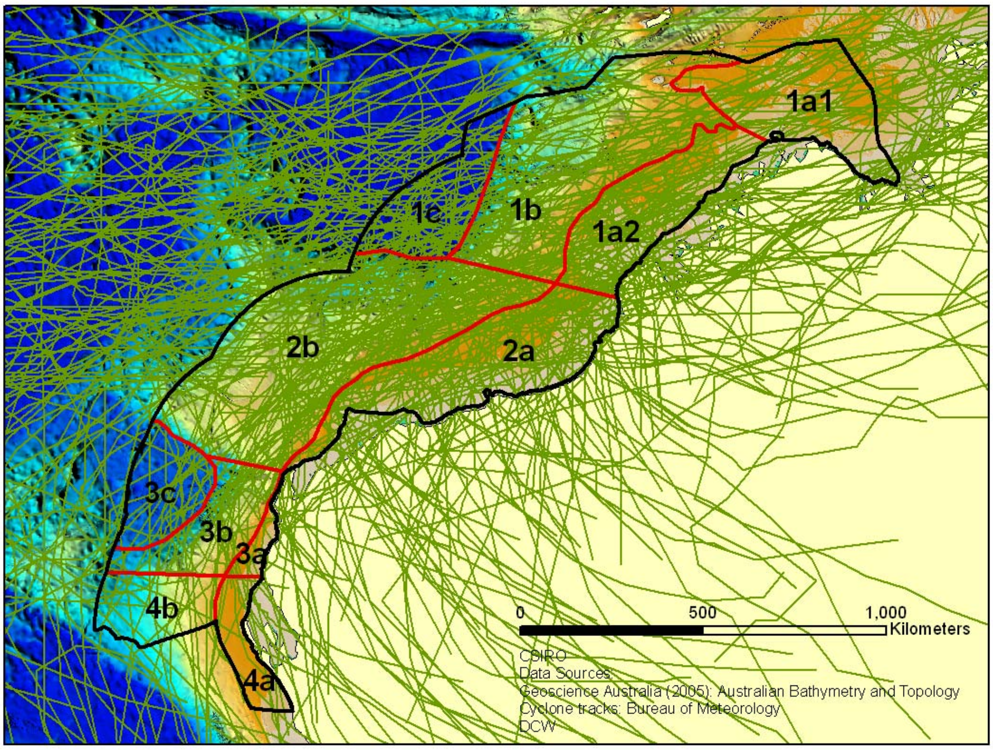


Figure 5-7 Cyclone tracks (1906-2000) for the North West Marine Region Data derived from Bureau of Meteorology cyclone data.

The influx of the ITF waters across the Sahul Shelf, which in part may comprise deeper nutrient enriched waters, would favour filter feeding and benthic producers as discussed above. In the Kimberley Shelf, tidal stirring is a unique driver along with the relatively high runoff (relative within the context of the North West in general) combined with the highly fractal nature of the coastline and the diversity of shelf geomorphic structures. As such, this system is a very unique marine environment nationally and probably also by international standards. The highly dynamic nature of the environment suggests attached flora and fauna may play a key role as the stable producer elements subject to a range of predatory bentho-pelagic consumers. In advective environments we are likely to see communities aligned according to the major flow patterns, intensity of bottom stresses and availability of suitable substrates in order to receive access to planktonic prey, nutrients or particulate matter. These are all hypotheses that need to be investigated as possibilities from a system approach to identifying trophic systems. The slope communities are poorly studied but even so Last *et al*. (2005) find that the Timor Province slope comprises suites of endemic fish species.

Systems 2 and 3: The location of the transitional front zone defines the northern and southern limits of these systems (Figure 5-9) and we again used the slope and shelf regionalisations to guide the boundary to the coast from the offshore. The split between System 2 and System 3 occurs at about North West Cape which is a major faunal boundary in the demersal shelf and slope regionalisations (Figure 5-10). The offshore boundary between Systems 2 and 3 was set at the southern edge of the Exmouth Plateau which marks a significant sub-surface topographic boundary and it is also associated with sporadic enhanced productivity as noted previously.

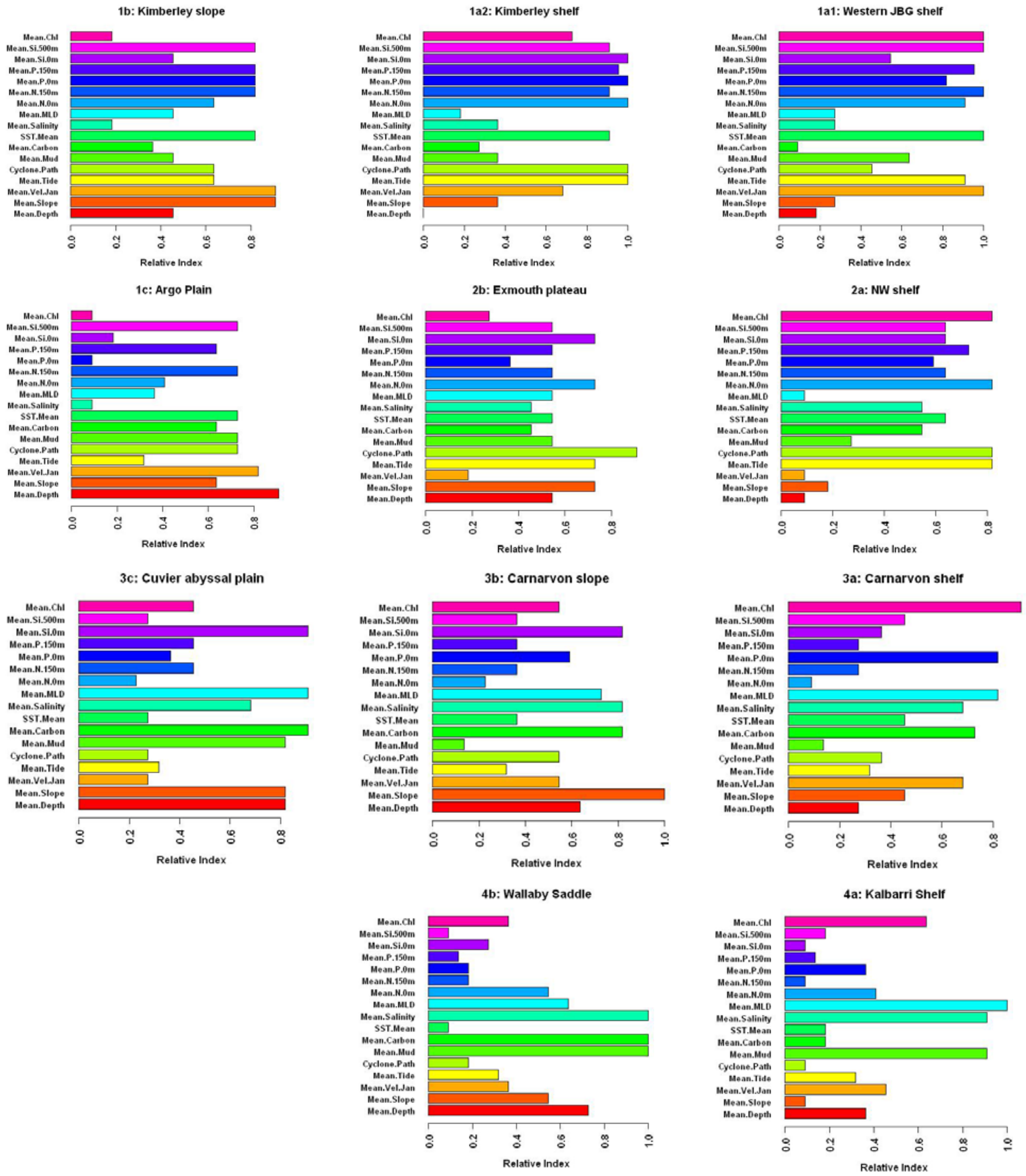


Figure 5-8 Histograms showing relative levels for 16 different physical parameters for each of the 11 sub-regions of the NWMR. Parameters are mean surface chlorophyll, mean silicate concentration at 500 m, mean silicate at the surface (0 m), mean phosphorous at 150 m, mean phosphorous at the surface, mean nitrate at 150 m, mean nitrate at the surface, mean mixed layer depth (MLD), mean surface salinity, mean sea surface temperature (SST), mean percentage carbonate in the sediments, mean percentage mud content, mean cyclone path per square kilometre per year, mean tidal exceedance, mean surface current velocity (January), mean sea bed slope and mean depth of the sub-region. For more detail see Appendix 1. Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one from data presented in Table 5-2.

System 1: The southern boundary of this system is set by the location of the ITF pelagic boundary up to the edge of the shelf. There is good concordance with the demersal slope boundary. On the shelf, we relied upon the demersal shelf regionalisation which showed a boundary extending out from about Broome (Figure 5-9, Figure 5-10).

The North West Shelf has a wide continental shelf in the north and narrows in the south where there is a high density of islands and seamounts. In the sandy/shelly environment of the North West, gaining a good foothold is a critical requirement for survival especially when this area is highly vulnerable to cyclones (Figure 5-7). Productivity in this region is forced below the surface due to the thick overlying layer of ITF-derived oligotrophic waters. Upwelling doesn't often occur in the expected way of a surface signature of cool nutrient enriched waters that trigger off a phytoplankton boom. Instead, upwellings are unlikely to reach the surface and may be limited to subsurface zones above the thermocline and the productivity associated with the subsurface deep chlorophyll maximum (see Herzfeld *et al*., 2006, Furnas, 2007). The intersection of the thermocline with the mid-shelf environment is an important area where internal wave breaking activity and the seiching of waves along the seafloor may critically control the flux of nutrients onto the shelf system (see later discussion). Hard seafloor areas support a diverse array of communities (Lyne *et al*., 2006) compared to the expanses of seafloor with more mobile sediments. Again the slope environment is not well studied but was classified by Last *et al*. (2003) as containing a well defined province (one that contains endemic suites of species arising from biogeographic speciation processes) in the southern half. Productivity in this region is also enhanced on the shelf through the existence of the offshore islands and seamounts together with limestone pavement substrates that support a rich array of benthic filter feeders and producers. The Exmouth Plateau is unique but not much is known of the trophic systems it supports. From satellite imagery it appears that the northern and southern flanks are characterised by extensive fronts of enhanced productivity. We obviously need to understand whether or not the plateau supports a unique and valued set of deep water/plateau communities that is not replicated anywhere else.

System 4: The remnants of the NWMR in the south that are not part of Systems 1-3. This remnant is part of the northern class of water masses associated with the Indian Ocean Central Water. For completeness, this system is demarcated in the NWMR but we note that it is a small part of a much larger system that is outside the study region.

This southern part of the study area is the origin of the Leeuwin Current proper while at the same time it has a very narrow shelf and is in intimate proximity to deep water communities. Nutrient delivery onto the shelf is likely to be controlled by the action of internal tides and the turbulent mixing on the inshore side of the Leeuwin Current system. Thus the Ningaloo region is a very unique region in its close proximity to deepwater and the start of the jet-like flow of the Leeuwin Current. However, it relies upon the flow of resources passing through the region rather than local production. Thus even though the shelf species are diverse and rich they may reflect communities that are not resident or endemic to that area. It many ways, this is the marine equivalent of the cosmopolitan city. Offshore, the Carnarvon Canyon and Wallaby Saddle are features that are unique and would interact strongly with the Leeuwin Current (if not affecting its flow and eddies). Here again we need to understand how communities have adapted to the flow of the current and its eddies.

Following the definition of the system boundaries discussed above, sub-regions were defined as Shelf (coast out to the shelf-break as defined in the National Marine Bioregionalisation, 2005); Slope from the shelf-break down to 3000m, and Abyss was anything deeper than 3000m. These considerations resulted in the units shown in Figure 5-10 and Table 5-1. Names for these units are as tabled below, along with summary statistics derived from the National Marine Bioregionalisation datasets (kindly computed by Mike Fuller of CMAR)

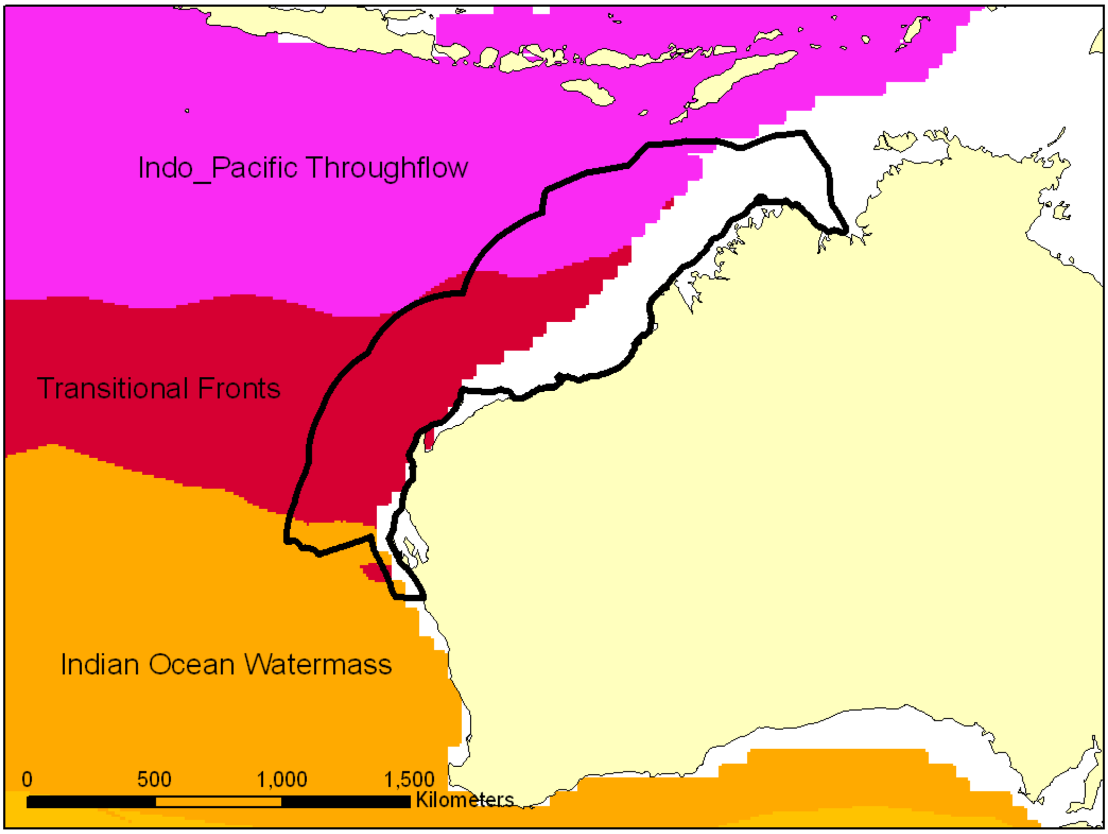


Figure 5-9 Location of major surface watermasses (excluding shelf waters) off Western Australia (from Lyne *et al*., 2006).

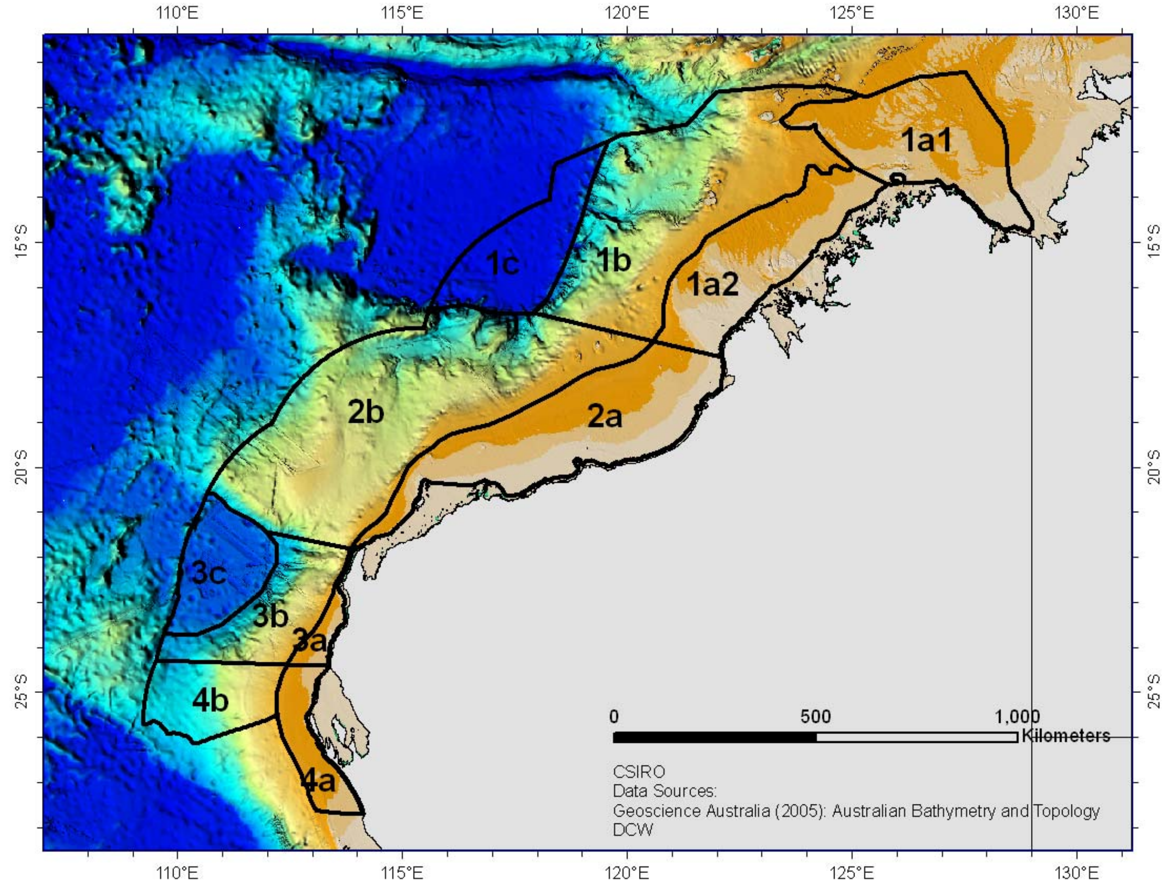


Figure 5-10 Map of North West Marine Region with location of major trophic systems. See Table 5-1 for sub-region names.

Table 5-1 Names for Primary and Secondary trophic systems for the North West Marine Region.

Primary System		**Secondary system (sub-region)**		**Area (km^2)**
1	ITF Influence	1a1	Western JBG shelf	112,889
		1a2	Kimberley shelf	102,490
		1b	Kimberley slope	217,931
		1c	Argo Plain	73,667
2	Northern transitional fronts influence	2a	NW shelf	143,531
		2b	Exmouth plateau	275,833
3	Southern transitional fronts influence	3a	Carnarvon shelf	11,107
		3b	Carnarvon slope	63,551
		3c	Cuvier abyssal plain	53,870
4	Central Indian Ocean influence	4a	Kalbarri Shelf	30,023
		4b	Wallaby Saddle	49,648

Table 5-2 Summary physical data from the trophic sub-regions of the North West Marine Region (Full data descriptions are contained in Appendix 1). Sub-region numbering matches names shown in Table 5-1.

	Ave. Depth (m)	**Ave Slope (%)**	**Surface currents (m/s)**	**Tidal excedance (%)**	**Cyclones (m/km2/yr)**	**Sediment % mud**	**Sediment % carbonate**
1a1	84.1	0.36	0.13	25.0	1.34	41.0	61.1
1a2	80.3	0.37	0.09	33.2	2.98	14.9	83.0
1b	1,509	2.83	0.13	8.2	1.97	24.4	84.6
1c	5,571	1.91	0.11	0.0	2.40		
2a	83.5	0.27	0.03	24.7	2.58	10.0	91.4
2b	1,614	2.26	0.05	9.6	2.64	31.2	88.1
3a	112.0	0.65	0.09	0.0	1.19	0.3	
3b	2,359	3.90	0.08	0.0	1.83	0.3	
3c	5,007	2.43	0.05	0.0	1.08		
4a	115.4	0.26	0.08	0.0	0.77		80.3
4b	2,585	1.80	0.07	0.0	0.93		

	Avg SST (Cº)	**Avg salinity (ppt)**	**Mixed layer depth (m)**	**N (µM) 0m/150m**	**P (µM) 0m/150m**	**Silicate (µM) 0m/500m**	**Chlorophyl (mg/m3)**
1a1	28.6	34.8	32.5	0.18/16.2	0.15/1.15	3.52/66.1	0.51
1a2	28.5	34.8	31.4	0.21/16.1	0.19/1.15	5.10/57.6	0.30
1b	28.5	34.6	33.2	0.09/15.5	0.15/1.07	3.46/56.2	0.11
1c	28.1	34.5	32.7	0.05/12.8	0.11/0.85	3.16/43.4	0.09
2a	27.3	35.2	29.2	0.14/11.6	0.14/0.86	3.53/34.2	0.36
2b	26.8	34.9	35.7	0.11/9.5	0.13/0.70	3.65/26.8	0.12
3a	24.5	35.2	37.9	0.03/2.0	0.15/0.30	3.33/10.5	0.39
3b	24.4	35.2	37.4	0.04/2.7	0.14/0.32	3.67/8.1	0.22
3c	24.4	35.2	38.0	0.04/3.2	0.13/0.34	3.86/7.2	0.19
4a	23.2	35.4	44.5	0.05/1.2	0.13/0.24	2.86/7.1	0.27
4b	22.8	35.4	37.4	0.06/1.4	0.12/0.24	3.21/6.1	0.17

5.3 Comparison with IMCRA provincial regionalisation

The construction and descriptions of systems in this study, following the conceptual approach detailed above, uses a range of bioregionalisation information documented in a number of references, notably the original demersal and pelagic shelf regionalisations by Lyne and Last (1996) which were mainly incorporated into IMCRA Version 3.3 (1998); the demersal slope bioregionalisation by Last *et al*. (2003); the pelagic regionalisation by Lyne and Hayes (2005) and the National Bioregionalisation of Australia (NBA) 2005. These regionalisations provide the structural components from which the sub-regions of the NWMR are developed and described (Table 5-3). As discussed previously, our approach in developing the sub-regions was to use the pelagic regions as the highest level (largest scale) for defining the different major types of systems. Within that structure, the depth-based structures from the demersal and the pelagic regionalisations were determined and then the smaller scale systems were defined around specific major features of the larger systems.

With that as a background, the top level system boundaries closely follow the pelagic regionalisation boundaries in the offshore region and in the southern part of the study. The exceptions here are in the shelf environment to the north where the national scale pelagic regionalisation, based on a coarse (compared to the shelf width) 0.1 degree grid, was given lesser importance than the shelf regionalisations of Lyne and Last (1996). The offshore pelagic large scale regionalisations were also never meant to apply to the shelf region which is affected by processes such as coastal runoff, tidal and wind-driven mixing and other process variability at a variety of space/time scales that are not experienced in the open ocean. The main shelf boundaries affected by these considerations were the Joseph Bonaparte Gulf, the boundary off Broome (between systems 1 and 2) and the additional boundary inserted off North West Cape.

In the offshore region, the depth structures followed the model by Hedgepeth (1957) which was described in Lyne and Last (1996) and in the National Marine Bioregionalisation 2005. The demersal slope regionalisation boundaries aligned well with the major pelagic boundaries but the additional detail in the provincial demersal bioregions were not incorporated in defining the top level compartments. Thus, we viewed the demersal bioregions as being embedded within a larger scale pelagic structure which provided the continuity and process linkage between habitats/bioregions and the other ecological components.

The key departures from IMCRA are in the offshore region (Figure 5-11) where the compartmentalisation had to accommodate the three-dimensionality of the oceans into a two-dimensional map. The pelagic regions were given precedence due to their central role in defining the connectivity and the environment within the systems. The offshore demersal units which were based on seafloor geomorphology therefore do not necessarily align with the system boundaries. Likewise, we could not accommodate the full three-dimensionality of the various depth-related pelagic water masses. We instead gave precedence to the structure of the near surface layers. In keeping with the philosophy of the system definition approach adopted for this project. Bioregions are embedded within their relevant System. The overriding criteria we applied was for a sub-region description where components were intimately tied by interrelationships with the environment and drivers, and were as self-contained as possible while being differentiated from neighbouring sub-regions. Thus, the IMCRA bioregions were seen as components to be integrated into the sub-regions.

Table 5-3 Use of the IMCRA information in the compartmentalisation process

Structure	***Demarcation***	***IMCRA Information Used***	***Comments***
Top Level Compartments	Determined by major pelagic bioregions	Lyne and Last, 1996 Lyne and Hayes, 2005	Pelagic regionalisation not valid for shelf; greater reliance on demersal shelf bioregions. Offshore, greater reliance on pelagic region c.f. geomorphic features.
Depth Structures	Follows Hedgepeth's model	Lyne and Last, 1996 National Marine Bioregionalisation, 2005	Shelf edge boundary defined as maximum gradient turnover instead of the 200m isobath
System Features	Unique within compartment, and within depth zone, systems characterised by unique pelagic and/or geomorphology	Lyne and Hayes, 2005 National Marine Bioregionalisation, 2005	Attempts to follow the Key Ecological Features concept in determining important features within the main system

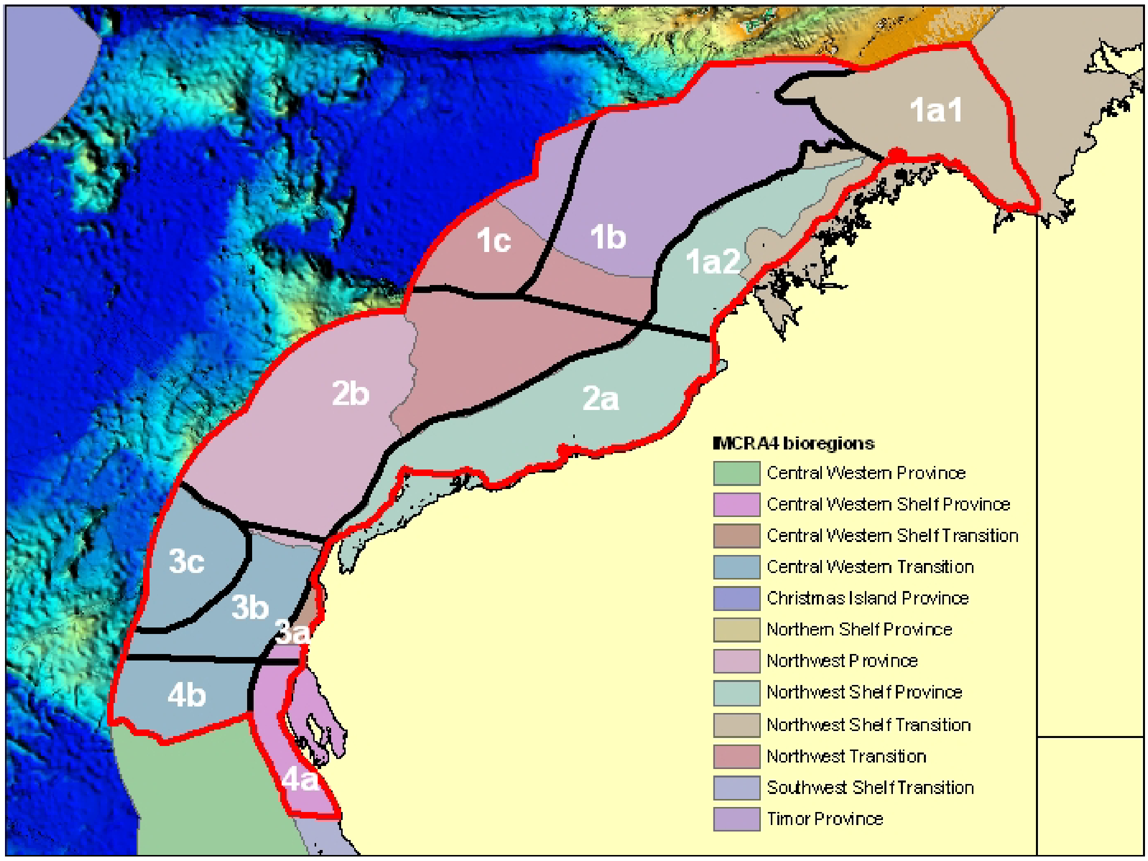


Figure 5-11 Map of North West Marine Region (heavy red line) with location of major trophic systems (heavy black lines with alpha numeric labels) and IMCRA4 bioregions (pastel zones associated with Figure legend).

6. DESCRIPTION OF TROPHIC SYSTEMS

6.1 Western Joseph Bonaparte Gulf Shelf (1a1)

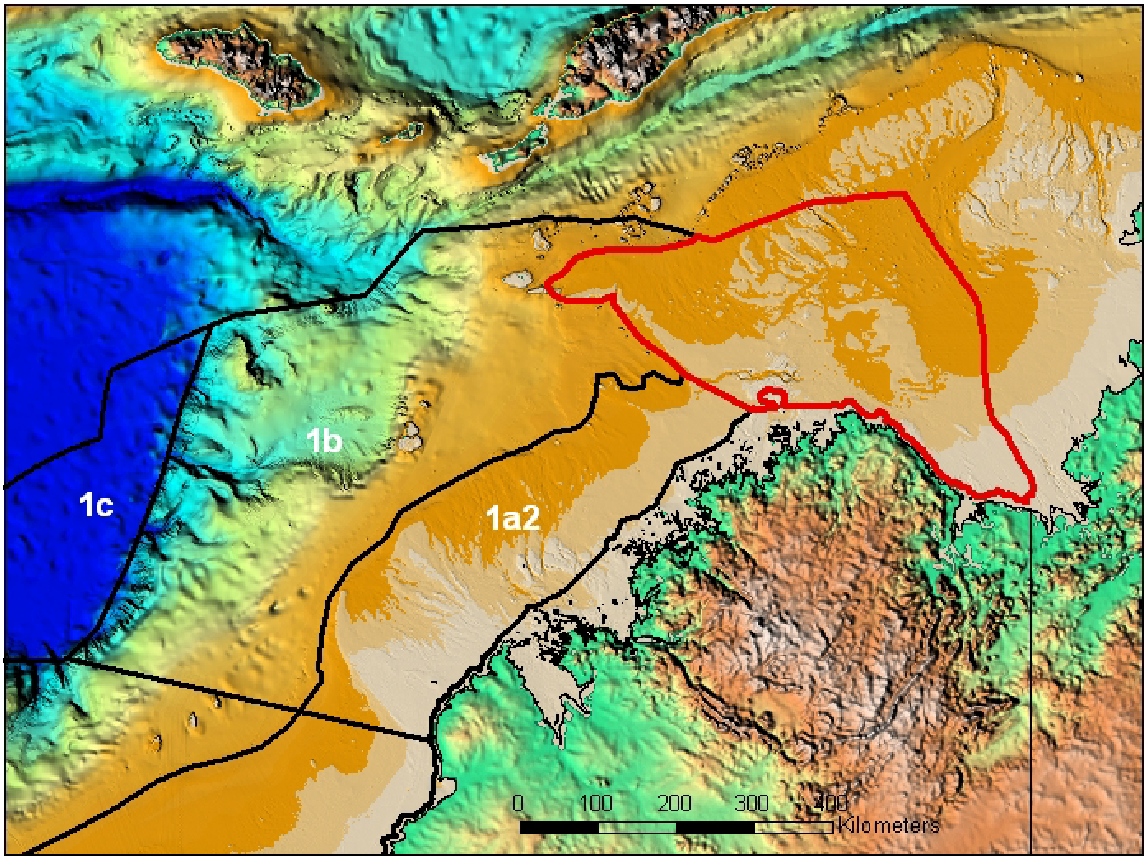
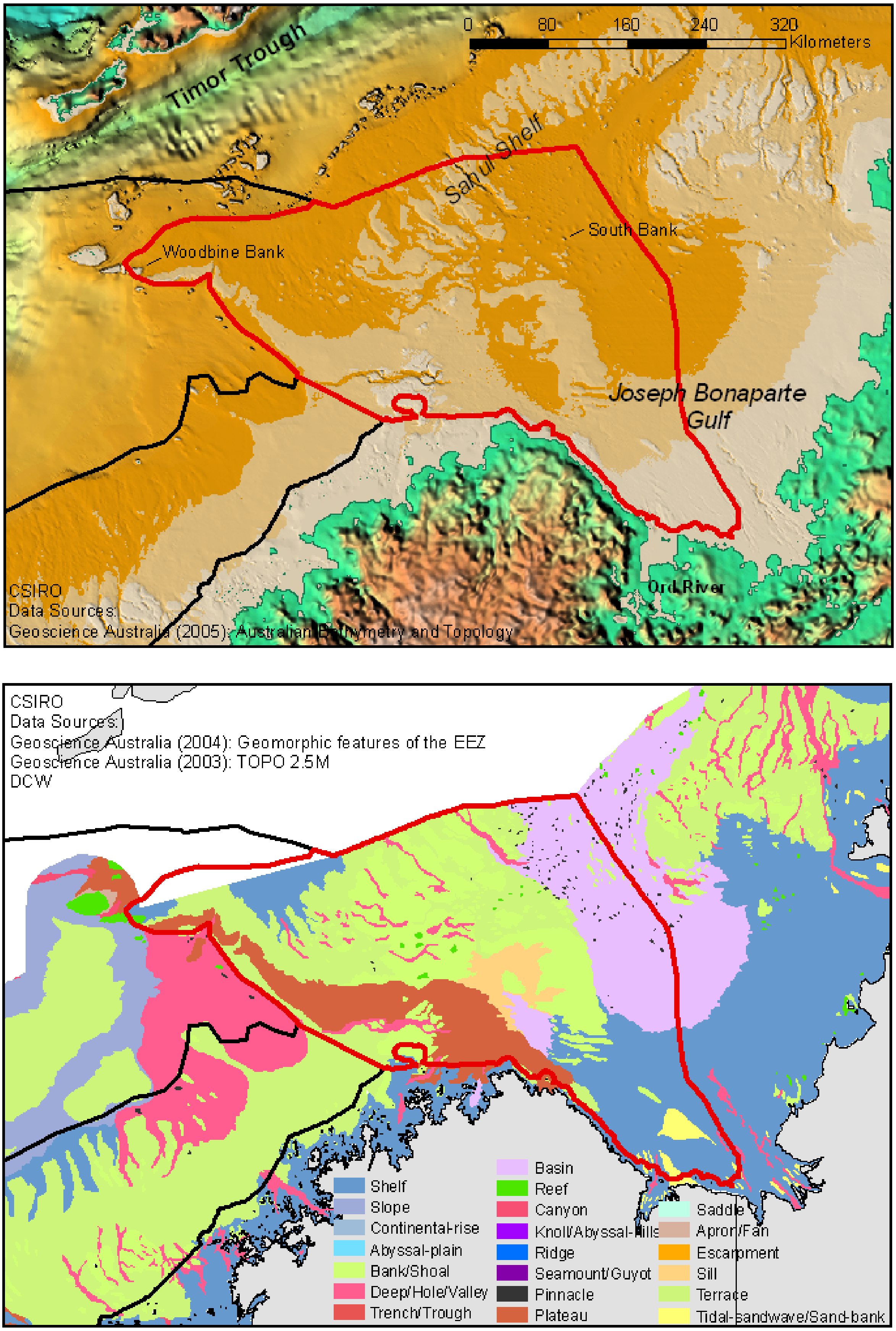


Figure 6-1 Western Joseph Bonaparte Gulf (red outline) and neighbouring sub-regions.

6.1.1 Drivers and physical features

The Western Joseph Bonaparte Gulf (WJBG) is the most easterly sub-region in the NWMR. It lies in the Timor Sea and encompasses the area of the Sahul Shelf from the western boundary of the North Marine Region to Woodbine Bank (Figure 6-1). The sub-region is unique in the NWMR, but has some similar features to the adjacent "Joseph Bonaparte Gulf" sub-region of the North Marine Region. Both share similar inshore (to about 20 m depth), mid-shelf (20 to 50 m depth) and basin (>50 m depth) environments, and are likely to have similar floral and faunal assemblages, and similar trophic systems. The JBG shelf environment, straddling the North and North West Marine Regions is a unique marine environment nationally and globally, due to a range of unique habitats, communities and endemic species described below.



CSIRO
Data Sources:
Geoscience Australia (2005): Australian Bathymetry and Topology

CSIRO
Data Sources:
Geoscience Australia (2004): Geomorphic features of the EEZ
Geoscience Australia (2003): TOPO 2.5M
DCW

Figure 6-2 Western Joseph Bonaparte Gulf sub-region showing selected features (upper) and geomorphology (lower).

The WJBG sub-region is unique in the NWMR, in having the shallowest depths (to 271 m, avg 84 m), high surface currents, second highest tidal exceedance[2] (Appendix 1), highest percent mud (and lowest percent carbonate content) in the sea bed sediments, highest sea surface temperatures, high N and P concentrations and highest chlorophyll concentrations (Table 6-1, Appendix 1). The sub-region has a range of geomorphological features, including coastal, shelf and basin zones, dissected banks, shoals and terraces (Figure 6-1). The Indo-Pacific Throughflow brings warm, low salinity water into the region from the tropical western Pacific Ocean and may drive upwellings of cold water onto the shelf from the deep Timor Trough to the north.

The Joseph Bonaparte Gulf (JBG) is subject to the highest tidal exceedance in Northern Australia. High energy tidal currents along much of the region's coastline stimulate mixing and sediment movement throughout the year creating a highly turbid inshore environment. Stratification of the water column occurs in summer through most of the system, especially on the mid and outer-shelf. Monsoonal winds have an important influence on productivity and the depth at which phytoplankton are concentrated because of this stratification.

The JBG inshore zone is characterised by terrestrial inputs of freshwater, sediments and detritus which are generally restricted to a distinct coastal boundary layer. The salinity of this sub-region is relatively low due to this influence (Appendix 1). The sea bed sediments are comprised of relatively fine mud and silt with a highly turbid and mixed water column due to a combination of high tidal energy, strong monsoonal winds, cyclones and wind-generated waves, to a depth of about 20 to 30 m.

The mid-shelf environment is also dominated by soft sediments with relatively little sea bed structure or sessile epibenthos, with a scattering of shoals, terraces and pinnacles rising from about 80 m to about 40 m depth (e.g. "South Bank"; Heyward *et al*. 1997b), especially on the outer shelf. These vary from low rises with fine sediments to higher pinnacles with steep banks, harder substrate and a relatively high diversity of organisms (e.g. hard and soft corals, sponges and associated fish communities). The basin surrounding these pinnacles has a substrate dominated by relic muds in the deeper basin on the outer mid-shelf, but may have a greater terrestrial influence in the more inshore mid-shelf (Figure 6-5).

Table 6-1 Summary physical data for the Western Joseph Bonaparte Gulf sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents (m/s)	Tidal excedance %	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
84.1	0.36	0.132	25.01	1.34	41.0	61.1

Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
28.65	34.76	32.50	0.18/16.16	0.15/1.15	3.52/66.10	0.51

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[2] Tidal exceedance is the percentage of time that currents are predicted to mobilise sediments of mean grain size

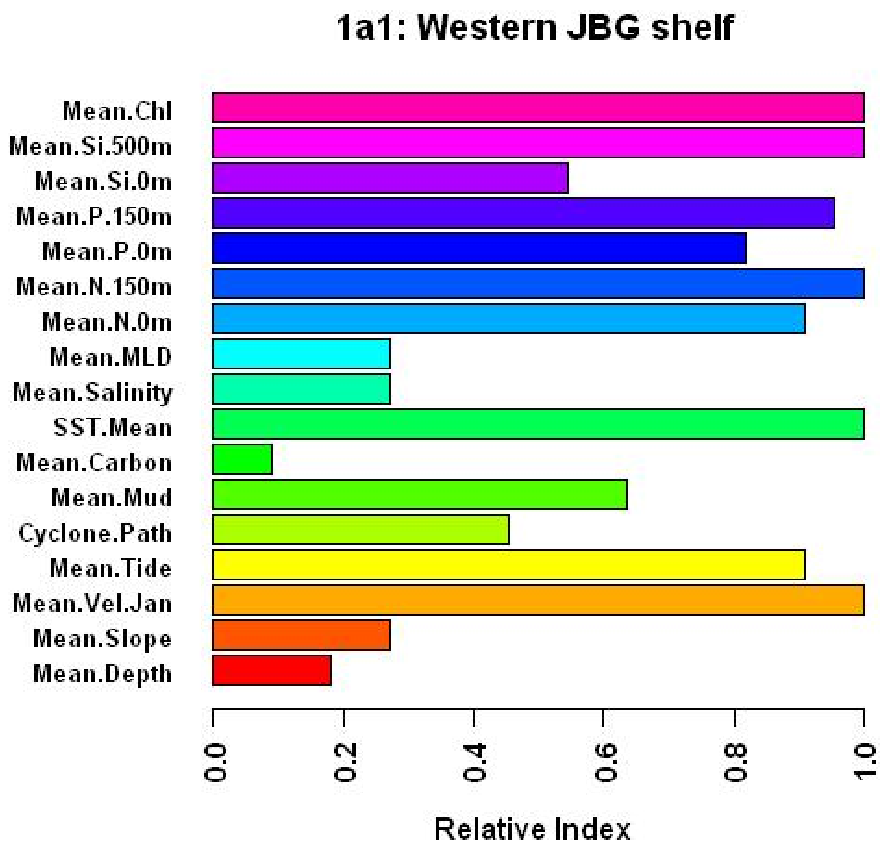


Figure 6-3 Summary physical data for the Western Joseph Bonaparte Gulf sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

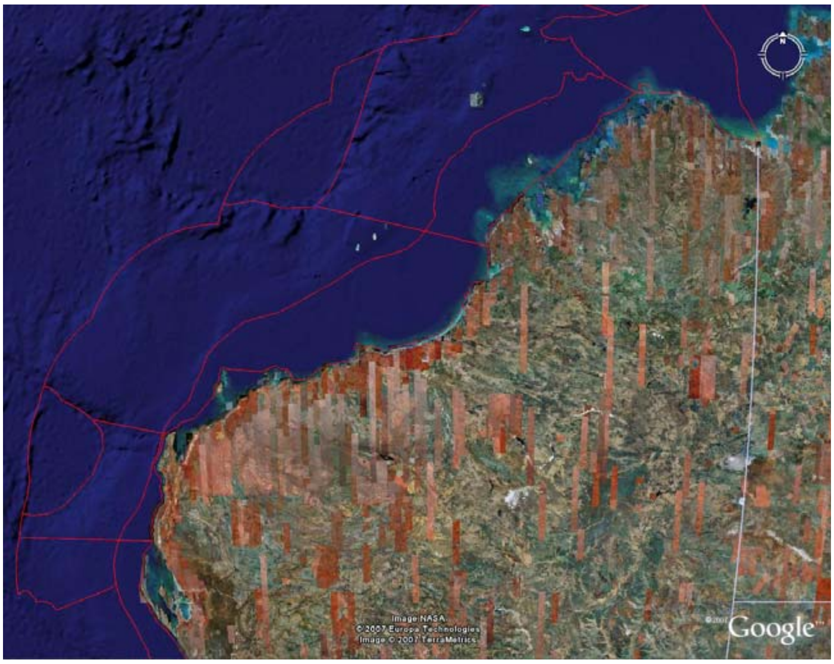


Figure 6-4 North West Marine Region showing the coastal turbidity plumes and sub-regional boundaries (extract from Google Earth).

6.1.2 Trophic system features and dynamics

The main sources of primary productivity in the WJBG trophic system vary with location in this relatively complex sub-region. Coastal productivity is supported by nutrients associated with sediments and detritus from the Ord, Pentecost, Durack and other river systems. Outer-shelf productivity is supported by upwelling of nutrients over the Sahul Shelf. However, this may not extend far into the WJBG trophic system, as much of the outer shelf lies to the north of the region (Figure 6-1). The euphotic zone of the outer shelf extends to 100 m depth (Pinceratto, 1997) and primary productivity is probably low, nutrient limited and relying on seasonal winds and tides to resuspend benthic deposits into the water column. There may also be localised high productivity at the heads of deep cross-shelf channels which are likely to bring ocean currents, tidal flows and upwellings of cold oceanic water onto localised areas of the outer and mid-shelf.

The coastal environment is relatively productive with seasonal land-based nutrient and sediment inputs supporting a trophic system that is largely based on bacteria and other organisms that don’t rely on clear water and sunlight. These organisms are attached to the high concentrations of fine sediment and suspended floc particles (or ‘marine snow’) (DEW workshop – Northern Marine Region, April 2007). Phytoplanktonic production is also relatively high at the top of the water column, as indicated by high surface water chlorophyll concentrations (Hayes *et al.* 2005), but limited by light at depth. The inshore communities of consumer organisms are poorly understood, but are likely to be relatively abundant, based on the high productivity of the region and the productivity of the adjacent mid-shelf demersal communities (described below). These communities are also likely to be highly diverse and unique to the region, like the adjacent mid-shelf communities.

It is unclear whether there is significant transfer of nutrients from coastal to the mid-shelf waters, although there are likely to be many demersal species that are abundant in, and migrate between both zones. This relationship between offshore communities and estuarine and inshore communities has been described by Blaber *et al*., (1994, 1995) in several regions of the neighbouring Gulf of Carpentaria It follows that coastal productivity may be partly responsible for sustaining a relatively high biomass of demersal fauna, as reflected in high catches of demersal organisms in the JBG prawn trawl fishery (424 kg h^{-1}, Brewer *et al.* 2006) – targeting Red-legged banana prawns, *Penaeus indicus* – compared to related fisheries (e.g. Gulf of Carpentaria tiger prawn fishery ~240 kg h^{-1}, Stobutzki *et al.* 2001). The offshore extent of this productivity is unknown, but may coincide with the extent of the fishery’s high effort area from about 35 to 70 m depth. This link between the more coastal productivity and the abundant fishery bycatch may be linked through the inshore – offshore migratory patterns of many of these demersal species (Blaber *et al.* 1994, 1995) and the extensive mixing of the pelagic and benthic environments, especially during the northeast and southwest monsoons and cyclones. Basin and shelf productivity may also be partly dependent on internal nutrient cycling and the upwelling of productive oceanic waters penetrating over the Sahul Shelf, although this is not well understood.

The inner mid-shelf trophic system appears to be dominated by a diverse demersal community of small fish and invertebrates, consuming detritus and suspension feeding small invertebrates. Some primary and secondary order consumers have been found in unusually large numbers at times – e.g. the small Cornflake crab, *Charybdis* *callianassa,* the detritivorous Threadfinned scat (*Rhinoprenes pentanemus*) and the piscivorous Bombay duck (*Harpadon translucens*). Although poorly known, mid-shelf tertiary consumers are likely to comprise mainly small sharks, tunas and dolphins, typical of other prawn trawling environments (Brewer *et al.* 1991, Griffiths *et al*., 2007).

Much of the outer mid-shelf is covered by a relatively featureless, sandy-mud sea bed with a sparse covering of sessile organisms dominated by filter-feeding heterotrophs such as gorgonians, sponges, soft corals, echinoderms and detritus-feeding crabs and echinoderms. This is especially true of the non-trawled areas in the deeper water, and the soft bottomed rises (Heyward *et al*., 1997*b*). However, the many limestone banks are likely to be a key ecological feature of this region. They have a harder substrate and are likely to support a more diverse range of sessile benthos such as hard and soft corals, gorgonians, encrusting sponges and macroalgae; and consequently, a more reef associated fish and elasmobranch fauna. Although these waters may be relatively oligotrophic for part of the year, these communities probably rely on primary productivity from phytoplankton and commensal zooxanthellae (within hard corals).

Although the outer-shelf banks outside the NWMR have been described by Heyward *et al.* (1997*b*), the mid-shelf banks are poorly understood. However, they are likely to support a unique and diverse invertebrate and fish fauna, with communities that change significantly with depth along their slopes.

The cross-shelf channels are likely to be a source of localised productivity, especially at the heads of the channels where upwellings of cold, nutrient rich water may occur. These should support a diverse benthic fauna of suspension feeders and filter-feeding heterotrophs such as gorgonians, sponges, soft corals and echinoderms, and a variety of small and large secondary and tertiary consumers, including serranid and lutjanid fish species. The northern Demersal Scalefish fishery operates in 30-200 m targeting deep water snapper (*Pristipomoides* spp), Emperors (*Lethrinus* spp) etc., and these species are likely to be the major tertiary consumers in these demersal habitats.

Little is known of the communities associated with the outer-shelf regions of the WJBG Shelf system. However, it may be a relatively productive region based on nutrients from sporadic upwellings over the Sahul Shelf. This may result in the clear waters of this region supporting a relatively high biomass of pelagic communities, including schools of baitfish (e.g. Engraulidae, Clupeidae), small pelagics (e.g. Scombridae) and larger pelagics (e.g. tunas, dolphins).

System 1a1 - Western JBG shelf

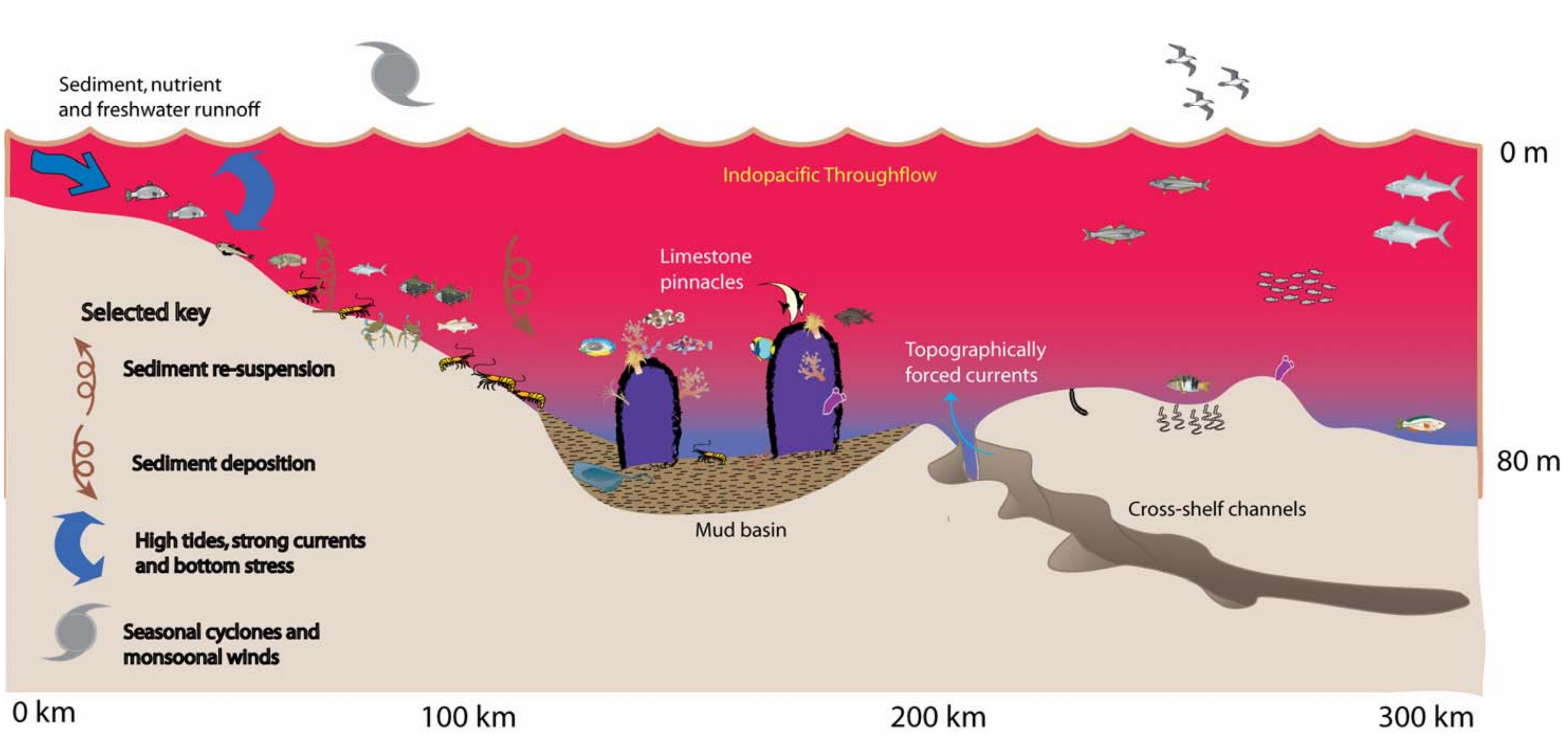


Figure 6-5 Habitat diagram of the Western Joseph Bonaparte Gulf sub-region showing selected important drivers and features.

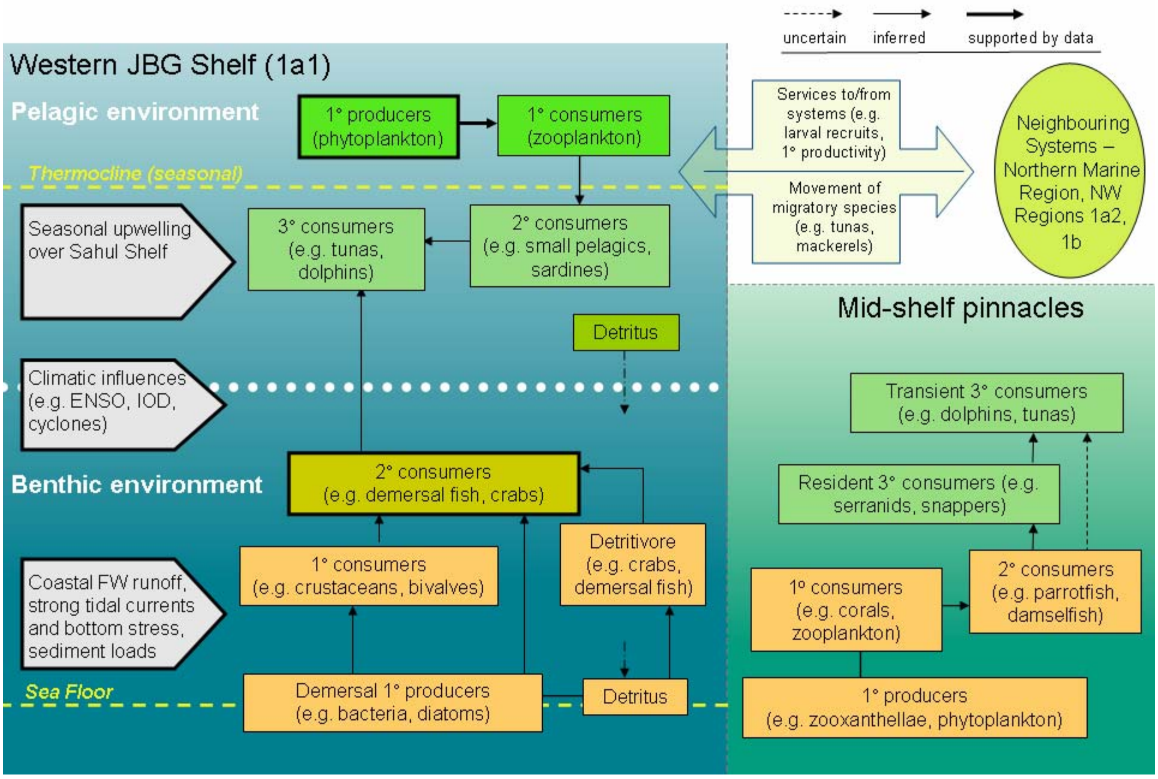


Figure 6-6 Schematic trophic model of the Western Joseph Bonaparte Gulf sub-region, showing information on the extensive habitat in the coastal and central shelf region (left) and a less extensive but important habitat (right).

6.1.3 Services and linkages

Nutrients and planktonic organisms (including many species of larval recruits) are transported to and from this sub-region by the southerly movement of the Indo-Pacific Throughflow and the SE and NW monsoonal wind-driven currents. These conditions provide a particularly strong delivery of surface waters into the Kimberly Shelf, Kimberly Slope, waters to the north of the NWMR, and to a lesser extent, the eastern JBG.

The Joseph Bonaparte Gulf (JBG) prawn fishery has become an important component of the Northern Prawn Fishery (NPF) in the past 10 years. It catches Red-legged banana prawns (*P. indicus*) and large volumes of bycatch (Brewer *et al.* 2006) which are discarded, mostly dead, back into the system (Hill and Wassenberg 1990, 2000). The outer shelf habitats support fisheries (mainly use trap and line) targeting deep water snapper (*Pristipomoides* spp), Emperors (*Lethrinus* spp), Snappers (*Lutjanus* spp) and other tertiary consumers.

The communities of the inner shelf of the JBG are likely to move freely between the NWMR and the adjacent Northern Marine Region. The inner-shelf environments of the two regions appear to be very similar, having large terrestrial freshwater input, high seasonal and tidal mixing and fine sediment substrates grading into a deeper basin environment. They probably share recruits from most species groups and serve as a broad home range for larger more pelagic and mobile species such as tunas, sharks and dolphins. The Kimberly Shelf sub-region has a smaller influence from coastal runoff, and a different shelf structure. It is likely have some important differences in species composition with the WJBG system, although little is known about the biological communities in the Kimberly region.

6.1.4 Key species interactions

The WJBG trophic system comprises a range of different habitats. The physical characteristics of the region have been reasonably well described but the biological communities are poorly understood in most habitats. The inner mid-shelf supports the JBG component of the NPF and the bycatch has been recently described (Brewer *et al.*, 2006). This study indicates that a relatively high biomass demersal community inhabits this region. It also describes occasional very large catches of some species, such as the Cornflake crab, *Charybdis callianassa*. These are likely to be spawning aggregations are warranting protection or risk assessment. Sea turtles were not recorded in catches, mainly due to the use of Turtle Excluder Devices, although sea snakes (another listed species group) are caught in this fishery. Other tertiary consumers impacted by this fishery include some species of rays, sawfish and sharks.

Little is known about species groups in the inshore or outer shelf habitats, including the limestone pinnacle habitats. AIMS have studies several of the shoals and banks outside the region. However, it is well known that the health of the sessile benthos cover on these pinnacles directly affects the diversity and abundance of other associated species, such as reef associated fish, mobile invertebrates and algae.

6.1.5 Resilience and vulnerability

The WJBG trophic system provides important habitats for a very broad range of organisms. However, the most vulnerable of these is likely to be the species impacted directly or indirectly by fishery activity (i.e. demersal fish and invertebrates, elasmobranchs, sea snakes, seabirds), those dependent on specific habitat types (e.g. reef-associated organisms), and those with narrow range tolerances (e.g. requiring productive oceanic water such as shallow water soft and hard corals).

Recent studies of the bycatch of the JBG prawn trawl fishery demonstrate that this region has high levels of endemism in its demersal fauna (Brewer *et al.*, 2006). Although the overall effort in the NPF has been dramatically reduced over the past 20 years (from about 280 to 53 vessels) the proportion of the fleet fishing the JBG has substantially increased in recent years. The level of modification to the demersal system is unknown and there are no baseline data by which we can determine the nature of change to these communities. Broad-based risk assessments show that there are few species currently at risk in the NPF. However, this unique region warrants the integration of improved knowledge of the relationship between species impact and effort levels in the JBG fishery, to provide improved risk assessments.

Flatback turtles (*Natator depressus*) have two distinct stocks in the NWMR – a NW Shelf stock and one that inhabits the JBG to Cape Dommet (Arnhem Land) (Colin Limpus Qld NPWS, pers comm.). It will be important to protect the nesting and feeding grounds of this species in the WJBG sub-region. The reefal habitats in the photic zone are key feeding habitats for Green (*Chelonia mydas*) and Hawksbill turtles (*Eretmochelys imbricate*). The pinnacle habitats on the mid-shelf may be very important habitats along the migration paths for these species in this sub-region.

The inshore communities and related mid-shelf communities currently appear to be in a relatively pristine state. Their living environments are relatively disturbed and variable, being shallow, influenced by large, seasonal volumes of freshwater runoff from river systems, high tidal mixing and flow, nutrient loads etc. Consequently, most species in these habitats have broad tolerances to natural variability and may be relatively tolerant to significant climatic change events. However, these tolerances do not apply to trace metal or other pollutants and any upsteam or coastal development (e.g. expansion of the Ord R Scheme, or dams) should be carefully considered with respect to any pollution or nutrient loads into these aquatic systems.

The more offshore, oceanic habitats are likely to contain communities with lower tolerances to physicochemical change, such as the sessile communities on the pinnacles of the outer mid-shelf. These may also be in a relatively pristine state although the impact of illegal fishing is not well documented.

6.1.6 Information gaps

The major information gaps, mostly described in the above sections, are summarised below.

Demersal and pelagic communities in most habitats are poorly understood (other than the demersal community in the region fished by the JBG component of the NPF), in particular:

The inshore consumers at all levels

Mid-shelf tertiary consumers

All functional groups associated with the outer mid-shelf pinnacles

- All functional groups in the mid-shelf basin
- Communities associated with upwelling areas at heads of cross shelf channels
- Outer shelf demersal and pelagic communities in the north-western corner of the system

Other gaps in our knowledge include:

- The extent of upwelling from the heads of cross-shelf channels
- The level of ecological dependence between systems such as the inshore and mid-shelf demersal communities
- Differences between WJBG and Kimberly shelf inshore communities.

6.2 Kimberly Shelf (1a2)

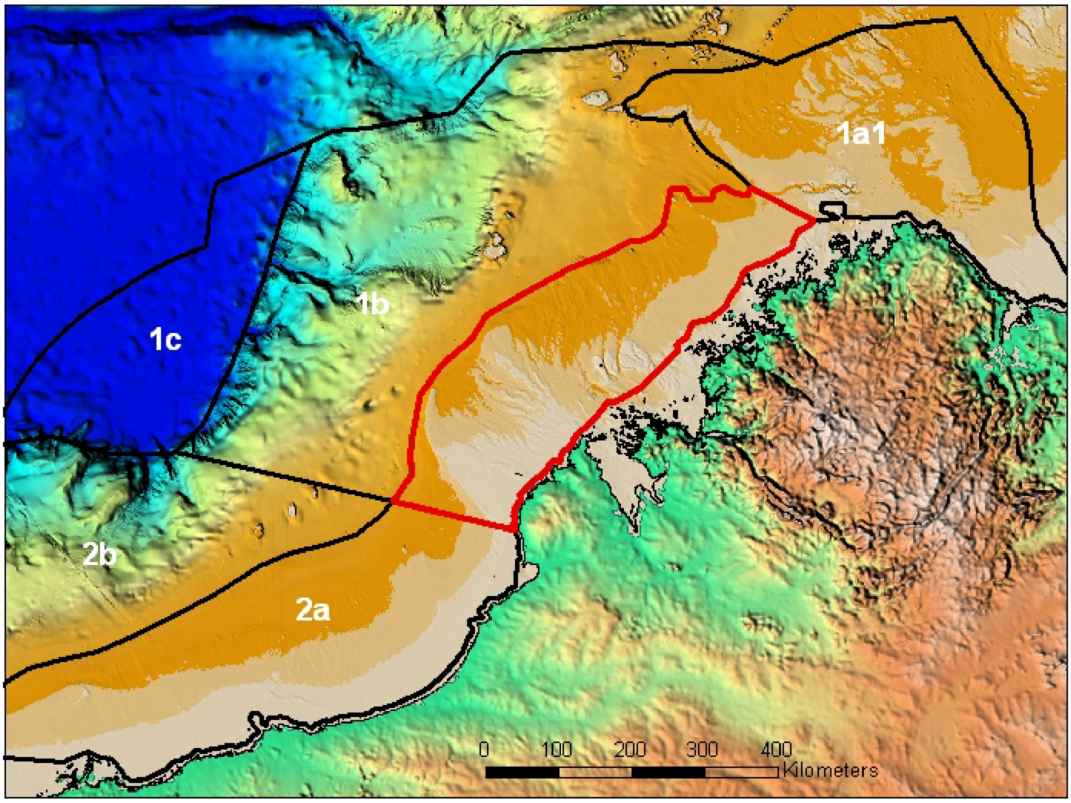


Figure 6-7 Kimberley Shelf (red outline) and neighbouring sub-regions.

6.2.1 Drivers and physical features

The Kimberly Shelf sub-region continues from the western inshore edge of the WJBG sub-region at about Cape Bougainville. It is bounded by the 200 m depth contour along its western edge and the 3 nm state waters jurisdictional margin to the east. The sub-region varies from about 100 km in width at its northern boundary to about 200 km at its widest point off King Sound. The sub-region's southern boundary is the approximate boundary between the Indo-Pacific Throughflow and transitional water masses located just north of Broome on the Western Australian Coast (Figure 5-9, Figure 6-7).

This sub-region contains a continental shelf trophic system with influences from the Indo-Pacific Throughflow (e.g. temperature regime, productivity), internal breaking waves and benthic re-suspension on the mid to outer-shelf and terrestrial inputs of freshwater, dissolved and particulate matter in the more coastal areas; especially from the Prince Regent and Fitzroy Rivers. The sub-region has some similarities to the WJBG in that it is shallow (to 283 m, avg 80 m), has very high tidal exceedance (33.22 %) and a tidal range between 3 m (neaps) and 10 m (springs), high surface water temperatures (28.48°C), seasonal low salinity, and high N and surface chlorophyll concentrations (Table 6-2, see Appendix 1 for more detailed data and definitions).

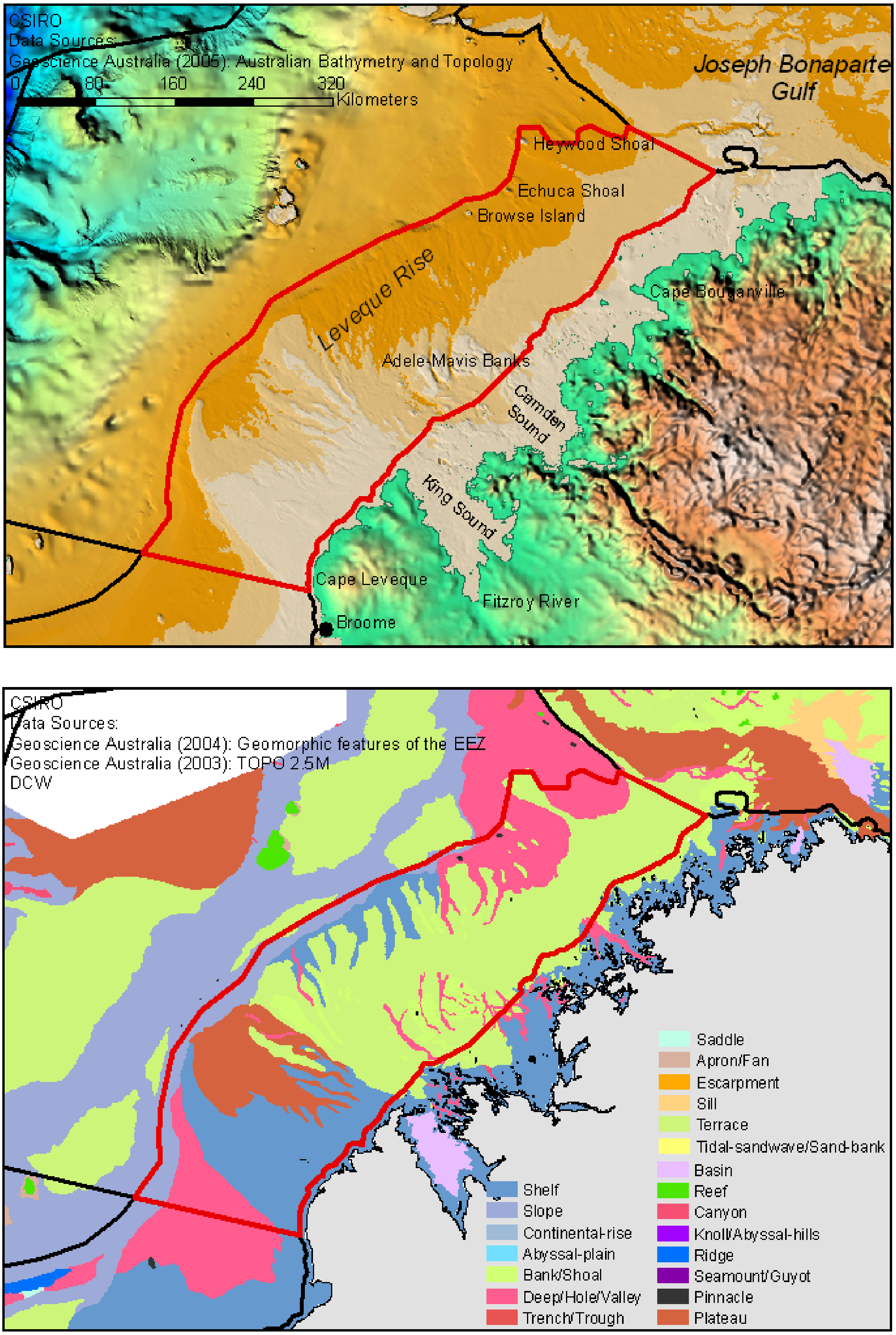


Figure 6-8 Kimberley Shelf sub-region showing selected features (upper) and geomorphology (lower).

However, the sub-region is unique in the NWMR and in an Australian context in having the highest cyclone impact (Figure 5-7), low mud and high gravel content in the sediments and the highest concentration of silicate than any other sub-region. Seasonal cyclones, strong tidal influences and internal waves create shear stresses strong enough to re-suspend sediment in depths shallower than about 170 m (Figure 6-10). These influences may be holding the finer grade particulate matter in suspension, contributing to the low mud content in sediments, high turbidity seen in the sub-region's coastal zone and in a net down-slope transportation of sediments (Figure 6-4). The low mud content may also be a feature of the rivers and catchments of the region. High gravel content is also a feature of these high flow areas across the mid to outer-shelf. These dynamics provide a transition from courser sandy to finer muddy sediments where the shelf edge merges into the upper continental slope. The high silicate concentrations tend to reflect localised terrestrial inputs in tropical waters (Hayes *et al.* 2005) and lend weight to the unique influence of seasonal river inputs into the ecological and trophic dynamics of this sub-region.

The geomorphology of the sub-region is complex in having a fractured coastline and a series of channels and dissected banks of differing depths and lengths running out from the coast towards the continental slope. This creates a relatively heterogeneous and undulating sea floor, especially in the southern half of the sub-region (Figure 6-7) providing a complex and diverse habitat for many species groups (below). This heterogeneity also extends to the presence of outer-shelf islands and shoals (e.g. Browse Island, Echuca Shoal and Heywood Shoal) in the deeper, shelf edge waters of this sub-region (Figure 6-10).

6.2.2 Trophic system features and dynamics

This Kimberly Shelf sub-region receives an influx of nutrients from coastal runoff and from outer-shelf mixing brought about by internal waves and benthic re-suspension (Figure 6-10). The influence of the warmer, low salinity Indo-Pacific Throughflow depresses productivity in the surface waters. However, the region is highly dynamic and the factors affecting productivity in this sub-region vary spatially and with depth, and are generally not well understood.

Table 6-2 Summary physical data for the Kimberly Shelf sub-region (taken from Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
80.3	0.37	0.090	33.22	2.98	14.9	83.0

Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
28.48	34.78	31.39	0.21/16.06	0.19/1.15	5.10/57.62	0.30

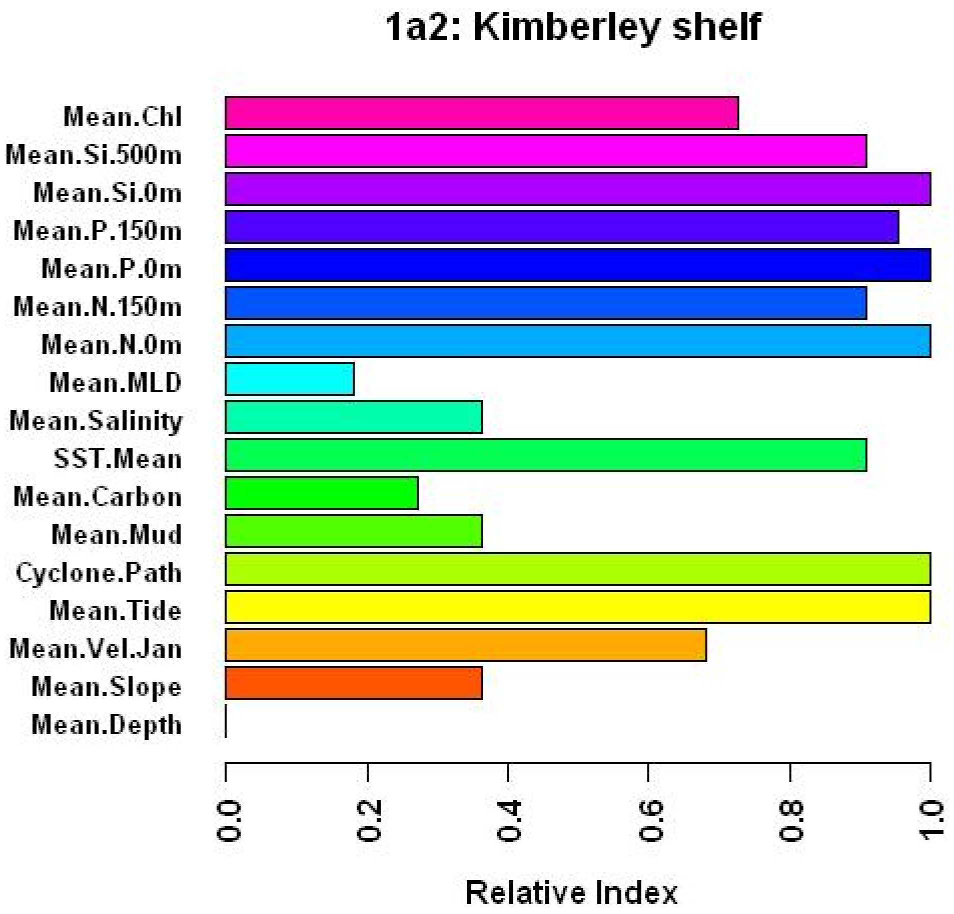


Figure 6-9 Summary physical data for the Kimberly Shelf sub-region (taken from Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

The nutrients inputs, along with year-round high light levels, and seasonal mixing provide the ingredients for phytoplankton-based system in a large part of this sub-region. These conditions support a deep chlorophyll maxima at about 70 m depth where more nutrient rich waters are sporadically mixed with the surface layer due to the influence of internal breaking waves on the shelf, seasonal winds and cyclonic events (Figure 6-10).

The phytoplankton is characterised by diatoms, typical of habitats with high silicate concentrations (Hayes *et al.*, 2005), and higher, persistent nutrient availability, although the phytoplankton community is not described and likely to be quite complex. Many of the benthic habitats are fuelled by nepheloid layers formed from upper ocean detrital fallout and benthic resuspension of sediments stripped from the ocean floor by currents. The seasonal cycles of biological productivity on the continental shelf (and slope), and the spatial distribution of production regimes still remain largely unknown, with the exception of selected areas (e.g. the Adele-Mavis Banks, Cresswell and Badcock, 2000). In El Niño years, vertical mixing and upwelling are enhanced, while lack of precipitation and consequent low runoff from land may reduce productivity in the coastal zone.

The shallower coastal turbid zone is poorly understood but may support significant populations of filter feeding invertebrates such as sponges and bivalves, and scavengers such as crabs, shrimps and demersal sharks and fish. There is likely to be an abundant demersal community dominated by primary and secondary consumers. However, little is known of their species composition in this zone. Tertiary consumers are also poorly understood in this coastal zone, but are likely to include Queenfish (*Scomberoides* spp), Mackerel (*Scomberomorus* spp), King salmon (*Elutheronema tetradactylum*) and Barramundi (*Lates calcarifer*).

The channel and bank habitats are widespread and occur mainly on the Leveque rise, in almost all depths throughout this sub-region. The heterogeneous nature of the sea bed in these areas provides a variety of niche environments for crevice dwellers and attached flora and fauna. They contain significant areas of high flow and harder bottom environments capable of supporting firmly attached, sessile, filter feeding invertebrates, and a diverse range of site attached fishes. However, the species composition of these demersal communities will vary depending on their depth and exposure to currents and suspended food material. These habitats are unique on the Australian western continental shelf, support a relatively diverse and abundant fauna, including genetically distinct populations (see below) and could be considered an 'important trophic system' within this sub-region.

In general, the channel and bank habitats provide refuge for a wide range of demersal secondary consumers such as small planktivorous and omnivorous fish and crustaceans. These, in turn, play a role in supporting populations of larger fish species (usually tertiary consumers) such as the deep water snappers (e.g. *Pristipomoides* spp) red snappers (e.g. *Lutjanus sebae, L. malabaricus*), sweetlip (e.g. *Lethrinus nebulosus*) and groupers (Serranidae) (Figure 6-11). These fish are common over hard bottoms where ridges, rises, reefs and large epibenthos occur and are targeted by the Northern Demersal Scalefish Managed Fishery (trap and line) (Newman and Dunk, 2002, 2003).

The outer-shelf islands and shoals are also important habitats that provide topographical structure and habitat for sessile megabenthos. These habitats benefit from shelf-edge upwelling. This combination of features results in biomass hot spots due to the elevated productivity which supports suspension-feeding sponges, corals, crinoids, and ascidians (Rogers, 1994) that are rare or absent from surrounding habitats (dominated by deposit-feeding invertebrates). This allows resident fishes to feed on passing zooplankton and small fishes in the water column and to take refuge amidst the epibenthic invertebrate communities. These habitats are similar to the bank and channel habitats, above, and also support many of the tertiary consumers targeted by the Northern Demersal Scalefish Managed Fishery.

Mid and outer-shelf habitats that are between channels, banks, islands and shoals have been described mainly from trawl surveys (Nowara and Newman 2001). These areas are likely to have sandy-mud substrates, relatively sparse populations of infauna and epibenthos (both suspension and deposit-feeding), as well as a wide range of benthic primary and secondary consumers such as crabs, shrimps, echinoderms and small fish. The demersal communities in these habitats are typical of other tropical trawl grounds in also having a diverse range of small to medium-sized fish (e.g. monocle bream (Nemipteridae), grinners (Synodontidae), grunter (Haemulidae) and goatfish (Mullidae)) (Nowara and Newman 2001) Squid, sharks and rays. In the past, these habitats have been trawled for the larger more commercially important fish species such as Checkered snapper (*Lutjanus decussates*), Orange-striped emperor (*Lethrinus obsoletus)* and Pink ear emperor (*L. lentjan*). Although the channel and bank areas would have been the main targets of these trawling operations due to the higher abundances of snappers, emperors etc., although only in the less rugose areas that could be trawled without damaging their nets.

The effects of seasonal influences on these trophic systems is not clearly understood. The high incidence of cyclones (Figure 5-7) and freshwater input during the summer monsoon provides mixing and nutrients during this time and strong offshore winds provide nutrients into the water column from upwelling off the continental slope, especially in winter (Figure 5-6). Surface chlorophyll concentrations appear to be relatively high in this sub-region throughout the year (Hayes *et al.* 2005) indicating a constant nutrient supply, possibly dampening any major seasonal effects on trophic system dynamics. However, it may be that species in the coastal zone use the summer productivity to drive feeding and reproductive patterns and that the more offshore regions of the shelf do the same in winter. Some of the larger pelagic species have been well enough studied to discern seasonal patterns, such as Spanish mackerel (*Scomberomorus commerson*) (Mackie *et al*., 2005), juvenile Black marlin (*Makaira indica*) and some tunas (e.g. Griffiths *et al.,* 2007). However, the seasonal abundances and feeding patterns of almost all species in these regions have not been documented.

Like other shelf systems, the link between the pelagic and benthic communities is strong in the shallower inshore part of the shelf where strong tidal currents, monsoonal winds and sporadic cyclones mix the water column and associated nutrients. The pelagic and benthic communities in the deeper part of the shelf are much less integrated. There is some mixing of the deeper, more nutrient rich waters into the oligotrophic surface layer due to strong currents, winds and cyclones, as well as breaking internal waves (Figure 6-10). There are also species that migrate between the two habitats, including plankton (e.g. calanoid copepods), micronekton (e.g. lanternfish and shrimps), some tunas and cetaceans.

6.2.3 Services and linkages

The southerly flowing Indo-Pacific Throughflow current provides a path for nutrients and planktonic organisms, including larval recruits, to the NW shelf, in particular, and other neighbouring sub-regions. Seasonal offshore wind driven currents may also distribute planktonic organisms off the shelf into the Kimberly slope and beyond.

This sub-region contains populations of several fish species groups (e.g. snappers, emperors, mackerels and sharks) that support commercial fisheries; in particular the Northern Demersal Scalefish Managed Fishery (trap and line); Western Australian Mackerel Fishery (trolling and hand lining) and Combined Northern Tropical Shark Fisheries (dropline, longline and gill netting). These animals may also provide recruits for populations and fisheries in surrounding sub-regions. However, little is known about spawning locations or likely larval dispersal pathways for these species.

Other species are important to recreational fishers in the region (e.g. Queenfish, *Scomberoides* spp; King salmon, *Elutheronema tetradactylum*; and Barramundi, *Lates calcarifer*), particularly in the more inshore habitats.

The demersal and pelagic communities in this sub-region are likely to provide an important feeding area (probably seasonally) for many migratory species (e.g. mackerel – *Scomberoides* spp and long-tailed tuna – *Thunnus tonggol*), for both adults and new larval recruits. Toothed cetaceans such as dolphins and killer whales also use these productive areas during their feeding migrations.

The region also is an important area for whale migrations. Camden Sound, for example, is the only known calving area for Group IV population of Humpback whales (*Megaptera novaeangliae*) (Jenner *et al.,* 2001). Whale watching is an important tourist activity in this region, especially north of Cape Leveque**,** between about July and October.

6.2.4 Key species interactions

Trophically-important species in the Kimberly Shelf sub-region may include the large epibenthic invertebrate species that provide shelter, food and structural diversity for the channels, banks, islands and shoals that characterise this region. These are poorly studied but are likely to include gorgonians, sponges, hard and soft corals, bryozoans, ascidians and echinoderms. These ultimately support higher order predators, such as Lutjanid snappers (especially *L. sebae, Pristipomoides multidens* and *L. malabaricus*), Lethrinid emperors or sweetlip (especially *L. nebulosus*) and various cods and groupers (Serranidae). These species are also likely to play a critical role in regulating the demersal community structure and composition.

A range of pelagic higher order predators may also be playing a key role in controlling trophic system dynamics of the region, including mackerels (especially Spanish mackerel, *Scomberomorus commerson* and Grey mackerel, *S. semifasciatus*), tuna (especially Bonito, *Sarda australis*; Yellowfin tuna, *Thunnus albacares*; Longtail tuna *T. tonggol* and Skipjack tuna, *Katsuwonus pelamis*), Dolphinfish (*Coryphaena hippurus*) and various species of trevally (Carangidae). These are also fished in this sub-region by commercial and recreational fishers. At least one of these species, Spanish mackerel, is known to use this sub-region as a spawning ground between about August and November (Mackie *et al*., 2005).

Foreign fishing vessel sightings have increased in recent years, especially in the southern half of the region, probably targeting sharks (for fins) and finfish.

6.2.5 Resilience and vulnerability

The important species suggested above vary in their vulnerability to unnatural sources of mortality. Epibenthic invertebrate communities vary widely in their vulnerability to physical damage, with some species groups and communities likely to take decades to recover (e.g. from repeated trawling, Pitcher *et al.,* 2000). Many of the tertiary consumers are also reasonably vulnerable to unusually high sources of mortality (e.g. fishing). Slow growing and long lived species have low natural mortality and mature late in their life cycle (e.g. Ralston and Williams, 1989; Pilling *et al*., 2000). These characteristics suggest that they are unlikely to sustain high fishing pressures and could be rapidly overexploited (Fry *et al.*, 2006) and require appropriately targeted spatial fishery closures (Newman and Dunk, 2003).

This unique character of the Kimberly region is partly demonstrated by evidence that populations of some species are genetically distinct from other in northern Australia (e.g. Goldband snapper, *P. multidens* (Ovenden *et al.*, 2002) and the Leader prawn, *Penaeus monodon* (Benzie *et al.*, 1992 and 1993). These and possibly other local populations are vulnerable because of their restricted distribution.

Much of this region appears to be in one of three states: (i) recovering from heavy exploitation – especially the southwestern and northwestern corners of the sub-region that were subject to heavy fishing activity (up to 50 pair trawlers) between 1980 and 1990 (Nowara and Newman 2001); (ii) currently fished at ‘fully exploited’ levels – especially the channel and bank areas exploited by the Northern Demersal Scalefish Managed Fishery or (iii) lightly exploited – much of the remaining sub-region, subject to some recreational fishing.

As in the WJBG, the more coastal habitats are populated by communities with relatively wide tolerances to parameters such as salinity, current flow, turbidity etc. These communities may well be quite resilient to significant climate change events compared to the more offshore species and communities.

6.2.6 Information gaps

Little is known off the processes and communities (all trophic levels) of the inshore, shallower, turbid zone of this sub-region. The sources of primary productivity are inferred, but not clearly understood and the relatively high chlorophyll signal in this region may be partly reflecting suspended sediment and/or bottom reflectance and not primary productivity (Hayes *et al.* 2005).

The benthic invertebrate species forming key habitats on the channels, banks, islands and shoals are not described, nor are the benthic communities of the less structured mid-shelf regions between the key habitats.

The reproductive patterns (e.g. spawning areas, migrations and timing) of most key species (both migratory and site attached species) are poorly understood, as are the likely dispersal pathways for their larvae, and hence the potential importance of the sub-region to neighbouring sub-regions.

The impacts of the trap and line fishery on channel and bank trophic systems is poorly understood.

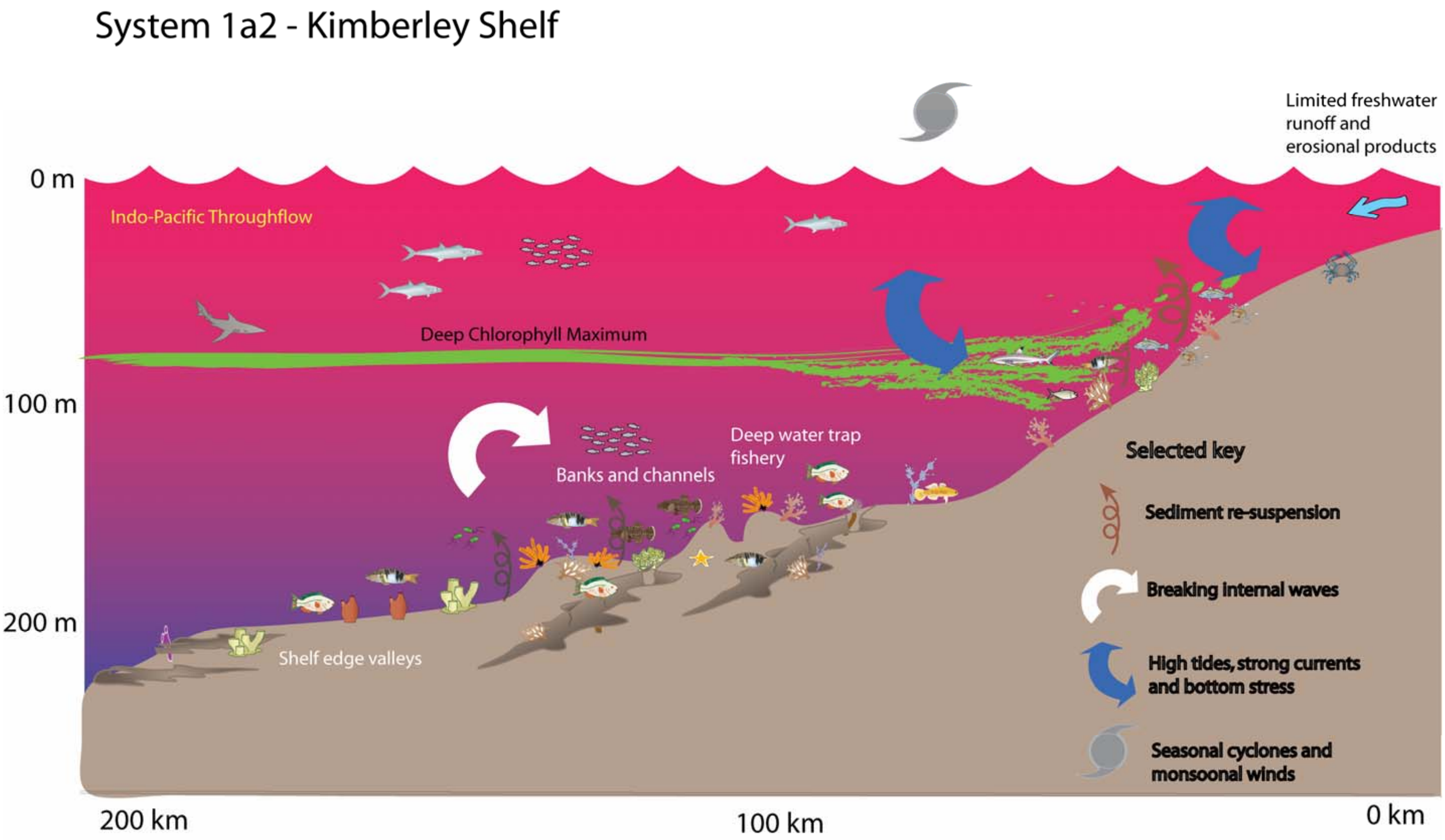


Figure 6-10 Habitat diagram of the Kimberly Shelf sub-region showing selected important drivers and features.

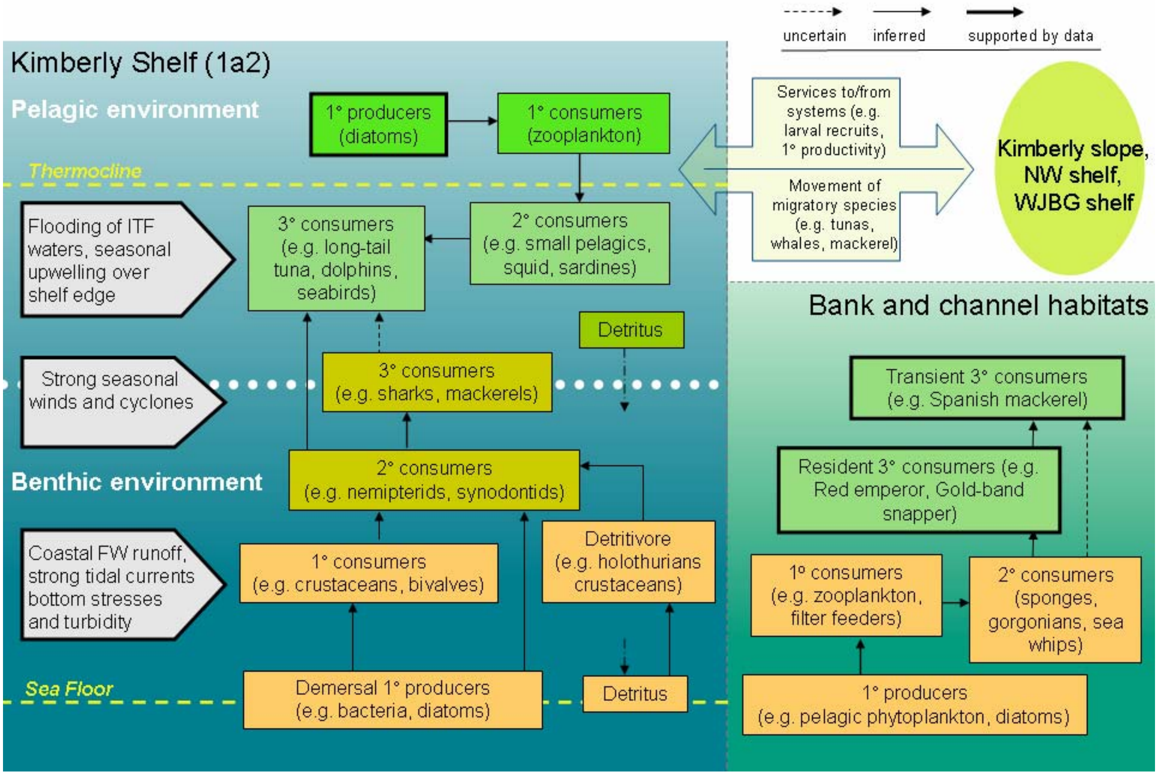


Figure 6-11 Conceptual trophic model of the Kimberly Shelf sub-region showing information on the extensive habitat in the coastal and central shelf region (left) and the important bank and channel habitats in the central and southern areas (right).

6.3 Kimberly Slope (1b)

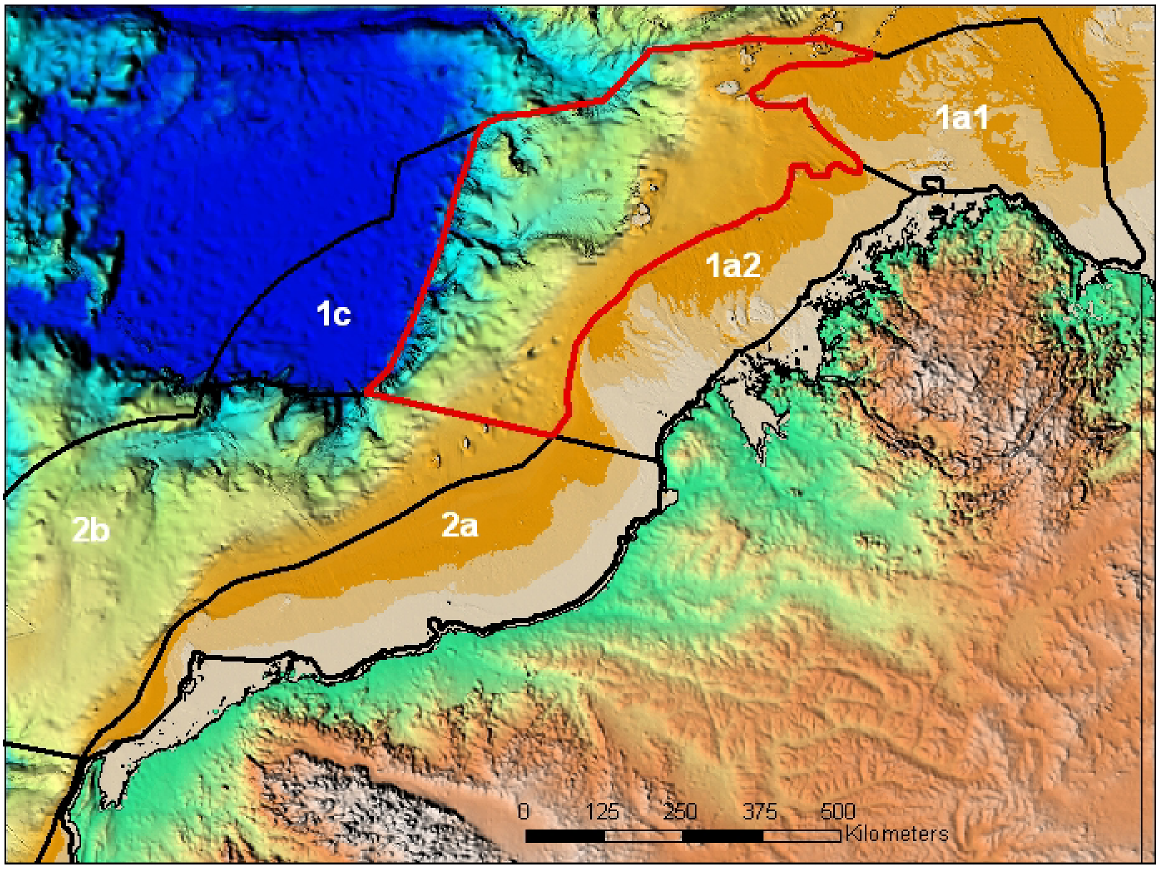
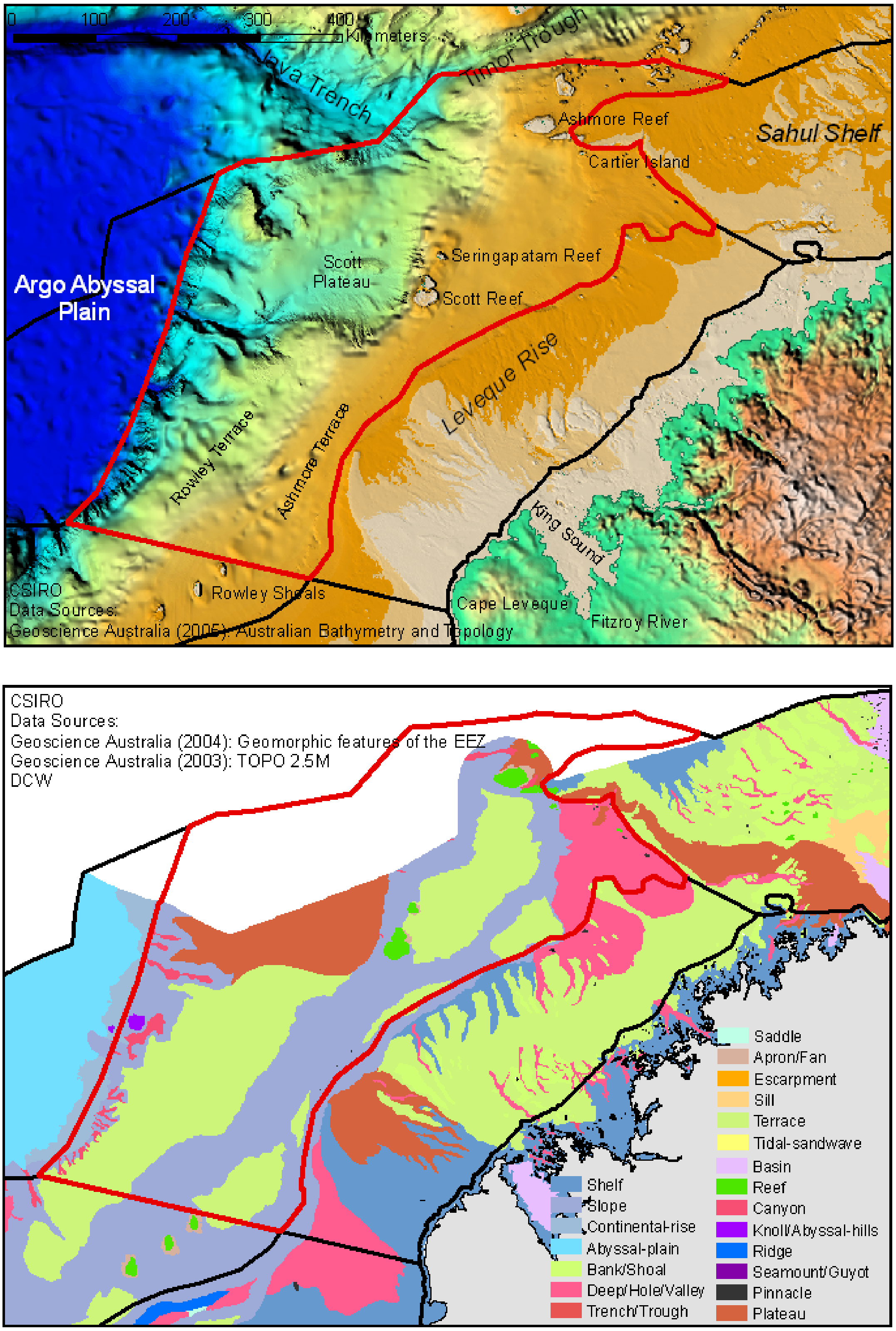


Figure 6-12 Kimberley Slope (red outline) and neighbouring sub-regions.

6.3.1 Drivers and physical features

The Kimberly Slope sub-region is adjacent to the north-western corner of the WJBG sub-region and encompasses the continental slope from the 200 m depth contour to the beginning of the Argo Abyssal Plain (sub-region 1c), at a depth of ~5,000 m. The northern edge is bounded by the 200 nm limit of the NW Marine region; the southern edge by the Exmouth Plateau sub-region (an adjacent continental slope sub-region – 2b) and along its eastern edge by the Kimberly Shelf sub-region (1a2, described above). The sub-region varies in width from about 350 km in the north to about 270 km in the south, and is about 750 km from north to south.

The better known aspects of this region are the oceanography, geomorphology, regional climate, demersal fish communities and the flora and fauna of selected offshore islands, and reefs.



CSIRO
Data Sources:
Geoscience Australia (2005): Australian Bathymetry and Topology

CSIRO
Data Sources:
Geoscience Australia (2004): Geomorphic features of the EEZ
Geoscience Australia (2003): TOPO 2.5M
DCW

Figure 6-13 Kimberly Slope sub-region showing selected features (upper) and geomorphology (lower).

The main physical drivers on the trophic systems of this region include the very wide range of depths down the continental slope; complex geomorphology, including islands, reefs, spurs, shoals, canyons plateaus and deep holes; the deep, warm, oligotrophic surface water of the ITF; the monsoonal South Java Current in the northern part of this region; strong seasonal winds; the complex layering of currents below the thermocline; and; strong internal waves and tides on the upper slopes

The waters in this sub-region are dominated by tropical water masses (Tranter 1977), with the surface waters typical of the ITF (described above) compared to the deeper, cooler, nutrient-rich water from the Indian Ocean. Below about 3800m is the Antarctic Bottom Water which enters from the Indian Ocean from south of Australia. Above that is the Indian Deep Water up to about the 1500-2000m depth (Tomczak and Godfrey, 2005). The Antarctic Intermediate Water layers above this and has a core of low salinity but relatively high oxygen. The waters of the surface and thermocline are subject to considerable seasonal variability (Tomczak and Godfrey, 2005). Other physical characteristics of the sub-region (compared to other sub-regions in the NWMR) include it’s relatively high mean sea surface temperature; low mean surface salinity; low mean N and P concentrations at the surface, but high N and P concentrations at 500 m depth and deeper; low mean surface chlorophyll concentrations; highest mean wave exceedance; high, but seasonal mean surface currents; high average cyclone path length (Figure 5-7); and a high percent mud content in the sediments (Table 6-3, Figure 6-14).

The strong seasonal influences in the Kimberly region include strong NW winds and cyclones during the NW monsoon (summer and early autumn) and strong SE winds during the SE monsoon (winter and early spring) (Figure 5-6).

The Kimberly Slope sub-region has a unique and diverse range of geomorphologic features, including islands, reefs, banks, shoals, canyons and deep holes (Figure 6-16). These features, together with changes in the bathymetry, currents and water masses, provides for several distinct habitats and biological communities, often in close proximity to each other (e.g. shallow reef with associated localised upwelling compared to adjacent deeper water and a muddy seabed habitat). Some of these features are well studied, such as Ashmore and Scott reefs. But others such the deep holes and canyons have not been studied in any detail. A large canyon structure in the deep north western end of this region marks the eastern end of the Java Trench. There are also vast areas where the dominant sediment type is fine muds, including the Rowley and Ashmore terraces and Scott plateau.

Table 6-3 Summary physical data for the Kimberley Slope sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
1,509.6	2.83	0.130	8.19	1.97	24.4	84.6

Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
28.47	34.59	33.20	0.09/15.48	0.15/1.07	3.46/56.21	0.11

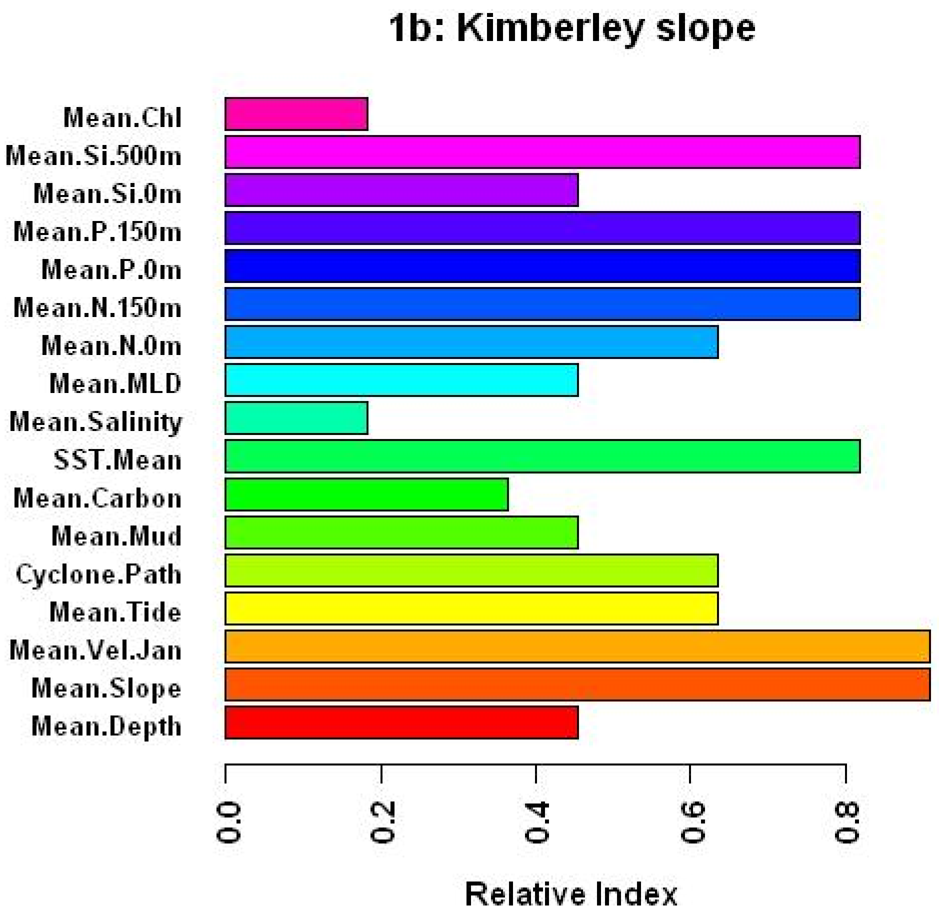


Figure 6-14 Summary physical data for the Kimberley Slope sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

6.3.2 Trophic system features and dynamics

Pelagic environments

The ITF Current is relatively oligotrophic, warm and of low salinity. Overall, the ITF waters limit productivity in much of the upper pelagic waters of the sub-region. However, the reversing monsoonal currents lead to enhanced upwellings off the southern Java coast seen in satellite images and as previously noted by Wyrtki (1961). Likewise, the northern and southern edges of the South Equatorial Current are more productive as evident from the seabird studies by Dunlop et al (1988). Most of the pelagic habitat relies on phytoplankton based productivity to underpin biological production. These open ocean surface waters are poorly studied, but we can expect copepods to be the dominant primary consumers. Secondary consumers will consist of a wide range of larger planktonic taxa, including small adult and larval fish and invertebrates. This widespread, but relatively depauperate pelagic system will also include small pelagics (herring, sardines, anchovies, jack mackerel, cephalopods etc) providing primary and secondary consumer roles, and larger pelagic teleost fish, sharks and mammals feeding on those (Figure 6-15).

Where the sea bed rises into the warm surface waters in the form of islands and reefs, there is a convergence of benthic and pelagic communities. The warmer surface waters provide an environment that is conducive to coral growth, which supports reef associated pelagic and demersal communities. These oceanic islands also act as internal wave generators. For example, around Scott Reef, 60 m internal waves (peak-to-trough) occur at the semi-diurnal frequencies (Wolanski and Delasalle, 1995). These appear to be locally generated by the interaction of the tidal currents and the bathymetry. They can bring nutrients from below the thermocline (located at about 100 m depth) to within 40 m of the surface and into the euphotic zone. Here other small-scale flow processes in the spur-and-groove system of coral reefs may make them available to the coral reefs near the surface). This combination of warm waters mixing with high nutrient water stimulates phytoplankton production above background values, leading to zooplankton blooms, which attract planktivorous squids (Lansdell and Young, 2007) and fishes such as anchovies (Engraulidae), small carangids and pelagics, and their predators such as dolphins, Striped marlin (*Tetrapturus audax*), tunas and wahoo (*Acanthocybium solandri*).

These island and reef habitats are biodiversity hot spots and have a range of unique, pelagic and benthic ecological characteristics (e.g. seagrass and associated dugong communities on Ashmore Reef) and could be considered 'important trophic systems' within this sub-region.

The effects of seasonal influences on these trophic systems are not clearly understood but high productivity can be expected as discussed above. The high incidence of cyclones during the summer monsoon (Figure 5-7) provides mixing and nutrients during this time, and strong offshore winds during the North-east monsoon provide nutrients into the water column from upwelling in winter (Figure 5-6). The subsequent plankton development and observed distribution of micronekton constitute parts of the same trophic sequence, on which the feeding aggregations of whales are a later expression (Tranter and Kerr, 1977).

The ITF is at a maximum during the summer monsoon (May - October) and at a minimum during the winter monsoon (December - April) (Tomczak & Godfrey, 2005). At its low, the ITF flow is opposed by the winds resulting in a deepening of the thermocline and suppressed production. At its maximum the ITF flow and wind act in concert and upwellings occur at the edges of the current and along the Java coast (Wyrtki, 1961)

The suppression of the thermocline by the ITF waters leads to a deep chlorophyll maxima. Under oligotrophic conditions, nutrient recycling processes are important in maintaining standing crops of nanoplankton feeders. Bacteria are an important component of this system by aiding the breakdown of detritus and regeneration of nutrients.

Benthic environments

The complex bathymetry of this sub-region gives rise to a range of trophic systems, including those associated with the different demersal slope communities, reef systems on the mid-shelf atolls, islands and shoals, demersal communities associated with the canyons, banks and deep holes and those associated with the muddy substrates found on the Ashmore and Rowley Terraces and the Scott Plateau.

The sub-region overlaps strongly with the Timor Province identified in the continental slope regionalisation of demersal fish (Last *et al*., 2005). The continental slope extends through a wide range of depths (200-5644 m) and has two distinct demersal community types (biomes) (Last *et al.* 2005). They describe an upper slope biome ranging from 225-500 m and a mid-slope biome from 750-1000 m; but no mid-upper slope biome, as identified in other Australian continental slope provinces. The Timor Province is identified as a ‘strong’ province, based on factors such as the number of endemics and the distinction of the species composition (Last *et al.,* 2005). Distinct communities were not identified below the mid-slope due to a lack of data, although they suggest that is a transition biome between 1125 m and 1600 m, and a lower slope biome from 1600 m to at least 2000 m. Communities below 2000 m are likely to be less heterogeneous, more sparse in nature.

Although little is known about the trophic dynamics these demersal communities they are reliant on a bacteria and detritus-based system where mieofauna, deposit feeding infauna and epifauna (e.g. nematodes, harpacticoid copepods, polychaete worms, shelled molluscs and a variety of crustaceans) become prey for a range of secondary consumers such as teleost fish, larger molluscs and crustaceans. Tertiary consumers may include carnivorous fish (e.g. anglerfish), deep water sharks (e.g. Six-gill shark, *Hexanchus griseus*), large squids and toothed whales.

The islands, reefs, atolls and shoals are a conspicuous feature of this sub-region and support a diverse and productive fauna. Scott, and Seringapatam Reefs are true atolls that rise from about 400-500 m depth, whereas Ashmore Reef and Cartier Island sit on the shallower upper slope on the edge of the Sahul Shelf. Ashmore Reef is distinguished by its relatively high seagrass cover and sandy lagoon (Skewes *et al*., 1999; Brown and Skewes, 2002). It also supports some of the most important seabird rookeries on the North-west Shelf and is an important staging point for migratory wetland birds.

The diversity and complexity of these reef habitats and their trophic structure warrant further understanding and are described here as an 'important ecological feature' of the Kimberly Slope sub-region. These features provide topographical structure and habitat for sessile megabenthos, including hard and soft corals, gorgonians other sessile suspension feeding megabenthos and macroalgae (Skewes *et al.*, 1999). This habitat provides shelter and food for a diverse range of primary and secondary consumers including echinoderms (holothurians, urchins, sea stars etc), schooling fish (e.g. herring and damselfish), parrotfish, groupers etc; which support many different species of higher order consumers such as trevally, coral trout, emperors, snappers, dolphinfish (*Coryphaena hippurus*), marlin, sailfish, several kinds of tuna and Wahoo (*A. solandri*).

The deeper slopes of these islands and atolls (below the thermocline) is also affected by altered oceanic circulation patterns, creating local upwellings, turbulent mixing and closed circulation cells. These currents deliver food to and remove wastes from their sessile, sedentary, and resident inhabitants. These habitats are also likely to support structurally complex communities of suspension-feeding sponges, corals, crinoids, and ascidians that are rare or absent from surrounding habitats dominated by deposit-feeders. Even in the absence of upwelling, islands and atolls might support high animal biomass because they offer a combination of strong currents and structurally complex seafloor habitat. This allows resident fishes to feed on passing zooplankton and small fishes in the water column, such as lanternfishes (Myctophidae and Neoscopelidae), and to take refuge amidst the epibenthic invertebrate communities. The abundance of demersal life and distinctive oceanographic phenomena attract highly migratory pelagic predators including cetaceans, seabirds, sharks, tunas (Young *et al*, 2001) and billfishes (Young *et al*, 2003; Norse and Crowder, 2005).

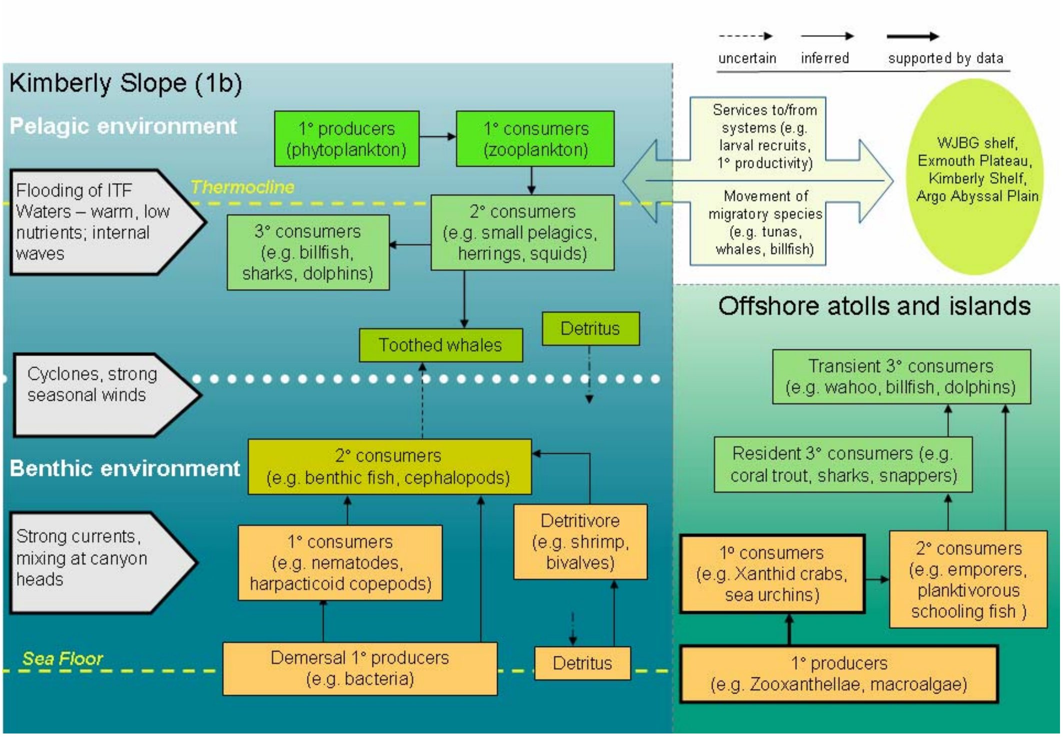


Figure 6-15 Conceptual trophic model of the Kimberly Slope sub-region showing information on the extensive mid-slope habitats (left) and the less extensive but important offshore island and atoll habitats (right).

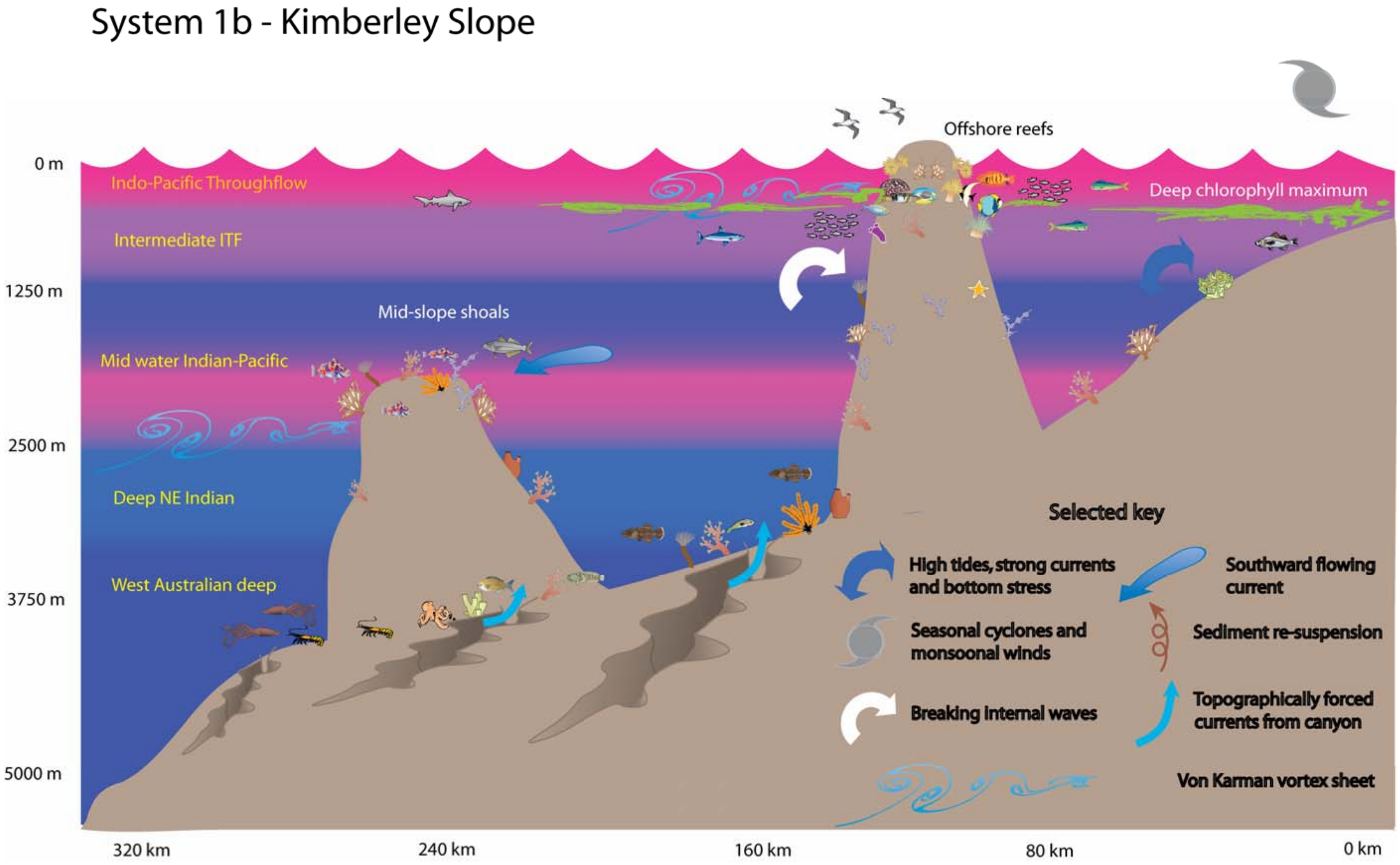


Figure 6-16 Habitat diagram of the Kimberly Slope sub-region showing selected important drivers and features.

6.3.3 Services and linkages

There is evidence from the species composition of reef fauna that currents flowing from the Pacific and Indonesian archipelago (ITF) provide larval transport for the islands and atolls on the Kimberly Slope. However, at times northerly, wind-driven surface currents may also link Ashmore and Scott reefs, and Rowley Shoals.

North West Slope Trawl Fishery fishes in 260-500 m, on muddy bottoms for scampi and deepwater prawns. The Northern Tropical Shark Fisheries use dropline and longline fishing to target shark species less vulnerable to overfishing such as black-tip sharks (*Carcharhinus* spp), although other species such as Lemon sharks (*Negaprion acutidens*), Hammerhead sharks (Sphyraenidae), Tiger sharks (*Galeocerdo cuvier*), Shovelnose rays (Rhinobatidae) and other Whaler sharks (Carcharhinidae) are caught. Foreign fishing vessel sightings are also a significant impact in the southern half of this sub-region, possibly targeting sharks (for fins) and finfish.

The reefs of the sub-region have been subject to intense fishing pressure by Indonesian fishers fishing under the MOU that allows visits by traditional Indonesian fishing craft. Depleted species include sea cucumbers, trochus and sharks (Skewes *et al*., 1999). Although Ashmore Reef and Cartier Island were declared Nature Reserves some years ago, their reef resources are still considered as depleted (Smith *et al*., 2003).

Scott and Seringapatam reefs and Ashmore and Cartier Islands are tourism destinations. They are used for snorkelling or SCUBA diving encounters with reef species, Humpback whales, manta rays etc; and are also targeted by fishing expeditions.

6.3.4 Key species interactions

The mid-slope islands, reefs and atolls support a diverse benthic and pelagic communities and may also serve as rendezvous points where some pelagic and epipelagic fishes converge to mate or spawn. Live corals and macro-algae, in particular, are a key species that provide food and shelter for many species. Loss of these species groups will result in the collapse of both biological diversity and biomass on and around these habitats. The coral reefs of the sub-region have been impacted by a severe coral bleaching event in 1998, which was estimated to have killed up to 90 % of live corals on the large southern atoll, Scott and Seringapatam Reefs (AIMS refs). The cascading ecological impacts of this mortality are likely to include a shift in the trophic guild structure of reef fishes.

The key species on the deeper slope communities are not known, although deep water snappers such as *Pristipomoides* and *Etelis* species may be important tertiary consumers that provide an ecological balancing role in depths to about 400 m.

6.3.5 Resilience and vulnerability

Much of this region appears to be either near-pristine or lightly exploited. Much of the slope habitats, and especially the deep water, appear to be a relatively unaffected by human impacts. Lightly exploited environments include the deep water trawl habitats (260-500 m) and the waters surrounding islands and reefs subject to recreational fishing. The level of exploitation in areas impacted by local and illegal foreign shark fishing is unknown.

Sharks are highly vulnerable to fishing pressure due to their being long-lived and having low fecundity. Several shark species are fished by legal and illegal fisheries, for both trunks and fins, respectively. This combination of impacts may be causing population declines and local extinction of some species.

The demersal mid and upper slope fishes within the Timor Province include a relatively high number (64) of endemic species (Last *et al.,* 2005). These and the deeper slope communities are one of the least understood in the Australian marine environment and like better known deep water communities, may be highly vulnerable to any unnatural sources of mortality.

The coral reefs in the region are adapted to relatively stable, oceanic conditions and appear to be highly vulnerable to the effects of raised sea level temperatures and other climate significant changes to climate. Higher temperatures have caused widespread coral bleaching to the southern reef atolls and any increase in sea surface temperatures may further deplete corals communities. This would greatly reduce the diversity and abundance of many species groups including other demersal invertebrate communities, benthic and pelagic fish. Under these conditions, the reef is likely to be dominated by macroalgae, echinoderms and selected herbivorous fish.

Pelagic species appear to be relatively resilient to low impact fishing (e.g. recreational fishing) and climate impacts due to their ability to migrate. However, large scale shifts in water temperature are likely to cause changes in their natural distributions.

6.3.6 Information gaps

Little is known about the deep water demersal communities (deeper than 850 m) and the trophic dynamics of all demersal slope communities and the continental slope off NW WA is recognised as a high priority for future research (Last *et al.,* 2005). The opening of the deep water passages in the Indo-Pacific Archipelago has allowed deep water species to exchange between the north-west and north-east of Australia. Even so, Last *et al.* (2005) find that only about 40% similarity in species between these two regions. We need a better understanding of how species are being exchanged between these two regions, particularly in light of possible impacts on currents and water properties being brought about by climate change.

The impact of internal waves on mixing and productivity on the upper slope and against islands and atolls is not well understood and more research is needed before they can be modelled successfully.

6.4 Argo Plain (1c)

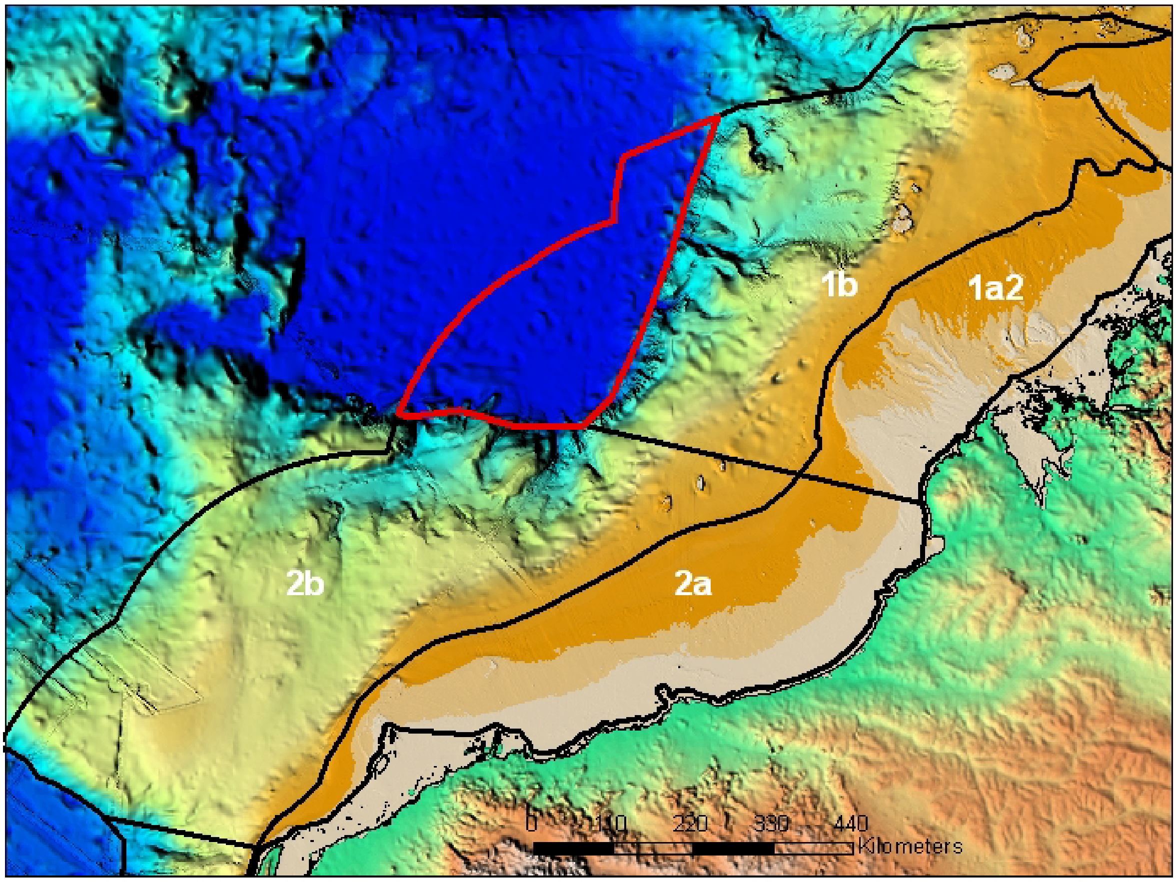


Figure 6-17 Argo Plain (red outline) and neighbouring sub-regions.

6.4.1 Drivers and physical features

The Argo Abyssal Plain is an area of deep seabed with very low relief (Figure 6-17). The surface tilts gently to the north, and forms an outer ridge to the Java Trench. It is not totally surrounded by a continental rise. Swales (shallow trough like depressions) have been recognised in the southwestern regions of the plain (Harris *et al.*, 2005).

This deep water trophic system is characterised by the deep (>4,000 m) abyssal plain, a habitat type that is among the Earth's flattest and smoothest regions, and the least explored. Deep abyssal plains cover approximately 40% of the ocean floor. They are typically covered by silt, much of it deposited from turbidity from the continental margins and planktonic remains which sink from the upper pelagic waters. There may also be some scattered regions of hard bottom particularly on the margins at the base of the continental slope.

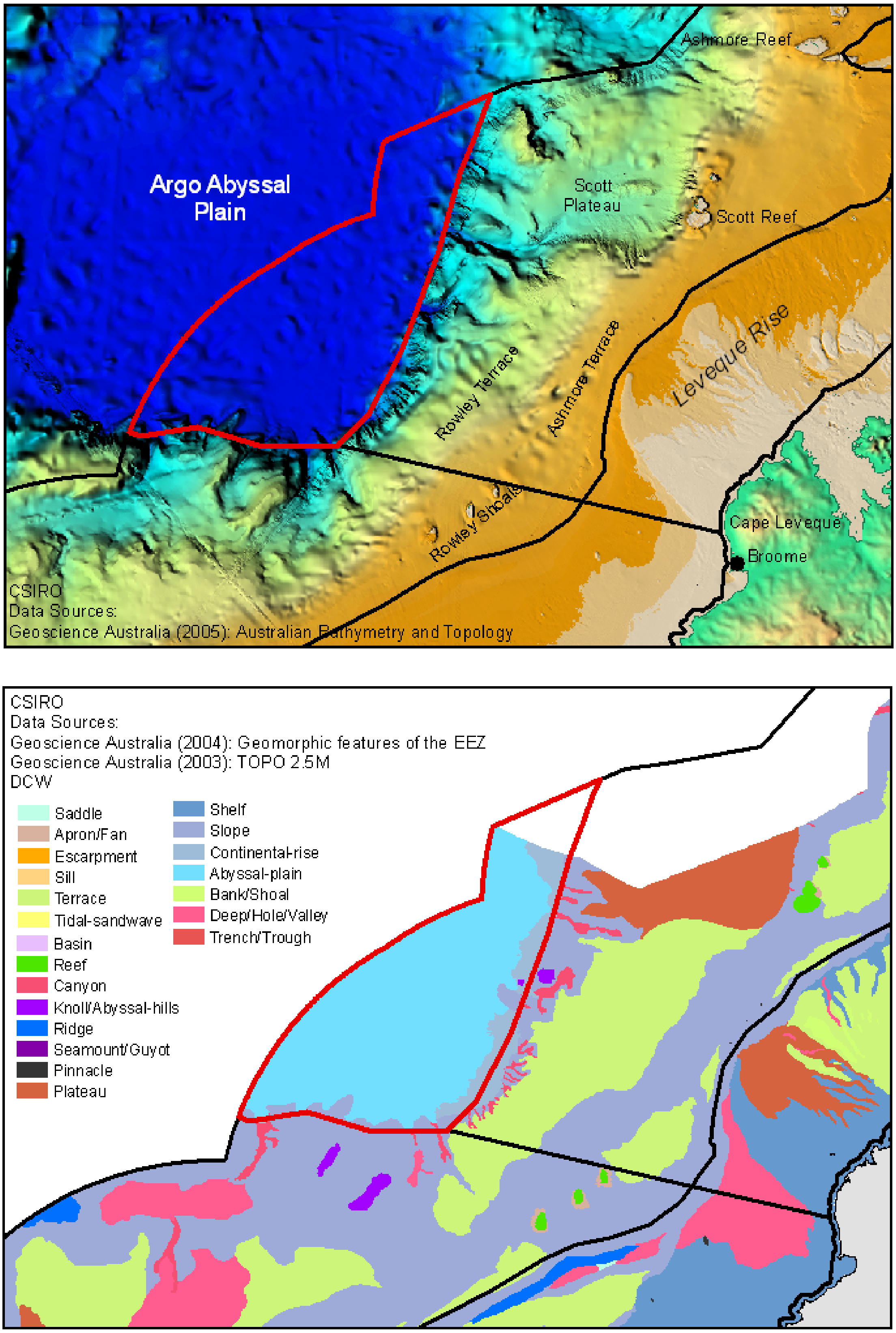


Figure 6-18 Argo Plain sub-region showing selected features (upper) and geomorphology (lower).

The Argo Abyssal Plain is located in the influence of the Indo-Pacific Throughflow (ITF) watermass with the transitional fronts zone to the south. The ITF is at a maximum during the summer monsoon (May - October) and at a minimum during the winter monsoon (December - April) (Tomczak & Godfrey, 2005). At its low, the ITF flow is opposed by the winds resulting in a deepening of the thermocline and suppressed production. At its maximum the ITF flow and wind act in concert and upwellings occur at the edges of the current and along the Java coast (Wyrtki, 1961).

The suppression of the thermocline by the ITF waters leads to a deep chlorophyll maxima. Under oligotrophic conditions, nutrient recycling processes are important in maintaining standing crops of nanoplankton feeders. Bacteria are an important component of such systems in aiding the breakdown of detritus and regeneration of nutrients.

This region has a relatively simple watermass composition (Figure 5-4, Figure 5-5). This trophic system is a more topical version of the Cuvier Abyssal Plain to the south. Water temperatures at the surface are tropical, averaging 28° C and with a small seasonal range. Water temperature regime for the sub-region is strongly dominated by decreasing temperature with depth, with the surface temperature reflecting climatic processes, and the deeper water reflecting global water-formation and transport processes (Hayes *et al.*, 2005).

The surface waters of this trophic system are low in nutrients (nitrate and phosphate) and silicate (Table 6-4, Figure 6-19) for most of the year. However, levels increase rapidly below the surface mixed-layer from nutrient rich water-masses such as the Antarctic intermediate water-mass that carries nutrient-rich water at depth throughout the region. Wind stress during most of the year is very low, (Hayes *et al.*, 2005) and there is little vertical mixing through the pycnocline to bring additional nutrients into the euphotic zone.

The dynamics associated with the seasonally reversing surface currents and mixing at the continental edge results in advected nutrients and associate productivity in the sub-region.

The Argo Abyssal Plain is the deepest sub-region in the NWMR and is also unique in extending for hundreds of kilometres to the west and north of the region.

6.4.2 Trophic system features and dynamics

Pelagic environments

The surface waters of this trophic system are low in nutrients, resulting in low surface primary productivity in the mixed layer, especially during summer, when the strong thermocline results in low advection of nutrient rich water from deeper water. While the low nutrient surface waters results in a relatively low chlorophyll and low productivity, there is likely to be some subsurface productivity from deeper plankton production at the nutricline near or below the 1% light depth (Lyne *et al.*, 2005).

The low but seasonally variable primary productivity provides food to primary consumers dominated by pelagic, vertically migrating zooplankton (such as crustaceans, larval molluscs, larval fishes, etc.). Pelagic secondary consumers such as jellyfish and salps are likely to occur, as are nekton secondary consumers such as transient small-fish schools and squid. The main tertiary consumers of interest in the Argo Plain include transient populations of highly migratory pelagic species such as juvenile Southern bluefin tuna (SBT) (*Thunnus maccoyii*) and other pelagic predators such as sharks that either migrate seasonally or range through the system following schools of small pelagic fish. Seabirds are expected to be included in the latter category.

Table 6-4 Summary physical data for the Argo Plain sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
5,571.6	1.91	0.114	0.00	2.40		

Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
28.06	34.55	32.70	0.05/12.81	0.11/0.85	3.16/43.45	0.09

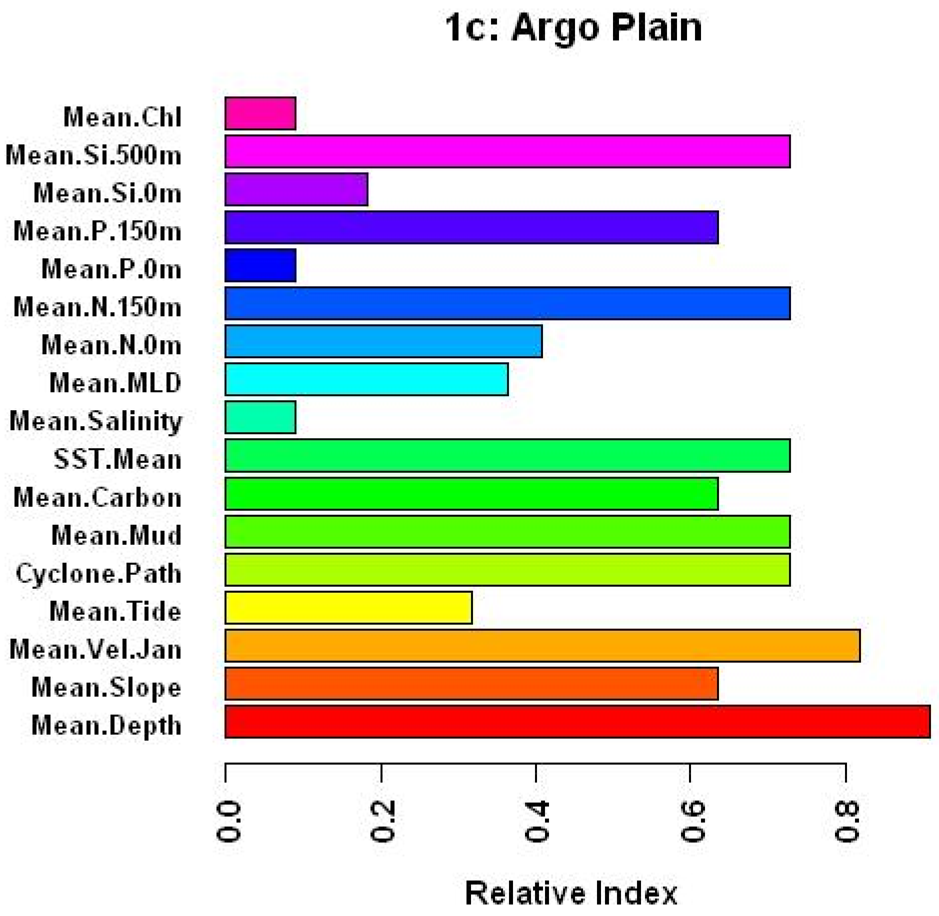


Figure 6-19 Summary physical data for the Argo Plain sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

Benthic environments

The deep demersal environment is reliant for its energy input on falling detritus or particulate organic matter (POM) (detritus, zooplankton faecal matter), on nutrients in sediments that move down the continental slope (e.g. through major slumps or finer scale flows), and the occasional large carcass directly supplied by the pelagic environment. Much of the detrital energy is cycled through bacterial-detrital food webs. Very few species will migrate between the pelagic and benthic environments. Therefore, the productivity flows in the pelagic and demersal portions of the deep sea environment in this sub-region are somewhat disconnected, with falling POM from the pelagic environment providing the main linkage (Figure 6-21).

In the benthic habitat, the relatively low nutrient/productivity of the pelagic environment may be partly causing a low biomass in the benthic habitats. The benthos is likely to consist of meiofauna (e.g nematodes and harpacticoid copepods), larger infaunal (e.g. polychaete worms and isopods) and epi-benthic communities of a range of trophic groups. There is likely to be a very sparse distribution of mobile epibenthos including holothurians, crabs and polychaetes. Much of the benthic biomass will likely be made up of the infauna (meiofauna and microfauna) including filter-feeders and detritivores. Sea bed adjacent to the continental slope will be subject to downslope processes including sediment making it a dynamic system.

These epi-benthic communities may support a sparse population of bentho-pelagic fish and cephalopods may also be present in low densities. Fish assemblages would be expected to include grenadiers (*Macrouridae*), hatchetfish (*Argyropelecus* spp.) and small, bioluminescent species that may vertically migrate. These organisms are typically present is very low abundances and are very patchily distributed.

6.4.3 Services and linkages

There is very little fishing activity in the Argo abyssal plain, although adult SBT use this region for spawning and juvenile SBT as a nursery area.

In some deep abyssal areas, especially those with a low terrigenous sediment load such as the Argo Abyssal Plain, manganese nodules can occur in high densities that contain significant varying concentrations of metals, including iron, nickel, cobalt, and copper. These nodules may provide a significant resource for future mining ventures.

Movement of pelagic planktonic organisms from this sub-region, including larval recruits, occurs by way of the southerly movement of ITF current, and seasonal monsoonal wind driven currents. Little is known about linkages between the deep benthic environments.

6.4.4 Key species interactions

SBT spawning grounds occur in an area bounded by latitudes 13-19°S and longitudes 111-121°E (Lyne *et al*. unpublished, 1994). Transient populations of pelagics such as SBT will be impacted by processes external to this trophic system.

6.4.5 Resilience and vulnerability

The dynamics of the SW monsoon and its impacts on the deep chlorophyll maxima during winter will impact the pelagic productivity and benthic systems of this trophic system. Changes in climate may therefore be expected to influence this productivity. The deeper environments are low energy highly and stable nature of these systems, and likely to have relatively narrow physicochemical tolerances. It is not clear how climate change impacts would affect these deeper communities. However, any physical disturbance may cause significant habitat and community degradation. For example, any new mining ventures that disturb these deeper environments are likely to have long-term impacts.

6.4.6 Information gaps

Very little known about the deep abyssal benthic ecosystems. The abundance and diversity of the deep abyssal biota has been rarely sampled, including the Indian Ocean abyssal environments.

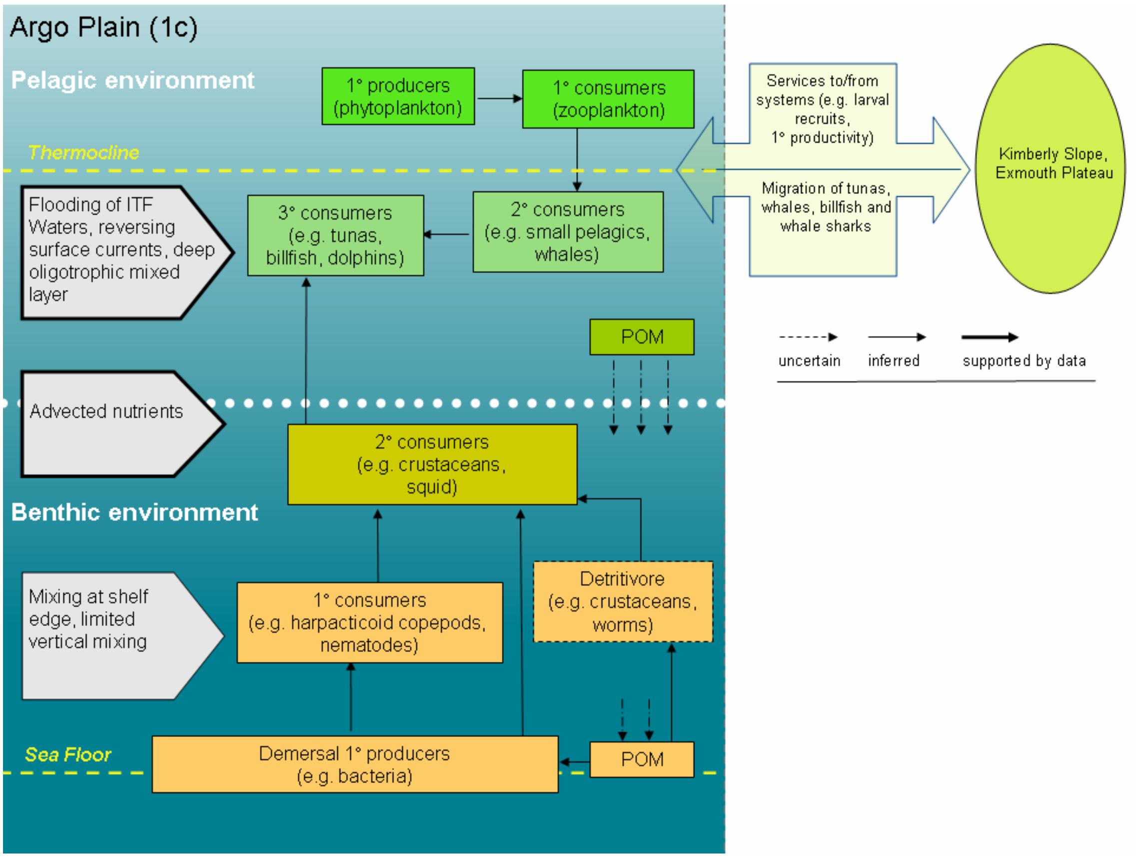


Figure 6-20 Conceptual trophic model of the Argo Plain sub-region showing information on the main habitat in the central basin.

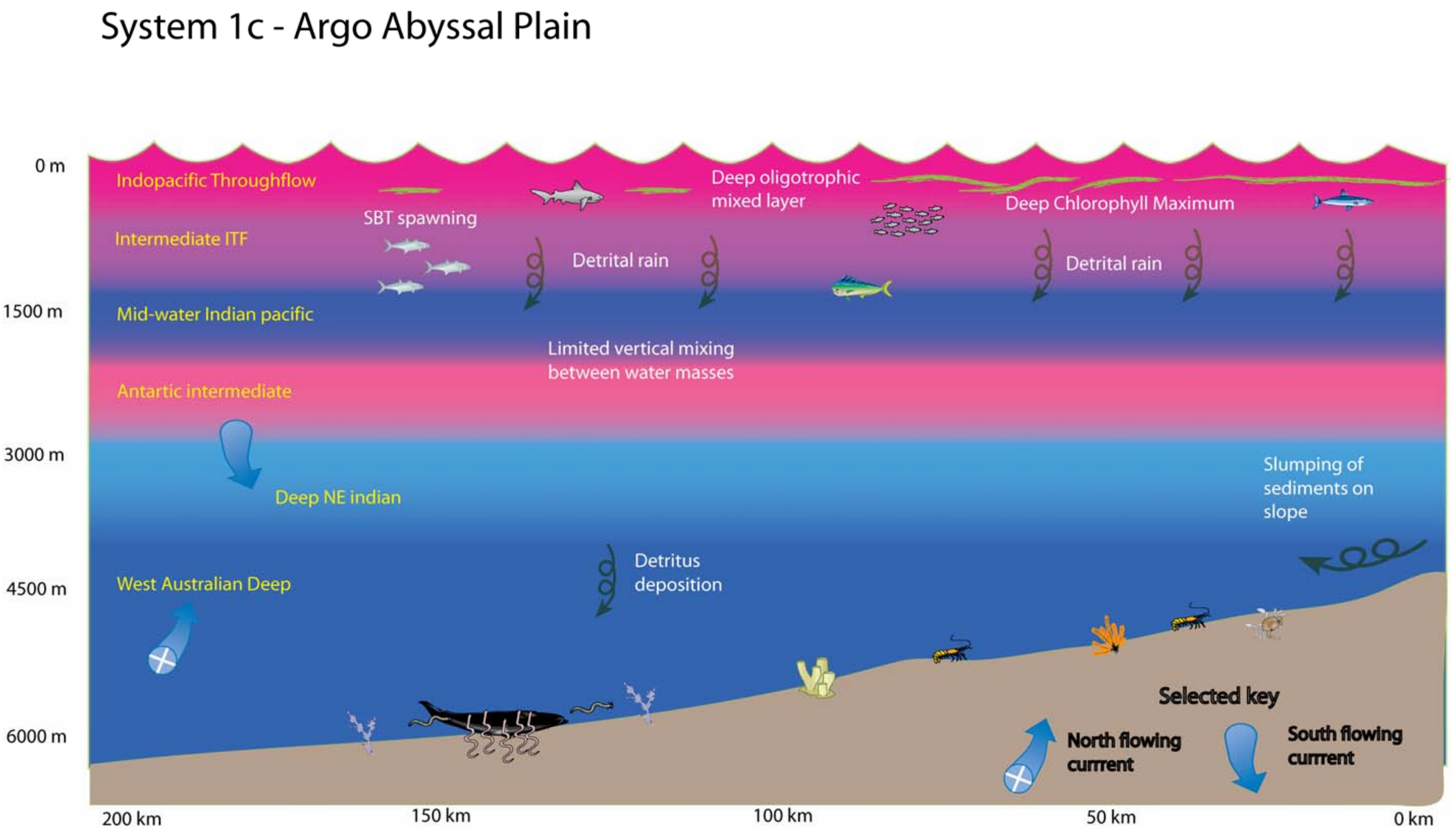


Figure 6-21 Habitat diagram of the Argo Plain sub-region showing selected important drivers and features. 70-100 m deep chlorophyll maximum not shown.

6.5 North West Shelf (2a)

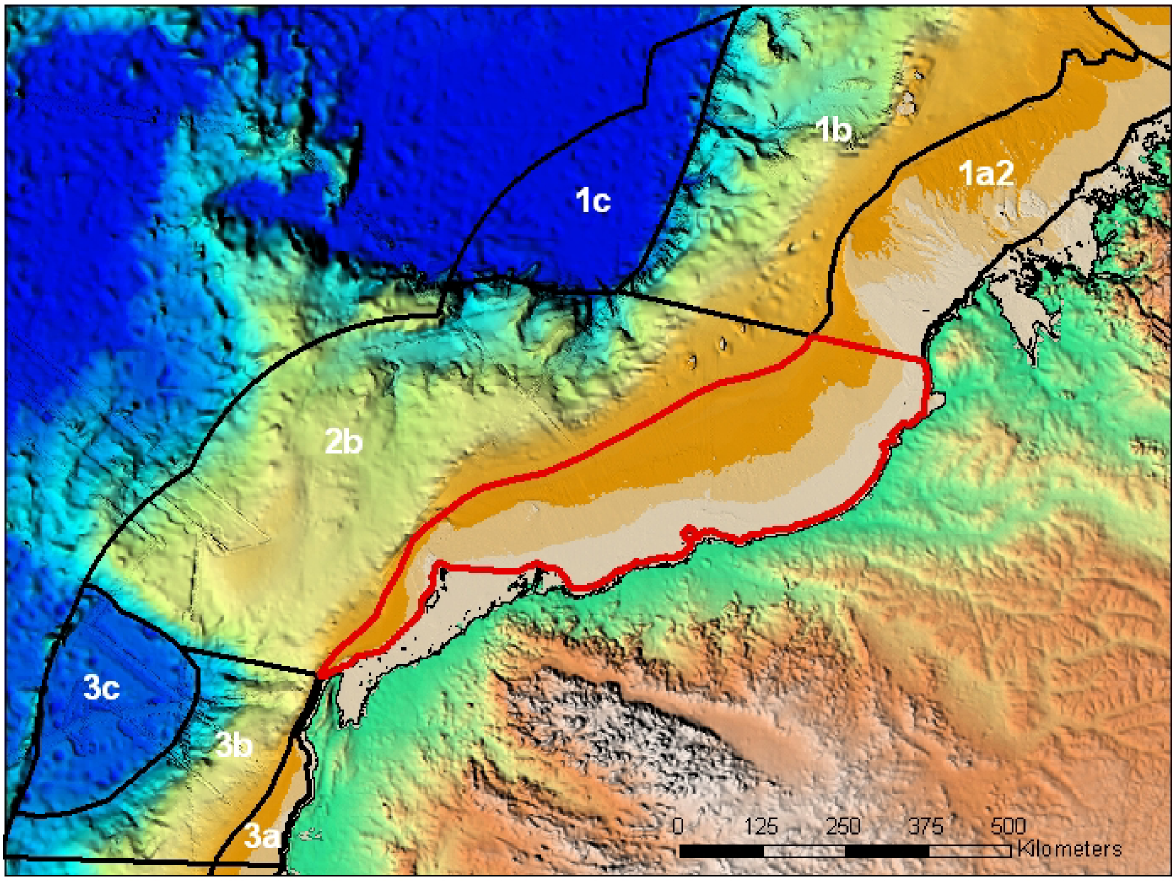


Figure 6-22 North West Shelf (red outline) and neighbouring sub-regions.

6.5.1 Drivers and physical features

The North West Shelf is at the eastern boundary of a major oceanic frontal system that spans almost the width of the Indian Ocean basin. To the north is the ITF system and to the south is the offshore gyre of the Indian Ocean Central Water and the Leeuwin Current proper along the edge of the shelf. The offshore waters are therefore derived from a mixture of those to the north and south and substantial temporal variability can be expected. It is an area of high cyclone activity (Figure 5-7), with the most destructive cyclones located in the southern half of this region. It is part of the area of high tidal activity and internal wave activity at the shelf break region. Geomorphologically, the north and south are different with smooth, shelly, sandy and wide shelf and slope habitats to the north; and in the south the shelf and slope is narrower with more hard ground, numerous islands, and seamounts. Nationally, it is one of the regions where the traditional definition of the shelf-break as the 200m isobath differs significantly when compared to the isobath of maximum gradient change (National Marine Bioregionalisation, 2005). This suggests unique geomorphic processes operated, or are operating, in this region. Rainfall is low except during cyclone activity, temperatures are high and evaporation plays a key role in the formation of shelf and offshore waters. Nutrient sources are from the offshore via advection of mixed waters formed from breaking of internal waves and other shelf-edge processes and possibly derived from the land through the action of tides, coastal currents and storms including cyclones. Nutrients from offshore intrude into the deep layer on the shelf (Herzfeld *et al.*, 2006). Our expectation is that nutrient recycling processes would play a key role in sustaining the shelf trophic system of the north.

Table 6-5 Summary physical data for the North West Shelf sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
83.5	0.27	0.033	24.68	2.58	10.0	91.4

Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
27.35	35.15	29.22	0.14/11.65	0.14/0.86	3.53/34.18	0.36

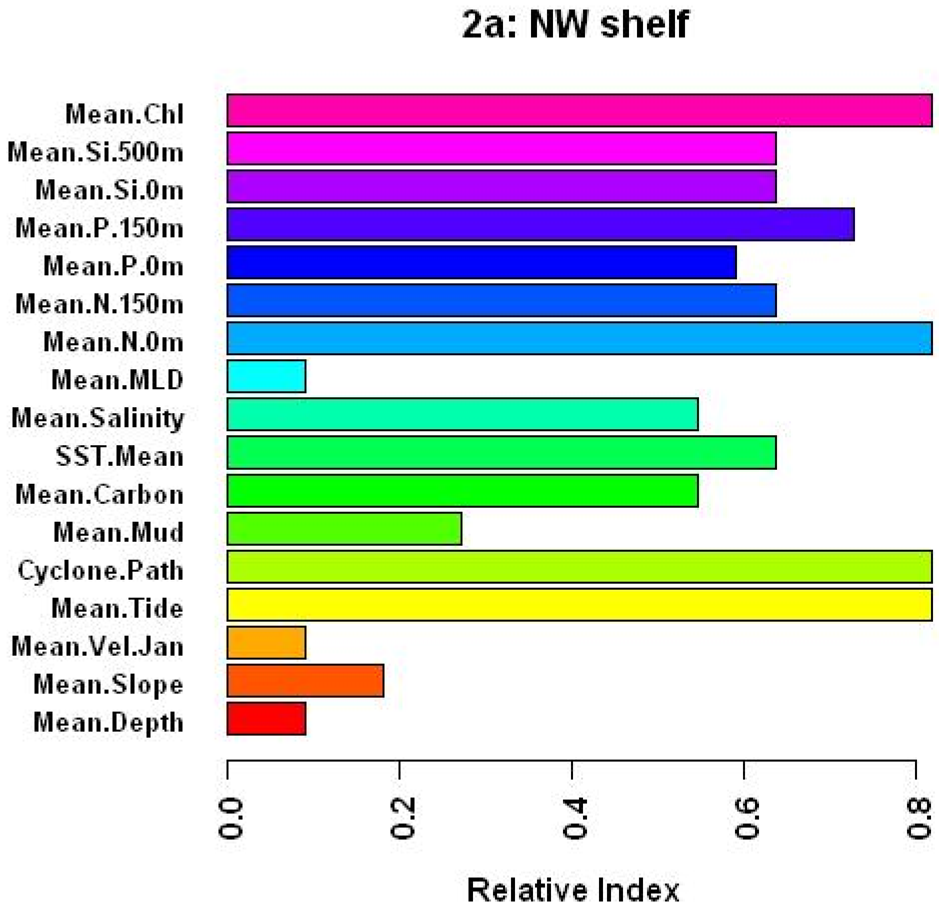


Figure 6-23 Summary physical data for the North West Shelf sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

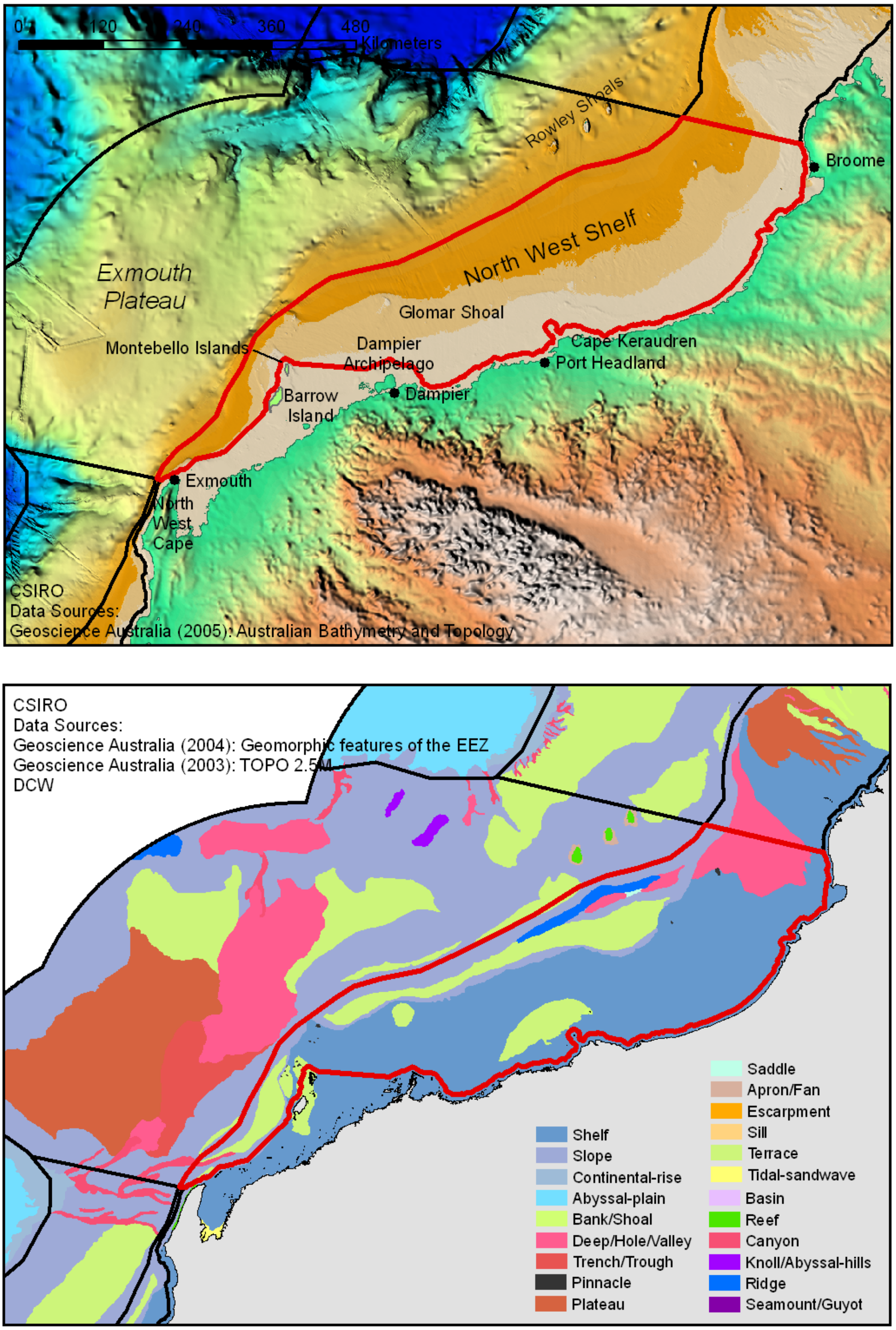


Figure 6-24 North-west shelf sub-region showing selected features (upper) and geomorphology (lower).

The Northwest Shelf is a tropical shelf primarily covered by carbonate sediments of mostly skeletal origins, overlying a thick carbonate wedge. Relict biogenic littoral outcrops (such as the Glomar Shoals) and shell communities are principal sources for carbonate material in the northern half. In the south, sediments comprise coarse to medium-grained biogenic sediments that are subject to active reworking. The mid-shelf and inner-shelf regions have along-shelf variations, with a change from shelly sands in the southwest to oolitic sands and micrite casts in the northeast. Tidal stress increases towards the northeast causing active transportation of sediments. Reefs, depressions and sand waves ranging from 5 to 10 m in height, are locally present along the shelf surface particularly landward of the shelf break in waters 70 to 90 m deep, and are likely to be formed by the action of internal tides breaking where the thermocline intersects the shelf seafloor. McLoughlin and Young (1985) analysed 354 sediment samples from an area of the NW Shelf spanning 116^{o}E to 119.5^{o}E and from depths of 20m to 150m. Their results show that sediments comprised coarse skeletal detritus in the south-west to carbonates in the form of oolites, pellets and infilled biogenic particles in the north-east. Sediment grain size decreases from shallow to deep waters, and carbonate muds are found on the continental slope. Carbonate content of sediments ranges from 60 to 100% of the total sediment weight with some clay and small quantities (less than 1 %) of fine grains of angular quartz are present. At the Glomar Shoals region,the sediments were coarse shelly sand at depths of about 25m to 70m.

Tidal currents are an important pervasive disturbance on the North West Shelf region (Holloway & Chatwin 2001). Tidal amplitudes increase northwards from about 0.95m near Exmouth to over 3m on the inner shelf near Broome. Maximum spring tide amplitudes are over 2m at Exmouth, 2.5m at Onslow, 4.5m at Dampier and close to 6m at Port Headland (Heyward *et al*., 2006). The increase in amplitude is most evident north of the Montebello Islands where the width of continental shelf increases significantly. During the lowest tides large areas of intertidal habitat are exposed (Heyward *et al*., 2006). From Feb to June the ITF and Leeuwin Current dominate circulation on the NW Shelf. However at other times of the year strong winds from the southwest cause intermittent reversals of these currents with occasional weak upwellings of cold deep water onto the shelf (Condie *et al*., 2006).

There is an extensive array of small barriers and fringing reefs in shallow water around the Dampier Archipelago, and the Pilbara coast .

Compared to other sub-regions in the NWMR, mean levels of chlorophyll and nutrients (Nitrate (N), Phosphate (P) and Silicate (Si)) are above average – consistent with a relatively high chlorophyll status – while temperature and salinity are moderate (Figure 6-23, Table 6-5). Tides and cyclones (Figure 5-7) are high but the mean surface currents and slope are low. So, despite the wide shelf environment, this system is relatively productive which suggests that the energetic processes (tides, currents) and nutrient delivery mechanisms are effective in this relatively shallow environment. The southern half of this region contains the highest concentration of Category 3 to 5 cyclones (Figure 5-7). This is one of the highest tidal dissipation areas in the world and high turbidity waters occur at the coast, which could partly be responsible for the misclassified high satellite-derived chlorophyll – because of calibration errors in the remote sensing algorithm in converting spectral signatures to chlorophyll values. Tsunami impacts have been felt at the north-eastern area of the Barrow Island which is located near deep waters. Strong evaporative processes at the coast lead to underflows of hot salty water.

Lyne *et al*. (2006) classified the habitats of the Pilbara region, from North West Cape to Cape Keraudren using a variety of datasets from experts, published sources and the comprehensive research trawl data compiled by CSIRO as part of a management study on the effects of trawling on benthic habitats and fisheries. Data from the research trawl catches of fish were primarily used to classify the region offshore of the 20m depth and showed that the main structure was related to depth and secondary structures could be associated with topographic and seafloor features such as the Glomar Shoals discussed above.

The studies of McLoughlin and Young (1985) and Lyne *et al*. (2006) show a strong depth related structuring of the benthic environment. The pattern of variation of key benthic features with depth mirrors that derived from the fish community information. This implies a close association between fish communities and benthic habitats. A key conclusion derived by McLoughlin and Young (1985) was the general gradation towards finer sediment sizes with increasing depth with a relatively sharp change at about 120m. McLoughlin and Young (1985) inferred from the sediments that the mid- and outer-shelf was the highest energy zone. How this observation concords or not with the notion that the shelf-break is a region of high energy is yet to be resolved. One potential explanation that is in line with both observations is that the sporadic nature of high energy internal tide activity is not having a discernible effect on sediment distributions at the shelf edge. And, that in keeping with the nutrient studies, such as those by Herzfeld *et al*. (2006) and Holloway *et al*. (1985) (see following section) that the persistent tides and currents are primarily drivers of the North West Shelf

Numerical biochemical modelling studies of primary productivity on the North West Shelf by Herzfeld *et al*. (2006) indicate a subsurface deep chlorophyll *a* maximum (DCM) at a depth of about 70 m and at concentrations of about 1 to 1.5 mg Chl*a* m^{-3} . Herzfeld *et al*. (2006) used a water column and sediment nutrient cycling model as shown in Figure 6-26.

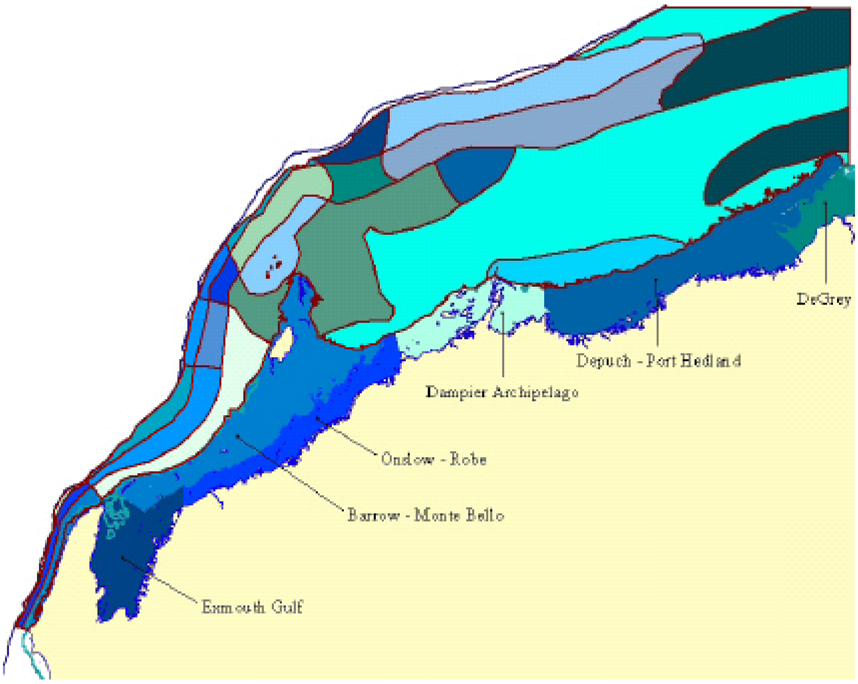


Figure 6-25 Spatial regionalisation of the North West Shelf from Lyne *et al.* (2006) based on expert information, research trawl data on fish catches and satellite/aerial images. The structures on the shelf, deeper than 20m or so are based on the CSIRO research trawl data (see Lyne *et al*. (2006) for details).

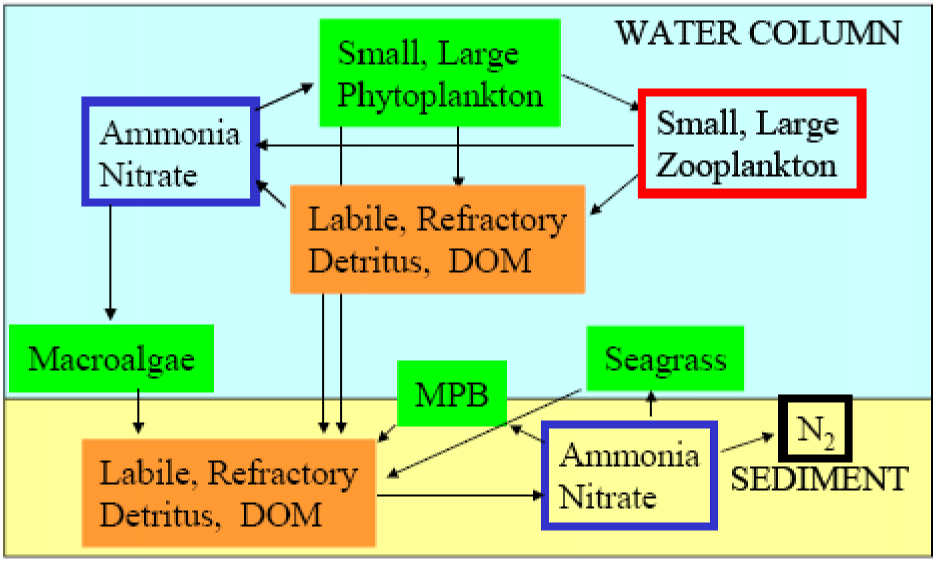


Figure 6-26 Schematic depiction of the model for nitrogen cycling for the North West Shelf used by Herzfeld *et al*. (2006) showing the interaction of pelagic, benthic and infaunal processes. (Figure reproduced from Hezfeld *et al*. (2006) with permission from Mike Herzfeld, CSIRO CMAR, Hobart). MPB is Micro Phytobenthos and DOM is Dissolved Organic Matter. For completeness, assume that the two pools of Ammonia/Nitrate are linked (both ways).

Two pools of labile/refractory detritus and DOM (dissolved organic matter) provided nutrients to primary producers in the water column and sediments.

Key conclusions made by Herzfeld *et al*. (2006) included:

- The DCM was locally maintained by a vertical flux of nitrate from below while its depth responds to changes in light intensity/light penetration, grazing intensity and changes in the vertical flux of nutrients.
- Horizontal fluxes of nutrients replenish the deep pool.
- Modelled variability of the DCM occurs on timescales of the spring neap tide (when it is found further offshore and nearer to the surface) and on seasonal timescales when the DCM is closer inshore in the wet season, and more dispersed offshore in the dry. This is attributed to changes in mixed layer depth.
- Tropical cyclones increase primary productivity only marginally due to the competing roles of upwellings and nutrient dilution from enhanced vertical mixing. However vertical motions in the thermocline/DCM after the cyclone's passage can increases productivity above and within the DCM.

Holloway *et al*. (1985) in their study of the mechanisms supplying nitrate to the shelf similarly concluded that tides and persistent upwellings contributed substantially to the flux of nitrate while large sporadic events, such as cyclones, contributed a minor portion of the flux. They also dismissed nitrate supply from river outflow as a significant contributor for the flux. Which suggests that coastal productivity is largely driven via nutrient recycling and advection from offshore sources.

Cyanobacteria are an important primary producer for this region and diatoms are dominant when nitrogen and phosphorous concentrations increase (Miles Furnas, pers comm., 2007). Furnas and Mitchell (1999) found that in the southern half of the region the phytoplankton were productive despite nutrients levels being low, which suggests rapid recycling of nutrients, organic matter and suspended particulate materials.

6.5.2 Trophic system features and dynamics

An EcoPath/EcoSim model of the North West Shelf was developed by Bulman (2006). The model was specifically designed to investigate trophic interactions affecting the fisheries of the North West Shelf (between depths of 30m to 200m on the continental shelf) and thus is more focussed on these issues than our generic trophic system template which is wider in scope but less detailed than the Bulman model on certain functional groups. The Bulman model is designed to more fully investigate species and group interactions which are consistent with existing information derived from various fisheries, research cruise and gut content analyses and remotely sensed data on primary production. Key groups and species used in the model are shown in Table 6-6. A simplified version of the model showing the spatial structuring across the shelf is depicted in Figure 6-27.

Table 6-6 Bulman's compilation of representative species in various trophic groups of the North West Shelf. References to dietary information (last column) are to be found in

Group No.	Group name	Representative species in group	References
1	Coastal sharks	*Sphyrna mokarran*	Cortes, 1999
		Galeocerdo cuvieri	
		Carcharhinus plumbeus	
		Carcharhinus sorrah	Brewer et al. 1995
		Hemigaleus microstoma	
		Loxodon macrorhinus	
2	Rays	*Dasyatididae*	
		Dasyatis thetidis	
		Himantura toshi	Salini et al. 1994
		Himantura uarnak	
		Rhynchobatus djiddensis	
		Taeniura meyeni	
3	Small tunas	*Thunnus obesus*	Kim et al. 1997 in *FishBase*
		Scomberomorus commerson	Brewer et al. 1995
		Euthynnus affinis	Blaber et al. 1990
		Katsuwonus pelamis	Roger 1993. Sierra, L.M., R. Claro and O.A.
			Popova, 1994. *FishBase*
		Thunnus albacares	Maldeniya, 1996; Pimenta, Marques, Lima and Amorim, 2001
		Scomberomorus queenslandicus	Salini et al. 1994; Begg and Hopper, 1997
4	Shallow Lethrinids	*Lethrinus* sp	Unpub. Sainsbury
		Lethrinus nebulosus	Salini et al. 1994
			Walker, 1978
5	Red Emperor	*Lutjanus sebae*	Salini et al. 1994
6	Shallow Lutjanids	*Lutjanus malabaricus*	Salini et al. 1994
			unpublished raw data
		Lutjanus vittus	Salini et al. 1994
		Lutjanus erythropterus	Salini et al. 1994
		Pristipomoides multidens	Kailola et al. 1993; Richards, 1987
		Pristipomoides typus	
7	Shallow Nemipterids	*Nemipterus furcosus*	Sainsbury and Jones (unpub)
		Nemipterus celebicus	
		Scolopsis monogramma	Salini et al. 1994
8	Deep Nemipterids	*Nemipterus bathybius*	Russell, 1990.
		Nemipterus virgatus	
9	Shallow Serranids	*Epinephalus multinotatus*	estimate
10	Frypan bream	*Argyrops spinifer*	Salini et al. 1994
11	Shallow carangidae (juvenile)	*Carangoides caeruleopinnatus*	Salini et al. 1994
		Carangoides chrysophrys	Salini et al. 1994
		Carangoides gymnostethus	Salini et al. 1995
		Seriolina nigrofasciata	Salini et al. 1994
		Carangoides malabaricus	Salini et al. 1994
12	Deep carangidae (adult)	*Carangoides caeruleopinnatus*	Salini et al. 1994
		Carangoides chrysophrys	Salini et al. 1994
		Carangoides gymnostethus	Salini et al. 1994
		Seriolina nigrofasciata	Salini et al. 1994
		Carangoides malabaricus	Salini et al. 1994
		Carangoides equula	Salini et al. 1994

Group No.	Group name	Representative species in group	References
13	Small pelagic fishes	*Sardinella albella* *Herklotsichthys koningsbergeri* *Decapterus russelli* *Auxis thazard*	Okey and Mahmoudi, 2002 Blaber et al. 1990
14	Shallow lizardfish	*Saurida undosquamis*	Sainsbury and Whitelaw; Venkata Subba Rao, 1981
15	Deep lizardfish	*Saurida filamentosa*	Salini et al. 1994
16	Shallow mullidae	*Parupeneus heptacanthus*	based on deep group
17	Deep mullidae	*Upeneus moluccensis*	*FishBase*: Lee, 1973
18	Shallow Triggerfish	*Abalistes stellaris*	FishBase: Randall, 1985; Ivantsoff, 1999
19	Shallow Sweetlip	*Diagramma labiosum*	Salini et al. 1994
20	Deep Ponyfish	*Leiognathus bindus*	*FishBase*: Cabanban, 1991; Kulbicki and Wantiez, 1990; Nasir, 2000: Yamashita et al. 1987
21	Shallow small fish	small fish (<30 cm)	*FishBase*: various authors
22	Deep small fish	small fish (<30 cm)	*FishBase*: various authors; Yamashita et al. 1987
23	Shallow medium fish	medium fish (30-50 cm)	*FishBase*: various authors
24	Deep medium fish	medium fish (30-50 cm)	*FishBase*: various authors
25	Shallow large fish	large fish (>50 cm)	*FishBase*: various authors
26	Deep large fish	large fish (>50 cm	*FishBase*: various authors
27	Sessile epibenthos		Okey and Mahmoudi, 2002
28	Megabenthos	bivalves	Okey and Mahmoudi, 2002
29	Macrofauna	small infauna	Okey and Mahmoudi, 2002
30	Prawns	commercial	Gribble, 2001; Chong and Sasekumar, 1981
31	Cephalopods	squids	Okey and Mahmoudi, 2002
32	Large zooplankton	Zooplankton >20 mm, carnivorous jellies, ichthyoplankton	Okey and Mahmoudi, 2002; Optiz, 1993; Silvestre et al. 1993
33	Small zooplankton	zooplankton <20 mm including pelagic copepods	As above
34	Pelagic phytoplankton		
35	Benthic phytoplankton		
36	Microphytobenthos		
37	Detritus		

Bulman (2006).

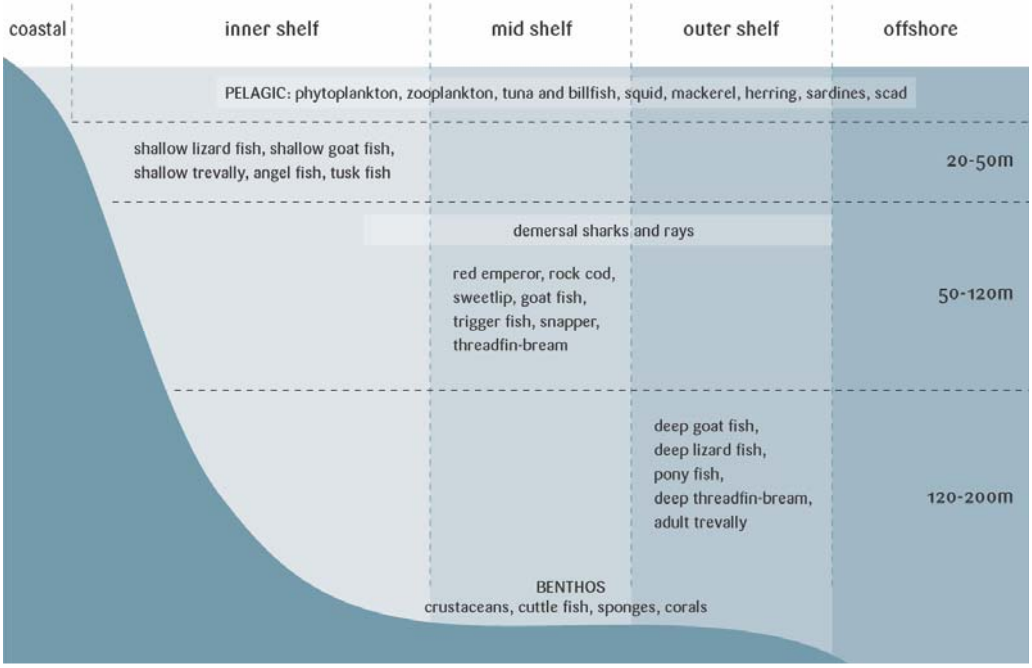


Figure 6-27 A spatial representation of key functional groups and species from the Bulman (2006) EcoSim/EcoPath model (Figure unpublished by Bulman and others (CMAR, CSIRO), pers. comm.)

Using annual average information from the fisheries, and simplified assumptions on environmental forcing (i.e., no advection or migration processes), trophic interactions and habitat modification (basically no modification), the key conclusions derived were that:

1. Statistical calibration of the trophic status suggest that the system has lost maturity (meaning the trophic level has lowered) through the effects of fishing.
2. Some statistics suggest a complex web structure indicative of a mature system, however other statistics derived from primary production and biomass indicate an “immature” system,
3. Primary production exceeds utilisation, suggesting that the pelagic biomass exceeds that of the benthic system and that the previous balance may have been altered by heavily exploited of demersal species by the foreign trawl fishery
4. Nearly all trends in biomass of fish species are replicated by the model but the major inconsistency is in the prediction of an increase in Emperors (Lethrinidae) when the available data suggests a decline. A number of possible factors such as interactions with habitat types and feeding behaviours were suggested for future investigation.
5. While removal of benthos was not considered in the model, it was acknowledged that some species such as lizardfish favour more open habitats and this is considered to be a key factor responsible for the increase in lizardfish (Synodontidae).

One concern we have with the analyses is that the phytoplankton production data used appears to have very high concentrations at the coast. It is commonly known that satellite remotely sensed data is adversely influenced by turbidity and re-suspended sediment in areas of high bottom stress. This is the case with the high tidal energy coastal environment of the North West Shelf and the satellite data needs to be reviewed to assess the extent of this problem in relation to the conclusions about the maturity of the NW Shelf ecosystem. The nutrient model studies by Herzfeld *et al.* (2006) and Holloway *et al.* (1985) discussed above both suggest offshore sources are driving new production on the NW Shelf so any (new) coastal production must either rely upon the flux from offshore or alongshore. By and large, high concentrations of chlorophyll at the coast can only be supported by local recycling of nutrients. However, we suspect that while such recycling does occur, the persistent high signatures seen in satellite images are due to turbidity signals misclassified as high chlorophyll. Thus our tentative conclusion from these studies and observations is that the NW Shelf trophic system is indeed a mature system driven largely by regular tidal stirring and advection processes which bring in nutrients from offshore sources.

According to Bulman (2006), the balanced Ecopath model showed that the dominant group in the ecosystem were the Nemipterids which comprised about 10% of the fish biomass and consumed about 9% of all the fish. lizardfishes were voracious consumers; they represented only about 1.5% of fish biomass but consumed 4% of all fish, comprising mostly small demersal and pelagic fish. The biomass of small pelagic and small demersal fish were the largest (34% and 26% respectively) and they were a key component of the total fish consumed (31% and 17% respectively). Overall, the small fish categories accounted for at least three-quarters of the fish biomass. Squid ate the highest proportion of all fish eaten (13%) as a result of their preference for small pelagic fishes.

McLoughlin and Young (1985) contend that faunal distributions on the North West Shelf evident from related studies show statistically significant density differences in fish fauna (Lutjanidae and Lethrinidae) between the eastern and western sections of the study area, with greater densities in the western section. Epifauna biomasses were also noted as being higher in the west. The data also showed the fish fauna of the shelf and the continental slope differed at about the 120m depth isobath, which also corresponded to the boundary between the fine muds on the slope and the shelly sands on the shelf.

Other studies of epibenthos (corals and sponges) show a decrease in observed percentage cover with increasing depths, and potential relationships with grain size and topography (Fulton, *et al*, 2006).

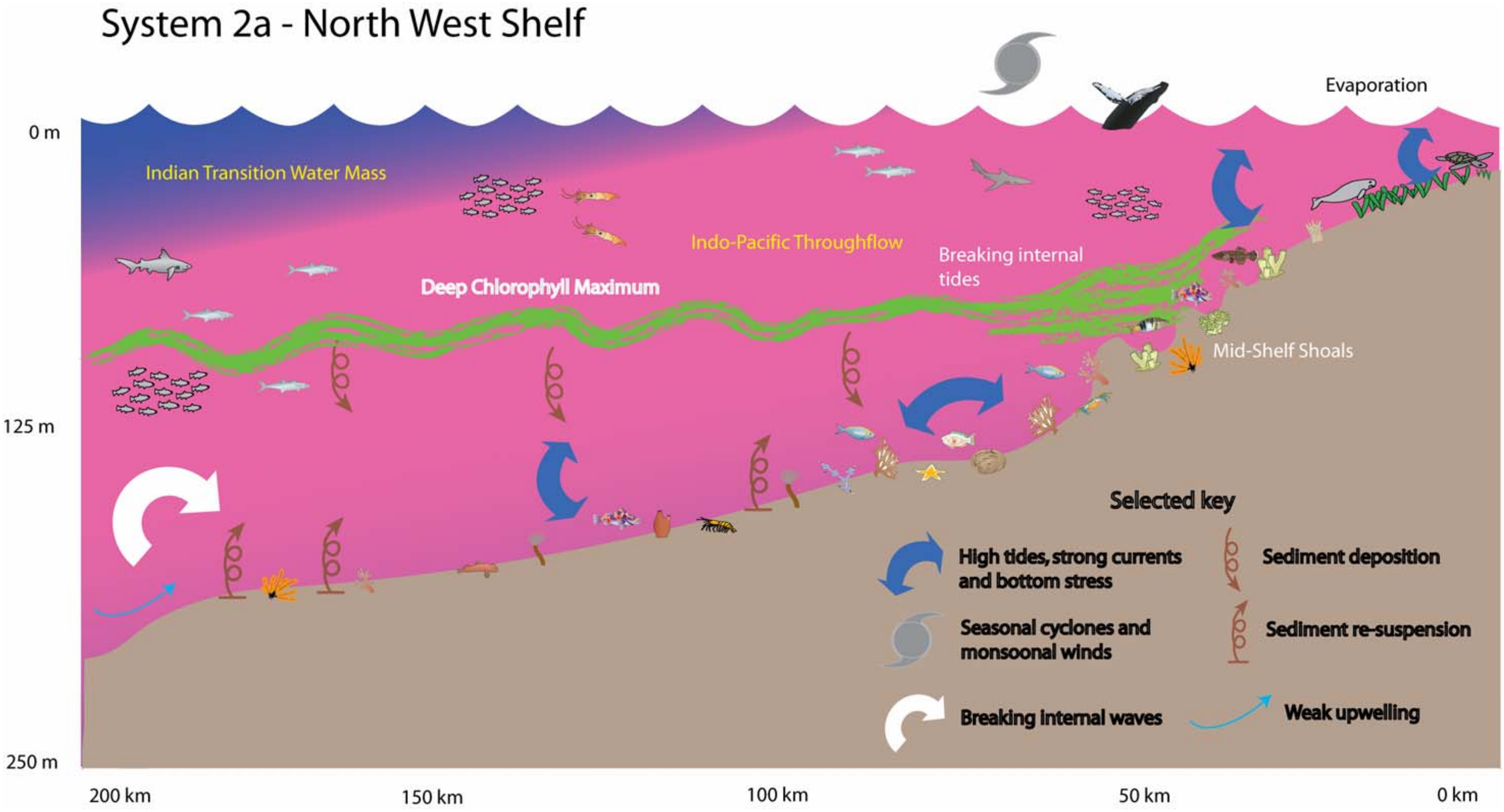


Figure 6-28 Habitat diagram of the NW Shelf sub-region showing selected important drivers and features.

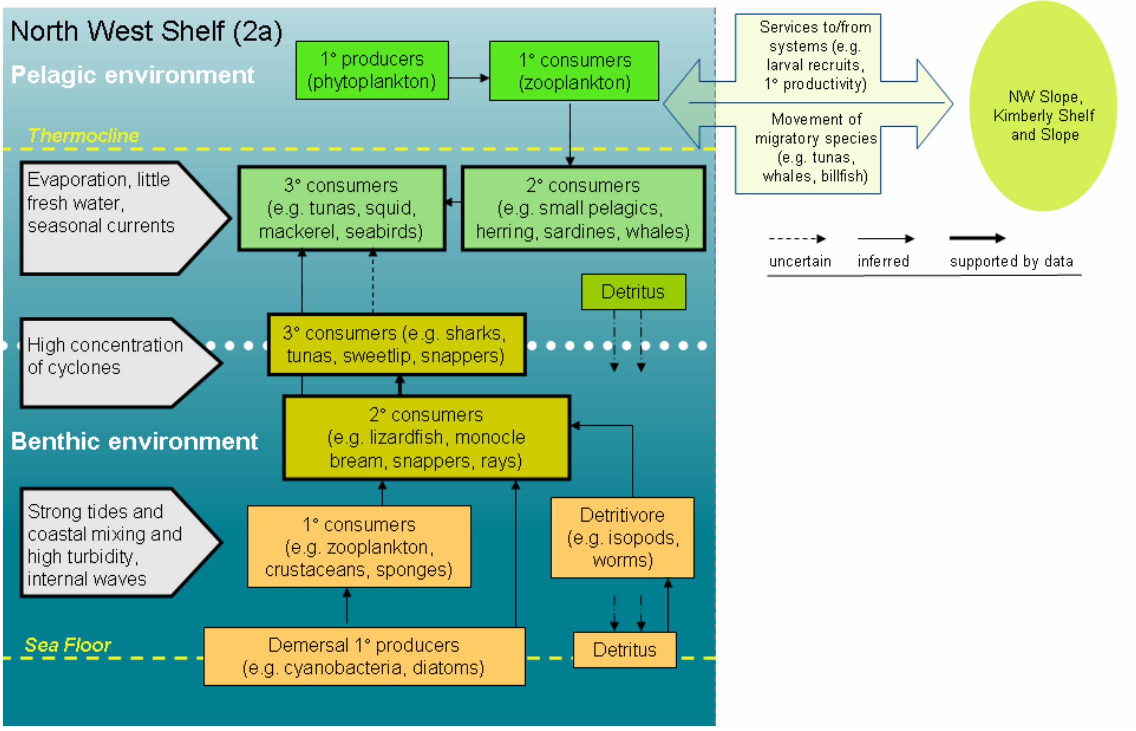


Figure 6-29 Conceptual trophic model of the NW Shelf sub-region showing information on the main habitat in the mid-shelf.

6.5.3 Services and linkages

There is a key connection with offshore nutrient delivery as the productivity on the shelf is, to a large extent, dependent on the offshore currents and their variability.

Coastal production and nutrient recycling sustains inshore species; spawning and recruitment in sheltered habitats. Thus the coast provides critical habitats for adult species that may inhabit offshore areas.

Features such as the Glomar Shoals appear to be relevant to biodiversity but are also important for specialised commercial fish species such as the Rankin cod - *Epinephelus multinotatus*, the Brownstripe snapper - *Lutjanus vitta*, Red emperor - *Lutjanus sebae*, Crimson snapper - *Lutjanus erythropterus* and the Frypan bream - *Argyrops spinifer* all of which appear to have a core area (of catches) associated with the shoals (see Althaus *et al.*, 2006 for further details). Benthic production occurs in deeper depths due to the clarity of water (offshore) and bottom/mid-depth nutrient input. This appears to lead to a zone of high productivity at mid-shelf which qualitatively appears to also relate to the sediment zones mapped by McLoughlin and Young (1985), the spatial structures determined by Lyne *et al.* (2006) and high catches of commercial fish (see Althaus *et al.*, 2006). The geomorphology review (DEW report, 2007) also identifies this region as having topographic and sediment properties which are unique and related to the location of the depth at which the thermocline intersects the shelf seafloor.

As bottom stress increases towards the northern end of the shelf in this region (see Margvelashvili *et al.*, 2006), resuspended matter and drift of organism will be expected to come into the North West Shelf from the Kimberley region. Likewise, offshore current systems will be expected to affect the connectivity of species between the island chain of Glomar Shoals and the more northern offshore islands in the Exmouth Plateau sub-region.

Pearl oysters are an established aquaculture species for this region.

6.5.4 Key species interactions

Analyses of benthic trawls from research cruises conducted by CSIRO on the North West Shelf primarily north from Barrow Island and in waters deeper than 20 m were categorised by Drs Peter Last and Alan Williams into two habitat types; one describing the substrate type (Habitat 1) and the other describing the location of the species habitat in the water column (Habitat 2):

Habitat 1	Description
G	General
H	Hard substrate
M	Macrobenthos
MH	Macrobenthos + Hard
S	Soft substrate
SM	Soft + Macrobenthos

Habitat 2	Description
B	Benthic
BP	Bentho-Pelagic
P	Pelagic

Using these descriptors each of 585 species of fish were categorised with respect to the two Habitat categories.

Species occurrences	Habitat2			
Habitat1	**B**	**BP**	**P**	**Grand Total**
G	1	6	66	73
S	128	51	2	181
M		50		50
H	45	91		136
MH	4	27	7	38
SM	32	69	6	107
Grand Total	**210**	**294**	**81**	**585**

Some salient points to note from the table are:

1. As expected, the bottom trawls are primarily trapping benthic and bentho-pelagic fish although some pelagics (16% of total) are also caught but no distinct bottom type can be attributed to catches of pelagics.

2. Bentho-pelagics are slightly more numerous than benthic species and are mostly associated with habitats that have macrobenthos or are hard. Benthic species on the other hand are mostly associated with soft substrates.

3. Bentho-pelagic species outnumber benthics on substrates which have hard elements and/or macrobenthos. Species counts from species associated with soft substrates with or without macrobenthos are more numerous those from the other substrates not including the General category. Likewise, species associated with soft substrates alone outnumber those associated with hard substrates (alone; but about the same if the MH category is included)

In the southern half of this system, south of Barrow Island, studies by Wilson *et al.* (2003) of euphausiids, notably *Pseudeuphausia latifrons*, suggests that they are highly abundant in coastal waters throughout the year. A summer survey suggested that the species is a detritus feeder rather than depending on a highly productive phytoplankton food chain characteristic of upwellings areas. Inshore reefs, mangroves and seagrass beds were suggested as possible sources of detritus. The narrower width of this shelf area together with an increase in the distribution of islands and topographic irregularities and the funnel shaped constriction of the shelf in the south (compared to the north) all suggest that recycling may be a major contributor to the standing crop in this area.

Dugongs and turtles of various species are charismatic fauna of this region typically in the coastal zone or near shore zone of islands. Potential interactions with other species and fisheries are likely to occur where fisheries are operating near seagrass habitats and turtle nesting beaches. Interactions may also occur during the migratory phases of these species.

Exmouth Gulf is an important resting area for migrating humpbacks along with the Montebello-Barrow Islands. The North West Shelf has resident populations of the common bottlenose and Indo-Pacific humpback dolphins. Seabirds that utilise the region include: crested terns, Australian gannets, white-faced storm petrels, little shearwaters and yellow-nosed albatrosses which are more numerous over cooler waters.

6.5.5 Resilience and vulnerability

If we assume that overall ecosystem resilience in the North West Shelf is related to the degree of variability and reliability of nutrient delivery, then the offshore areas beyond the mid-shelf would appear to be the most resilient. Isolated features such as the Glomar Shoals would however be exceptions that may be vulnerable to local disturbances. The coastal system relies upon nutrient cycling and new nutrient that has to make its way from the north by advection and/or from the offshore. Thus it is constrained in its production by the variability and reliability in the supply of offshore nutrient and in the transport mechanisms delivering nutrient into the coast. High coastal turbidity also plays a key role in suppressing potential production. Thus coastal production could be expected to display perhaps a lagged response to variability in the supply from remote nutrient sources. In this respect, the seasonal and interannual variability in the flow of the ITF and its influence on the depth of the overlying oligotrophic surface water mass is an important feature determining vulnerability.

In the southern half of the region, the shelf is narrower and there is a greater array of geodiversity available for habitat formation. Thus by comparison to the north, we would expect the system there to be more resilient (and biodiverse).

6.5.6 Information gaps

Some tantalising links have been postulated between species, nutrient delivery mechanism and diversity. However, these hypotheses are based on separate studies that need to be integrated.

Key information gaps exist in the offshore zone of the shelf particularly on the mechanisms, and variability, of nutrient delivery mechanisms. There is also a lack of understanding about the processes in the coastal zone and the degree to which this zone provides habitats suitable for spawning and recruitment of offshore species.

6.6 Exmouth Plateau (2b)

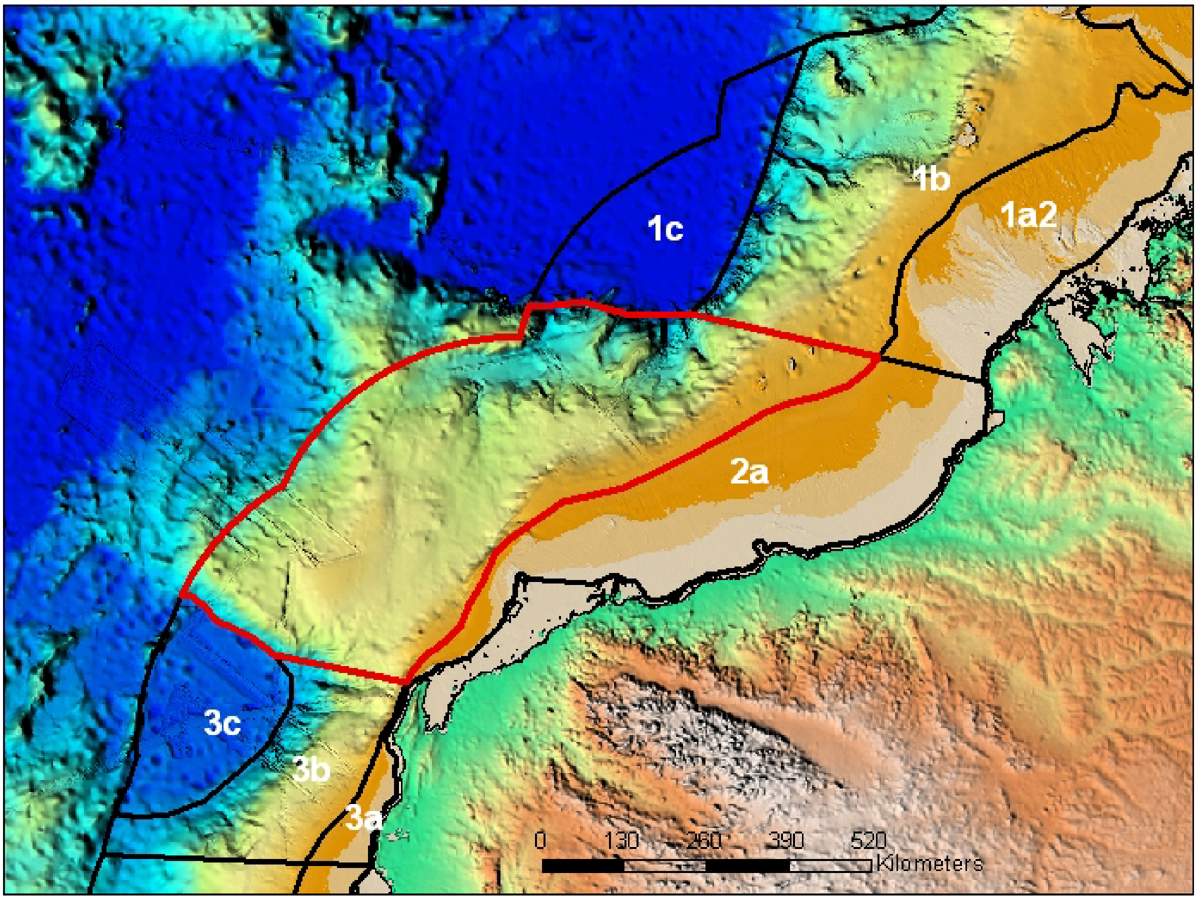


Figure 6-30 Exmouth Plateau (red outline) and neighbouring sub-regions.

6.6.1 Drivers and physical features

The Exmouth Plateau is a regionally and nationally unique tropical deep sea plateau abutting the continental slope which is overlaid by the oceanic frontal system located between the ITF and the Indian Ocean Central Water. The waters on the Exmouth Plateau are therefore a mixture and the frontal zone which overlays it can be expected to display substantial temporal variability at seasonal and longer timescales associated with the fluctuations of the ITF and other climate variability. Strong tidal activity and internal waves act at the shelf break region causing upwellings of deepwater and increased productivity at the shelf break. The mixed waters intrude offshore and overly the Exmouth Plateau where it helps support the productivity of the Deep Chlorophyll Maximum.

By comparison to the adjoining North West Shelf, this is a steeply sloped environment but with a unique large deepwater feature in the form of Exmouth Plateau which broadly peaks at about the 1000 m depth level. Deep current systems which form the beginnings of the Leeuwin Current flow off the shelf (Holloway and Nye, 1985). The southern edge of the ITF in the form of the South Equatorial Current also impinges on the northern edge of the Plateau. Both the northern and southern edges are seen in satellite images as zones of increased chlorophyll concentration. Likewise, the shelf edge appears to be highly productive and supports high catch rates of commercial species. However, overall chlorophyll levels are low which suggests that the high production events are sporadic.

The density of cyclone frequency is highest in this part of the NWMR and in particular in the southern half of this region the frequency of strong cyclones (categories 3 to 5) is highest (Figure 5-7).

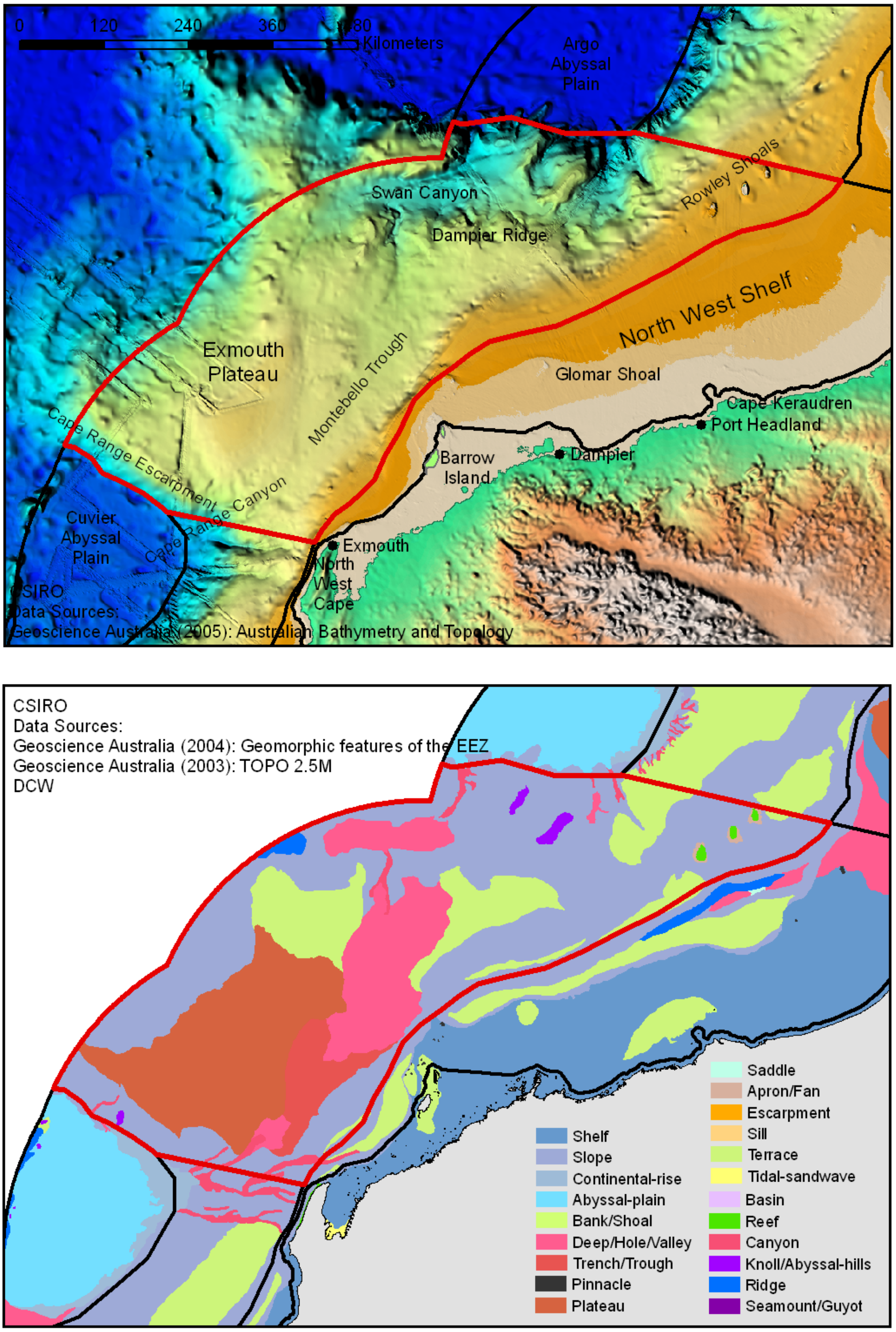
The upper slope varies in width. It is narrow and very steep slope to the north of Barrow Island/Monte Bello and wider and less steeply inclined immediately to the north.

Holloway's (1994) measurement and analysis of the Leeuwin Current at two latitudes in the region (17oS and 19oS) shows a weak but broad and deep current transporting approximately 4 Svedrups to the south with a flow reversal of about the same magnitude at depth. The undercurrent was weak in the southern section but the poleward flow was approximately the same. The current reached down at least 440 m depth and extended out to 250 km in width in the northern section. The current at this location is characterised by a core with a low salinity (less than 35.2) with lower salinity patches indicating possible eddies. It was persistent all through May 1993. Other current measurements quoted by Holloway (1994) at 20oS, state that the flow is poleward from December to March.

The top of Exmouth Plateau is incised by broad channels, the most distinct of which is the Montebello Trough which lies just off the continental slope on the southern side of the plateau and drains towards the Cape Range Canyon. The northern portion of the plateau comprises the Dampier Ridge extending out from the continental slope and the Swan Canyon system located to the north and offshore.

The Rowley Shoals are a chain of coral atolls and comprises three reefs (Mermaid, Clark and Imperiuse Reefs) rising from about the 350 m depth (Figure 6-31, Figure 6-33). Mermaid Reef comprises a reef flat 500 to 800 m wide, shelving into shallow back-reefs rich in corals, and into a large lagoon, up to 20 m deep. This reef has no features above the high-water mark. The Clarke and Imperiuse Reefs are similar, but their lagoonal systems are shallower and more complex. The surface of the terrace is a low-relief platform, which is cut in the south, by erosional channels of over 300 m depth. The sediments of the Rowley Shoals are pelagic carbonate muds, often with an important foraminiferal sand component producing muddy sands in some areas.

Burns et al (2001) used sediment traps on the North West Shelf and Exmouth Plateau to estimate vertical fluxes of hydrocarbons, organic matter and inorganic elements from the surface photic zone. Dry weight fluxes into the traps ranged from 124 to 616 mg m-2 day-1 and POC fluxes ranged from 22.8 to 43.9. The biogenic flux of hydrocarbons consisted of marine zooplankton, phytoplankton and bacteria. Significant components of petroleum-derived hydrocarbons were detected that were approximately 4 times the biogenic hydrocarbon flux at shallow stations and up to 7 times at the most offshore station. The molecular makeup of the hydrocarbons indicated a mature and moderately degraded crude oil from source rocks of marine sediments with a calcareous lithology. Commercially exploited oils of similar composition are mostly not known on the NW



CSIRO
Data Sources:
Geoscience Australia (2005): Australian Bathymetry and Topology

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Data Sources:
Geoscience Australia (2004): Geomorphic features of the EEZ
Geoscience Australia (2003): TOPO 2.5M
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Figure 6-31 Exmouth Plateau sub-region showing selected features (upper) and geomorphology (lower).

Shelf and Burns *et al* (2001) postulated that it bears similarities to oil from an active petroleum system in the southern Carnarvon Basin. The implications of the hydrocarbon flux for productivity and uptake through the food chain is unknown. It is clearly an area that deserves further investigation.

The interaction of the semi-diurnal tides with the topography of the Exmouth Plateau appears to generate internal tides of about the same strength as barotropic tides (Holloway, 1988). Thus this area is responsible for the internal tides impinging upon the North West Shelf. The tides are strongest during the months from January to March.

Table 6-7 Summary physical data for the Exmouth Plateau sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
1,614.4	2.26	0.046	9.62	2.64	31.2	88.1
Ave. SST (C°)	**Ave salinity (ppt)**	**Mixed layer depth (m)**	**N (µM) 0m/150m**	**P (µM) 0m/150m**	**Silicate (µM) 0m/500m**	**Chlorophyl (mg/m3)**
26.84	34.89	35.68	0.11/9.49	0.13/0.70	3.65/26.85	0.12

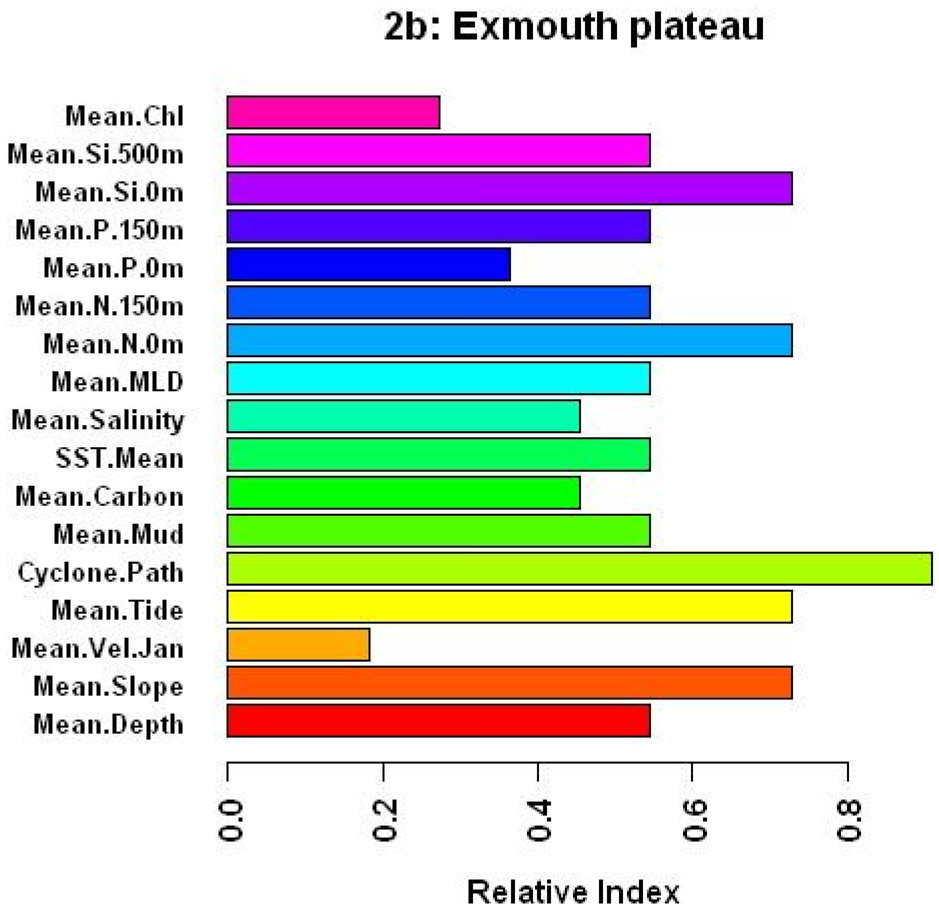


Figure 6-32 Summary physical data for the Exmouth Plateau sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

6.6.2 Trophic system features and dynamics

Mapping of fishing effort in the Commonwealth fisheries (Mike Fuller, pers comm. 2007) indicates that the continental margin of this region contains high densities of effort for the NWMR. Particular aggregations of effort occur in the association with the slope region above the Montebello Trough and with the Dampier Ridge, suggesting possible associations of these structures with enhanced production.

Very little appears to be known about the biology on the Plateau itself. This region contains the North West Slope province (from North West Cape to Dampier – see Last *et al.*, 2005). It is the richest slope province of Australia with some 508 fish spp. of which 76 are endemic. Last *et al.* (2005) found distinct biomes located at depth ranges of 150 to 225m, 300 to 530 m, 650 to 780 m, 900 to 1100 m. Sediments on the Plateau and slope are primarily muddy sand and sandy mud. All of which suggests that scavengers, benthic filter feeders and epifauna are to be expected to be found on Exmouth Plateau, particularly at the intersection with the continental margin.

Above the plateau and within the upper slope pelagic water column, nekton and small pelagics may be expected in response to sporadic but widespread upwellings visible in satellite imagery. Nekton in the deep scattering layers would in turn interact with biota on the continental margin and on the Plateau through the rain of detritus. Internal waves would sweep depth layers across the slope and possibly onto the continental shelf. So, while overall productivity above the plateau is low (see above), the main sources of production would appear to be derived from energetic but sporadic events.

A national survey of sponge biodiversity by Hooper and Ekins, (2005) showed that Rowley Shoals had no similarity with any other locality – in other words that it is a unique faunal feature.

Overall, trophic interactions are between the water column and the plateau through vertical processes, while advective and vertical processes may be relevant in the interaction with the slope. Benthic interactions would be expected between the continental slope components and the plateau through migratory animals and from geophysical processes associated with topographic features such as canyons and valleys.

6.6.3 Services and linkages

The Exmouth Plateau serves an important role in its interaction, as a topographic obstacle, that modifies the flow of deep waters, as a generator of internal tides and in uplifting deep water nutrients, and other water properties, closer to the surface. The plateau itself serves as a receptacle for settling detritus and other matter which support the organisms on the plateau. Matter and (fine) sediments may also get transported via the valleys and channels to repositories on the sides of the plateau.

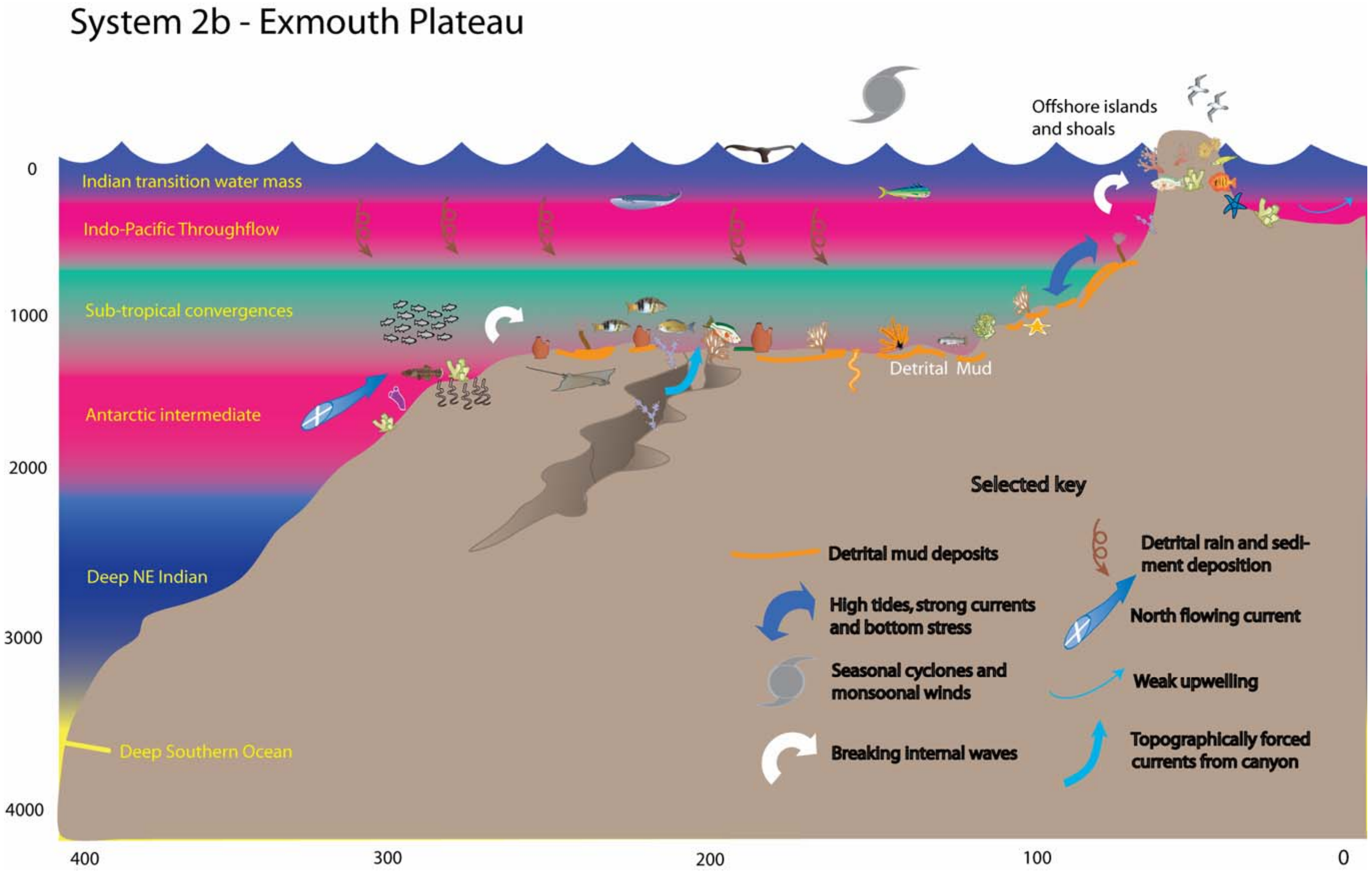


Figure 6-33 Habitat diagram of the Exmouth Plateau sub-region showing selected important drivers and features. 70-100 m deep chlorophyll maxima not shown.

The beginnings of the Leeuwin Current broadly sweeps across the top layer of the waters bringing with it tropical Indo-Pacific organisms over the plateau. The interaction of this flow with the topography can be expected to generate unique circulations that may be utilised by species living on the plateau. The suggestion from the work by Hooper (2005) that sponge assemblages on the Rowley Shoals are unique indicates little connectivity between the Rowley Shoals and other neighbouring habitats, although this should be investigated further.

Some local production and species can also be expected to flow south to the next system at the surface while at depths where the Leeuwin Current reverses; transport from the southern areas can be expected into this region. Hydrocarbon uptake in this system may find its way via the Leeuwin Current to systems further south.

The nutrients from the Exmouth Plateau and slope play a key role in the productivity of the adjacent shelf system through the action of internal tides and upwellings at the shelf edge and onto the continental shelf.

6.6.4 Key species interactions

The Exmouth Plateau provides an expanded surface area extending offshore for communities located at about the 1000 m depth level. Interactions with the major current systems are also likely to bring deepwater species into closer proximity to those on the plateau and likewise, strong near-surface current and tidal interactions may bring shallower species into contact with the deeper ones.

The surface of the plateau and it channels and valleys may provide conduits for the delivery of materials and sediments to the deeper slope and abyss which in turn may sustain a unique set of communities at the base of the plateau.

Satellite observations suggest that productivity is enhanced along the northern and southern boundaries of the plateau and along the shelf edge which in turn suggests that the plateau is a significant contributor to the productivity of the region.

6.6.5 Resilience and vulnerability

Production and trophic interactions on the Plateau and along the continental margin is to a large extent controlled by the ITF which on the one hand causes a general suppression of production through the overlay of deep oligotrophic waters, and on the other hand, the mixing from current system itself causes an enhancement of the production. Thus, the trophic system on Exmouth Plateau is exposed to variations in the ITF and potential interactions with the tidal currents. The dependence of the trophic system on sporadic events for generating the occasional high productivity suggests, as a hypothesis, that the system may be resilient to temporal variability in the supply of production events. However, there is also a dependence or adaptation to the continual exposure to high tides and associated current impacts on the upper continental slope.

The high fishing effort and its location to major oil and gas exploration and production are potential threats to the trophic system on the slope and on the Plateau via downslope transport and vertical deposition.

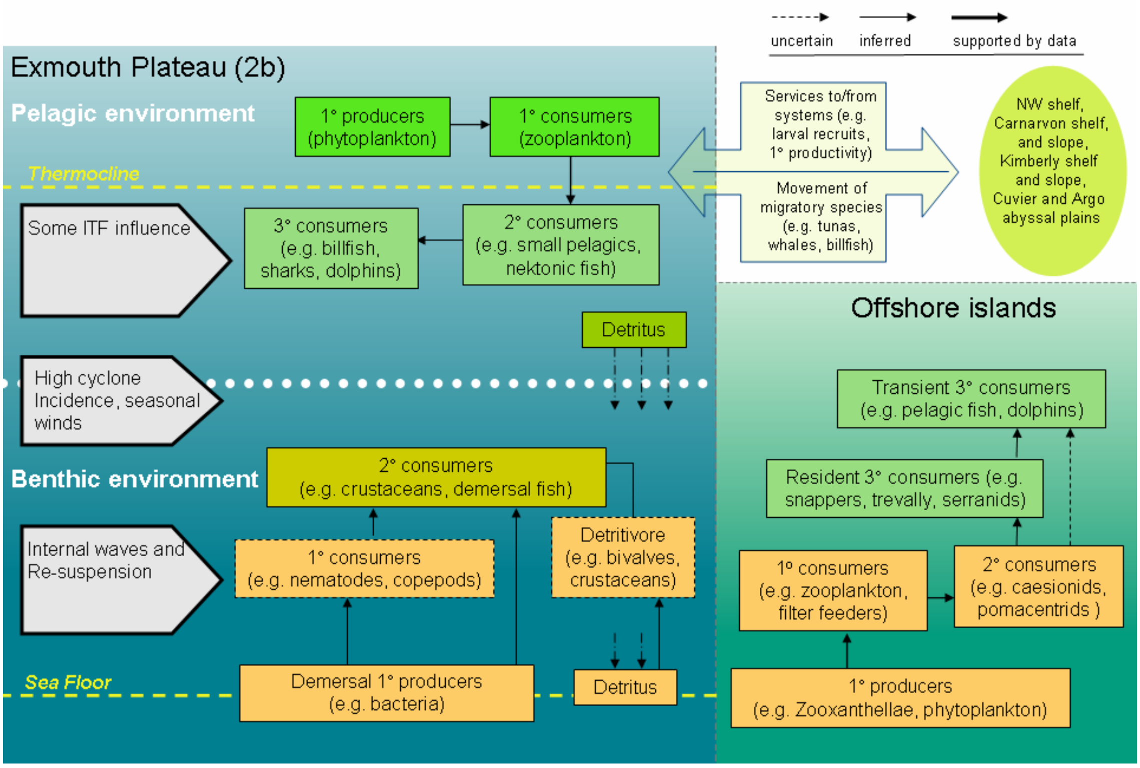


Figure 6-34 Conceptual trophic model of the Exmouth Plateau sub-region showing information on the extensive mid-slope habitats (left) and the less extensive but important offshore island habitats (right).

The uniqueness of the Rowley Shoals requires further investigation as to its reliance on local processes versus those from remote locations.

6.6.6 Information gaps

We lack information about what biota exists on the Plateau and their dependence on habitats of the Plateau. The intersection between the Plateau and the continental margin may be an important transport pathway linking the two structures. We need a much better understanding of the flow of deep water and surface waters and how they are affected by the Plateau structure. The Plateau may serve as an important receptacle for detrital matter and its transport to the deep abyss via various topographic channels, valleys and canyons.

Endemism is high for fish on the continental slope but we have little knowledge of why that is the case, let alone what its response might be to natural changes and pressures from anthropogenic activities.

The findings by Burns *et al* (2001) of significant fluxes of hydrocarbon (from the southern Carnarvon Basin) in sediment traps suggests potential interaction with phytoplankton and the subsequent flow-on effects to the food chain. With the increasing oil and gas exploration interests in the region, it is imperative that baseline studies are established to determine the role hydrocarbons currently play in the marine ecosystem of the North West Shelf and the Exmouth Plateau.

6.7 Carnarvon Shelf (3a)

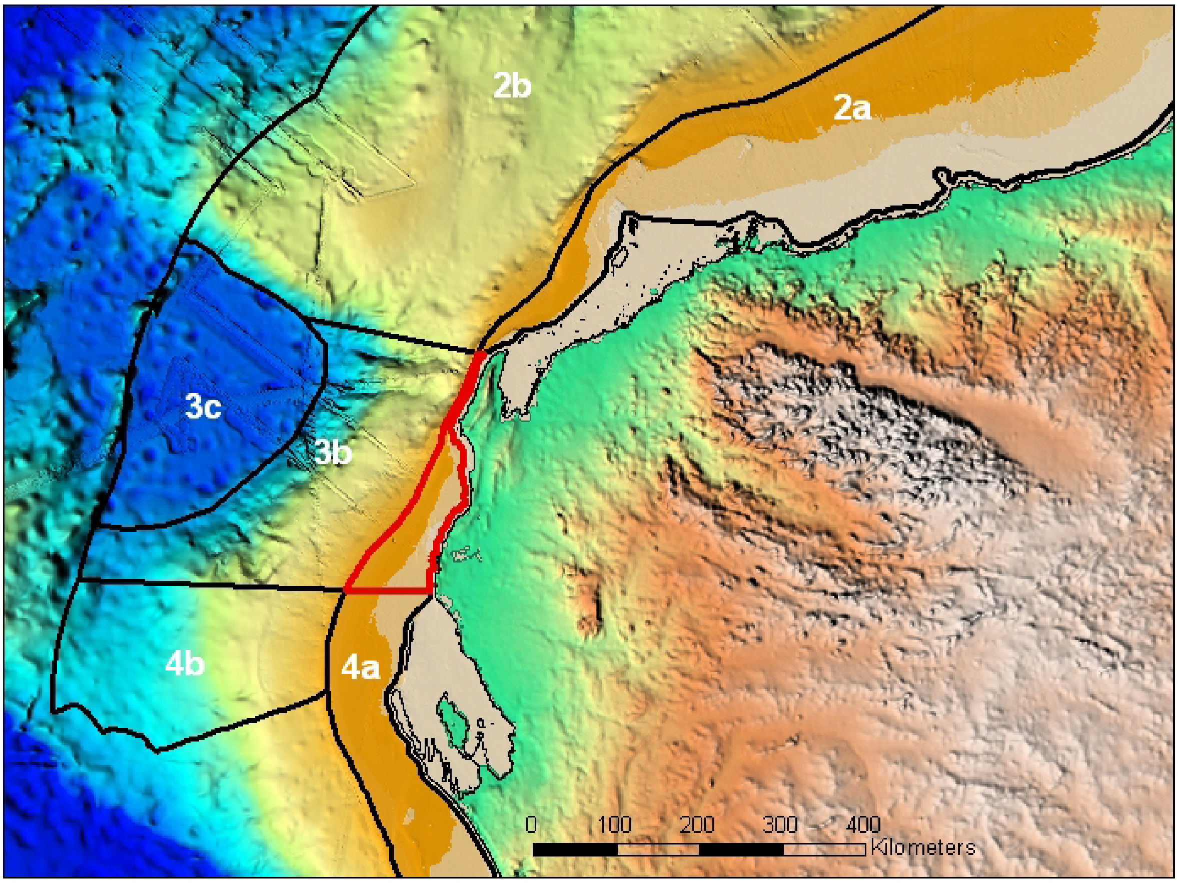


Figure 6-35 Carnarvon Shelf (red outline) and neighbouring sub-regions.

6.7.1 Drivers and physical features

The Carnarvon Shelf sub-region covers a section of the continental shelf, between the North West Cape southwards to the northern extent of Shark Bay (Figure 6-35, Figure 6-37). It ranges in depth from shallow coastal waters (~ 30 m deep) to the shelf break (~ 200 m). It is unique in having a relatively narrow shelf, particularly at the northern extent, adjacent to the North West Cape and Ningaloo Reef, where the shelf break is only about 10 km offshore. Consequently, the slope and shelf edge processes have a strong influence in this sub-region than in others in the NWMR. In the southern part of the sub-region, the shelf is broader (80 to 100 km wide) flat and sandy. There is little freshwater runoff or any other coastal influence on this shelf.

There is a marked seasonal variation in SST, with the sub-region being at the boundary of tropical and subtropical waters. Surface currents (mostly driven by the Leeuwin and Ningaloo counter current) are relatively high, especially during winter. However, tidal currents are generally low and do not exceed the speed at which significant sediment mobilisation occurs. The area is subject to moderate cyclone influence (Figure 5-7).

However, cyclones in this sub-region tend to run parallel to the coastline and have a significant impact on the benthos. The substrate is dominated by gravel inshore, and sand offshore, with relatively low mud content throughout and high in carbonates, especially in the inshore areas.

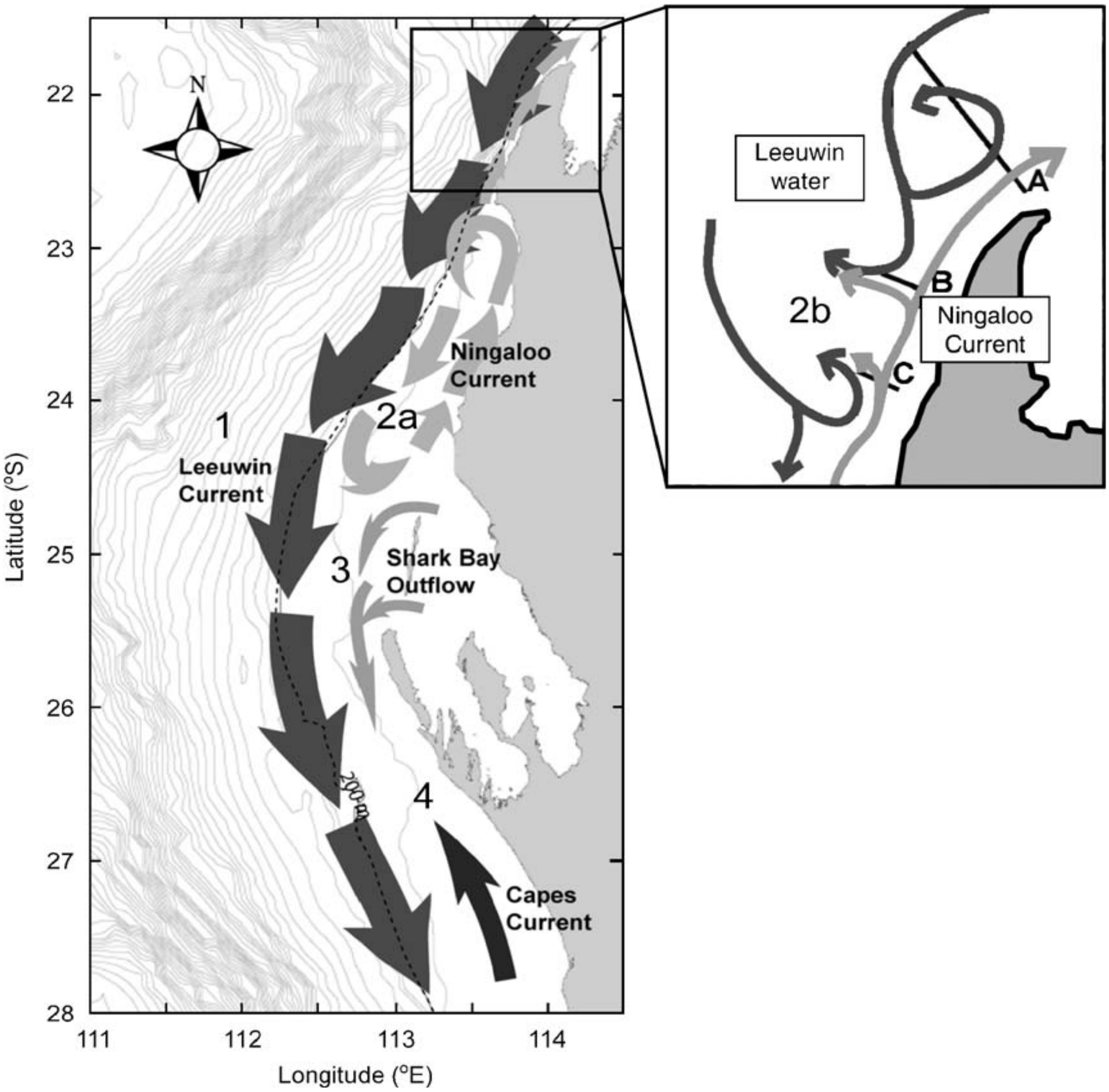
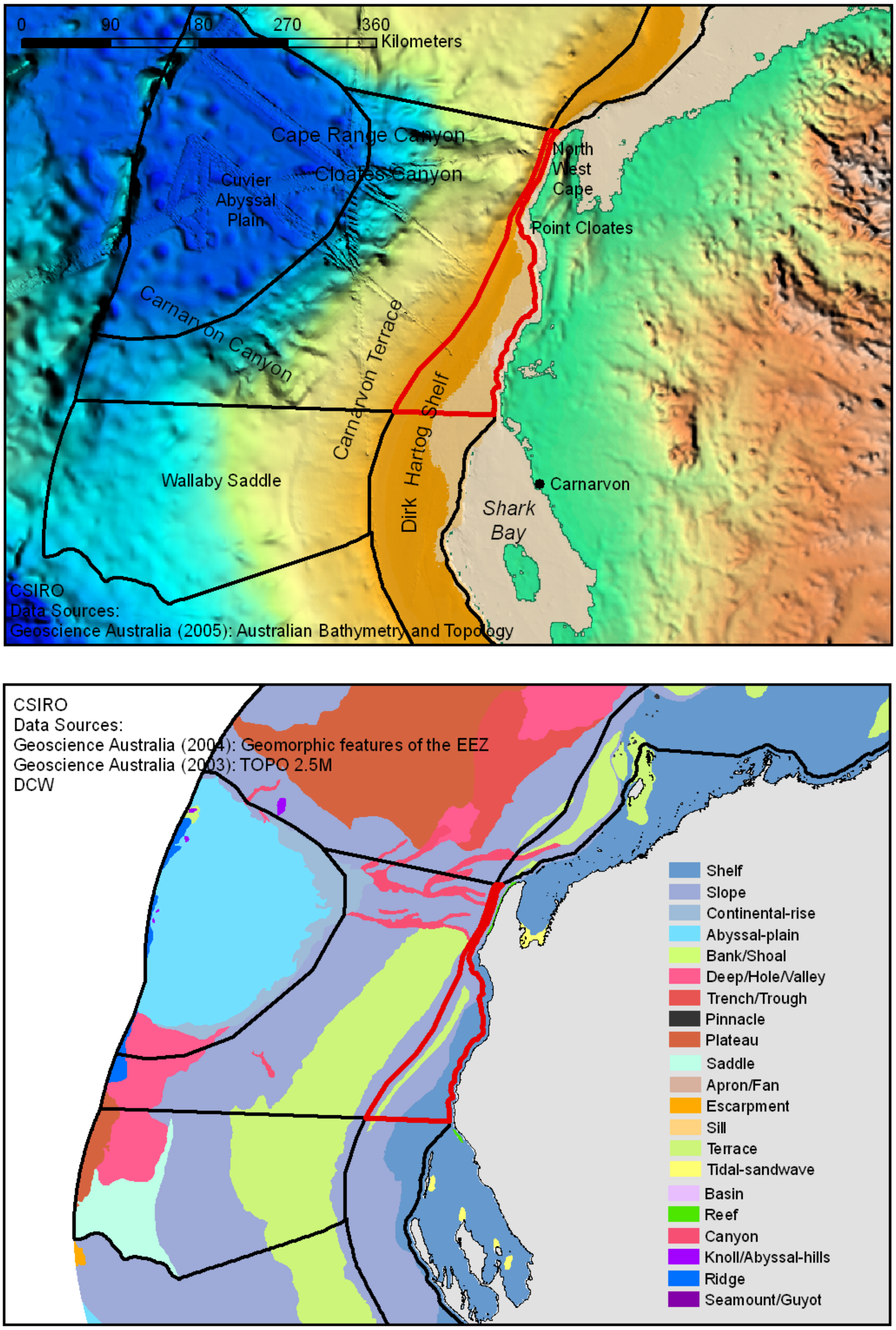


Figure 6-36 Relative positions of the Leeuwin, Ningaloo and Capes Currents, and the Shark Bay Outflow, in the region of the West Australian coastline between Kalbarri and NW Cape (from Hanson *et al.*, 2005).

The sub-region is characterised by having relatively very low average nitrate N in waters down to 150 m deep but relatively high phosphorous P in the surface and low at depth, and low silicate Si, especially in the southern section of the sub-region. However, higher nutrient levels occur in certain areas. A band of high-depth integrated nitrate is often located along most of the shelf break. This is an area of active mixing, and may promote nutrient fluxes into the euphotic zone. Relatively high levels of nutrients are also associated with the Ningaloo counter current, which occurs inshore, and from advection of shelf-edge production to the midshelf region (Figure 6-36).



CSIRO
Data Sources:
Geoscience Australia (2005): Australian Bathymetry and Topology

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Data Sources:
Geoscience Australia (2004): Geomorphic features of the EEZ
Geoscience Australia (2003): TOPO 2.5M
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Figure 6-37 Carnarvon Shelf sub-region showing selected features (upper) and geomorphology (lower).

This area, together with the adjacent Carnarvon Slope sub-region, is in the start of the Leeuwin Current proper. At this latitude, the current is relatively narrow (~50 km wide) and more or less centred on the shelf break (~ 200 m). Consequently, it mainly has influence on the offshore portion of the shelf sub-region. The Leeuwin Current drives warm, low-nutrient surface waters south along the continental shelf. The current is strongest during autumn and winter (April-September). It weakens during the spring and summer (September-April), due mainly to southerly winds during that time (Figure 5-6). However, the strength and position of the Leeuwin Current and the depth of its mixed layer varies spatially and temporally on other scales as well, and this is not well understood (Hanson *et al.*, 2005).

The southerly winds during summer (Figure 5-6) drive a significant north-flowing counter current, the Ningaloo Current (Figure 6-36). This current is a smaller north-flowing coastal current that oscillates in a north-south direction between the Leeuwin Current and the shelf adjacent to Ningaloo Reef (Taylor and Pearce, 1999; Hanson *et al.*, 2006). The Ningaloo Current is wind-driven and limited to the surface (< 50 m) (Gersbach, 1999; Woo *et al.*, 2006), but is sufficient to influence cold water upwelling from depths of around 100 m making it relatively nutrient rich. However, it is still lower than other upwelling-influenced zones off California, NW Spain and Southern Africa (Hanson *et al.*, 2005). Characteristic oceanographic features of the Ningaloo Current include a series of anti-cyclonic eddies that circulate in a south-westerly direction at various locations along the shelf (particularly just south of Point Cloates) where flow is interrupted by the south flowing Leeuwin Current and changes in bathymetric gradient (Taylor and Pearce, 1999; Woo *et al.*, 2006).

Seasonal winds have a large impact on the current patterns. Wind stress during most of the year is very low (Hayes *et al.*, 2005), and there is little vertical mixing. However, higher nutrient waters also reach the surface of this trophic system as the result of offshore winds during the SW monsoon, creating nutrient rich water that is carried south to about 20° S and then deflected offshore (Lyne *et al.*, 2005).

Table 6-8 Summary physical data for the Carnarvon Shelf sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
112.0	0.65	0.090	0.00	1.19	0.3	

Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
24.52	35.19	37.91	0.03/2.03	0.15/0.30	3.33/10.54	0.39

6.7.2 Trophic system features and dynamics

The hydrodynamics and related biogeochemistry of the region is highly dynamic. Phytoplankton production in the shelf system is tied to ambient nutrient levels, and this is reflected in the distribution of phytoplankton in the region, which is extremely variable on temporal and spatial scales.

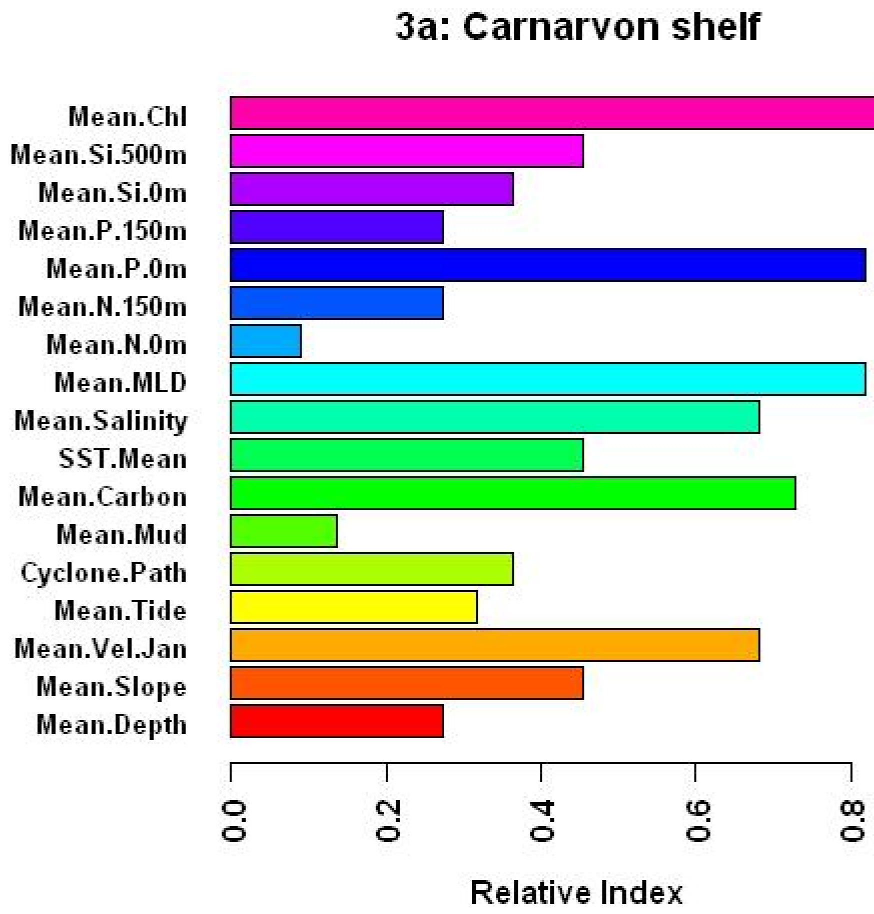


Figure 6-38 Summary physical data for the Carnarvon Shelf sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

Furnas (2007) measured phytoplankton biomass, community and size structure, primary production and bacterial production at stations on the shelf and continental slope near North West Cape, Western Australia during the summers of one El-Nino and two La-Nina years. In the El-Nino year, the flow of the Leeuwin Current declined, thermocline depths shallowed bringing nutrients closer to the surface. Episodic intrusions of thermocline waters onto the shelf increased primary and bacterial production by 2 to 4-fold compared to La-Nina years, while total phytoplankton standing crop increased by nearly 2-fold. Larger phytoplankton in the form of diatoms dominated summer Chlorophyll standing crops in the El-Nino year. Furnas (2007) observed that while no surface signs of upwellings were evident, primary production rates episodically reached very high levels (3–8 gCm^{-2} day^{-1}). Bacterial production ranged between 0.6 and 145 percent (median of 19 percent) of concurrent primary production. Furnas (2007) concluded that variations in the Leeuwin Current may have episodic, but significant influences on pelagic productivity along the western margin of Australia.

The low surface nutrient levels associated with the Leeuwin Current limits productivity at higher trophic levels (Hanson *et al.* 2005), leading to oligotrophic conditions to similar levels as the Coral Sea. Average Leeuwin Current phytoplankton biomass is characteristic of low productivity oceanic waters like the Indian, Pacific and Atlantic Oceans (Hanson *et al.*, 2005). However, mixing associated with the boundaries of the

Leeuwin Current and the upwelling associated with the Ningaloo Current brings high nutrient loads and hence, relatively high productivity when it is at its strongest in spring and summer.

Mean depth-integrated chlorophyll is also significantly higher in Ningaloo Current waters than Leeuwin Current and offshore waters (Hanson *et al.*, 2006). Shelf-edge dynamics and eddies associated with the interaction of the Leeuwin and Ningaloo Currents contributes to higher productivity of offshore waters. This high primary productivity leads to high densities of primary consumers, such as micro and macro-zooplankton, such as amphipods, copepods, mysids, cumaceans, euphausiids. These are important prey items of large planktivours such as manta rays and whale sharks which are mostly found nearshore in shallower waters (Sleeman *et al.* 2007).

This high, though somewhat sporadic, inshore productivity has a significant influence on the adjacent coastal region that contains Ningaloo Reef. The narrow shelf meand that this productivity, when it douse occur, ad immediately available to the reef consumers, however, the intermittent lower nutrient conditions promotes the dominance of coral rather than algal communities. The lack of coastal runoff, and the narrow nature of the shelf at the NW Cape, means that the Ningaloo Reef is almost solely dependant on the offshore nutrient inputs provided by the dynamics of the Ningaloo and Leeuwin currents.

In the offshore zone of the sub-region, productivity and trophodynamics are influenced more by processes at the shelf break. South of Point Cloates, the 200 m isobath forms the boundary between highly productive continental shelf waters and the more depauperate offshore waters. The shelf break appears to be an area of active mixing, promoting nutrient fluxes into the euphotic zone and fuels localised production and biomass peaks. However, the spatial distribution and periodicity of these dynamic events is not well known.

Offshore shelf areas also benefit from advected productivity from the localised upwelling associated with the Ningaloo Current resulting in pulses of phytoplankton and zooplankton flooding across the shelf then inshore onto Ningaloo Reef. This productivity is critical in sustaining the unique conditions of the Ningaloo region such as its high reef biodiversity and high density of megafauna such as whale sharks.

Productivity in benthic habitats is likely to be enhanced by seagrass and algal beds, especially in the inshore, clear water areas of the sub-region. The benthic habitats are dominated by sandy substrates likely to support relatively sparse invertebrate community, including holothurians, urchins and crabs and polycheates. There is limited evidence that patchy harder substrates also occur throughout the shelf. These are likely to support a low density of sessile invertebrates, such as sponges and gorgonians. Consequently fish fauna may be more diverse than those on the barer sandy areas.

There is likely to be a gradient of epibenthos density from inshore to offshore. The benthic environment in the shallow inshore regions out to the mid shelf (~100 m depth) would be in direct connection with the pelagic system, thorough mixing and vertical migration of plankton (Tranter & Leech 1987), and sessile filter feeders have direct access to live phytoplankton below the pycnocline. Offshore habitats >100 m deep would receive detrital input from subsurface phytoplankton and particulate organic matter (POM) (detritus, zooplankton faecal matter) more than from phytoplankton living below the pycnocline. The shelf break is also likely to support populations of epibenthos, on the harder substrates, and rely on detrital input from higher productivity on the shelf edge waters. Bentho-pelagic fishes such as deep water snappers (e.g. *Paracaesio* spp, other *Pristipomoides* spp, and *Eletis* spp) are also likely to be associated with this shelf edge habitat.

The sub-region is the location of a significant biogeographic faunal boundary between tropical and temperate species. For example, the NW Cape is identified as a boundary point for demeral shelf and slope fish communities (Last *et al.*, 2005) and sponge fauna (Hooper and Ekins, 2004). Therefore the species composition of the benthic environment in particular would be a mix of tropical and temperate species with a north-south gradient. The very narrow shelf is in intimate proximity to deep water communities and the Carnarvon Shelf is a very unique region in that context. Consequently, even though the shelf species are diverse and abundant, they may reflect communities that are not resident or endemic to that area.

6.7.3 Services and linkages

The narrow nature of the shelf means that most of the systems within the sub-region are in intimate connection with the deep-water communities, whereas the relatively narrow shelf, particularly at the northern extent, reduces the interaction with adjacent shelf regions as a result of low/restricted advective flow along the shelf.

The sluggish flow of the Leeuwin Current from the shelf-edge of the North West Shelf brings with it tropical species and potential production from the Exmouth Plateau region. The Leeuwin Current is key driver of this system not only from it’s advective influence but also in the sporadic boundary mixing associated with it that brings deep nutrient layers closer to the surface.

Significant extractive fisheries occur on the offshore (Western Tuna and Billfish Fishery) and inshore (Ningaloo recreational finfish fishery) of this sub-region. However, the generally low nutrient waters of the Leeuwin Current appears to result in a low overall biomass of fishery species. For example, only a small proportion of the states Spanish Mackerel catch is taken in the Carnarvon Shelf sub-region.

6.7.4 Key species interactions

High productivity on variable temporal and spatial scales results in schools of zooplankton, including krill. This in turn supports a range of large planktivores such as whale sharks and manta rays which feed on plankton that thrive in this environment of elevated productivity. Humpback whales are a conspicuous seasonal visitor, and are at their highest density either side of the 200m depth contour (Sleeman *et al.*, 2007). However, they are thought not to feed during their migration and their occurrence is not correlated with local productivity but more reflecting seasonal migration patterns.

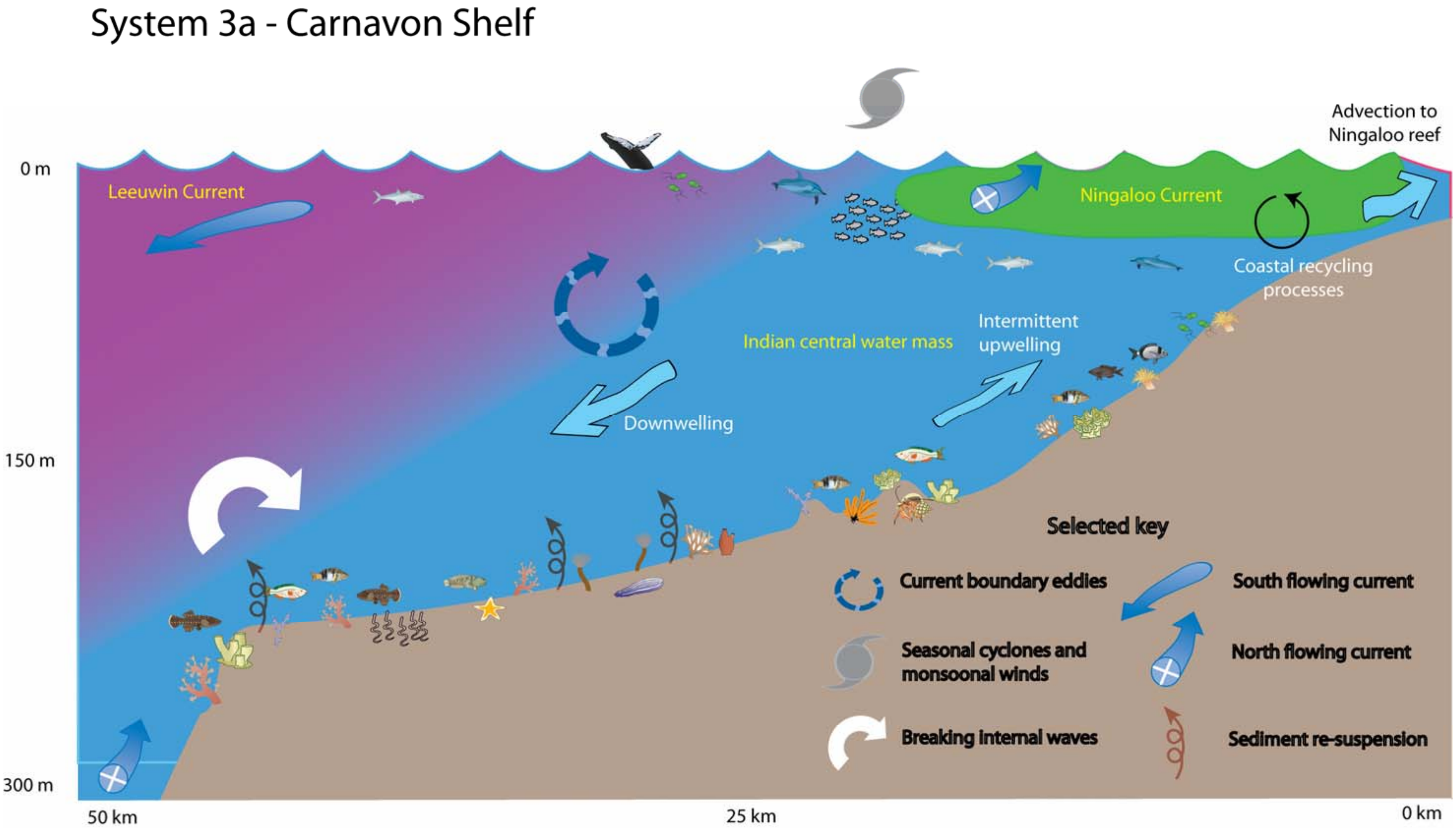


Figure 6-39 Habitat diagram of the Carnarvon Shelf sub-region showing selected important drivers and features.

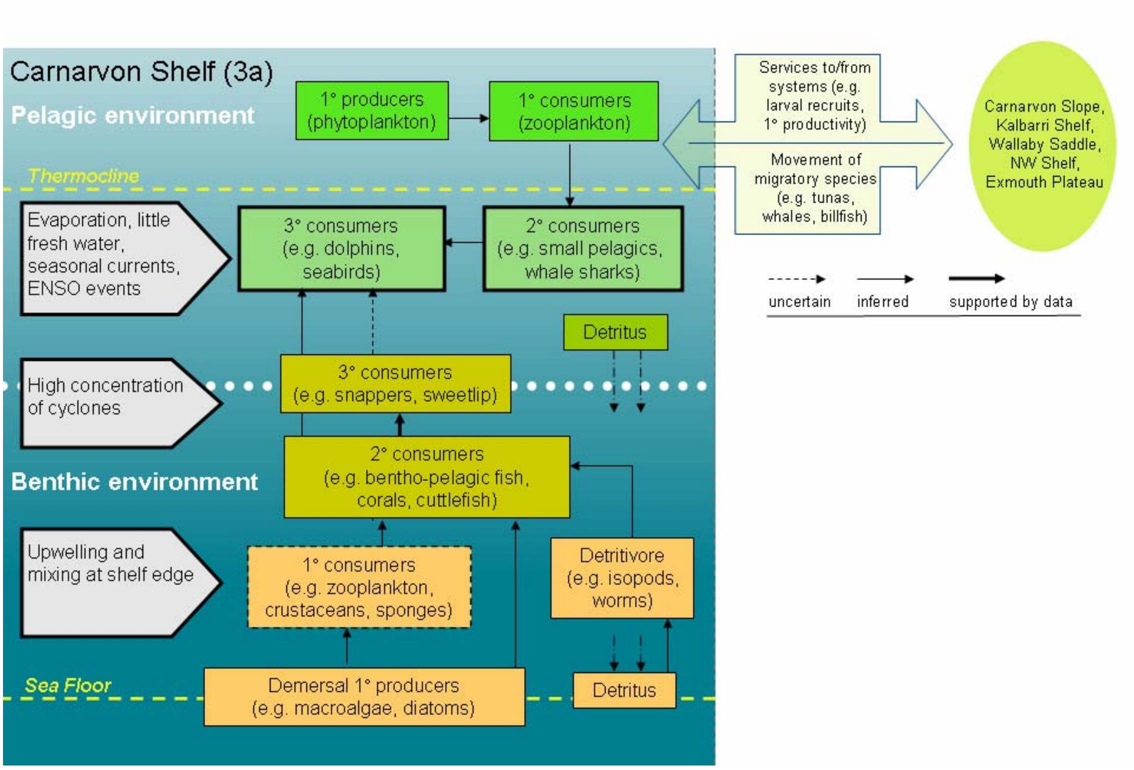


Figure 6-40 Conceptual trophic model of the Carnarvon Shelf sub-region showing information on the main habitat in the mid and inner shelf.

6.7.5 Resilience and vulnerability

Hanson *et al.* (2005) cite evidence that the strength and position of the Leeuwin Current and the depth of its mixed layer varies spatially and temporally along the west coast of WA. Therefore the biological impact of any upwelling in this region is a function of:

- The depth of the Leeuwin Current's nutrient-depleted upper layer (as influenced by mixing and the rate of phytoplankton consumption)
- The strength and duration of upwelling-favourable winds (i.e. the intensity of upwelling); and
- the geographical location, primarily with respect to the width of the continental shelf and resultant proximity of upwelling flows to deep nutrient pools

It has also been shown to be distinctly stronger during a La Nina year and weaker during an El Nino year (Feng *et al.*, 2003, Furnas, 2007). This has been shown to affect the water temperatures in the region, with relatively lower temperatures and reduced sea-level height during El Nino years when the current is weaker (Wilson *et al.*, 2003, Furnas, 2007). Nutrient layers are higher in the water column as well (Furnas, 2007). Changes to these broad current patterns caused by shifts in global climate patterns, such as greenhouse climate shifts that could increase the frequency of ENSO events and change the productivity of the system in way that are difficult to predict.

Seasonal winds also have a large impact on the current patterns. The strength of the Ningaloo counter current is directly related to the southerly winds during summer (Figure 5-6). Changes in the strength of these currents will have the impact on the dynamics and nutrient regimes of the region in unknown ways. However, the Leeuwin Current is known to have strong influences on the lifecycles and recruitment of many fish and invertebrate species (Caputi *et al.*, 1996), and changes in this dynamic could result in recruitment failures for some species.

Cyclones are known to have a large impact on the benthic environment of the shallow shelf regions. Wind driven waves and surge currents will remove or destroy epibenthic communities. Cyclones in this sub-region will tend to travel in an alongshore orientation which will maximise the potential for damage (Figure 5-7). At this stage, the number of cyclones in the region is relatively moderate. However, under a likely greenhouse influence they may become more frequent and possibly stronger.

6.7.6 Information gaps

The temporal and spatial dynamics of the Leeuwin and Ningaloo Currents and their impact on nutrient dynamics and productivity is not well known, although a very recent study by Furnas (2007) has provided the first insights into the impact of variability on phytoplankton ecology. However beyond the plankton system, the relationships are not so clear. For example, while there is a relationship between Leeuwin Current flow and recruitment strength of western rock lobsters, the mechanisms behind it are unclear (Caputi *et al.*, 2001).

The strength and position of the Leeuwin Current and the depth of its mixed layer varies spatially and temporally at different scales although this is not well understood (Hanson *et al.*, 2005, Furnas, 2007). The spatial distribution and periodicity of shelf edge mixing processes is also poorly known.

The demersal benthic communities of the shelf are not well studied or understood, including the distribution and abundance of sessile megabenthos, epifauna and infauna and their association with different sediment regimes.

6.8 Carnarvon Slope (3b)

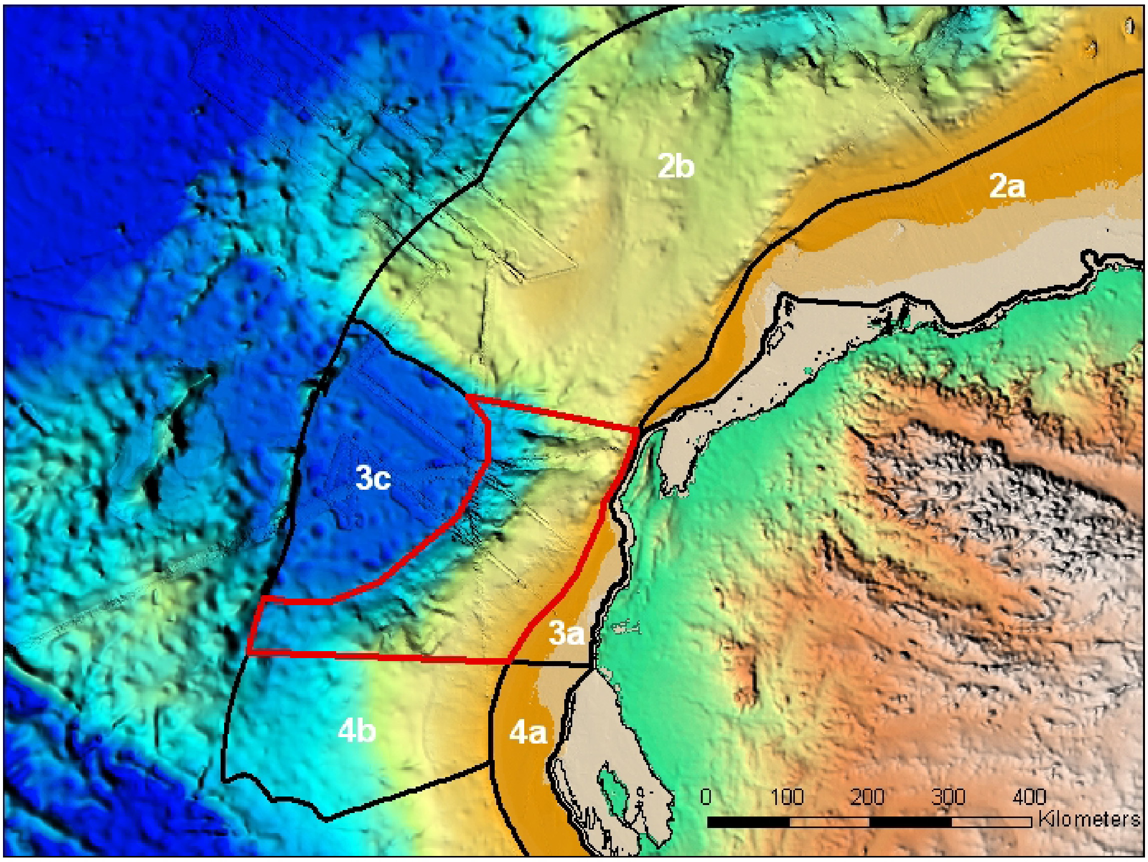
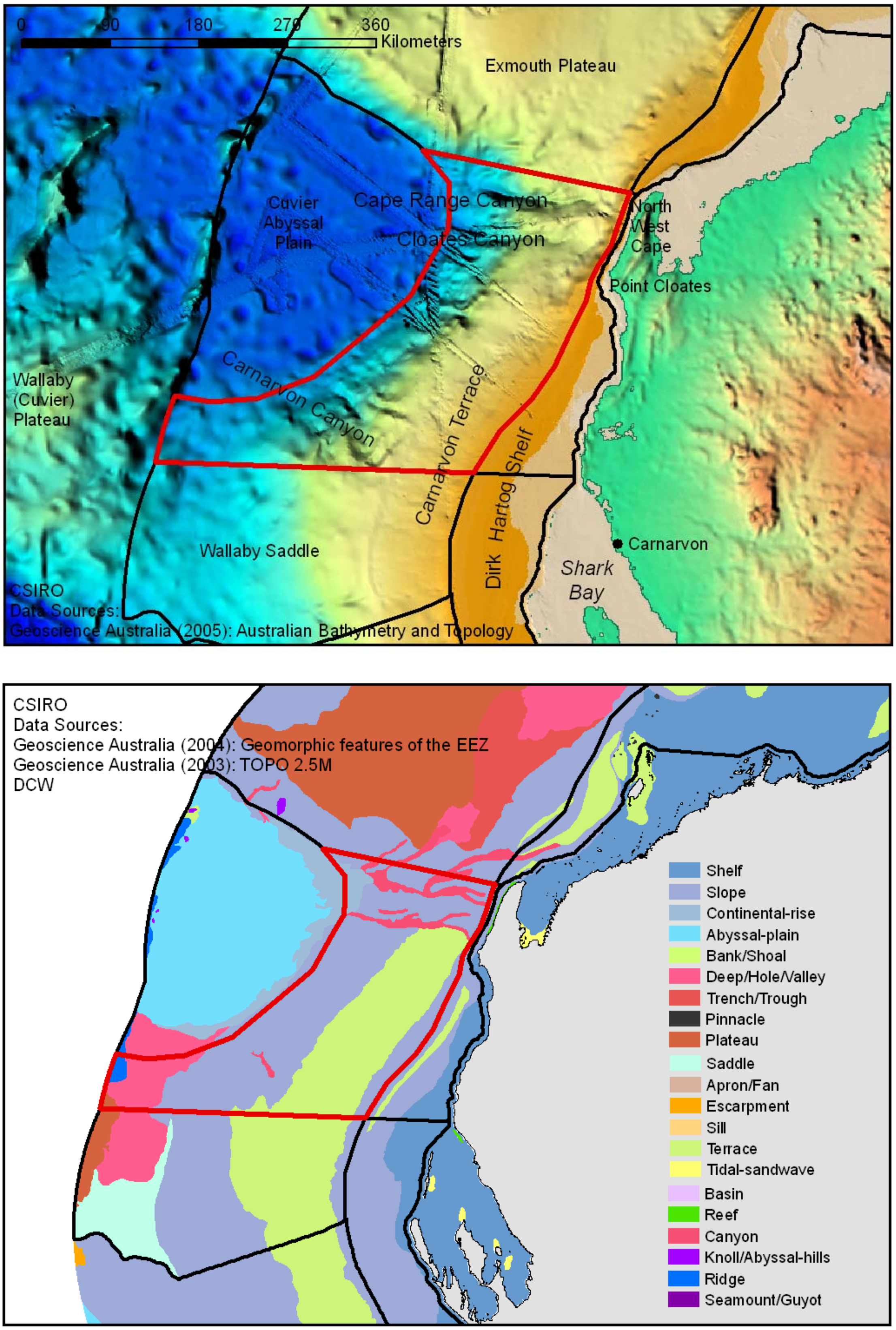


Figure 6-41 Carnarvon Slope (red outline) and neighbouring sub-regions.

6.8.1 Drivers and physical features

The Carnarvon Slope sub-region covers an area of the continental slope between the Exmouth Plateau to the north and the Wallaby Saddle to the south (Figure 6-41). Its northern limit is adjacent to North West Cape and it extends southwards to the northern extent of Shark Bay. It ranges in depth from about 200 m at the shelf break to the bottom of the slope where it adjoins the deep abyss of the Cuvier Abyssal Plain at about 4,500 m. This sub-region is unique in having the highest average slope of all the sub-regions in the NWMR (Table 6-9). It is characterised by having low average surface nutrients (N and P) and low silicate to a depth of 500 m. There is only moderate seasonal variation in sea surface temperature, and moderate surface currents (mostly driven by the Leeuwin Current). The area is subject to moderate cyclone influence (Figure 5-7). The substrate is low in mud and likely to be low in carbonates.

The sub-region is also unusual, for a slope ecosystem, in its close proximity to the coastal region, especially in the north adjacent to the shallow reefs of the Ningaloo region, where the shelf edge is only 10 km from shore. However, this close proximity does not appear to result in a strong coastal influence due to low freshwater runoff in this area.



CSIRO
Data Sources:
Geoscience Australia (2005): Australian Bathymetry and Topology

CSIRO
Data Sources:
Geoscience Australia (2004): Geomorphic features of the EEZ
Geoscience Australia (2003): TOPO 2.5M
DCW

Figure 6-42 Carnarvon Slope sub-region showing selected features (upper) and geomorphology (lower).

Table 6-9 Summary physical data for the Carnarvon Slope sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal exceedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
2,359.3	3.90	0.078	0.00	1.83	0.3	
Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
24.43	35.21	37.44	0.04/2.71	0.14/0.32	3.67/8.07	0.22

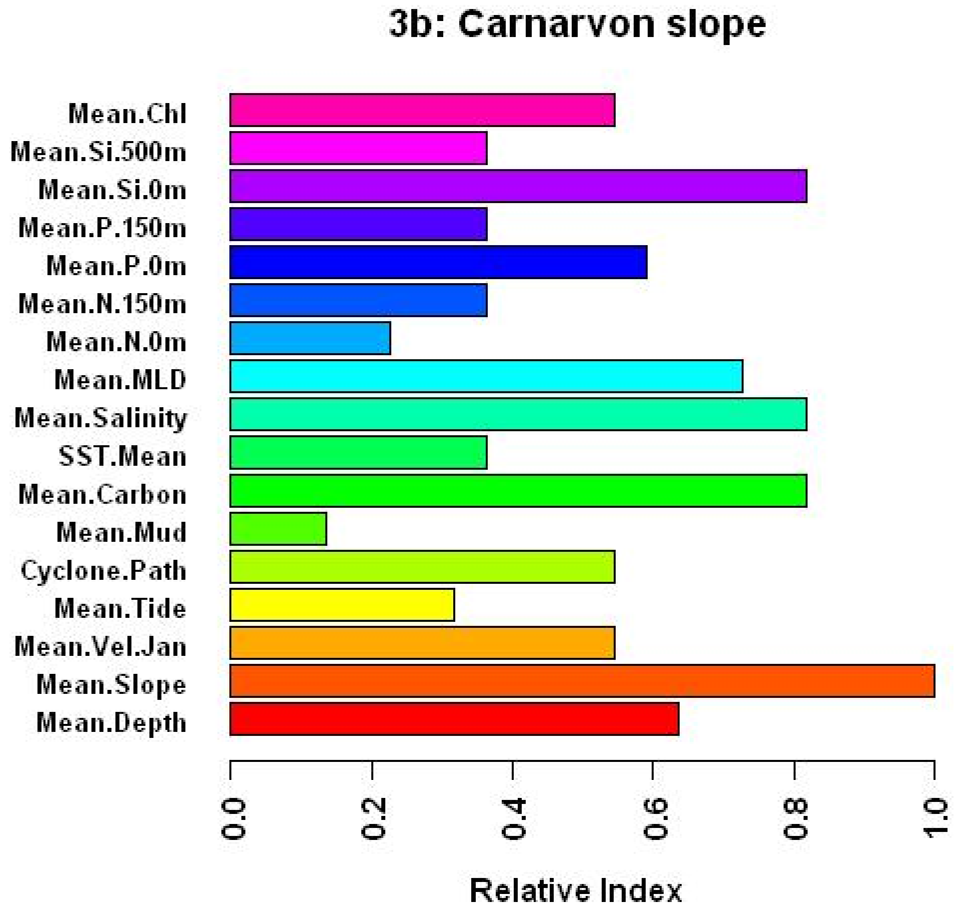


Figure 6-43 Summary physical data for the Carnarvon Slope sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

The geomorphology of the Carnarvon Slope is dominated by large submarine canyons, such as the Cloates Canyon and Cape Range Canyon adjacent to the NW Cape. These large canyons are features that are unique in the NWMR. The canyons and the Leeuwin Current interact to produce eddies inside the heads of the canyons resulting in a spilling out of higher nutrient cooler waters at their ends. The upper slope canyons are impacted by boundary currents and other processes, such as strong internal tides, creating upwelling at the canyon heads. The canyons are also repositories for particulate matter deposited from the shelf and sides of the canyons.

This area, together with the adjacent Carnarvon Shelf sub-region, is strongly influenced by the Leeuwin Current proper. However, this current is narrow at this latitude (~50 km wide) and centred on the shelf break (200 m isobath), and therefore only has influence on the inshore part of the sub-region. The Leeuwin Current drives warm, low-nutrient surface waters south along the continental shelf and influences biological production in proportion to its strength throughout the year. The current is strongest during autumn and winter (April-September), and weakens during the spring and summer (September-April) due to southerly winds that dominate during winter.

The surface waters throughout this sub-region are relatively low in nutrients (nitrate and phosphate) and silicate (Table 6-9) for most of the year. However, nutrient levels increase rapidly below the surface mixed-layer. Deeper waters have higher nutrient levels from the Antarctic Intermediate water-mass that carries nutrient-rich water at depth throughout the region. Spatially and temporally patchy high productivity events occur in the sub-region from localised processes such as upwelling and frontal dynamics which results in nutrient rich waters being brought to the euphotic zone. This occurs primarily at the heads of the large canyons and at the shelf break, especially during winter.

Seasonal winds have a large impact on the current patterns. Wind stress during most of the year is very low (Hayes *et al.*, 2005) and there is little vertical mixing. However, higher nutrient waters also reach the surface in this sub-region as the result of offshore winds during the SW monsoon creating localised upwelling of nutrient rich water that are driven south to about 20° S and then deflected offshore (Lyne *et al.*, 2005).

6.8.2 Trophic system features and dynamics

Pelagic environments

In the pelagic portion of the slope ecosystem, productivity flows are expected to be dominated by classical tropical pelagic processes of primary productivity (phytoplankton), being consumed by vertically migrating zooplankton (such as crustaceans, larval molluscs, larval fishes). Primary consumers such as jellyfish and salps will form prey for secondary consumers as such small schooling fishes, other micronekton and cephalopods.

Phytoplankton production in the region is tied to ambient nutrient levels, which in turn are strongly influenced by local oceanography (Hanson *et al.*, 2005). Usually the low nutrient waters of the sub-region result in low phytoplankton biomass. However, the winter offshore upwelling and the dynamics associated with inshore counter currents such as the Ningaloo Current have meant that higher productivity will occur on variable temporal and spatial scales.

This is especially prevalent in the heads of the canyons, and adjacent to the shelf break. The canyon’s proximity to boundary currents and other processes such as strong internal tides impinging on the upper slope create upwelling at the canyon heads that support enhanced local and downstream productivity, causing concentrations of primary and secondary consumers. The seasonally and spatially patchy higher productivity supports a range of pelagic filter feeders, including whale sharks in the inshore sections.

The main tertiary consumers of interest in the Carnarvon Slope ecosystem are transient billfish and tuna, such as: Broadbill swordfish (*Xiphius gladius*), Bigeye tuna (*Thunnus obesus*), Yellowfin tuna (*T. albacares*), and Striped marlin (*Tetrapturus audax*); and locally based pelagic predators such as sharks and dolphins that range through the sub-region following fish schools. These large pelagics have their highest density (based on spatial fishery catch data) in the shallower sections of the sub-region, in water depths between the 200 m and 2,000 m.

The region is an important migrating pathway for many species, including Blue whales (*Balaenoptera musculus*), Fin whales (*B. physalus*), Dwarf (*B. Acutorostrata*) and Antarctic minke whales (B. *bonaerensis)*, and in particular Humpback whales (*Megaptera novaengliae*). Most whales (apart from humpbacks) tend to migrate along or outside the 200 m contour (i.e. in waters outside the edge of the shelf) where they feed on tropical krill species such as *Pseudeuphausia latifrons*. However, while most species are weakly correlated with productivity, Humpback whales appear not to feed during their migration and their distribution is probably influenced more by current patterns rather than productivity. In this sense Humpback whales are not an integral part of the trophics of the region (Sleeman *et al.*, unpub).

Toothed whales and dolphins are significant predators of cephalopods (squid, octopus and cuttlefish), fish, and crustaceans (krill, amphipods and copepods) in the sub-region, with some species diving to take deep water prey at depths of up to 1500 m.

Benthic environments

In the benthos, the regional hydrodynamics will cause near-bottom currents that will result in larger seabed grain sizes or concreted facies associated with canyons and ridges. These support high epibenthic community density, (Gage and Tyler, 1991) by providing attaching surfaces and suspended food material for filter-feeders. Although poorly studied in this region, deepwater habitats elsewhere contain populations of meiofauna (mainly nematodes and harpacticoid copepods) that feed mainly on bacteria. They are also known to support larger infauna and benthic animals that are characterised by groups such as crabs, cephalopods, echinoderms and other suspension-feeding epibenthic organisms that may include deepwater corals (typically azooxanthellate).

The soft-bottom environment at the bases of canyons, primarily in the deeper slope regions, are likely to support patchy distribution of mobile epibenthos that is typical of the deep seafloor. These organisms, including holothurians, ophiuroids, echinoderms, polychaetes, sea-pens and other epifauna that are typically supported by microbial processes at the sediment surface. They also support infaunal assemblages dominated by detritivores. Down-slope transport of eroded shelf sediments and channelling of terrigenous sediments trough deep submarine canyons and troughs is also believed to be important for influencing patterns of deep benthic communities.

Fish and cephalopods are an ecological feature of the demersal environment of the slope. However, these communities change with depth from the shelf break to the deeper slope. Studies of fish communities have indicated the existence of at least three ecological communities (or biomes) among the fish fauna (Last *et al.*, 2005) based largely on depth. Faunal assemblages could not be assessed beyond the mid slope due to a lack of data (Last *et al.*, 2005). There is generally a reduction in the number of species with depth. Structural complexity and hard substrates of the canyons provide habitats for deep water snappers (e.g. Gold band snapper - *Pristipomoides multidens*) and associated species (e.g. other snapper - *Paracaesio* spp, other *Pristipomoides* spp, and *Eletis* spp). The slope in this sub-region is characterised as a transitional region for slope fisheries, in that it contains a mix of tropical and temperate species (Last *et al.*, 2005).

In the deeper slope biome (> 1500 m), assemblages would probably include small, bioluminescent species that vertically migrate, including Hatchetfish (*Argyropelecus* spp.), Dragonfish (*Melacosteus* spp.), Viperfish (*Chauliodus* spp.) and a number of squid and eel species. In addition, more bottom-attached species such as conger eels, macrourid cods and tripod fish are also expected to occur there. These organisms are typically present is very low abundances and are very patchily distributed.

The demersal trophic systems on the slope are mostly of the direct influence of pelagic primary production and primary consumers. The deeper communities are largely reliant on down-slope transport of sediments/nutrients and cycling of particulate organic matter (such as marine snow and other falling organic matter and detritus) through bacterial detrital food webs. Consequently, the productivity flows in the pelagic and demersal portions of the sub-region are somewhat disconnected, with falling detritus from the pelagic environment and, to a lesser extent, whale-falls, providing the main avenue of linkage. However, in the shallower zones of the sub-region, the productivity flows between the pelagic and demersal environment are expected to be more closely linked as the distance between the two environments decreases and they become more inter-connected. The shallow regions of the slope (<500 m) are likely to have micronekton (e.g. small fish and crustaceans) and some planktonic species migrating between the benthic to pelagic realms under a diel rhythm (e.g. Benoit-Bird and Au, 2006). Other connections include the temporary feeding movements of large tunas (e.g. Yellowfin and Longtail tuna, Shane Griffiths pers comm) and whales.

6.8.3 Services and Linkages

The Leeuwin Current transports surface water nutrients and planktonic organisms into the southern sub-regions of the NWMR and the SWMR. Downslope transport of sediments and associated nutrients and organisms also feed and pool in the deep waters of the Cuvier Abyssal Plain.

Several fisheries (WTBF, WDTF, WDSCIMF) operate in this sub-region, and these have significant amounts of fishing effort on a wide range of the tertiary consumers in both the pelagic and shallow benthic habitats. In the WTBF there is a significant catch and effort, which is amongst the highest in the NWMR, especially in the area adjacent to the NW Cape. This is indicating a high density of: Broadbill swordfish (*Xiphius gladius*) (which makes up over half the catch), Bigeye tuna (*Thunnus obesus*), Yellowfin tuna (*T. albacares*), and Striped marlin (*Tetrapturus audax*). Most of the fishing effort is adjacent to the 200m isobath.

6.8.4 Key species interactions

Impacts on top level predators in the marine environment are unclear, but believed to have potentially major impacts on their overall community structure, due to a regulatory function on lower food web levels. These may be the most important groups in this sub-region although little is known about the role of other species and communities in the sub-region.

6.8.5 Resilience and vulnerability

Wilson *et al.* (2003) also describes variability in the Leeuwin Current associated with El Niño and La Niña years. During El Niño years the current is weak and water temperatures along the coast of Western Australia are relatively low, while in La Niña years the current is stronger and water temperatures are higher. The effects of this dynamic are poorly understood, and complex interactions will occur with seasonal wind strength and direction. For example, stronger winter winds will result in upwelling, while at the same time slow the Leeuwin Current, reducing overall system current dynamics and therefore reducing eddies and upwelling.

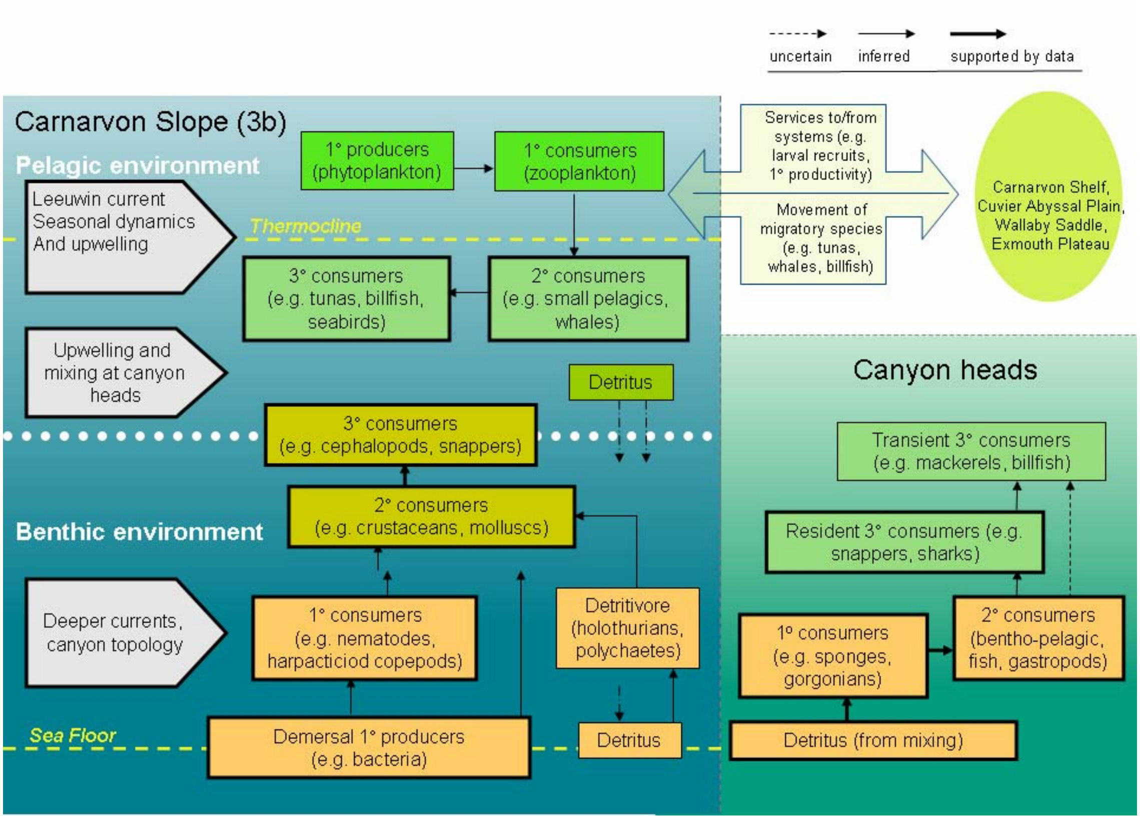


Figure 6-44 Conceptual diagram of the Carnarvon Slope sub-region showing information on the extensive mid and upper slope habitats (left) and the less extensive but important canyon head habitats (right).

6.8.6 Information gaps

The influences of the Leeuwin Current, its strength, location, and effects on the trophic system in the region are not well understood. Secondary consumers in both the demersal and pelagic systems are not well known or described.

The deep slope communities are poorly studied. Faunal assemblages have not been described beyond the mid-slope (Last *et al.*, 2005).

System 3b - Carnarvon Slope

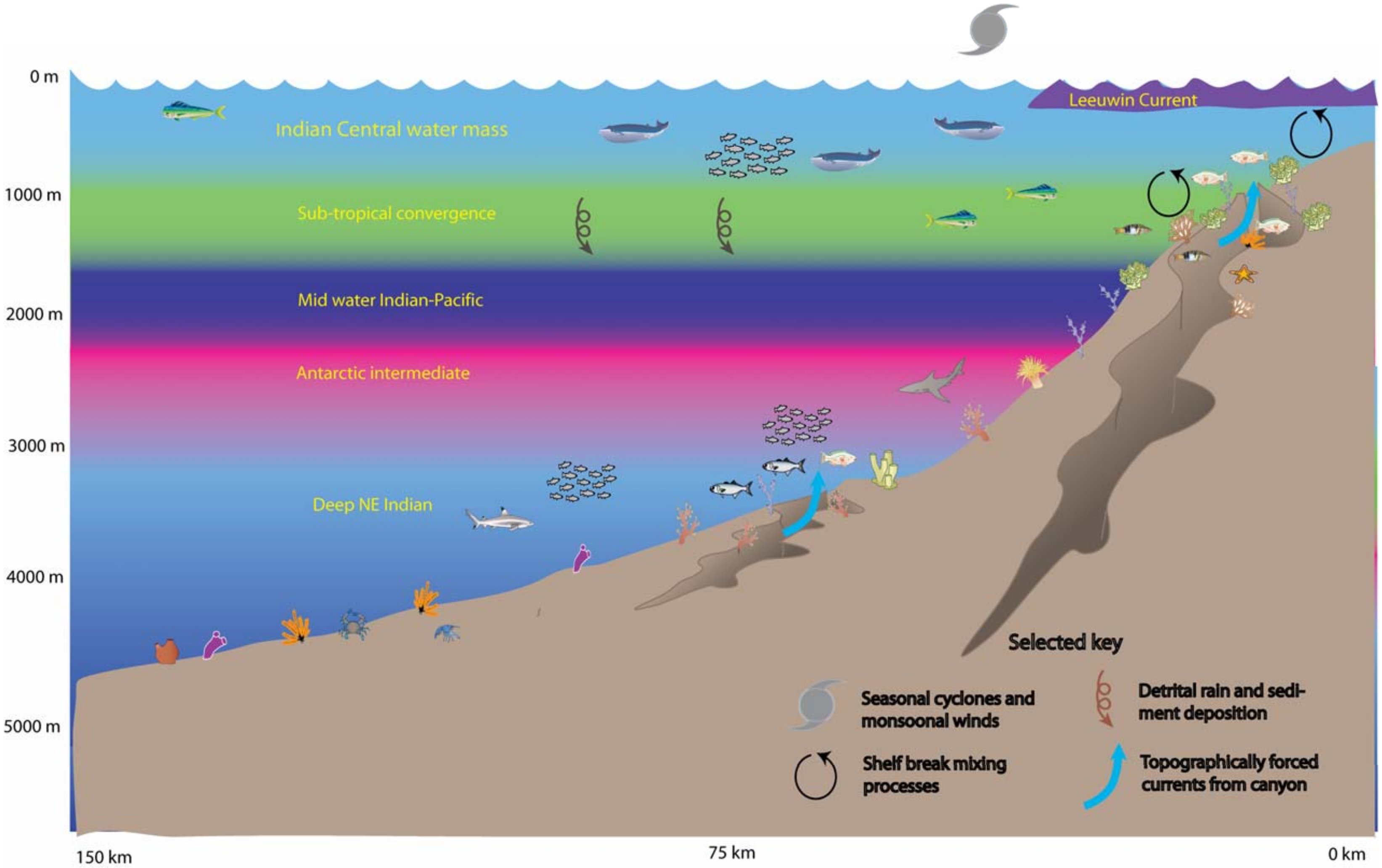


Figure 6-45 Habitat diagram of the Carnarvon Slope sub-region showing selected important drivers and features. 70-100 m deep chlorophyll maxima not shown.

6.9 Cuvier Abyssal Plain (3c)

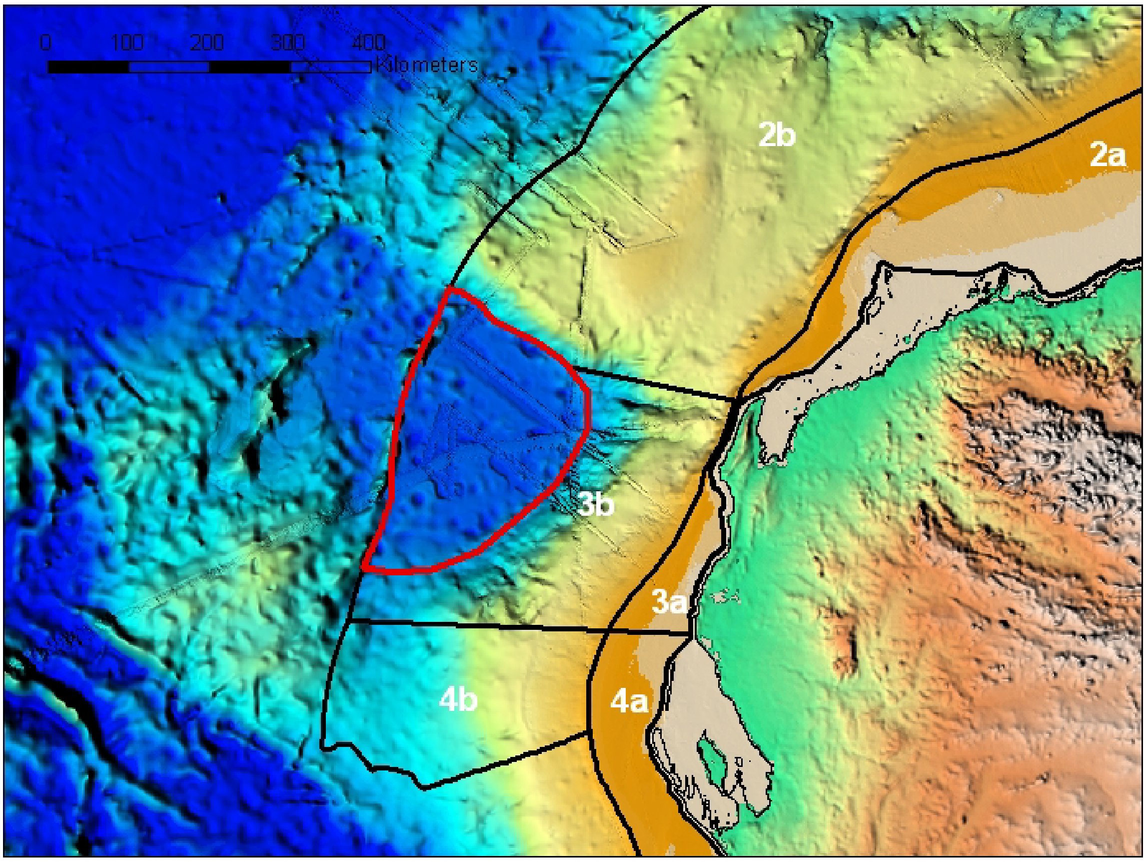


Figure 6-46 Cuvier Abyssal Plain (red outline) and neighbouring sub-regions.

6.9.1 Drivers and physical features

The Cuvier Abyssal Plain is a deep water sub-region located between the Wallaby Saddle and Exmouth Plateau, and just offshore from the Carnarvon slope sub-region (Figure 6-46). It is bounded on the eastern side by the continental slope, and on the west by the Sonne Ridge, which extends for 230 km, is 40 km wide and rises to water depths of about 3,800 m (Figure 6-47).

The deep abyssal plain occurs in water depths of over 5,000 m. This deep water habitat type that is among the least explored in the NWMR. Deep abyssal plains cover approximately 40% of the ocean floor. They are typically covered by silt, much of it deposited from turbidity from the continental margins and planktonic remains which sink from the upper pelagic waters. The Cuvier Abyssal Plain in particular is thought to receive a large amount of terrigenous sediment from the continent, due to it's close proximity to the coast and the location of large canyons on the adjacent slope sub-region. There may also be some scattered regions of hard bottom particularly on the margins at the base of the continental slope and along the Sonne Ridge.

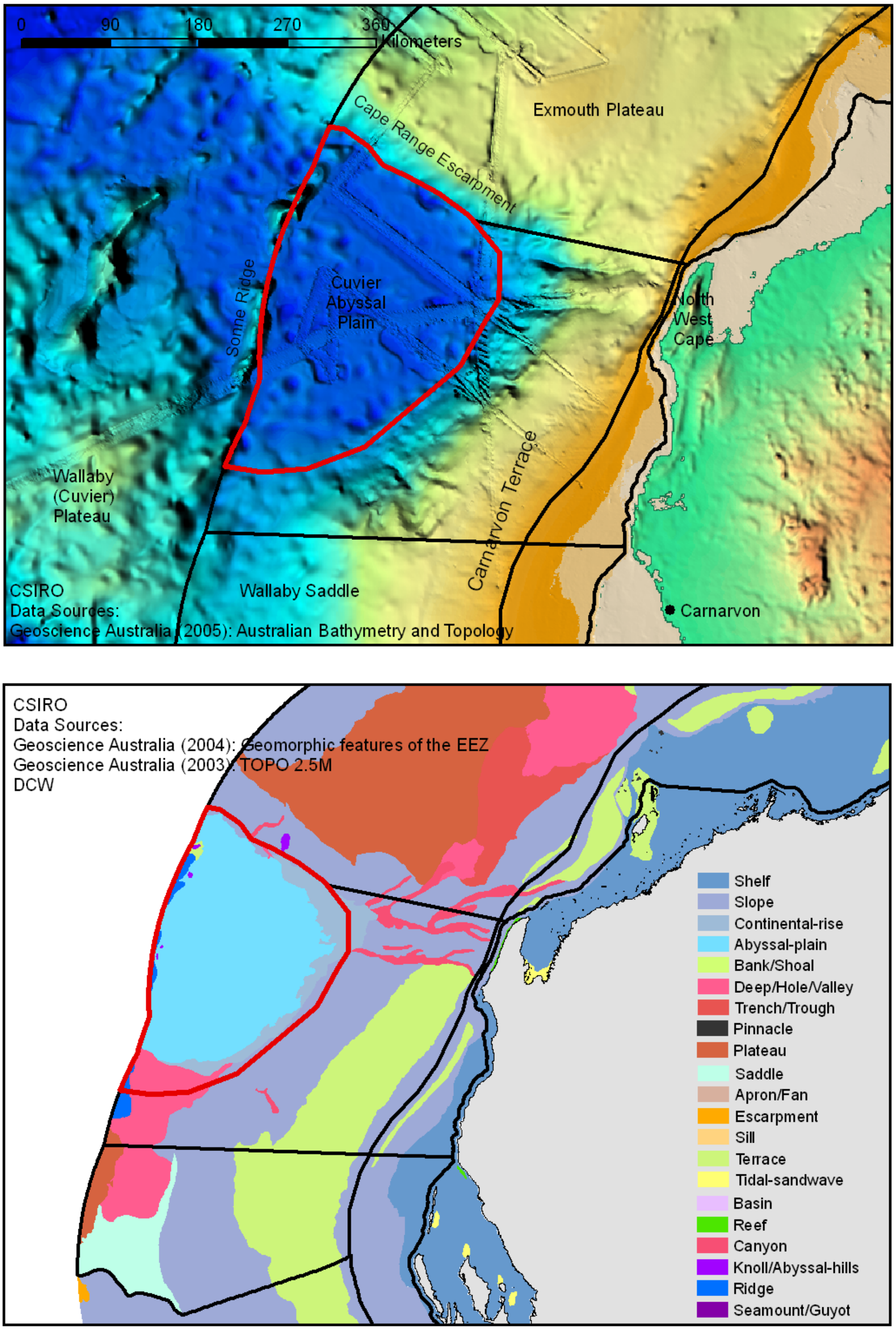


Figure 6-47 Cuvier Abyssal Plain sub-region showing selected features (upper) and geomorphology (lower).

The Cuvier Abyssal Plain is located in the southern extent of the transitional fronts zone, with Indian equatorial water to the south. This region has a complex watermass composition, with remnants of the Indo-Pacific Throughflow water at the surface, overlain by midwater Indian Pacific water (Figure 6-49). This trophic system is a more temperate version of the Argo plain to the north. Water temperatures at the surface are sub-tropical, averaging 24.4° C and with a small seasonal range. The temperature regime for the trophic system is a strongly dominated by decreasing temperature with depth, with the surface temperature reflecting climatic processes, and the deeper water reflecting global water-formation and transport processes (Hayes *et al.*, 2005).

The surface waters of this sub-region are relatively low in nutrients (nitrate and phosphate) and silicate (Figure 6-11) for most of the year. However, levels increase rapidly below the surface mixed-layer and waters deeper than about 1000 m have higher nutrient levels from nutrient rich water-masses such as the Antarctic intermediate water-mass that carries nutrient-rich water at depth throughout the region. Wind stress during most of the year is very low, (Hayes *et al.*, 2005) and there is little vertical mixing through the pycnocline to bring additional nutrients into the euphotic zone. However, there are some dynamics in the system associated with the Indian Ocean frontal system that results in nutrient rich deeper water reaching the euphotic zone during winter especially in the vicinity of the Cape range escarpment along its northern edge (Lyne *et al.*, 2005). Higher nutrient waters also reach the surface waters of this trophic system as the result of offshore winds during the SW monsoon (Figure 5-6) creating nutrient rich water that gets carried south to about 20° S and then deflected off shore (Lyne *et al.*, 2005).

Table 6-10 Summary physical data for the Cuvier Abyssal Plain sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
5,007.6	2.43	0.048	0.00	1.08		

Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	NO_3 (μM) 0m/150m	P (μM) 0m/150m	Silicate (μM) 0m/500m	Chlorophyl (mg/m3)
24.38	35.19	37.98	0.04/3.21	0.13/0.34	3.86/7.19	0.19

6.9.2 Trophic system features and dynamics

Pelagic environments

The surface waters of this sub-region are relatively low in nutrients, resulting in low surface primary productivity in the mixed layer, especially during summer, when the monsoonal weather pattern results in low advection of nutrient rich water from inshore and deeper water. While the low nutrient surface waters results in a relatively low chlorophyll and low productivity, there is likely to be some subsurface productivity from deeper plankton production at the nutricline near or below the 1% light depth (Lyne *et al.*, 2005).

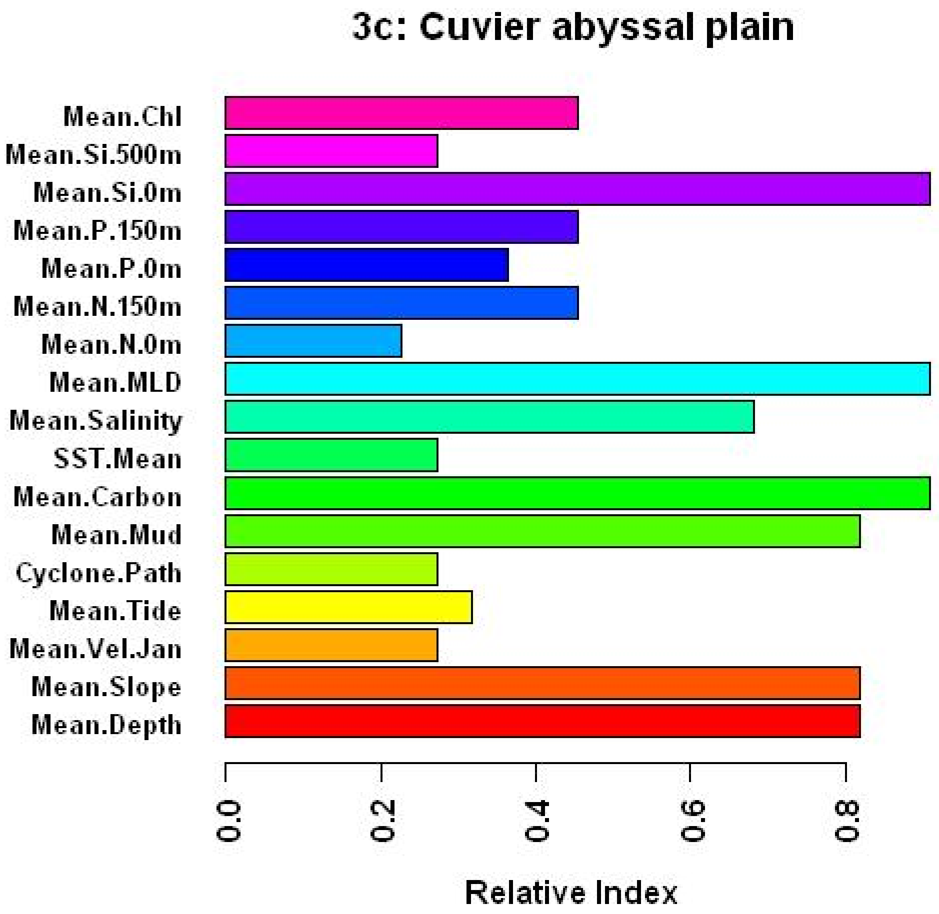


Figure 6-48 Summary physical data for the Cuvier Abyssal Plain sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

The low but seasonally variable primary productivity provides food to primary consumers dominated by pelagic, vertically migrating zooplankton (such as crustaceans, larval molluscs, larval fishes, etc.). Pelagic secondary consumers such as jellyfish and salps are likely to occur, as are nekton secondary consumers such as transient small-fish schools and squid. The main tertiary consumers of interest in the deep sea environment include transient populations of highly migratory pelagic species such as juvenile Southern bluefin tuna (*Thunnus maccoyii*) on their southward migration and other pelagic predators such as sharks that either migrate seasonally or range through the system following schools of small pelagic fish. Seabirds are expected to be included in the latter category.

Benthic environments

The deep demersal environment is reliant for its energy input on bacterial production that is grazed by very small animals, especially nematodes and harpacticoid copepods; falling detritus or particulate organic matter (POM) (detritus, zooplankton faecal matter); and the occasional large carcass directly supplied by the pelagic environment. Much of the detrital energy is cycled through bacterial-detrital food webs.

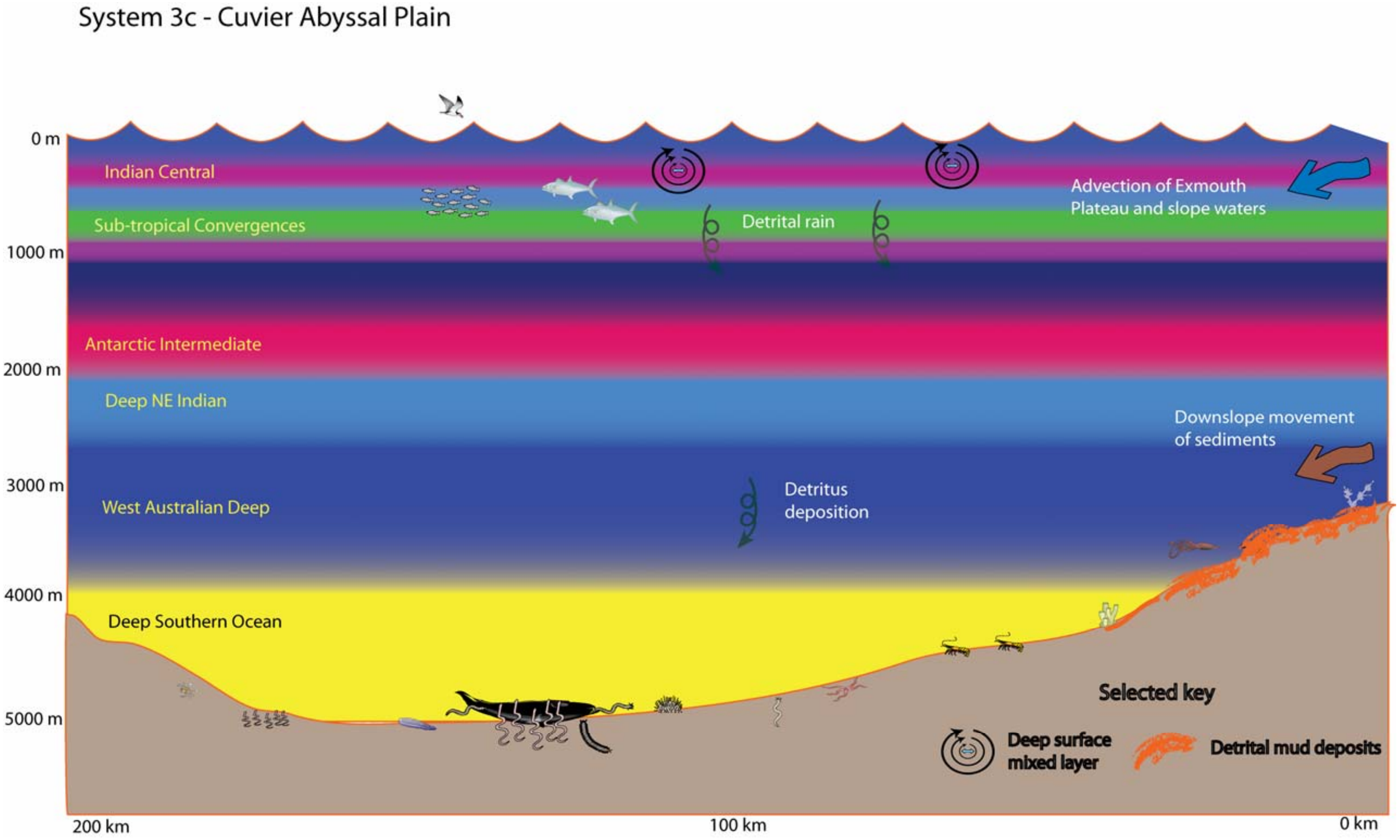


Figure 6-49 Habitat diagram of the Cuvier Abyssal Plain sub-region showing selected important drivers and features. 70-100 m deep chlorophyll maxima not shown.

In this case, the relatively low nutrient/productivity of the pelagic environment is results in a low biomass in the benthic habitats supporting sparsely populated infaunal and epi-benthic communities of a range of trophic groups. There is likely to be a very sparse distribution of mobile epibenthos including holothurians, crabs and polychaetes. Any harder seabed facies that occur in the area may contain established, more resident deep epibenthic communities that may include crabs, cephalopods, echinoderms and other suspension-feeding epibenthic organisms including deepwater corals (typically azooxanthellate). Much of the benthic biomass will likely be made up of infauna (meiofauna and microfauna) including filter-feeders and detritivores

These epi-benthic communities may support a sparse population of bentho-pelagic fish and cephalopods may also be present in low densities. Fish assemblages would be expected to include grenadiers or rattails (*Macrouridae*), hatchetfish (*Argyropelecus* spp.) and small, bioluminescent species that may vertically migrate, such as myctophids. These organisms are typically present is very low abundances and are very patchily distributed.

Therefore, the productivity flows in the pelagic and demersal portions of the deep sea environment in this sub-region are somewhat disconnected, with falling POM from the pelagic environment providing the main linkage (Figure 6-50).

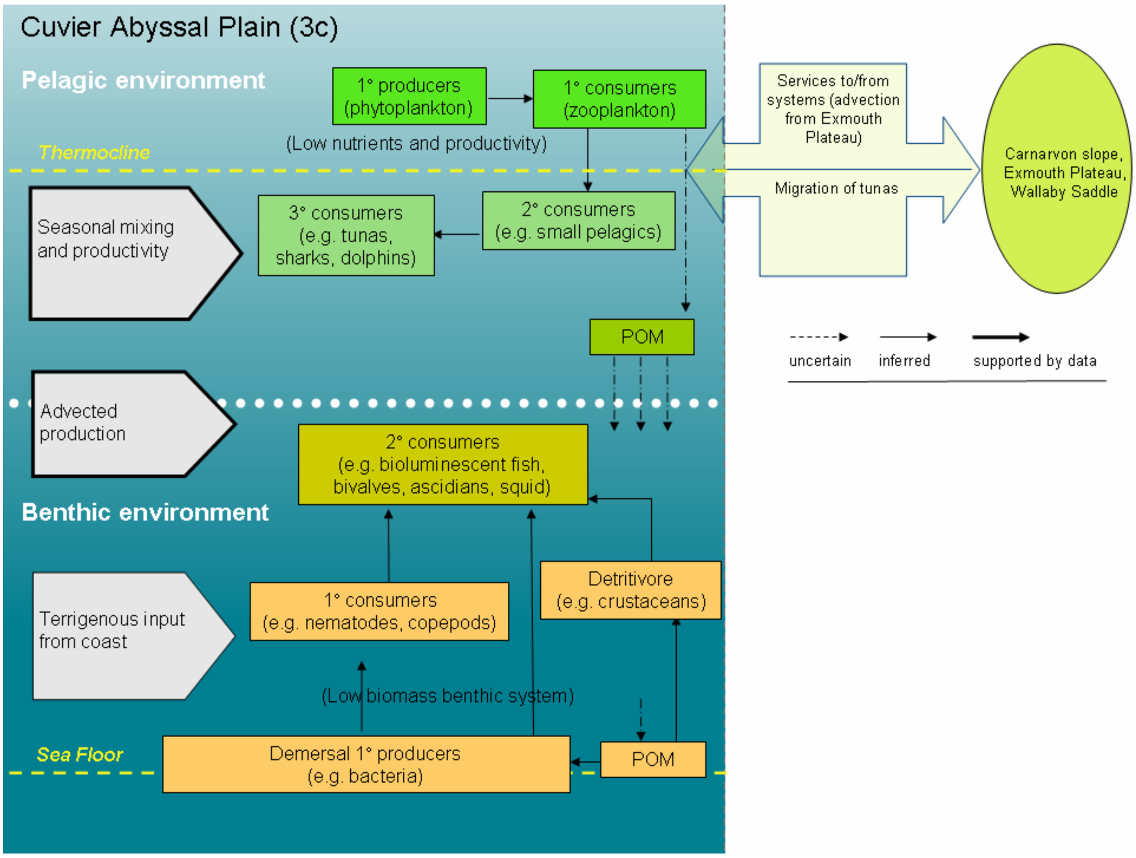


Figure 6-50 Conceptual diagram of the Cuvier Abyssal Plain sub-region showing information on the main habitat in the central basin.

The geometry of the deep basin, in the form of a semi-enclosed structure suggests that recirculation processes may play a critical role at depth in the spatial distribution of detrital products. Above the depths of the sills, one in the south associated with the Wallaby Saddle and the northern one associated with the Exmouth Plateau, the flow is also likely to be recirculatory due to well known topographic steering of any deep flows that attempt to cross the sill or flow across from the Exmouth. We postulate that this recirculatory mechanism which bears resemblance to the circulation associated with the Bass Canyon system in the south-east of Australia is in part responsible for the biological attraction of this region.

6.9.3 Services and linkages

There is very little fishing activity in the Cuvier abyssal plain, although juvenile SBT use this region on their southward migration. High nutrient water from this trophic system will flow into the canyons to the east and influence the NW Cape trophic system.

6.9.4 Key species interactions

Within the NWMR, this sub-region is one of only two deep basins, and in this particular case, it is a unique area where the deep ocean is located so close to the continental slope and shelf. Thus, pelagic species of the Cuvier Abyssal Plain are able to interact closely with those on the slope and shelf. Likewise, offshore eddies spawned off by the Leeuwin Current may carry with it species from the shelf and slope that may interact with this sub-region.

Transient populations of pelagics such as SBT will be impacted by processes external to this trophic system.

6.9.5 Resilience and vulnerability – phase change

The dynamics of the SW monsoon and its impacts on the nutrient maxima during winter will impact the pelagic productivity and benthic systems of this sub-region. Changes in climate may therefore be expected to influence this productivity. The deeper environments are relatively unproductive and may be resilient to climate and fishing impacts.

6.9.6 Information gaps

Very little known about the deep abyssal benthic ecosystems. The abundance and diversity of the deep abyssal biota has been rarely sampled, and certainly not in the Indian Ocean.

6.10 Kalbarri Shelf (4a)

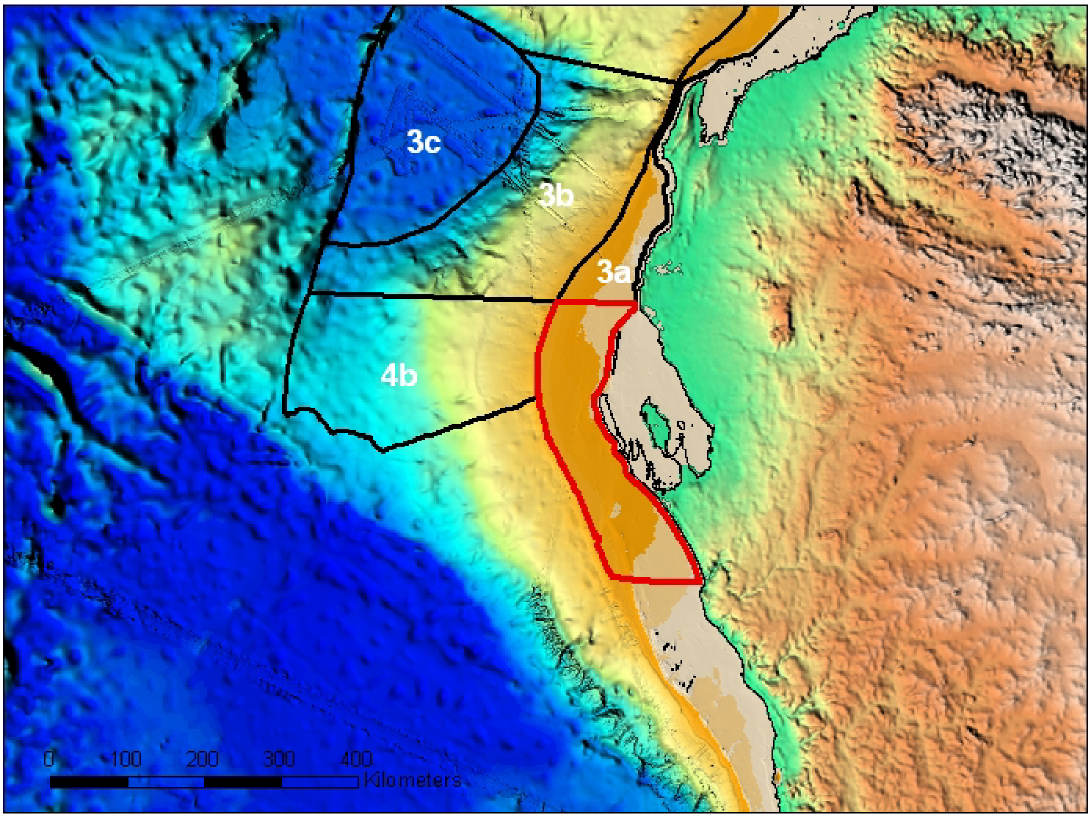


Figure 6-51 Kalbarri Shelf (red outline) and neighbouring sub-regions.

6.10.1 Drivers and physical features

The Kalbarri Shelf sub-region covers a section of the continental shelf between the northern extent of Shark Bay to the lower boundary of the NW Marine Region at Kalbarri (Figure 6-51, Figure 6-52). It ranges in depth from shallow coastal waters (~ 30 m deep) to the shelf break (~ 200 m). However, much of the shelf plateaus at about 100m depth, before dropping sharply at the shelf break (Woo *et al.*, 2006). The shelf is about 60 to 90 km wide throughout the sub-region, and it is almost 400 km in length north–south. The shelf is part of the Dirk Hartog Shelf, that extends from south of the NWMR to North West Cape. In this area, it is very flat, having the lowest average slope of any sub-region in the NWMR.

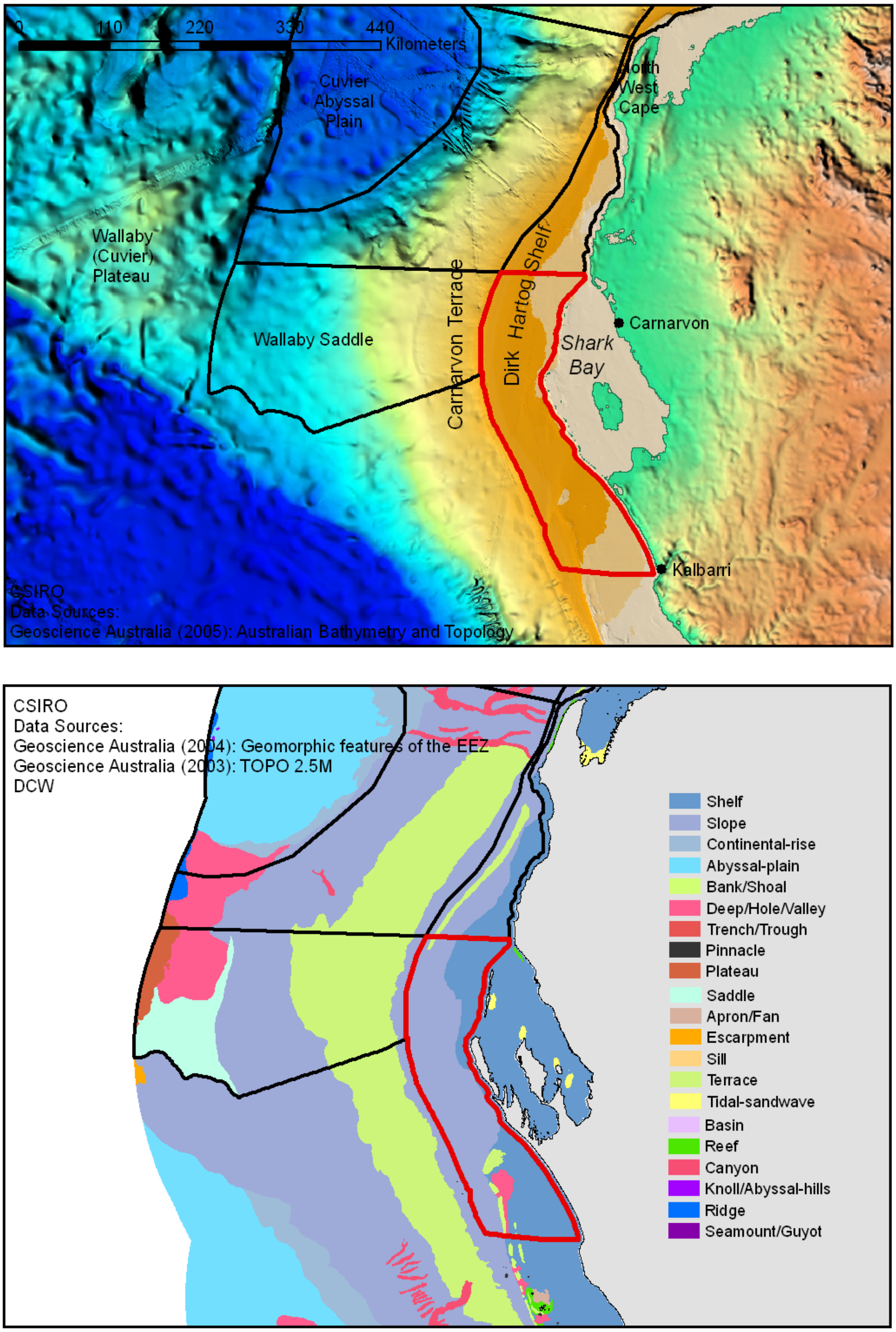
The sub-region has a marked seasonal variation in SST, and is on average almost a degree and a half cooler than the Carnarvon Shelf immediately to the north (Table 6-11). Average salinity is relatively high. There is little freshwater runoff or any other coastal influence on this shelf, and the shelf is influenced by high salinity water out-flowing from Shark Bay. Surface currents (mostly associated with the Leeuwin Current) are relatively high, especially during winter. However, tidal currents are generally low and do not exceed the speed at which significant sediment mobilisation occurs. The area is subject to relatively low cyclone influence (Figure 5-7). However, cyclones that do occur in the sub-region tend to run parallel to the coastline and have a significant impact on the shallow shelf benthos. The substrate is mostly sand, much of it foraminiferous, with relatively low amounts of spiculitic mud in areas of low wave energy.

This sub-region, and its off-shore neighbour, the Wallaby Saddle sub-region, have been differentiated from the sub-regions to the north based on their location within the Indian Ocean water mass (Figure 5.8, Section 5). The sub-regions to the north sit in the waters of the Transitional Fronts zone or the Indo-Pacific Throughflow and are adapted to the characteristics of these water masses (Section 5, Figure 5.8). The trophic systems of these most southerly sub-regions are likely to be more closely related to the sub-regions adjacent to their southern borders (in the SW Marine Region).

The sub-region is under the influence of dynamic physical oceanographic processes. The main influences are: the southward-flowing Leeuwin Current, which, at this latitude, is relatively narrow (50-100 km wide) and more or less centred on the shelf break (~ 200 m isobath); the hypersaline Shark Bay outflow, which mixes with the Leeuwin Current water and forms a distinctive water mass that flows poleward from Shark Bay; and the northern extension of the Capes Current which flows northwards during summer on the inner shelf in the southern parts of the sub-region (Figure 6-36) (Woo *et al.*, 2006).

The Leeuwin Current drives warm, low-nutrient surface waters southwards along the continental shelf, although it becomes cooler and more saline as it travels south due to entrainment of offshore and inshore waters. The current strength varies by a factor of two over the year, being strongest during autumn and winter (April-September) and weakest during the spring and summer (September-April), due mainly to seasonal southerly winds that prevail during the austral summer (Figure 5-6, Furnas, 2007). However, the strength and position of the Leeuwin Current and the depth of its mixed layer varies spatially and temporally on other scales as well, and this is not well understood (Hanson *et al.*, 2005). Below the southward flow, extending down to around 250m, an equator-ward undercurrent brings high salinity high oxygen waters northwards (Fieux *et al.*, 2005).

Inshore of the Leeuwin Current, the Capes Current extends along the southwest coast of Western Australia (Pearce and Pattiaratchi, 1999; Woo *et al.*, 2006), generally inshore of the 50 m isobath (Figure 6-54). The Capes Current is wind-driven and limited to the surface (Gersbach, 1999;), but is sufficient to influence cold water localised Ekman-driven upwelling from depths of around 100 m making it relatively nutrient rich. However, the Capes Current water type is characteristic of previously upwelled water – low nitrate/high productivity signature meaning that the upwelling occurs further south and therefore outside the boundaries of the sub-region (Woo *et al.*, 2006). This is in contrast to the Ningaloo Current to the north where the increased productivity of the inshore regions was through local upwelling and mixing processes, caused by the shelf being so narrow in this area. While it is relatively high in nutrients, it is still generally lower in nutrients than the Ningaloo counter current to the north, and other upwelling-influenced zones off California, NW Spain and Southern Africa (Hanson *et al.*, 2005).



CSIRO
Data Sources:
Geoscience Australia (2005): Australian Bathymetry and Topology

CSIRO
Data Sources:
Geoscience Australia (2004): Geomorphic features of the EEZ
Geoscience Australia (2003): TOPO 2.5M
DCW

Figure 6-52 Kalbarri Shelf and Wallaby Saddle sub-regions showing selected features (upper) and geomorphology (lower).

In the north of the sub-region, the inshore areas are dominated by the hypersaline, Shark Bay outflow, which mix with Leeuwin Current water to form a distinctive water mass that flows southward from Shark Bay (Hanson *et al.*, 2005). Shark Bay waters are higher in salinity than Leeuwin Current waters, due to higher evaporation rates in the semi-enclosed coastal embayment and minimal terrestrial runoff into the Bay. However, the timing and strength of this current may be quite variable and dependant on northern winds in Shark Bay (Hanson *et al.*, 2005).

This mix of oceanographic features means that the sub-region is characterised by having overall a very low average nutrient levels (N and P) in waters down to 150 m, and low silicate, due to the dominant influence of the low nutrient Leeuwin Current, and the downwelling associated with this current during most of the year. Inshore, higher nutrient levels occur during summer, associated with the Capes Current and the Shark Bay outflow. There is also sometimes a band of high-depth integrated nitrate located in offshore waters of the sub-region associated with mixing processes along most of the shelf break. This is an area of active mixing, and may promote nutrient fluxes into the euphotic zone.

Table 6-11 Summary physical data for the Kalbarri Shelf sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
115.4	0.26	0.077	0.00	0.77		80.3

Ave. SST (C°)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
23.19	35.39	44.48	0.05/1.16	0.13/0.24	2.86/7.07	0.27

6.10.2 Trophic system features and dynamics

The low surface nutrient levels associated with the Leeuwin Current limits productivity at higher trophic levels (Hanson *et al.* 2005), leading to oligotrophic conditions to similar levels as the Coral Sea. Average Leeuwin Current phytoplankton biomass is characteristic of low productivity oceanic waters like the Indian, Pacific and Atlantic Oceans (Hanson *et al.*, 2005). Mean chlorophyll is very low in comparison with other shelf sub-regions, especially during winter. However, higher nutrient and associated productivity levels are associated with the mixing processes on the shelf break and inshore (<50 m deep) through higher nutrient levels in the Capes Current and the Shark Bay outflow. The Capes Current mainly occurs during summer but has been shown to be highly productive, and with low silicate levels and a high proportion of centric diatoms (Hanson *et al.*, 2005).

A common feature throughout much of the sub-region is higher chlorophyll concentrations at depth (Figure 6-54), either near the seabed or as distinct peaks within the water column. This deep chlorophyll maximum is generally deeper offshore than inshore, with highest levels found near the seabed in shelf waters (Hanson *et al.*, 2005).

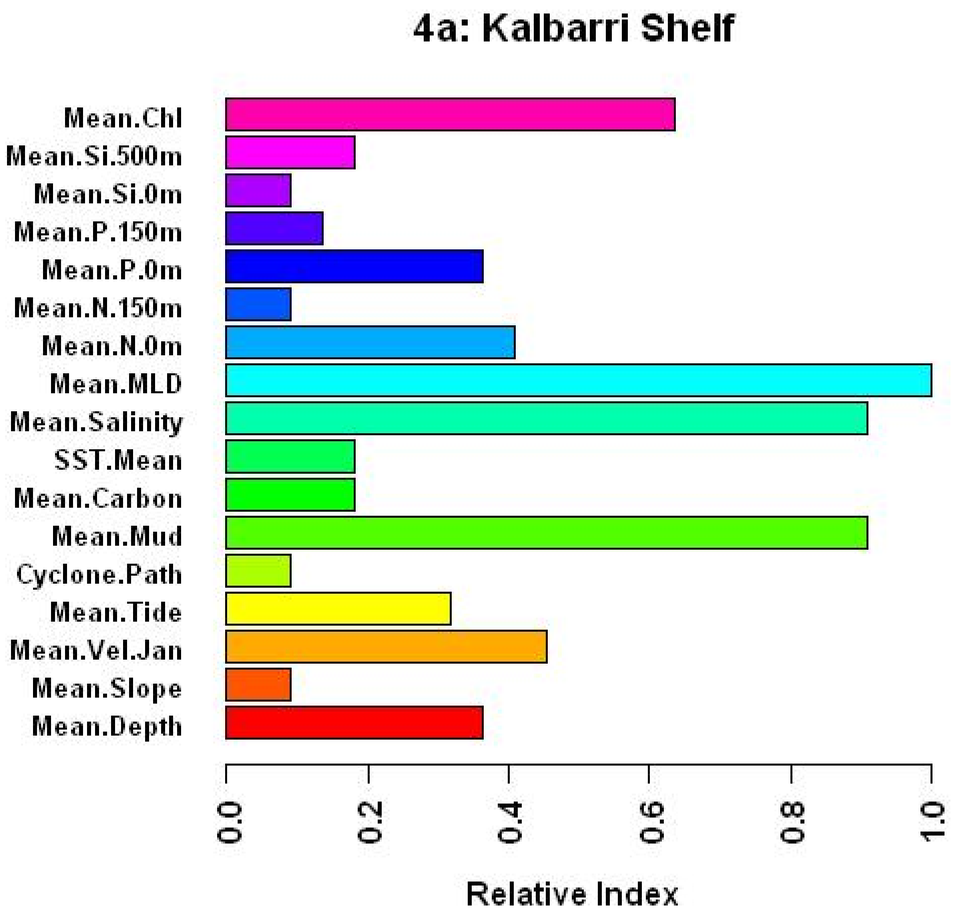


Figure 6-53 Summary physical data for the Kalbarri Shelf sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

Processes that affect the strength and depth of the Leeuwin Current will also impact on local production. Furnas (2007) found a two to four fold difference in phytoplankton production rates between El Nino and La Nina years near North West Cape, just to the north of this sub-region. In the El Nino year, the flow of the Leeuwin Current declined, thermocline depths shallowed bringing nutrients closer to the surface compared to La-Nina years. Furnas (2007) concluded that variations in the Leeuwin Current may have episodic, but significant influences on pelagic productivity along the western margin of Australia, and this probably applies to this sub-region as well.

This high pelagic primary productivity leads to high densities of primary consumers, such as micro and macro-zooplankton (e.g. amphipods, copepods, mysids, cumaceans and euphausiids). These are important prey items of pelagic fishes and large planktivores such as manta rays and whale sharks which use the nearshore waters of the sub-region.

In the offshore areas of the sub-region, productivity and trophodynamics are influenced more by processes at the shelf break. The 200 m isobath forms the boundary between highly productive continental shelf waters and the more depauperate offshore waters. The shelf break appears to be an area of active mixing, promoting nutrient fluxes into the euphotic zone and fuels localised production and biomass peaks. However, the spatial distribution and periodicity of these dynamic events is not well known (Hanson *et al*., 2005).

Productivity in benthic habitats is likely to be enhanced by seagrass and algal beds, especially in the inshore, clear water areas of the sub-region. The benthic habitats are dominated by sandy substrates likely to support relatively sparse invertebrate community, including holothurians, urchins and crabs and polychaetes. It is likely that patchy harder substrates also occur throughout the shelf. These would to support a low density of sessile invertebrates, such as sponges and gorgonians, and a more diverse fish fauna than on the barer sandy areas.

There is likely to be a gradient of epibenthos density from inshore to offshore. The benthic environment in the shallow inshore regions out to the mid-shelf (~100 m depth) would be in direct connection with the pelagic system, thorough mixing and vertical migration of plankton (Tranter & Leech 1987), and sessile filter feeders have direct access to live phytoplankton below the pycnocline. Offshore habitats >100 m deep would be receiving some detrital input from subsurface phytoplankton and particulate organic matter (POM) (detritus, zooplankton faecal matter). The shelf break is also likely to support populations of epibenthos, on the harder substrates, and rely on detrital input from higher productivity on the shelf edge waters. Bentho-pelagic fishes such as deep water snappers (e.g. *Pristipomoides* spp, and *Eletis* spp) and sweetlip (*Lethrinus* spp) are also likely to be associated with this shelf edge habitat.

The sub-region is under the influence of subtropical and temperate conditions, and therefore contains a suite of species more in common with the South West Marine Region, such as high density of the Western rock lobster, *Panulirus cycnus*, and subtropical seagrasses such as *Amphibolis antarctica*. The Cape Current probably provides a cool water conduit for the transport of adult and larval marine species (Pierce and Patterierachi, 1999). The southern part of the sub-region overlaps significantly with the subtropical, Central Western Province (Lyne and Last, 1996).

Western rock lobster, *P. cycnus*, are likely to play an important role as a consumer in coastal ecosystems, and has the ability to impact on a number of invertebrate prey species (Macarthur, 2007). However, their generally low abundance in the sub-region indicates that they are not particularly significant ecologically in these waters, except perhaps for the southern part of the sub-region, south of Shark Bay.

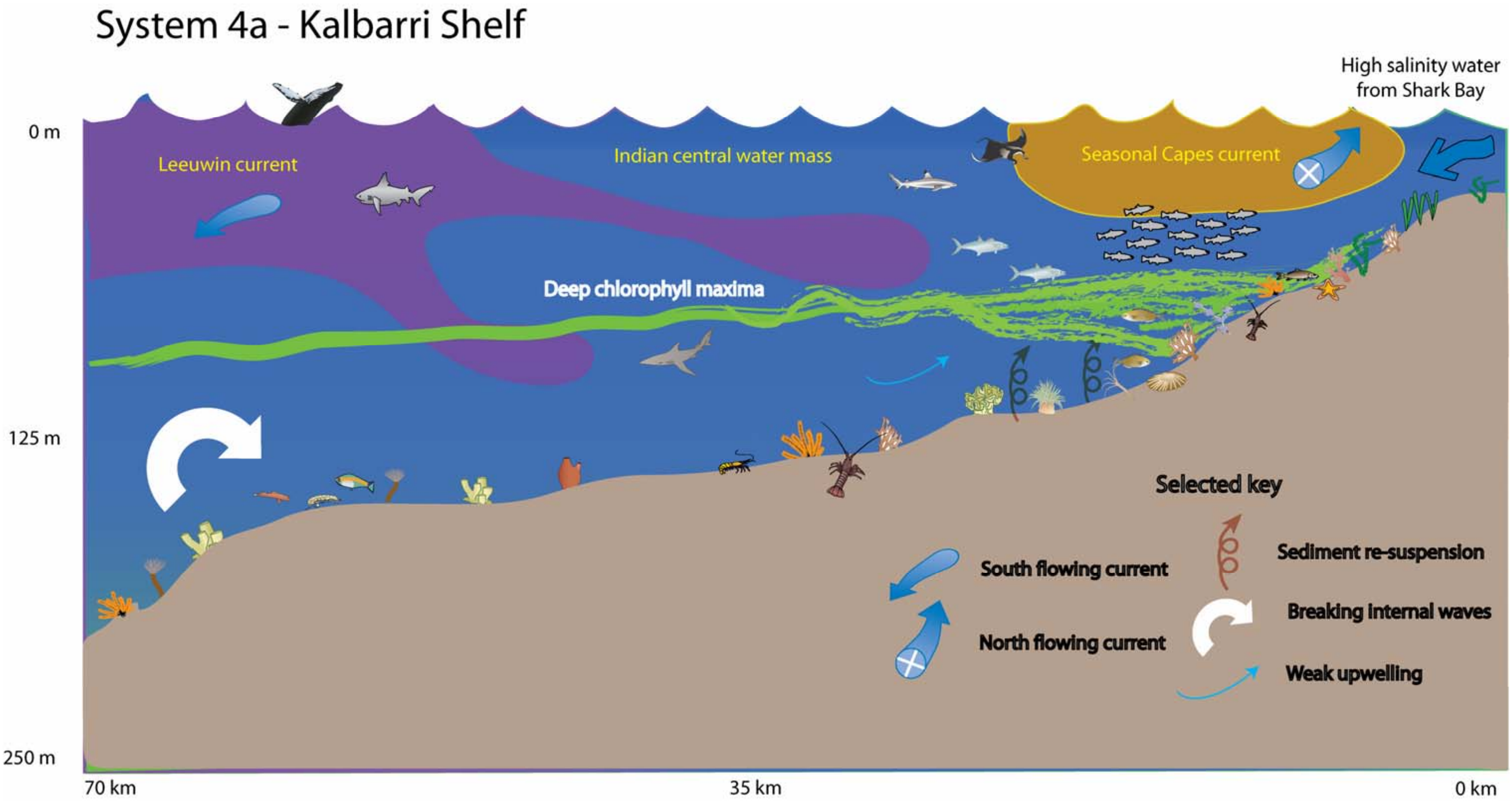


Figure 6-54 Habitat diagram of the Kalbarri Shelf system showing selected important drivers and features.

6.10.3 Services and linkages

This sub-region is intimately linked (nutrient and larval advection) to neighbouring sub-regions by the advective current systems that run through from north to south on the outer shelf (Leeuwin Current) and from south to north on the inner shelf (Capes). The Capes Current links this sub-region strongly with the systems of the SW Marine Region.

The sub-region is also linked to inshore coastal processes by the influence of the Shark Bay outflow. The relatively narrow nature of the shelf means that most of the systems within the sub-region are in close connection with the deep-water communities.

Significant extractive fisheries occur offshore of the sub-region (Western Tuna and Billfish Fishery). However, the generally low nutrient waters of the sub-region appears to result in a low overall biomass of fishery species. The exception is that the sub-region is the northern extent of the western Rock lobster fishery.

6.10.4 Key species interactions

The Western rock lobster, *P. cygnus* is an important coastal species in the sub-region. They inhabit the continental shelf in waters between 1 and 100m deep, but most live in water shallower than 60m. Juveniles are commonly found in caves and under reef ledges surrounded by seagrass, in water 10-30m deep. Adults inhabit similar habitats in deeper water. This species is an omnivore and feeds at night. Their diet changes with their moult stage, season and habitat. Postmoult rock lobsters prefer epiphytic coralline algae, and intermoult forms eat similar, but larger, food to that of juveniles, such as epiphytic coralline algae, small crustaceans, polychaete worms and peanut worms (Sipunculida). Finfish, sharks and octopus prey on both adult and juvenile rock lobsters.

Although the region to the north is known to be a significant feeding ground for whale sharks and manta rays, their occurrence in this sub-region is not well documented. Dolphins and dugong are abundant in Shark Bay and likely to migrate into the shelf at times and may be important tertiary and primary consumers (respectively) in this sub-region.

6.10.5 Resilience and vulnerability

Hanson *et al.* (2005) cite evidence that the strength and position of the Leeuwin Current and the depth of its mixed layer varies spatially and temporally along the west coast of WA. Therefore the biological impact of any upwelling in this region is a function of:

- The depth of the Leeuwin Currents nutrient-depleted upper layer (as influenced by mixing and the rate of phytoplankton consumption)

- The strength and duration of upwelling-favourable winds (i.e. the intensity of upwelling); and

- the geographical location, primarily with respect to the width of the continental shelf and resultant proximity of upwelling flows to deep nutrient pools

The current has also been shown to be about 40% stronger during La Nina years and weaker during El Nino years (Feng *et al.*, 2003; Furnas, 2007)). This has been shown to affect the water temperatures in the region, with relatively lower temperatures during El Nino years when the current is weaker (Wilson *et al.*, 2003). Furnas (2007) found a two to four fold difference in phytoplankton production rates between El Nino and La Nina years near North West Cape, just to the north of this sub-region. Changes to these broad current patterns caused by shifts in global climate patterns, such as greenhouse climate shifts that could increase the frequency of ENSO events and change the productivity of the system in way that are difficult to predict.

Seasonal winds also have a large impact on the current patterns. The strength of the Capes Current is directly related to the southerly winds during summer (Figure 5-6). Changes in the strength of these currents will have the impact on the dynamics and nutrient regimes of the sub-region in unknown ways. However, the Leeuwin Current is known to have strong influences on the lifecycles and recruitment of many fish and invertebrate species (Caputi *et al.*, 1996), and changes in this dynamic could result in recruitment failures for some species.

Cyclones are known to have a large impact on the benthic environment of the shallow shelf regions. Wind driven waves and surge currents will remove or destroy epibenthic communities. Cyclones in this sub-region will tend to travel in an alongshore orientation which will maximise the potential for damage (Figure 5-7). At this stage, the number of cyclones in the region is relatively low. However, under a likely greenhouse influence they may become more frequent and possibly stronger.

6.10.6 Information gaps

The temporal and spatial dynamics of the Leeuwin and Capes Currents and their impact on nutrient dynamics and productivity is not well known. For example, while there is a relationship between Leeuwin Current flow and recruitment strength of western rock lobsters, the mechanisms behind it are unclear (Caputi *et al.*, 2001). The strength and position of the Leeuwin Current and the depth of its mixed layer varies spatially and temporally at different scales although this is not well understood (Hanson *et al.*, 2005). The spatial distribution and periodicity of shelf edge mixing processes is also poorly known.

The demersal benthic communities of the shelf in this sub-region are not well studied or understood, including the distribution and abundance of sessile megabethos, epifauna and infauna and their association with different sediment regimes.

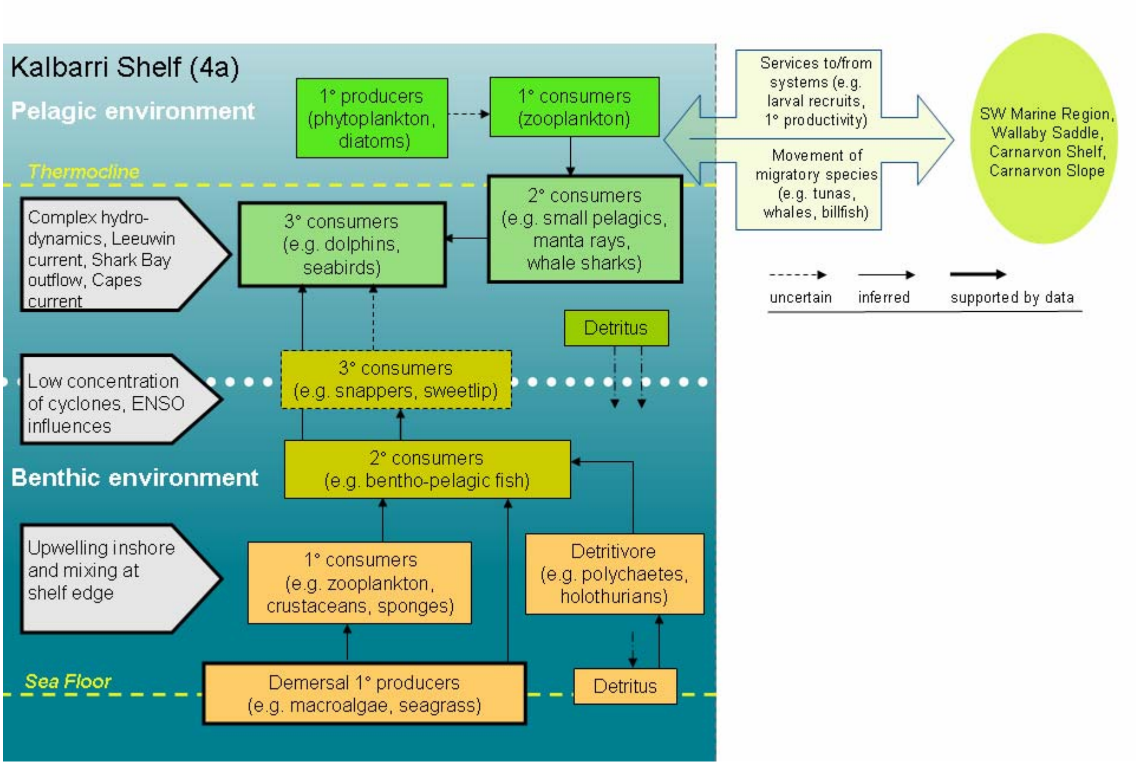


Figure 6-55 Conceptual diagram of the Kalbarri Shelf sub-region showing information on the main habitat in the mid and inner shelf.

6.11 Wallaby Saddle (4b)

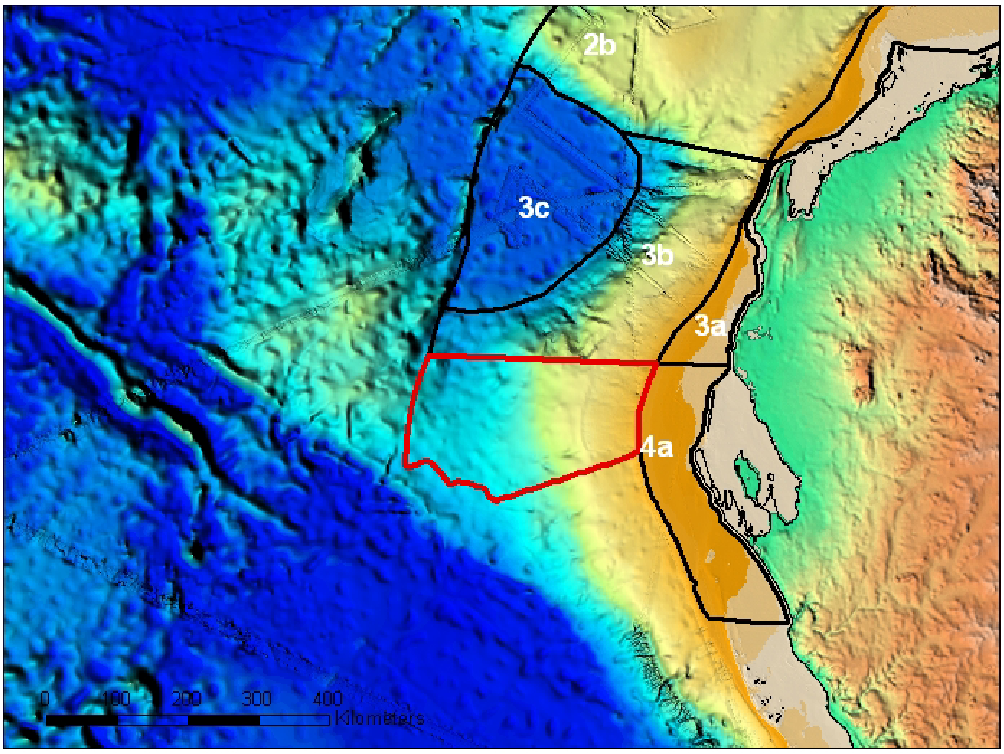


Figure 6-56 Wallaby Saddle (red outline) and neighbouring sub-regions.

6.11.1 Drivers and physical features

The Wallaby Saddle sub-region continues from the southern boundary of the Carnarvon Slope sub-region and encompasses the continental slope from about the shelf break (200 m depth contour) to 4586 m on the Wallaby Saddle bathymetric feature at the south-western extent of the NW Marine Region. The western boundary lies inside the Wallaby Plateau. The shelf sub-region (4a, Kalbarri Shelf) lies to the east of the Wallaby Saddle sub-region and is described above. The Wallaby Saddle sub-region is about 300 km wide and about 200 km north-south (Figure 6-56).

This sub-region lies adjacent to the SW Marine Region. The Wallaby Saddle and Kalbarri Shelf sub-regions have been differentiated from the sub-regions to the north based on their location within the Indian Ocean water mass (Figure 5-9, Section 5, above). The sub-regions to the north sit in the waters of the Transitional Fronts zone or the Indo-Pacific Throughflow and are adapted to the characteristics of these water masses. The trophic systems of two most southerly sub-regions are likely to be more closely related to the sub-regions adjacent to their southern borders (in the SW Marine Region).

It is important to note, therefore, that the boundaries of this sub-region are somewhat arbitrary. Firstly in it's northerly extent, because the boundary of the Transitional Fronts water varies temporally (seasonally) and we have placed the sub-region boundary at it's approximate average location. Secondly, the southern boundary is defined by the NW Marine Regional boundary. If the NW and SW Marine Regions were not segregated by this boundary, the Wallaby Saddle and Kalbarri Shelf sub-regions would probably be part of a larger area that currently straddles both marine regions.

The physical systems of the Wallaby Saddle are very poorly understood. Like most of the other sub-regions in the NW Marine Region, its better known properties are the oceanography, geomorphology and regional climate. The main physical influences on the trophic systems of this region include: the Indian Ocean Central Water (Figure 5-3, Figure 5-4, Figure 5-5); the warm, low salinity, low nutrient waters of the Leeuwin Current; the strong southerly winds that prevail for much of the year (Figure 5-6); the very wide range of depths down the continental slope (Figure 6-59); and the relatively simple geomorphology.

This sub-region, together with the adjacent inshore sub-region (Kalbarri Shelf), is strongly influenced by the Leeuwin Current (Figure 6-59). However, this current is relatively narrow at this latitude (~50-100 km wide) and centred on the shelf break (200 m isobath). The Leeuwin Current drives warm, low-nutrient surface waters south and influences biological production in proportion to its strength throughout the year. The current is strongest during autumn and winter (April-September), and weakens during the spring and summer (September-April) due to southerly winds that dominate during winter.

The surface waters throughout this sub-region are relatively low in nutrients (nitrate and phosphate) and silicate (Table 6-12) for most of the year. However, nutrient levels increase rapidly below the surface mixed-layer. The deeper water masses carry nutrient-rich water into the surface layers as the result of offshore winds during the SW monsoon, creating localised upwelling of nutrient rich water that are driven south to about 20° S and then deflected offshore (Lyne *et al*., 2005). However, the Wallaby Saddle itself (Figure 6-56) is an obstruction to the flow of the deep ocean water, which has to partly skirt around it and partly flow over it. Wind stress during winter is very low (Hayes *et al*., 2005) and there is little vertical mixing during this time (Figure 5-6).

Other unique physical characteristics of the sub-region (compared to other NW Marine sub-regions) include it's low sea surface temperature (mean = 28.5^{o}C); high surface salinity (mean = 34.6 ppt); low mean N and P concentrations, especially at the surface (0.06 and 0.12 uM, respectively); low mean surface chlorophyll concentrations (0.17 mg m^{-3}); low mean wave and tide exceedance (0.33% and 0, respectively). Other physical parameters are about average for the NW Marine Region.

The geomorphology of the sub-region is relatively simple compared to other continental slope sub-regions in the NWMR. The sub-region sits outside a relatively narrow continental shelf (90 km wide, described above) although there is not a strong coastal influence due to low freshwater runoff in this area. The sub-region has two main features, the Carnarvon Terrace (grading westward from 400 m to 1600 m deep) in the eastern half and the Wallaby Saddle to the west (a deep northerly sloping trough to about 4,000 m) (Figure 6-52). Virtually all of this sub-region is below the depths where cyclones and wave can have an impact, making them low energy environments. The sediments of the slope have no gravel, consistent with the regions to the south.

Table 6-12 Summary physical data for the Wallaby Saddle sub-region (more information available in Appendix 1).

Ave. Depth (m)	Ave Slope (%)	Surface currents	Tidal excedance	Cyclones (m/km^2/yr)	Sediment % mud	Sediment %carbonate
2,585.6	1.80	0.069	0.00	0.93		

Ave. SST (Cº)	Ave salinity (ppt)	Mixed layer depth (m)	N (µM) 0m/150m	P (µM) 0m/150m	Silicate (µM) 0m/500m	Chlorophyl (mg/m3)
22.83	35.45	37.41	0.06/1.37	0.12/0.24	3.21/6.10	0.17

6.11.2 Trophic system features and dynamics

Pelagic environment

Primary production in the pelagic environment peaks seasonally in autumn and winter to the north of the sub-region (as measured by satellite-based ocean chlorophyll concentrations; Hayes *et al.,* 2005), and is transported south into the sub-region. However, the cause of the seasonal production or mechanism that moves it south is not clear (Hayes *et al.,* 2005). The seasonal primary productivity may to be regulated by seasonal offshore winds in winter (Figure 5-6) that create mixing and localised upwelling, bringing high nutrient sub-surface waters into the euphotic zone. The Leeuwin Current is likely to be responsible for advecting the high chlorophyll containing water south into the sub-region, but only on the shelf and upper slope.

These phytoplankton blooms may fuel a seasonally productive pelagic food web. Although the regulatory mechanisms for primary production or how they flow on to influence higher order consumers not understood. We expect the pelagic productivity flows to be characterised by recognised tropical planktonic species. These probably include a range of phytoplankton species (e.g. picoplankton, nanoplankton, large diatoms and the blue-green alga, *Trichodesmium* – Hallegraeff and Jeffrey, 1984), which will be consumed by vertically migrating zooplankton, such as sergestids, larval molluscs, salps and larval fishes (Figure 6-58). Some of these species such as diatoms and salps are capable of very large population blooms in this region although the mechanisms for this are not well understood.

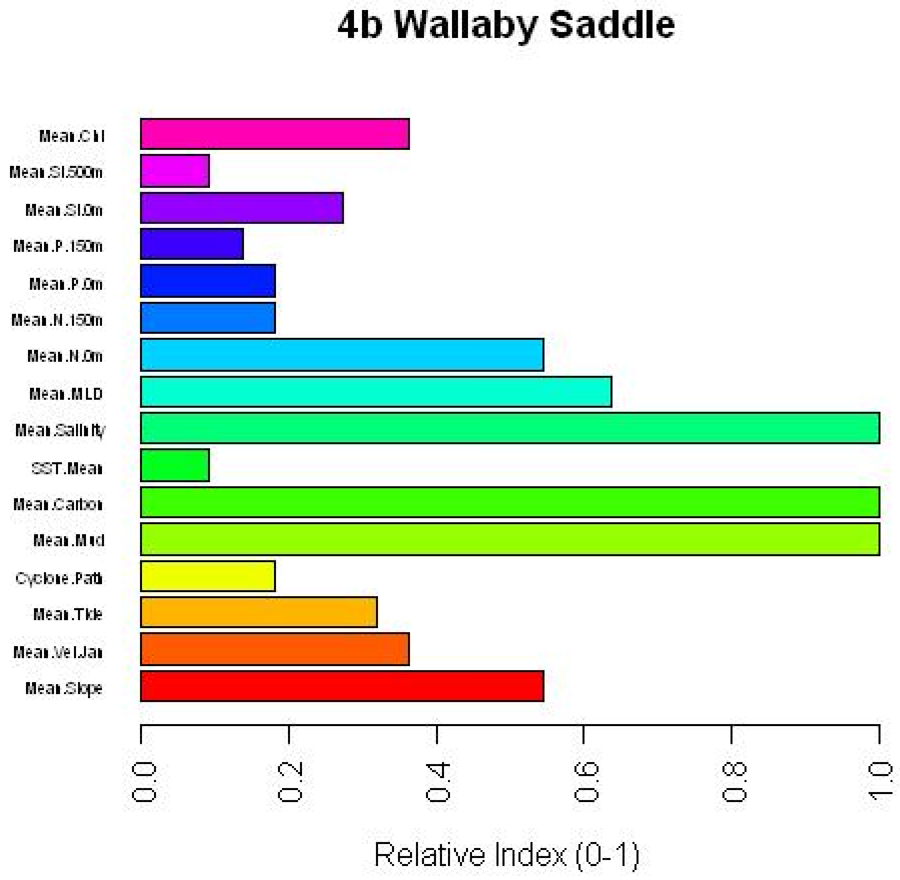


Figure 6-57 Summary physical data for the Wallaby Saddle sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

Secondary consumers in this pelagic system are likely to include ctenophores, engraulids, larval fish and other micronekton. These form prey for a range of small and large predators such small schooling fishes, squid and other micronekton.

The higher order consumers in this pelagic system include tunas, Swordfish (*Xiphias gladius*), Dolphinfish (*Coryphaena hippurus*) and seabirds and many of the larger fish form the basis for a significant tuna and billfish fishery (Western Tuna and Billfish Fishery, WTBF). These large pelagics have their highest density (based on spatial fishery catch data) in the shallower sections of the sub-region, in water depths between the 200 m and 2,000 m. These and related species (e.g. smaller tunas) are likely to provide an important regulatory role in the pelagic trophic system in this sub-region.

Toothed whales and dolphins may also be significant predators of cephalopods (squid, octopus and cuttlefish), fish, and crustaceans (krill, amphipods and copepods) in the sub-region, with some species diving to take deep water prey at depths of up to 1500 m. However, the role of these species in trophodynamics is not well understood.

Benthic environment

Unlike much of the slope environment in the NW Marine Region, the Wallaby Saddle sub-region is relatively featureless. The sediments are likely to be dominated by fine particulate matter, mainly deposited from the water column and from down-slope transport of eroded, fine shelf sediments (Figure 6-59).

Like the other slope habitats in the region, there appears to be several distinct demersal communities differentiated along the depth gradient of the slope (Last *et al.,* 2005). However, this part of the slope has been defined as a transitional zone between the North Western Province and the Central Western Province (Last *et al.,* 2005), and as such, is not characterised by endemic species. Instead, it has a mixture of species from these two core slope provinces that flank the sub-region. The demersal communities of the benthic habitats in this sub-region are poorly understood.

The benthic environments are likely to be relatively uniform due to the lack of geomorphological heterogeneity and hard substrates for attachment of sessile benthic invertebrates. The substrates are likely to consist mostly of fine muds throughout most of the depth ranges. The benthic habitat is likely to have a relatively sparse communities of infauna and epifauna (Figure 6-59), dominated by detritivorous and scavenging deposit feeders such as polychaete worms, ascidians, crustaceans various echinoderms. Some suspension feeders such as deepwater, azooxanthellate corals may also be present.

Despite the possible substrate similarities throughout the sub-region, there will be distinct differences in species composition between depth zones. The shallower habitats are likely to have an overall higher biomass of animals, as partly reflected by the fishery catches in these depths (see 6.11.3 below). In the deeper slope biome (> 1500 m), assemblages would probably include small, bioluminescent species that vertically migrate, including Hatchetfish (*Argyropelecus* spp.), Dragonfish (*Melacosteus* spp.), Viperfish (*Chauliodus* spp.) and a number of squid and eel species. In addition, more bottom-attached species such as conger eels, macrourid cods and tripod fish are also expected to occur there. These organisms are typically present is very low abundances and very patchily distributed.

The productivity flows between the benthic and pelagic realms of the sub-system are weakly connected. The benthic habitats are out of the direct influence of pelagic primary production and primary consumers, and are largely reliant on down-slope transport of sediments/nutrients and cycling of particulate organic matter (such as marine snow and other falling organic matter and detritus) through bacterial detrital food webs. The shallow regions of the slope (<500 m) are likely to have micronekton (e.g. small fish and crustaceans) and some planktonic species migrating between the benthic to pelagic realms under a diel rhythm (e.g. Benoit-Bird and Au, 2006). Other connections include the temporary feeding movements of large tunas (e.g. Yellowfin and Longtail tuna; Shane Griffiths, pers comm) and whales.

6.11.3 Services and linkages

The WTBF operates in this sub-region taking mainly Bigeye tuna (*Thunnus obesus*), Yellowfin tuna (*T. albacares*) and Broadbill swordfish (*Xiphius gladius*) by a variety of methods. Other species caught here include Albacore Tuna (*Thunnus alalunga*), Southern Bluefin Tuna (*Thunnus maccoyii*), Dolphinfish (*Coryphaena hippurus*), Escolar (*Lepidocybium flavobrunneum*), Rays Bream (*Bramidae spp*.) and Blue Sharks (*Prionace glauca*). Other tertiary consumers that are impacted by this fishery include the albatrosses and shearwaters which are caught as bycatch in the WTBF. Longtail tuna (*T. tonggol*) are caught here mainly by recreational fishers.

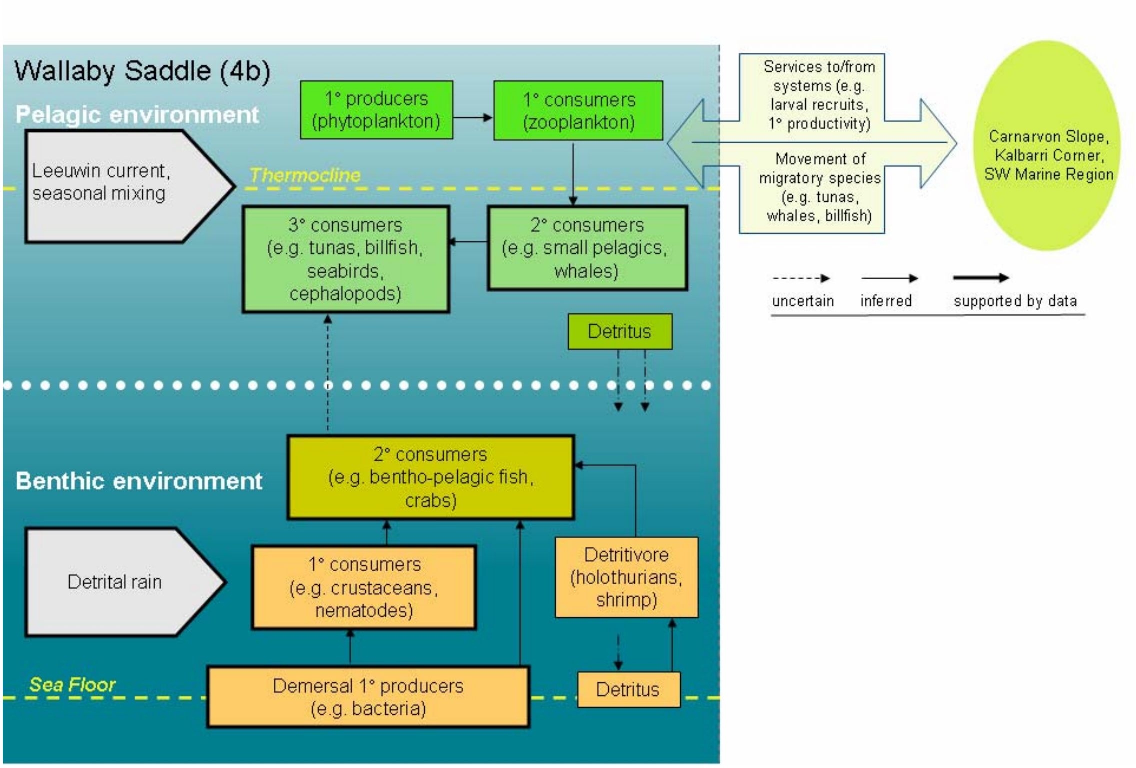


Figure 6-58 Conceptual model of the Wallaby Saddle trophic system showing information on the main habitat in the mid-slope.

Another fishery that operates on the upper slope (150-1200 m) is the West Coast Deep Sea Crab Interim Managed Fishery (WDSCIMF). This targets three species; the Crystal (or snow) crab (*Chaceon* spp), Champagne crab (*Hypothalassia acerba*) and Giant crab (*Pseudocarcinus gigas*). This fishery uses pots and little bycatch is reported by the fishery. This fishery operates from the NT border to Cape Leeuwin and the proportion of the fisheries effort in this sub-region was not obtained.

The region is an important migrating pathway for many species, including blue whales, fin whales, dwarf and Antarctic minke whales, and in particular humpback whales. Most whales (apart from humpbacks) tend to migrate along or outside the 200 m contour (i.e. in waters outside the edge of the shelf) where they feed on tropical krill species such as *Pseudeuphausia latifrons*.

6.11.4 Key species interactions

Like the Carnarvon Slope (above), the WTBF, WDTF and WDSCIMF operate in this sub-region and these have significant amounts of fishing effort on a range of the tertiary and secondary consumers, in both the pelagic and shallower benthic habitats. As in the other regions, the impacts on 'top level predators' are unclear, but believed to have potentially major impacts on their overall community structure.

6.11.5 Resilience and vulnerability

The Wallaby Saddle has been impacted by a crab fishery on the upper slope and a fishery for large pelagic species mainly in surface waters. The crab fishery uses traps and will have had little impact on the benthic habitat and small impacts on other species. The pelagic WTBF will be removing a proportion of the tertiary consumers from the pelagic environment. Although the exact nature of this impact is not clearly known it is likely to have cascading effects into the lower trophic levels, increasing the relative abundances of species groups that were used as prey for these fished species with cascading effects into their prey and other predators.

The potential effects of climate change are poorly understood, mainly due to the potential flow-on impacts of global scale oceanographic processes. However, it is known that most marine species have temperature distinct tolerances and if water temperatures increase then we can expect a shift in distribution for whole communities. This would also be seen in fisheries. For example, the WTFB may well shift further south and consequently be influenced by different levels of productivity or differences in other important processes.

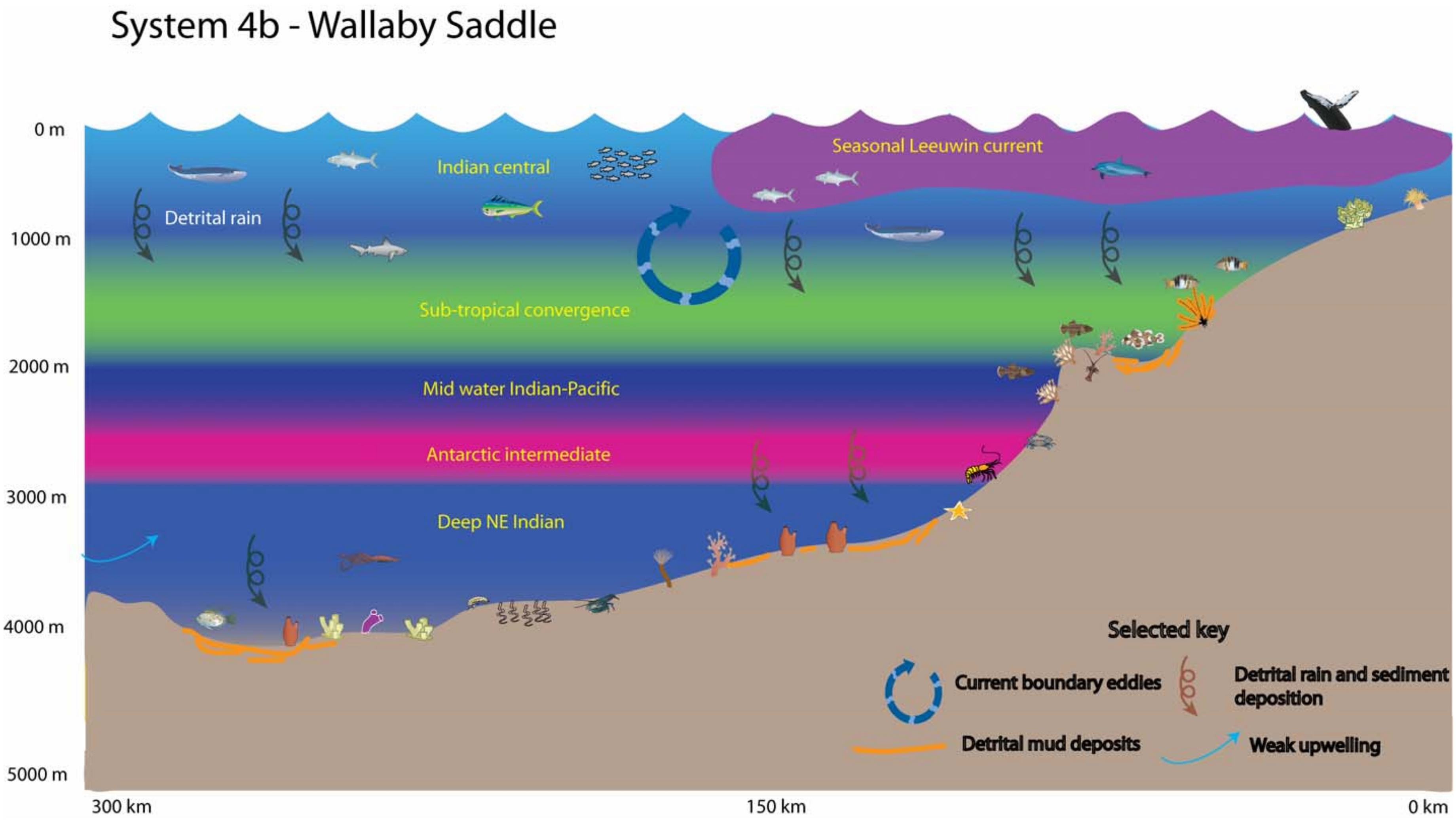


Figure 6-59 Habitat diagram of the Wallaby Saddle sub-region showing selected important drivers and features. 70-100 deep chlorophyll maxima not shown.

6.11.6 Information gaps

The trophic systems in the Wallaby Saddle sub-region are not well understood. The mechanisms regulating primary productivity and its consequences for all consumer levels are complex are not well studied. The ecological consequences of fishing the highest level predators in the pelagic and demersal systems are also poorly understood, although there is some evidence that it can invoke changes to species composition at all levels.

The impact and dependence of toothed whales and dolphins on certain species such as cephalopods (squid, octopus and cuttlefish), fish, and crustaceans (krill, amphipods and copepods) is not well understood. A better understanding of these processes will enable a broader understanding of how to protect these species.

Trawling typically has relatively high levels of bycatch and the bycatch of the Western Deepwater Trawl Fishery appears to be poorly documented. The risk to these species is not well understood and require a quantitative risk assessment to help define the fishery impact on their populations and thee demersal communities.

The demersal communities of the benthic habitats in this and other deep-water sub-region are poorly understood.

7. DISCUSSION AND CONCLUSIONS

7.1 Similarities and differences between trophic systems

The general understanding on similarities and differences between the trophic systems we have come to of the NWMR are summarised as follows:

General Similarities
At the NWMR scale, physical processes constrain the productivity of the trophic system. The ITF outflow, its suppression of the thermocline and instigation of the start of the Leeuwin Current are key drivers of the NWMR. Biological adaptions to low nutrient, high current stress environments have resulted in trophic components that are highly adept at rapidly stripping any nutrients out of the water column. Recycling processes sustain standing crops of plankton and nekton while new production is rapidly consumed and transported away as detrital rain. Energetic events and their interaction with the seafloor or coast are key mechanisms for the supply of new production. Under oligotrophic conditions, picoplankton, microbial and filter feeders play a key role in recycling and sustaining productivity in the surface layers. Below the surface layer, subsurface upwellings may play a key role in supplying the productivity of the NWMR. Seasonal and interannual variability in physical processes controlling the thermocline depth, such as the intensity of the ITF and wind-driven currents/mixing are key processes affecting the variability of productivity of the NWMR.

General Differences
At the NWMR scale, the broad scale differences are associated with the change from north to south in the relative influences of the ITF and the Indian Ocean Central Water mediated by the seasonal monsoonal changes in climatic variables. Thus, high seasonal variability in physical conditions is experienced, including changes in the flow of the ITF, shelf currents and productivity changes and the timing and strength of the Leeuwin Current system. On the shelf, differences in the nearness to deep water critically affect shelf productivity. In the north, the ITF brings some nutrients to the Sahul Shelf whereas in the NW Shelf, nutrients are injected at depth by the breaking of internal tides and have to make their way to the coastal system. On the slope, internal waves and boundary currents interact with topographic structures and irregularities to control the availability of subsurface nutrients. Upwelling is very limited and confined largely to the coast south of the North West Cape. Deep ocean basins exist in only two of the sub-regions we identified. The Argo Abyssal Basin is overlaid at the surface by the monsoonal ITF currents and is flanked to the north by the productive Java upwellings while the Curvier Basin is overlaid by the seasonal Leeuwin Current and may experience detrital flows along its eastern margin from the Carnarvon Slope and in the north from the Exmouth Plateau.

The individual sub-regions described in this report have some similarities, but these are usually only superficial. The communities and trophic structures are influenced by a combination of features unique to each sub-region. In general, the shelf, slope and abyssal habitats are markedly different. But even within these zones, there are no two sub-regions that appear to be similar in their habitats, communities and hence, their trophic systems. The WJBG and Kimberly Shelf sub-regions are both wide sections of the continental shelf with seasonal, coastal freshwater input, and some nutrient and larval connection. However, the WJBG has a considerably larger freshwater input and coastal boundary layer and it's outer shelf includes a large basin area and limestone pinnacles; both with unique, though largely undescribed communities and trophic relationships. The Kimberly Shelf deepens towards the shelf edge and is dominated by a series of banks and rises that is impacted by internal breaking waves and supports a unique benthic community. The NW Shelf has almost no coastal freshwater input, a relatively homogeneous shelving sea bed, a very high concentration of cyclones (Figure 5-7) and other unique features. The Carnarvon Shelf is different again being very narrow, and hence, influence strongly by shelf edge processes and the seasonal, high-nutrient Ningaloo Current which promotes high primary productivity and a unique pelagic community in the region. The Kalbarri Shelf to the south is influenced by the Indian Ocean water mass and the higher salinity waters flowing from Shark Bay. It is nutrient poor compared to the Carnarvon Shelf and supports a unique, though poorly understood trophic system.

Like the shelf sub-regions, the continental slope sub-regions each support unique communities and hence trophic structures, particularly the benthic environments. They sit in three different pelagic water masses, have different combinations of geomorphic features and associated habitats and have been shown by Last et al., (2005) to have distinctly different demersal fish communities. The Abyssal plains too are at different depths, have different geomorphic features and are influenced by different slope environments.

Trophic Summary

Physical processes strongly control the trophic systems of the NWMR which are highly adapted to take advantage of new production while being very efficient in recycling detrital matter. Trophically, the key defining drivers are the availability of new production, its duration and its frequency. The ability of recycling processes to retain detrital matter and the depth at which nutrients are available in relation to the photic depth are key aspects of the productivity and standing crop in the trophic systems. Biological migration, whether mediated by currents or not, are key perturbations of the trophic systems, particularly those that rely upon recycling. Likewise, the disturbances due to cyclones. By and large, the productivity of the sub-regions are driven by the regular and persistent processes rather than the infrequent highly energetic ones. Benthic productivity on the shelf is constrained at the coast by high turbidity and lack of nutrients while at mid-shelf, nutrients are higher and light levels are moderate. Benthic production is thus likely to increase away from the coast before declining again in deeper water in the outer shelf. Benthic trophic processes play a key role on the shelf while bentho-pelagic groups play a pivotal role in transferring productivity between the pelagic and benthic subsystems.

Differences from other Australian marine regions

The NWMR has a unique combination of features that distinguish it from the other marine regions around Australia. These include a wide continental shelf, very high tidal regimes, very high cyclone (Figure 5-7) incidence, unique current systems, warm oligotrophic surface waters, and a range of unique features including the highly productive Ningaloo reef region, the expansive Exmouth Plateau slope region and offshore reefs. Although there is some connectivity with the North Marine Region (NMR) via larval advection within the Indo-Pacific throughflow, a large proportion of the demersal and benthic fauna in particular are relatively unique to the region. There is some overlap with the NMR in that the WJBG and western extents of the NMR are show a high degree of similarity in habitats, communities, and hence their trophic systems. Similarly, the most southern sub-regions (Kalbarrri Shelf and Wallaby Saddle) are probably closer in character to the SWMR than the NWMR; to the extent that a slight manoeuvring of the boundary edges of these ‘edge’ regions may make more ecological sense. However, the majority of the NWMR is ecologically unique, as borne out in the limited number of studies that have assessed aspects of these communities in a broad context (e.g. Last et al., 2005; Hooper and Ekins, 2004)

Resilience and vulnerability

The resilience and vulnerability of trophic systems in the NWMR varies between different sub-regions and more locally between different trophic communities. Some communities are adapted to coping with environmental variability such as the shelf regions in the north of the NWMR, which are subject to highly variable coastal freshwater and nutrient input, highly variable tidal currents and/or sporadic major climate events such as cyclones. These environments are likely to be more resilient to other climatic variability such as variations to seasonal patterns, more frequent or more intense weather patterns. However, their tolerance to increased water temperatures is less certain, and their tolerance to anthropogenic disturbance is likely to be low, as demonstrated in marine environments elsewhere.

Other trophic communities appear to be less tolerant of environmental change, such as the offshore coral reefs that are subject to bleaching and high mortality under slightly elevated sea temperatures; or the productive trophic system adjacent to Ningaloo Reef which relies on the seasonal flow of the Ningaloo Current. The continental slope sub-regions have relatively narrow physical tolerances but are adapted to some physical disturbance such as sediment slumping. The deeper communities survive in a relatively narrow range of tolerances. They are removed from many potential sources of impact, but are unlikely to be able to tolerate physical, chemical or environmental changes.

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Col Limpus (QNPWS) 2007. Marine turtles of the NWMR.

Mike Fuller, 2007. CSIRO Marine and Atmospheric Research.

Miles Furnas, 2007. Australian Institute of Marine Science.

APPENDICES

Appendix 1. Abiotic statistics generated for the eco-physical systems of the North-west Marine Region

Depth and slope statistics for the trophic system compartments of the North-western Marine Region. Data generated from gridded bathymetry (Geosciences Australia)

Name		Mean depth (m)	Min Depth (m)	Max Depth (m)	Mean slope (%)	Min slope (%)	Max Slope (%)
Western JBG shelf	1a1	-84.05	0	-271	0.36	0	40
Kimberley shelf	1a2	-80.28	-4	-283	0.37	0	14
Kimberley slope	1b	-1509.59	34	-5644	2.83	0	247
Argo Plain	1c	-5571.65	-3674	-5977	1.91	0	69
NW shelf	2a	-83.53	0	-378	0.27	0	20
Exmouth plateau	2b	-1614.40	-1	-5710	2.26	0	175
Carnarvon shelf	3a	-112.03	-32	-563	0.65	0	32
Carnarvon slope	3b	-2359.35	-184	-5334	3.90	0	251
Cuvier abyssal plain	3c	-5007.57	-3289	-5456	2.43	0	65
Kalbarri Shelf	4a	-115.44	-33	-320	0.26	0	12
Wallaby Saddle	4b	-2585.58	-174	-4586	1.80	0	21

Temperature (C°) for the trophic system compartments of the North-western Marine Region - annual mean (and seasonal (monthly) for SST) at the surface (SST), 150 m, 500 m, 1000 m and 2000 m; and monthly. SST from NOAA, depth data derived from CARS.

Name		SST Mean	SST Jan	SST April	SST July	SST Oct	Ave Temp 150m	Ave Temp 500m	Ave Temp 1000m	Ave Temp 2000m
Western JBG shelf	1a1	28.65	29.87	29.91	26.41	28.81	19.27	7.89		
Kimberley shelf	1a2	28.48	29.67	30.47	26.36	27.88	19.39	8.09	4.89	
Kimberley slope	1b	28.47	29.53	30.10	26.61	28.19	19.73	8.05	4.91	2.41
Argo Plain	1c	28.06	29.24	29.85	26.28	27.28	20.31	8.24	4.95	2.41
NW shelf	2a	27.35	29.61	29.72	24.50	25.73	21.11	8.27	5.03	
Exmouth plateau	2b	26.84	28.11	29.09	25.17	25.07	20.44	8.52	5.01	2.39
Carnarvon shelf	3a	24.52	24.99	27.16	23.73	22.01	21.26	8.68	4.96	
Carnarvon slope	3b	24.43	25.15	27.01	23.28	22.17	20.02	9.26	4.93	2.38
Cuvier abyssal plain	3c	24.38	24.97	26.72	23.36	22.23	19.90	9.55	4.94	2.38
Kalbarri Shelf	4a	23.19	23.47	25.51	22.77	20.88	20.53	8.96	4.48	
Wallaby Saddle	4b	22.83	23.46	25.00	21.98	20.84	18.88	9.51	4.74	2.39

Average salinity (ppt) for the trophic system compartments of the North-western Marine Region at the surface, 150 m, 500 m, 1000 m and 2000 m depth. (Derived from CARS)

Name		Mean surface salinity	Mean salinity 150m	Mean salinity 500m	Mean salinity 1000m	Mean salinity 2000m
Western JBG shelf	1a1	34.76	34.50	34.57		
Kimberley shelf	1a2	34.78	34.64	34.61	34.61	
Kimberley slope	1b	34.59	34.64	34.60	34.61	34.73
Argo Plain	1c	34.55	34.81	34.65	34.61	34.73
NW shelf	2a	35.15	34.92	34.65	34.63	
Exmouth plateau	2b	34.89	35.11	34.67	34.63	34.72
Carnarvon shelf	3a	35.19	35.39	34.66	34.63	
Carnarvon slope	3b	35.21	35.55	34.72	34.61	34.72
Cuvier abyssal plain	3c	35.19	35.55	34.75	34.61	34.72
Kalbarri Shelf	4a	35.39	35.59	34.67	34.50	
Wallaby Saddle	4b	35.45	35.75	34.75	34.57	34.72

Average Nitrate (uM) and Phosphate (uM) concentration for the trophic system compartments of the North-western Marine Region at the surface, 150 m, 500 m, 1000 m and 2000 m depth. (Derived from CARS)

Name		Mean N 0m	Mean N 150m	Mean N 500m	Mean N 1000 m	Mean N 2000 m	Mean P 0m	Mean P 150m	Mean P 500m	Mean P 1000 m	Mean P 2000 m
Western JBG shelf	1a1	0.18	16.16	36.20	38.90		0.15	1.15	2.26	38.90	
Kimberley shelf	1a2	0.21	16.06	36.37	39.31	32.35	0.19	1.15	2.21	39.31	2.52
Kimberley slope	1b	0.09	15.48	33.40	37.20	32.93	0.15	1.07	2.17	37.20	2.56
Argo Plain	1c	0.05	12.81	28.53	35.40	34.14	0.11	0.85	1.96	35.40	2.61
NW shelf	2a	0.14	11.65	29.79	38.17		0.14	0.86	1.84	38.17	
Exmouth plateau	2b	0.11	9.49	25.41	37.01	34.11	0.13	0.70	1.64	37.01	2.59
Carnarvon shelf	3a	0.03	2.03	18.80	38.52	37.57	0.15	0.30	1.26	38.52	2.52
Carnarvon slope	3b	0.04	2.71	16.40	37.33	36.91	0.14	0.32	1.16	37.33	2.53
Cuvier abyssal plain	3c	0.04	3.21	15.53	36.44	36.28	0.13	0.34	1.12	36.44	2.55
Kalbarri Shelf	4a	0.05	1.16	15.95	36.13	36.78	0.13	0.24	1.18	36.13	2.27
Wallaby Saddle	4b	0.06	1.37	13.13	34.77	35.73	0.12	0.24	1.09	34.77	2.47

Average disolved oxygen (mg/l) concentration for the trophic system compartments of the North-western Marine Region at the surface, 150 m, 500 m, 1000 m and 2000 m depth. (Derived from CARS)

Name		Mean surface DO	Mean DO 150m	Mean DO 500m	Mean DO 1000m	Mean DO 2000m
Western JBG shelf	1a1	4.55	2.84	2.12	2.25	
Kimberley shelf	1a2	4.52	2.78	2.13	2.22	3.24
Kimberley slope	1b	4.54	2.75	2.31	2.20	3.18
Argo Plain	1c	4.55	2.99	2.95	2.15	3.14
NW shelf	2a	4.61	3.27	3.48	2.19	
Exmouth plateau	2b	4.65	3.50	3.98	2.18	3.25
Carnarvon shelf	3a	4.79	4.45	5.11	2.36	3.40
Carnarvon slope	3b	4.79	4.44	5.29	2.42	3.38
Cuvier abyssal plain	3c	4.77	4.31	5.29	2.41	3.36
Kalbarri Shelf	4a	4.91	4.62	5.34	2.99	3.52
Wallaby Saddle	4b	4.91	4.78	5.43	2.79	3.44

Average silicate concentration (uM) concentration for the trophic system compartments of the North-western Marine Region at the surface, 150 m, 500 m, 1000 m and 2000 m depth. (Derived from CARS)

Name		Mean surface silicate	Mean silicate 150m	Mean silicate 500m	Mean silicate 1000m	Mean silicate 2000m
Western JBG shelf	1a1	3.52	34.50	66.10	103.28	
Kimberley shelf	1a2	5.10	34.64	57.62	99.42	134.15
Kimberley slope	1b	3.46	34.64	56.21	97.17	131.12
Argo Plain	1c	3.16	34.81	43.45	95.77	129.24
NW shelf	2a	3.53	34.92	34.18	96.77	
Exmouth plateau	2b	3.65	35.11	26.85	94.84	128.30
Carnarvon shelf	3a	3.33	35.39	10.54	86.05	119.47
Carnarvon slope	3b	3.67	35.55	8.07	84.74	118.87
Cuvier abyssal plain	3c	3.86	35.55	7.19	84.34	119.29
Kalbarri Shelf	4a	2.86	35.59	7.07	67.99	102.33
Wallaby Saddle	4b	3.21	35.75	6.10	78.18	112.61

Mean annual and and monthly Chlorophyll concentration (mg/m^3) for the trophic system compartments of the North-western Marine Region. (Derived from MODIS Aqua Ocean Colour Satellite)

Name		Mean Chlorophyll	Mean Chlorophyll January	Mean Chlorophyll April	Mean Chlorophyll July	Mean Chlorophyll October
Western JBG shelf	1a1	0.513	0.389	0.472	0.811	0.380
Kimberley shelf	1a2	0.299	0.237	0.311	0.384	0.263
Kimberley slope	1b	0.111	0.075	0.106	0.173	0.090
Argo Plain	1c	0.090	0.064	0.089	0.122	0.084
NW shelf	2a	0.357	0.329	0.381	0.407	0.314
Exmouth plateau	2b	0.125	0.070	0.092	0.180	0.157
Carnarvon shelf	3a	0.386	0.224	0.210	0.468	0.643
Carnarvon slope	3b	0.220	0.101	0.101	0.332	0.345
Cuvier abyssal plain	3c	0.192	0.096	0.097	0.295	0.278
Kalbarri Shelf	4a	0.275	0.137	0.189	0.322	0.451
Wallaby Saddle	4b	0.170	0.096	0.093	0.205	0.285

Mean wave and tidal exceedance (%) for the trophic system compartments of the North-western Marine Region generated from estimates from surface wind speed (Met Bureau regional atmospheric model) as inpout to the Wave Model, WAM. Exceedance is defined as the percentage of time that currents are predicted to mobilise sediments of a mean grain size.

Name		Mean wave exceedance	Mean tide exceedance
Western JBG shelf	1a1	0.44	25.01
Kimberley shelf	1a2	0.83	33.22
Kimberley slope	1b	1.42	8.19
Argo Plain	1c		
NW shelf	2a	1.32	24.68
Exmouth plateau	2b	0.08	9.62
Carnarvon shelf	3a	0.65	0.00
Carnarvon slope	3b	1.19	0.00
Cuvier abyssal plain	3c		
Kalbarri Shelf	4a	0.42	0.00
Wallaby Saddle	4b	0.33	0.00

Mean mixed layer depth (m) for the trophic system compartments of the North-western Marine Region, calculated from salinity cast data used to generate CARS2000.

Name		Mean mixed layer depth	Min mixed layer depth	Max mixed layer depth
Western JBG shelf	1a1	32.50	28	38
Kimberley shelf	1a2	31.39	27	38
Kimberley slope	1b	33.20	27	40
Argo Plain	1c	32.70	29	40
NW shelf	2a	29.22	18	38
Exmouth plateau	2b	35.68	30	42
Carnarvon shelf	3a	37.91	36	39
Carnarvon slope	3b	37.44	36	40
Cuvier abyssal plain	3c	37.98	34	41
Kalbarri Shelf	4a	44.48	38	49
Wallaby Saddle	4b	37.41	35	42

Mean annual and monthly surface current (m/s) for the trophic system compartments of the North-western Marine Region; surface currents are generated from steric-height fields, and tidal currents are generated from a tide model for the Australian shelf

Name		Mean Surface currents January	Mean surface currents April	Mean surface currents July	Mean surface currents October
Western JBG shelf	1a1	0.132	0.103	0.112	0.110
Kimberley shelf	1a2	0.090	0.051	0.065	0.065
Kimberley slope	1b	0.130	0.076	0.082	0.096
Argo Plain	1c	0.114	0.083	0.095	0.105
NW shelf	2a	0.033	0.040	0.060	0.037
Exmouth plateau	2b	0.046	0.055	0.052	0.057
Carnarvon shelf	3a	0.090	0.107	0.120	0.073
Carnarvon slope	3b	0.078	0.094	0.109	0.060
Cuvier abyssal plain	3c	0.048	0.047	0.081	0.044
Kalbarri Shelf	4a	0.077	0.120	0.106	0.074
Wallaby Saddle	4b	0.069	0.095	0.069	0.056

Total (1906-2000) and mean annual cyclone activity for the trophic system compartments of the North-western Marine Region, including cyclone path per square km within each compartment, and average path length for cyclones within each compartment. Data derived from Met Bureau cyclone data.

Name		Path per sq km (m)	Path per sq km per yr (m)	Average path length (km)
Western JBG shelf	1a1	125.61	1.34	157.55
Kimberley shelf	1a2	280.11	2.98	226.05
Kimberley slope	1b	185.20	1.97	255.45
Argo Plain	1c	225.63	2.40	182.66
NW shelf	2a	242.93	2.58	237.20
Exmouth plateau	2b	248.27	2.64	339.02
Carnarvon shelf	3a	112.15	1.19	44.49
Carnarvon slope	3b	171.63	1.83	139.84
Cuvier abyssal plain	3c	101.37	1.08	118.71
Kalbarri Shelf	4a	72.16	0.77	120.36
Wallaby Saddle	4b	86.98	0.93	154.23

Mean sediment parameters for the trophic system compartments of the North-western Marine Region. Mean grain size (mm) and mud etc content (weight %) were compiled from Geoscience Australia's marine sediment database (MARS –Table includes number of samples). Sediment mobility is a representation of the relative importance of tidal currents and ocean waves in mobilising sediments of mean grain size on the seabed, as computed by Geoscience Australia's sediment dynamics model, GEOMAT.

Name		Samples	Mean grain size (mm)	Mean % mud	Mean % sand	Mean % gravel	Mean % carbonate	Mean sediment mobility
Western JBG shelf	1a1	82503	0.22	40.98	48.23	10.76	61.06	4.65
Kimberley shelf	1a2	63868	0.72	14.92	53.51	31.57	83.02	4.48
Kimberley slope	1b	32614	0.43	24.38	61.57	14.05	84.60	2.56
Argo Plain	1c							
NW shelf	2a	100837	0.45	9.97	77.62	12.42	91.37	3.82
Exmouth plateau	2b	31258	0.31	31.20	60.33	8.48	88.13	3.22
Carnarvon shelf	3a	2543	0.79	0.27	91.87	7.88		0.39
Carnarvon slope	3b	325	0.80	0.27	91.52	8.21		0.00
Cuvier abyssal plain	3c							
Kalbarri Shelf	4a	6960	0.50				80.27	0.25
Wallaby Saddle	4b							

Appendix 2. List of GIS files/layers and other datasets provided as part of the project delivery to DEW

Public Doman (existing datasets)

1. Data summaries processed from National Marine Bioregionalisation 2005.
2. Cyclone tracks (1906-2000) for the North West Marine Region Data derived from Bureau of Meteorology data.

New Data

1. Sub-regional boundaries created for the description of trophic systems in the NWMR.

Appendix 3. Glossary of Terms

Advection	Transport in a fluid from one region to another, can be vertically or horizontally.
Basin	A geological feature where a large part of the earth is covered by seawater, often where the edges of the feature are shallower then the central portion.
Biodiversity	In an oceans context, the variety of living organisms in the estuaries and oceans, their genes, and the ecosystems of which they form a part (National Strategy for the Conservation of Australia's Biological Diversity, 1996)
Bioregion	An area defined by a combination of biological, social and geographic criteria, rather than by geopolitical considerations. Generally, a system of related, interconnected ecosystems (Commonwealth of Australia 1996).
Bioregionalisation	A process of identifying and mapping broad ecologicalpatterns based on physical and/or biological attributes for planning and management purposes.
Community	A group of organisms, both animals and plants, living together in an ecologically related fashion in a defined area or habitat.
Driver	A feature or process that promotes or controls the onset and onward course of an action.
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (UNEP Convention on Biological Diversity, June 1992)
Ecosystem structure	The components of an ecosystem including plants, animals, micro-organisms and the non-living environment.
Ecosystem function	The biological, physical and chemical processes that link components of the ecosystem.
EEZ	The Exclusive Economic Zone. The area between the lines 12 nautical miles and 200 nautical miles seaward of the territorial sea baselines. In this area, Australia has the right to explore and exploit living and non-living resources, and the concomitant obligation to protect and conserve the marine environment.
Functional group	Groups of organisms that occupy a similar position in a trophic system or food web.

Gyre	Circulation or rotation of ocean water usually dictated by prevailing winds and the Coriolis effect
Habitat	The place or type of site where an organism or population naturally occurs (UNEP 1994).
IMCRA	Interim Marine Coastal Regionalisation for Australia. An ecosystem-based classification for marine and coastal environments. It provides ecologically based regionalisations at the meso-scale (100–1000 km) and at a provincial scale (greater than 1000 km).
MPA	Marine Protected Area. An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means (IUCN 1994).
State waters	Australia’s Offshore Constitutional Settlement established Commonwealth, State and Territory jurisdictions over marine areas. States generally have primary jurisdiction over marine areas to 3 nautical miles from the baseline.
Trophic systems	Is the interconnected web that describes the various positions which organisms that live within an area occupies in a food chain (what it eats and what eats it).
Upwelling	An oceanographic phenomenon that involves the movement of dense, cooler, and usually nutrient-rich water towards the ocean surface, replacing the warmer, usually nutrient-depleted surface water.