A Characterisation of the Marine Environment of the North-west Marine Region

A summary of an expert workshop convened in Perth, Western Australia, 5-6 September 2007

Prepared by the North-west Marine Bioregional Planning section, Marine and Biodiversity Division, Department of the Environment, Water, Heritage and the Arts

Background

The Department of the Environment, Water, Heritage and the Arts (DEWHA) is developing a North-west Marine Bioregional Plan under the *Environment Protection and Biodiversity Conservation Act 1999* (hereafter referred to as the Act). The primary aim of the Plan is to provide specific guidance for making decisions of relevance to the North-west Marine Region (the Region) under the Act. The Department requires scientific input at the following key stages in the development of the Plan:

1. During the Bioregional profiling stage of Marine Bioregional Planning - to ensure that the description of the ecological systems of the Region is based upon comprehensive and up to date scientific knowledge, integrated across the relevant disciplines. For the North-west Marine Region, the Department is drawing on:
    a) the Integrated Marine and Coastal Regionalisation of Australia (IMCRA), which is based on a synthesis of biological, geological and oceanographic data
    b) a comprehensive review of relevant literature, supplemented by a number of key reports, including:
        - *Trophic Systems of the North West Marine Region* (Brewer et al., 2007); and
        - A number of species reports on Sharks & Rays, Cephalopods, Sea Snakes and Small Pelagic Fish (numerous authors).
    c) the outcomes of this expert workshop - on developing a multidisciplinary characterisation of the natural systems in the marine environment of the North-west Marine Region.
2. During the assessment of threats to regional conservation values, to incorporate current understanding of likely responses of the Region's ecological systems to current and future pressures.
3. During the identification of key information and research needs and indicators for monitoring the state of the marine environment in the Region, and consideration of the adequacy of existing measures to protect it.

The Expert Workshop

This paper summarises the outcomes and discussions of an expert workshop convened in Perth, Western Australia in September 2007 by the Department of the Environment, Water, Heritage and the Arts. The objective of this workshop was to characterise the marine environment of the North-west Marine Region to improve the Department's understanding of how the Region's natural systems work. More specifically, the Department's aims for the workshop were:

- to characterise functional systems within the Region on the basis of their location, their biological and physical components and how these interact
- to understand links across functional systems and the broad scale drivers of ecosystem function across the Region, including the importance of the interface between functional systems and the key processes that link neighbouring systems
- to identify the key areas of uncertainty in our understanding of the Region's ecological systems, as well as identify those areas for which empirical evidence is available.

Background papers were circulated in advance of the workshop to provide the participating scientists with a broad overview of the marine planning policy and process, as well as to explain the purpose and structure of the workshop.

Approach to characterising the North-west Marine Region

The Department commissioned CSIRO Marine and Atmospheric Research (CMAR) in 2006 to develop a framework for characterising marine environments. The Department and CMAR 'road-tested' the framework using data from and experts familiar with the South-east Marine Region (http://www.environment.gov.au/coasts/mpa/southeast/index.html). The findings were used to refine the framework which was then applied in workshops to characterise the environment of the South-west Marine (http://www.environment.gov.au/coasts/mbp/publications/south-west/sw-characterisation.html) and North Marine Regions in September 2006 and April 2007 respectively. The approach is illustrated in Figure 1 below.

A range of resources were made available at the workshop, including a number of hard copy maps depicting regional data layers such as bathymetry, geomorphic features and species assemblages. Participants were also encouraged to bring any relevant data/tools/maps/reports that may be helpful.

The North-west workshop was run over two days and was facilitated by Professor Bruce Mapstone. The workshop was structured around a series of steps to characterise the marine environment of the North-west Marine Region:

Step 1 – Identifying major eco-physical systems within the Region

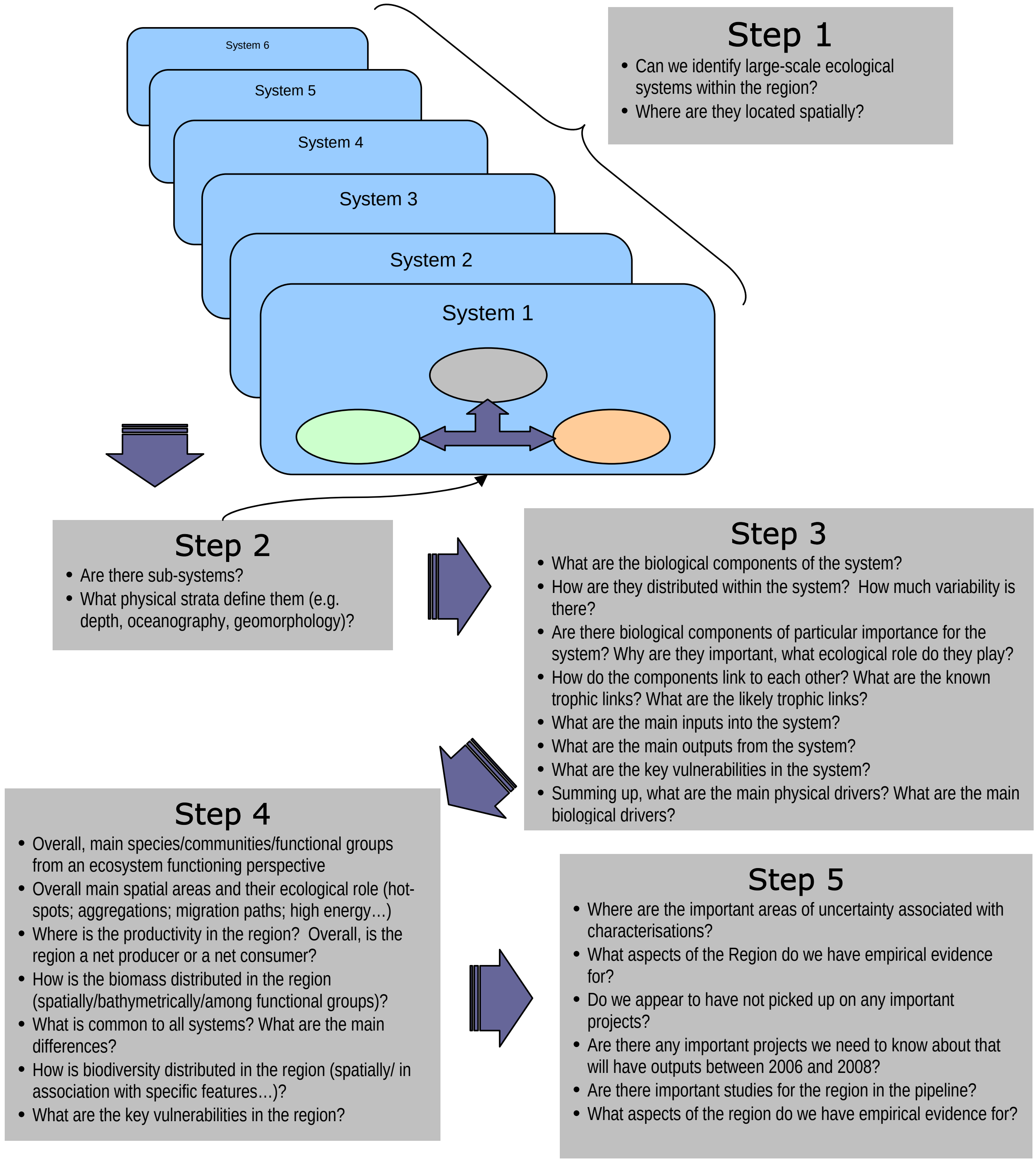
Step 2 – Identifying eco-physical sub-systems

Step 3 – Characterising the ecological systems through conceptual modelling

Step 4 – Reflecting on regional-scale interactions and processes

Step 5 – Understanding the state of knowledge and identifying areas of uncertainty

Figure 1 – Framework for characterising the marine environment using regional knowledge and expertise.
Each step is described by a series of questions. These are meant to illustrate the scope and focus of the discussion at each step, but are not intended to be prescriptive.



The Workshop Report

This report aims to capture the agreed outcomes of discussion at the workshop. Its structure therefore reflects the process followed by the workshop and thus discusses in sequence:

- the characteristics and key drivers of the North-west Marine Region as a whole
- the Region's major systems; and
- the sub-systems within each identified regional system and areas of uncertainty.

The content of the report is reliant upon the discussion that occurred at the workshop and therefore 'new' information (i.e. published papers and reports made available to the workshop participants) have not been reviewed and integrated into this report.

DEWHA circulated the report to all workshop participants with annotated questions to seek further comments, clarifications and corrections from the experts that participated in the workshop. This paper is the final workshop report following incorporation of participants' comments. It captures a representation of the functional relationships among ecological properties of the North-west Marine Region based on the expertise of participants, and it is intended to complement the existing biogeographical and geomorphological classifications of the Region. The report is available on the DEWHA website (http://www.environment.gov.au/coasts/mbp/north-west/index.html).

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Attendance at workshop

The workshop was attended by a broad range of marine scientists with expertise in geomorphology, oceanography, nearshore ecosystems and offshore ecosystems. Participants were:

Prof. Bruce Mapstone (Chair) – CRC for Antarctic Climate and Ecosystems

Prof. Greg Ivey – University of Western Australia

Ass. Prof. Lindsay Collins – Curtin University

Dr Ryan Lowe – University of Western Australia

Dr Anya Waite – University of Western Australia

Dr Harriet Paterson – University of Western Australia

Ass. Prof. Jeremy Prince – Biopspherics Pty Ltd

Dr Trevor Ward – Greenward Consulting, Western Australia

Ian Le Provost – Le Provost Environmental Pty Ltd

Curt Jenner – Centre for Whale Research (WA) Inc.

Tim Skewes – CSIRO Marine and Atmospheric Research

Dave Brewer – CSIRO Marine and Atmospheric Research

Dr Vince Lyne – CSIRO Marine and Atmospheric Research

Mike Fuller – CSIRO Marine and Atmospheric Research

Susan Wijffels - CSIRO Marine and Atmospheric Research

Dr Jane Fromont – WA Museum

Diana Jones – WA Museum

Clay Bryce – WA Museum

Luke Smith – Australian Institute of Marine Science

Dr Chris Simpson – Department of Environment and Conservation, Western Australia

Dr Bob Prince - Department of Environment and Conservation, Western Australia

Dr Ray Masini - Department of Environment and Conservation, Western Australia

Dr Alan Kendrick - Department of Environment and Conservation, Western Australia

Dr Kelly Waples - Department of Environment and Conservation, Western Australia

Dr Andrew Heap – Geoscience Australia

Dr Anthony Heart – Department of Fisheries, Western Australia

Dr Stephen Newman – Department of Fisheries, Western Australia

Lynda Bellchambers – Department of Fisheries, Western Australia

Roy Melville-Smith – Department of Fisheries, Western Australia

Ian Cresswell – Department of the Environment, Water, Heritage and the Arts

Rowan Wylie – Department of the Environment, Water, Heritage and the Arts

Louise Wicks – Department of the Environment, Water, Heritage and the Arts

Paula Tomkins – Department of the Environment, Water, Heritage and the Arts

Jennifer Hoy – Department of the Environment, Water, Heritage and the Arts

Nadeena Beck – Department of the Environment, Water, Heritage and the Arts

Matt Davis – Department of the Environment, Water, Heritage and the Arts

Cath Frampton – Department of the Environment, Water, Heritage and the Arts

Ben Addison – Department of the Environment, Water, Heritage and the Arts

Nancy Dahl-Tacconi – Department of the Environment, Water, Heritage and the Arts

The North West Marine Region

The North-west Marine Region includes all Commonwealth waters (from 3 nm from the territorial baseline to the 200 nm EEZ boundary) from offshore of Kalbarri in Western Australia to the Western Australian/Northern Territory border, covering an area of some 1.07 million square kilometres, (see Figure 2).

Figure 2: The North-west Marine Region

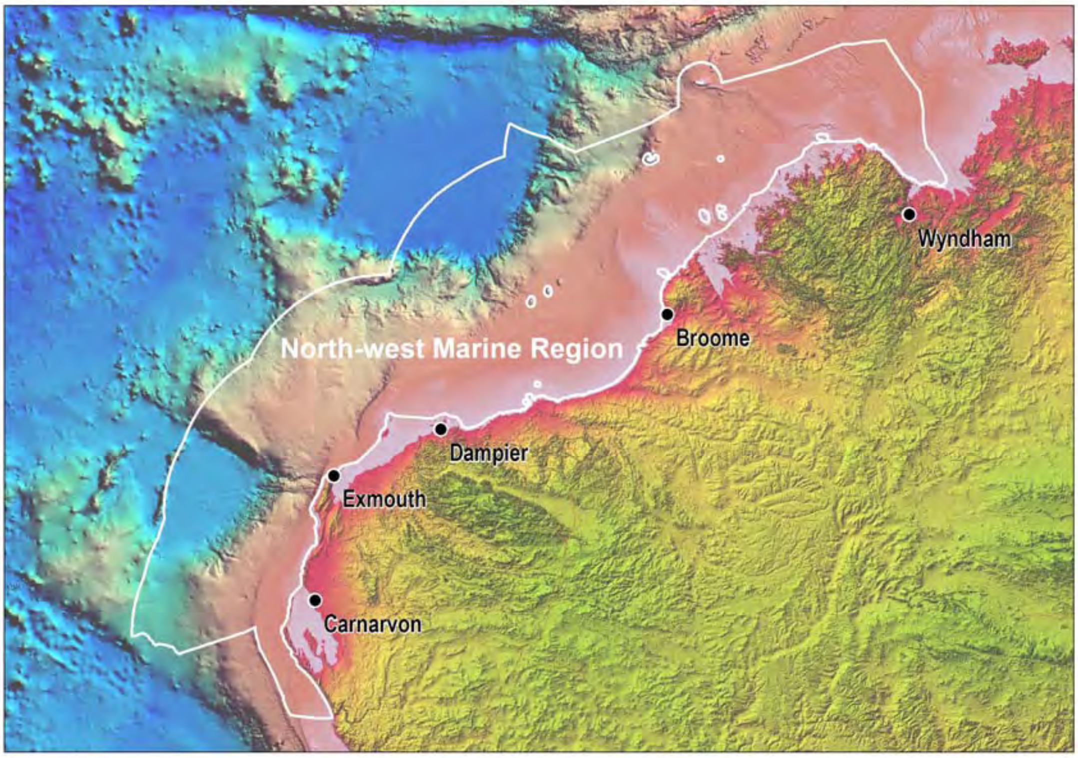


Figure 2: Key Physical Drivers of the Region's Ecosystems

1. Geological history and geomorphology

The tectonic history of the North-west Marine Region has had a major influence on the Region's geomorphology. Since approximately 300 million years ago, tectonic plate movements resulted in the formation of a wide ocean basin (the Westralian Basin), which progressively filled up with a thick sequence of sediments, During the period, rifting, seafloor spreading , subsidence of marginal plateaux and formation of mid-slope terraces occurred. This resulted in the broad continental shelf present in the northern parts of the Region (i.e. North West Shelf and off the Kimberley). The latest rifting event occurred approximately 135 million years ago, when the separation of India and Australia resulted in a narrow continental shelf in the area south of North West Cape.

As the Australian Plate moves north, it converges with the Eurasian Plate. The resulting warping and flexure of the Australian Plate has resulted in distal uplift of the northwestern Australian continent and creation of the island of Timor and the Timor Trough. The morphology of the northern area of the Region (i.e. offshore from the Kimberley - from Cape Leveque northwards) is characterised as a rimmed ramp (i.e. the outer edges of the margin are slightly higher than the inner parts), whereas the southern half of the North West Shelf (between Cape

Leveque and North West Cape) and the continental shelf south of Ningaloo is characterised as a distally-steepened ramp (i.e. the outer edges of the margin are lower than the inner parts).

The seafloor of the Region consists of four general feature types: continental shelf; continental slope; continental rise; and abyssal plain (or deep ocean floor). The majority of the Region consists of either continental slope (61 per cent) or continental shelf (28 per cent). Relative to Australia's EEZ as a whole, the North-west Marine Region has a significantly larger percentage of slope, and a far lower percentage of abyssal plain/deep ocean floor (Baker et al, 2008).

The seafloor across the Region is distinguished by a range of topographic features such as canyons, plateaux, terraces, ridges, reefs, and banks and shoals. Over half of the total area of banks and shoals across Australia's marine jurisdiction occur within the North-west Marine Region.

The Region's major known geomorphic features are shown in Figure 3. These include the Region's marginal plateaus (i.e Exmouth Plateau, Scott Plateau), mid-slope terraces, shelf channels in the Kimberley (e.g. Penguin Deeps) and reefs (i.e. Rowley, Scott, Ashmore, Cartier and Ningaloo). The cross-shelf structure in the Kimberley and Pilbara is generally similar out to 200m depth, with a generally gently sloping profile, although there are significant differences in shelf substrates between the two areas.

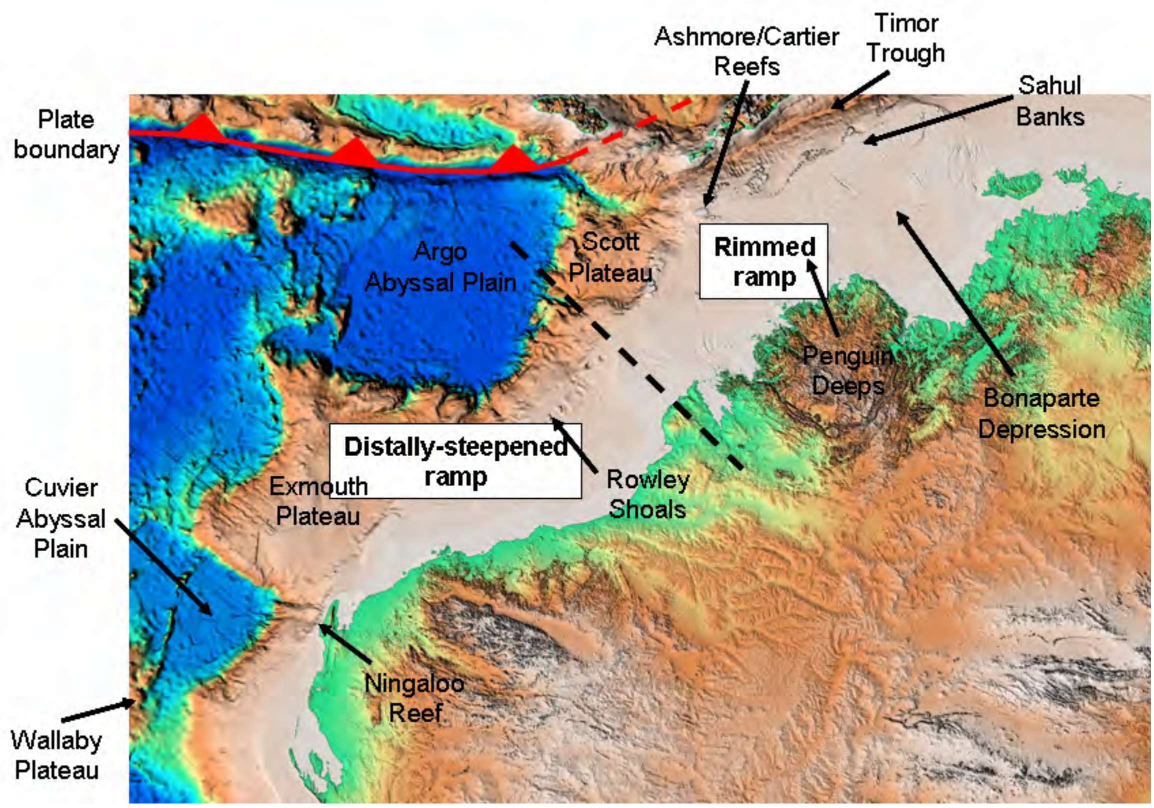


Figure 3: Regional geomorphology

The reefs of the North-west Marine Region generally fall into two categories; algal dominated reefs which occur north of Camden Sound and which are influenced by the warm waters of the Indonesian Throughflow (ITF: a dominant current flowing through Indonesia into the NW Region); and coral dominated reefs to the south of Camden Sound. However, recent (2006-07) coral surveys at the Maret Islands, north of Camden Sound (Figure 4), have revealed rich coral diversity in intertidal and subtidal reefs. The variation in reef types is thought to be due to variation in the availability of nutrients, as algae out compete corals where nutrients are relatively abundant. There are also numerous submerged reefs and some evidence of reef association with hydrocarbon seepage, particularly on the edge of the Sahul Banks. For example, the Rowley Shoals and Scott Reef are associated with deep structures suggestive of hydrocarbons, although there is no evidence of seepage occurring today.

The regional sedimentology is dominated by marine carbonates as a result of the Region receiving little terrigenous input throughout its evolution. On average, 60% of the sediments in the Region are carbonate derived. The highest carbonate contents occur on the shelf, including areas associated with reefs and algal banks. The deepest areas of the abyssal plain/deep ocean are muddy, and any potential particulate carbonate content would have been removed through dissolution as it sank beneath the carbonate compensation depth[1]. Terrigenous sediments are mostly restricted to the coast/inner-shelf and to small areas within these zones. Sediments in coastal waters, particularly in areas of strong currents, are higher in gravel content, whereas shelf and other shallow areas contain high percentages of sand (over 40%). Mud is the dominant size fraction in the deeper waters of the outer shelf/slope (although less than 60%), (Baker et al 2008).

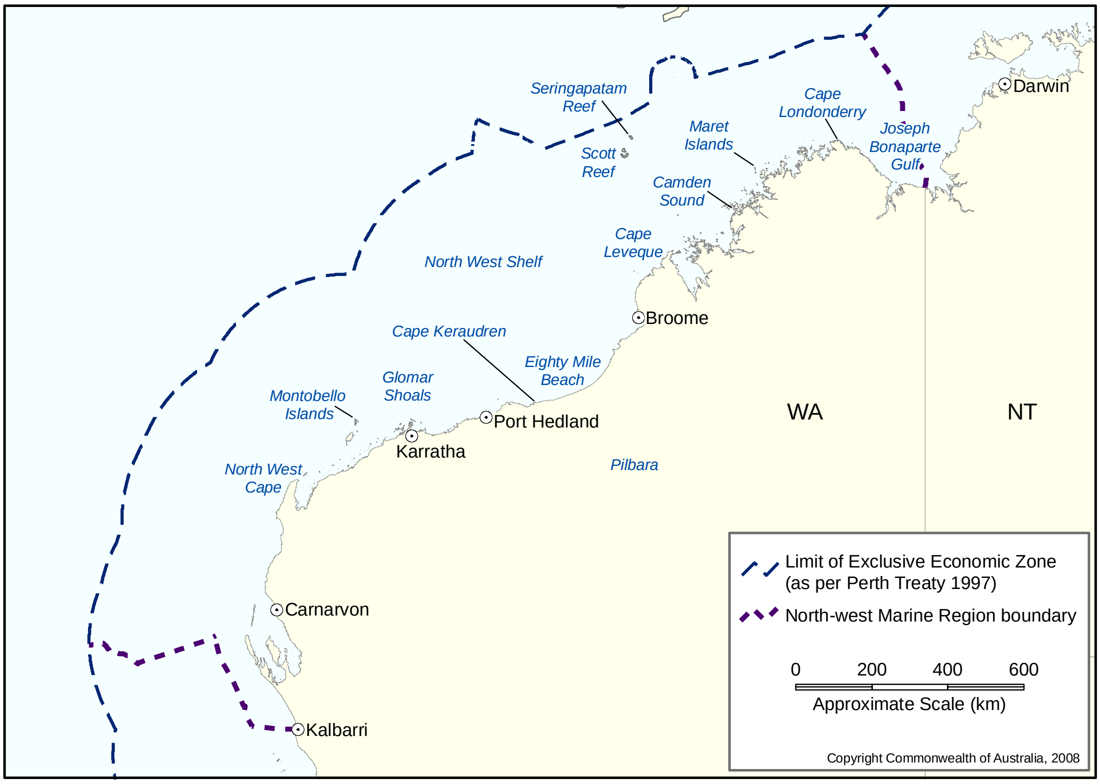


Figure 4: Place names referred to in this report

[1] The carbonate compensation depth is the level in the oceans below which the rate of supply of calcium carbonate (calcite and aragonite) equals the rate of dissolution, such that no calcium carbonate is preserved.

2. Oceanography

Ocean currents, temperature, salinity and other water column properties are key drivers of marine ecosystems as they can influence sediment transport and turbidity patterns, primary production in the water column and bottom sediments, recruitment patterns for organisms with pelagic phases in their life cycles as well as the distribution of benthic communities (i.e. high current vs low current communities).

The North-west Marine Region is part of the Indo-Australian Basin, the ocean region between the northwest coast of Australia and the Indonesian islands of Java and Sumatra. Dominant currents in the Region include: the South Equatorial Current, the ITF; the Eastern Gyral Current, and the Leeuwin Current. Figures 5 and 6 depict the main surface and subsurface currents of the region (information sourced from a range of publications and a mix of scientific expertise).

Figure 5: Regional oceanography – surface currents

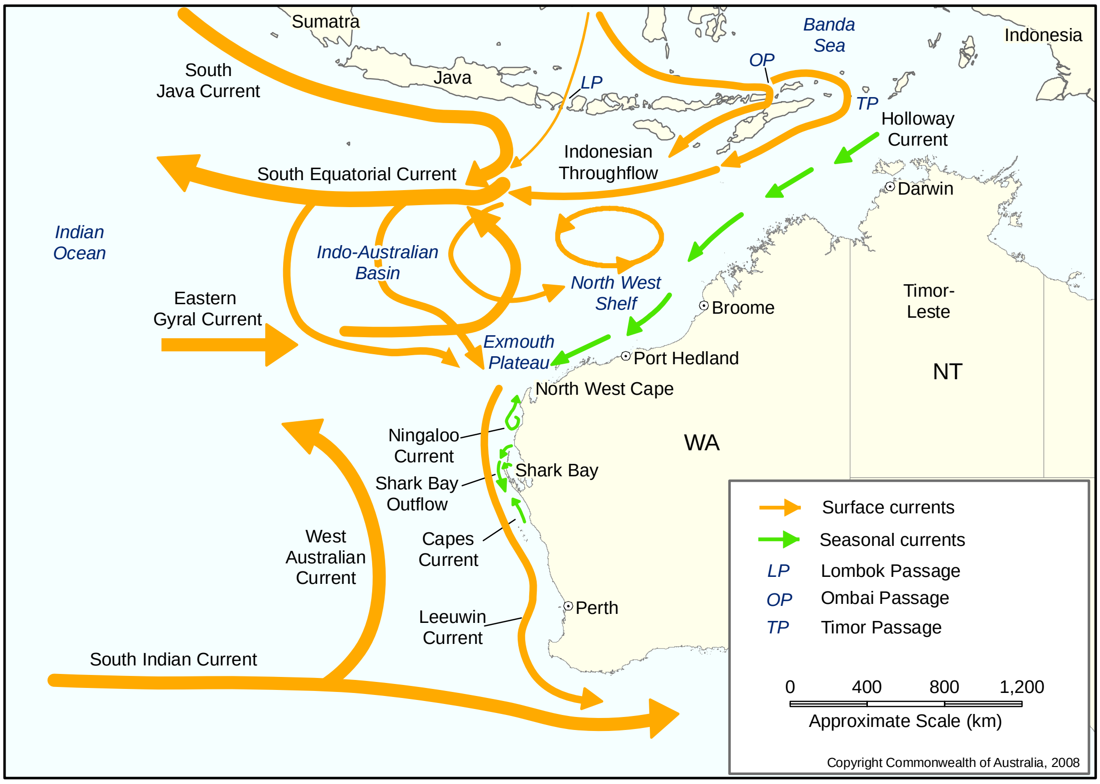
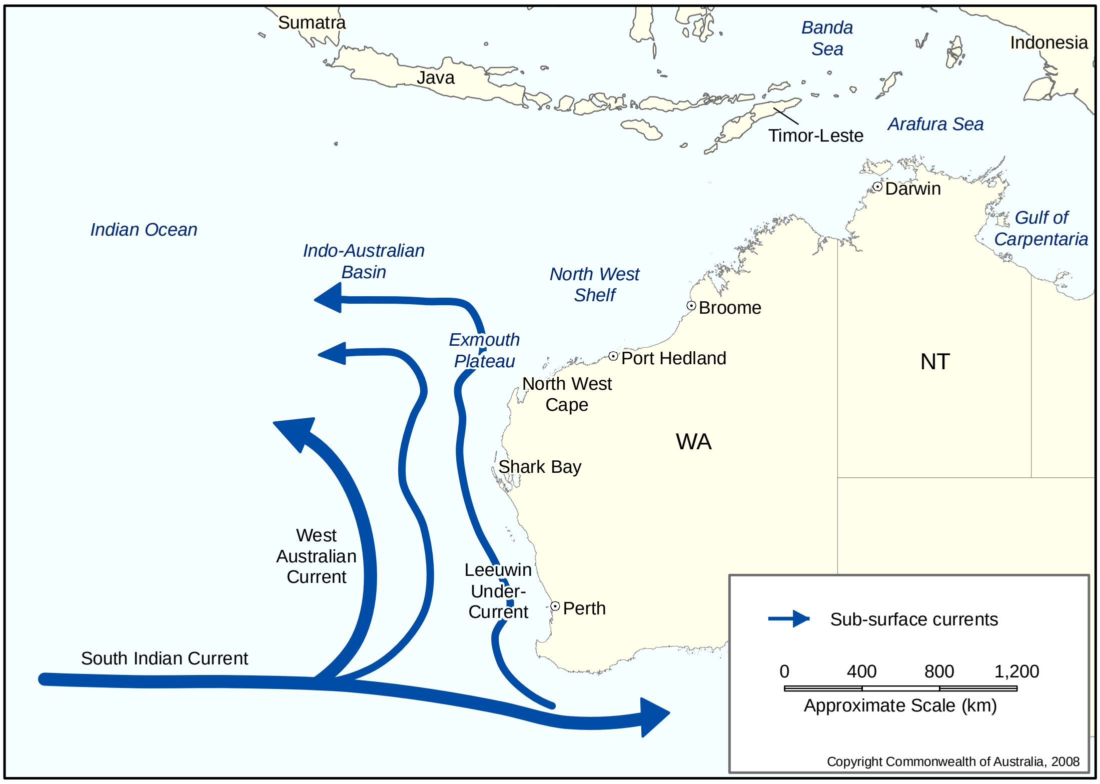


Figure 6: Regional oceanography – subsurface currents



Overall, a key characteristic of the regional oceanography of the North-west Marine Region is the pole-ward flow of the main surface currents. The significant difference in steric height between the Pacific and Indian Oceans drives Pacific waters through the Indonesian archipelago via ITF into the Indian Ocean. A portion of these waters eventually travel polewards via a strong alongshore pressure gradient. This pressure gradient is not present along the eastern edge of other major oceans and makes the Western Australian system unique globally. The pressure gradient may be reinforced through surface cooling of waters as they move southwards.

South Equatorial Current and Indonesian Throughflow

In this region, the ITF's water properties become characteristically warm, oligotrophic and of low salinity as a result of freshwater inputs through runoff from high rainfalls over Indonesia. The ITF exits into the Indo-Australian Basin, through three main outflow straits: Lombok, Ombai and Timor Passage (Fig 5). These filaments of the ITF coalesce into the Indo-Australian Basin to form the westward flowing South Equatorial Current, which is augmented by South Indian Ocean currents as it crosses the basin. The ITF has been recorded as influencing the upper 1250 m of the water column and its upper mean transport is likely to be near 10 Sv (where 1 Sv = 1 km^3/s) (Sprintall *et al* 2004), though it is subject to significant variability and there is little knowledge of its deep transport characteristics.

Indonesian Throughflow waters are believed to recirculate into the North-west Marine Region by two pathways (see Figure 5).

1. Via the South Equatorial Current or via the Eastern Gyral Current which transports waters over the Argo Abyssal Plain and associated slope regions, possibly as a result of local winds and an associated pressure gradient. This may even push waters further eastwards seasonally, toward the Eighty Mile Beach area. Recirculation of ITF waters into the Region can take routes of varying length via the Eastern Gyral Current, with regions closer to Ashmore Reef having a shorter circuit than those on the

southern North West Shelf. The longer the circuit, the more saline and colder the waters become as a result of surface cooling and evaporation;

2. Via southward flow across the shallow Timor shelf from the Banda and Arafura Sea and directly south into the Region. Evidence is building to show that in March, on the termination of the Northwest Monsoon, an ‘extended Leeuwin Current’, currently known as the Holloway Current, develops. This is the result of a build-up of Banda and Arafura ITF waters in the Gulf of Carpentaria as a result of the dominant winds of the NW Monsoon. When the monsoon ceases these waters flow southwards over the shelf perhaps as far south as NW Cape.

Recirculation of ITF waters into the Region via these pathways largely contributes to surface flows off the shelf break, the slope and over the abyss. The origin and movement of shelf waters is not well understood, but it is believed that ITF waters flood the shelf via the offshore pathway (the Eastern Gyral Current) and the Holloway Current. It is also likely that local eddies and internal tides affect cross-shelf transport and modify water properties through vertical mixing.

At depth, below the main thermocline (a steep temperature gradient in the ocean where the layer above is a different temperature from the layer below) the Region’s waters are influenced by Banda Intermediate Water from the north, and Subantarctic Mode Water and Antarctic Intermediate Water from the south. Below about the 1000m depth, slope waters are a mixture of Lower Circumpolar Deep Water and much older Indian Ocean Deep Water.

Leeuwin Current

The southward flowing Leeuwin Current is broadly recognised as a distinct current south of about North West Cape where it tends to be relatively narrow (about 50 km wide) and centred on the shelf break (about the 200 m depth contour) (see Figure 3). The properties of the Leeuwin Current demonstrate its links with the ITF/Eastern Gyral Current (i.e. its waters are warmer and less saline than the salty, cool subtropical waters further offshore). Generally, there is no direct flow from the Timor Strait into the Leeuwin current - rather waters recirculate eastward via the Eastern Gyral Current into the North-west Marine Region. Their continued poleward flow is dominant the pathway by which equatorial waters form the Leeuwin Current. However, on a seasonal basis, the Holloway Current does produce a direct pathway along the shelf, and could be partly responsible for the autumn surge in strength of the Leeuwin Current.

In the southern part of the Region, shelf waters inshore of the Leeuwin Current are cooler and more saline. In winter these waters are driven northward by strong southerlies giving rise to the seasonal Capes Current which, although extending into the North-west Marine Region, originates in the South-west Marine Region.

The subsurface Leeuwin Undercurrent flows northwards at depth in the opposite direction to the Leeuwin Current. The source waters of the Leeuwin Undercurrent include the more saline and dense South Indian Central Water and Subantarctic Mode Waters. Both water mass characteristics and model results suggest that there is considerable exchange between the Leeuwin Current and the Leeuwin Undercurrent and that the adjacent Subtropical Indian Ocean Gyre is both a source and a sink for the boundary currents.

Offshore from the Leeuwin current is the West Australian Current (see Figure 5), which has a broad deep flow that forms the north-eastern limb of the anticlockwise circulation of the Subtropical Gyre of the southern Indian Ocean.

Annual and Inter-annual variability

The North-west Marine Region's large scale surface currents are subject to strong seasonal variations, largely due to annual variation in the alongshore pressure gradient which is the main driver of the Region's surface currents. The South Equatorial Current and Eastern Gyral Current intensify during July-September (Domingues, 2006). Similarly the Leeuwin Current is strongest in autumn, and diminishes during the Northwest Monsoon (Dec–March). It has been suggested that the release of water build-up in the Gulf of Carpentaria via the Holloway Current triggers a strengthening of the Leeuwin Current in autumn.

A number of seasonal localised wind-driven equatorward (i.e. north flowing) currents also occur on the west Australian shelf in the North-west Marine Region. They are the Capes Current, the Ningaloo Current and the Shark Bay Current (Figure 5).

In addition to seasonal variability, the oceanography of the North-west Marine Region demonstrates significant inter-annual variability, which is particularly evident between El Niño/Southern Oscillation (ENSO) and La Niña years. Wind changes associated with ENSO modulate the thermocline depth in the western Pacific Ocean, which is translated to the Indian Ocean via the ITF. Thus, during El Nino events, the thermocline moves to shallower depths, sea level drops, sea surface temperatures fall and, as such, the ITF and Leeuwin Current are relatively weak (Pearce, 1991). During La Niña years, higher sea level anomalies, warmer sea surface temperatures and deeper thermoclines result in a stronger ITF and Leeuwin Current (several authors, as cited in Domingues, 2006; Wijffels and Meyers 2004).

3. Biological Productivity

Scientists believe that there are a number of important factors influencing primary production in the North-west Marine Region, that are closely tied to the physical drivers of the Region and their seasonal interactions. Some of the different mechanisms for productivity in the North-west Marine Region are discussed below.

The ITF has an important effect on productivity in the northern areas of the North-west Marine Region. Generally its deep, warm and low nutrient waters suppress upwelling of deeper comparatively nutrient-rich waters, thereby forcing the highest rates of primary productivity to occur at depths associated with the thermocline. The thermocline is generally at 70-100m depth in most areas of the Region. When the ITF is weaker, the thermocline lifts bringing deeper, more nutrient-rich waters into the photic zone and hence resulting in conditions favourable to increased productivity.

Similarly, the Leeuwin Current has a significant role in determining primary productivity in the southern areas of the Region. As with the ITF, the overlying warm oligotrophic waters of the Leeuwin Current suppress upwelling. A subsurface chlorophyll maximum is therefore formed at a depth in the water column where nutrients and light are sufficient for photosynthesis to proceed. The deep chlorophyll maxima has recently been measured at between 43-53m depth around North West Cape (Jenner, *pers comm*., 2007). Seasonal changes in the strength of the Leeuwin Current influence primary productivity levels and seasonal interactions between the Leeuwin and Ningaloo Currents in the south of the Region are believed to be particularly important. The Ningaloo Current is a coastal, wind-driven counter current that is strongest in summer, when the Leeuwin Current is at its weakest. The northward movement of the Ningaloo Current interacts with the narrow shelf and steep slope to cause upwelling along the coastal margin, and its interaction with the Leeuwin Current brings nutrient rich waters into the photic zone near the shelf break. The waters around the Cape Range Peninsula are therefore regarded as a regional 'hotspot' for primary production. The higher productivity of this area contributes to the ecological importance of the Ningaloo region generally, exemplified by the occurrence of feeding aggregations of whale sharks and manta rays.

The interaction between currents (including tides) and geomorphology are strong influences on productivity in the Region. In many inshore areas adjacent to the Pilbara and Kimberley, productivity levels are strongly influenced by the suspension and re-suspension of sediment due to tidal action. Internal tides (defined as internal waves generated by the barotropic tide) are a striking characteristic of many parts of the Region and are associated with highly stratified water columns and are generated between water depths of 400m and 1000m where bottom topography results in a significant change in water depth over a relatively short distance. The changes in bottom topography required for generation of internal tides or waves are found on some parts of the continental slope and the shelf break, including the heads of submerged canyons. Where internal waves are generated they may travel both towards the shore across the shelf, and out into deeper water.

Internal tides can raise cooler, generally more nutrient rich water higher in the water column – and sometimes into the photic zone. The passing of an internal wave is unlikely to raise cooler, more nutrient rich water into the photic zone long enough to have any significant impact on productivity. The breaking of an internal wave and near bottom associated near-bottom turbulence, however, can result in effective vertical mixing in the water column over longer periods. If nutrients are available, this in turn can result in increases in productivity. Isolated topographic features that may give rise to the breaking of internal waves include Ashmore, Scott and Seringapatam Reefs and the Rowley Shoals, but breaking and energy loss can occur over gently sloping shelf regions as the shore-ward propagating waves enter shallower water. It is possible that internal wave breaking may be associated with some parts of the ancient coastline at 80-100m depth where it is reflected as a submerged escarpment, as well as in the head of canyons.

Cyclones are episodic events in the North-west Marine Region which contribute to spikes in productivity through enrichment of surface water layers due to enhanced vertical mixing of the water column. The power of cyclones can move large volumes of sediment suspending much it for a time in the water column, as well as pushing offshore waters into shallower areas. Temporary increases in primary productivity as a result of cyclones generally last between one and two weeks. Generally, it is believed that cyclones' impacts are generally limited to waters less than 100m deep and to affect benthic communities more substantially than pelagic systems.

Trichodesmium blooms are another potential episodic event associated with heightened productivity in the system. Blue-green algae fix nitrogen from the water and air, thereby making it available to phytoplankton. *Trichodesmium* blooms have been observed most commonly along the Pilbara coast (i.e. between North West Cape and Port Hedland), and between North West Cape and Kalbarri, but have also been observed around the Bonaparte Archipelago in the Kimberley. These blooms are thought to be very minor episodic contributors to overall productivity in the Region.

Water depth also has a significant overriding influence over productivity in the marine environment, due to its influence on light availability. This is reflected by distinct onshore and offshore assemblages of major pelagic groups of phytoplankton, microzooplankton, mesoplankton and ichthyoplankton.

Together, these factors strongly influence the structure of trophic systems in the Region. Communities and trophic structures in coastal areas are strongly influenced by localised drivers, such as wind and tide action. Generally, communities and trophic structures in deeper waters are more strongly influenced by oceanic currents and water masses. Tracing the intersection between the chlorophyll maxima and the photic zone may be a useful way to describe the boundary between onshore and offshore communities.

Broadly productivity in the North-west Marine Region follows a boom and bust cycle. Productivity booms are thought to be triggered by seasonal changes to physical drivers or episodic events, as detailed above, which result in rapid increases in primary production over short periods, followed by extended periods of lower primary production. The trophic systems in the North-west are able to take advantage of blooms in primary production, enabling nutrients generated to be used by different groups of consumers over long periods.

Little detailed information is available about the trophic systems in the Region. The utilisation of available nutrients is thought to differ between pelagic and benthic environments, influenced by water depth and vertical migration of some species groups in the water column.

In the pelagic system, it is thought that approximately half of the nutrients available are utilised by microzooplankton (e.g. protozoa) with the remainder going to macro/mesozooplankton (e.g. copepods). As primary and secondary consumers, gelatinous zooplankton (e.g. salps, coelenterates) and jellyfish are thought to play an important role in the food web, contributing a significant proportion of biomass in the marine system during and for periods after booms in primary productivity. Salps are semi-transparent, barrel-shaped marine animals that are able to reproduce quickly in response to bursts in primary productivity and provide a food source for many pelagic fish species.

There is a wide diversity of pelagic and bentho-pelagic fish that feed on salps and jellyfish. These include tuna, billfish, bramids, lutjanids, serranids and some sharks. However, these species preferentially feed on other secondary consumers, such as squid and bait fish when available. Other large secondary consumers include blue whales, whale sharks and manta rays, which feed on mesozooplankton and tropical krill and which are often present in high numbers during boom periods. Leatherback, loggerhead and olive ridley turtles also forage in the pelagic zone and feed on gelatinous zooplankton and may also feed on other primary producers, such as pteropods.

In shallower waters, there are close connections between the pelagic and the benthic systems. However in waters further offshore there is less interaction and the water column is highly stratified. In deeper environments (occurring in depths of approximately 200-1000m), it is thought that bentho-pelagic species groups play a key role in competing for nutrients in both the pelagic and benthic systems, as they vertically migrate through the water column and therefore facilitate the transfer of nutrients between the benthic and pelagic environments. Many species are sessile or are closely associated with the bottom. The benthic communities are comprised chiefly of scavengers, detrital feeders and filter feeders, which are preyed on by a variety of sessile invertebrates, and tertiary consumers, such as snapper and red emperor.

In waters greater than 1000m depth, the trophic system is pelagically-driven with benthic communities reliant upon particulate matter ‘falling’ to the seafloor.

Systems of the Region

The workshop divided the North-west Marine Region into three large scale ecological systems on the basis of broad agreement from workshop participants over the influence of major ocean currents, major seafloor features and major eco-physical processes (e.g. climate, tides, freshwater inflow) upon the Region. The three large scale systems (see Figure 5) were named after adjacent terrestrial regions and are as follows:

System	Summary of system characteristics
1. Kimberley: Northern boundary the limit of the NW Marine Region, southern boundary extends west of Broome to the northern edge of the Exmouth Plateau	• tropical monsoonal climate, • strong influence from Indonesian Throughflow, • predominantly tropical Indo-Pacific species, • moderate off-shore tropical cyclone activity, • large tides, • freshwater input from terrestrial monsoonal run-off, • turbid coastal waters (i.e. light limited systems), • dominated by shelf environments, • predominantly hard substrates in inner to mid-shelf environments, • has a number of shelf-edge atolls (i.e. Scott Reef, Rowley Shoals).
2. Pilbara: Northern boundary extends west of Broome to the northern edge of Exmouth plateau; southern boundary follows a line west of North-west Cape along the southern boundary of Exmouth Plateau.	• tropical arid climate, • transition between Indonesian Throughflow and Leeuwin Current dominated areas, • predominantly tropical species, • high cyclone activity with frequent crossing of the coast, • transitional tidal zone, • internal tide activity, • large areas of shelf and slope, • dry coast with ephemeral freshwater inputs.
3. Ningaloo-Leeuwin: Northern boundary extends from shore at North West Cape directly out along Cape Range escarpment, southern boundary is the limit of the NW Marine Region.	• subtropical arid climate, • Leeuwin Current consolidates, • transitional tropical/temperate faunal area, • higher water clarity in near-shore and off-shore environments, • narrow shelf and slope, • marginal tidal range, • seasonal wind forcing more dominant influence on marine environment

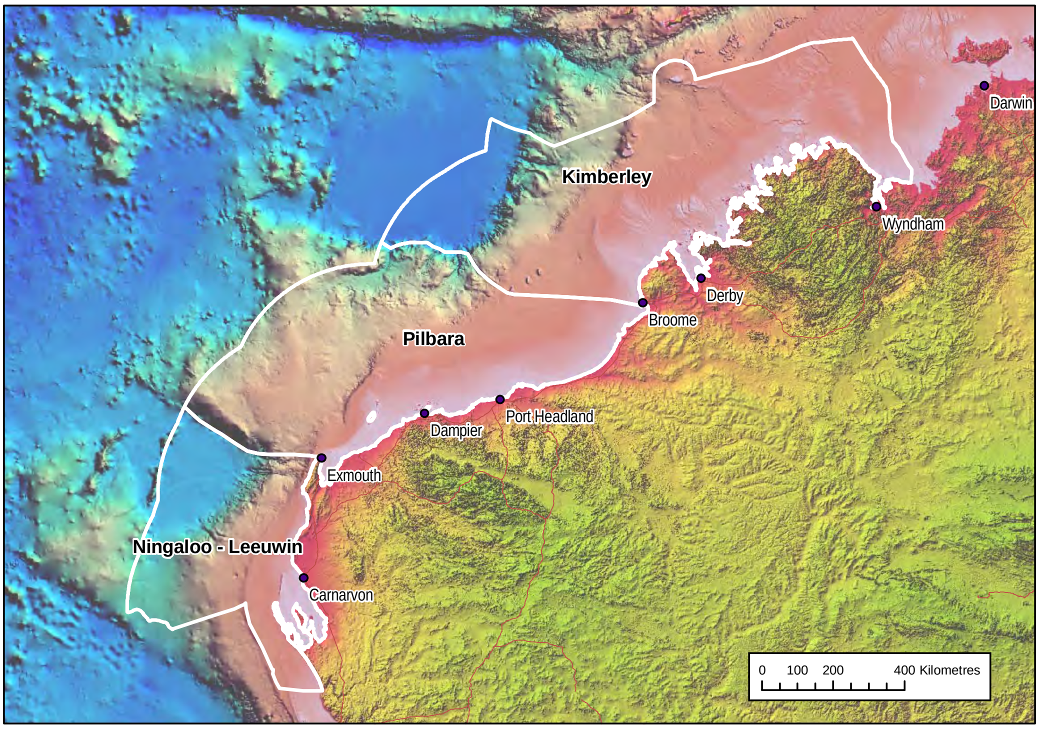


Figure 7: Systems of the North-west Marine Region

Although workshop participants identified these large-scale systems as being relatively ecologically distinct from 6 should be regarded as approximate, as there are many examples of connectivity between the systems (i.e. as a result of the regional oceanography).

The boundary between the Kimberley and Pilbara systems was regarded as particularly 'fuzzy' due to uncertainty about the extent of the influence of the ITF, whereas the boundary between the Pilbara and Ningaloo-Leeuwin system was generally more easily defined due to certainty about differences between the systems north and south of Cape Range Canyon. There was also considerable discussion about whether the deeper abyssal basins to the north and south of Exmouth Plateau should be regarded as distinct systems due to obvious differences in depth, likely bottom types, water flow and associated species compositions. A view was also expressed that the Joseph Bonaparte Gulf could be considered as a separate system in the high level regionalisation. The workshop process, however, dealt with segregation of these systems as part of the process associated with dividing the large-scale systems into sub-systems.

The following characterisations of each of the three large-scale systems have been developed to better understand the differing physical environments and the range of ecosystems that each system supports in the Region.

System 1 – Kimberley

The large scale eco-physical features that define the Kimberley system include the characteristic "Ria" coast of drowned ancient river valleys with a rocky coastline of blunt cliffs. The wide shelf is the dominant geomorphic feature of the marine system, however there is a wide diversity of geomorphic features in this system. The granite substrate in waters adjacent to the Kimberley is characteristically resistant to erosion and is different to the substrate found in the Pilbara system. This difference in substrate type is an important distinction between the two systems.

The ITF is the dominant oceanographic feature in this system and therefore this system is predominantly characterised by warm oligotrophic waters. Broadly, the ITF flows westward through the Timor Trench and reconstitutes itself as the South Equatorial Current south of Java. Little is known of the exact movement of ITF waters through the Kimberley system, but it is thought that ITF waters arrive in the Kimberley system from offshore in the Eastern Gyral Current, as well as via shallow flows from the Arafura Sea and Gulf of Carpentaria. It may be possible that both these pathways operate at different times of the year. For example, in autumn the Gulf of Carpentaria pathway may dominate when the Holloway Current is active. However, there is little knowledge of how these pathways affect the levels of nutrients and productivity of the shelf habitats.

The tropical waters of the Kimberley system are typically highly stratified and thus subject to a very strong vertical temperature gradient. The depth of the water layer mixed through wind and wave action (i.e. the surface mixed layer) is therefore strongly influenced by monsoonal changes in the direction and strength of winds. The surface mixed layer intersects with the seafloor at depths of approximately 70m or less, although the depth to which mixing occurs varies between seasons. At bottom depths of less than 50m, the water column is generally fully mixed. The Kimberley system is also subject to episodic offshore cyclonic activity. Cyclones tend to generate offshore and move south, rarely crossing the coast until they reach the Pilbara region. They can contribute to mixing of water layers as well as play an important role in the dispersal of sediments and species.

The extent of the turbid zone in the Kimberley system is a distinguishing feature. The Kimberley coastline experiences large tidal regimes and high volumes of freshwater and organic matter inputs which can extend great distances during high rainfall events, especially around major rivers, such as the Fitzroy and Ord Rivers. The turbid zone can extend as far out as the 100m depth contour from the coast at times, but varies depending upon the season (i.e. the amount of freshwater runoff) and location. The boundary between turbid and clear water is generally thought to occur around the 60m depth contour.

There appears to be limited advection or mixing between near-shore and offshore waters, and therefore a relatively sharp distinction exists between waters seaward of the turbid boundary and the inshore turbid waters. Within the turbid zone benthic communities reflect differences in substrate. There are numerous submerged reefs associated with hard substrates in the turbid waters. The Kimberley's wide tidal range is associated with the generation of internal waves. The internal waves are likely to impact on nutrient mixing in this region, along with stability of sediments (and hence ecosystem structure) and flow dynamics generally.

Further offshore, a number of shelf edge atolls and coral reefs are present. These atolls include the Rowley Shoals and Scott, Seringapatam and Ashmore Reefs. Banks and channels occur on the shelf, and shallow canyons also occur on the slope. The system also includes deep abyssal plain/ deep ocean floor areas (i.e. the Argo Abyssal Plain).

The influence of the ITF restricts upwelling across the Kimberley System. However, small-scale topographically associated current movements and upwellings are thought to occur which may inject nutrients into specific locations within the system and result in 'productivity hot-spots'. Similarly, it is believed that internal waves, generated at the shelf break could play a role in making nutrients available in the photic zone.

Fish spawning in summer/autumn in the Kimberley is thought to correspond with peaks in production and current movements. There is a strong delineation in demersal slope fish communities in the Kimberley in comparison to systems further south. Last *et al.* (2005) found that the Timor Province, on the continental slope between the Rowley Shoals and the Timor Trench, is the most strongly defined province for demersal slope fish species in the Australian slope bioregionalisation.

There is thought to be a disjuncture at Cape Londonderry between habitats and species west and east of it. This disjuncture is partly why Joseph Bonaparte Gulf was identified as a distinct sub-system of the Kimberley system, but clearly distinguishing between the Joseph Bonaparte Gulf and the Kimberley is hampered by a lack of information.

The workshop participants noted that while the eastern boundary of the North-west Marine Region artificially splits the Joseph Bonaparte Gulf between the North-west and the North Marine Regions, the entire Gulf is a recognisable ecological system. The information presented here therefore reflects only the discussion of this sub-system by the North-west workshop participants. In compiling the North-west Bioregional Profile, the North-west Planning Team will work closely with the North Planning Team in compiling a full characterisation of the adjacent Northern portion of the Joseph Bonaparte Gulf.

<u>Sub-systems in the Kimberley</u>

Workshop participants identified six different sub-systems within the Kimberley, which are shown in Figure 8. The distinctive features and key characteristics of each of these sub-systems are described in more detail below. As with the identification of systems, the boundaries of sub-systems are not necessarily distinct and have been drawn at a point which are thought to broadly reflect a change in physical and/or biological characteristics sufficient to differentiate the area (sub-system) from adjoining areas.

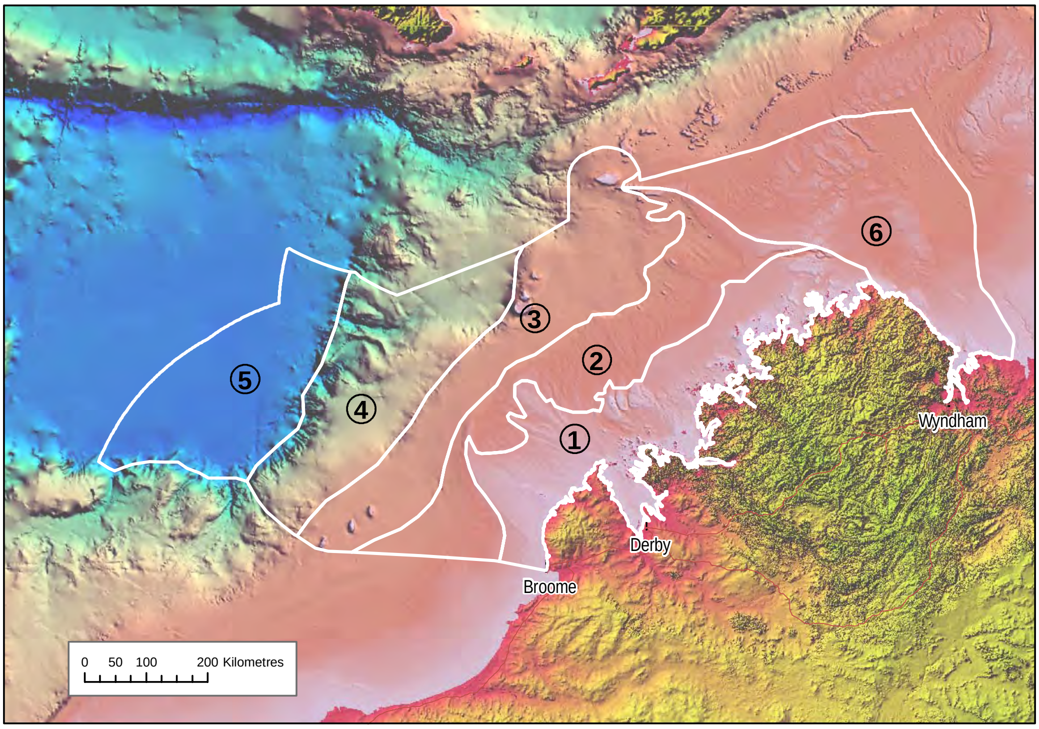


Figure 8: Sub-systems of the Kimberley

1. Inshore/Inner Shelf Turbid Zone: Extending from the coast to between the 50 and 100m depth contours

Extent and Distinctive Features	Description of sub-system characteristics
Characterised as the inshore turbid zone of the shelf, which generally occurs out to 70 m depth, but the boundary of which can occur anywhere between 50-100 m depth, depending upon seasonal and physical characteristics. The northern boundary follows the eastern side of the west Londonderry rise and the sub-system includes all inshore islands. Important features include: ▪ Montgomery Reef is a significant inshore reef which supports turtles and significant fish communities. ▪ The Adele and Lacepede Islands contain important breeding habitat for many species, including turtles, migratory birds and other sea birds. ▪ Dugongs and seagrass communities are widely distributed, but most are located in State waters. *Thalassia hemprichii* is the most prominent hard reef seagrass species. Important sites for cetaceans include: ▪ Camden Sound to Raft Point, south of Adele Island near Frost and Tasmanian Shoals, and near Pender Bay are high density areas for calving humpback whales during July-November. ▪ Roebuck Bay for Irrawaddy (snub-fin), bottlenose and Indo-pacific humpback dolphins ▪ Waters around Quandong Point appear to be a migratory waypoint and high density area for northbound humpback whales in July-August, false killer whales, pygmy blue whales and a number of dolphin species ▪ Beagle Bay and Pender Bay for bottlenose and Indo-pacific humpback dolphins ▪ Tidal creeks around Yampi Sound and between Kuri Bay and Cape Londonderry are important year-round habitats for a number of small cetaceans ▪ Humpback whales regularly seen in coastal waters and out to 50km offshore from Camden Sound to Joseph Bonaparte Gulf during winter months ▪ The area from Beagle Bay to Adele Island to Kuri Bay to Montgomery Reef to Cape Leveque is the core of the Group IV humpback whale calving area. Kuri Bay to	The entire sub-system occurs on the continental shelf and includes a diversity of bottom types, both hard (i.e. limestone reef) and soft. For example, the Lacepede Islands are characterised as a sandy cape system with a limestone base, whereas areas around King Sound are hard bottomed with some mud but very little sand. South of Cape Leveque is characterised as being mostly sandy substrate. The greatest diversity in bottom types is believed to occur in waters 40-120 m deep. The 30-60 m zone is characterised by softer sediments with interspersed hard substrate communities. The hydrological influences in this sub-system can be categorised as including: ▪ Indonesian Throughflow waters – warm and oligotrophic. The influence of the movement of Indonesian Throughflow waters at the end of the NW monsoon 'draining' out across this sub-system from the Gulf of Carpentaria is largely unknown; and ▪ High levels of freshwater and sediment (inc. nutrient) input from river runoff during the NW monsoon (e.g. Fitzroy River) making the coastal waters highly turbid. Turbidity is enhanced by tidal re-suspension and this region experiences some of the largest tides in Australia. Cyclones may also resuspend sediments episodically. Productivity within this sub-system is driven primarily by tidal movement and terrestrial runoff whereby nutrients are mixed by tidal action and new inputs of organic matter come from the land. Mangrove communities, and microalgae on the mangroves, have a key role in primary production in inshore waters. On fringing reefs, such as Montgomery Reef, coralline algae are an important contributor to productivity. In waters less than 30 m deep, there are shallow water sponge and coral communities which are regarded as highly diverse. For example, Montgomery Reef is a significant inshore reef which has clear enough waters to allow coral growth and includes a high biomass of coral. Turtle aggregations have been reported here, along with significant fish communities, including lutjanid snappers, such as gold band snapper. Roebuck Deep, to the east of Broome, is known for its high concentrations of prawn larvae and it is likely to be regionally significant for prawn species. Productivity in this location is likely to be associated with detritivores. The sub-system also includes a number of sites which are important for cetaceans. For example, waters

Cape Londonderry is a recent extension of this core.	around Quandong Point are highly productive with large numbers of birds and baitfish occurring. Large numbers of humpback whales have also been reported here during their breeding season of June to mid-November and it is thought to be an important stop-over point between the Kimberley coast and the Rowley Shelf for other cetaceans (i.e. false killer whales, pygmy whales, dolphins). There is some speculation that the northern split of the Eastern Gyral Current may hit the coast around Quandong Point. This may help to account for the perceived unusual levels of productivity here, and the presence of humpback whales. The outer area of the NW Kimberley coast zone appears to harbour resources which are attractive for foraging flatback turtles. Also Holothuria Reef is an attractive area for NW Kimberley breeding flatback turtles. A number of the inshore islands in this sub-system are believed to be important sites for listed species. For example, Adele and the Lacepede Islands have significant brown booby populations. The Lacepede Islands also host the largest regional green turtle breeding population.

2. Mid to outershelf: Extending from edge of turbid zone (50-100m) to the 200m depth contour

Extent and Distinctive Features	Description of sub-system characteristics
Characterised as the clear waters of the mid to outer shelf region, broadly between 50-100 m to the edge of the continental shelf – approximately 200m. Important features or species include: ▪ Seafloor features such as submerged cliffs are thought to be sites of localised higher productivity. ▪ Species migration along ancient coastlines (approximately the 120m isobath – which was the shoreline during the last glacial age). Some suggestions humpback whales may follow the former coastline on their migration. ▪ Sponge communities and submerged reef communities as biodiversity hotspots. There is a high likelihood that a number of these communities exist that have not yet been discovered. ▪ Browse Island is an important site for bird and turtle communities as well as a site of upwelling. Upwelling around the island is believed to be associated with increased concentrations of tropical krill. These tropical krill aggregations may be important as there have been possible, but unconfirmed, sightings of humpback whales feeding	Large aggregations of flying fish occur around the 80m depth contour in the North at the beyond the turbid zone. A number of seafloor features occur in this sub-system including an ancient coastline at the 120 m isobath and submerged cliffs. Submerged cliffs occur throughout this area, and have been identified at 120-150m depth, 200m and also in water depths of up to 300m. Generally, the granitic substrate throughout is hard and rough due to its erosion resistance and provides a diversity of habitats for benthic flora and fauna. The hard substrate provides suitable conditions for sessile epibenthic fauna and therefore sponge communities are likely to be dominant in the benthic environment There is also evidence of some recovery in the sponge communities following a past history of demersal trawling. Submerged reefs are also present and are thought to be focus points for biodiversity (including significant fish communities) and may therefore act as significant feeding sites for migratory species. The deep overlying ITF waters generally suppress upwelling. However, as a result of the seabed morphology, this sub-system appears to have reasonably high productivity. Productivity pathways

around Browse Island. Antarctic waters are currently the only known feeding location for southern hemisphere humpbacks.	and seasonality are not well understood. The "breaking" of internal waves on the shelf edge and around significant breaks in slope (e.g. west of Browse Island and around submerged cliffs) may play an important role in nutrient generation and thus enhanced productivity. The elevation of deeper more nutrient rich waters into the photic zone by breaking internal waves may facilitate localised bursts in primary production. Similarly when the ITF is weaker (during El Nino years) the thermocline is lifted and conditions are generally more favourable for increased productivity. The planktonic communities are believed to change between seasons and therefore support different communities at different times. Higher order consumers include seabirds and demersal and pelagic fishes, such as red emperor, Spanish mackerel and snapper. Some of these fishes are targeted by demersal finfish fisheries in this area. The occurrence of these species is believed to be reflective of reasonably high levels of productivity in the area.

3. Upper slope and associated reefs and islands: Extending between the 200 and 500 m depth contours

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates the shelf break to mid-slope, including emergent and submerged reef platforms and mounds (e.g. Rowley Shoals, Scott Reef) Important features or species include: ▪ Scott, Seringapatam, Ashmore and Cartier Reefs as sites of high productivity and associated biodiversity ▪ Canyon heads as sites of enhanced productivity and possible aggregations of sperm whales ▪ Migration of blue whales along approximately the 500 m contour	The upper slope region is characterised by hard substrates that are overlain by unconsolidated sandy sediments, predominantly carbonates. The slope is relatively flat, but includes a number of large canyon heads which were probably excavated during and after continental break-up by sediment and water movements. Reefs in this sub-system include the coral atoll reefs of Scott and Seringapatam, which occur on large mounts rising from deep water (500-1500 m depth), and Ashmore Reef, which is a platform reef rising from shallower waters (100-200 m depth). Overall, this sub-system is thought to have low productivity, largely due to the influence of the ITF and hence the chlorophyll maximum is too deep to facilitate high primary production on a regular basis. Productivity would be associated with ephemeral events, such as topographically induced water movement around geomorphic features (i.e. coral reefs, canyon heads), therefore causing some mixing of the water column. It was suggested that eddies may form on the inshore side of the emergent reefs and islands in this sub-system and therefore could be an important mechanism for mixing the water column and thereby stimulating primary production. Repeating patterns of swirling vortices caused by the unsteady separation of flow around islands (referred to as Van Karman vortex streets) are thought to occur around the islands (on their leeward sides) of this sub-

	system, and may result in enhanced horizontal and vertical mixing of waters around the islands. These ephemeral but repeating events may support large populations of pelagic fish and seabirds. The presence of sperm whales as evidenced by Nineteenth Century whaling industry data suggests occasional bursts in production, which may be associated with variations in slope (such as canyon heads) and may support species at a number of trophic levels. The old sperm whaling grounds (as reported by Townsend) lie to the north and west of Scott Reef. Blue whales also migrate along the 500 m to 1000m contour on the edge of the slope and are likely to be feeding on ephemeral krill aggregations. Humpback, sperm and blue whales may use the north-easterly flowing offshoot current of the Eastern Gyral Current as a migratory aid. Evidence from current tracking buoys off the North West Shelf between North West Cape and Port Hedland covering depths from 200 to 800m coincides with the scant satellite whale tracking data but data from the Kimberley system is lacking. The islands and reefs are a key biodiversity focal point in this subregion. Associated pelagic communities provide a constant food source for cetaceans, dogtooth tuna, Spanish mackerel and pelagic sharks. The reefs themselves have a distinct flora and fauna. Regional oceanography does facilitate the transfer of genetic material south from Indonesia into the North-west Marine Region. However, this transfer generally occurs over longer time periods and there are many genetic differences between Scott and Ashmore reefs, both having quite distinctive coral assemblages. Overall Scott reef has a lower coral diversity in comparison to Ashmore, but has a distinct deep coral assemblage due to depth and morphology rather than the influence of current. There are also differences in seagrasses, sea snakes and birds between Ashmore and Scott. Scott Reef has been overfished and has a relatively low abundance of fish species. The sponge diversity between reefs of this sub-system is also very distinct and is a feature of their biological characteristics. Sponges have larvae that do not move very far, and settle out of the water column quickly. Many are negatively buoyant or phototaxic, and there is a tendency for them to settle close to the parent populations. Recent work on Scott, Seringapatam and Mermaid (Fromont and Vanderklift *in prep*) suggest that these reefs have unique sponge faunas, with a large component of each only found on a single reef system. Distinctive fish fauna has been identified in this sub-system. The muddy sediments of the slope support the NW Slope Trawl fishery which currently targets scampi and has previously targeted prawns. Recently, surveys conducted by Woodside using Remotely Operated Vehicles, have identified prawns in deep water

	environments.

4. Slope and marginal terraces: 500-5000m

Extent and Distinctive Features	Description of sub-system characteristics
This region encompasses the waters from the edge of the upper-slope, out to the edge of the abyssal plain. It incorporates the mid-slope and includes Rowley Terrace and Scott Plateau. Important features or species include: ▪ Based on 19th century American whaling records, it is believed that Scott Plateau may be the site of a sperm whale feeding and breeding ground, and possibly also supports beaked whales. Beaked whales are typically not migratory and may be both feeding and breeding in this area.	Very little is known of the physical and biological characteristics of this sub-system. Some characteristics include: ▪ The ITF waters form a deep overlying surface layer, down to approx 1200 m depth (although this varies interannually). ▪ Water column understood to be highly stratified. ▪ Sediments are likely to be largely unconsolidated and would accumulate at the foot of the slope. ▪ Sub-system would contain some hard substrate. ▪ Due to the deep overlying ITF waters, productivity is understood to be generally low with few events likely to trigger bursts in production. The subsystem therefore probably supports a low, sparse biomass of large pelagic fauna in addition to benthic communities reliant on detritus (particulate organic matter – POM). ▪ The tropical oceanic waters between Australia and Java are the only known spawning location for southern bluefin tuna in the world. The waters above the slope would therefore be a site for migrating tuna.

5. Abyssal Plain: >5000 m

Extent and Distinctive Features	Description of sub-system characteristics
Includes the oceanic waters and seafloor of the Argo Abyssal Plain. A lack of information on this sub-system prevents the identification of important features or species.	Participants acknowledged that very little is known of the physical and biological characteristics of the abyssal sub-system. Some characteristics include: ▪ The ITF waters form a deep overlying surface layer, down to approx 1200 m depth. ▪ Water column understood to be highly stratified. ▪ Sediments are likely to be unconsolidated ▪ Drilling of deep sea drill holes in this sub-system has revealed layers of planktonic skeletal remains (up to 10 m deep). ▪ POM accumulates on the abyssal plain, and POM provides food for benthic communities,

	before there is only a skeleton left. ▪ Due to the depth of the water in this sub-system, the demersal ecosystem would differ significantly to that on the slope and shelf. However, the pelagic ecosystem is likely to be similar across the outer shelf, slope and the abyss. ▪ Migrating southern bluefin tuna pass through these waters on their way to spawning grounds.

6. Joseph Bonaparte Gulf: 0-200m

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates all waters east of Cape Londonderry, through to the eastern edge of West Londonderry rise to Ashmore Reef Important features or species include: ▪ Limestone pinnacles ▪ Carbonate banks ▪ Penguin Deeps - attractive feeding area for flatback turtles breeding in the NW Kimberley. Penguin Deeps are a sediment and water conduit between Joseph Bonaparte Gulf and the Kimberley region. They are shelf channels that are probably characterised by hard substrates, compared with the surrounding seabed.	This sub-system is categorised as a rimmed continental shelf area bordering a deep trench (i.e. the Timor Trench) to the north. It has a relatively smooth bottom, overlain by soft, muddy sediments which tend to accumulate. The basin has relatively high mud content because the basin bottom is below the influence of waves. This is a significantly different bottom type in comparison with the rest of the Kimberley system. Many of these sediments are thought to be relict from previous sea-level transgressions, as the Joseph Bonaparte Gulf is likely to have been a lake during the last glacial maximum where muddy river sediments would have been deposited. As such, sediments are likely to be a mix of relict mud, modern carbonate and terrigenous mud. The main hydrological influence in this sub-system is the ITF's warm and oligotrophic waters. ITF waters are thought to drain across this sub-system from the Arafura Sea/Gulf of Carpentaria in the form of the Holloway Current at the end of the Northwest Monsoon, but would also comprise surface waters at other times of the year. Seafloor mounds (limestone pinnacles), up to 50 m high and between 50 and 100 km long, occur throughout this sub-system. Carbonate banks occur in the north-eastern part of the sub-system. It is unclear whether they support *Halimeda*. Hydrocarbon seeps may be associated with the formation of these banks and they are thought to be relatively productive. Water depths are relatively shallow and while the sub-system still experiences strong tidal movements the variations in tide height are not as large as the inshore/inner shelf sub-system (Sub-system 1). Cape Londonderry is known as an amphidromic point, a point within a tidal system where the tidal range is significantly lower than in surrounding locations. Internal tides also occur in this sub-system, however there is little information about their action or influence, although they may be associated with upwellings.

	It is postulated that internal tide action may be the cause of a lack of coral development on the banks in this region, as vertical mixing may expose corals to temperatures not conducive to their development (i.e. waters less than 20°C). Generally, productivity in the system would be associated with the subsurface chlorophyll maxima. High levels of bycatch, especially small fish and epibenthic fauna, in the JBG prawn fishery indicates that the sub-system could be regarded as reasonably productive, especially closer to shore. The biomass of fishes is relatively high in much of this region (prawn trawl fishery and adjacent habitats), but benthic communities are likely to be more sparse. Upwelling is known to occur to the north and outside of this sub-system along the southern Indonesian coast and along the edge of the Timor Trench, but it is likely that the ITF exerts a significant influence on this sub-system. Upwellings may occur as a result of the interaction of internal waves upon changes in slope and could support ephemeral populations of mackerel, snapper and dolphins. Generally, the biodiversity of the sub-system is poorly understood. The soft bottom habitats probably support mobile invertebrate communities such as prawns and crabs (e.g. cornflake crabs) and this sub-system marks the end of the beche-de-mer fishery and the beginning of the prawn fisheries. Assemblages of filter feeders, such as ascidians and bryozoans, and suspension filter feeders probably also occur. Lobsters may be present in areas with rockier bottoms. Dugongs are known to occur and would be associated with seagrass communities in the inshore waters of the Gulf (i.e. waters less than 5m deep).

Uncertainties in our understanding of the system and its component sub-systems

- It was broadly acknowledged that the Kimberley system is the least studied area of the North-west Marine Region, largely due to its isolation and the associated difficulties with conducting research there (i.e. the presence of saltwater crocodiles in the region makes research that requires diving particularly risky on inshore reefs, walking traverses are also limited by the rapidity and range of tidal changes). Consequently very little is known to western science about the inshore areas of the Kimberley, generally the best understood areas of other systems, as well as areas further offshore. During discussions at the workshop, there was considerable debate as to whether the 200 m contour (shelf-break) was the approximate point of demarcation between inshore and offshore waters and further research would assist in clarifying this point.
- The influence of the ITF on the Kimberley is thought to be very important. Nevertheless, its influence and behaviour throughout this system is poorly understood and more research is required to understand the influence of this current upon the system's biology and ecology.

- The region is an important area for humpback whales and several species of smaller cetaceans. The workshop highlighted the possibility of humpback whale feeding on tropical krill associated with upwelling around Browse Island, however this observation requires validation. Offshore waters once supported substantial populations of sperm whales and recent acoustic evidence (post-workshop) suggests that blue whales move between Scott Reef and Browse Island during July (moving north) and again in October/November (moving south).
- The Joseph Bonaparte Gulf is an important part of the Northern Prawn Fishery. Significant by-catch is associated with the fishery. Our understanding of the Gulf's natural systems is very rudimentary. In the absence of better information it is difficult to determine what the effects of by-catch on the Gulf's ecology or long term sustainability of the fishery may be.
- The composition of the banks and mounds around the Bonaparte Depression and Joseph Bonaparte Gulf require further investigation, particularly whether they contain *Halimeda* and what communities they support. Some sampling in this region undertaken by Geoscience Australia has identified *Halimeda* in seabed samples, however the data set is limited and more studies are required to quantify this.
- There was some discussion regarding the possible effects of smoke from bushfires associated with deforestation in Indonesia and whether or not this may result in some nutrient loading of oceanic waters and hence have consequences upon marine communities. This would require further investigation.
- Trophic structures and pathways throughout the Kimberley system are poorly understood.

System 2 – Pilbara

The Pilbara system is a transitional oceanographic region between the strongly ITF-influenced surface waters to the north and the Leeuwin Current-influenced surface waters to the south. The source of ITF waters into this system is probably the recirculation of the South Equatorial Current into the Eastern Gyral Current, although it takes approximately one year for this cycle to transport water from Indonesia to the Pilbara coast. The along-shore pressure gradient in this system results in a predominantly southward movement of the surface water mass which becomes the source waters of the Leeuwin Current.

The Montebello Islands are thought to be a key point of disjuncture in water masses. Waters to the east are shallow and turbid inshore, whereas waters to the west are deeper oceanic waters. There is likely to be a historic biogeographic split around the Montebello Islands related to the last major sea-level transgression.

The continental shelf is a significant feature of this system and is relatively smooth and featureless (compared with the Kimberley and Ningaloo systems), and steepens in slope with distance offshore. The Exmouth Plateau also occupies a large area of this system (approximately 5,000km^2). The surface of the plateau occurs from mid-slope depths (from about 500 m) to over 5000 m.

Inshore areas of the system have predominantly sandy sediments, with mostly muddy sediments occurring offshore from the 200 m isobath. Grain size of sediments is confused by the presence of relict sediments and the sediments of the Exmouth Plateau have a strong biological component, due to the deposition of organic matter from the water column over a long period of time.

The Pilbara system is believed to have the strongest internal tides of the entire North-west Marine Region, which are thought to be an important physical driver in water depths of between 50 and 500 m depth on the shelf. The North West Shelf and Exmouth Plateau and ramp areas are areas of known high internal wave activity. Internal tides may result in the drawing of deeper cooler waters into the photic zone, stirring up nutrients and triggering primary productivity. Generally, there is confusion about the extent of influence of internal tides in this system and more generally throughout the North-west Marine Region and workshop discussions did not always result in a common view.

The zone between 50 and 500 m depth is thought to be the highest energy zone in the system (possibly correlated with an increased incidence of internal tides) and it is thought that broadly the greatest productivity is found around the 200m isobath associated with the shelf break.

Monsoonal winds are influential in the northern portion of this system and contribute to the mixing of surface waters.

Cyclones are a significant episodic event in this system and often cross the coast in the Pilbara. They give rise to large inputs of freshwater and sediment, which is significant as this system receives little if any terrestrial runoff at other times. They can also stimulate temporary 'spikes' in productivity of between one to two weeks' duration. Although cyclones have a large and intense physical impact when they occur, their infrequency on the whole means they probably have a low overall impact on the biological system. However, they can result in major disruption to the ecological community structures and processes within the coastal zone, including the scouring of sea floor and mobilisation of large volumes of sediment. Generally the effects of cyclones on habitats are determined by their tracking, footprint and sustained intensity. For example TC Vance had a region-wide impact extending from the NW Kimberley to Exmouth Gulf in 1999, whereas TC Steve was categorised as a lower intensity cyclone, but provided a significant input of rain to the coastal zone along the entire Pilbara coast.

Tides range from around 4 m in the south to around 10 m at Broome. The extent of turbid waters off the coast reflects the tidal range of the system and increases from south to north to approximately the 30 m depth contour around Broome. The narrow width of the turbid zone in this system is distinctly different to the Kimberley system.

The coastline of the Pilbara system is generally dry, broad and flat. The inshore habitat between Cape Preston and the northern limit of Eighty Mile Beach is predominantly sandy with little if any freshwater runoff in the absence of cyclones. Between Exmouth and Cape Preston, the coastal zone is dominated by mangrove communities and receives more freshwater runoff. Corals also occur along the coast and around coastal islands between Exmouth Gulf and Cape Preston.

There are no notable large populations of sponges in this system and some confusion as to why this is the case. Fishers and trawlers operating in Exmouth Gulf have reported large hauls of sponges in the past, but these sponge communities are no longer found in Exmouth Gulf. Today there is little knowledge of what sponge communities occur or occurred between Exmouth Gulf and Cape Preston. However, in areas with favourable substrate (hard substrate, broken pavement or reef, even with a sediment coating) it is thought that sponge communities would be present and be similar to those found to the south of Ningaloo Reef. Alternatively, in areas with predominantly soft substrates, very few sponge communities are likely to exist.

Biologically, the finfish fauna of this system is distinct from the Ningaloo-Leeuwin system. The system supports large prawn and crab populations, generally in inshore areas, along with pearl oysters. Other species known within the system include whales (humpback whales aggregate in Exmouth Gulf during their southern migration and pass through the system on their way to and from breeding grounds in the Kimberley), turtles and dugong.

Sub-systems in the Pilbara

Six different sub-systems were identified in the Pilbara system, differentiated by depth (see Figure 9). The distinctive features and key characteristics of each of these sub-systems are described in detail below. As with the identification of systems, the boundaries of sub-systems are not necessarily distinct and have been drawn at points which are thought to broadly reflect changes in physical and/or biological characteristics sufficient to differentiate one area (sub-system) from adjoining areas.

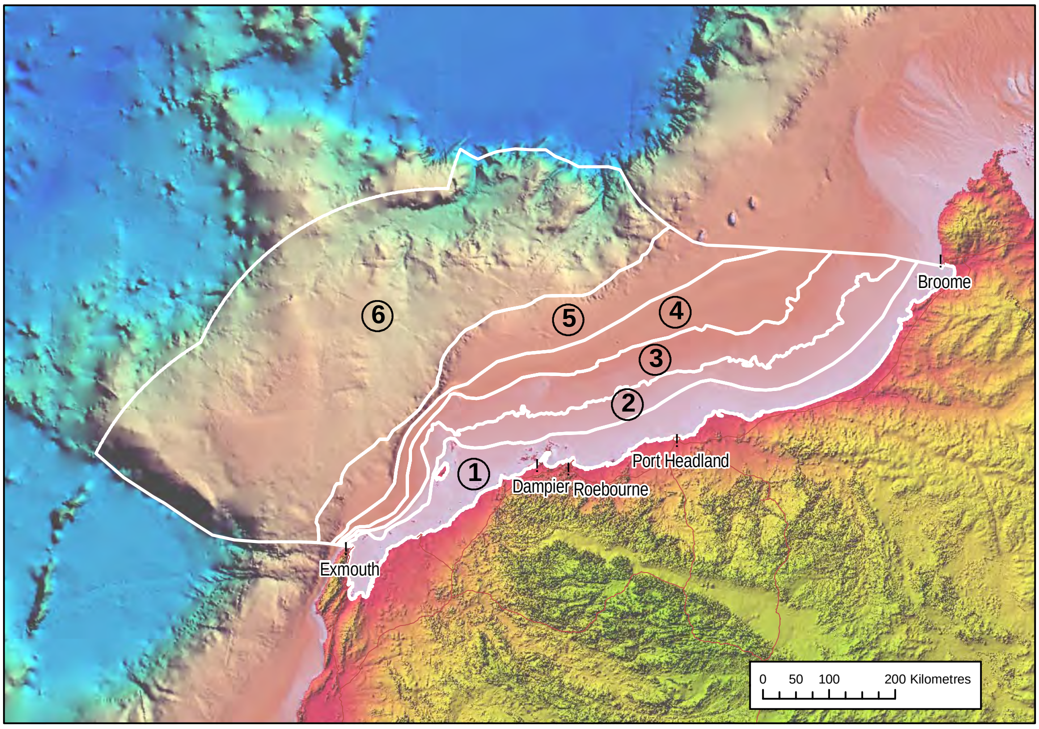


Figure 9: Sub-systems of the Pilbara

1. Coastal: 0-30 m

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates coastal waters out to 30m depth contour and associated coastal islands. Important features or species include: ▪ Mangrove habitat for fish (predominantly south of Cape Preston) ▪ Seagrass as habitat for dugong – primarily in the southern part of the subsystem ▪ Potentially important sponge habitats that are in recovery post trawling activities	The seafloor in this sub-system is virtually flat with the exception of around the Montebello Islands. The seafloor around the Montebello's is steeper here than areas further north. Therefore there is a decrease in shallow water species (e.g. dugongs feeding at 30m but not deeper) around the Montebello Islands. This coastal sub-system is characterised as a seaward sloping platform with turbid waters (particularly to 10 m and deeper in the north) and increasing tidal influence from south to north. Wind driven surface waves and tides are the main physical disturbance mechanism in this sub-system. Cyclones are also a major periodic

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Dampier Archipelago
Montebello Islands
Exmouth Gulf as resting area for humpback whales with calves on their southern migration
Numerous important breeding sites for green, hawksbill, flatback and loggerhead turtles. Extensive developmental habitat for juvenile sea turtles and residence of adults.
80 Mile Beach and Roebuck Bay provide important habitat for seabirds

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disturbance in this system.
Variation in coastal habitat occurs on a north-south gradient. The area between Exmouth Gulf and Cape Keraudren comprising a mangrove coast underlain by a limestone platform, with some freshwater input via river runoff. Between Cape Keraudren and the northern limit of 80 Mile Beach, the coast is sandy and dry and receives little freshwater input.
Inshore areas have sink holes that may vent freshwater plumes into coastal waters. They have formed on land in the karst terrain and flow via subterranean channels into the coastal zone. There is some conjecture about the occurrence of such features, and there is currently little data to support the freshwater venting hypothesis. There is some thought that this occurs in the northern end of this sub-system, but others suggest that it only occurs around Ningaloo,
The biology of this sub-system includes corals on the limestone flats in the southern section and prawn and crab (e.g. coral, blue swimmer, mud and decorator crabs) fisheries associated with the mangrove habitat. Seagrasses and algal mats also occur in the southern section, and algae and coral are dominant on shallow sandbars, platforms, reefs and ridges. Algae are thought to be the major primary producer in this system, followed by mangroves and corals in isolated areas.
Seagrass beds are believed to provide critical habitat for fish and dugongs and would be important for sustaining many of the system’s fish populations. However, seagrasses occur in scattered patches and can be severely degraded by disturbances such as cyclones. Dugongs are known to occur from Dampier to Exmouth, suggesting seagrasses are more prevalent in parts of this sub-system.
The sandy substrate of the northern section is believed to be suitable for benthic foraminifera and turtle grass in this area is critical for dugong foraging. The differences in biology evident between the north and south of this sub-system are also supported by fish studies.
The turbid waters would provide some species with key nutrients. Mangroves would also be a site of nitrogen fixation and algal mats would also be important for nutrient recycling.
In the past, the sub-system contained considerable sponge habitat, which was damaged by trawling activities. There is some evidence of recovery in the northern section; however there is a general lack of information about sponge composition and distribution throughout this sub-system.
Exmouth Gulf is an important resting and nursing location for humpback whales, particularly during their southern migration.
Other species known to occur include:
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	▪ Green, hawksbill, flatback and loggerhead turtles feeding and nesting in the area. Leatherback and olive ridley turtles also migrate through the subsystem and feed there. ▪ Dugongs and cetaceans - charter boat operators have reported humpback whales feeding on schools of anchovies off Barrow Island – another reported instance of humpback whales feeding outside Antarctic waters. ▪ Prawns, pearl shell ▪ International migratory waders ▪ Pelagic, demersal and reef fish species ▪ Whale sharks ▪ Sharks, rays and sawfish - large sawfish occur in shallows around Barrow-Lowendal-Montebello Islands area. ▪ Cephalopods ▪ Holothurians and urchins

2. Inner Shelf: 30-60 m

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates the inner shelf and waters between the 30 and 60 m isobaths. Important features or species include: ▪ Rhodolith beds ▪ Migration area and breeding aggregation areas for cheloniid sea turtles (of the Family Cheloniidae) and feeding area for resident turtles.	The shelf in this sub-system is again virtually flat and overlain by sparse sandy substrates, more prolific in the northern end with micro-castes. Relict sediments are also present and rhodolith beds of coralline red algae growing on rocks occur between 30-90 m. The water column is highly stratified and wind-driven surface waves are thought to be a dominant physical mixing process. The main currents in this subsystem are likely to be tidal currents. Primary productivity would be driven by algae in the photic zone utilising organic nutrients. Episodic nutrient flows from deeper waters offshore may also occur in this sub-system, and available nutrients are thought to be converted into organic matter and then transported again further offshore. The sub-system's sandy substrates are thought to support low density benthic communities of bryozoans, molluscs and echinoids. There was some speculation as to the presence of sponge communities, but no data are available to support this. Holothurians, urchins, crustaceans, prawns, squid are also present. Turtles (e.g. green, hawksbill, loggerhead and flatback) migrate through this subsystem, as do cetaceans. Fish species include lizardfish, goatfish, trevally, angelfish and tuskfish.

3. Mid Shelf: 60-100 m

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates the mid shelf and waters between the 60 and 100 m isobaths. Important features or species include: ▪ Glomar Shoals ▪ Humpback whale southern migration thought to be mostly inshore of the 100m depth contour	The edge of this sub-system marks a differentiation in sediments between the landward side of the 100 m isobath in comparison to deeper waters. Sediments in this sub-system comprise sands and gravels on cemented hard grounds. It is a reasonably barren substrate with 50% comprising relict reworked material (e.g. ooid old shoal) and hence there is little recent organic material. These substrates support a generally low biota. Rhodolith beds are known in this sub-system to depths of 90 m and the Glomar Shoals drowned reef is also located here and is believed to be a site of higher productivity, as evident in high catches of commercial fisheries in this area. The processes facilitating increased productivity at this location are not known. The waters are clear and the thermocline (and therefore chlorophyll maxima) intersects with the seafloor. Primary productivity is pelagic driven, but in the past would have included a significant benthic component which has been removed/damaged through trawling activities. Some recovery in benthic environments, particularly sponge communities, has resulted in their sparse distribution throughout the area. Internal waves are thought to provide some inflow of nutrients into the sub-system, as would the barotropic tide to a limited extent. The sub-system was described as comprising productivity fronts that form “lines” of nutrients which act as feeding routes for migratory species. Pelagic species feeding in the area include turtles, cetaceans, sharks and rays as well as fish species such as red emperor, rock cod, sweetlips, goatfish, trigger fish and threadfin bream. Benthic species would include foraminifera, bryozoans, molluscs and holothurians. Humpback whales on their southern migration would frequently traverse this sub-system. Trap and trawl fisheries are active in this sub-system.

4. Outer shelf: 100-200 m

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates the outer shelf and waters between the 100 and 200 m isobaths.	The outer shelf is characterised as a sea-ward sloping surface. There is a change in gradient at 120 m isobath which marks the location of the ancient coastline and forms a prominent scarp through much of

Important features or species include: ▪ Ancient coastline at approximately 120 m isobath as a possible migratory pathway for cetaceans (e.g. humpback whales) and other pelagic species such as the whale shark.	this sub-system. An absence of canyons on the outer shelf in the Pilbara is also notable. The sediments of the outer slope comprise sands and gravels, transitioning to muds with increasing distance offshore. Planktonic material (planktic forams) and relict substrates, including calcified tubeworms, are also present. This sub-system is influenced by internal tides which are thought to contribute to nutrient mixing in the water column and the movement of nutrients further offshore into deeper waters. Primary productivity is believed to be seasonal (associated with seasonality in internal tides) and is thought to be primarily pelagic. Detrital rain would transport some organic material to the seafloor, however there is believed to be very few benthic living organisms in this sub-system. Characteristic pelagic fish species include deep goatfish, deep lizardfish, ponyfish, deep threadfin bream, adult trevally, billfish and tuna. Leatherback, olive ridley and loggerhead turtles, sharks and whale sharks would also occur in this sub-system. None of the turtle species are currently abundant in this sub-system, but these species occur and may be found further out as well. It was suggested that the ancient coastline is used by cetaceans, including migrating humpback whales, and perhaps other pelagic species (i.e. whale shark) and may be an areas of enhanced productivity as well as a structural feature.

5. Slope: 200-1000 m

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates waters of the slope between 200 and 1000 m depths. Important features or species include: ▪ Northward flowing current at around 200m to 500m is a migratory pathway for mammals, such as humpback whales, blue whales and sperm whales. ▪ High endemicity of demersal fish species.	The hydrology of this sub-system was hard to characterise as the current systems are poorly defined. The Leeuwin Current is thought to have a seasonally variable influence in the southern part of this subsystem. There is also evidence of a northward flowing surface current through this sub-system and further north into the adjacent Kimberley system. This may be utilised by migrating whales and other migratory and/or pelagic species and may be associated with a zone of upwelling suppling nutrients and food. This may be associated with an offshoot of the Eastern Gyre. The shelf break occurs between depths of 200 and 500 m. The geomorphology is believed to comprise a smooth seafloor with pelagic derived sediments, such as foraminifera with pteropods. Between depths of 500 to 1000 m the seafloor would comprise sandy mud derived from nanoplankton ooze. Internal waves may occur in depths of between 200-

	500 m and may have a role in productivity processes. The highest nutrient biomass probably occurs in the deeper water layers and would comprise planktonic and detrital biomass. This appears to correlate with the occurrence of a number of pelagic fisheries in the deeper waters of this sub-system. The 200 m depth boundary may be important for migratory mammals. Although the shelf break does not occur at the same depth, it may be a feature that migratory mammals follow (possibly assisted by the northward flowing surface current) and may be associated with a zone of upwelling suppling nutrients and food. Confirmation of this possible association with migratory species may be warranted. It is thought that 70 of the 500 demersal fish species recorded on the slope are endemic. However, the reasons for the high level of endemism are not known. This sub-system has a number of pelagic fish species, including tuna. The communities of the benthic environment are less well known but are known to include benthic crustaceans. The scampi fishery also occurs in this sub-system.

6. Exmouth Plateau: >1000 m

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates waters in depths greater than 1000m and the seafloor of the Exmouth Plateau. Important features or species include: ▪ Canyons running from Exmouth Plateau to the Argo Abyssal Plain. ▪ The deep gully/saddle on the inner edge of the Exmouth Plateau for sperm whales and other migratory species such as blue whales, humpback whales and other cetaceans.	The Exmouth Plateau (in water depths of 800-3500 m) is a significant geomorphic feature in the North-west Marine Region. It has a relatively uneven seafloor and may include pinnacles. The sediments are assumed to comprise nanoplankton ooze with a volcanic ash component (i.e. abyssal red clay), which are probably limited to depths below the carbonate compensation depth (~5000m). On the northern section of the plateau is a gully margin and escarpments incised by canyon systems. They are thought to extend onto the saddle between the plateau and mainland Australia. These are recognised as a distinct feature, but little is known of their ecology and geomorphology. As with other deep areas of the marine environment, little detailed information on the physical oceanography of the plateau is available. It is thought that ITF waters via the Eastern Gyral Current occur over the plateau and that they become part of the headwaters of the Leeuwin Current further inshore. The exact mixing and movement of currents over the plateau is not clear. Internal tides are believed to occur here and could be associated with unconfirmed upwellings associated with topographic features, such as canyons. Little is known about productivity in this sub-system. Detrital rain is likely to play a role in nutrient cycling from pelagic to benthic environments; however other mechanisms for vertical and horizontal flow of nutrients

	and materials are unknown. There was some speculation about the role of *Trichodesmium* as a source of nitrogen in the sub-system, but there is no data to confirm its role. Hydrocarbons are known to be present in detritus and there is some thought that this may be a driver in benthic production. However, there appear to be no studies or data to support this hypothesis. Generally, it is believed that the benthic biomass in the midslope areas of this region would be much higher and more diverse than equivalent midslope areas of the east coast of Australia. The deep waters above the gully/saddle on the inner edge of the plateau are thought to be important for sperm whales which may feed in the region (based on nineteenth century whaling records. The reasons for this aggregation are not known. Other cetaceans are also believed to use north flowing currents through the deep gully/saddle to assist in their northward migration, similar the northward flowing offshoot of the Eastern Gyral Current. Other species known in the sub-system include turtles and whale sharks. Recent Position Tracking Terminal (PTT) observations of flatback turtles have recorded turtles in this subsystem. Loggerhead turtles do traverse this system, and leatherback and olive ridley turtles are likely to do so as well. PTT tracks have also been recorded for whale sharks through this subsystem. Very little is known about other pelagic species or benthic species.

Uncertainties in our understanding of the system

- A number of sub-systems in the Pilbara were identified; however participants cited a lack of fisheries or biological data to inform the sub-system boundaries. Primarily research data in this system is limited to Barrow Island and surrounds.
- Workshop participants cited numerous examples of differentiation between the northern and southern sections of the coastal sub-system (0-30 m). For example, AIMS research has shown different trophic systems to the north of Dampier in comparison to those to the south. For the purposes of this report, the differences were noted, but further work is required to better describe this sub-system.
- Our understanding of the behaviour of water bodies and currents and their role in ecological processes in the system is not well developed.
- With some exceptions, we have poor understanding of the biology of the system and particularly its deeper environments.

System 3 – Ningaloo-Leeuwin

The main hydrological characteristic of the Ningaloo-Leeuwin system is the Leeuwin Current which is broadly recognised as becoming identifiable as a surface current in this system, and is associated with the narrowing of the continental shelf and slope. This is an important distinguishing feature of this system in comparison with the Pilbara system. The current transports warm, low salinity waters, along approximately the 200 m contour and exerts a strong influence upon the areas biology, partly due to its close proximity to coastal waters.

There is minimal sediment input through river runoff and the clear waters result in a photic zone which is believed to extend to depths of approximately 100 m and a seasonal chlorophyll maxima forms at approximately 120 m during spring. On the shelf, this therefore results in a near bottom chlorophyll maximum which lifts off the bottom of the seafloor at the shelf break.

Broadly speaking, sediments in this system are thought to comprise coarse coral fragments and sand closer to the coast, with fine sediments occurring in offshore waters.

There are a number of deep water regions within the Ningaloo-Leeuwin system, including the Cuvier Abyssal Plain (at a depth of over 5000 m), the Wallaby Saddle (at a depth of approximately 4000 m) and a number of canyons that incise the slope between the shelf and the abyss. The benthic communities associated with these regions are not well understood.

Biologically, this system is distinct from the adjoining Pilbara system for a number of reasons. The system is characterised by a transition in biota from largely tropical species to temperate species commencing around North West Cape. The transition occurs at different latitudes for different species or groups of species. There are also a number of different species assemblages associated with changes in depth. For example, there are distinct assemblages of fish and molluscs associated with depths between 0-100 m, 100-200 m, 200-500 m and beyond 500 m with almost no overlap between them.

A distinct break in the distribution of crustaceans and commercial fish populations occurs in this system. The North West Cape area and Ningaloo coast show some biogeographic transitions for breeding and foraging cheloniid sea turtles. Adult flatback turtles do forage within Exmouth Gulf, but only occasional winter stranded juveniles are known from more southerly locations. Similarly, the breeding range of flatback turtles ends at the Muiron Islands.

The southerly breeding range of green turtles appears to lie along the Ningaloo coast, around the thermal transition off Point Cloates, where the Ningaloo Current pushes west. Resident adults and juveniles are found further south within the Shark Bay system, and their presence extends well down into the Jurien Bay region.

Transitions for the hawksbill turtle are not well defined, but their breeding range is thought to end around Point Cloates-Coral Bay, similar to green turtles. Their resident distribution is uncertain, but they are present in the Shark Bay system. Transport by the Leeuwin Current seems likely to account for more southerly records of occurrence.

The southern boundary of this system is arbitrarily defined by the Marine Bioregional Planning boundaries and most physical characteristics and species occurring at the southern end of this system extend into the northern areas of the South-west Marine Region.

Sub-systems in the Ningaloo-Leeuwin

Six different sub-systems were identified within the Ningaloo-Leeuwin system, which are shown in Figure 10. The distinctive features and key characteristics of each of these sub-systems are described in detail below. As with the identification of systems, the boundaries of sub-systems are not necessarily distinct and have been drawn at a point which broadly reflects a change in physical and/or biological characteristics sufficient to differentiate the area (sub-system) from adjoining areas.

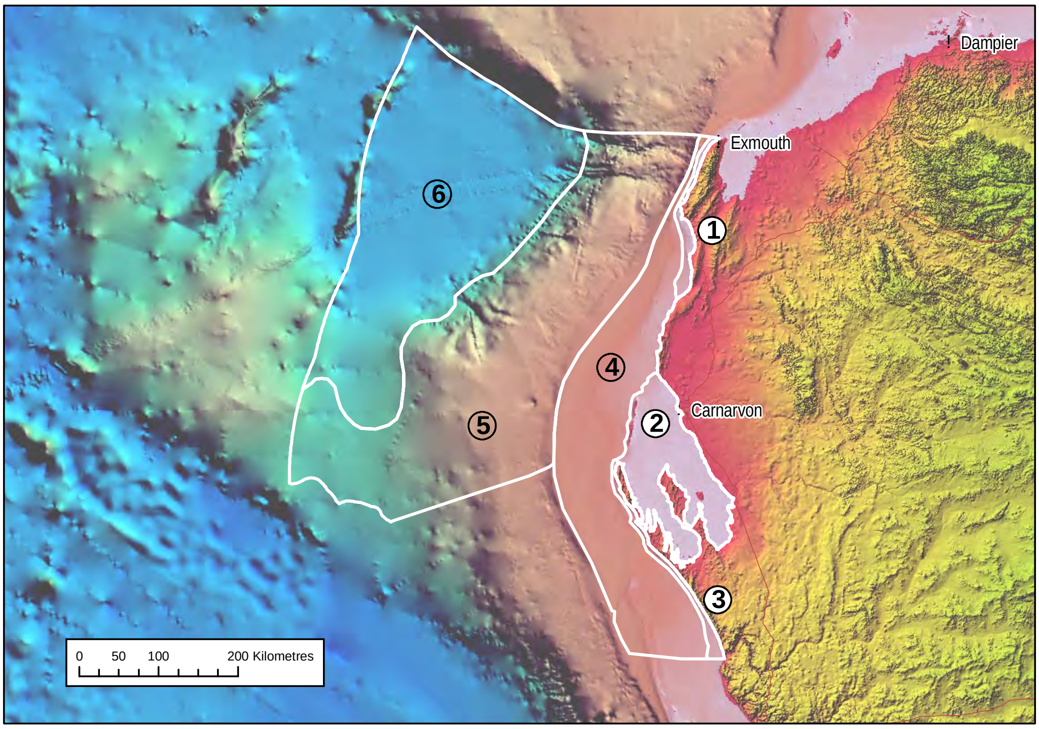

Figure 10: Sub-systems of the Ningaloo-Leeuwin region

1. Ningaloo Coast: 0-30 m

Extent and Distinctive Features	Description of sub-system characteristics
Extends from Exmouth to Cape Farquhar, incorporating the Ningaloo MPA between depths of 0-30 m. Important features or species include: ▪ Fringing reef system ▪ Important assemblages of clear water corals, which are unique due to their close proximity to the coast and prolific nature. ▪ Interaction between the Ningaloo Current and the Leeuwin Current as a site of enhanced productivity ▪ Zooxanthellae play an important role in productivity. ▪ Large algal beds associated with lagoon. ▪ High species diversity including manta rays and whale sharks, sea turtles and dugong, humpback and killer whales. Humpback whales migrate close to the reef edge, where killer whales frequently prey on humpback whale calves.	This sub-system is regarded as biochemically, physically and biologically distinct from anywhere else in the North-west Marine Region. It is characterised as a coastal sub-system incorporating a barrier reef and associated lagoon. At its southern extent, the reef narrows and the rocky reef is replaced by red sand. It is a very dynamic environment. For example: ▪ The Ningaloo Current during summer causes upwelling off Cape Range Peninsula. The interaction between the Ningaloo and the Leeuwin Current is believed to lift the chlorophyll maxima up to the surface along the Ningaloo reef. ▪ The action of waves breaking over the reef injects oxygen into the alkaline environment. ▪ It experiences large seasonal water temperature changes of between 5-8°C associated with upwelling and down welling systems directly adjacent to the reef. Ningaloo is a transitional zone for a number of tropical and temperate species (e.g. *Sargassum* is the dominant macro-algae of the lagoons of Ningaloo, but

	further south this is replaced by *Ecklonia*). In terms of seagrass species, distribution of *Thalassia hemprichii* extends down to the northern Ningaloo Reef, and *Posidonia coriacea* is found on northern parts of the reef. The whole Ningaloo Reef system acts as a giant filter feeder, taking all available nutrients out of the water column, thereby capturing the production and making it available to other organisms and species at subsequent levels in the food chain. As a consequence, there is a low detrital load from the reef as waters are stripped of all available nutrients. Low levels would accumulate in sediment and be utilised by sedimentary feeders (e.g. holothurians) or other detritivores. The sub-system is also significant because of a number of important relationships between coral and associated species. For example, these include: ▪ The symbiotic relationship between corals and zooxanthellae: corals survive on nutrients provided by zooxanthellae in low nutrient seasons. Scientists believe that the zooxanthellae act heterotrophically, taking 70% of the available chlorophyll out of the water column across the top of the reef. ▪ Epibenthic filter feeders use corals as substrate and consume chlorophyll a. ▪ Large numbers of tropical reef fish dependent upon the coral.

2. Shark Bay (incorporating Shark Bay transitional zone): 0-30 m

Extent and Distinctive Features	Description of sub-system characteristics
Incorporating Shark Bay and extending 30 m offshore. Important features or species include: ▪ High diversity in seagrass habitat and associated aggregations of dugongs. ▪ Largest single regional breeding site for loggerhead turtles occurs on northern end of Dirk Hartog Island. Large resident presence of adult and sub-adult green and loggerhead turtles. ▪ Major resting area for northward and southward migrating humpback whales.	The flow of the Leeuwin Current along the slope restricts outflow of waters from Shark Bay and hence it is a reasonably closed system. Waters within the bay are generally shallow and hypersaline. There is a transitional zone across the opening of Shark Bay within which seepage of the cooler hypersaline waters occurs and they continue to flow southwards with the Leeuwin Current. It is not known whether this saline outflow has much impact on the salinity of the Leeuwin Current, or whether the interface between the saline outflow and the Leeuwin Current is an area of increased productivity. There are a number of different habitats within Shark Bay itself which contribute to the Bay's high species diversity. Generally, the substrate consists of sands. A temperate reef system occurs at the mouth of Shark Bay. Both normal and hypersaline water systems are at work in Shark Bay. The main habitat types are seagrass, sandy plain, rocky shoreline – both high and low energy

	zones. Inside the islands, there are shallow fringing coral reefs which give way to both fine and coarse sand plains with occasional meadows of light garden bottom. Seagrass is a major habitat type from east to west bay shorelines. The outer west side of islands and cliffs can be found in high energy rocky shores, with narrow reef flats. These rapidly drop to 30-50m depth where algae and reef give way to extensive sponge gardens. The Faure sill and sediments off the Monkey Mia side are finer and very mobile with shifting banks. This is a rich area for bivalves and scaphopods. Biological significance of this sub-system has already been recognised in its World Heritage listing and it is characterised as an area of high primary pelagic productivity. However there is some thought that, due to the existence of extensive seagrass beds, benthic production could outweigh pelagic production. Other notable characteristics include: ▪ the presence of tropical clams ▪ northern-most extent of the Pink Snapper fishery ▪ Prawn fishery ▪ Humpback whales use the northern half of the Bay as a resting/staging area during their northern and southern migrations

3. Zuytdorp Cliffs – 0-30 m

Extent and Distinctive Features	Description of sub-system characteristics
Extends between Dirk Hartog Island and along the coastline to Kalbarri. Important features or species include: ▪ High temperate sponge biomass ▪ Endemic cowries occur in this sub-system.	This is a coastal sub-system incorporating coastal limestone cliffs, known as the Zuytdorp Cliffs. Characterised as a high energy coastline due to waves rebounding off the cliffs. The shelf is very narrow and therefore close to deeper more nutrient rich waters contributing to the area's high productivity. Following the transition between tropical and temperate waters, this subsystem contains more temperate species compared to the Shark Bay sub-system further north. Examples include: ▪ Brown algae dominance for first time in North-west Marine Region (i.e. *Ecklonia*) along temperate reef flats. ▪ Temperate fish communities with no distinction between coastal and shelf communities/species. Trophic relationships in this subsystem are temperate and reef-like. However, in contrast to the Ningaloo sub-system the reefs in this region do not include large numbers of filter feeders. It is not known why this

	absence exists. Isolated outcrops of staghorn corals in shallow habitats. There is also a high diversity of sponges in this sub-system. Fish species include jewfish and periodic/seasonal swarms of hardyheads that support a wide variety of species from fish to whales The cliff wall provides submarine feeding habitat (macroalgae) for green turtles all along this coast.

4. Shelf: 30-200 m

Extent and Distinctive Features	Description of sub-system characteristics
Includes the extent of the shelf from offshore of Exmouth to the southern boundary of the North-west Marine Region. Important features or species include: ▪ The narrow shelf which results in a close interaction between deeper more saline waters and coastal waters. This is generally a region of enhanced productivity, due to interaction between currents and topographically variable bathymetry. ▪ Biodiversity transition zone between tropical and temperate species. ▪ Diverse sponge and soft coral communities. ▪ Major migratory area for humpback whales. ▪ Ningaloo Marine Park.	This sub-system is recognised as containing the 'start'/headwaters of the Leeuwin Current and hence the hydrology is dominated by the south flowing Leeuwin Current (strengthening during autumn and winter) and the north flowing Ningaloo current during summer, which is driven by strong southerly winds. The width of the shelf is significantly narrower than areas further north and a series of sandbars have been identified on the shelf break at approximately 200m depth. Cooler, hypersaline waters seep out of the adjacent Shark Bay sub-system and travel southwards along the bottom of the shelf in this sub-system. There is speculation that this may be a factor in the make up of sponge communities in this sub-system, although there have been no direct studies of the sponge fauna. The sponge fauna is thought to be subtropical or possibly temperate in deeper waters. Key factors driving productivity in this sub-system are the current patterns, the narrow shelf, and the depth of the chlorophyll maxima. The chlorophyll maxima sits on the bottom of the seafloor to around depths of 70 m and this direct physical intersection is associated with a diverse benthic community of sponges, soft corals and associated demersal fish. Generally, it is thought that this is a highly productive system. Broadly, the sub-system is a transitional zone of tropical and temperate marine species influenced by the warm Leeuwin Current waters from the north, but also the incursion of cooler waters from the south. It is recognised that a change in species composition occurs at around Shark Bay. The benthic communities are diverse in this sub-system and differ on a north-south axis. For example, there are different species of sponges, cowries and fish (e.g. wrasse species) in the north versus the south. There are also variations with distance offshore, for example, the benthic communities occur closer to the shore in the south, but further out in the north. Sponge communities also change on a north-south axis, with an

	increase of subtropical/temperate species southwards. Despite the changing species composition from north to south, functionally the trophic systems are very similar the same across this sub-system, although not a great deal is known about the species that occur). There is some differentiation between fish and mollusc species at 100-200 m, and there tends to be decline in the shallow water specie, and a transition to deeper water species at these depths, in most fauna. It was noted that the sub-system is a pupping area for Dusky sharks.

5. Slope: 200-4000 m

Extent and Distinctive Features	Description of sub-system characteristics
Includes all areas of the slope, offshore from North West Cape to the southern boundary of the North-west Marine Region. Important features or species include: ▪ Possible aggregations of sperm whales around Wallaby Saddle. ▪ Potentially unique community assemblages in the canyons, including diverse epibenthic communities associated with hard substrate. ▪ Light-limited environment and therefore species adapted to capture all available light.	There is generally a poor understanding of both the physical oceanography and biological communities on the slope. There are two sections of the slope in this sub-system, the area known as the Wallaby Saddle at a depth of approximately 4000 m and characterised by a gentle slope, and the slope further north at depths of greater than 2000 m which is steeper and includes major canyons (e.g. Cape Range, Cloates and Carnarvon Canyons). Little is known about the movement of waters in the canyons of this sub-system and what is known is inferred from other areas. For example, in winter the more saline waters are thought to sink to the bottom of the canyon, intensifying bottom currents that drive upwards and thereby enhancing mixing. Resuspended sediments in the water column may support benthic and associated communities, resulting in canyons possibly being areas of high biodiversity. It is believed that pelagic productivity is a key driver in the sub-system to depths of approximately 2000 m after which the trophic system is likely to be benthic driven and have some similarities with the abyssal system at greater depth. The benthic system includes particulate organic matter (POM) feeders/scavengers such as molluscs and large isopods as well as detrital feeders/filter feeders. There is a distinct difference in fish communities between 200 and 500 m in this sub-system and scientists also noted a difference in the trophic structure of demersal fish species. Demersal fish communities on the flatter areas of the slope are more reliant upon detrital rain, but they would maintain links to the pelagic trophic system via live feeding of primary and secondary consumers that migrate between the benthic and pelagic environments (e.g. micronecton such as caridean shrimps and fish). The fish bioregionalisation (a bioregeographic appraisal

	of Australia's deepwater demersal fish fauna: Last et al, 2005) does not identify any endemism in slope fish communities, despite the difference in the slope habitats in this sub-system. The reasons for this lack of endemic species is not known. Bryozoans, sponges and encrusting coralline algae would occur in depths of 200-2000m in this sub-system. However, the sponge communities of southern Australia at these depths have not been studied. Sperm whales are said to aggregate around the Wallaby Saddle and some have postulated that aggregations of bait fish may also occur there providing a food source for the whales. This was attributed to the shallowness of the saddle in comparison to slope areas on either side, which causes the upward movement of deep cool waters up onto the saddle and hence the occurrence of some mixing or upwelling as a driver of increased productivity. The effect of seasonal changes on the saddle and hence the associated communities is unknown. Other species noted in this sub-system included: ▪ Sweet lip emperors associated with the top of canyons ▪ Big eye tuna feeding at depths of 1400 m ▪ Offshore of Ningaloo - migratory route for shark species on their way to 'pupping' areas on the shelf. Specific details of pupping locations are unknown.

6. Abyss

Extent and Distinctive Features	Description of sub-system characteristics
Incorporates the waters and seafloor of the Cuvier Abyssal plain. Important features or species include: ▪ Potentially specialised benthic fauna.	Very little is known about the physical oceanography, geomorphology and biological communities of the abyssal system. The abyss is characterised geomorphically as a separated basin which is likely to have a soft sediment bottom and associated benthic assemblages that are able to survive in the no light conditions. It was proposed that there may be protruding rocky mounds on the seafloor, however, most of this is speculation based on knowledge from other abyss areas around Australia. There appears to be little specific information on this sub-system. The benthos is likely to be sparse and include meiofauna (e.g. nematodes) which are capable of utilising the bacterial detritus/POM that would fall from the pelagic zone above. There was some speculation that the sub-system may comprise specialised unique benthic fauna in comparison with other abyssal areas due to the geomorphology of the basin. The biota in the abyss is likely to have a low overall

	biomass and therefore it was considered doubtful that the sub-system contains a highly diverse fauna.

Uncertainties in our understanding of the system and its component sub-systems

- Our understanding of the substrate, habitats and species of the deepwater areas (the slope and abyssal areas) is very poor and there is considerable uncertainty surrounding the use of geological surrogates for biodiversity in these areas.
- Little is known about the Cape Range, Cloates and Carnarvon Canyons, including how they were formed and what communities are associated with them.
- The biodiversity and geomorphology of the Wallaby Saddle is relatively poorly understood: there are no apparent canyons adjacent to the Wallaby Saddle nor are the saddle's benthic communities known. In addition, the reason for why sperm whales aggregate on Wallaby Saddle is unclear, although they could be following the southern convergent front or be attracted to the saddle because its bathymetry gives rise to processes that ultimately attract prey.
- Workshop participants also highlighted a lack of understanding about the communities of the shelf system.

Understanding the state of knowledge and areas of uncertainty

Workshop participants were confident about the following areas of understanding about marine systems:

- Bathymetry and geomorphology are key drivers in systems e.g. seafloor biota is largely determined by bathymetry and substrate. Depth is the primary driver in differences between inshore and offshore waters, largely through the variation in light availability.
- Oceanographic processes are also a key driver, particularly the composition of each water mass such as its physical and chemical composition and temperature. Currents are the agents for the movement of the differing water masses and therefore provide the link between systems in terms of connectivity between habitats, as well as being an agent in primary productivity and frequently in species reproduction.
- While our understanding of species and habitats is always evolving, research within the region to date has largely been focussed upon:
    - Fish and coral biology for inshore waters. This is true for some taxa only, for example there in a lack of information on sponges in the Kimberley, but reasonable information elsewhere.
    - Ningaloo Reef (not all taxa)
    - Offshore reefs and islands of Ashmore, Cartier, Scott, Seringapatam and Rowley Shoals.

  Scientists therefore have a reasonable understanding of the biodiversity of these areas.

Workshop participants were less confident about the following areas of understanding about marine systems in the North-west Marine Region:

- While the importance of oceanography at a regional scale is broadly understood, more research is required to improve our understanding of the sources and pathways of currents in the North-west Marine Region. Participants broadly acknowledged the significant influence of the ITF on ecological processes in the North-west Marine Region but there are still very significant gaps in our understanding. More research is required to understand:
    - how currents transport the ITF's waters through the Kimberley and Pilbara marine systems,
    - how long it takes for water bodies to travel through the Region and
    - what effect the NW monsoon, tides, seasonal and inter-annual variability has upon these systems.
- Similarly while it is recognised that the ITF is likely to be a major constraint on productivity across the whole region, there are significant variations in annual productivity which are not well understood. More research is required into sources, processes and locations of primary production in the North-west Marine Region. For example, the ITF's suppression of the thermocline is an important factor in determining productivity which requires further investigation. Nor is the influence of internal tides on ecological processes well understood. Scientists are also unsure of the role that sponges may play as a source of nitrogen for further primary production at depth.

- Generally our biological knowledge decreases with increasing distance offshore and hence our knowledge of deeper water (over 200m depth) is very scant. This is particularly evident in the abyss and deep water areas of the North-west Marine Region where very little is known of the habitats and composition of offshore pelagic and benthic communities, predominantly due to the difficulty and cost of research in these waters.
- Similarly, there is a lack of information on the full range of marine biodiversity (the variety of life in coastal and ocean environments, including plants, animals and micro-organisms; the genes they contain, and the ecosystems they live in). Most research undertaken to date relates to commercial fisheries, but there is a limited understanding of other species and communities of the marine environment and how they interact with each other. A significant limiting factor is the time required to analyse and interpret existing data (in conjunction with 'new' data) in order to generate a regional view. For example, participants highlighted the substantial amounts of existing data and information available for the North-west Marine Region as a result of research by Keith Sainsbury in the late 80's as well as other data held in CSIRO and the museums. However, there has been little analysis to date of this data from a regional perspective.
- While differences in fish communities have been identified with changing depths throughout the North-west Marine Region, more research is required to understand why these changes occur. Similarly, cetacean distribution, abundance and biology near significant oceanographic features, such as deep water canyons and seamounts, (habitats known worldwide to support a variety of unique cetacean populations) remain largely unstudied.
- The sponge communities of the North-west Marine Region are also relatively unknown. Generally, there are large areas throughout the Region with poor sponge coverage and smaller pockets with a high sponge density. In terms of species composition, there appear to be differences on a north-south gradient throughout the Region. More research is required to understand these differences and to understand how well the sponge communities are recovering from large scale trawling activities.
- Transboundary species (including large pelagic fish, some sharks, cetaceans and seabirds) are a more significant part of the North-west Marine Region relative to the other Marine Regions around Australia. Therefore, a more integrated understanding of the trophic interactions between other marine areas of Australia and internationally, as well as within systems and sub-systems of the North-west Marine Region is needed.
- Broadly, much more research is required to understand the impacts of climate change on the marine environment.

Conclusion

The workshop brought together experts from a range of relevant disciplines. Despite, or perhaps because of, the lack of information and very significant uncertainty in regard to many parts of the North-west Marine Region, there was a high degree of consensus between participants on the major systems and components of the Region. It was agreed that, in terms of oceanography and biology, the Region can be divided into three major systems (Kimberley, Pilbara and Ningaloo-Leeuwin). Further, participants agreed that these systems can be further subdivided, largely using depth contours and/or major geomorphic features.

While workshop participants were reasonably confident about identifying the major physical drivers in the Region, significant uncertainty exists regarding some of the processes by which these drivers influence the system. Discussion in the workshop was also frequently constrained by a lack of biological information.

The ecological characterisation and the key information gaps identified by the workshop provide a basis for improving our understanding and management of the Region, including through activities designed to address key gaps in our understanding. The Department will draw on the workshop's outcomes and other available information to begin to identify key ecological features and conservation priorities within the Region.

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