5. DESCRIPTION OF THE REGION AND ITS MAJOR SYSTEMS

5.1 GENERAL DESCRIPTION OF NW MARINE REGION

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

5.2 DEFINING TROPHIC SYSTEMS

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

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

5.2.1 Hierarchy of drivers

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

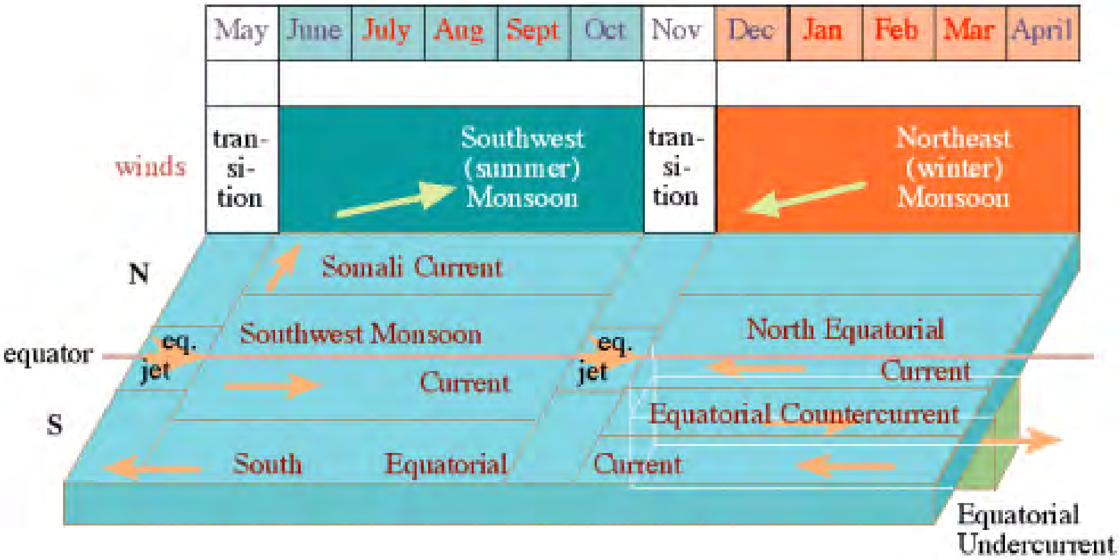

Figure 5-1 Tomczak and Godfrey's (2005) depiction of the monsoon system in the Indian Ocean. The top part indicates the wind cycle, the lower part shows the major currents that develop in response to the wind. (after Tomczak and Godfrey, 2005).

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

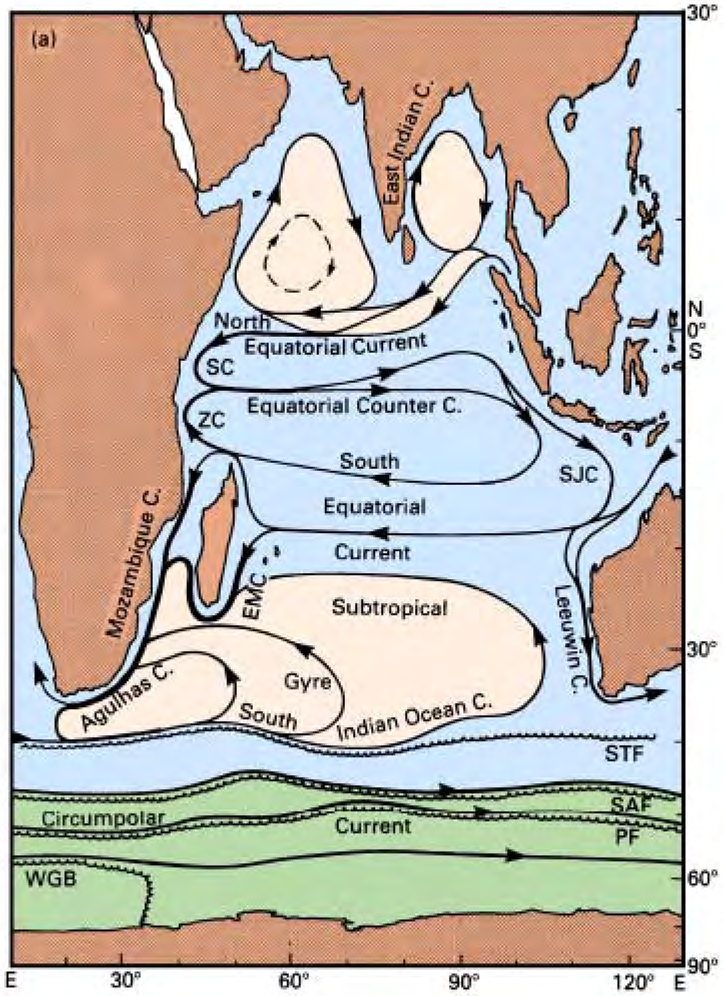

Figure 5-2 Tomczak and Godfrey's (2005) depiction of the surface currents in the Indian Ocean during the Northeast Monsoon (March-April) (after Tomczak and Godfrey, 2005)

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

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

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

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

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

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

Water mass descriptions

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

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

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

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

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

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

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

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

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

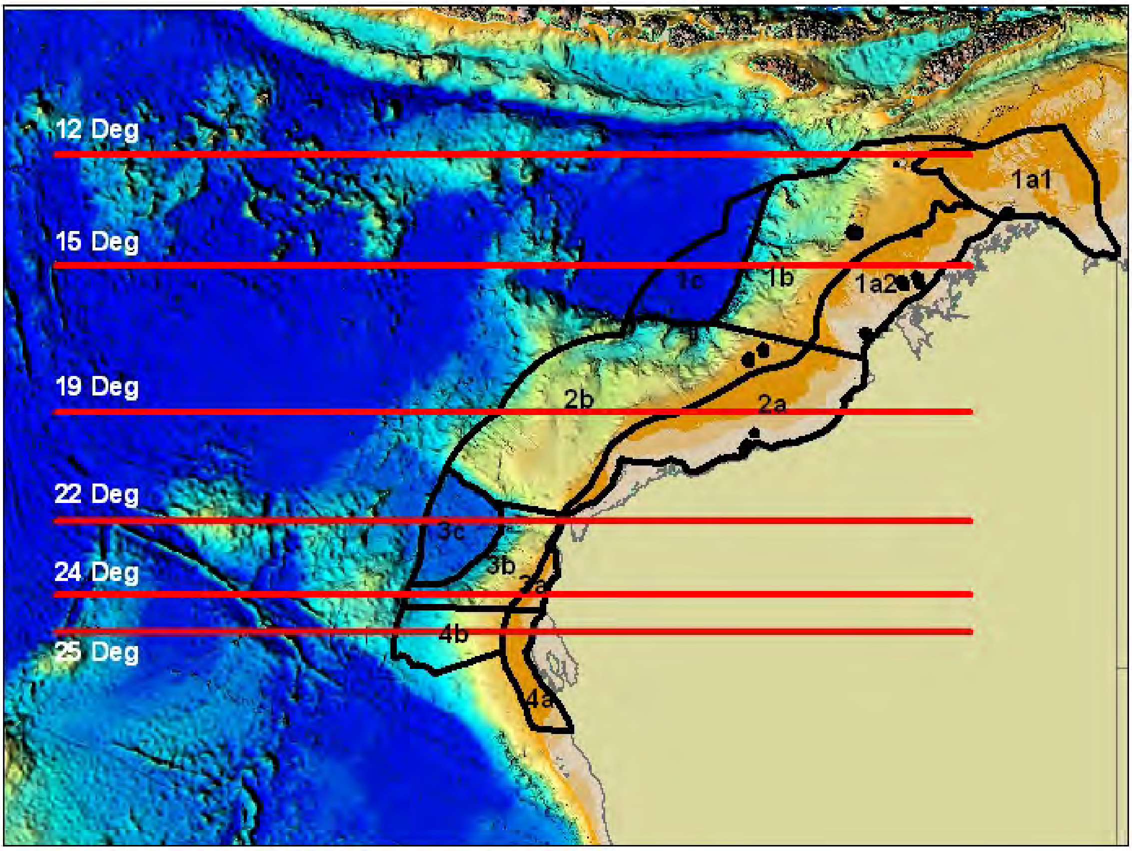

Figure 5-3 Water mass profile locations from six sections across the North West Marine Refgion. The water mass profiles are shown in Figure 5-4 and Figure 5-5.

5.2.2 Structure of the trophic systems

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

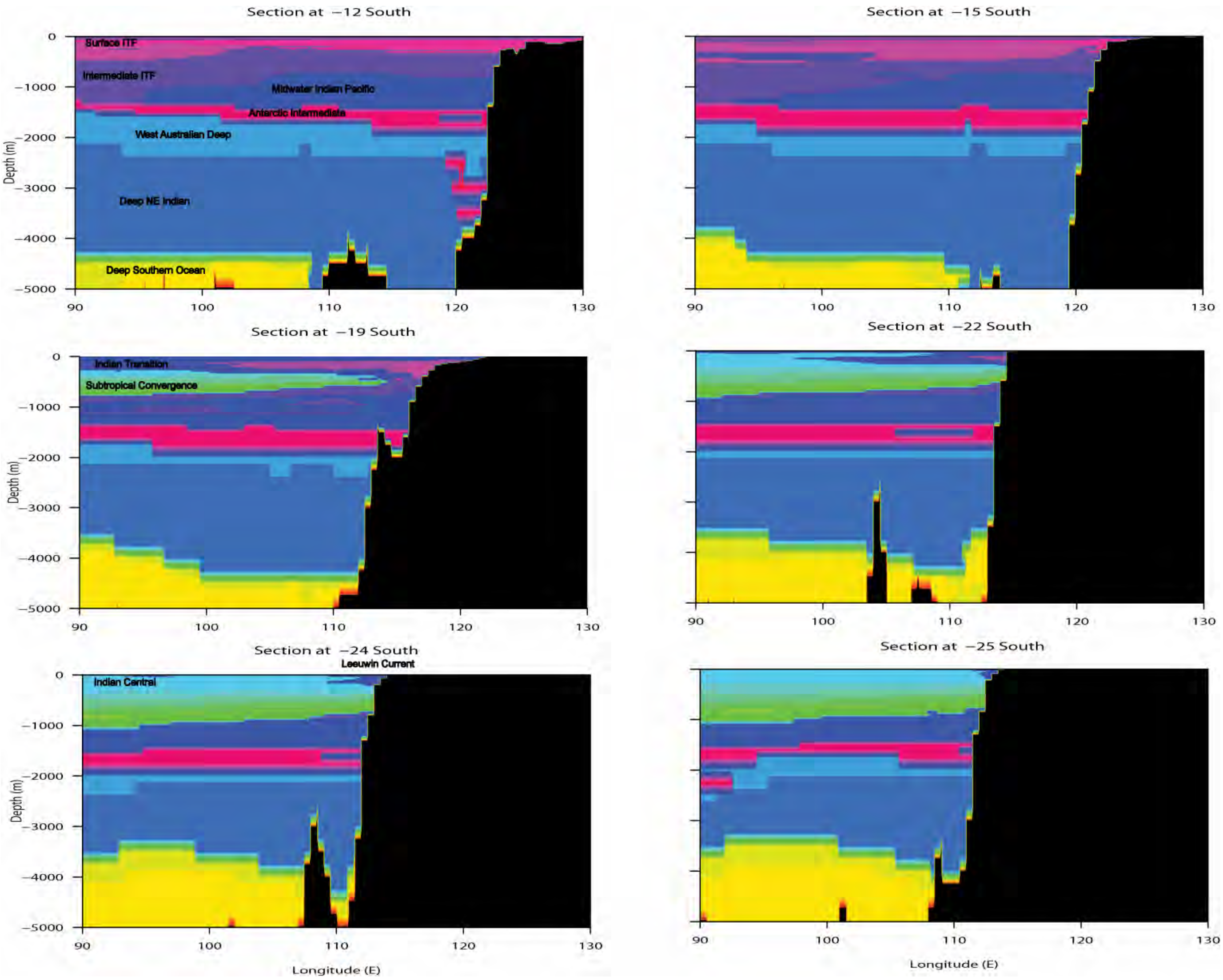

Figure 5-4 Water mass profiles from six sections across the NWMR to 5000 m depth. These were produced from data located at the cross-region transects shown in Figure 5-3. The unnamed water masses can be identified from the named water masses of the same colour and similar position.

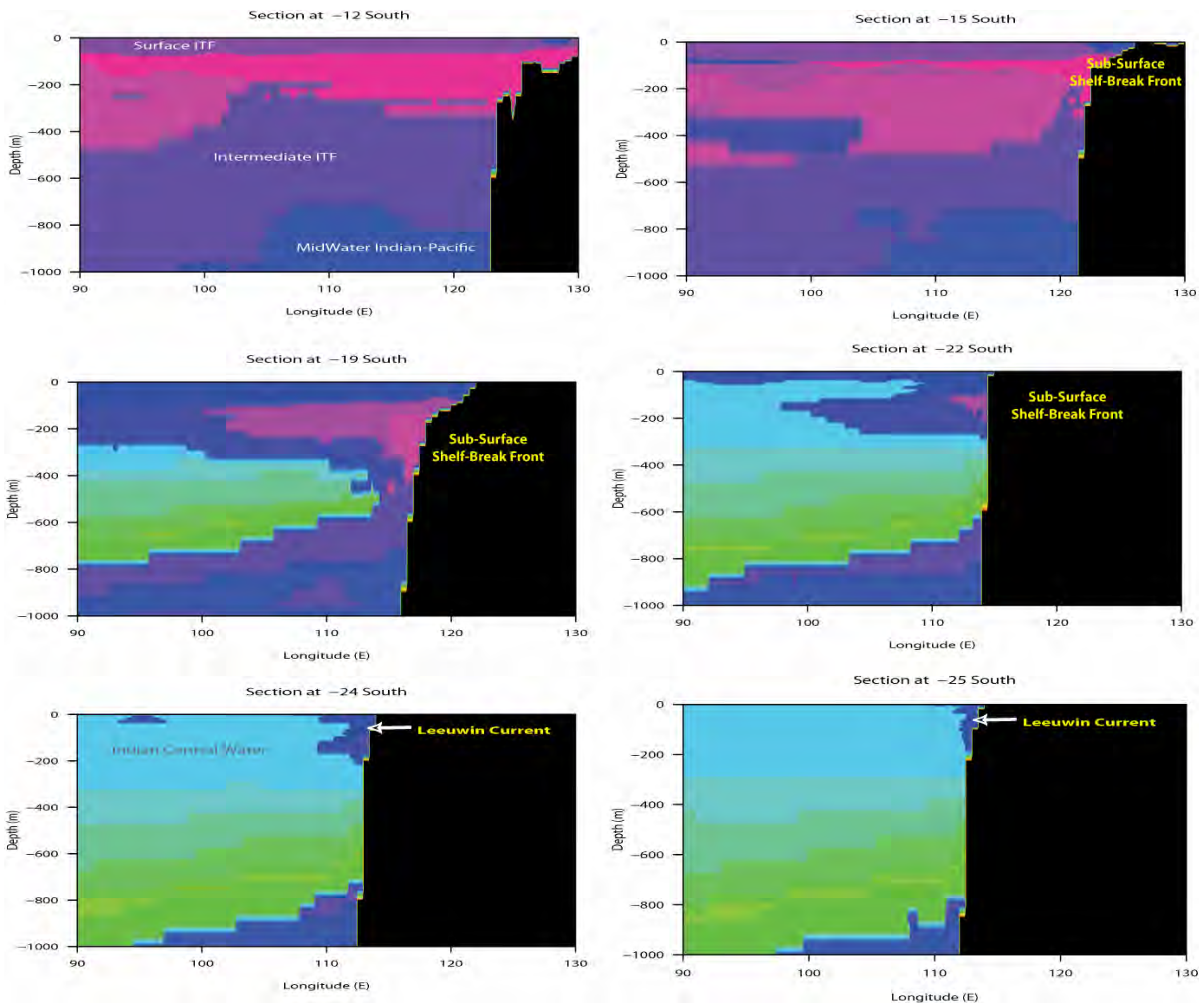

Figure 5-5 Water mass profiles from six sections across the NWMR to 1000 m depth. These were produced from data located at the cross-region transects shown in Figure 5-3. Water masses are labelled on Figure 5-4

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

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

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

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

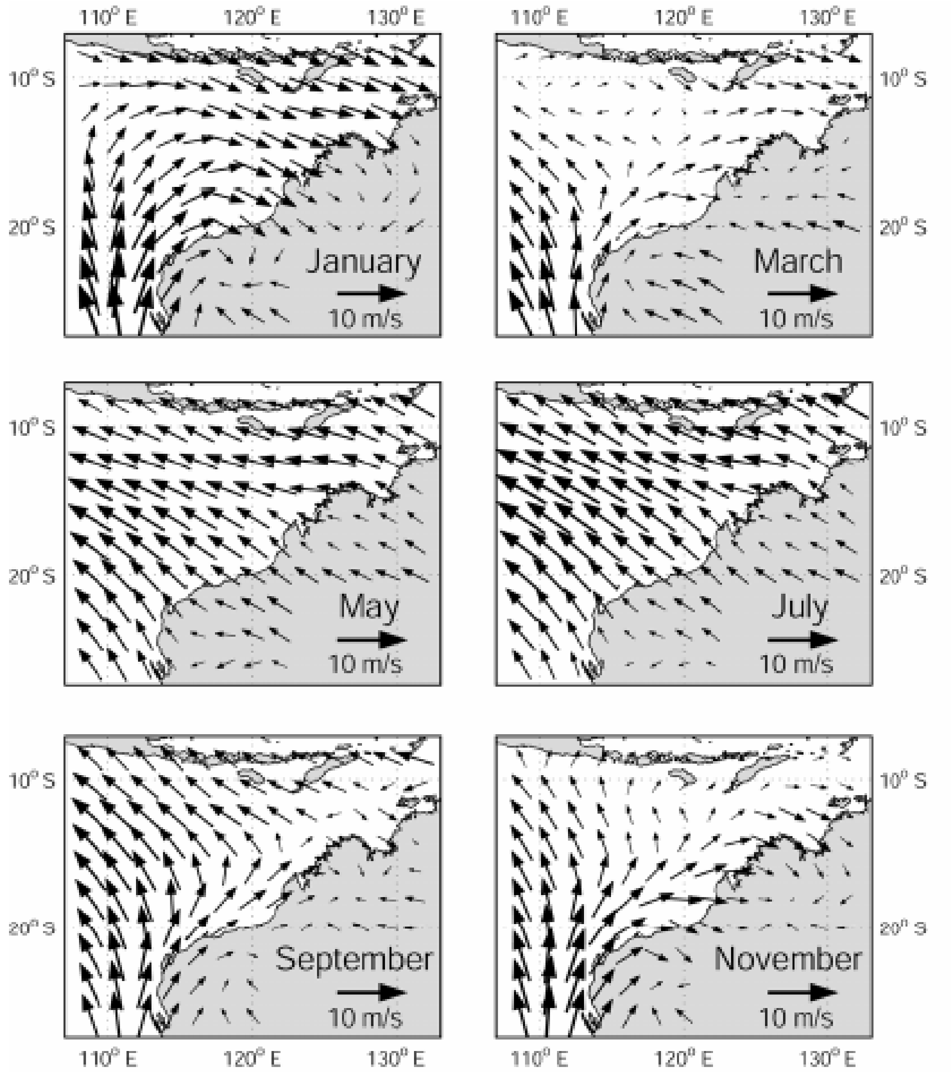

Figure 5-6 Seasonally averaged winds in the North West Marine Region at a height of 10 m above mean sea level during January, March, May, July, September, and November. These fields were calculated by vector averaging the 12 hourly outputs of the NCEP-NCAR re-analysis dataset across the years 1982 to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

Level 3. Regional scale trophic systems of the NWMR

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

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

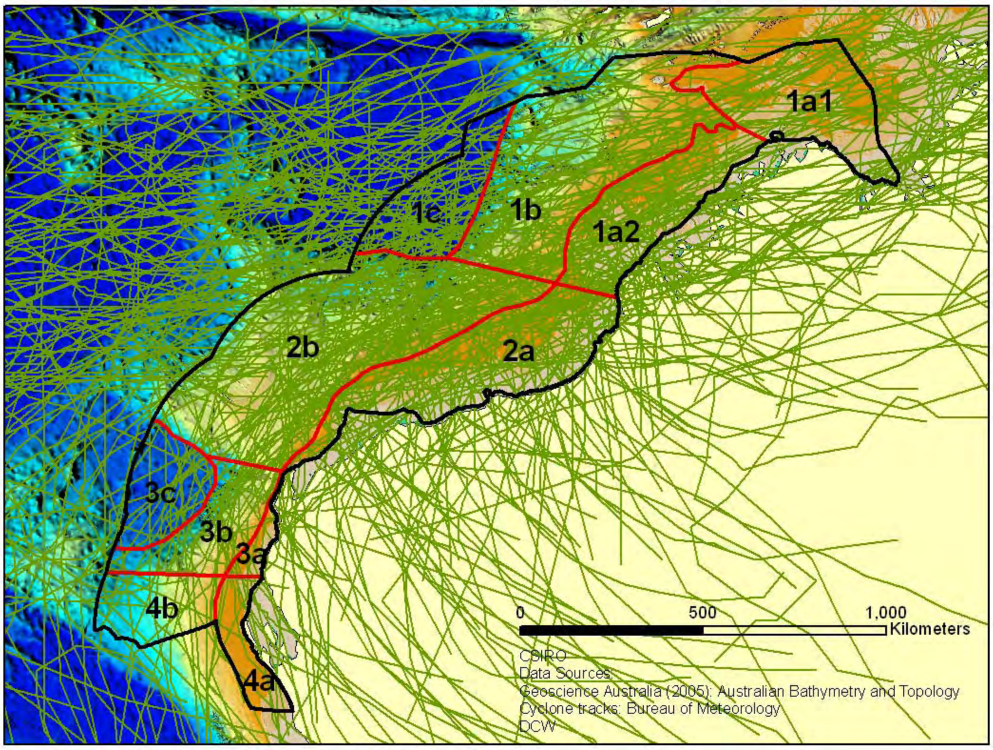

Figure 5-7 Cyclone tracks (1906-2000) for the North West Marine Region Data derived from Bureau of Meteorology cyclone data.

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

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

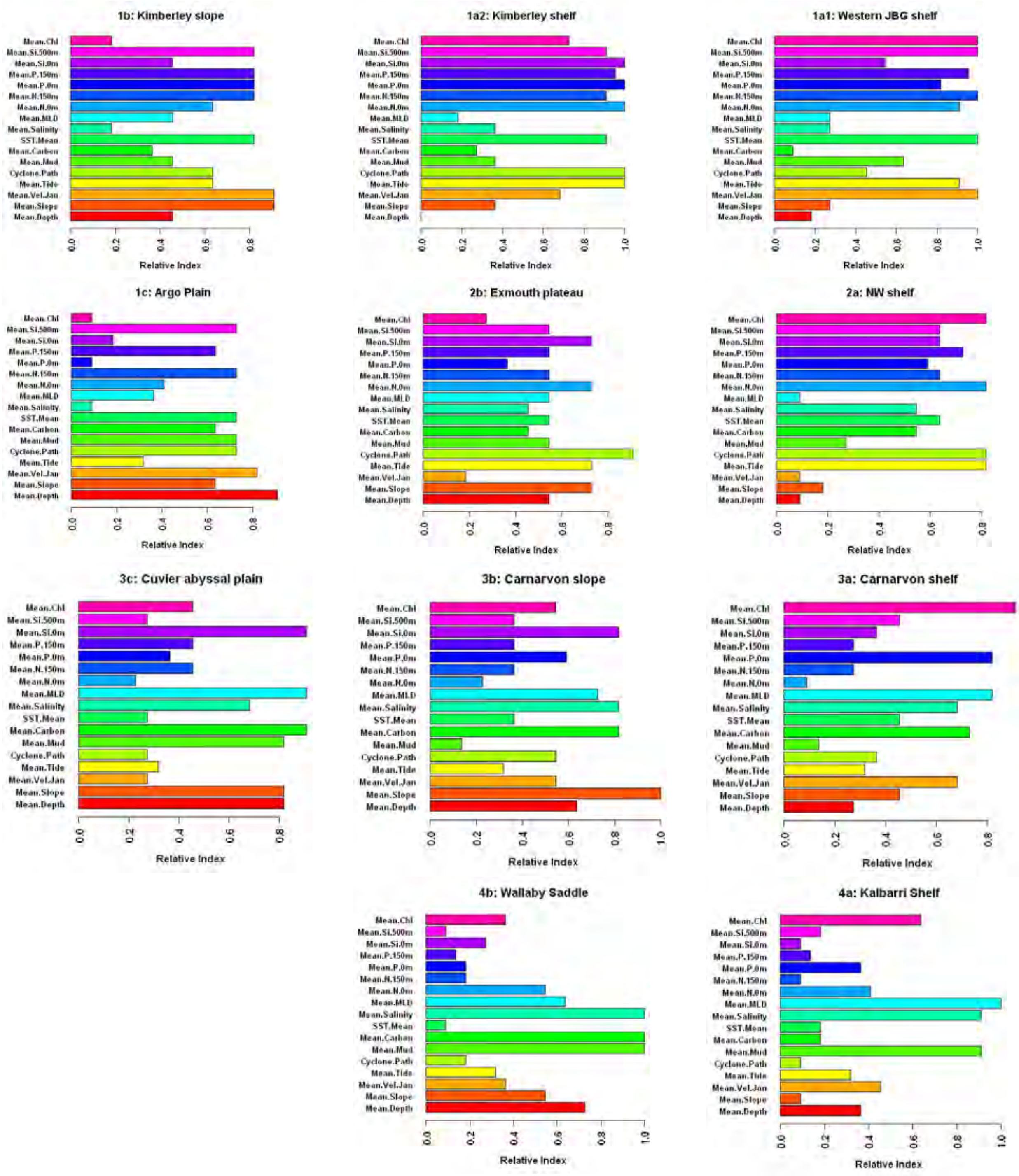

Figure 5-8 Histograms showing relative levels for 16 different physical parameters for each of the 11 sub-regions of the NWMR. Parameters are mean surface chlorophyll, mean silicate concentration at 500 m, mean silicate at the surface (0 m), mean phosphorous at 150 m, mean phosphorous at the surface,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

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

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

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

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

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

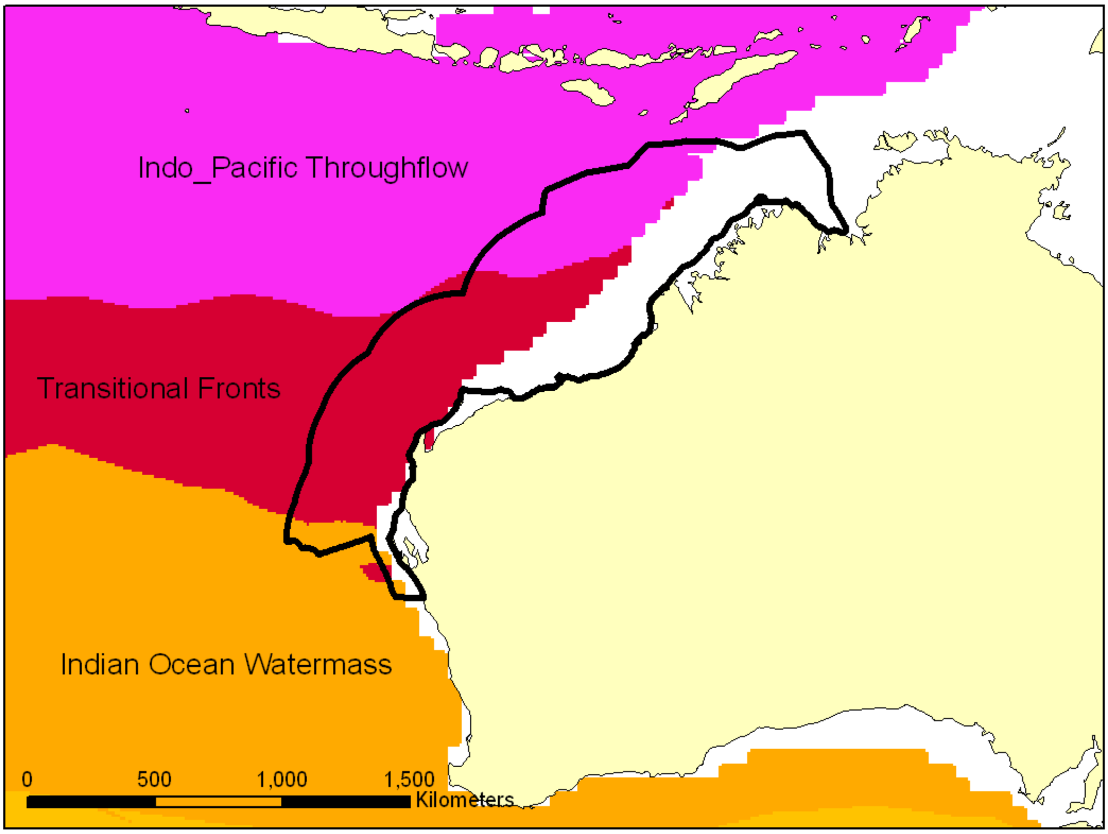

Figure 5-9 Location of major surface watermasses (excluding shelf waters) off Western Australia (from Lyne *et al*., 2006).

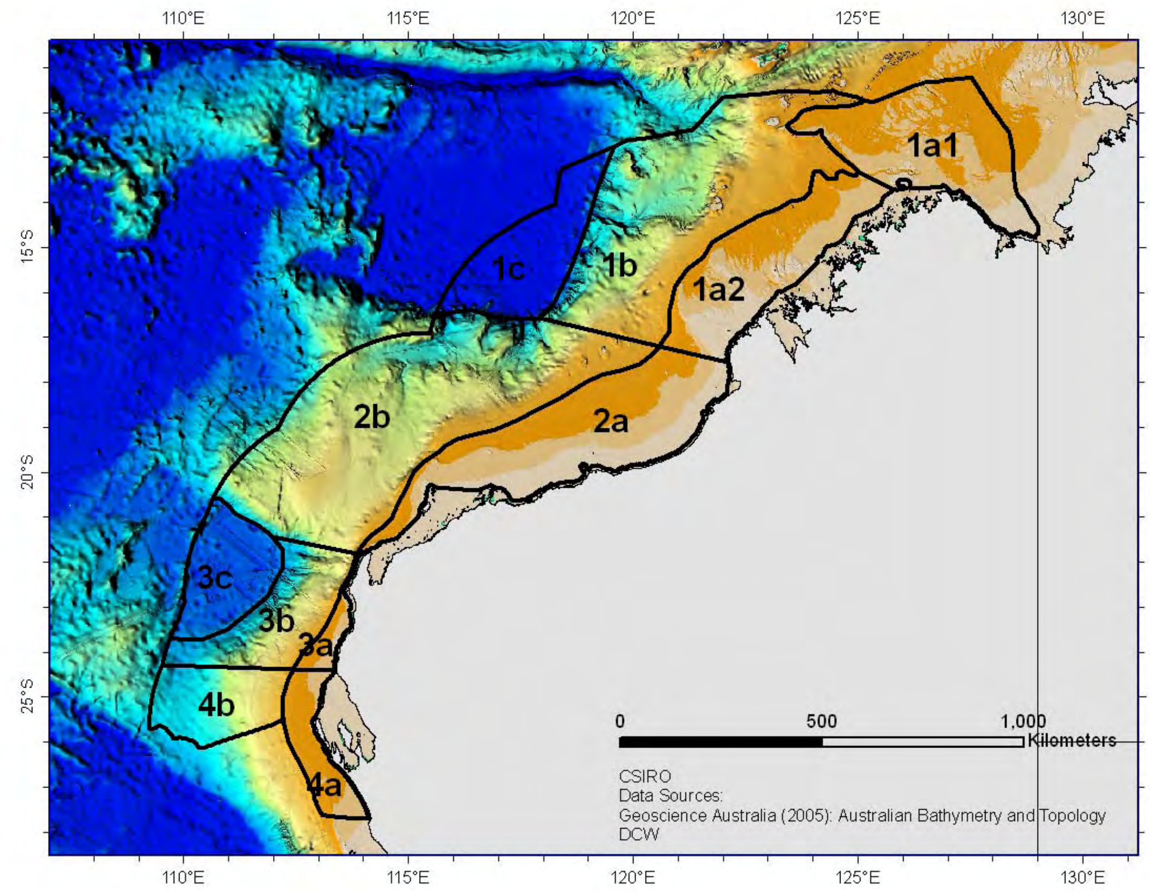

Figure 5-10 Map of North West Marine Region with location of major trophic systems. See Table 5-1 for sub-region names.

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

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

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

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

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

5.3 Comparison with IMCRA provincial regionalisation

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

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

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

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

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

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

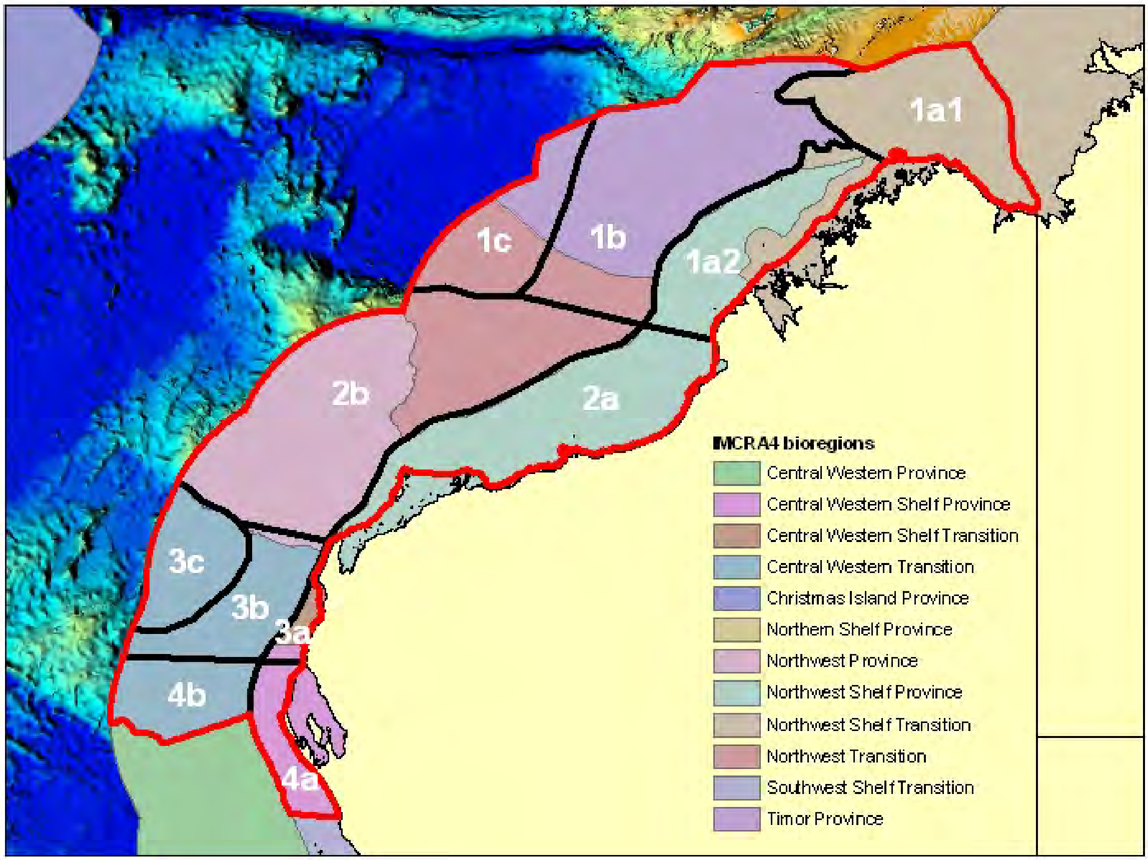

Figure 5-11 Map of North West Marine Region (heavy red line) with location of major trophic systems (heavy black lines with alpha numeric labels) and IMCRA4 bioregions (pastel zones associated with Figure legend).