6.6 Exmouth Plateau (2b)

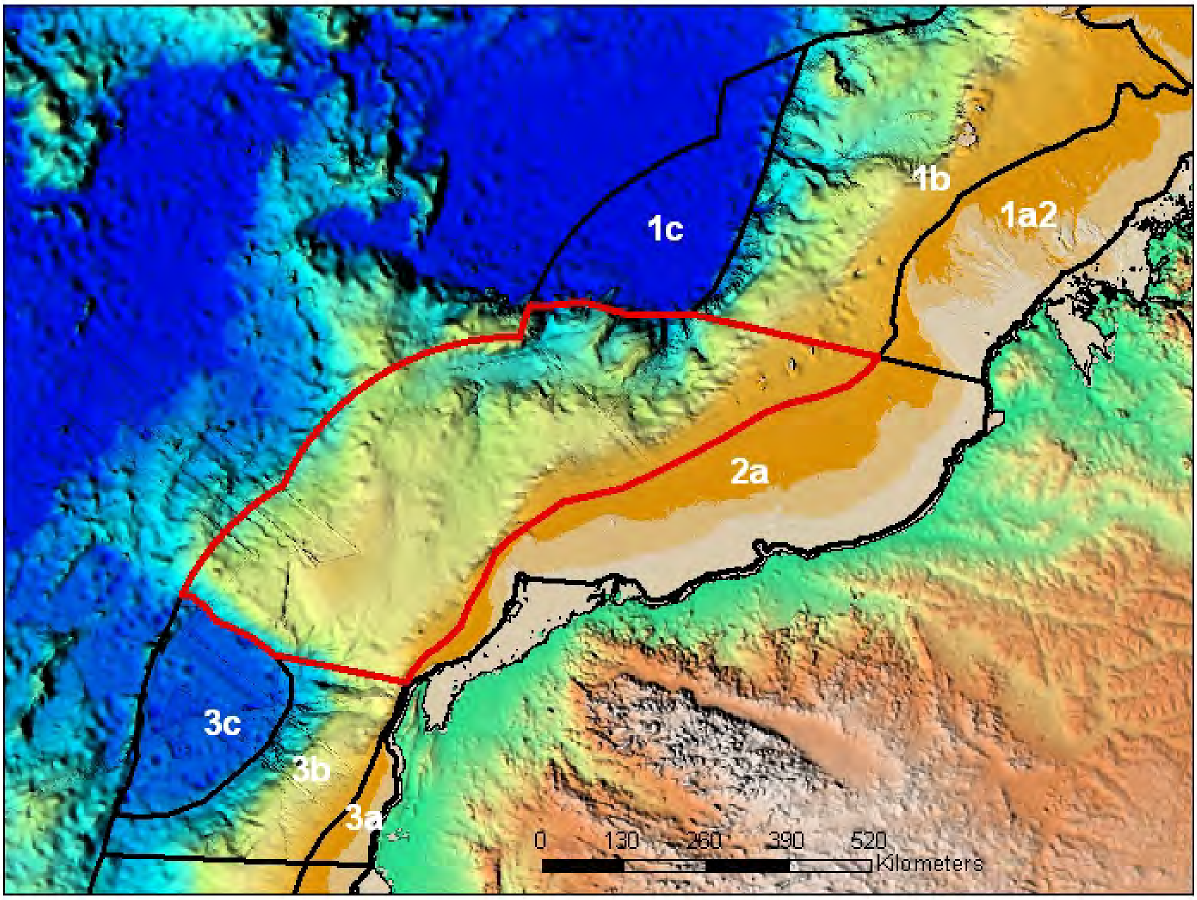


Figure 6-30 Exmouth Plateau (red outline) and neighbouring sub-regions.

6.6.1 Drivers and physical features

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

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

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

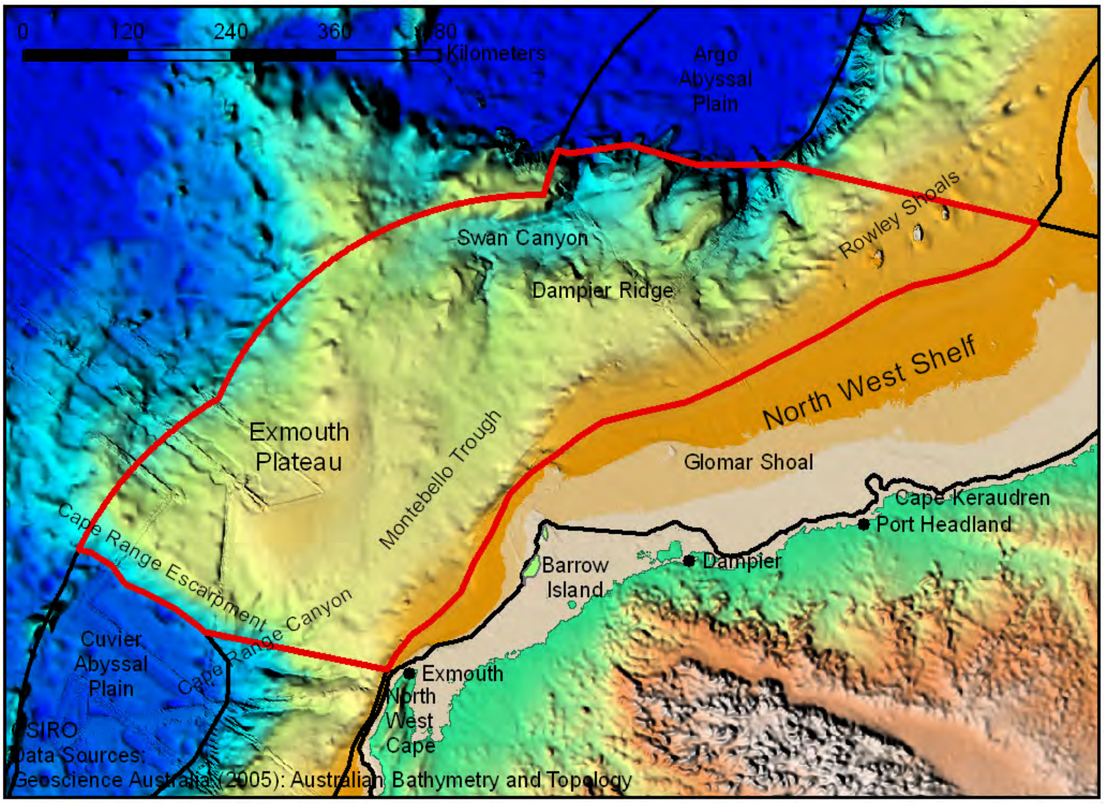
The upper slope varies in width. It is narrow and very steep slope to the north of Barrow Island/Monte Bello and wider and less steeply inclined immediately to the north.

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

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

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

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



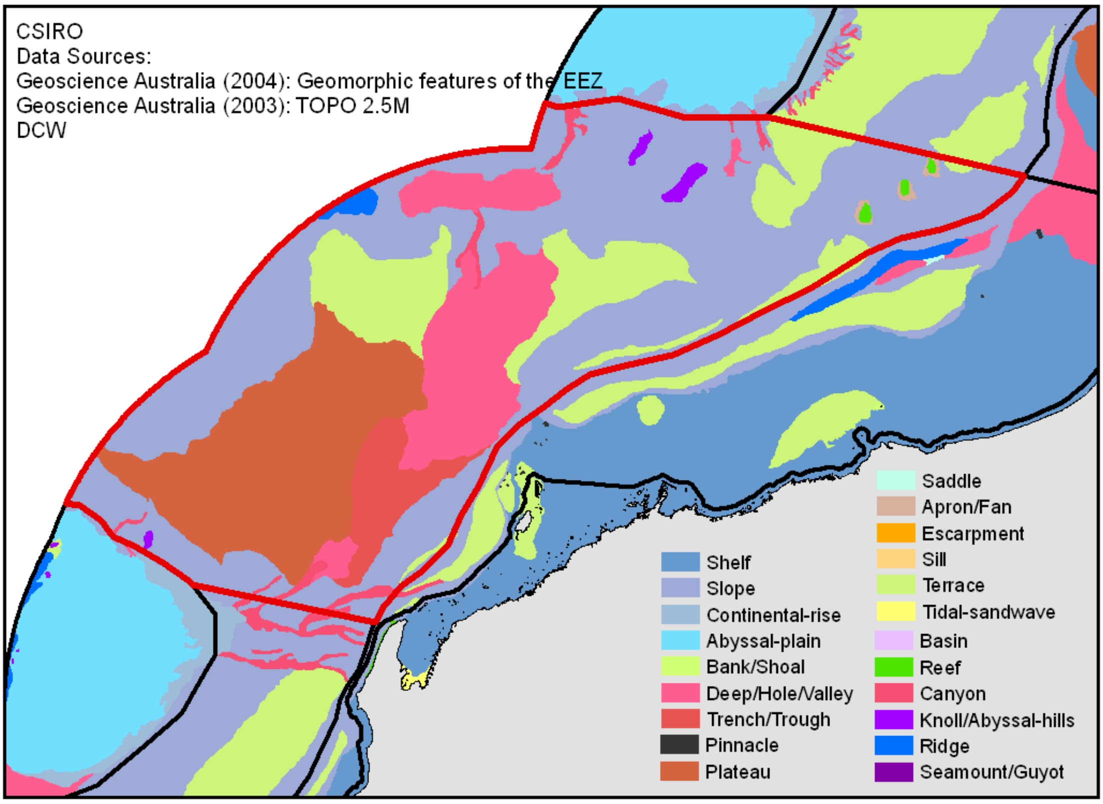


Figure 6-31 Exmouth Plateau sub-region showing selected features (upper) and geomorphology (lower).

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

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

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

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

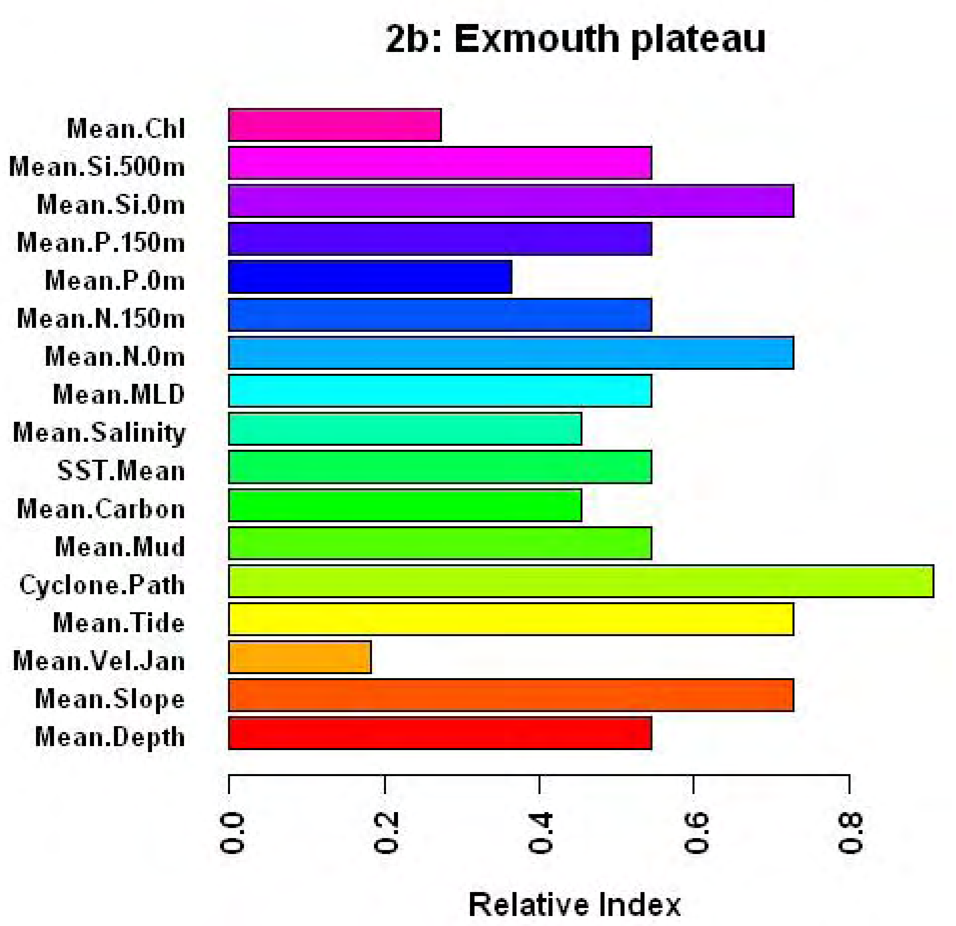


Figure 6-32 Summary physical data for the Exmouth Plateau sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

6.6.2 Trophic system features and dynamics

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

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

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

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

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

6.6.3 Services and linkages

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

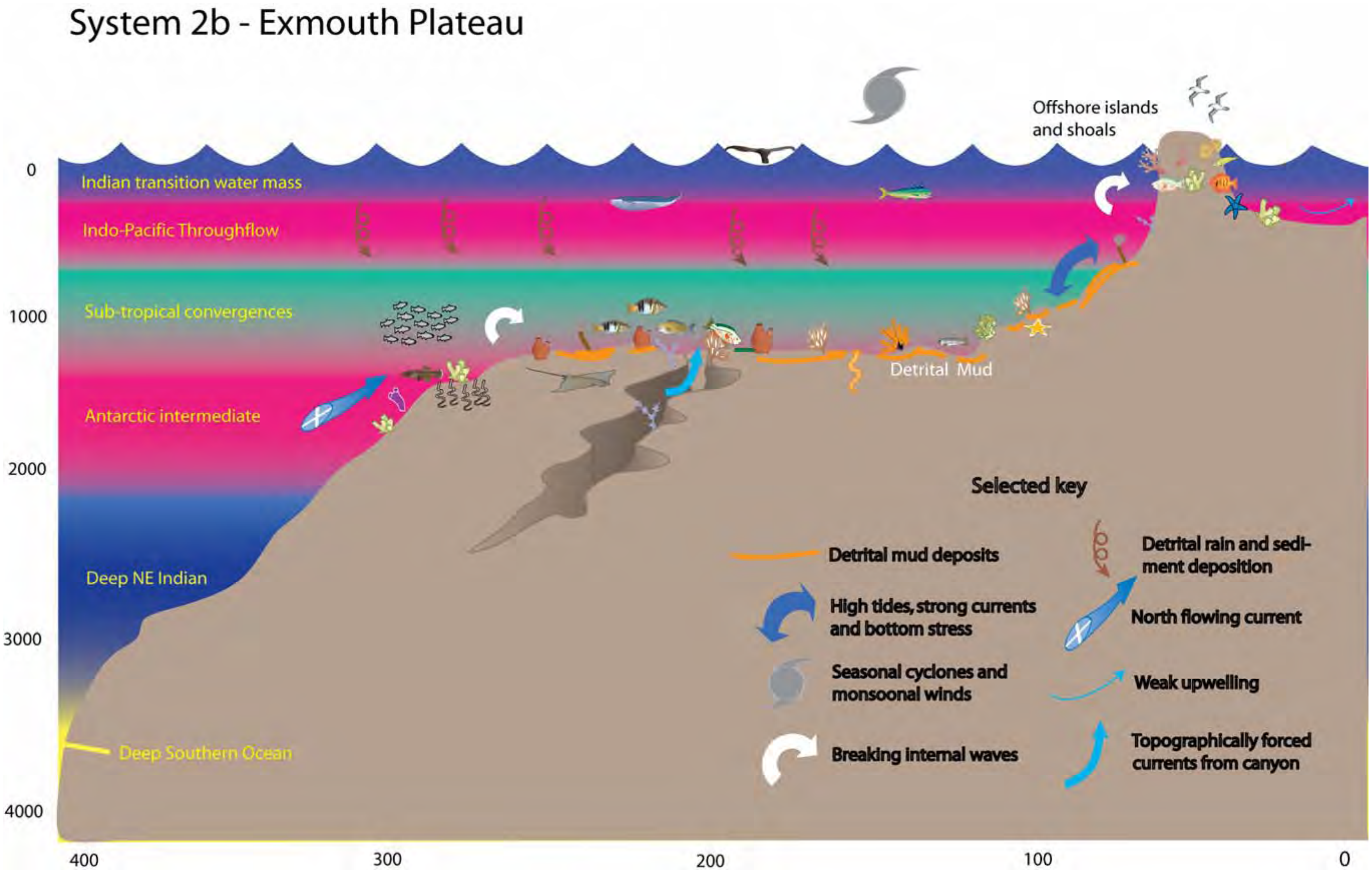


Figure 6-33 Habitat diagram of the Exmouth Plateau sub-region showing selected important drivers and features. 70-100 m deep chlorophyll maxima not shown.

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

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

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

6.6.4 Key species interactions

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

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

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

6.6.5 Resilience and vulnerability

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

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

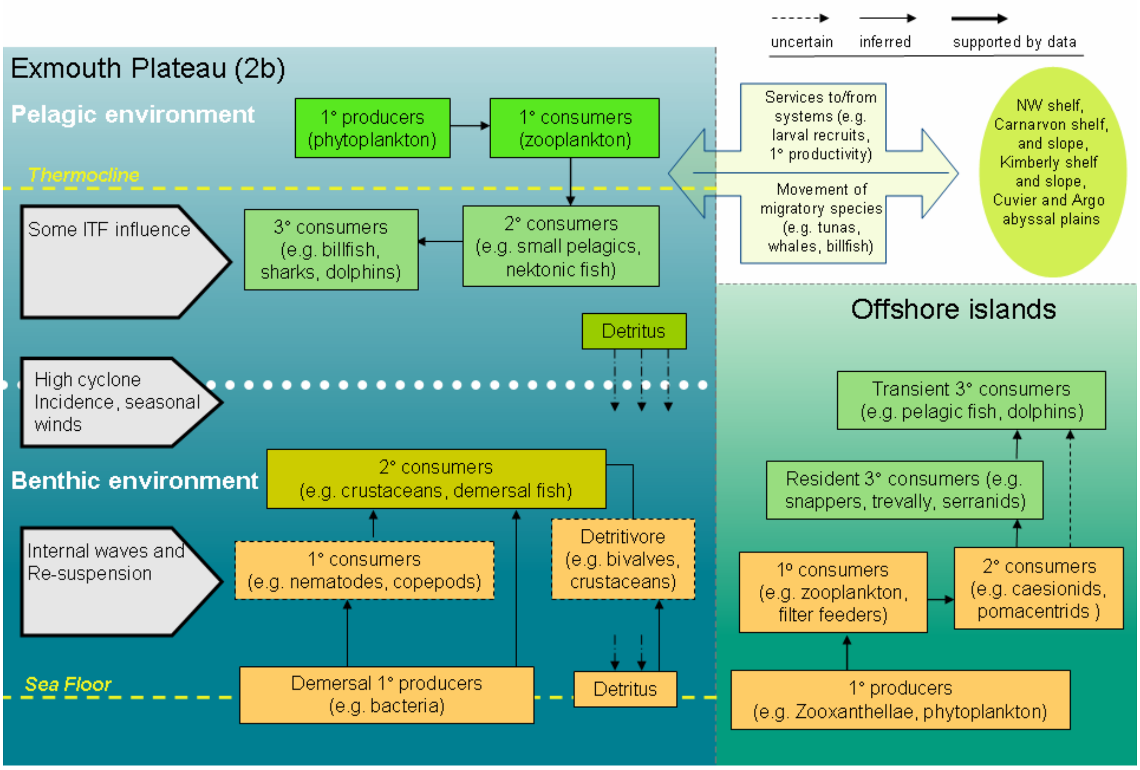


Figure 6-34 Conceptual trophic model of the Exmouth Plateau sub-region showing information on the extensive mid-slope habitats (left) and the less extensive but important offshore island habitats (right).

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

6.6.6 Information gaps

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

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

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

6.7 Carnarvon Shelf (3a)

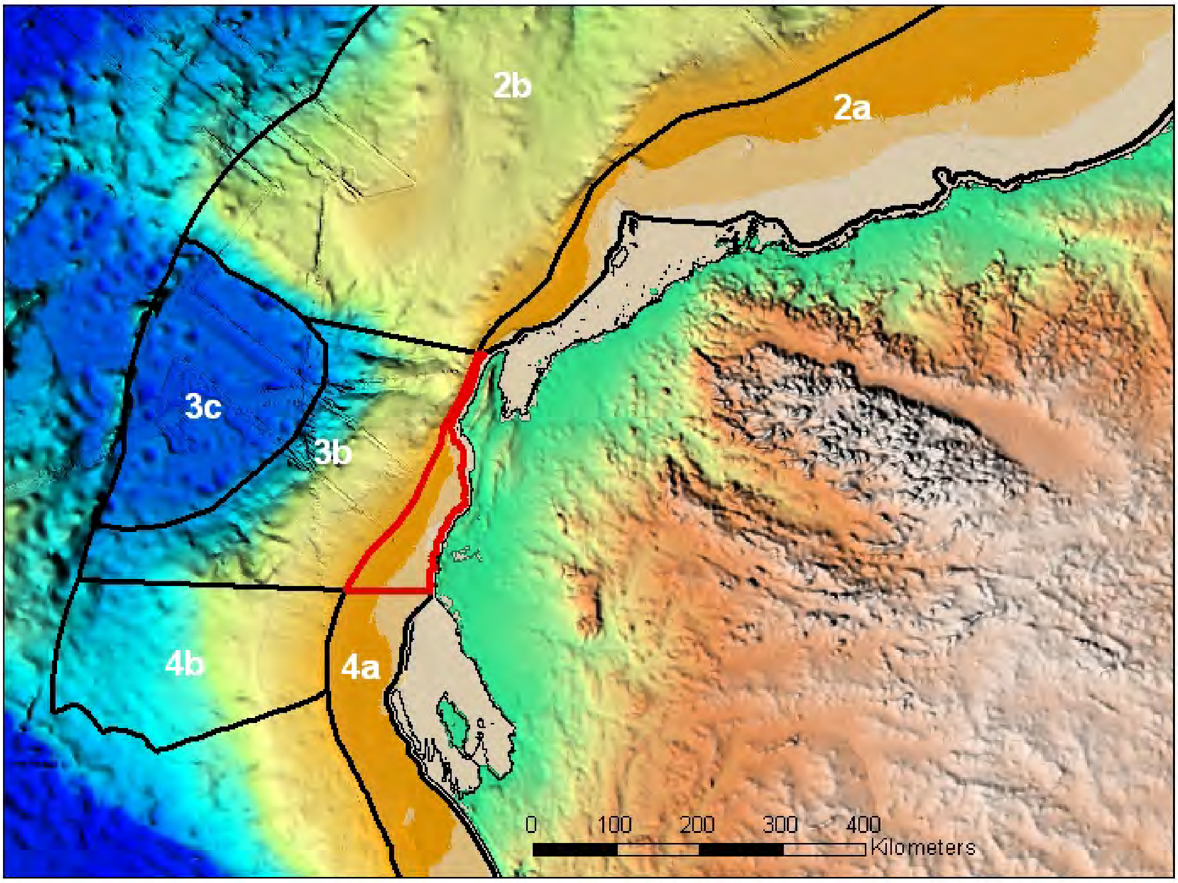


Figure 6-35 Carnarvon Shelf (red outline) and neighbouring sub-regions.

6.7.1 Drivers and physical features

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

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

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

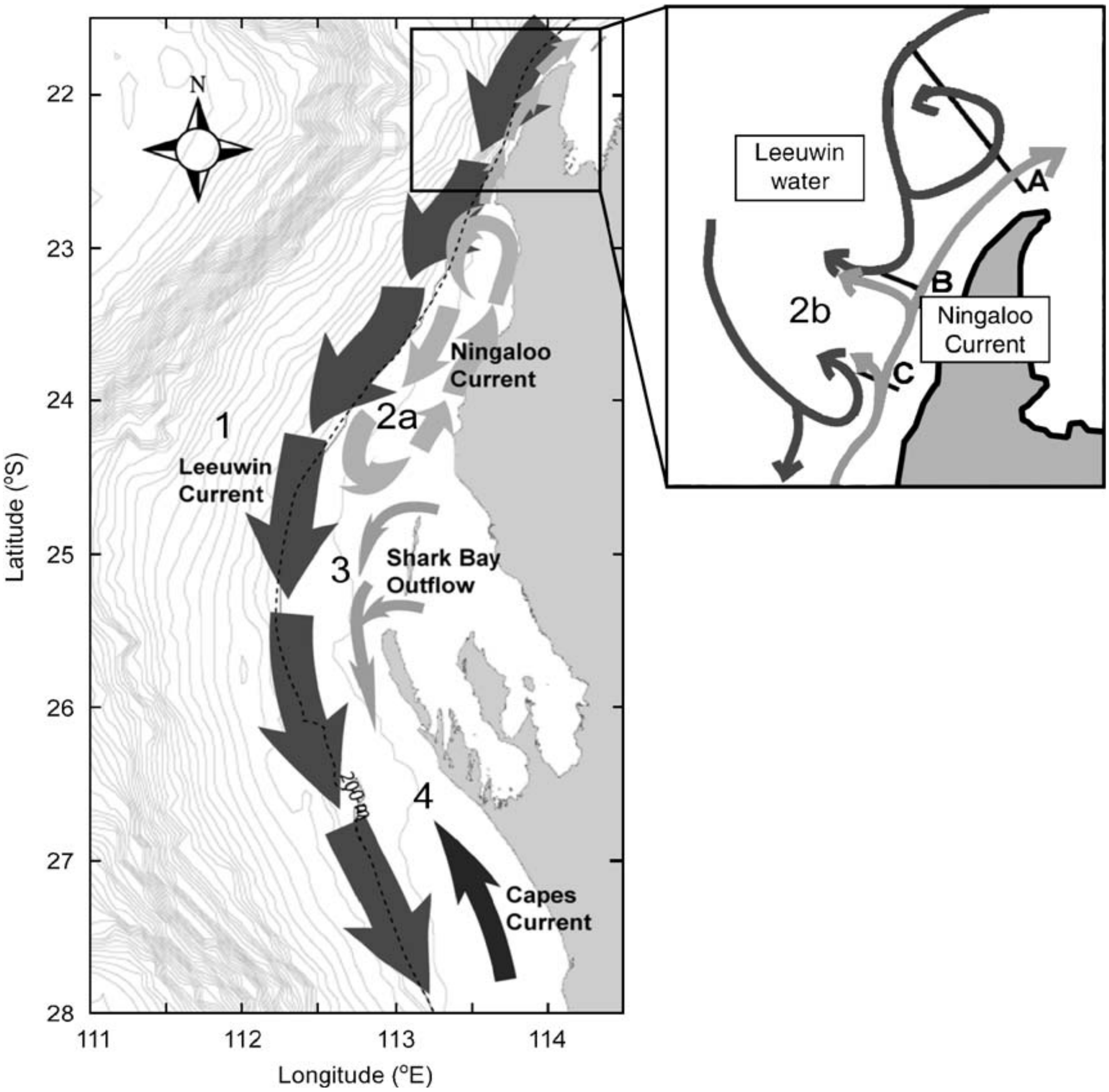
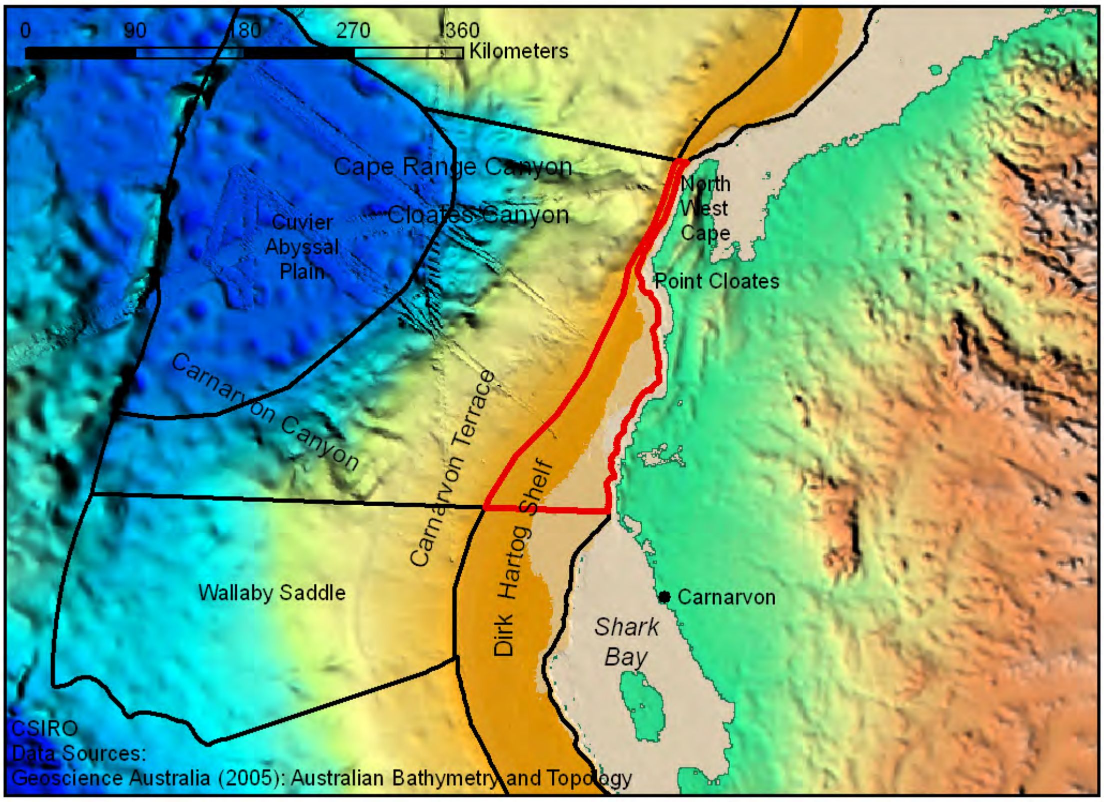


Figure 6-36 Relative positions of the Leeuwin, Ningaloo and Capes Currents, and the Shark Bay Outflow, in the region of the West Australian coastline between Kalbarri and NW Cape (from Hanson *et al.*, 2005).

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



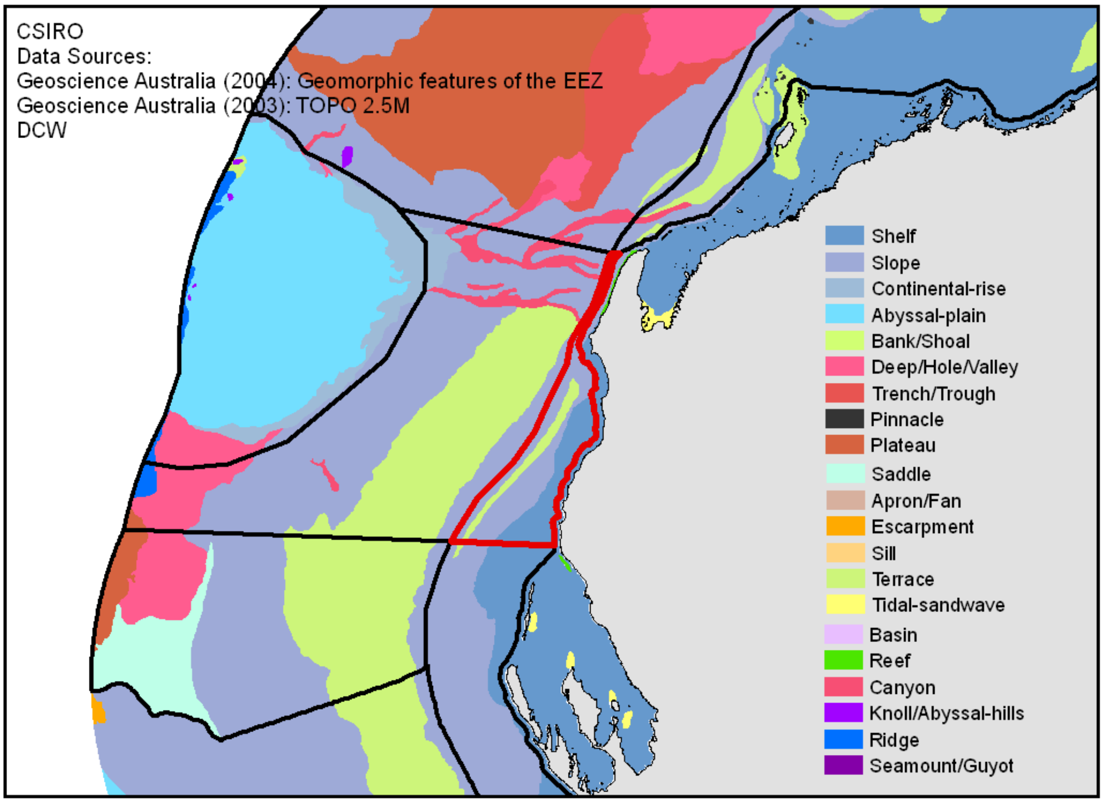


Figure 6-37 Carnarvon Shelf sub-region showing selected features (upper) and geomorphology (lower).

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

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

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

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

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

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

6.7.2 Trophic system features and dynamics

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

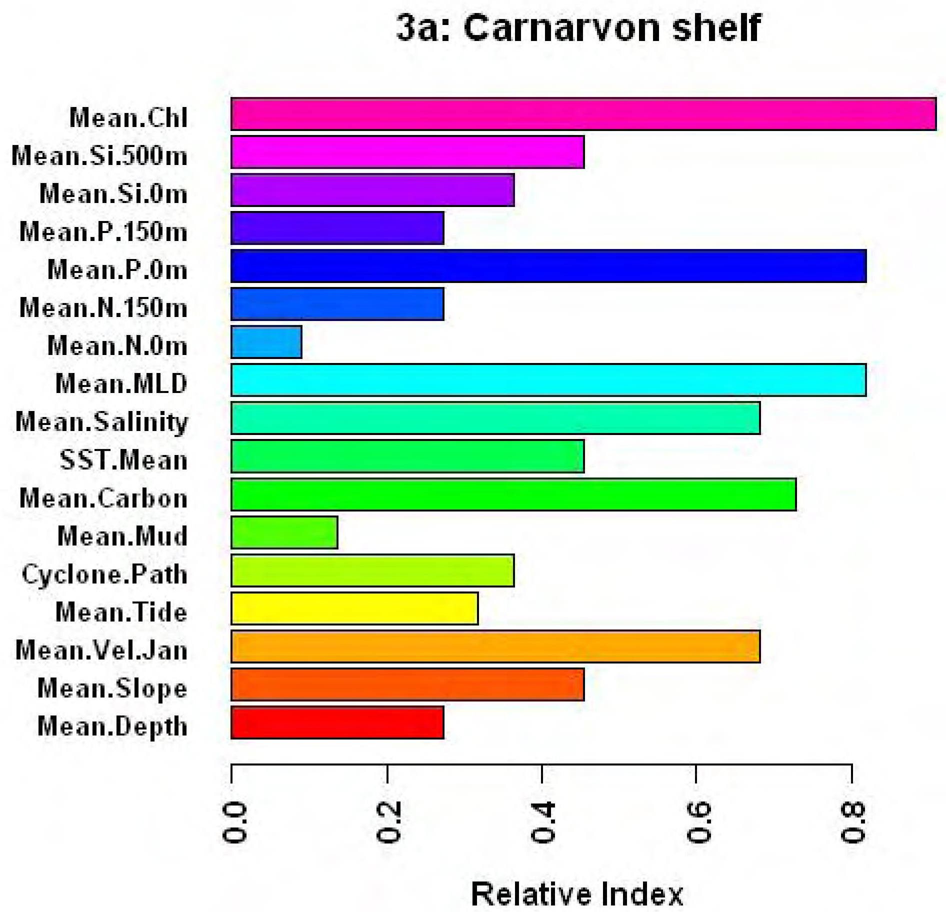


Figure 6-38 Summary physical data for the Carnarvon Shelf sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

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

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

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

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

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

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

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

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

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

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

6.7.3 Services and linkages

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

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

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

6.7.4 Key species interactions

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

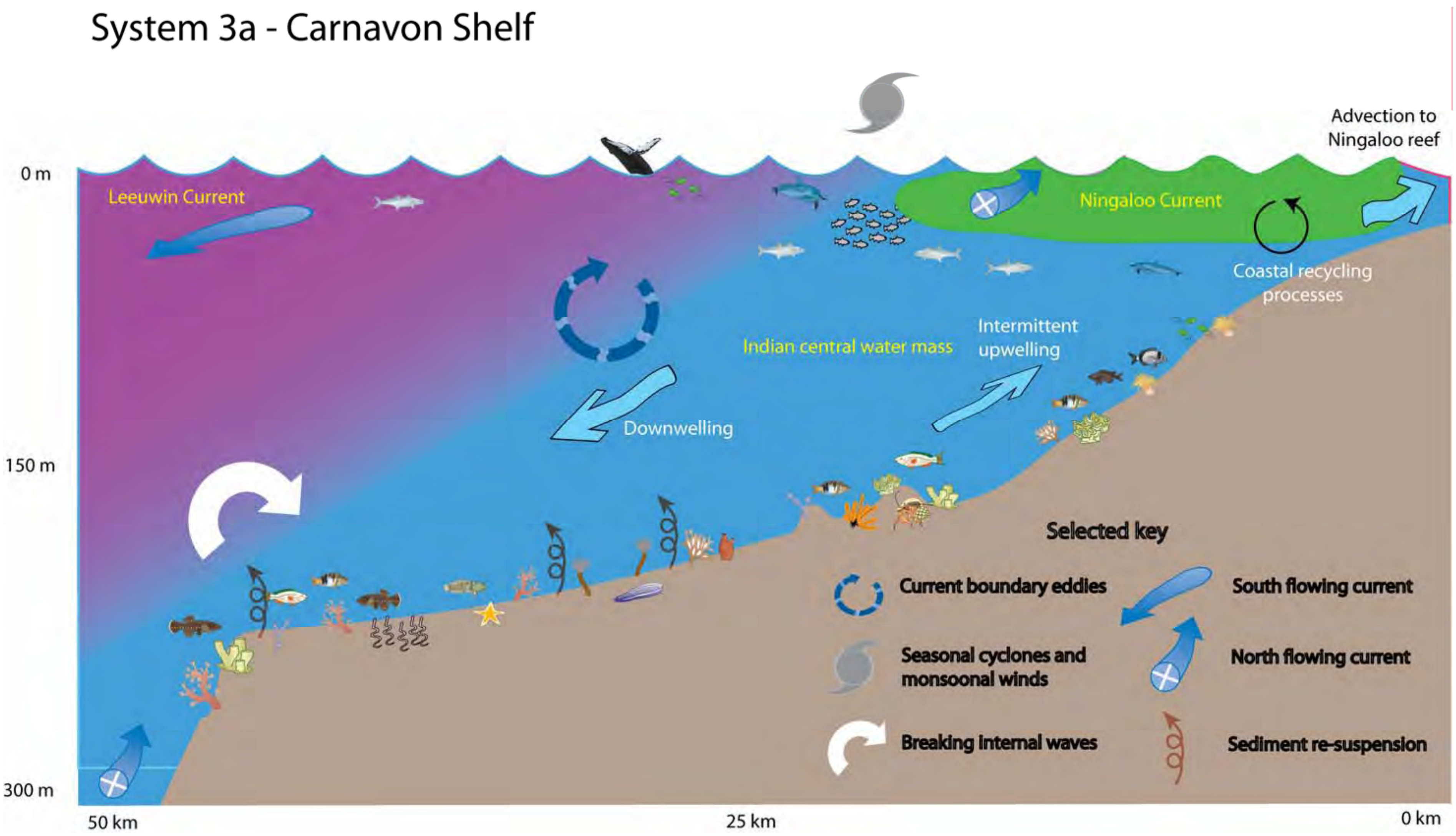


Figure 6-39 Habitat diagram of the Carnarvon Shelf sub-region showing selected important drivers and features.

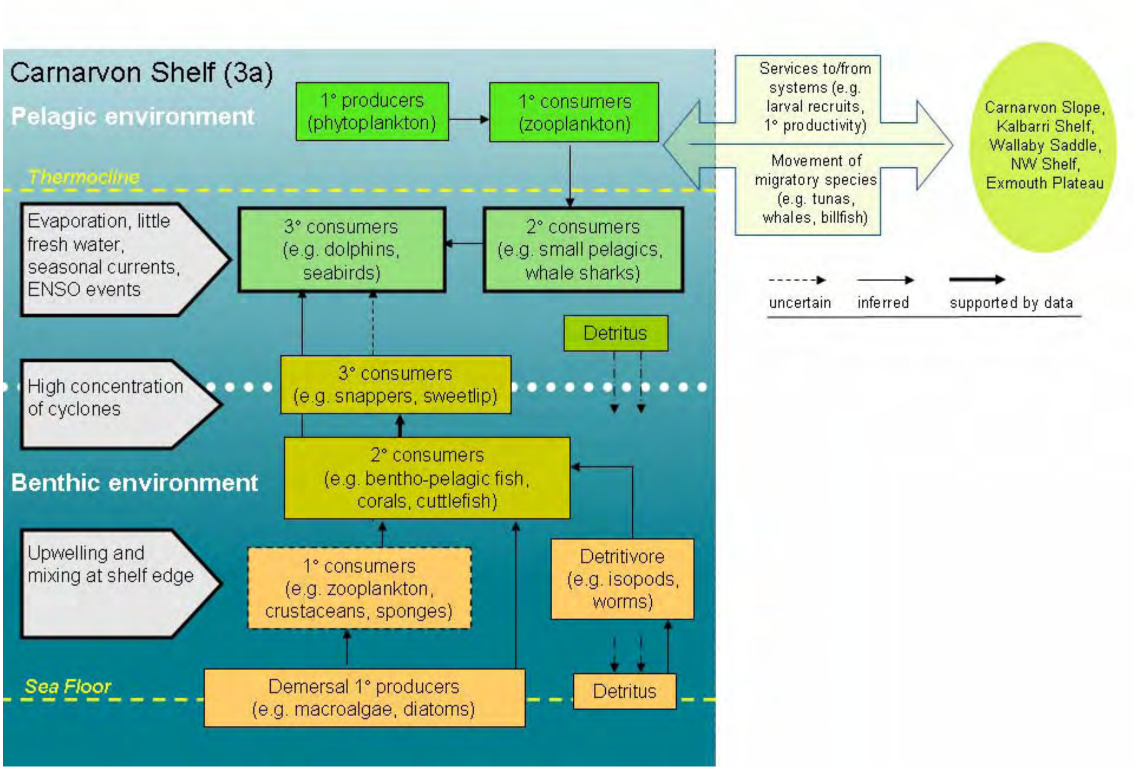


Figure 6-40 Conceptual trophic model of the Carnarvon Shelf sub-region showing information on the main habitat in the mid and inner shelf.

6.7.5 Resilience and vulnerability

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

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

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

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

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

6.7.6 Information gaps

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

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

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

6.8 Carnarvon Slope (3b)

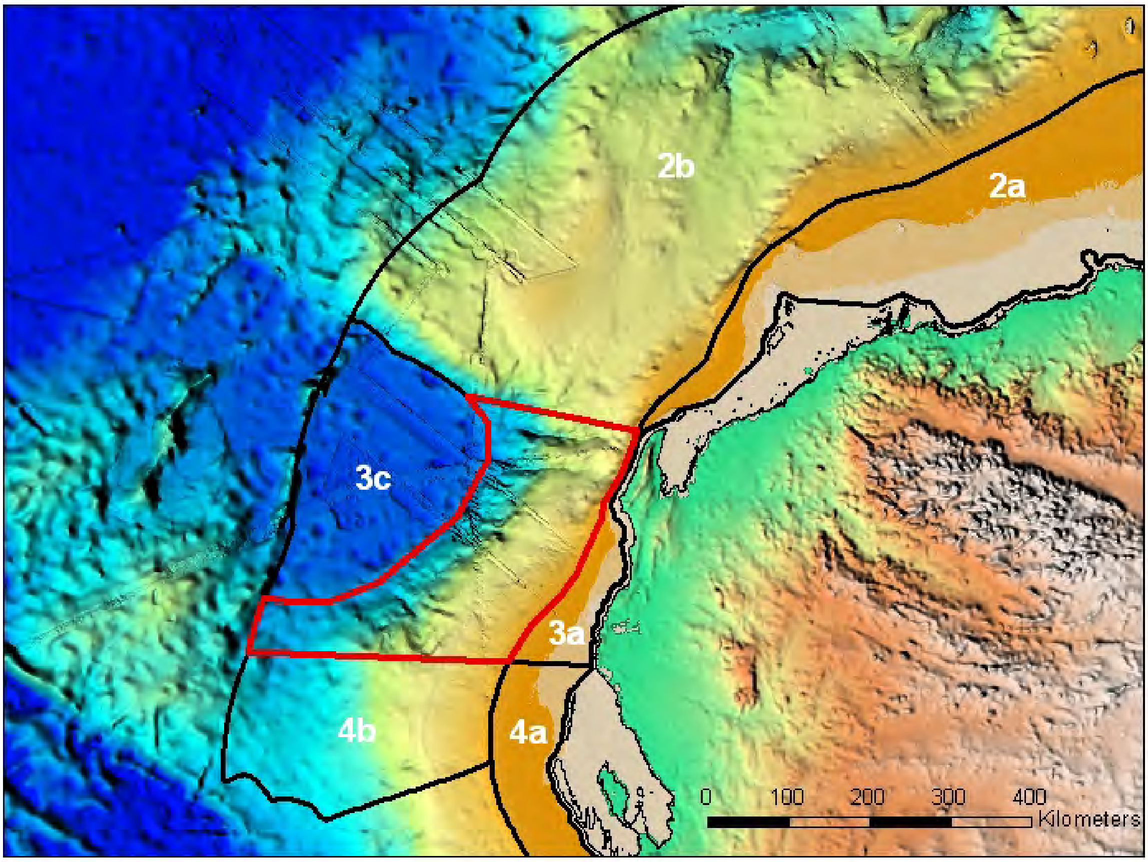


Figure 6-41 Carnarvon Slope (red outline) and neighbouring sub-regions.

6.8.1 Drivers and physical features

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

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

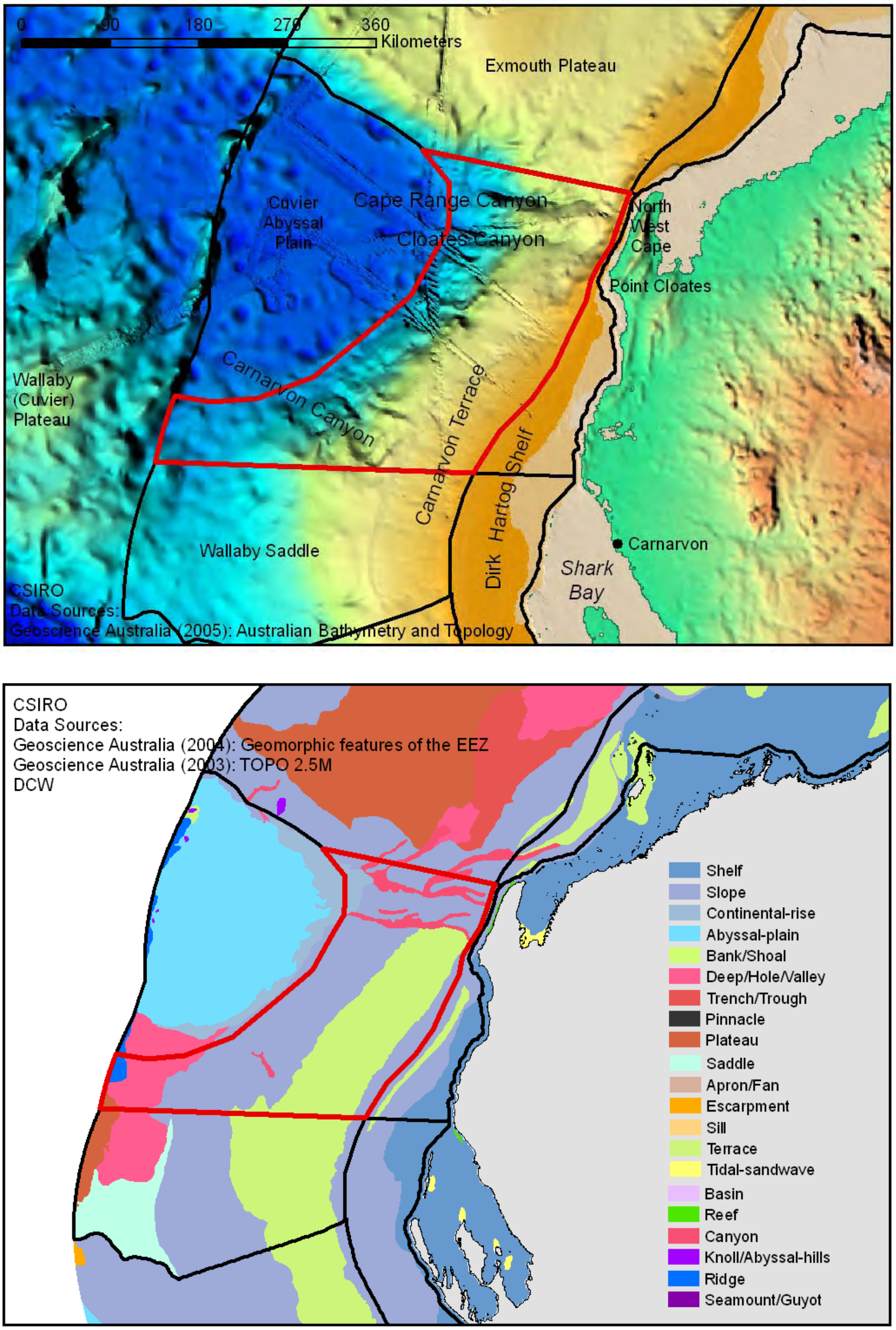


Figure 6-42 Carnarvon Slope sub-region showing selected features (upper) and geomorphology (lower).

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

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

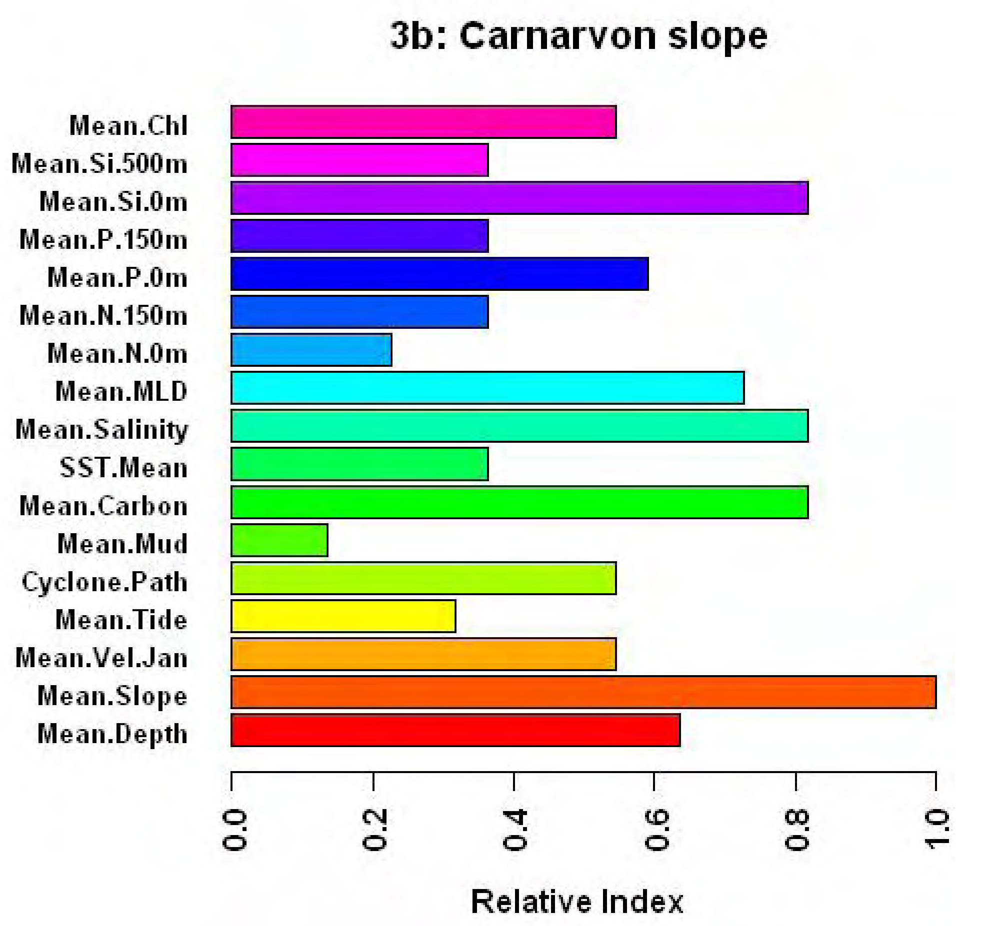


Figure 6-43 Summary physical data for the Carnarvon Slope sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

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

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

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

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

6.8.2 Trophic system features and dynamics

Pelagic environments

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

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

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

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

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

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

Benthic environments

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

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

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

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

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

6.8.3 Services and Linkages

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

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

6.8.4 Key species interactions

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

6.8.5 Resilience and vulnerability

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

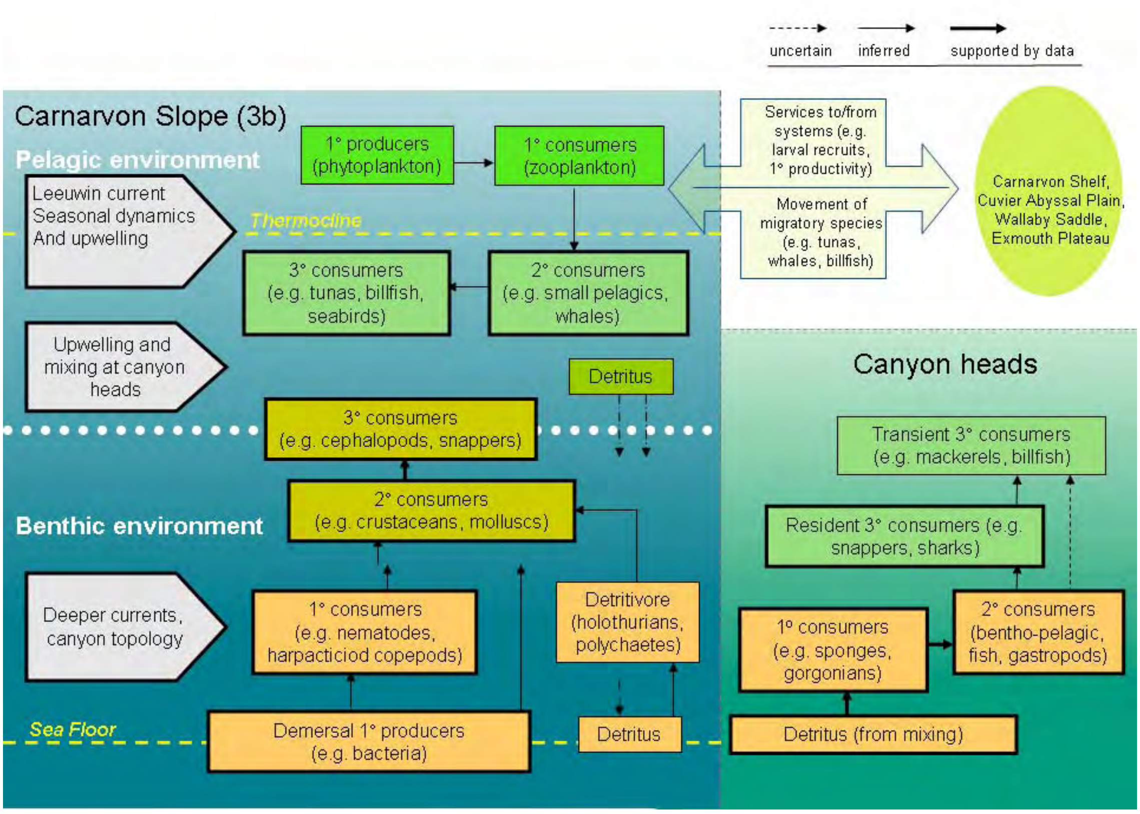


Figure 6-44 Conceptual diagram of the Carnarvon Slope sub-region showing information on the extensive mid and upper slope habitats (left) and the less extensive but important canyon head habitats (right).

6.8.6 Information gaps

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

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

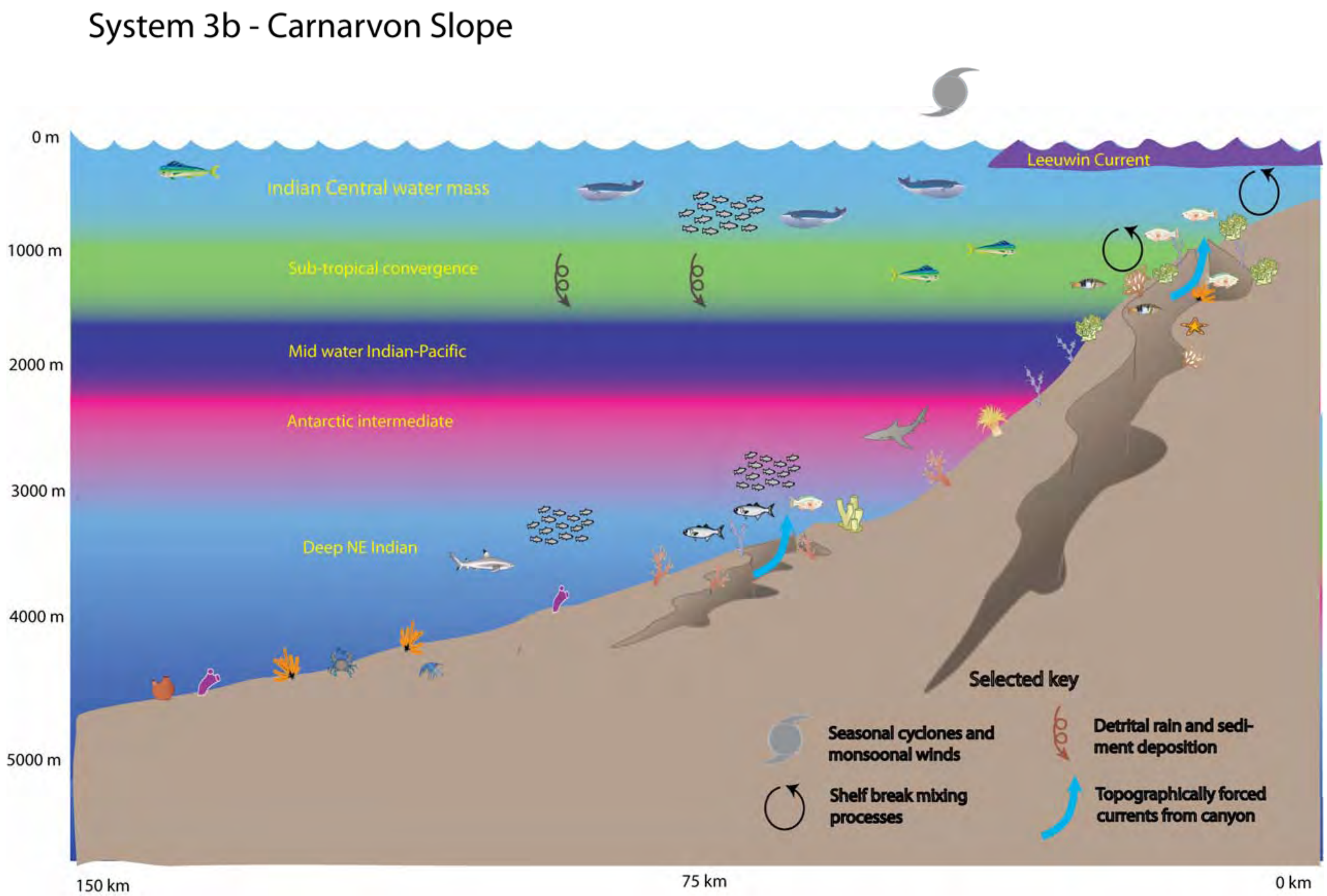


Figure 6-45 Habitat diagram of the Carnarvon Slope sub-region showing selected important drivers and features. 70-100 m deep chlorophyll maxima not shown.

6.9 Cuvier Abyssal Plain (3c)

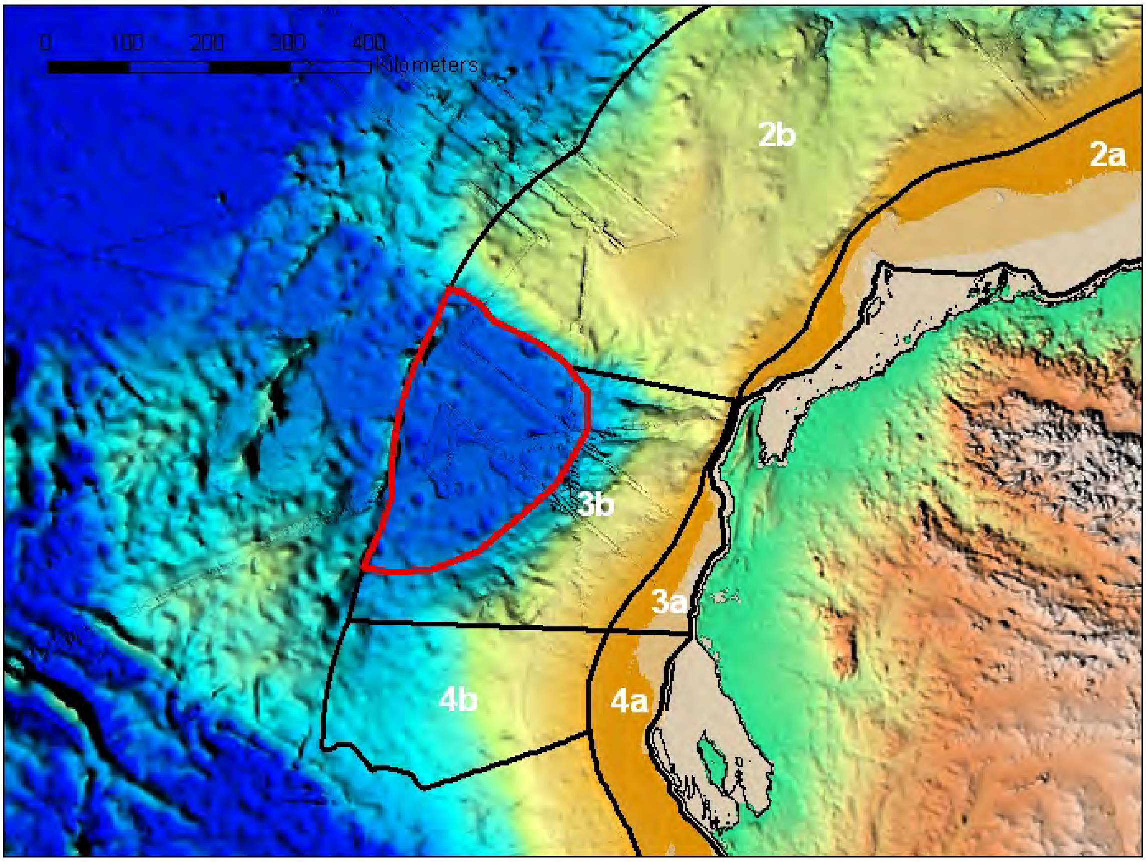


Figure 6-46 Cuvier Abyssal Plain (red outline) and neighbouring sub-regions.

6.9.1 Drivers and physical features

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

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

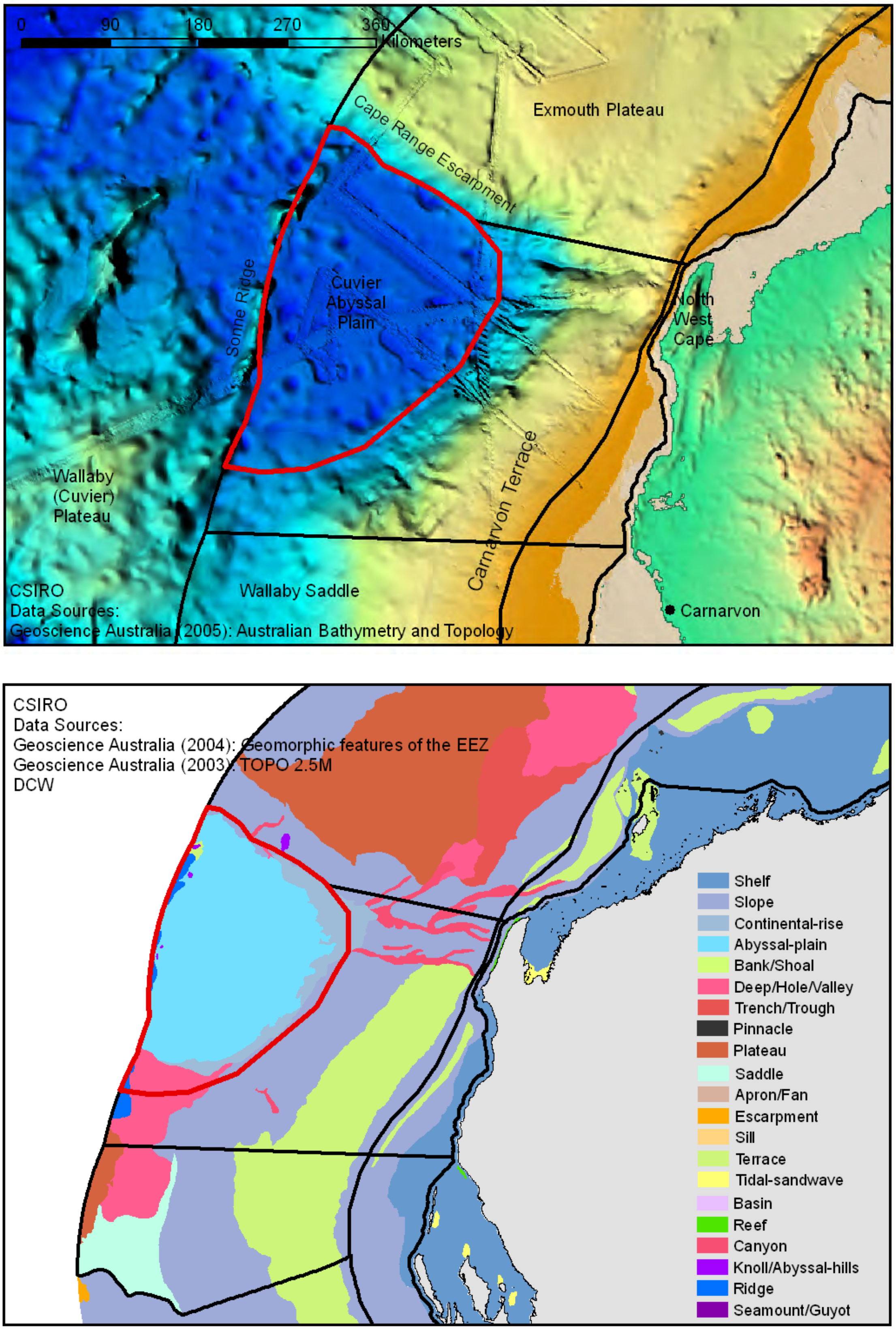


Figure 6-47 Cuvier Abyssal Plain sub-region showing selected features (upper) and geomorphology (lower).

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

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

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

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

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

6.9.2 Trophic system features and dynamics

Pelagic environments

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

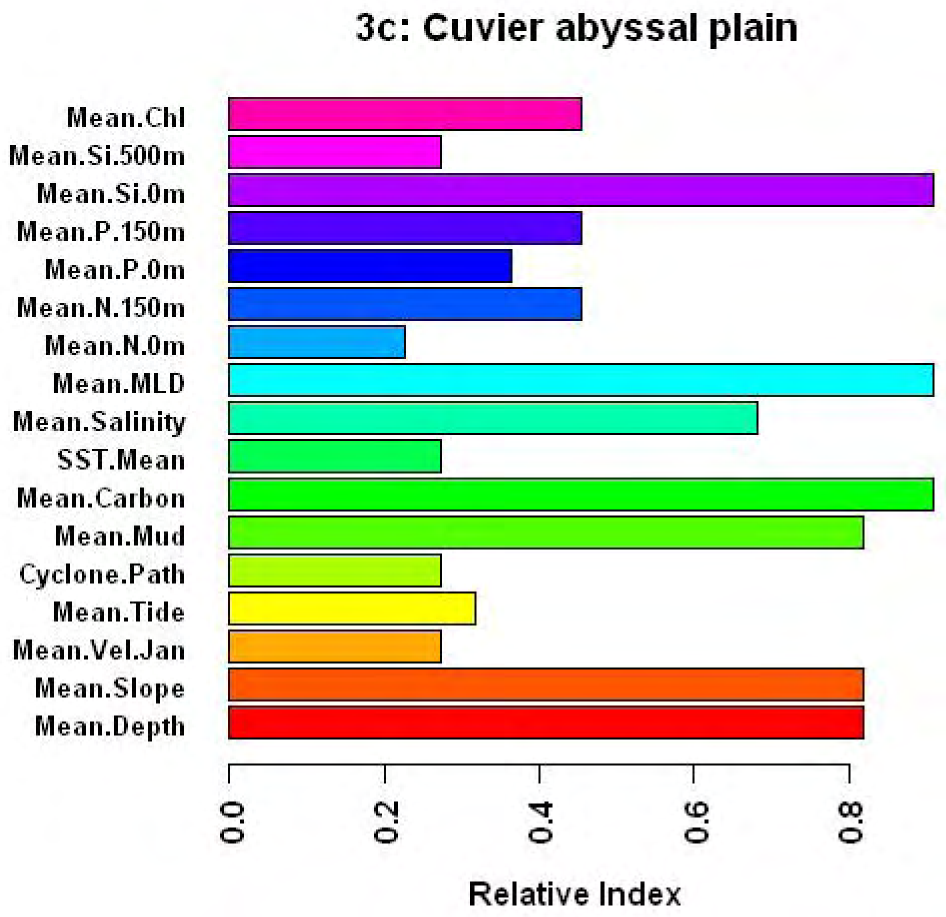


Figure 6-48 Summary physical data for the Cuvier Abyssal Plain sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

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

Benthic environments

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

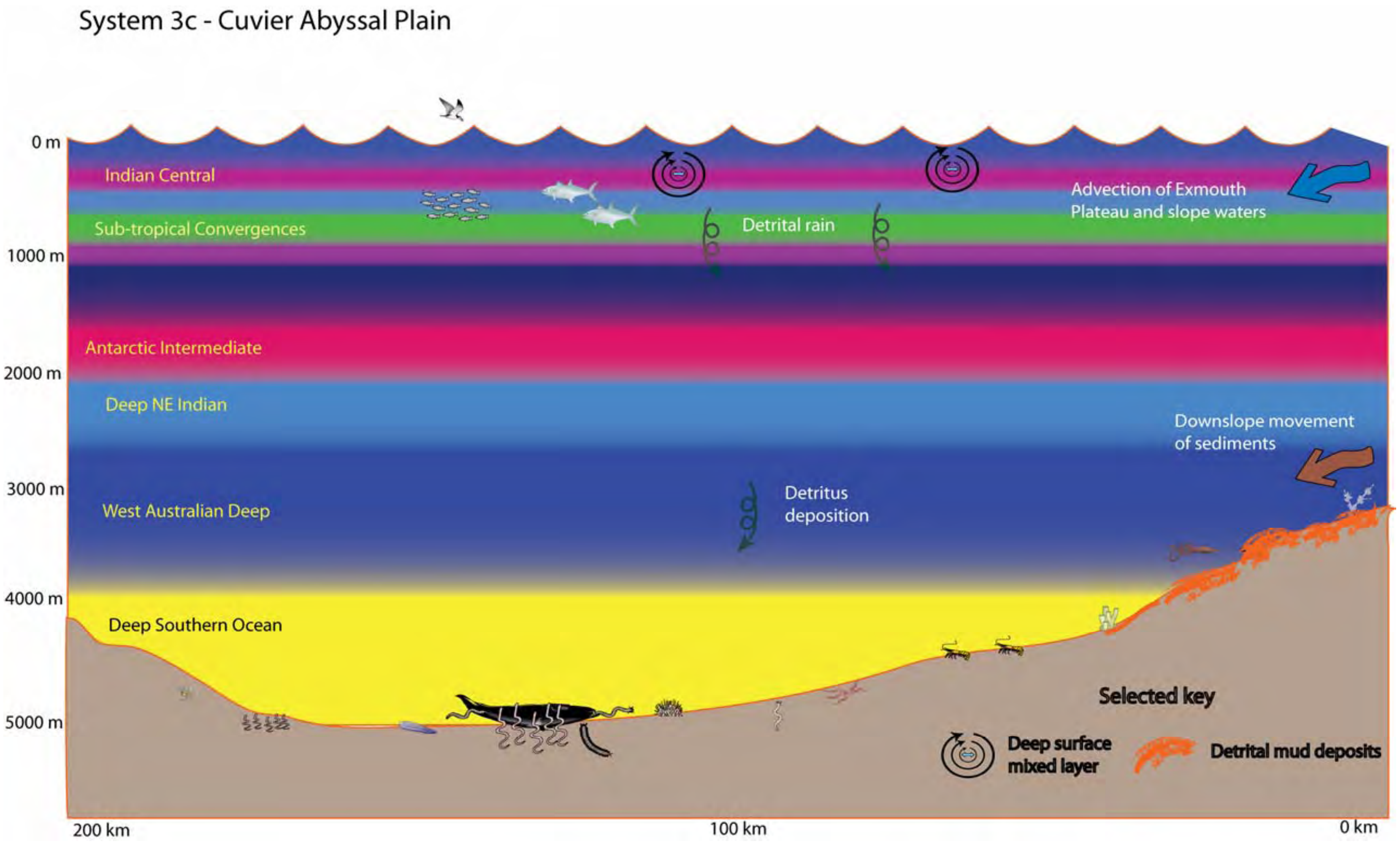


Figure 6-49 Habitat diagram of the Cuvier Abyssal Plain sub-region showing selected important drivers and features. 70-100 m deep chlorophyll maxima not shown.

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

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

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

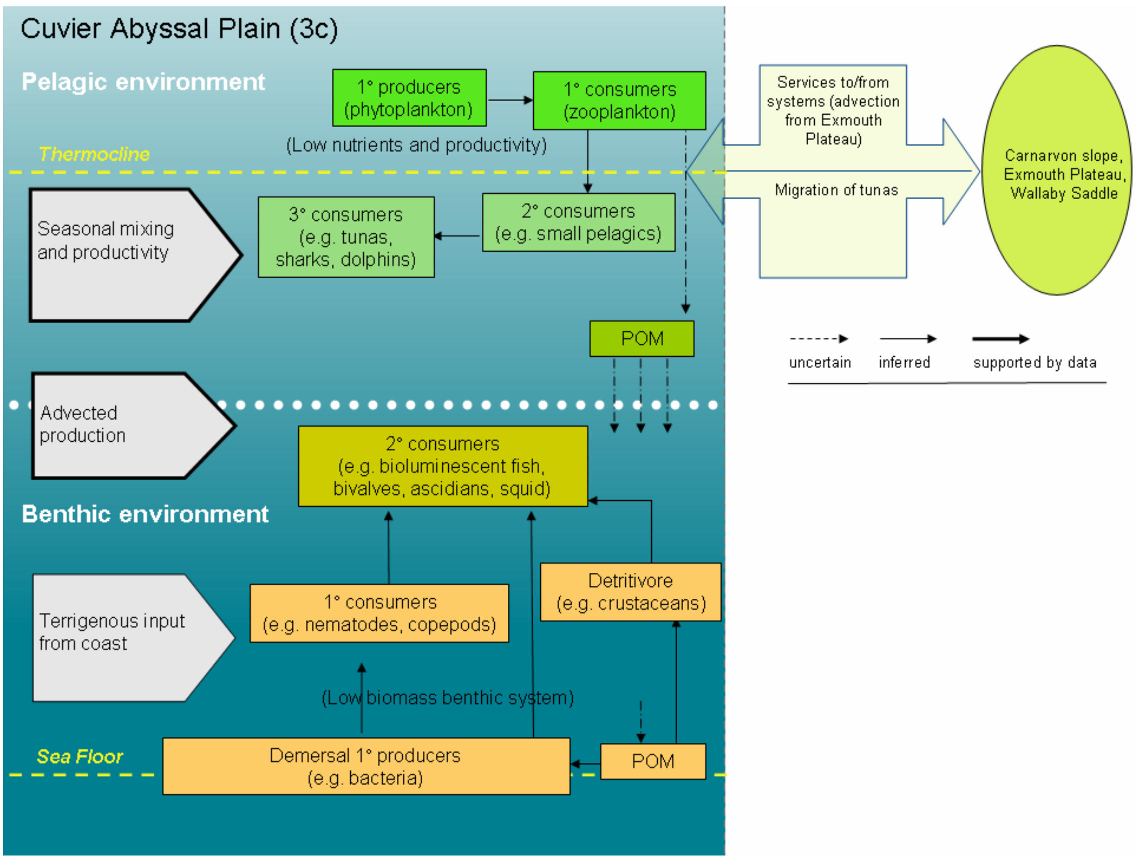


Figure 6-50 Conceptual diagram of the Cuvier Abyssal Plain sub-region showing information on the main habitat in the central basin.

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

6.9.3 Services and linkages

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

6.9.4 Key species interactions

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

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

6.9.5 Resilience and vulnerability – phase change

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

6.9.6 Information gaps

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

6.10 Kalbarri Shelf (4a)

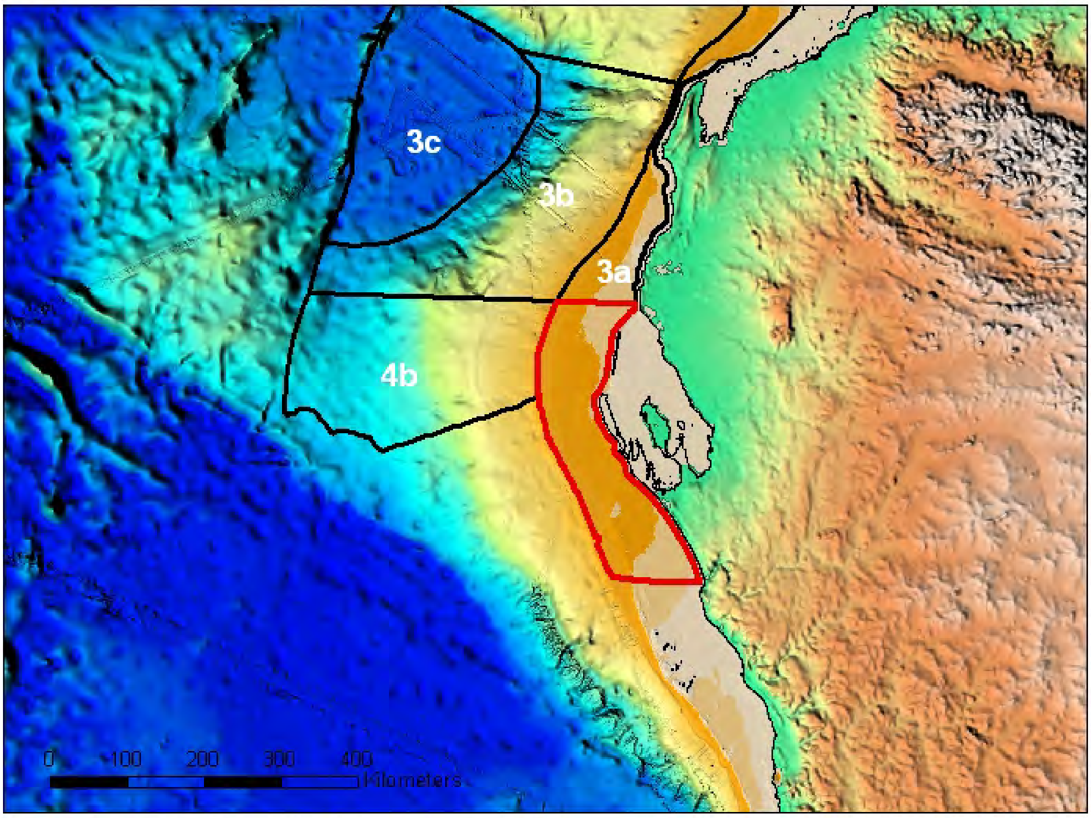


Figure 6-51 Kalbarri Shelf (red outline) and neighbouring sub-regions.

6.10.1 Drivers and physical features

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

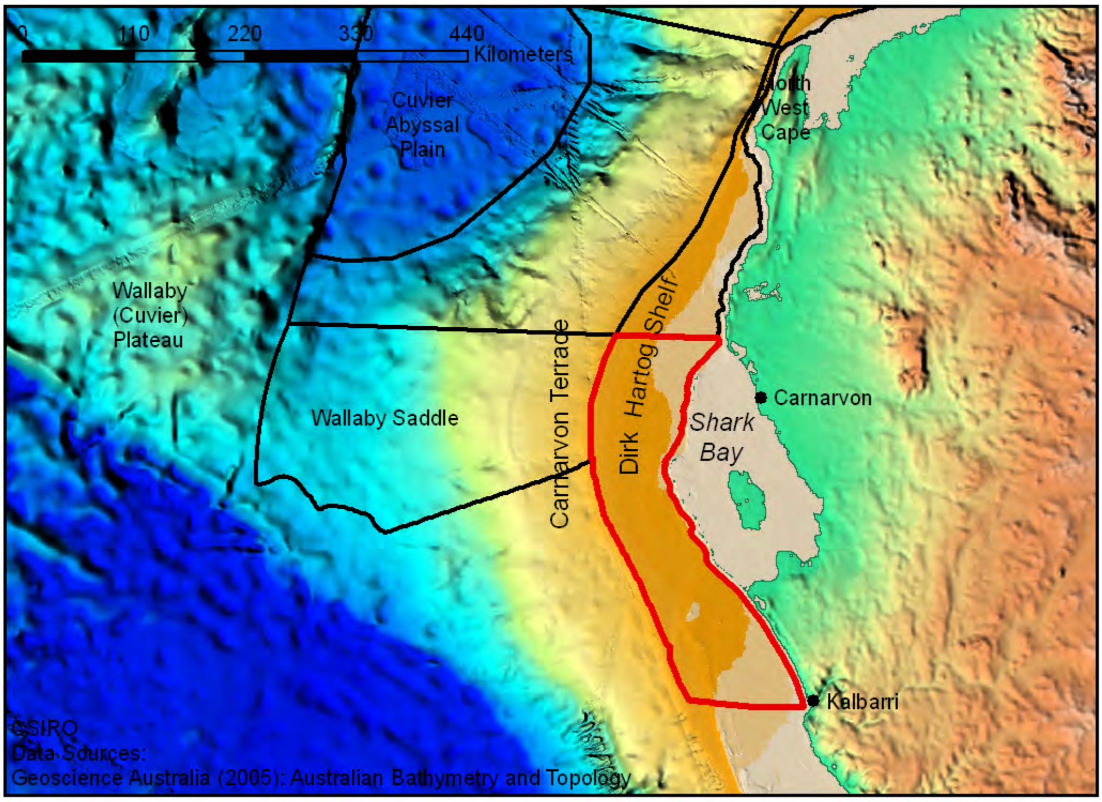
The sub-region has a marked seasonal variation in SST, and is on average almost a degree and a half cooler than the Carnarvon Shelf immediately to the north (Table 6-11). Average salinity is relatively high. There is little freshwater runoff or any other coastal influence on this shelf, and the shelf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

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

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

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

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



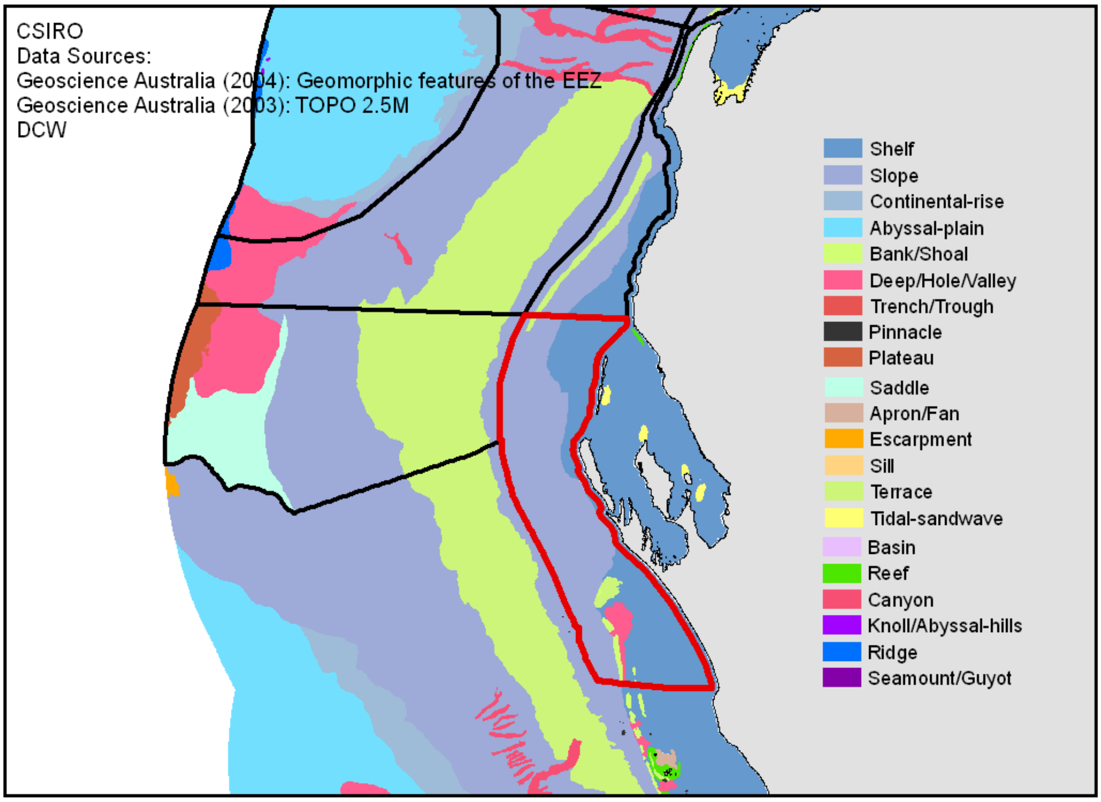


Figure 6-52 Kalbarri Shelf and Wallaby Saddle sub-regions showing selected features (upper) and geomorphology (lower).

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

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

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

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

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

6.10.2 Trophic system features and dynamics

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

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

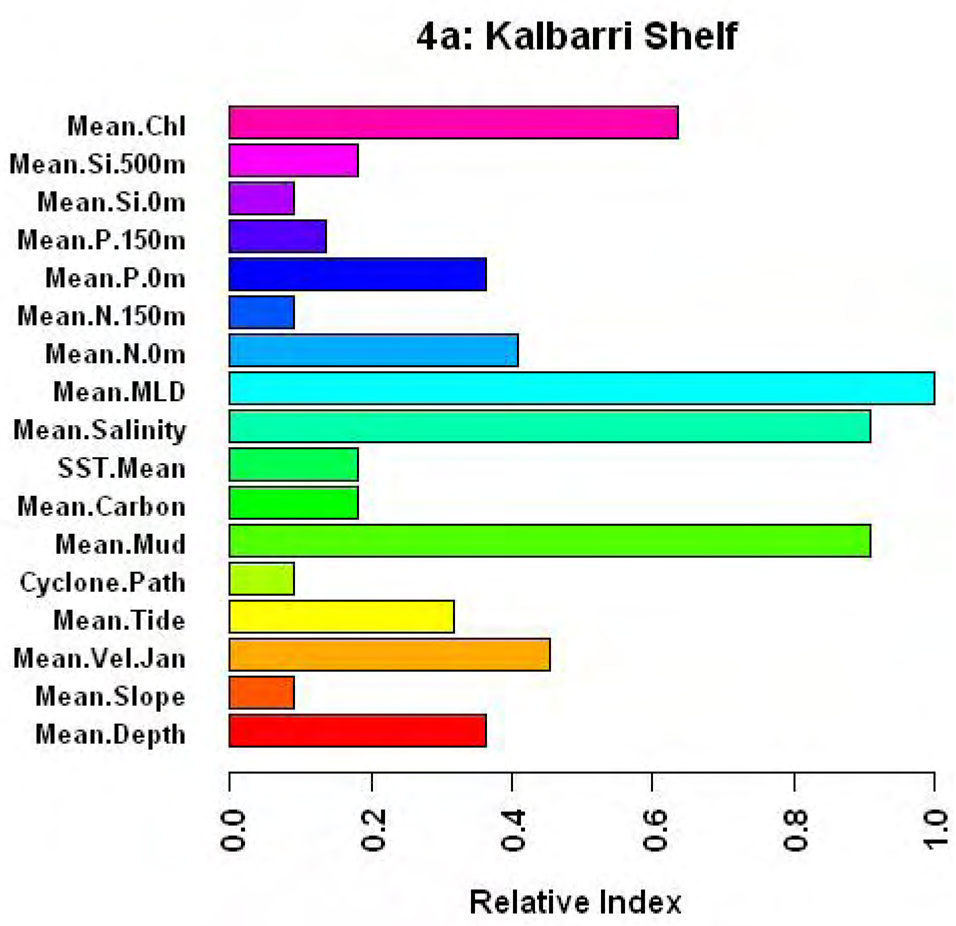


Figure 6-53 Summary physical data for the Kalbarri Shelf sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

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

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

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

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

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

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

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

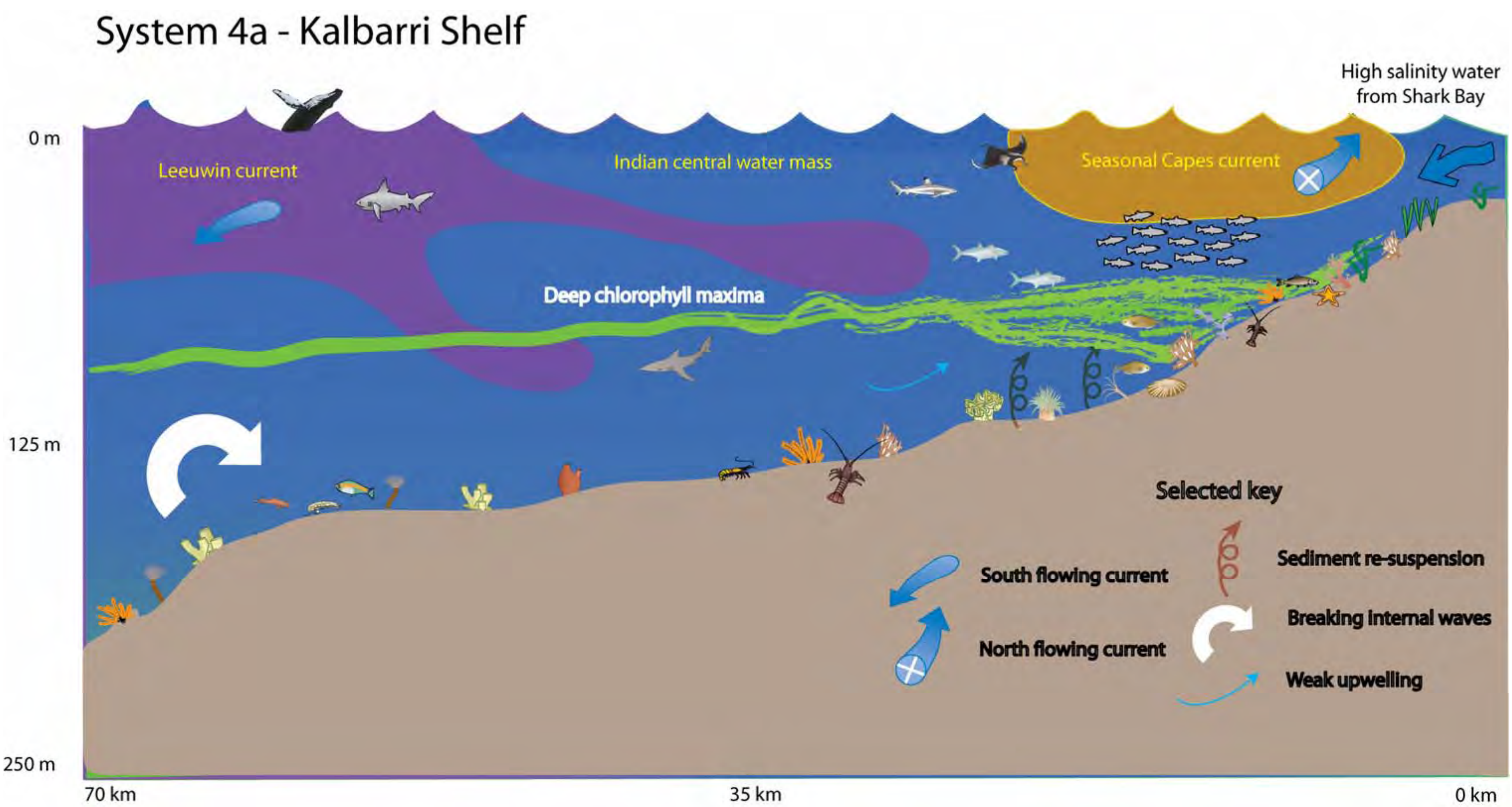


Figure 6-54 Habitat diagram of the Kalbarri Shelf system showing selected important drivers and features.

6.10.3 Services and linkages

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

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

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

6.10.4 Key species interactions

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

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

6.10.5 Resilience and vulnerability

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

- The depth of the Leeuwin Currents nutrient-depleted upper layer (as influenced by mixing and the rate of phytoplankton consumption)
- The strength and duration of upwelling-favourable winds (i.e. the intensity of upwelling); and

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

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

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

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

6.10.6 Information gaps

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

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

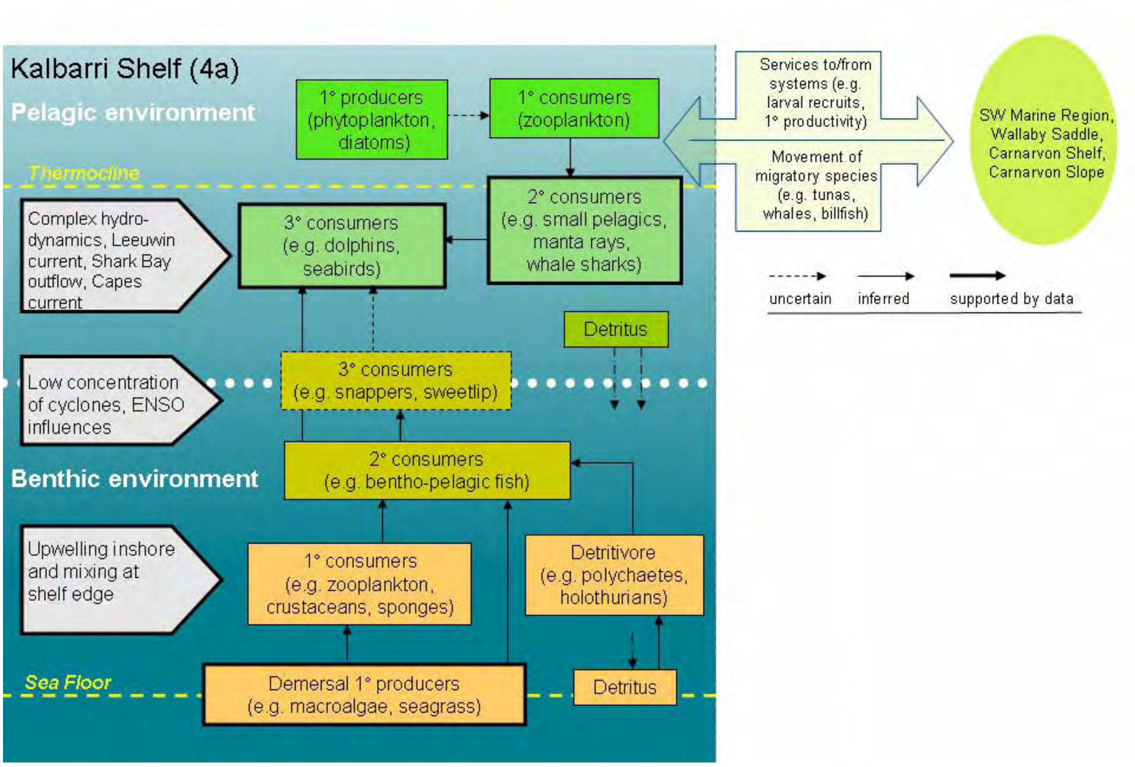


Figure 6-55 Conceptual diagram of the Kalbarri Shelf sub-region showing information on the main habitat in the mid and inner shelf.

6.11 Wallaby Saddle (4b)

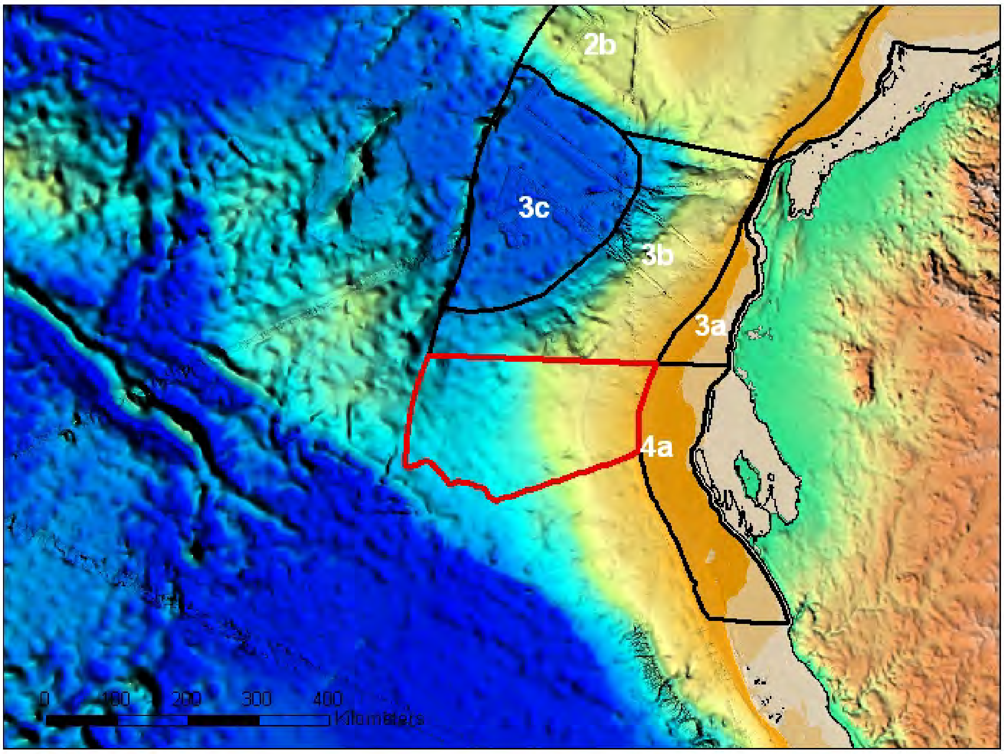


Figure 6-56 Wallaby Saddle (red outline) and neighbouring sub-regions.

6.11.1 Drivers and physical features

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

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

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

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

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

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

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

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

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

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

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

6.11.2 Trophic system features and dynamics

Pelagic environment

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

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

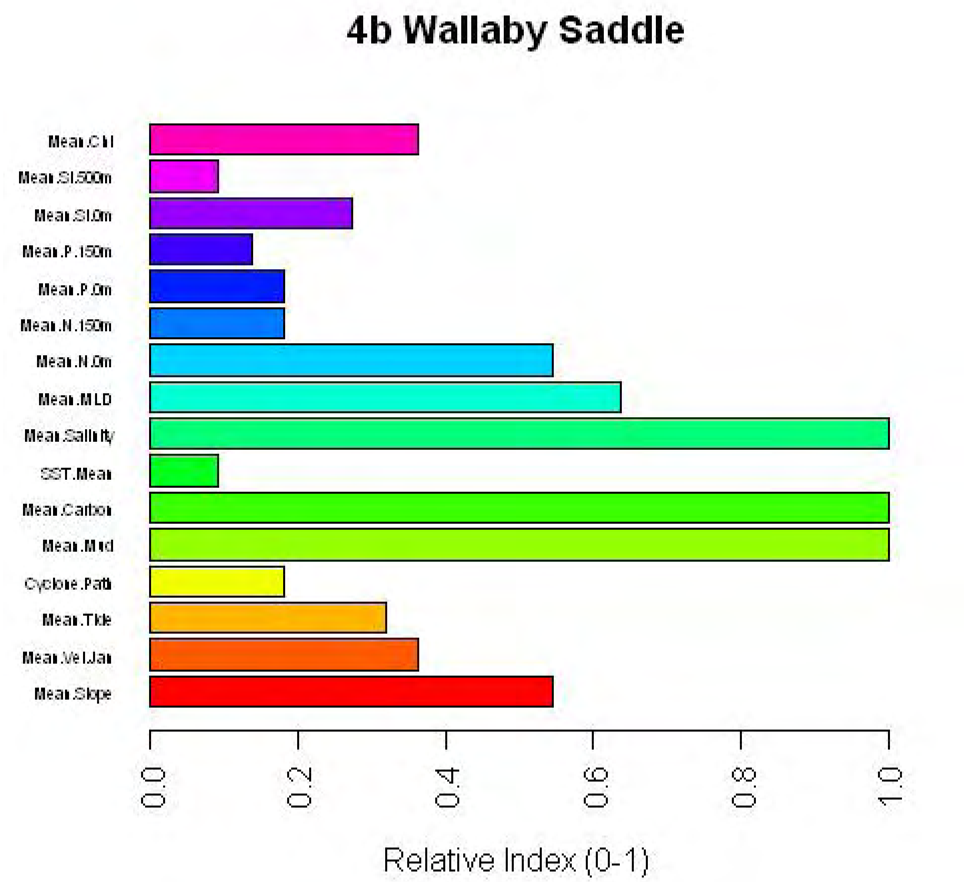


Figure 6-57 Summary physical data for the Wallaby Saddle sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

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

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

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

Benthic environment

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

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

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

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

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

6.11.3 Services and linkages

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

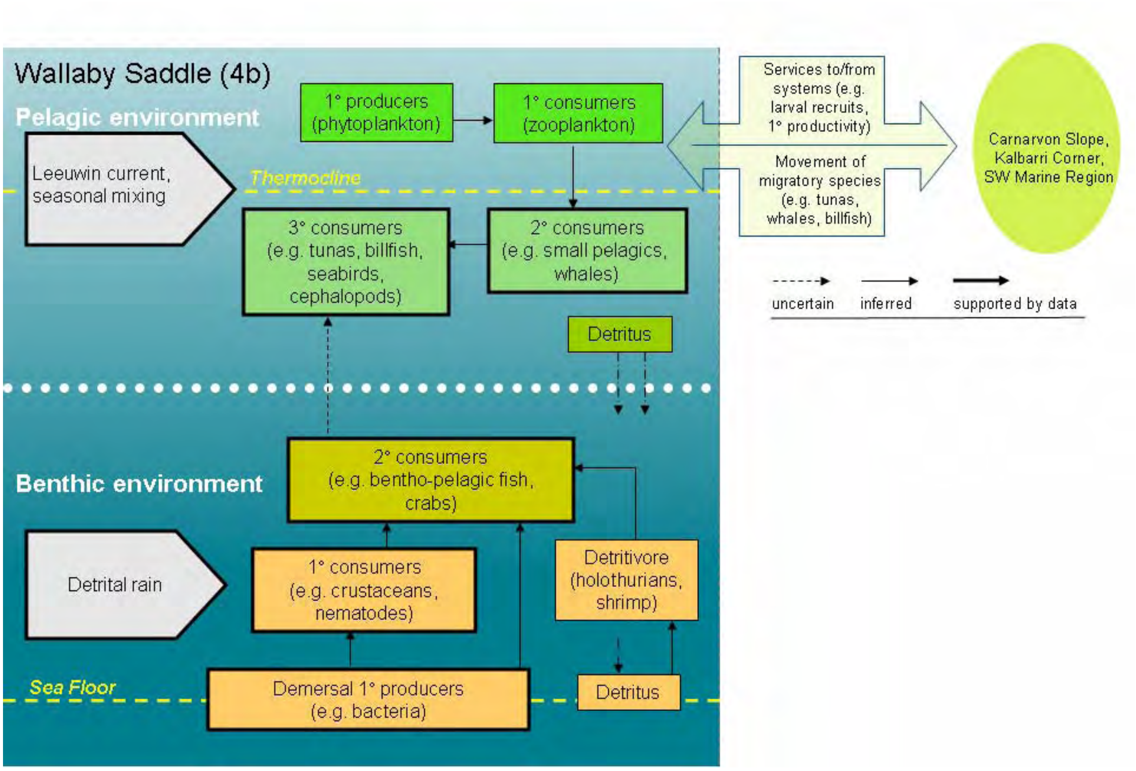


Figure 6-58 Conceptual model of the Wallaby Saddle trophic system showing information on the main habitat in the mid-slope.

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

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

6.11.4 Key species interactions

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

6.11.5 Resilience and vulnerability

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

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

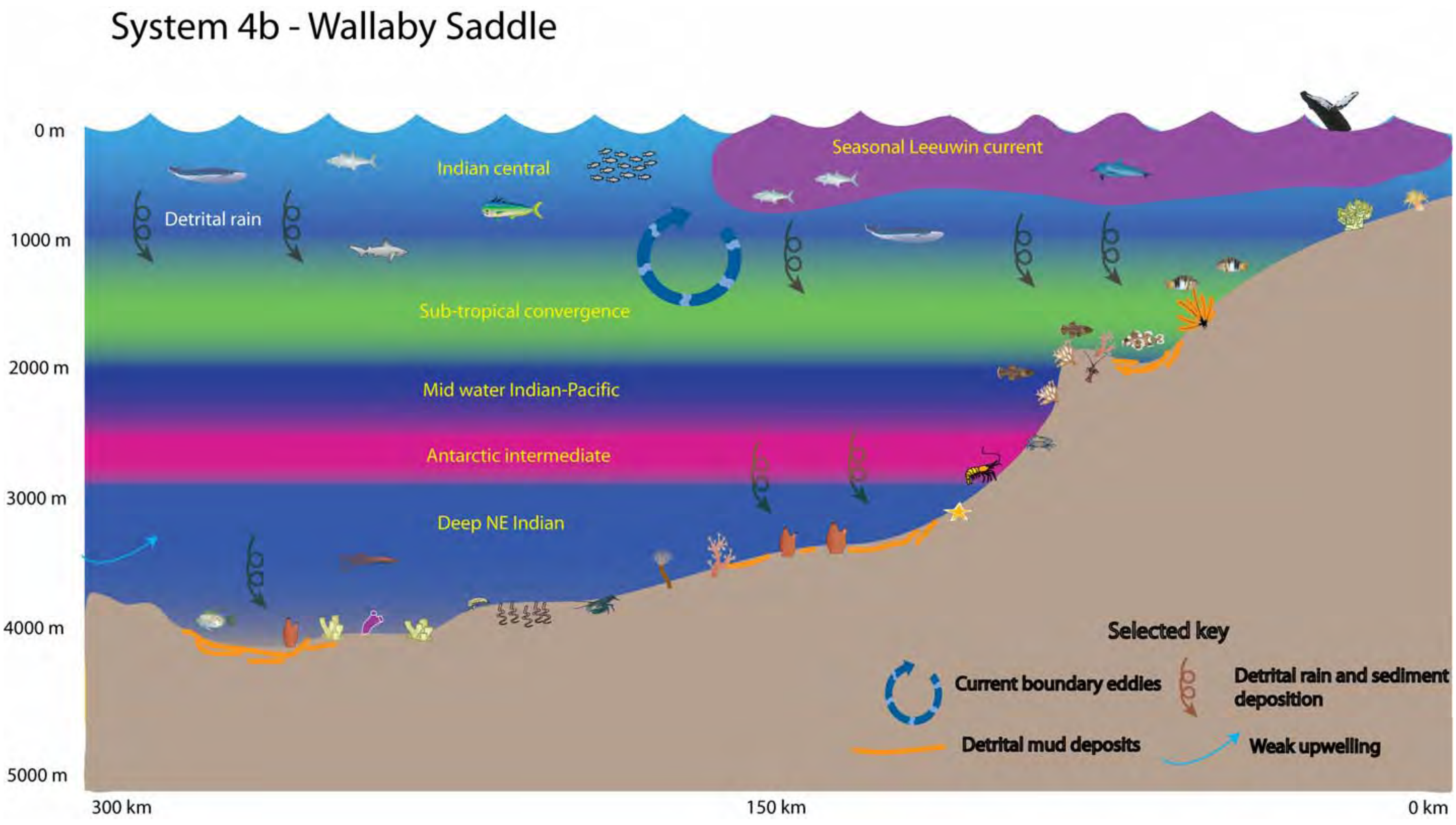


Figure 6-59 Habitat diagram of the Wallaby Saddle sub-region showing selected important drivers and features. 70-100 deep chlorophyll maxima not shown.

6.11.6 Information gaps

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

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

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

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