6. DESCRIPTION OF TROPHIC SYSTEMS

6.1 Western Joseph Bonaparte Gulf Shelf (1a1)

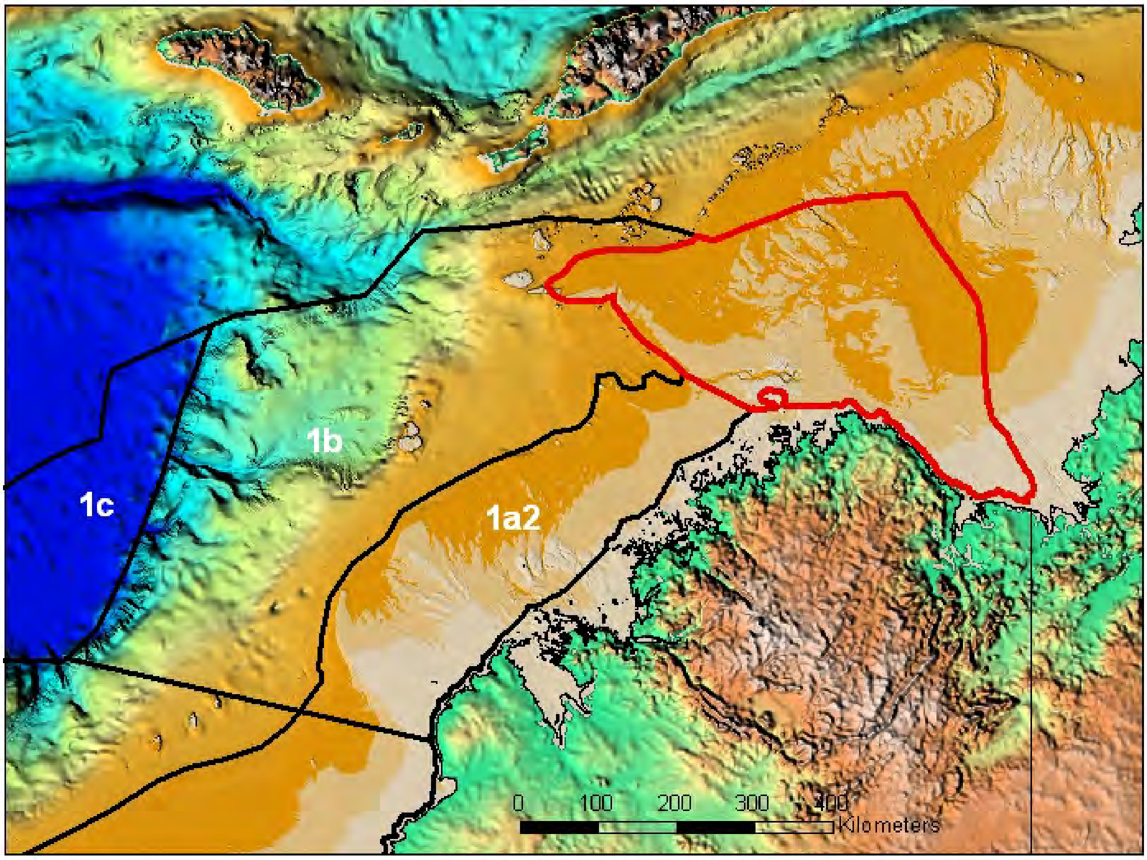


Figure 6-1 Western Joseph Bonaparte Gulf (red outline) and neighbouring sub-regions.

6.1.1 Drivers and physical features

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

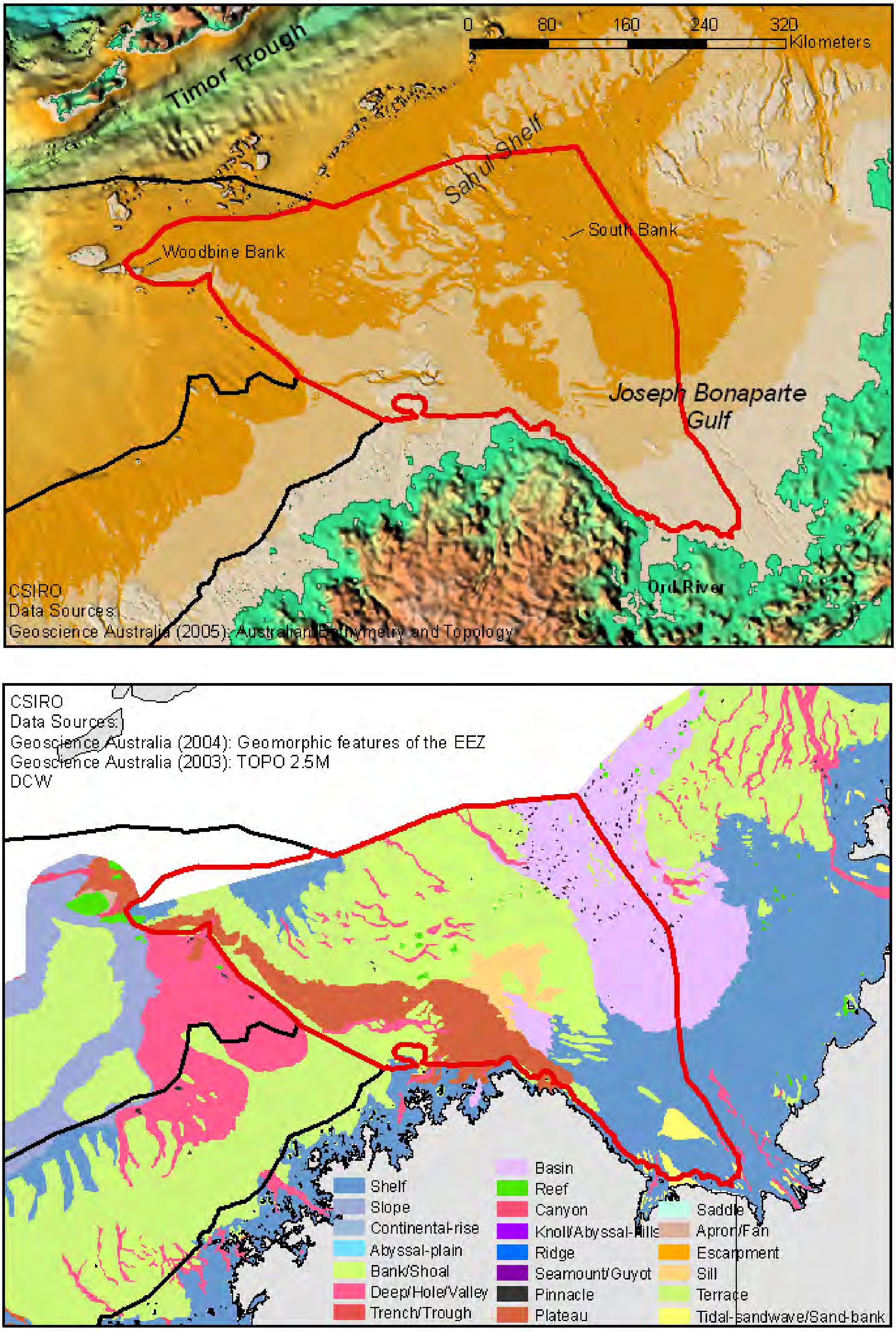


Figure 6-2 Western Joseph Bonaparte Gulf sub-region showing selected features (upper) and geomorphology (lower).

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

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

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

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

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

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

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

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

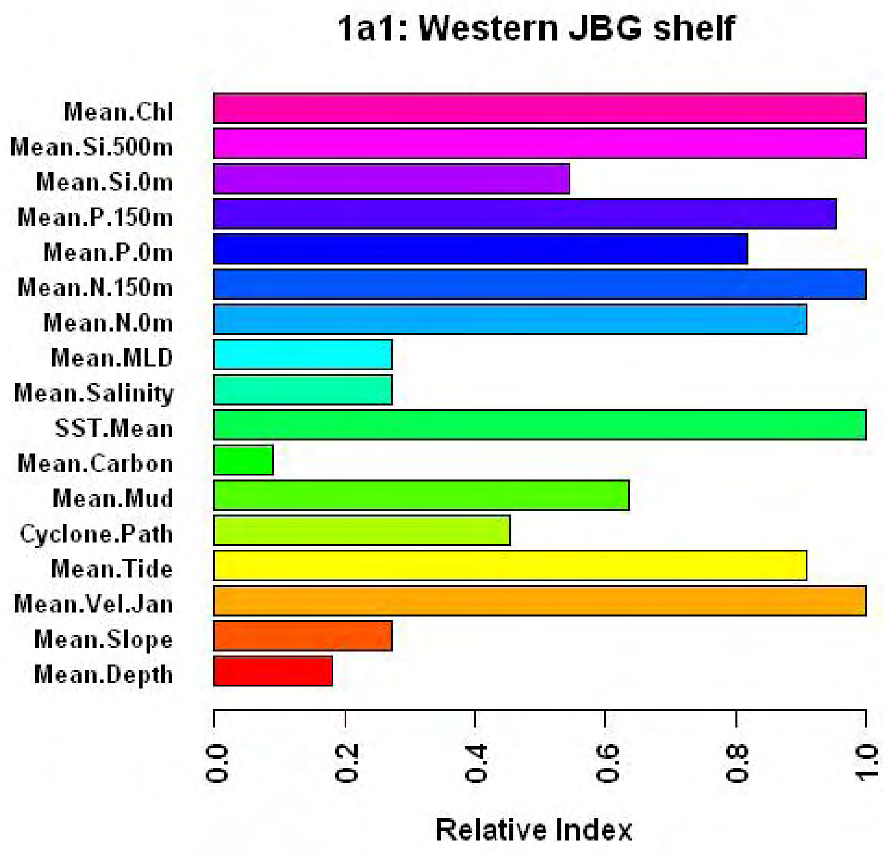


Figure 6-3 Summary physical data for the Western Joseph Bonaparte Gulf sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

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

6.1.2 Trophic system features and dynamics

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

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

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

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

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

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

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

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

System 1a1 - Western JBG shelf

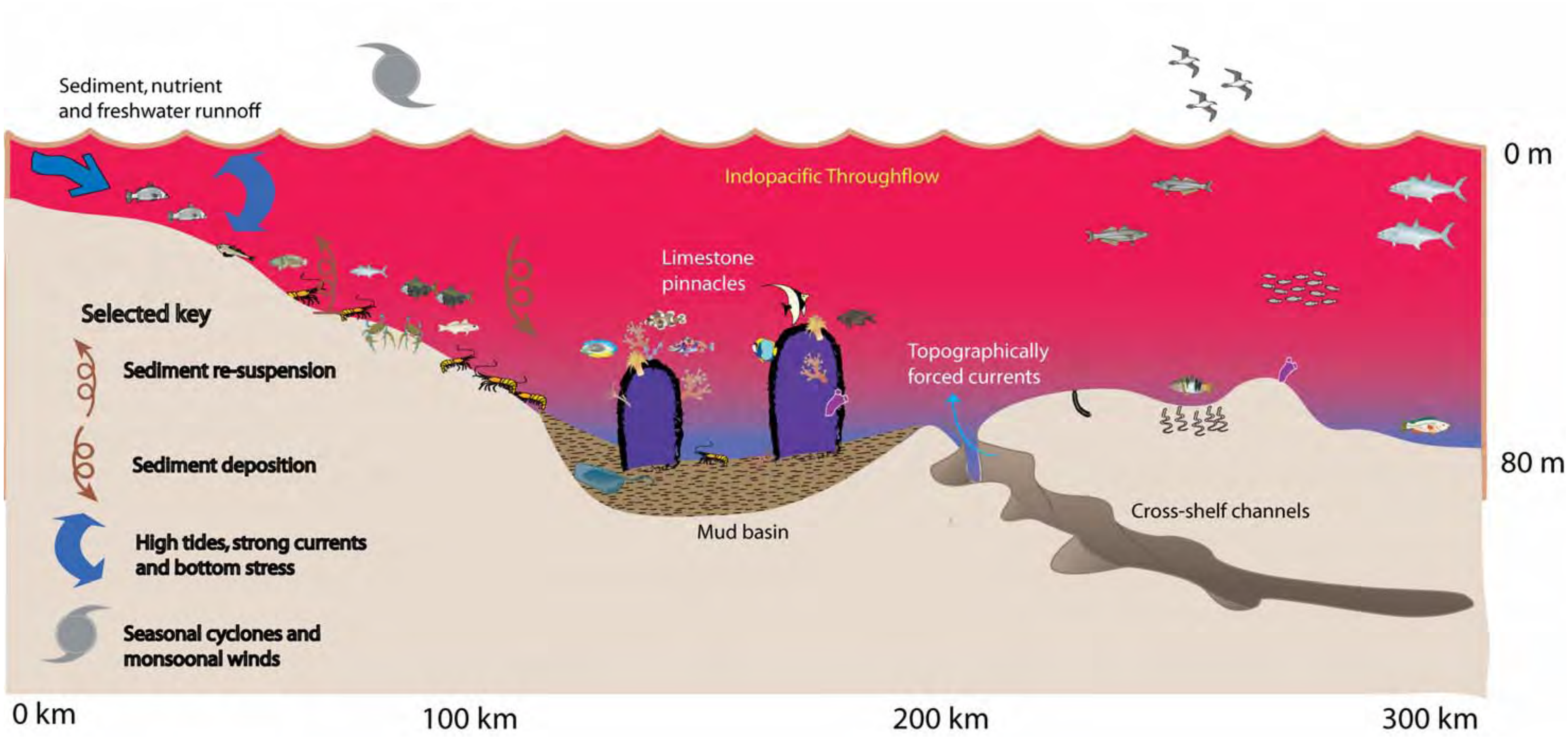


Figure 6-5 Habitat diagram of the Western Joseph Bonaparte Gulf sub-region showing selected important drivers and features.

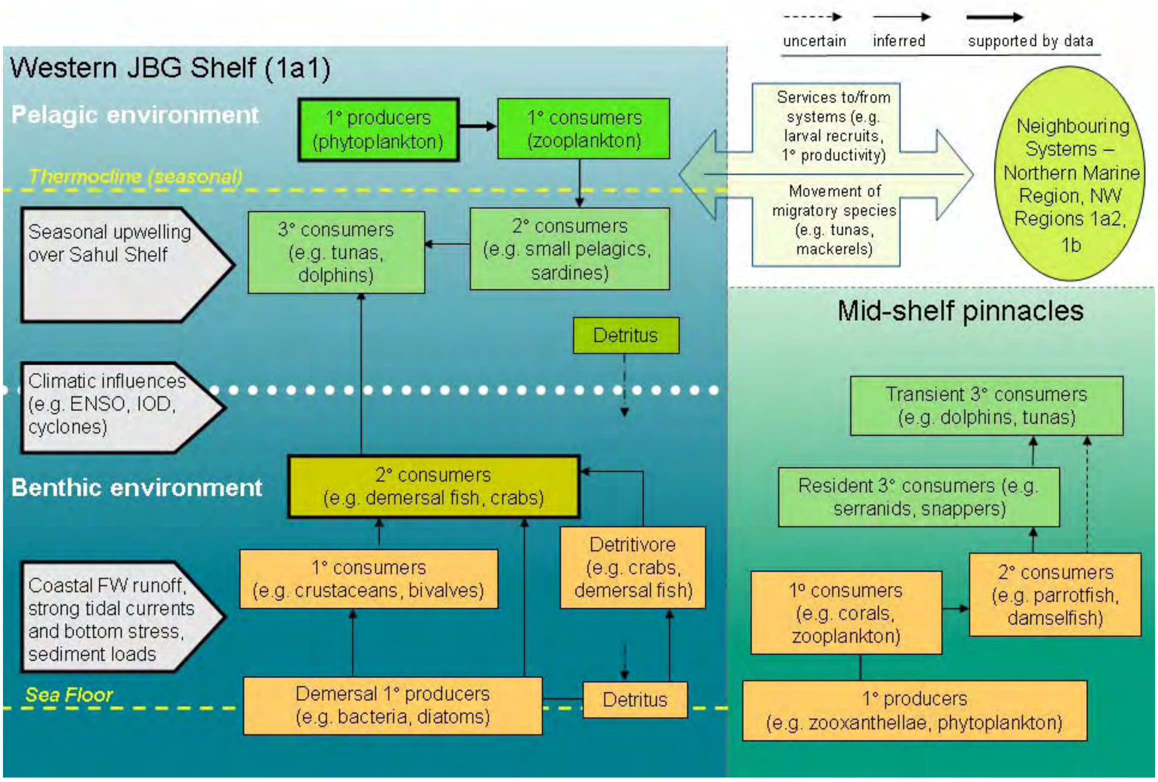


Figure 6-6 Schematic trophic model of the Western Joseph Bonaparte Gulf sub-region, showing information on the extensive habitat in the coastal and central shelf region (left) and a less extensive but important habitat (right).

6.1.3 Services and linkages

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

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

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

6.1.4 Key species interactions

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

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

6.1.5 Resilience and vulnerability

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

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

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

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

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

6.1.6 Information gaps

The major information gaps, mostly described in the above sections, are summarised below.
Demersal and pelagic communities in most habitats are poorly understood (other than the demersal community in the region fished by the JBG component of the NPF), in particular:
The inshore consumers at all levels
Mid-shelf tertiary consumers
All functional groups associated with the outer mid-shelf pinnacles

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

Other gaps in our knowledge include:

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

6.2 Kimberly Shelf (1a2)

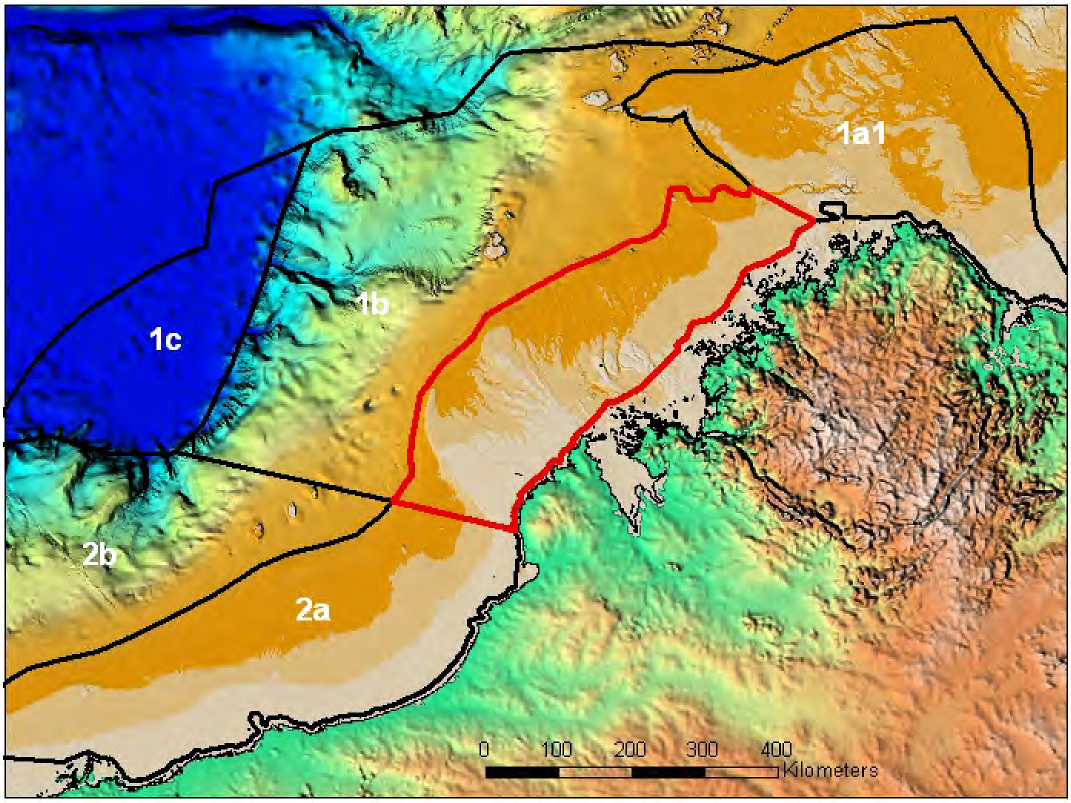


Figure 6-7 Kimberley Shelf (red outline) and neighbouring sub-regions.

6.2.1 Drivers and physical features

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

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

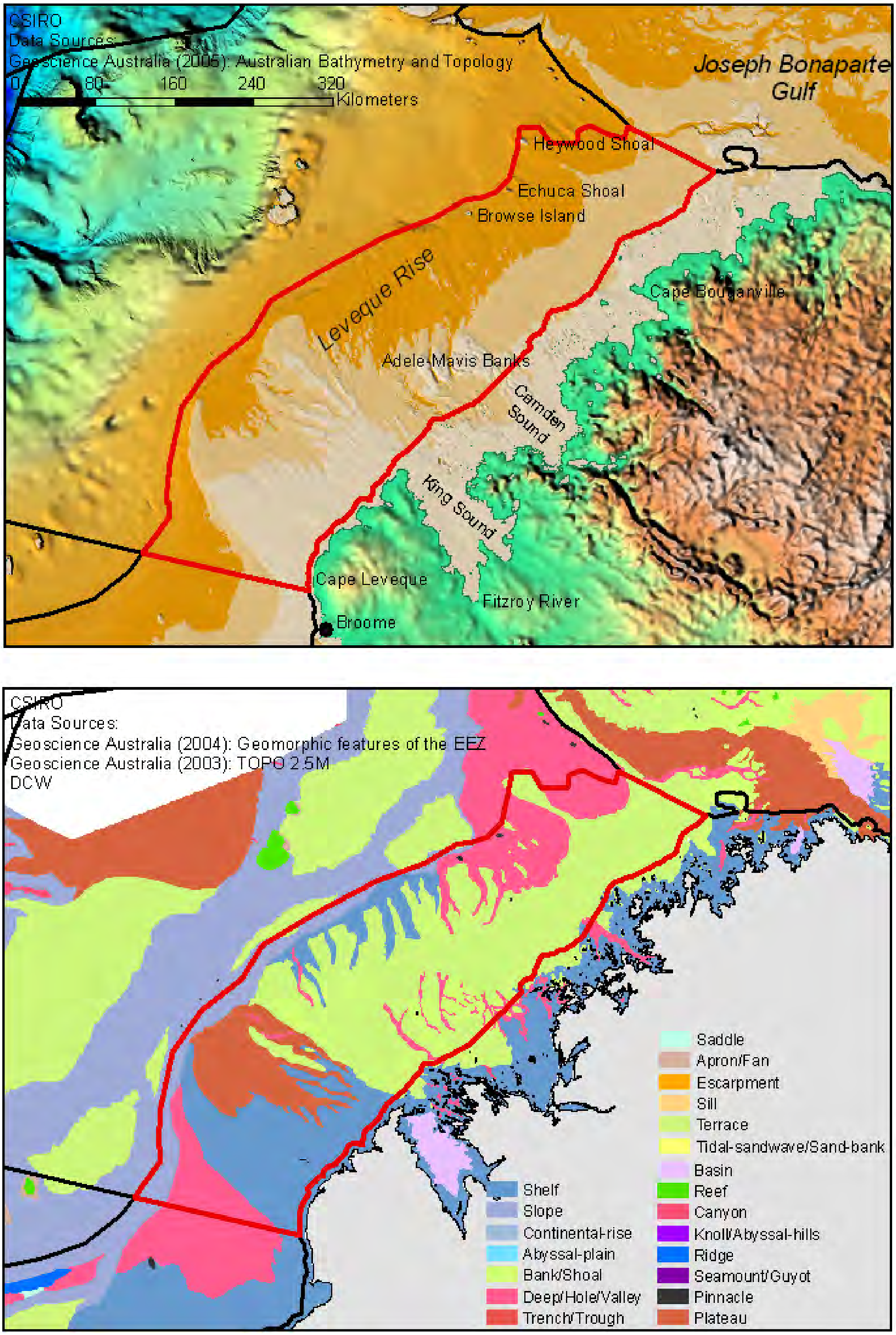


Figure 6-8 Kimberley Shelf sub-region showing selected features (upper) and geomorphology (lower).

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

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

6.2.2 Trophic system features and dynamics

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

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

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

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

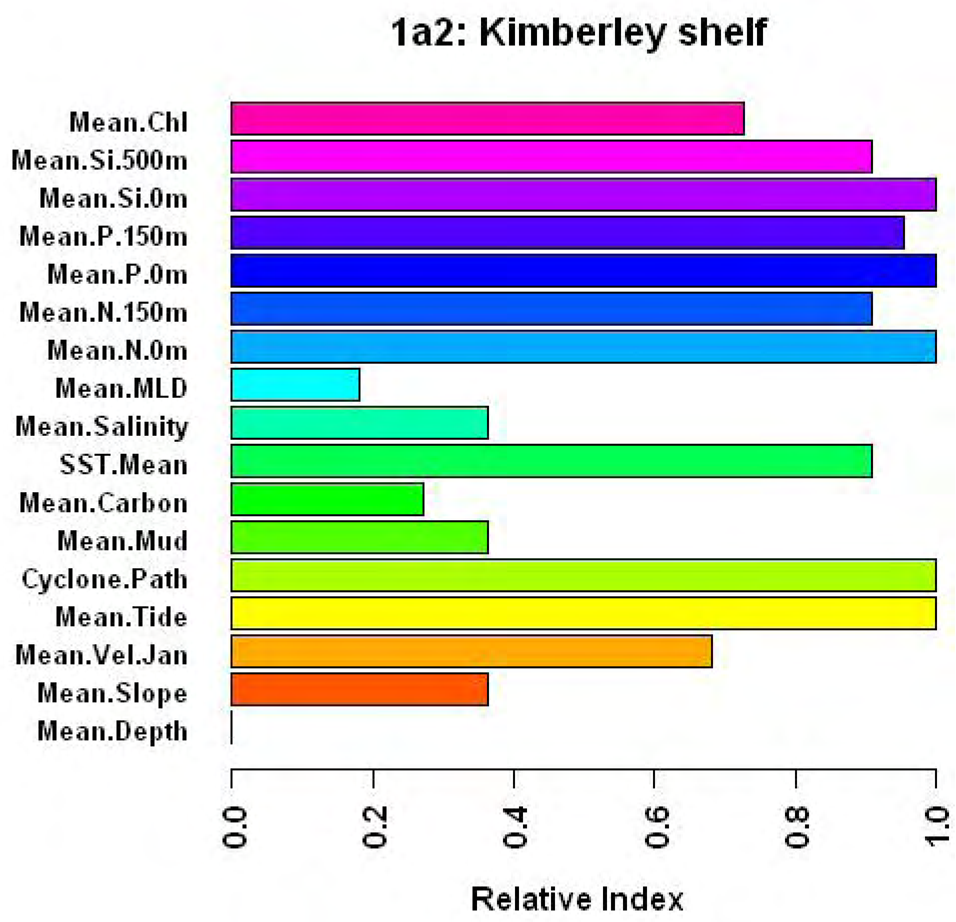


Figure 6-9 Summary physical data for the Kimberly Shelf sub-region (taken from Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

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

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

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

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

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

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

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

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

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

6.2.3 Services and linkages

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

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

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

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

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

6.2.4 Key species interactions

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

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

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

6.2.5 Resilience and vulnerability

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

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

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

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

6.2.6 Information gaps

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

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

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

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

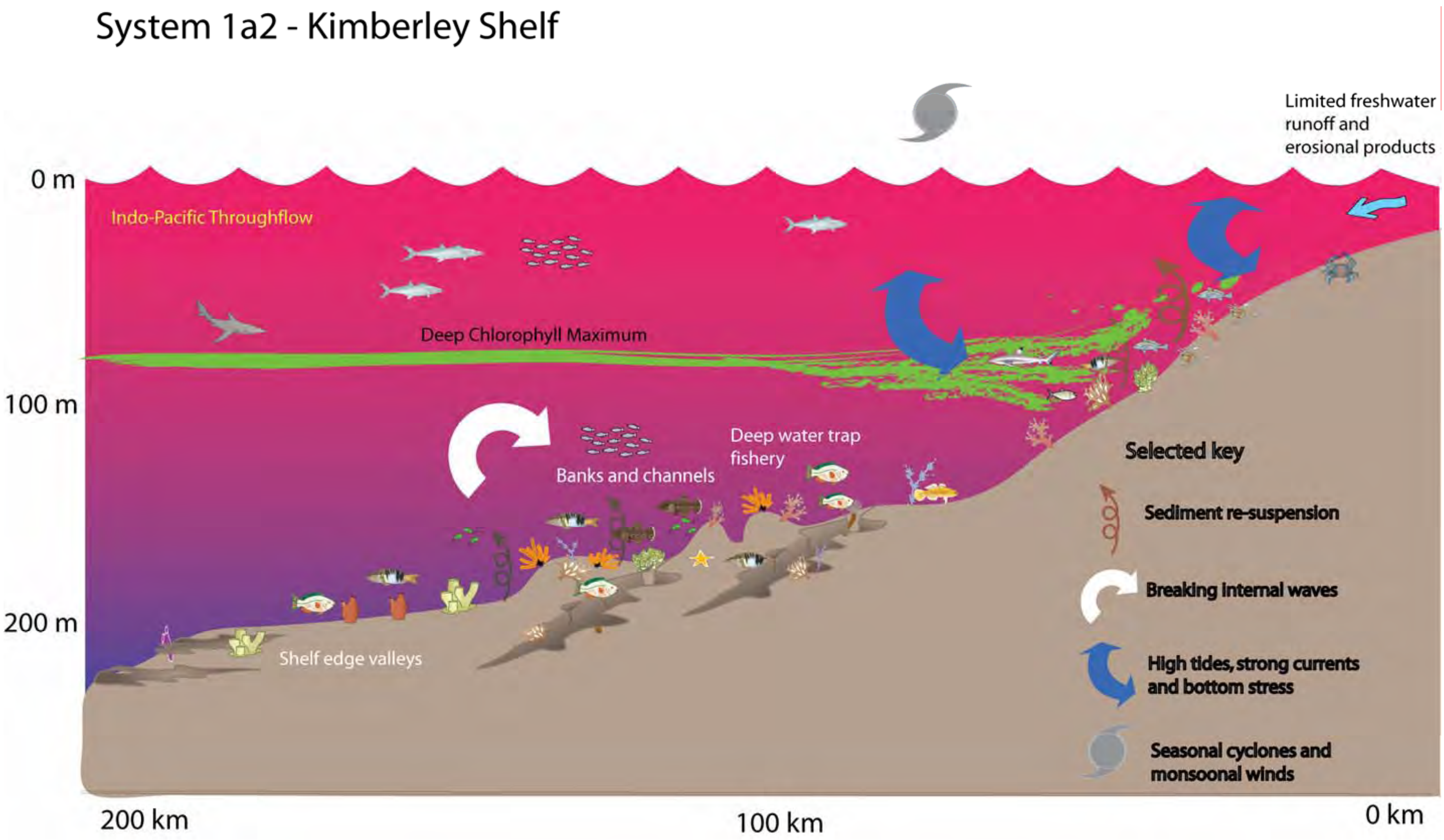


Figure 6-10 Habitat diagram of the Kimberly Shelf sub-region showing selected important drivers and features.

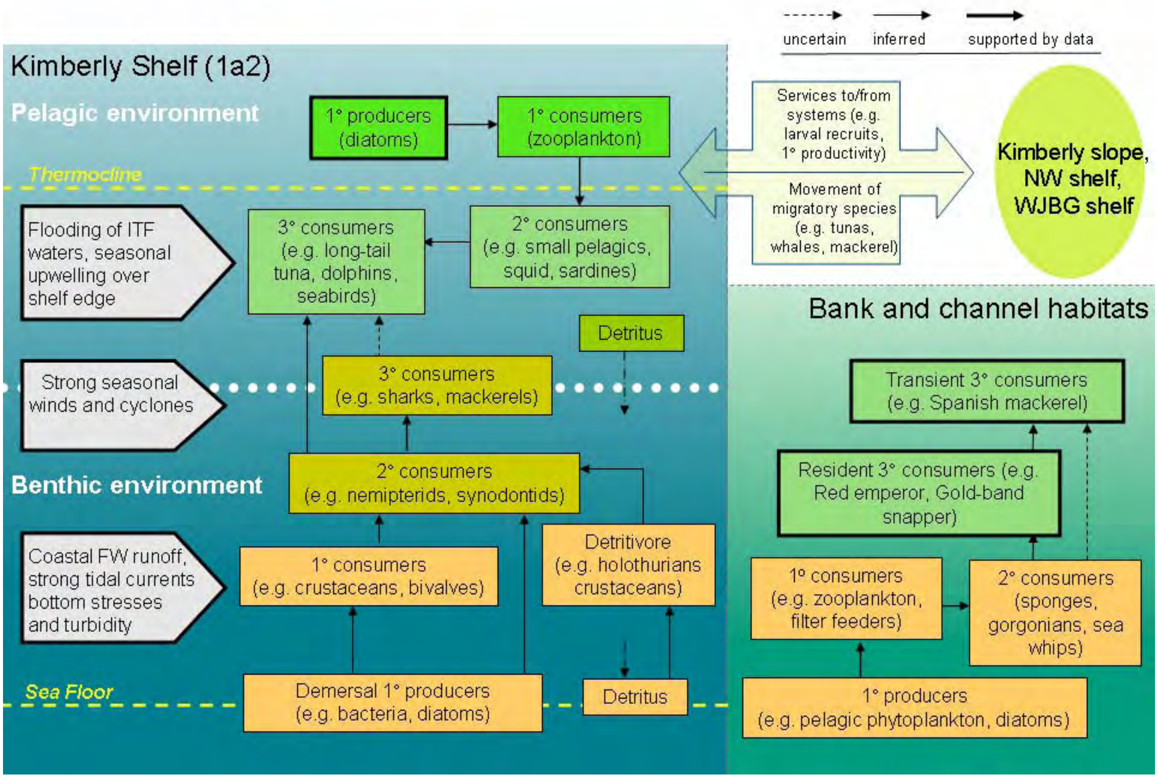


Figure 6-11 Conceptual trophic model of the Kimberly Shelf sub-region showing information on the extensive habitat in the coastal and central shelf region (left) and the important bank and channel habitats in the central and southern areas (right).

6.3 Kimberly Slope (1b)

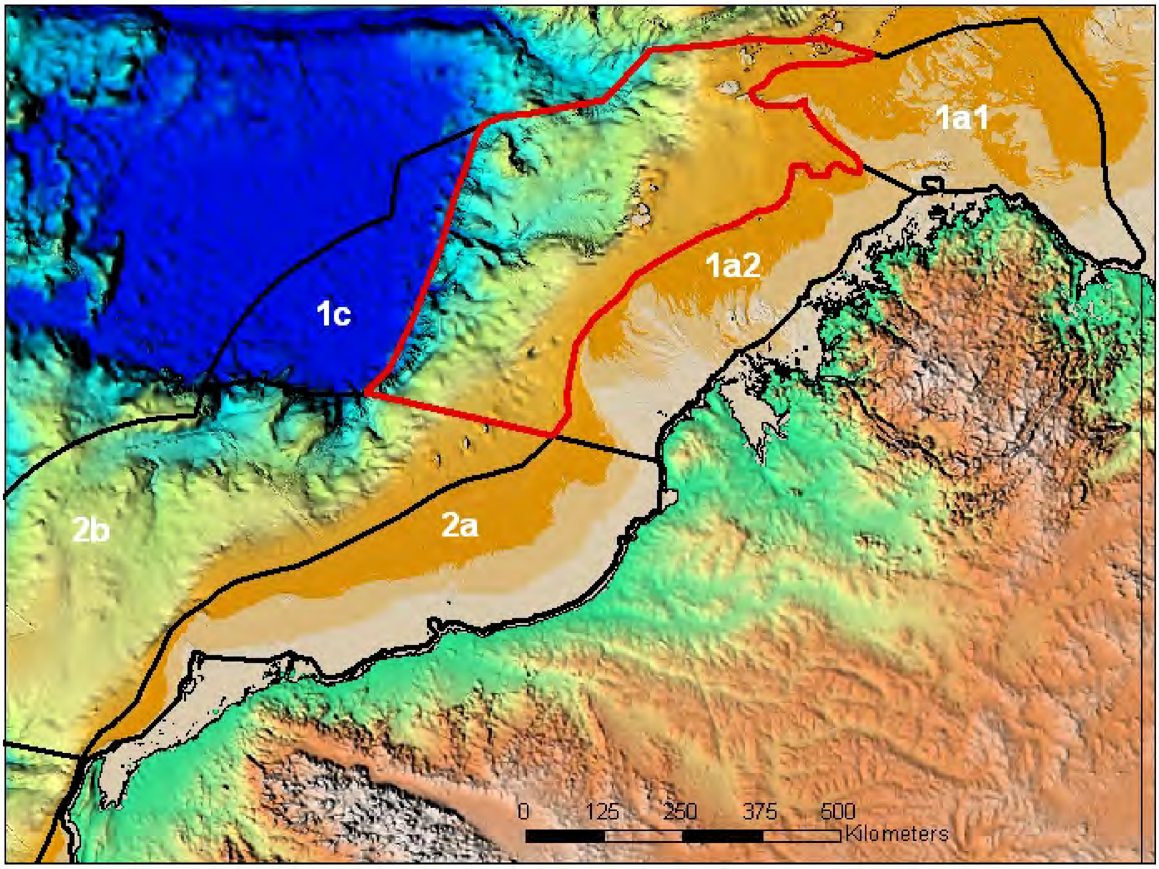
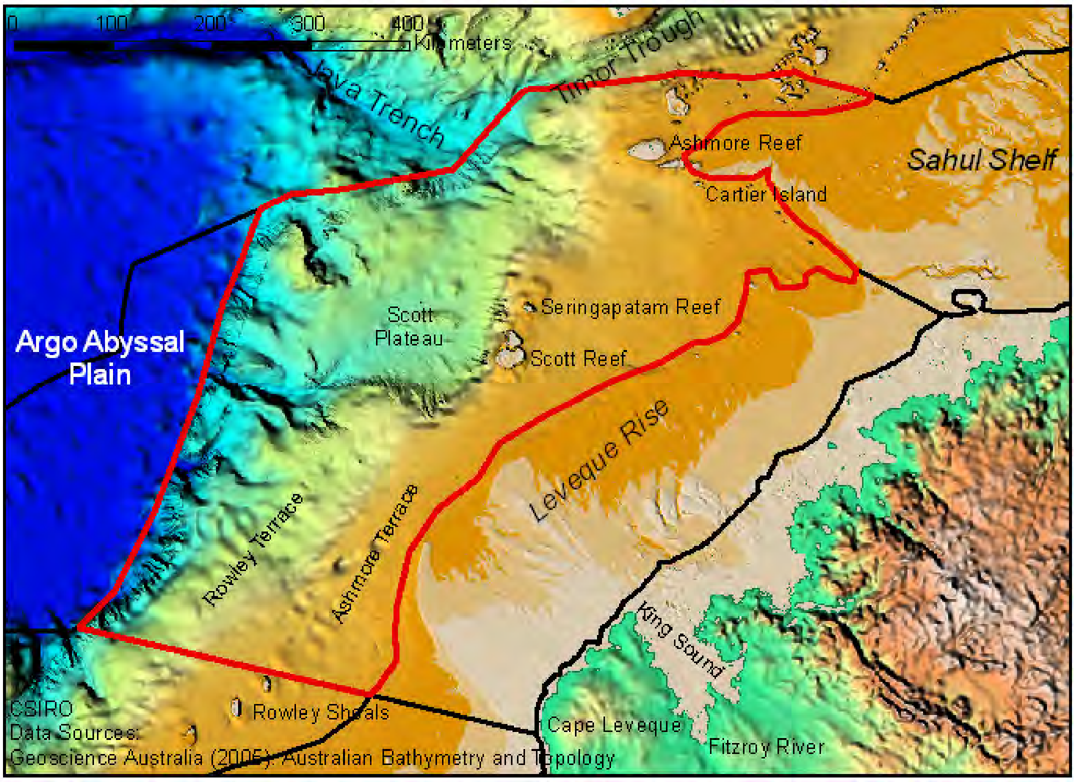


Figure 6-12 Kimberley Slope (red outline) and neighbouring sub-regions.

6.3.1 Drivers and physical features

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

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



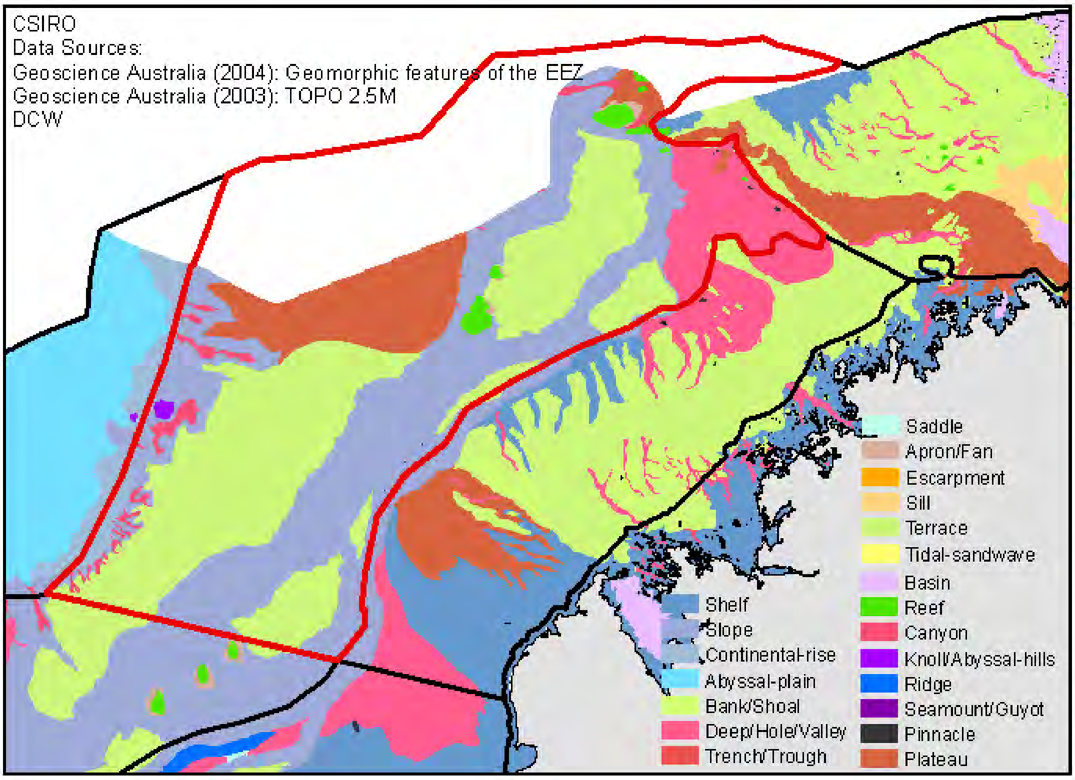


Figure 6-13 Kimberly Slope sub-region showing selected features (upper) and geomorphology (lower).

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

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

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

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

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

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

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

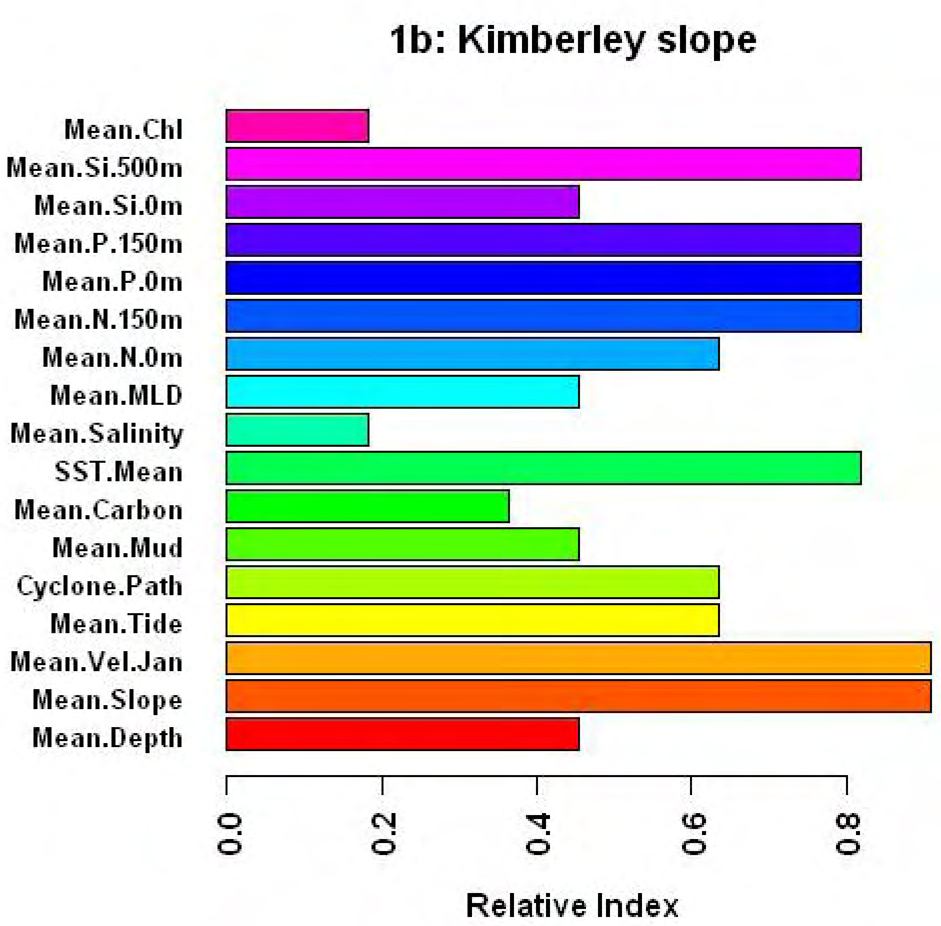


Figure 6-14 Summary physical data for the Kimberley Slope sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

6.3.2 Trophic system features and dynamics

Pelagic environments

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

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

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

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

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

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

Benthic environments

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

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

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

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

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

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

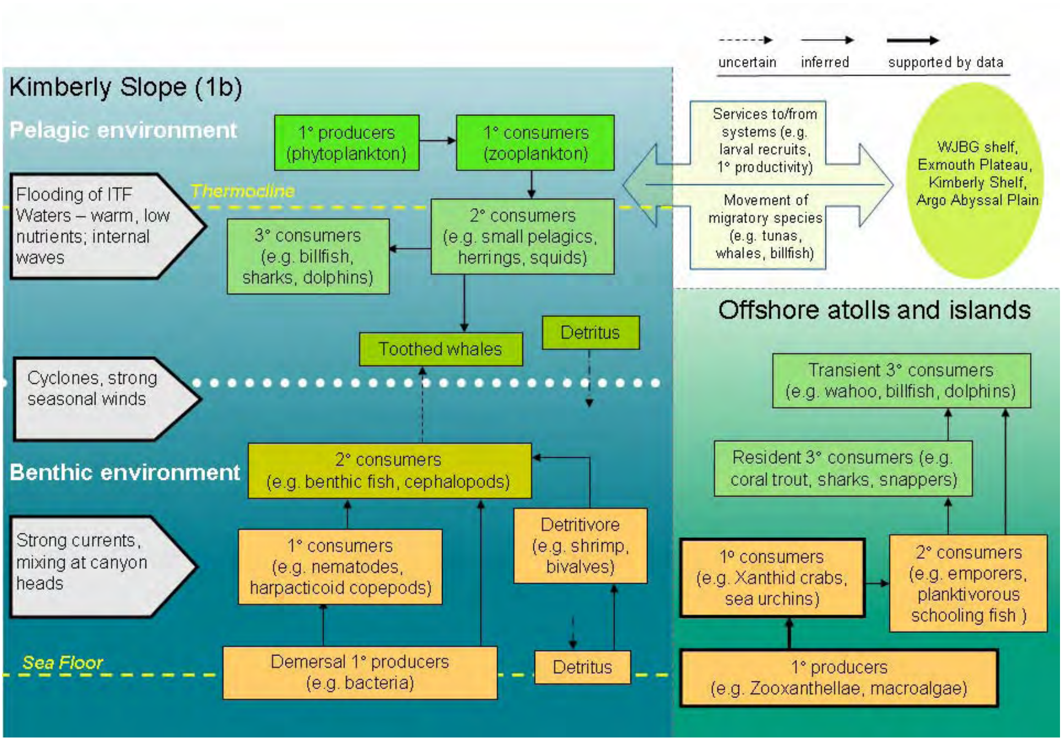


Figure 6-15 Conceptual trophic model of the Kimberly Slope sub-region showing information on the extensive mid-slope habitats (left) and the less extensive but important offshore island and atoll habitats (right).

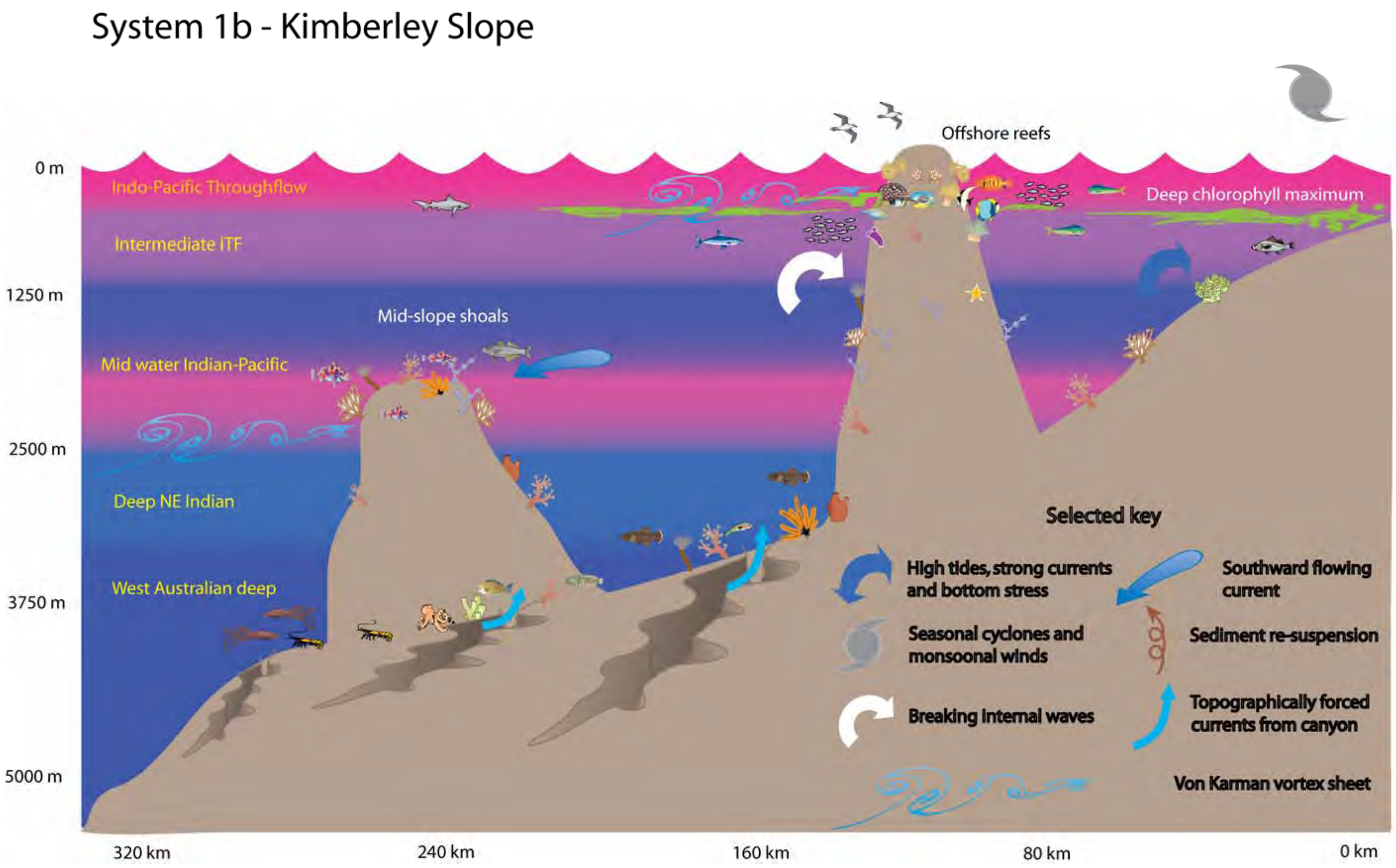


Figure 6-16 Habitat diagram of the Kimberly Slope sub-region showing selected important drivers and features.

6.3.3 Services and linkages

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

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

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

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

6.3.4 Key species interactions

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

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

6.3.5 Resilience and vulnerability

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

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

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

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

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

6.3.6 Information gaps

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

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

6.4 Argo Plain (1c)

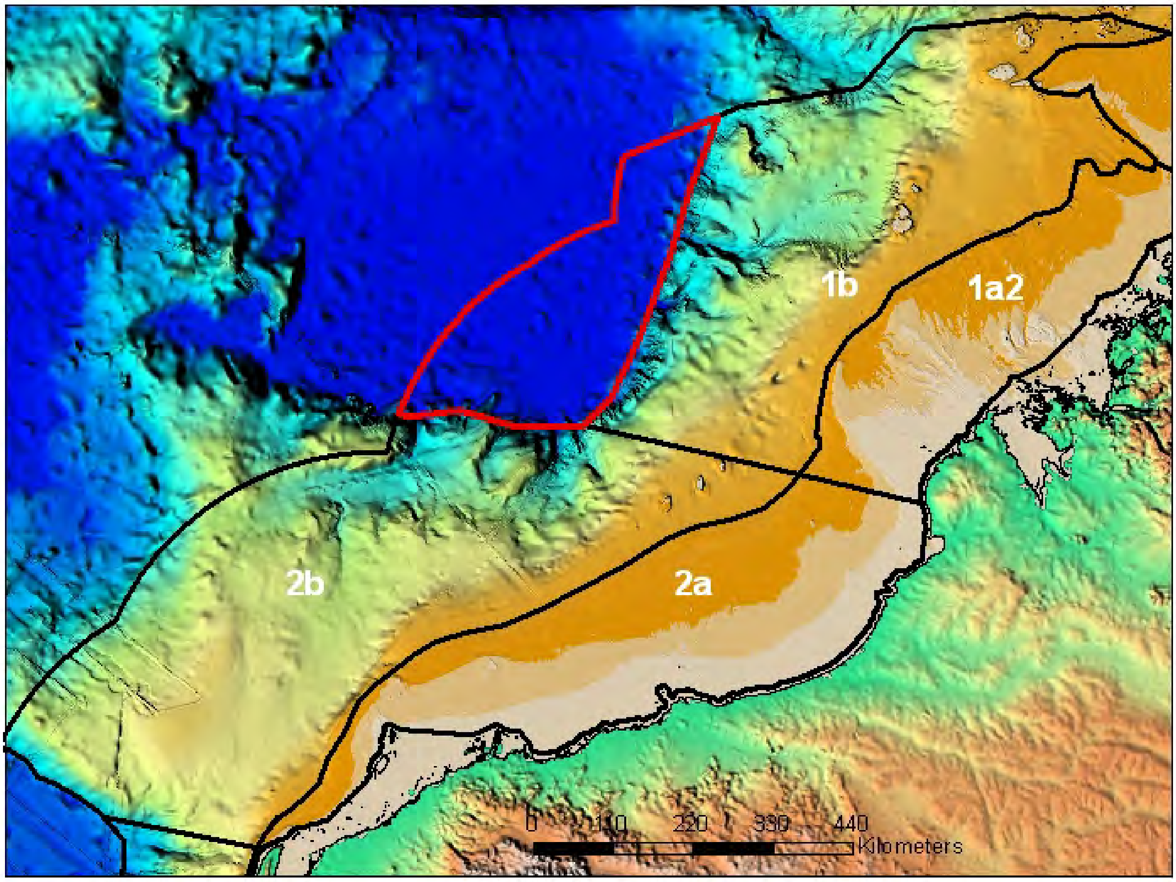


Figure 6-17 Argo Plain (red outline) and neighbouring sub-regions.

6.4.1 Drivers and physical features

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

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

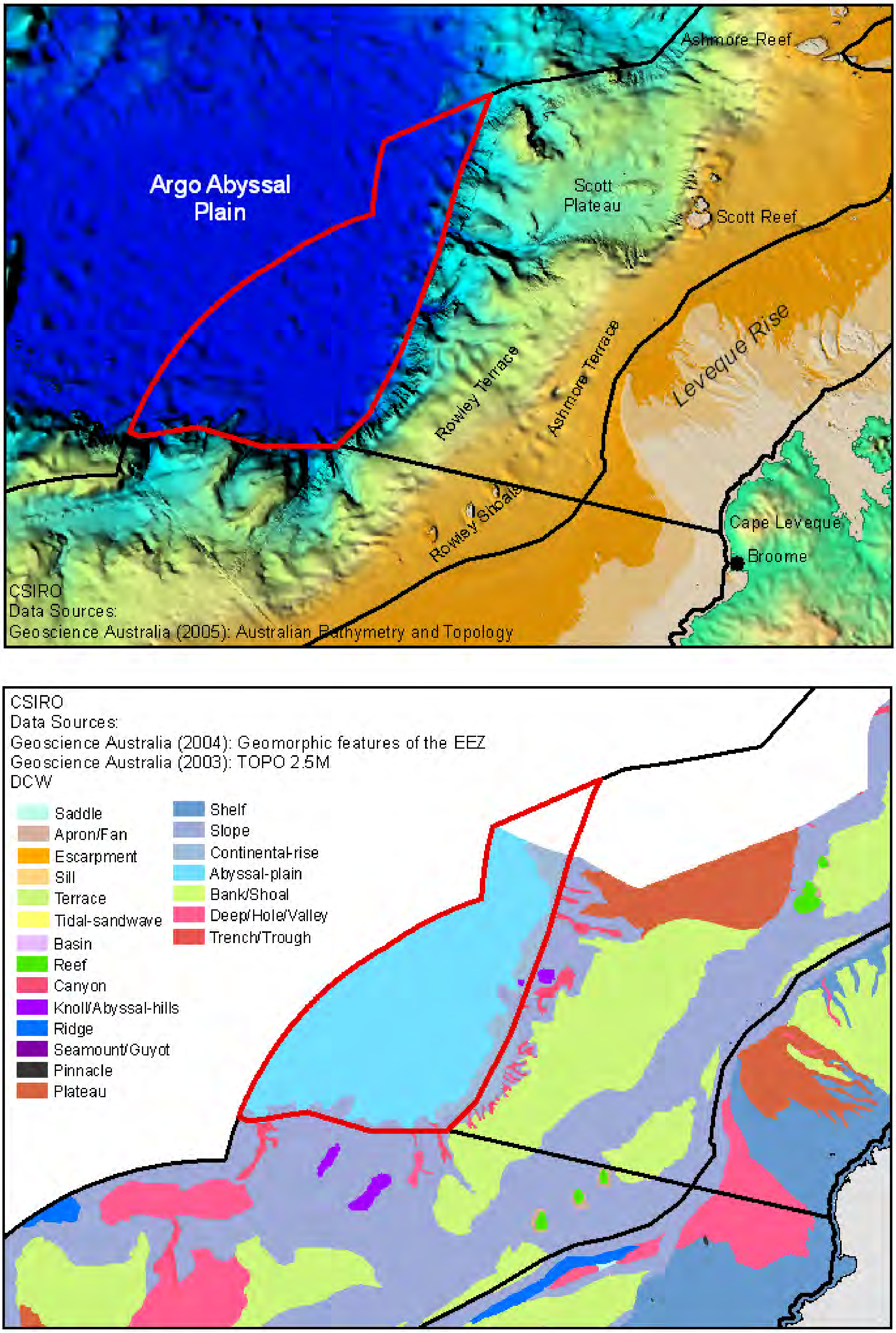


Figure 6-18 Argo Plain sub-region showing selected features (upper) and geomorphology (lower).

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

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

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

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

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

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

6.4.2 Trophic system features and dynamics

Pelagic environments

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

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

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

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

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

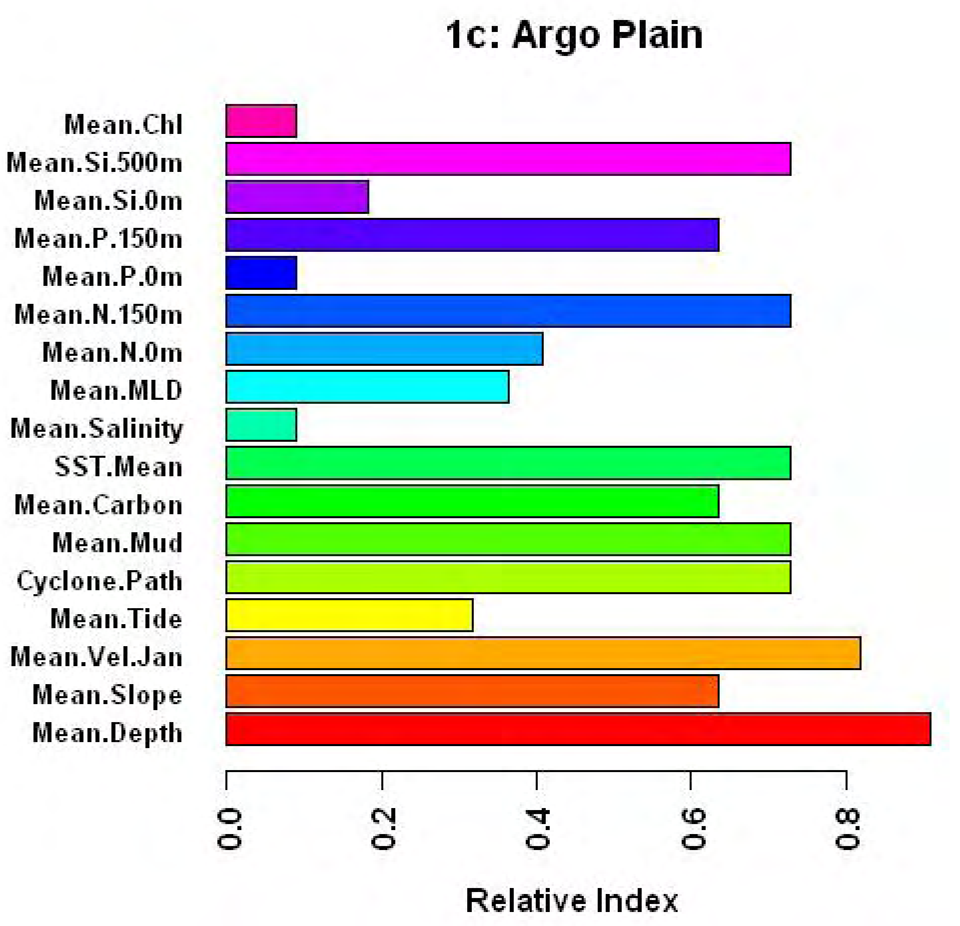


Figure 6-19 Summary physical data for the Argo Plain sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.

Benthic environments

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

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

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

6.4.3 Services and linkages

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

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

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

6.4.4 Key species interactions

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

6.4.5 Resilience and vulnerability

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

6.4.6 Information gaps

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

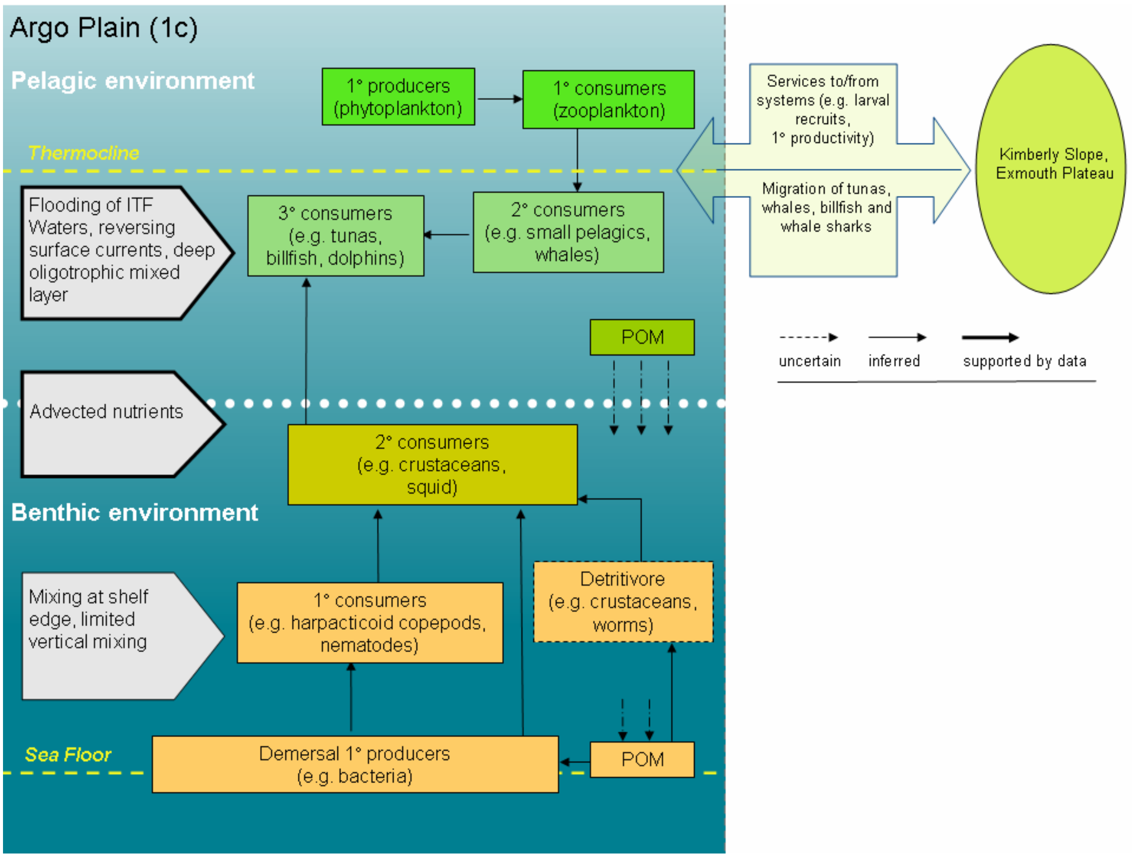


Figure 6-20 Conceptual trophic model of the Argo Plain sub-region showing information on the main habitat in the central basin.

System 1c - Argo Abyssal Plain

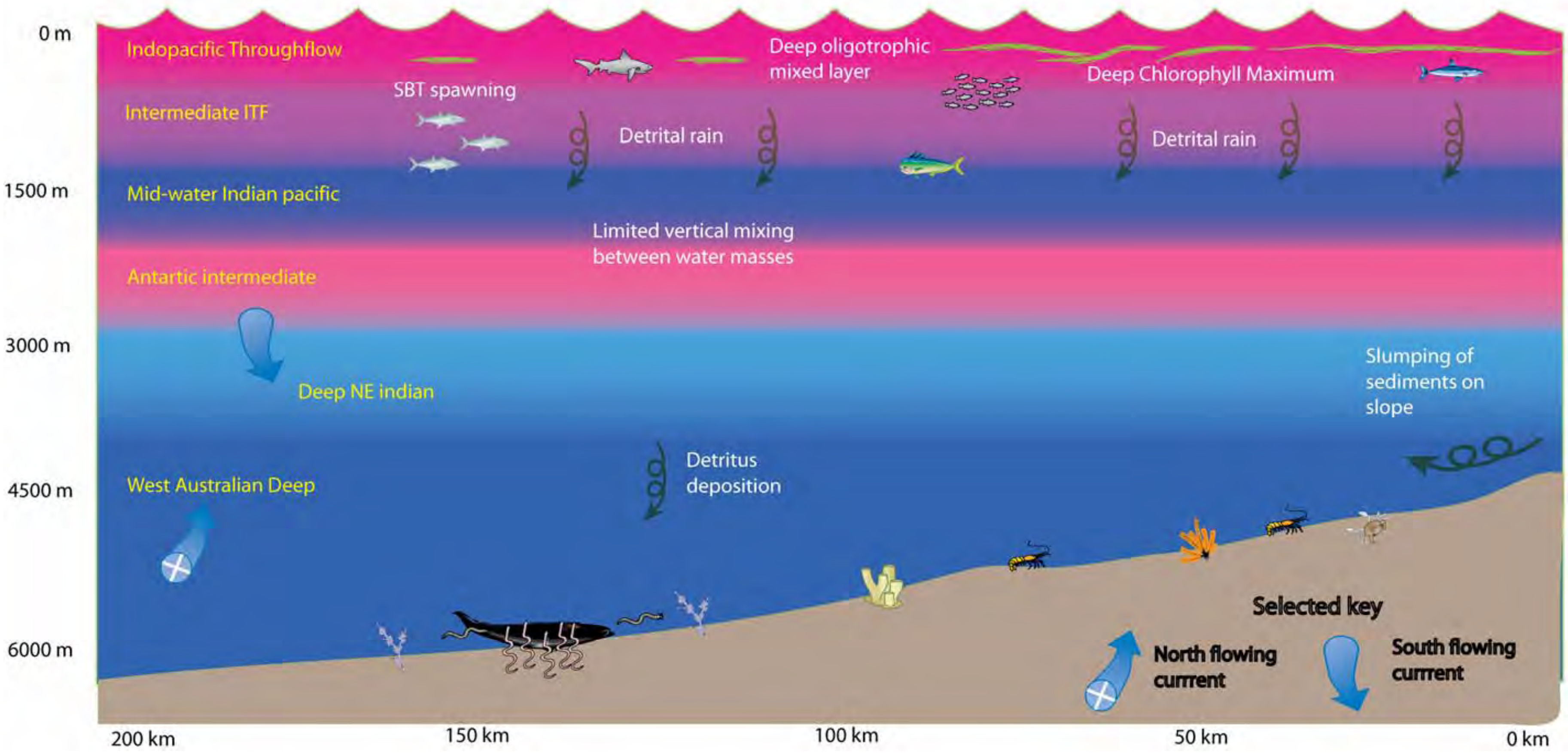


Figure 6-21 Habitat diagram of the Argo Plain sub-region showing selected important drivers and features. 70-100 m deep chlorophyll maximum not shown.

6.5 North West Shelf (2a)

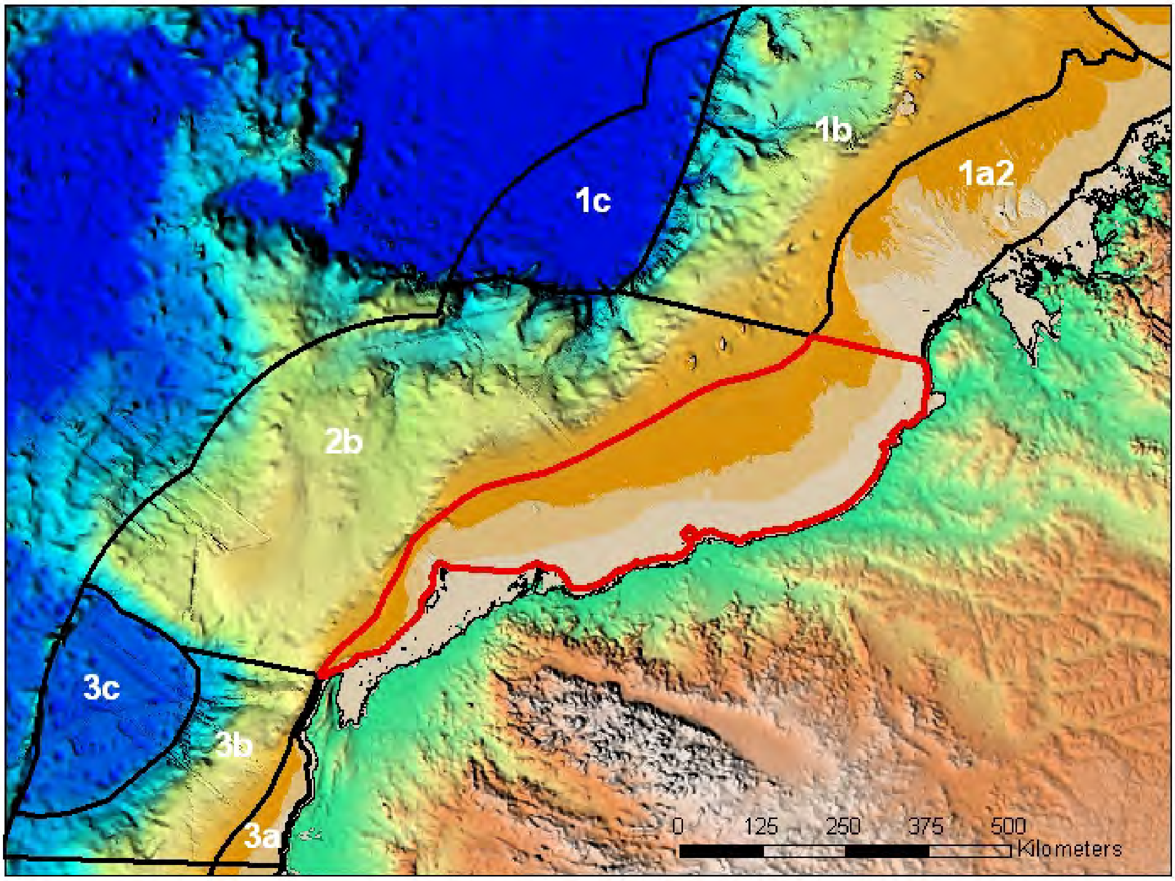


Figure 6-22 North West Shelf (red outline) and neighbouring sub-regions.

6.5.1 Drivers and physical features

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

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

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

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

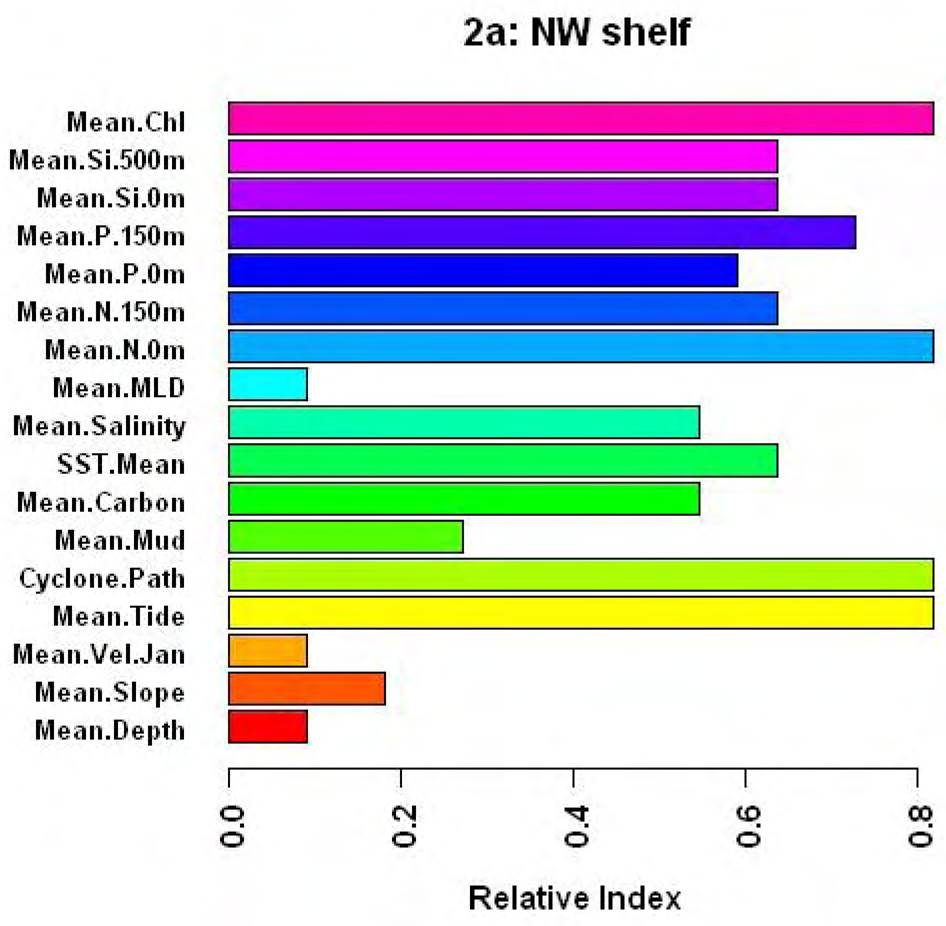
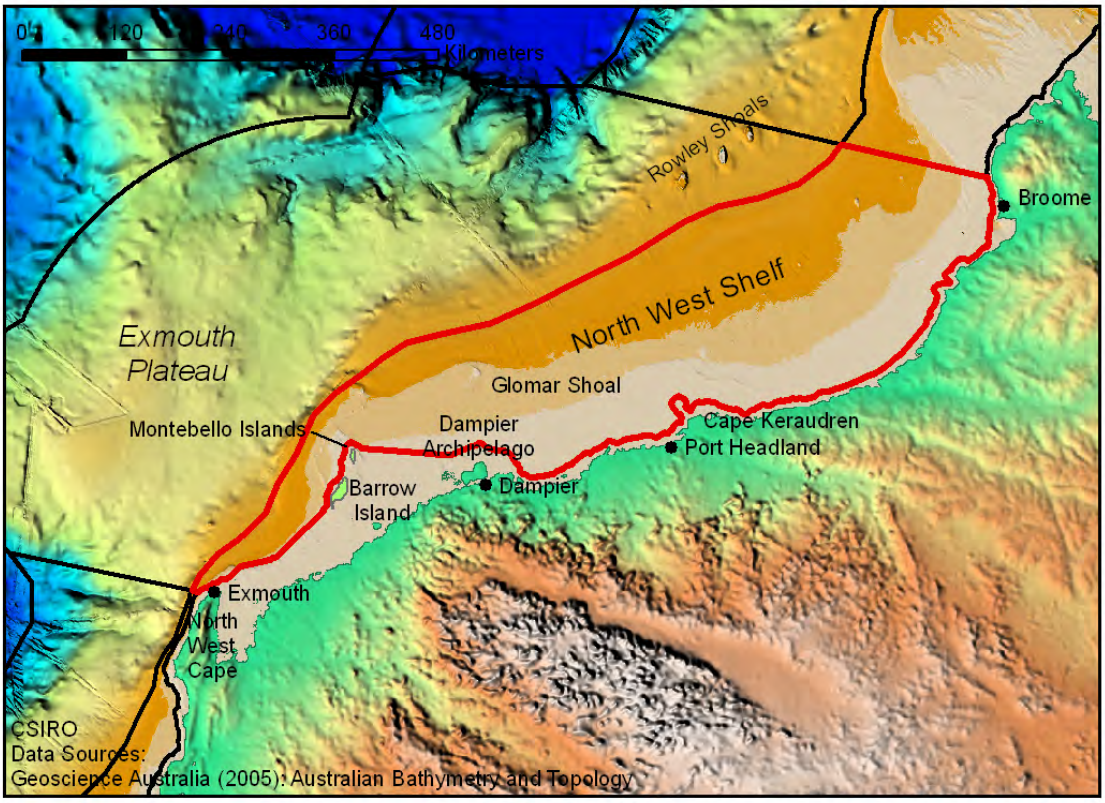


Figure 6-23 Summary physical data for the North West Shelf sub-region (more information available in Appendix 1). Each is relative to the highest value for that particular parameter within the North West Marine Region, standardised to a scale of zero to one.



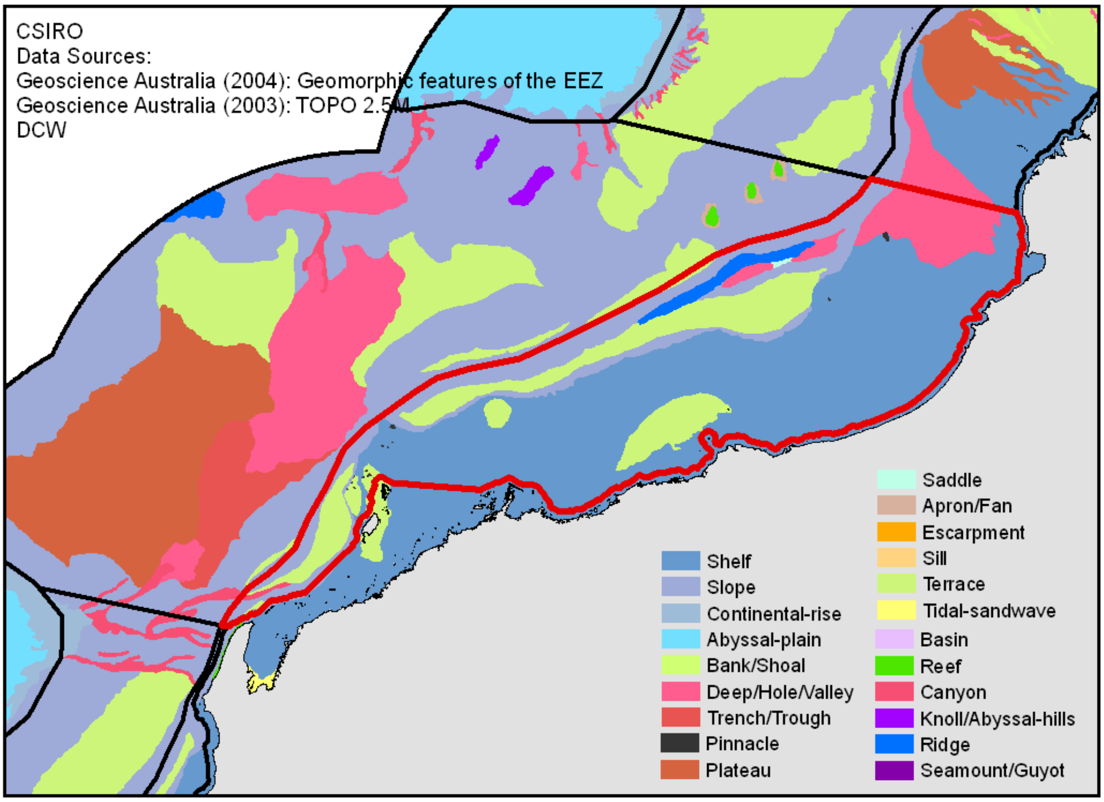


Figure 6-24 North-west shelf sub-region showing selected features (upper) and geomorphology (lower).

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

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

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

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

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

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

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

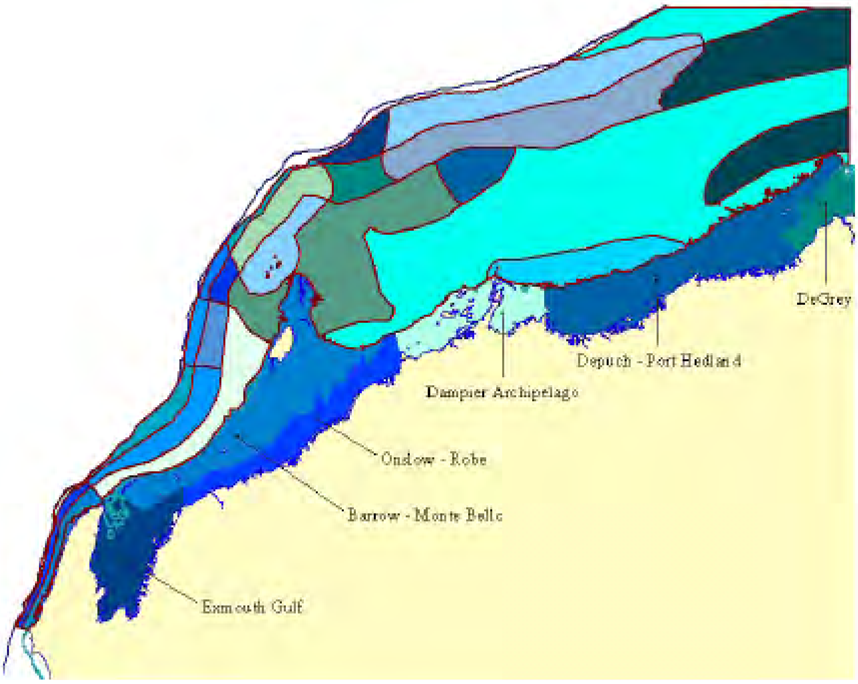


Figure 6-25 Spatial regionalisation of the North West Shelf from Lyne *et al.* (2006) based on expert information, research trawl data on fish catches and satellite/aerial images. The structures on the shelf, deeper than 20m or so are based on the CSIRO research trawl data (see Lyne *et al*. (2006) for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

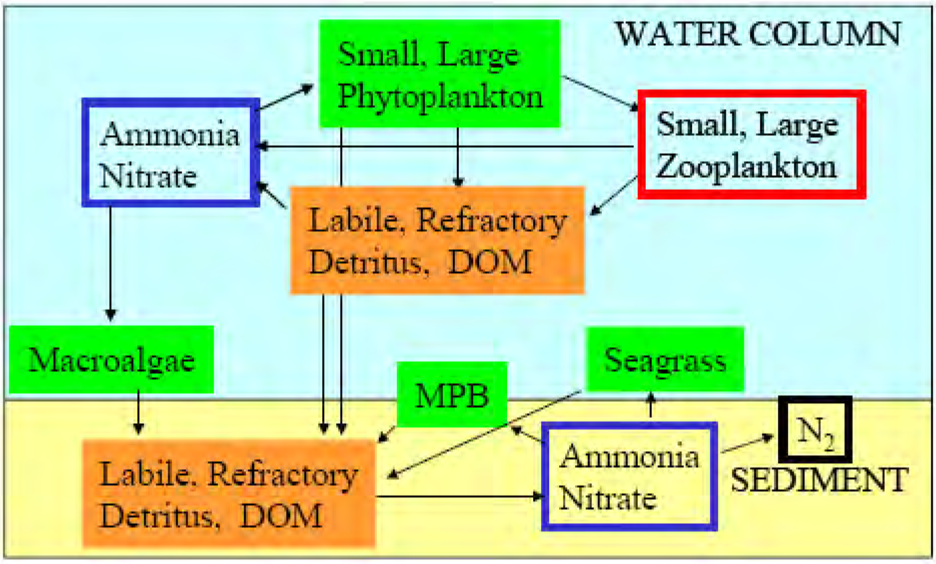


Figure 6-26 Schematic depiction of the model for nitrogen cycling for the North West Shelf used by Herzfeld *et al*. (2006) showing the interaction of pelagic, benthic and infaunal processes. (Figure reproduced from Hezfeld *et al*. (2006) with permission from Mike Herzfeld, CSIRO CMAR, Hobart). MPB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

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

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

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

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

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

6.5.2 Trophic system features and dynamics

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

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

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

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

Bulman (2006).

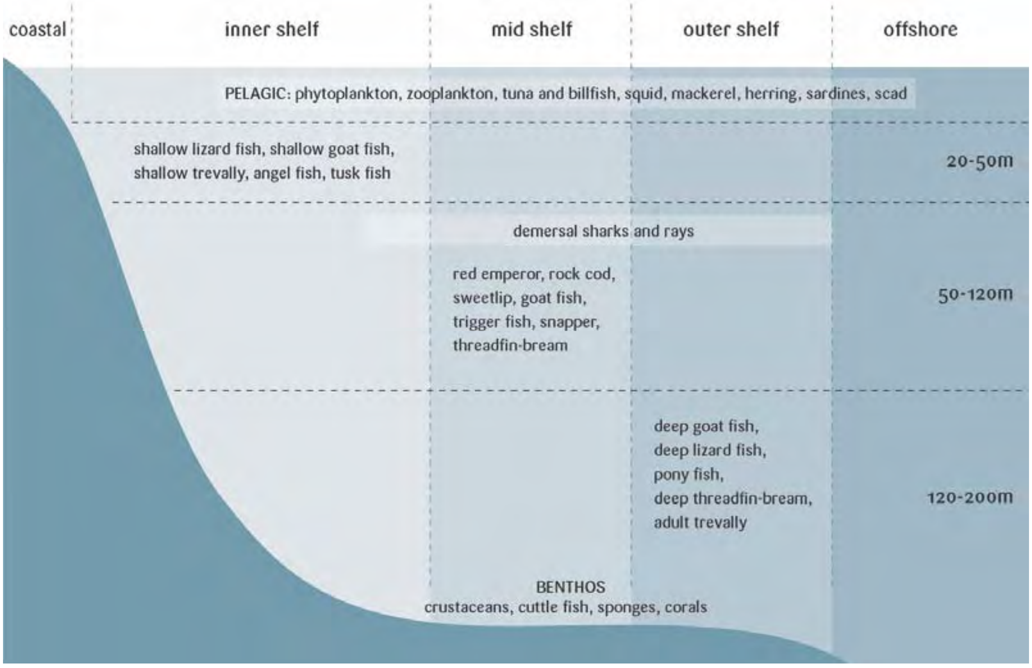


Figure 6-27 A spatial representation of key functional groups and species from the Bulman (2006) EcoSim/EcoPath model (Figure unpublished by Bulman and others (CMAR, CSIRO), pers. comm.)

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

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

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

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

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

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

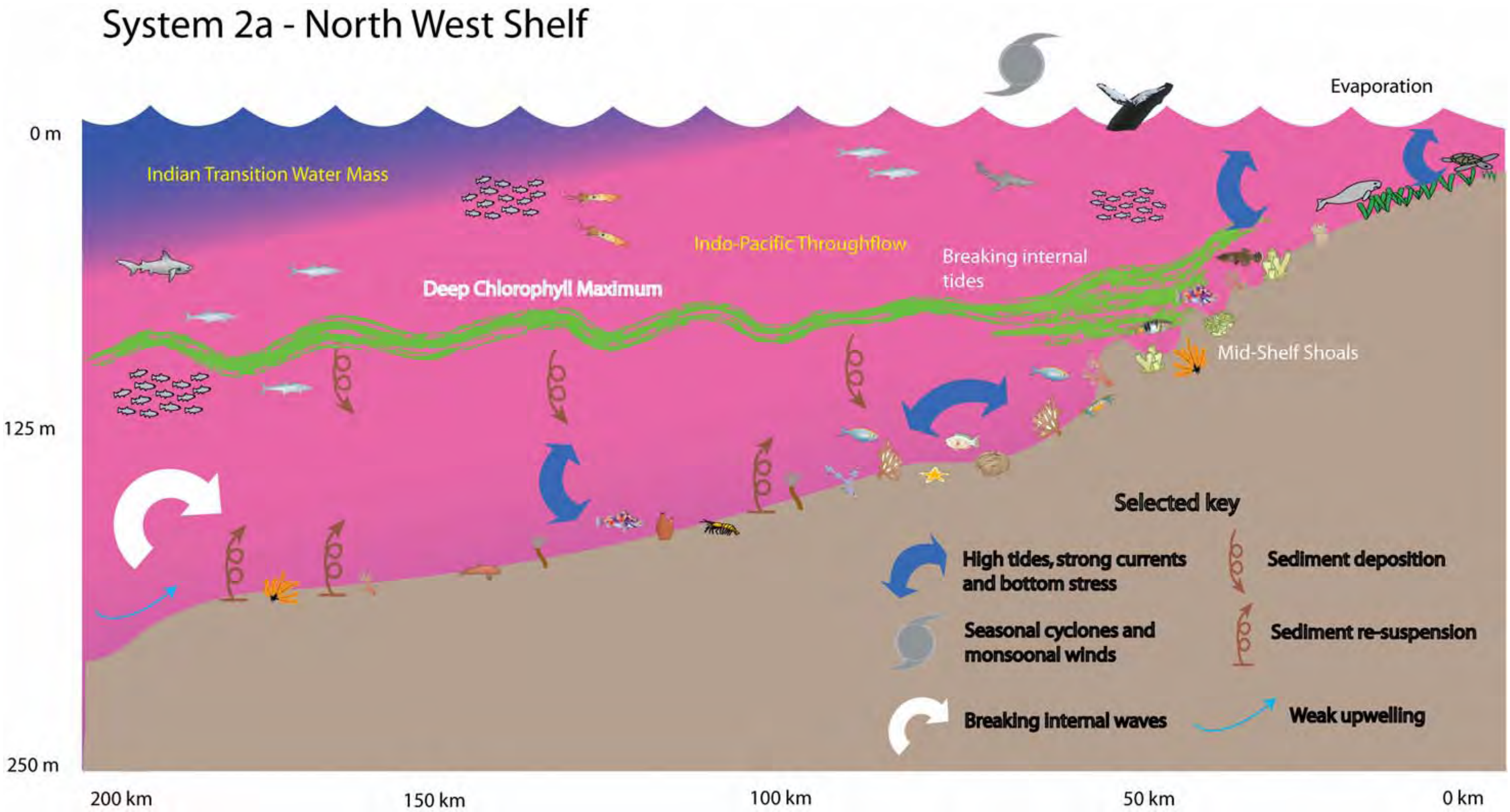


Figure 6-28 Habitat diagram of the NW Shelf sub-region showing selected important drivers and features.

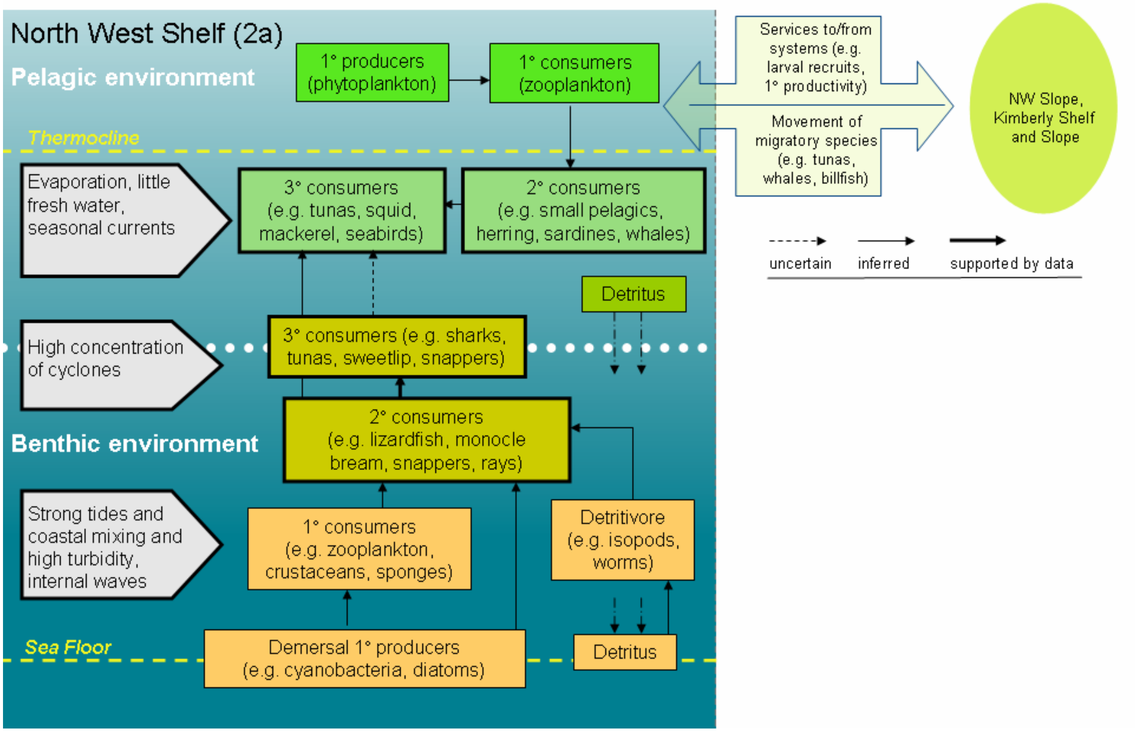


Figure 6-29 Conceptual trophic model of the NW Shelf sub-region showing information on the main habitat in the mid-shelf.

6.5.3 Services and linkages

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

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

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

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

Pearl oysters are an established aquaculture species for this region.

6.5.4 Key species interactions

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

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

Habitat 2	Description
B	Benthic
BP	Bentho-Pelagic
P	Pelagic

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

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

Some salient points to note from the table are:

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

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

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

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

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

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

6.5.5 Resilience and vulnerability

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

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

6.5.6 Information gaps

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

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