Marine Biodiversity Hub

National Environmental Science Programme

An eco-narrative of Kimberley Marine Park – North-west marine region

Marine Park Eco-narrative Series

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Project D1 – National data collation, synthesis and visualisation to support sustainable use, management and monitoring of marine assets

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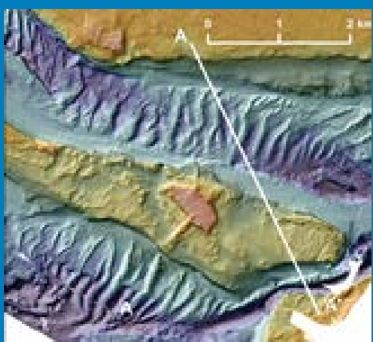
Final report on ecologically important features of selected Australian Marine Parks



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Important Disclaimer

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EXECUTIVE SUMMARY

This report is one in a series of eco-narrative documents that synthesise our existing knowledge of Australia's individual Marine Parks. This series is a product of the National Environmental Science Program Marine Biodiversity Hub Project D1, which seeks to collate, synthesise and visualise biophysical data within the parks. These documents are intended to enable managers and practitioners to rapidly ascertain the ecological characteristics of each park, and to highlight knowledge gaps for future research focus.

Kimberley Marine Park is characterised by a gently sloping seabed comprising platforms and terraces, crossed by a series of valleys and channels that incise 20 – 50 m into the seabed. These valleys define the ancestral pathways of the larger rivers that drain to the modern Kimberley coast, and where mapped in high resolution preserve the form of coastal estuaries. Today, these rivers do not supply large volumes of sediment to the offshore, with sediments in the marine park dominated by relict marine carbonates. Areas of stable hardground are restricted to small, flat-topped banks that rise to several metres above surrounding seabed. The oceanographic regime of the park is characterised by strong tidal currents, with the additional dynamic of internal waves that set-up strong currents with the capacity to transport sand as bedload. Together, these hydrodynamic conditions produce relatively turbid conditions and fields of large bedforms up to 8 m high. The regional-scale Holloway Current that feeds warm, oligotrophic waters from the north also influences the oceanography of the park. As a result, the surface waters have relatively low primary productivity.

The marine fauna observed within the park include a range of megafauna, notably humpback whales, dugong and turtles. The latter include a variety of turtle species that nest on islands outside Kimberley Marine Park (e.g. Lacepede Islands), but which have been tracked moving through the park. Similar tracking of humpback whales provides evidence that the park overlaps their migration route. Information on demersal fish and sharks within the park is lacking and is based on regional studies that suggest a high degree of endemism among the offshore fish species. Evidence of climate change influence in the Kimberley offshore region is provided in the sea surface temperature record, which shows a clear warming trend that is slightly higher than the national average; coupled with the impact of marine heat waves.

The benthic biological communities within Kimberley Marine Park include sessile and infaunal communities that are broadly typical of tropical northern Australia, though our knowledge of these assemblages is limited to a small number of surveys in targeted areas (e.g. Lynher Bank in the south of the park). These surveys observed relatively sparse epifauna communities, but included a number of species of coral and sponge that were observed for the first time in the park. It is therefore likely that the diversity of corals and sponges remains underestimated. Further sampling of these benthic communities is therefore warranted.

The information in this eco-narrative forms an initial characterisation of Kimberley Marine Park.

1. INTRODUCTION

Kimberley Marine Park is situated on the continental shelf and slope of the North-West Marine Region, and spans parts of the Kimberley and Northwest Shelf IMCRA mesoscale bioregions. Unlike many of Australia's marine parks, it extends to within 7 km of the mainland coast (Figure 1). The park covers an area of 74,468 km^2, across water depths of 0 – 614 m, and intersects two national Key Ecological Features (KEF's): (1) Continental Slope Demersal Fish Communities, and; (2) the Ancient coastline at 125 m depth contour. The park incorporates three levels of protection across four zones, including: a Multiple Use Zone (IUCN Vi) covering 62,411 km^2; two Habitat Protection Zones (IUCN IV) offshore from King Sound and together covering 5665 km^2, and: a National Park Zone (IUCN II) adjoining the Habitat Protection Zone and covering 6392 km^2.

The Kimberley Marine Park is adjacent to the Western Australian state marine parks – Lalang-garram/Camden Sound, North Lalang-garram and North Kimberley – thus providing a management framework that extends from the coast to offshore along the length of the Kimberley region.

This eco-narrative provides an overview of the current knowledge of the Kimberley Marine Park, including its oceanographic, geomorphic and biological values.

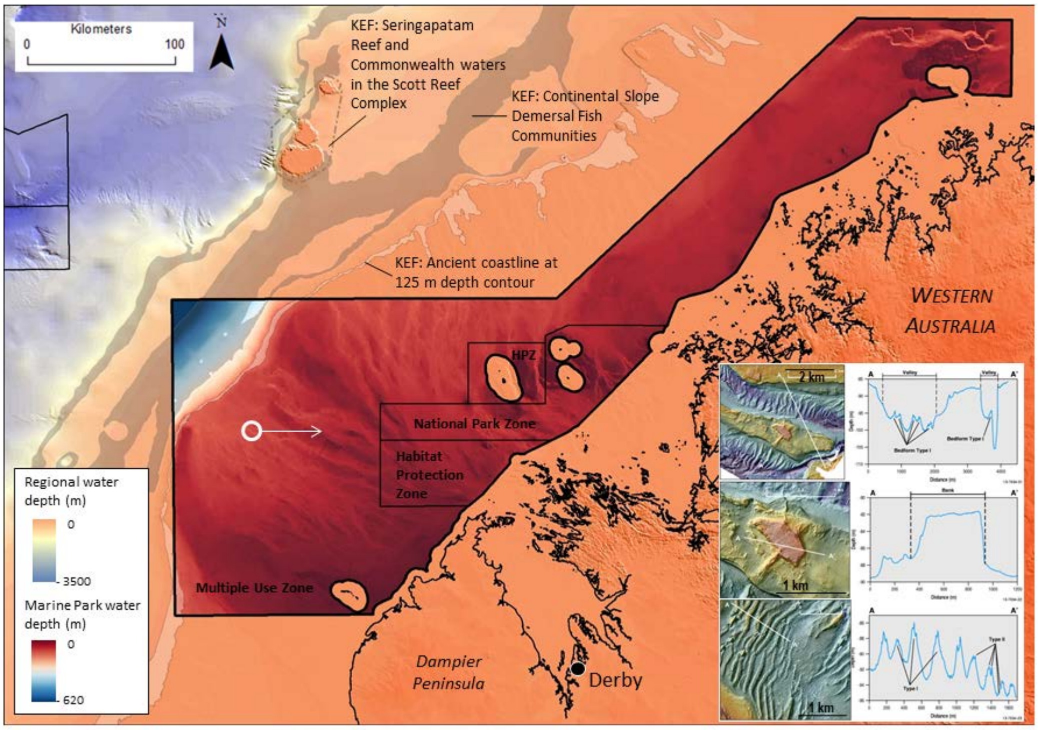

Figure 1. Kimberley Marine Park, showing hill-shaded 30 m bathymetry data (Geoscience Australia, 2018) overlaying the national 250m bathymetry grid (Whiteway, 2009). The park intersects two KEF's (labelled), and incorporates extensive palaeo-channel and palaeo-valley networks. Picard et al (2014) mapped high-resolution examples of bed features in the southern end of the park, illustrated in the inset figures of Valleys (top), Banks (middle) and Bedforms (bottom).

2. PHYSICAL SETTING

The Kimberley Marine Park is situated on Australia's North-West Shelf and slope, over the Leveque and Yampi shelves of the sedimentary Browse Basin (Picard et al., 2014). The park is over 700 km in length, is aligned sub-parallel to the shoreline, extends from 7 km to 270 km offshore, and is predominantly very low gradient (99% of the park has a gradient <2°). The Fitzroy River is the largest river in the region (Department of Water, 2015), and drains directly into King Sound near Derby (Figure 1). However, the Fitzroy River and abundant tributaries and tidal creeks that drain the Kimberley coastline contribute only negligible quantities of terrigenous sediment to the coast and Park, and sediments that comprise the seafloor are mostly relict marine carbonates (James et al., 2004; Collins, 2011; Picard et al, 2014).

Despite the proximity to the mainland coast and its position on the relatively shallow continental shelf, very little of the park is in particularly shallow water and lies mostly at a depth of 20-100 m. The low gradient submarine plain that dominates the park is traversed by a series of 20-50m deep valleys, palaeo-channels and valleys which extend sub-perpendicular to the shoreline in the southern region of the park, and terminate 200 km offshore near the "Ancient coastline at 125 m depth contour" KEF.

The climate in the Kimberley region is 'dry monsoonal', with distinct summer 'wet' (November to March) and winter 'dry' (May to September) seasons (Wilson, 2014). The monsoon season is dominated by the north-westerly winds, while the dry season is dominated by the south-easterly trade winds.

3. OCEANOGRAPHY

Overall, the surface waters in Kimberley Marine Park are characterised by relatively low primary productivity, with no obvious productivity hotspots. The long-term annual mean surface chlorophyll-a concentrations range from 0.2 - 0.8 mg/m^3, as modelled from satellite data (Figure 2a); winter and autumn levels are often higher than in summer and spring (http://northwestatlas.org/node/27500). While these values are among the highest in the north-west marine region and are consistent with measurements from field sampling (McLaughlin et al. 2019), they are similar to the national means.

Since 2002, satellite remote-sensing-derived sea surface temperatures (http://northwestatlas.org/node/27499) within Kimberley Marine Park display a clear warming trend at an annual rate of 0.054ºC (Figure 3a). This rate is slightly above the overall average across all Australian marine parks (0.046 ± 0.02ºC) (Figure 3b). The marine park is also impacted by marine heat waves, with the most recent being an unprecedented event in 2015-16 (Figure 3c), which was forced by a record El Nino event (Zhang et al., 2017; Le Nohaic et al., 2017). The 2015-16 marine heat wave started at the end of summer (Figure 3c&d), and continued well into spring (Figure 3c). The event peaked in July when SST reached 1.5ºC above average across the entire park (Figure 3c), and caused unprecedented regional mass bleaching of heat-tolerant corals off the coast of the Kimberley region (Le Nohaic et al., 2017).

Kimberley Marine Park is also affected by tropical cyclones, which can have destructive impacts on marine biological communities in shallower waters. Tropical cyclones affect both benthic and pelagic habitats by resuspending seafloor sediments. Such movement of sediment changes the seabed structure, increases turbidity and reduces light availability (Dufois et al., 2017). In the last 50 years, 88 tropical cyclones have crossed the marine park, the most recent of which were Tropical Cyclone Joyce (January 2018) and Tropical Cyclone Marcus (March 2018) (BOM). This translates to an average annual exposure to cyclone conditions that ranges from ~1.7 to 3.6 days in the far northeast to the far south east of the marine park respectively (https://atlas.parksaustralia.gov.au/amps/latest-maps/which-marine-parks-are-exposed-to-the-most-tropical-cyclone-activity?rsid=27184&featureId=AMP_NW_KIM – updated from Carrigan and Puotinen 2011).

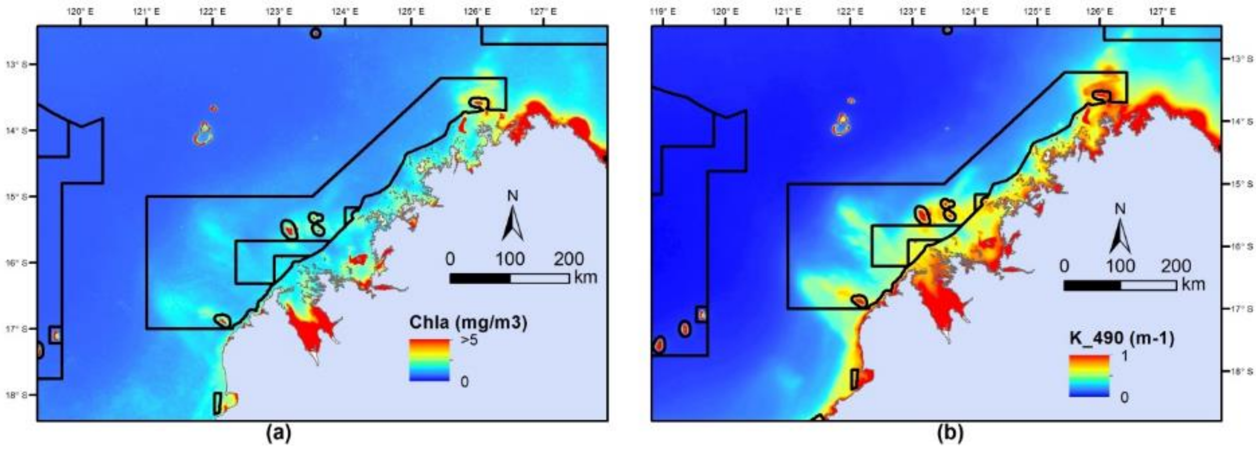

Figure 2: Sea surface properties across Kimberley Marine Park derived from MODIS satellite imagery for the period 2002 to 2017, showing: a) Mean annual chlorophyll-*a* concentration (0.48±0.145 mg/m^3); b) Mean annual K490 as a proxy for turbidity (0.065±0.025 m^{-1}).

The deepest waters of Kimberley Marine Park are influenced by the Holloway Current that flows to the south-west and parallel to the Kimberley coast (Holloway and Nye, 1985). The current is active throughout the year but exhibits strong seasonality, peaking in strength during autumn and winter (Holloway and Nye, 1985; Brink et al., 2007; D'Adamo et al., 2009; Bahmanpour et al., 2016). The Holloway Current transports warmer, lower salinity and oligotrophic water from the tropical regions into the Leeuwin Current (D'Adamo et al., 2009; Ridgway and Godfrey, 2015; Bahmanpour et al., 2016). Thus, it is likely to play an important role in transporting tropical species from the highly biodiverse, central Indo-West Pacific region to the north-western and south-western Australian regions (Wilson, 2014).

The inner shelf within Kimberley Marine Park, and indeed the entire Kimberley coast, is affected by strong tidal currents (Wilson, 2014) as the region has one of the highest tidal ranges in the world (up to 10m), and a semidiurnal spring-neap cycle (Holloway et al., 2001; Van Gastel et al., 2009). The tidal currents induce strong water column mixing and sediment resuspension, which produces higher turbidity and enhanced nutrient levels in some areas of the park (Figure 2).

Internal waves and internal tides also affect the Marine Park (e.g., Holloway, 1983; Holloway et al., 2001; Rayson et al., 2011), and in this region are generated by interactions between macro-tides, steep bathymetry across the shelf break and density stratification resulting from pronounced temperature differentials in the water column (Van Gastel et al., 2009; Rayson et al., 2011). The internal tide is generated over the upper-slope and shelf break during summer, forming reversing currents that flow both onshore and offshore at speeds up to 10- 50 cm/s near the seafloor (Holloway, 2001; Holloway et al., 2001; Rayson et al., 2011). These currents drive cross-shelf exchange via vertical mixing, sediment transport and biological productivity (Holloway, 2001).

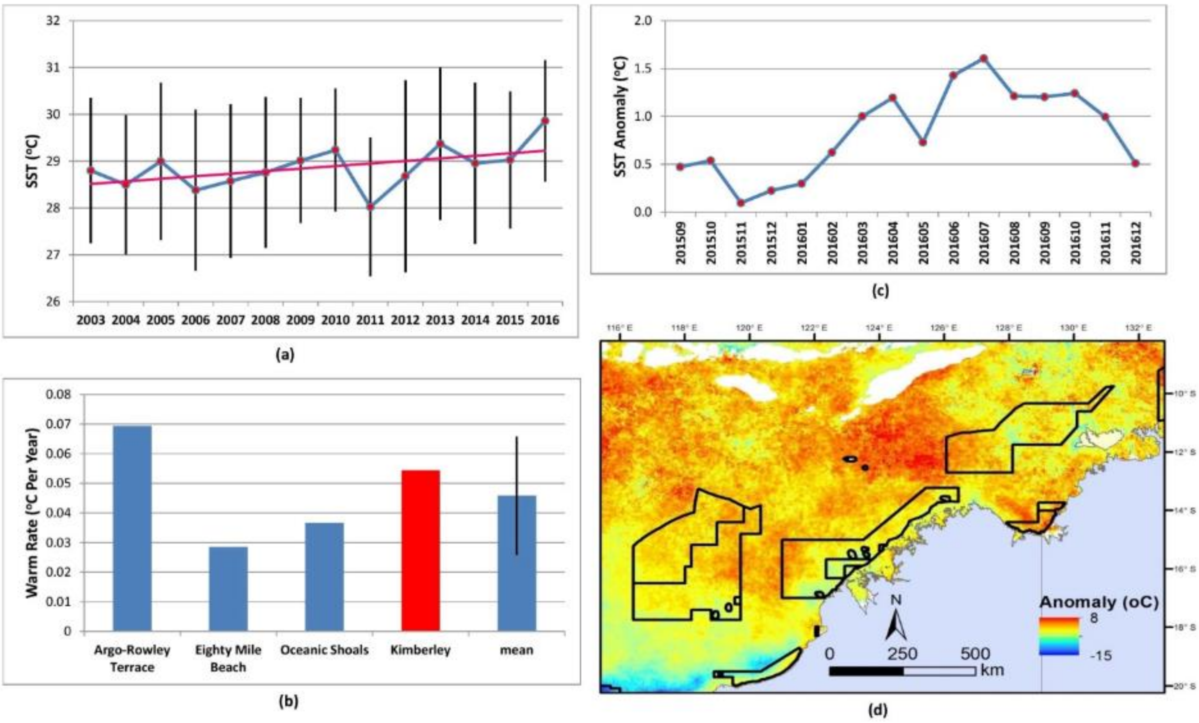

Figure 3. Sea Surface Temperature (SST) trends within Kimberley Marine Park, derived from MODIS satellite imagery for the period 2003 to 2016, showing: a) Annual average (blue line) and standard deviation (vertical bars); b) Warming rate (ºC per year) for Kimberley Marine Park and three other marine parks in the north-west region against the national mean (and standard deviation) for all marine parks; c) Monthly SST anomalies from the long-term average (2003-2016) in Kimberley Marine Park during the 2015-16 marine heat wave event; d) SST anomaly map for the marine heatwave of March 2016 when coral bleaching occurred in the north-west region (Le Nohaic et al., 2017).

In winter, dense shelf water cascades can occur in the Kimberley region and contribute to cross-shelf exchange within the marine park (Shearman and Brink, 2010; Mahjabin et al., 2016). This is caused by a cross-shelf density gradient, resulting from high evaporation during the summer and cooling during winter. Dense shelf water cascades drive higher density coastal water along the seabed in the offshore direction. As a result, they have potentially important ecological and biological implications in the park by transporting nutrient-rich coastal materials to deep water (Mahjabin et al., 2016).

4. GEOMORPHOLOGY AND POTENTIAL HABITATS

The Kimberley Marine Park is situated predominantly within the Browse Basin, a geological structure comprised of sub-horizontal accumulations of sediment on the shelf that extend offshore into thick (15 km deep), dipping successions on the continental slope and the abyss (Blevin et al., 1998). These deposits have been the focus of regional hydrocarbon extraction outside the park, and investigations for potential CO_2 sequestration within the south-western end of the marine park (Picard et al., 2014; Howard et al, 2016).

Regional-scale geomorphic features within the park include extensive platforms and terraces, with many smaller banks and shoals scattered across these low gradient features (Heap and Harris, 2008; Figure 4). Palaeo-channels and palaeo-valleys also dominate the seafloor as evidence that rivers and coastal lowlands formed on the shelf during periods of lower sea level in the recent geological past (e.g. last ice age, ca. 18,000 years before present).

Picard et al (2014) presented high-resolution (2 m) bathymetric and sub-bottom surveys of the south-western corner of the park. These data reveal that much of the seabed is characterised by a complex network of banks and terraces (Figure 1, inset), interspersed with valleys and channels that are remnants of drowned palaeo-estuaries. These channel networks are aligned sub-perpendicular to the shoreline in the southern half of the park, whereas channel-networks in the northern end of the park are aligned sub-parallel with the shoreline (Figure 1). In places the channels and valleys that traverse this drowned coastal system clearly link to the "Ancient coastline at 125 m depth contour" KEF.

The seafloor surface is cemented in many places, with veneers of relict and modern sand and gravel, typically rich in carbonate material (James et al., 2004; Picard et al, 2014). Picard et al. (2014) photographed small sand ripples, transported by the modern < 0.5 m/s near bed current speeds modelled by Holloway and Rayson (see Section 3), and identified small patches of pockmarks. Much larger ridges and bifurcating and sinusoidal crested ripples and dunes were also revealed in their survey; these are the reworked remnants of the lowstand palaeo-systems, preserved near the surface as a result of low modern sediment accumulation rates (Picard et al., 2014; Figure 1 inset). High tidal energy, cyclonic storms, long period swells, and internal waves that typify the region are capable of resuspending fine-grained modern sediments, resulting in high turbidity within the park (Margvelashvili et al., 2006) (Figure 2b).

A new seafloor mapping scheme Nanson and Nichol, 2018) has been applied to the 30 m resolution bathymetry grid, which covers 100% of the marine park (Geoscience Australia, 2018). By linking the seafloor morphology to geomorphic process and substrate we can provide an assessment of the potential habitats in the park. The seafloor is divided into three slope categories that represent broad habitat settings: 99% of the park area is classed as low gradient *Plane (*<2°) and 1% as either *Slope* (2-10°) or *Escarpment* (10-90°) (Figure 4).While *Plane* Surfaces dominate most of the Kimberley Marine Park, *Slope* and *Escarpment* features define the boundaries of the Banks, Shoals, Channels and Valleys. These steeper features are characterised by consolidated material close to the surface and presumably provide locally rare, but important, habitat for sessile organisms adjacent to the channels that probably function as conduits for high-energy, nutrient-bearing tidal flows.

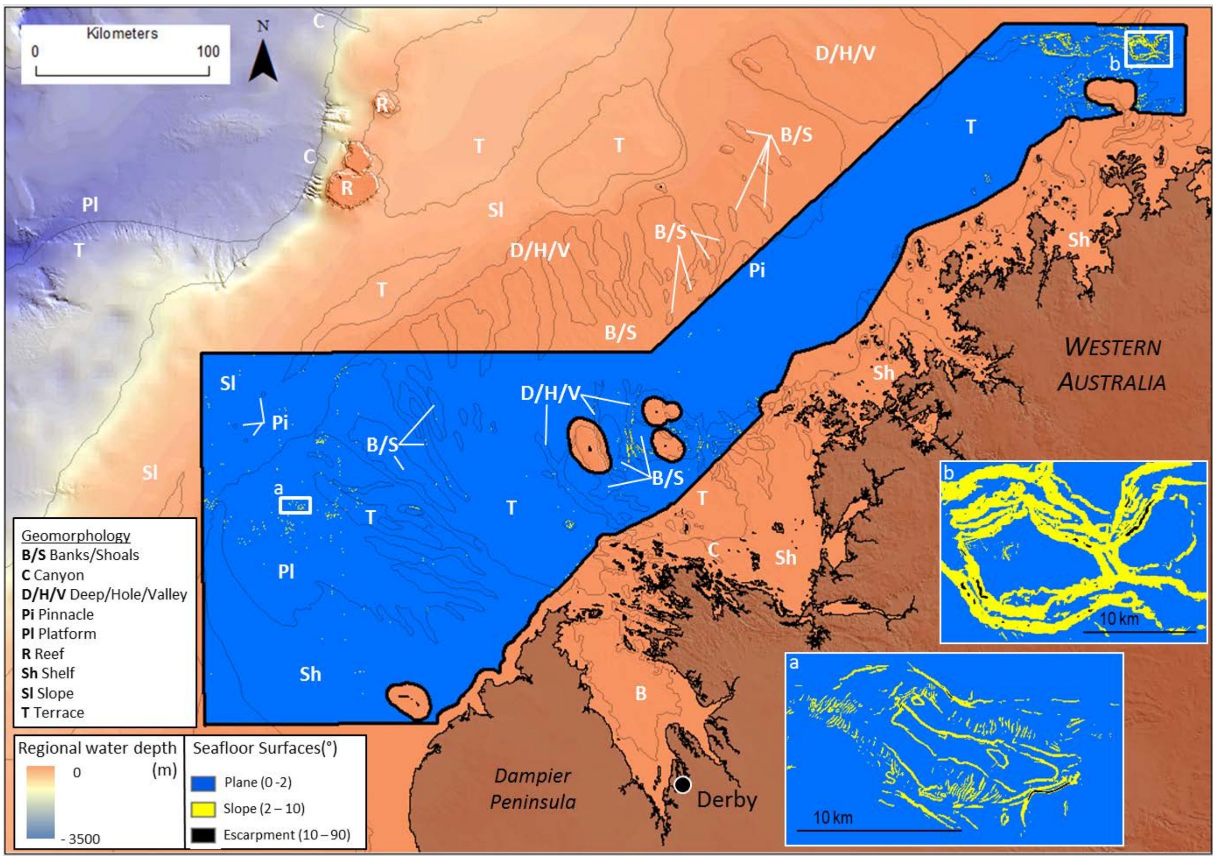

Figure 4. Geomorphic features of Kimberley Marine Park and adjacent area. Geomorphic units include Terrace, Platform, Banks and Shoals, and Deep/Hole/Valley (Heap and Harris, 2008). A 30 m bathymetry grid (Figure 1; Geoscience Australia, 2018) was used to classify seafloor Surfaces as Plane, Slope and Escarpment. While much of the Marine Park is dominated by low gradient Plane, insets (a; south-west) and (b; north-east) illustrate the steeper Surfaces that border valleys, channels and shoals.

5. THE ECOLOGICAL SIGNIFICANCE OF KIMBERLEY MARINE PARK

5.1 Marine megafauna

5.1.1 Cetaceans and dugongs

Kimberley Marine Park is on the migration route for a range of cetaceans, including humpback whales and possibly pygmy blue whales. Humpback whales (*Megaptera novaeangilae*) migrate between tropical breeding grounds of northern Australia and Antarctic feeding grounds (Rosenbaum et al 2014). They are currently listed in Australia as a threatened species under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) despite the IUCN recently downgrading their status on the Red List from ‘vulnerable’ to ‘least concern’ due to population recovery efforts (Bejder et al 2016). Within Kimberley Marine Park region, modelling of aerial survey data of humpback whales from 2006, 2007 and 2008 demonstrated that up to four whales per square km can be expected to be present within the south-eastern, and to a lesser degree, the north-eastern sections of the park, peaking in mid-August in waters around 35 m deep (Thums et al 2018). This may be an underestimate given that the data are now almost ten years old. A recent analysis of satellite tracking data of 35 humpback whales to estimate the probability distribution across the region (Figure 5) found a more expanded spatial area of use than suggested from aerial data. This is consistent with the greater spatial coverage of satellite-tracking data than aerial surveys (M. Thums, unpublished data).

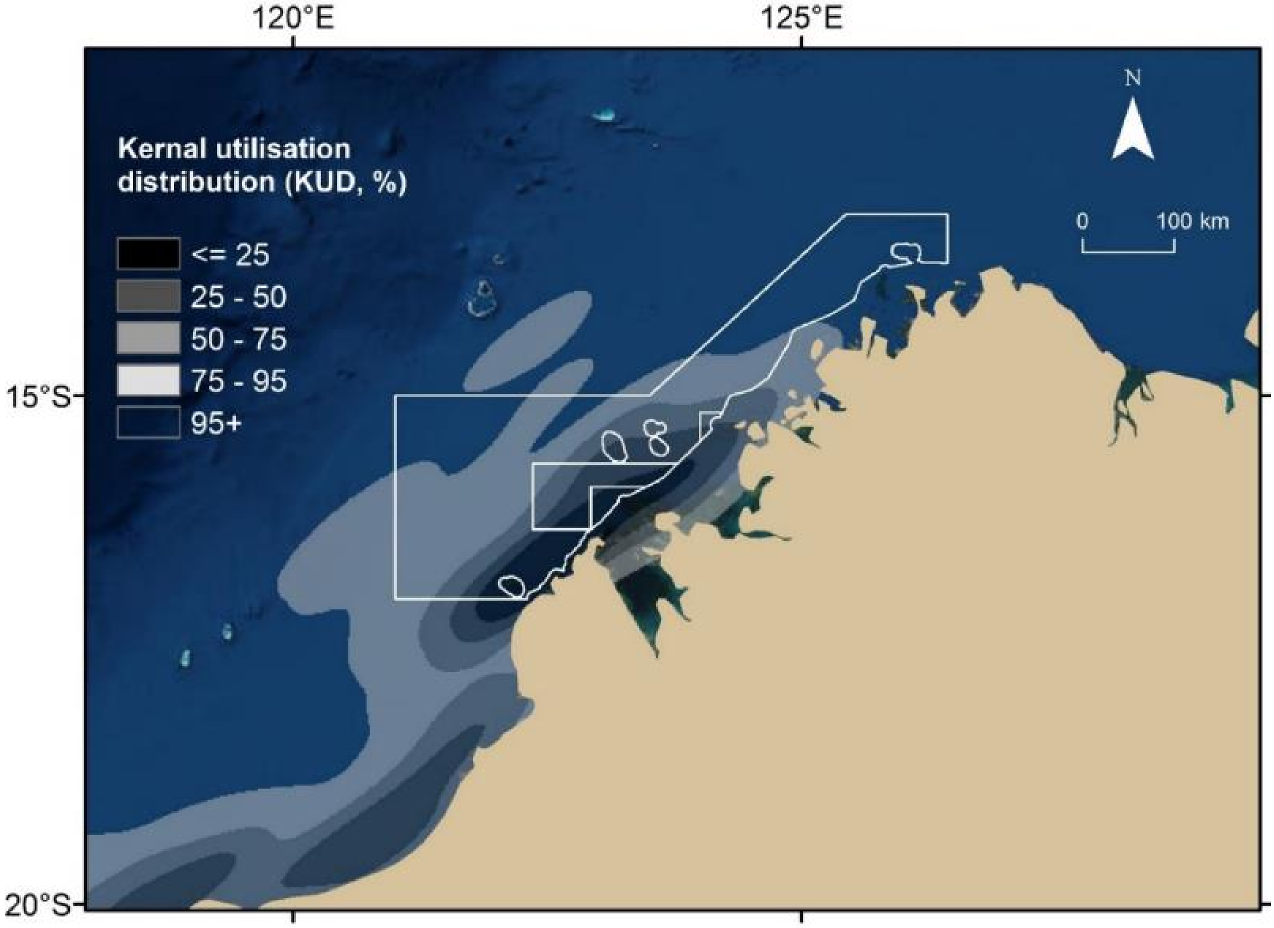

Figure 5. Probability distribution for the presence of humpback whales based on a kernel utilisation distribution (KUD) derived from satellite tracking data from 2009 and 2011. Lower KUD values indicate higher densities of points and thus greater likelihood of use by whales. Kimberley Marine Park boundary is shown in white.

Pygmy blue whales (*Balaenoptera musculus brevicauda*) are known to feed offshore from western and southern Australia in the austral summer, though in general their distribution and migration patterns are poorly known (Double et al 2014) and the IUCN Red List categorizes them as 'data deficient' (Cetacean Specialist Group 1998). Data from 11 pygmy blue whales fitted with satellite tags in Perth Canyon was used to measure the time each whale spent along the Western Australian coast (Double et al 2014). From these data, the probability distribution for the presence of pygmy blue whales was estimated as described above for humpback whales (Figure 6). However, only two whales were tracked long enough to traverse this area on their northern migration (unpublished data, M. Thums), and only one whale was tracked long enough to provide data during the southern migration. For the latter, the data were intermittent (Double et al 2014). Although there is no evidence that pygmy blue whales traverse the Kimberley Marine Park (Figure 6), the data are extremely limited, so they cannot be discounted as occurring in the park.

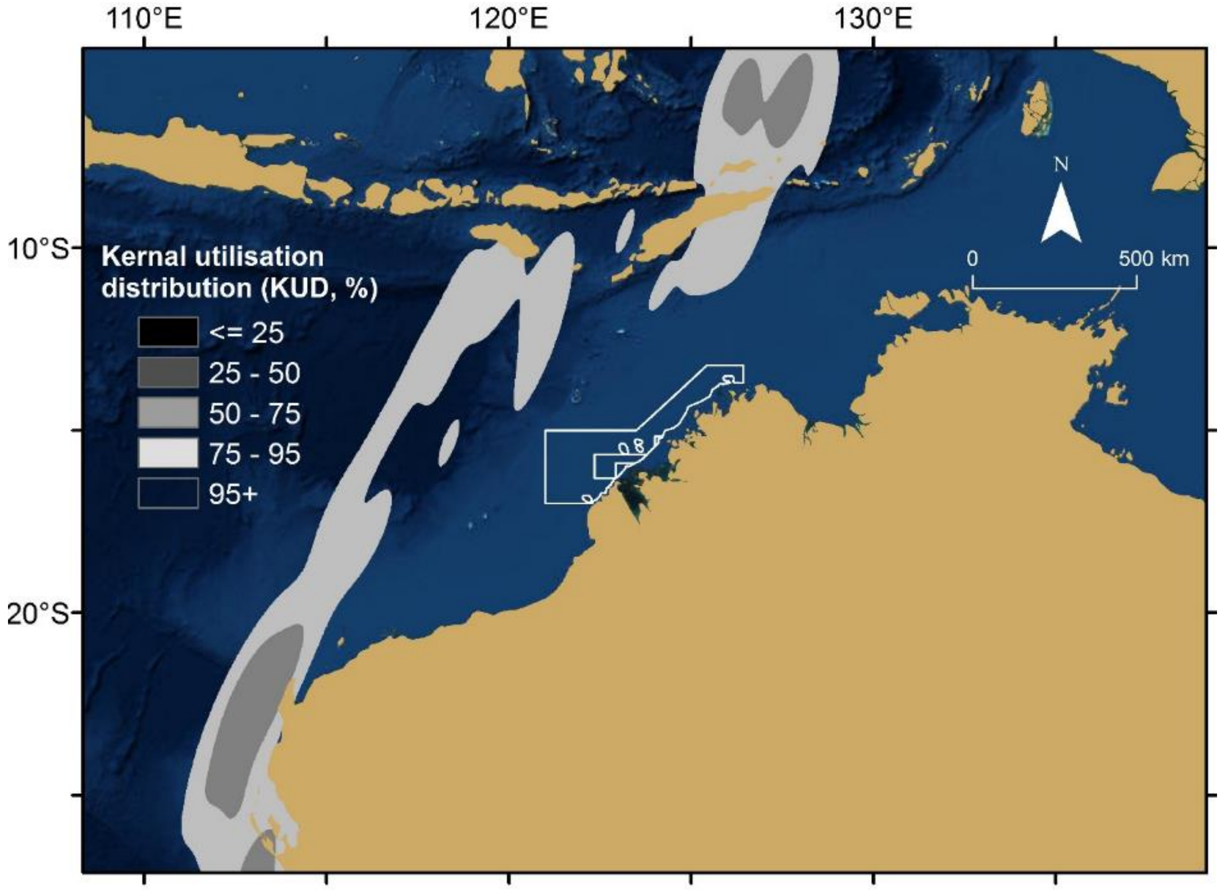

Figure 6. Probability distribution for the presence of pygmy blue whales based on a kernel utilisation distribution (KUD) derived from satellite tracking data for two animals. Lower KUD values indicate higher densities of points and thus greater likelihood of use by whales. Kimberley Marine Park boundary is shown in white.

The IUCN lists dugongs (*Dugong dugon*) as 'vulnerable to extinction' (IUCN 2011) due to global losses of their primary food – seagrass (Tol et al 2016). While seagrasses in many areas are under threat from coastal development and declining water quality (Hughes et al 2008), in north-eastern Australia, recent seagrass loss has been attributed to severe weather events (Tor et al 2016). Seagrass in coastal north-west Australia remains relatively free of threats from human activity (Bayliss and Hutton 2017) but more work is needed to assess their recent exposure to damage from storms. In Australia, dugongs range from Moreton Bay in south-east Queensland to Shark Bay in Western Australia (Marsh et al 1999), and have been observed in south-eastern parts of the Kimberley Marine Park (personal communication, M Thums) where shallow water (< 20 m) extends into the marine park (Figure 7). Indeed, a recent report used high resolution (5m) aerial survey data to confirm that a hotspot of dugong abundance exists in this section of the marine park (Bayliss and Hutton 2017).

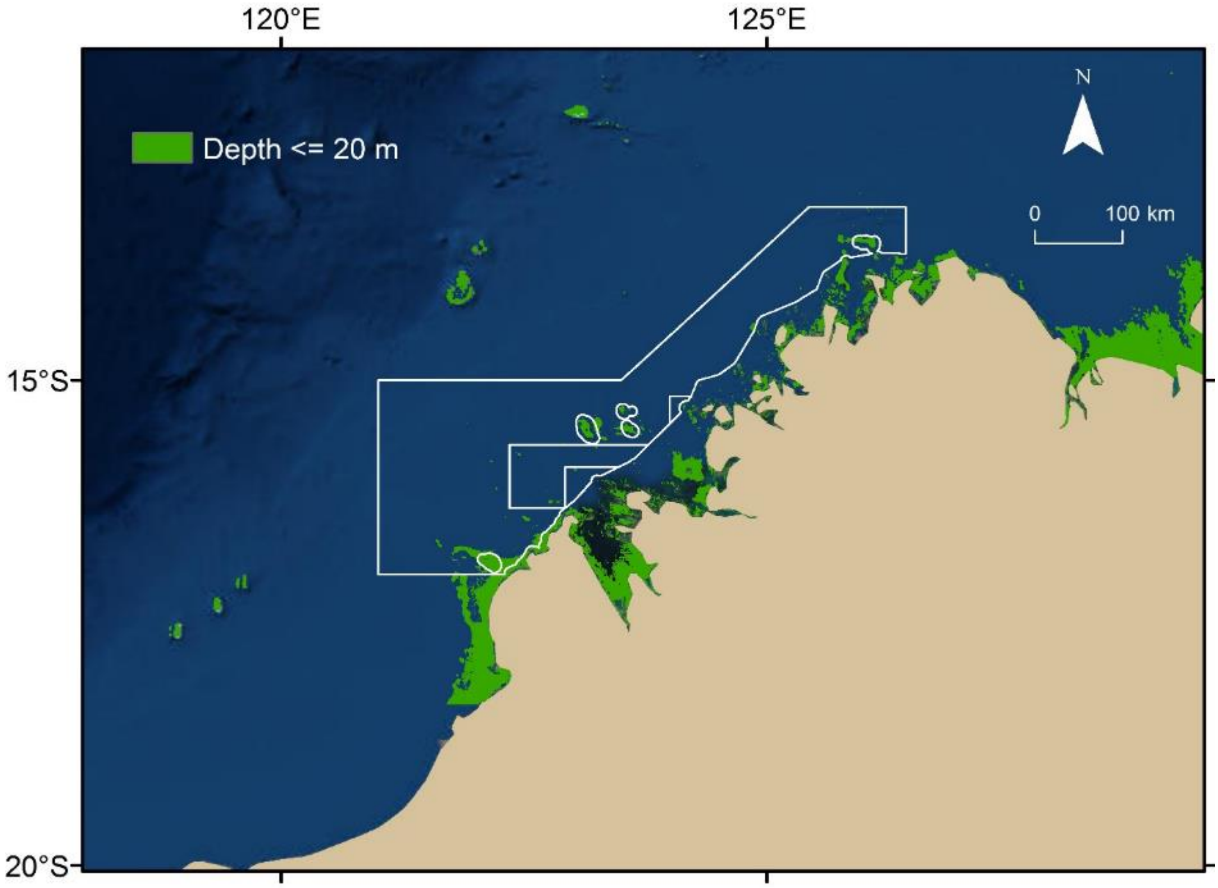

Figure 7. Distribution of shallow water (depth <= 20m) within and adjacent to the Kimberley Marine Park, where Dugongs are likely to occur in the Multiple Use Zone in the southeast of the park.

5.1.2 Turtles

All but one of the seven species of marine turtles either nest or forage, or both, in Australian waters, namely green, loggerhead, olive ridley, leatherback, hawksbill, and flatback turtles (Commonwealth of Australia 2017). All species are either listed as endangered, threatened or vulnerable under both the EPBC Act and the Western Australian Wildlife Conservation Act 1950 (WCA50). While none of these species are likely to nest inside the Kimberley Marine Park (several nest on the Lacepede Islands which are inside the boundaries, but excluded from, the marine park), their known or likely range overlaps at least in part with the Kimberley Marine Park (Commonwealth of Australia 2017). All are at risk from a number of threats, including climate change, marine debris, chemical and terrestrial discharge, predation from humans, fisheries bycatch, light pollution, habitat loss, Indigenous hunting, vessel interactions, noise, recreational activities and disease (Commonwealth of Australia 2017).

'Vulnerable' green turtles *(Chelonia mydas)* in Australia that nest along the North-West Shelf and at Scott Reef are known to disperse throughout the Kimberley Marine Park while foraging and migrating (Commonwealth of Australia 2017). Nesting areas identified as critical to their survival include the Lacepede Islands located near the park. Green turtles that nest along the North-West Shelf are most under threat from acute chemical and terrestrial discharge and light pollution, while climate change, and acute and chronic discharge most threaten those that nest at Scott Reef (Commonwealth of Australia 2017).

'Endangered' loggerhead turtles *(Caretta caretta)* that nest within Western Australia have been tracked throughout the Kimberley Marine Park (Commonwealth of Australia 2017). They are most threatened by climate change, acute discharges, and domestic fisheries bycatch (Commonwealth of Australia 2017).

'Endangered' olive ridley turtles *(Lepidochelys olivacea)* that nest in Indonesia may track within the northernmost parts of the Kimberley Marine Park (Commonwealth of Australia 2017). Threats to this stock of olive ridley turtles have not yet been documented.

'Endangered' (EPBC) and 'Vulnerable' (WCA50) leatherback turtles (*Dermochelys coriacea*) that nest throughout Indonesia likely track within the northernmost parts of the Kimberley Marine Park (Commonwealth of Australia 2017). These turtles are most at threat from climate change, ingestion of marine debris, international take outside of Australia's jurisdiction, and international and domestic fisheries bycatch (Commonwealth of Australia 2017).

'Vulnerable' hawksbill *(Eretmochelys imbricata)* have not been observed to track within the Kimberly Marine Park even though the park may fall within their home range (Commonwealth of Australia 2017). They are most at risk from international take outside Australia's jurisdiction, climate change and light pollution (Commonwealth of Australia 2017).

Flatback turtles (*Natador depressus*) nest only in northern Australia though they can forage as far afield as Papua New Guinea and Indonesia (Commonwealth of Australia 2017). Nesting areas identified as critical to their survival include the Lacepede Islands located within but excluded from the park. The area that they use during the inter-nesting period is contained within the park (Fig. 8a). Flatback turtles that nest in Western Australia are most at risk from international take outside Australia's jurisdiction, climate change and light pollution (Commonwealth of Australia 2017).

A recent study attached satellite trackers to 11 flatback turtles nesting in the Lacepede Islands (Figure 8-B) near Broome and tracked their movements for up to 830 days (Thums et al 2017). Switching state-space models were used to objectively determine the behaviour of the turtles from the tracks and then kernel utilisation distribution was used to map turtle space use overall, while nesting, while foraging and while migrating (transiting). Nesting (Fig 8-B) and migration areas (Fig 8-D) for flatback turtles are largely contained within the Kimberley Marine Park, but only an estimated 50 percent of the extensive core foraging area (orange line in Fig 8-C) falls within the park. Because the core foraging area is so large, protecting more of it could negatively impact other users of the park though alternative and appropriate management pathways (eg, changing vessel routes and speeds) are worth considering.

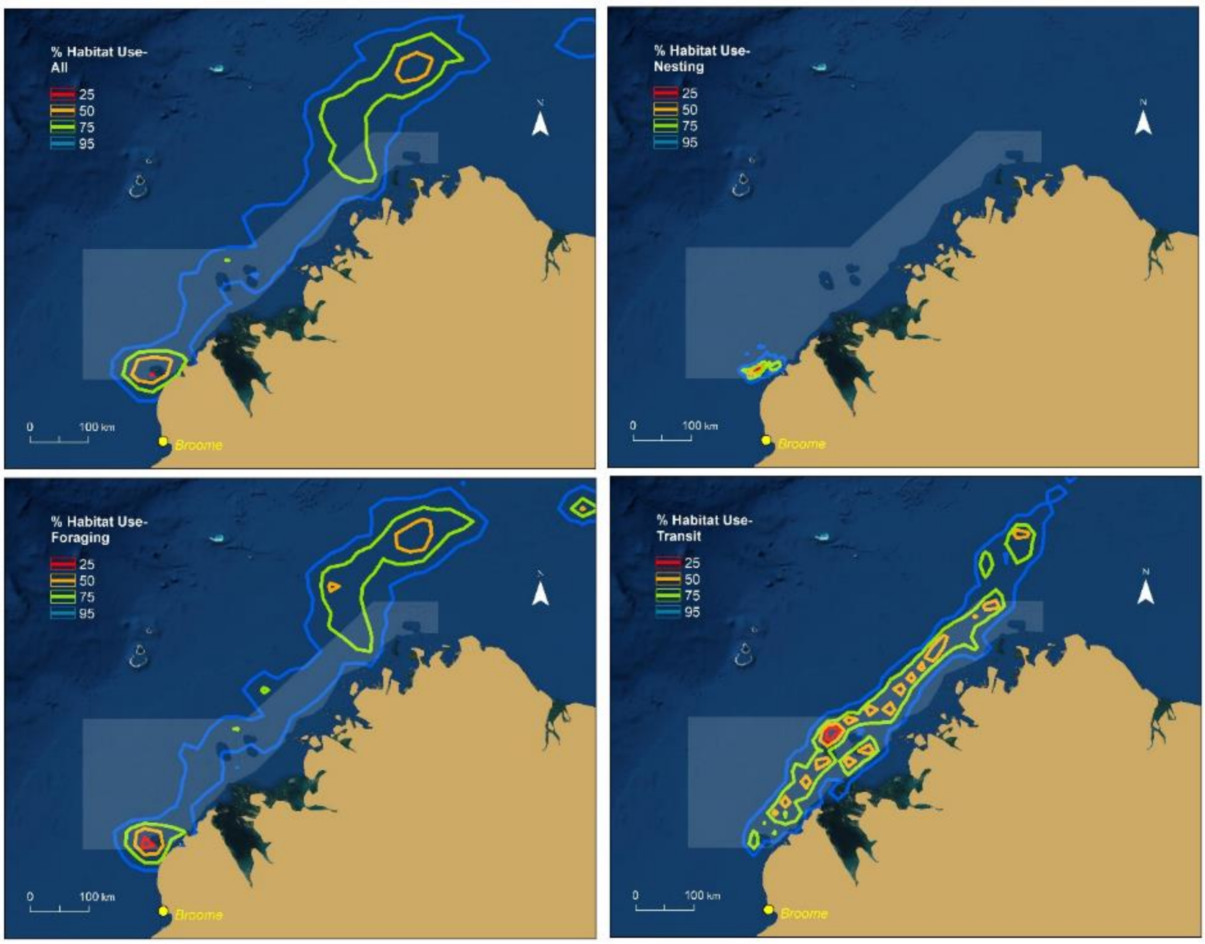

Figure 8. Home ranges of the 11 tracked flatback turtles during the inter-nesting period in waters off the Kimberley coast. The coloured contours represent the 25, 50, 75 and 95 % kernel utilisation distributions of turtles for: A – all behaviours, B – nesting, C – foraging, and D – transit. The Kimberley Marine Park is shaded gray-blue. For more information, see Thums et al 2017.

Habitat modelling revealed that flatback turtles prefer clear waters from 60–90 metres deep for foraging and that they are more likely to forage in areas where there is complex seabed geomorphology with seafloor features such as banks, terraces, deep holes and valleys. These areas typically support a rich diversity of sessile invertebrates, which are thought to be an important part of the flatback turtle diet. The models also found that the distance to the tidal front was an important predictor of the turtle's migratory behaviour, suggesting that they might follow these fronts along the coast (Thums et al 2017). Flatback turtles that nest in the south-west Kimberley are most at risk from acute chemical and terrestrial discharge. Flatback turtles that nest in the Pilbara, in contrast, are most threatened by climate change, acute chemical and terrestrial discharge, light pollution and habitat loss (Commonwealth of Australia 2017).

5.1.3 Seabirds

While there is no direct research available on bird populations in the Kimberley Marine Park, the entire Kimberley region is highly significant for shore and seabirds, which either breed on land and/or forage in the marine park. The tidal flats of the Kimberley coast provide rich feeding grounds for over 3.7 million shorebirds, with 90% of the coastal shorebirds occurring at just two sites: Eighty-mile Beach and Roebuck Bay which are characterised by the highest numbers of birds, and the greatest diversity of species (Pepping et al. 1999, Piersma et al. 2005).

The tidal flat systems surrounding Adele Island and the Lacepede Islands, which are located in close proximity to the marine park, are also important for some shorebird species, such as Pacific golden plover (*Pluvialis fulva*), Grey plover (*Pluvialis squatarola*), Lesser sand plover (*Charadrius mongolus*), Grey-tailed tattler (*Tringa brevipes*), Ruddy turnstone (*Arenaria interpres*) and Sanderling (*Calidris alba*, Rogers et al. 2011). Adele Island is also an important nesting site for a number of seabirds including Brown booby (*Sula leucogaster*), Lesser frigatebird (*Fregata ariel*), Red-footed booby (*Sula sula*), Masked booby (*Sula dactylatra*), and Lesser crested tern (*Thalasseus bengalensis*, DEWHA 2008).

Despite the remoteness of the Kimberley region, there are indications that populations of many migratory species on the Kimberley coast are declining, probably because of habitat loss in the East Asian areas where they stage on migration. The more local threats to the bird populations are associated with coastal developments around Broome (Roebuck Bay), where both the nutrient enrichment and increased disturbance levels from human activities have been observed (Rogers et al. 2011).

5.1.4 Fishes and sharks

Despite the fact that the demersal fish fauna of the continental shelf of the Kimberley region is relatively well documented by the WA Department of Fisheries, CSIRO, WAMSI and WA Museum (Sainsbury et al. 1985, Hutchins 1999, Nowara & Newman 2001, Newman & Dunk 2002, Travers et al. 2010, Molony et al. 2011, Depczynski et al. 2017), there is little information available on fish and sharks populations of the Kimberley Marine Park. The earlier research recognised longitudinal patterns in the composition of inshore fish fauna in the Kimberley (Hutchins 1999), with the WA Museum data highlighting a pronounced difference in species composition between inshore and offshore regions of the Kimberley, with only about 20% of species shared between the inshore and offshore regions (Moore et al. 2014). The WA Museum records also indicate that this area has a high diversity of Indo-West Pacific fishes (Sainsbury et al. 1985, Allen & Swainston 1988, Allen et al. 1997) with approximately 14% of the inshore species and 2% of the offshore species considered endemic to Australia (Moore et al. 2014). Furthermore, eleven species from the collection are considered endemic to the Kimberley area, namely *Pseudanthias sheni*, *Assiculoides desmonotus*, *Pomacentrus limosus*, *Cirrhilabrus morrisoni*, *Conniella apterygia*, *Cirripectes alleni*, *Ecsenius alleni*, *Meiacanthus naevius*, *Stonogobiops larsonae*, *Xenisthmus chi* and *Xenisthmus semicinctus* (Moore et al. 2014). This level of endemism is considered to be relatively high for tropical Australian fish communities (Hoese et al. 2006). However, high levels of endemism, long lifespan and habitat specialization are all recognised indicators of vulnerability to extinction or fishery impact (Stephenson & Jackson 2005, Bender et al. 2013) with recovery periods, such as in case of recovery from fishing impacts, in the order of a decade or more (Jackson et al. 2010).

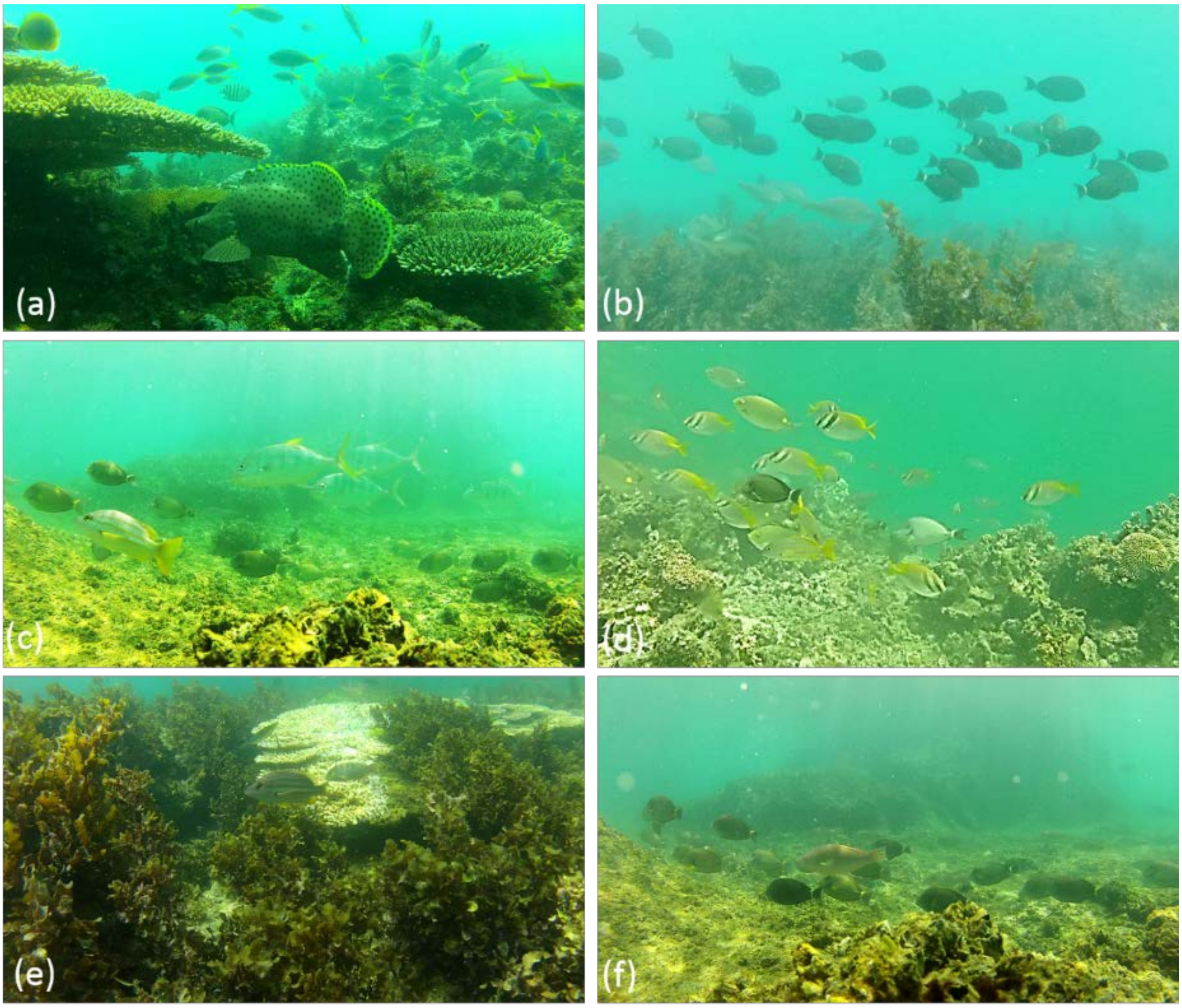

Figure 9 Examples of fauna commonly observed around Kimberley Marine Park. (a) Humpback grouper (Cromileptes altivelis) - centre, Golden butterflyfish (Chaetodon aurofasciatus) - top-left, Redbelly yellowtail fusilier (Caesio cuning) - background; (b) Finelined surgeonfish (Acanthurus grammoptils) – top front, Blue tuskfish (Choerodon cyanodus) - bottom; (c) Spanish flag snapper (Lutjanus carponotatus) – front left, Yellowspotted trevally (Carangoides fulvoguttatus) – front right, Finelined surgeonfish (Acanthurus grammoptils) – background; (d) Finelined surgeonfish (Acanthurus grammoptils) – middle, Spanish flag snapper (Lutjanus carponotatus) – bottom, Goldlined rabbitfish (Siganus lineatus) – top, Doublebar rabbitshish (Siganus virgatus) – left; (e) Spanish flag snapper (Lutjanus carponotatus) – centre, Blue tuskfish (Choerodon cyanodus) – back; (f) Blue-barred parrotfish (Scarus ghobban) – front, Finelined surgeonfish (Acanthurus grammoptils) – background. Images courtesy of Katherine Cure @ AIMS.

The Kimberley region is also a home to the pig-eye shark (*Carcharhinus amboinensis*). Despite large total lengths obtained by pig-eye sharks and subsequent potential for mobility, the genetic diversity of this species was partitioned between north-western Australia and Queensland. This Pacific/Indian Ocean barrier is common for species of coastal northern Australia (Chenoweth et al. 1998, Lukoschek et al. 2007) and is argued to be a consequence of the land bridge between Cape York and Papua New Guinea that formed during lower sea levels of the late Pleistocene epoch. This land bridge formed a barrier to movement and gene flow of marine animals between east and west coasts of Australia (Tillett et al. 2012).

Tiger sharks (*Galeocerdo cuvier*) were observed within the Kimberley Marine Park by a tracking study using fin-mounted satellite-linked transmitters deployed in 2007, 2008, and 2010 (Ferreira et al 2015). These sharks are large (over 5 m long), wide-ranging apex predators and scavengers found in most tropical marine ecosystems. Tiger sharks are currently classified as 'Near Threatened' by the IUCN (Simpfendorfer 2009) and are under threat from commercial fisheries and shark control programs.

Whale sharks (*Rhincodon typus*) are known to aggregate near Ningaloo Reef to the south of Kimberley region (Copping et al 2018). However, satellite tracking data from AIMS from 2005-2008 (Meekan and Radford 2010) shows that they sometimes pass through the Kimberley Marine Park as part of their long migrations (Figure 10), the longest of which from anywhere in the world was recently tracked as more than 20,000 km (Guzman et al 2018). Tracking data for various time periods collected by Reynolds et al (2017) and available on-line (https://zoatrack.org/projects/243/analysis) also shows an occasional track entering the marine park. However, they generally range much further offshore. Whale sharks are the world's largest known, extant fish species, growing up to 12.65 m long. They are listed as vulnerable and migratory under Australia's *Environment Protection and Biodiversity Conservation Act 1999* Act, and as endangered by the IUCN. Whale sharks are under threat from fisheries, bycatch losses and vessel strikes.

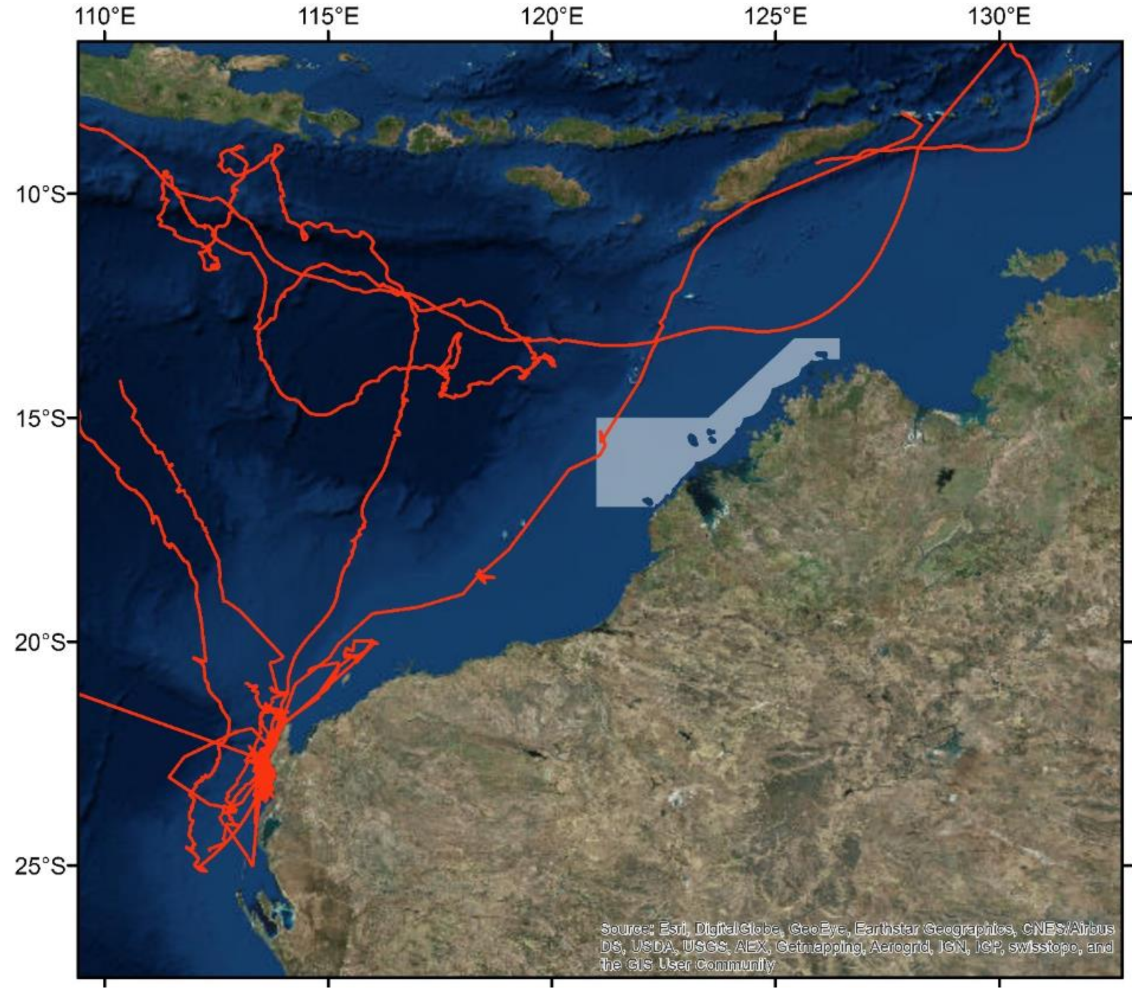

Figure 10. Satellite-tracked migration paths of whale sharks from tags deployed 2005-2008 near Ningaloo Reef. The Kimberly Marine Park shown in light blue.

The geographic scale of many commercial fisheries in the Kimberley, which often extend even beyond the region, combined with data confidentiality for the small fisheries, makes it challenging to comment on what proportion, if any, of fisheries catch comes from the marine park. Commercial fisheries in the region include the Kimberley Gillnet and Barramundi Fishery, the Northern Demersal Scalefish Fishery (NDSMF), the Mackerel Managed Fishery, the Joint Authority Northern Shark Fishery, and the WA North Coast Shark Fishery (Fletcher & Santoro 2018). These are multi-species fisheries targeting barramundi, threadfin salmon, snapper, emperor, grouper, Spanish mackerel, and sharks (www.wafic.org.au). The catches are often low and variable, particularly in the inshore zone of the NDSMF (Newman et al. 2008). As a result, most fisheries in the region have restricted number of licenses and fishing effort restrictions with only five permits issued for the 2015–16 NDSMF fishing season and two vessels active in the fishery (Newman et al. 2008, Patterson et al. 2017). The commercial invertebrate fishery in the region targets pearl oysters (*Pinctada maxima*), prawns, mud crabs and sea cucumbers (Fletcher & Santoro 2018). In addition, the North West Slope Trawl Fishery (NWSTF) operates off north-western Australia roughly between the 200 m isobath and the outer boundary of the Australian Fishing Zone (www.afma.gov.au). The NWSTF is predominantly targeting Australian scampi (*Metanephrops australiensis*) using demersal trawl gear. Smaller quantities of velvet scampi (*M. velutinus*) and Boschma's scampi (*M. boschmai*) are also harvested by this fishery (Patterson et al. 2017).

The commercial invertebrate fishery in the region targets pearl oysters (*Pinctada maxima*), which are primarily collected in the near-shore areas, with smaller catches recorded around the Lacepede Islands (Fletcher & Santoro 2018). A number of Aboriginal-owned fisheries operate in the Kimberley region targeting trochus (*Tectus niloticus*). None of them, however, appear to operate inside the Kimberley Marine Park.

Most of the recreational fishing activities in the Kimberley region occurs from small boats in state waters adjacent to the Kimberley Marine Park. Fifty-three fish species in the Kimberley are targeted both by commercial and recreational fishers, with 17 additional species being targeted only by the recreational fishers (Newman et al. 2004). The offshore recreational effort mainly targets tropical snappers, cods, coral and coronation trout, sharks, trevally, tuscfish, tunas, mackerels and billfish (Fletcher & Santoro 2018). The recreational fishing effort in the Kimberley is predicted to increase due to expected population growth around the existing population centres (e.g. Broome, Port Hedland, Karratha), which in turn will lead to increased boat ownership (Molony et al. 2011).

Some potential threats for the marine park are associated with infrastructure development in the Kimberley Region to support oil and gas industry. These could introduce noise pollution and impact megafauna and fish movement as result of seismic surveys as well as disturb marine habitats through drilling/ dredging activities, introduction of marine pests as result of increased shipping activities (Fletcher & Santoro 2018). This could potentially affect biota directly residing or migrating through the marine park. In addition, increased recreational fishing activity and boat traffic as a result of expected population growth in the region may result in increased pressure on the local fish stocks (Human & McDonald 2009). Lastly, some of the listed threatened species such as pipefishes, seahorses and sea snakes are known to occur in the area and are subject to bycatch from commercial trawling activities in the region (Fletcher & Santoro 2018).

5.2 Benthic fauna

There have been few targeted benthic faunal research surveys in the Kimberley Marine Park. Southern Surveyor Voyage SS05/2007 touched on the western-most edges of the park (Williams et al 2007). More recently in 2016, AIMS undertook a comprehensive survey of the benthic communities around Lynher Bank in the south of the marine park (RV Solander Voyage 6553). Additional records of benthic species in the Kimberley Marine Park exist in the Western Australian and Northern Territory museum collections.

While records of benthos are generally sparse, the number of observations of benthic biota (hard corals, soft corals, sponges, brittle stars, polychaetes and molluscs) in the Kimberley Marine Park are greater than in other marine parks in the North and Northwest Regions, and observations of sponges and soft corals are spatially well distributed across the park (Miller et al 2016). The known benthic fauna of the Kimberley Marine Park is characteristic of the offshore, sandy and turbid habitats in the Indo-Pacific region. There are few hard-substrate features within the park that might typically be associated with diverse assemblages (Figure 4), although the edges of paleo-channels may form areas of high current and more consolidated substrate that may act as habitat for filter feeding communities, a pattern that has been noted in the coastal Kimberley region (Heyward et al 2018a).

The banks and terraces within the park may also support diverse benthic assemblages, and the recent survey of Lynher Bank provided insight to the biodiversity associated with such features in the Kimberley Marine Park. This survey identified 197 species of crustacean, 86 species of mollusc, 14 hard corals, 54 soft corals, 195 sponges, 19 asteroids, and eight echinoids. These data greatly increased the number of biodiversity records for the Kimberley Marine Park (Figure 11), and emphasises that there is still much to understand about the benthic biodiversity of the area.

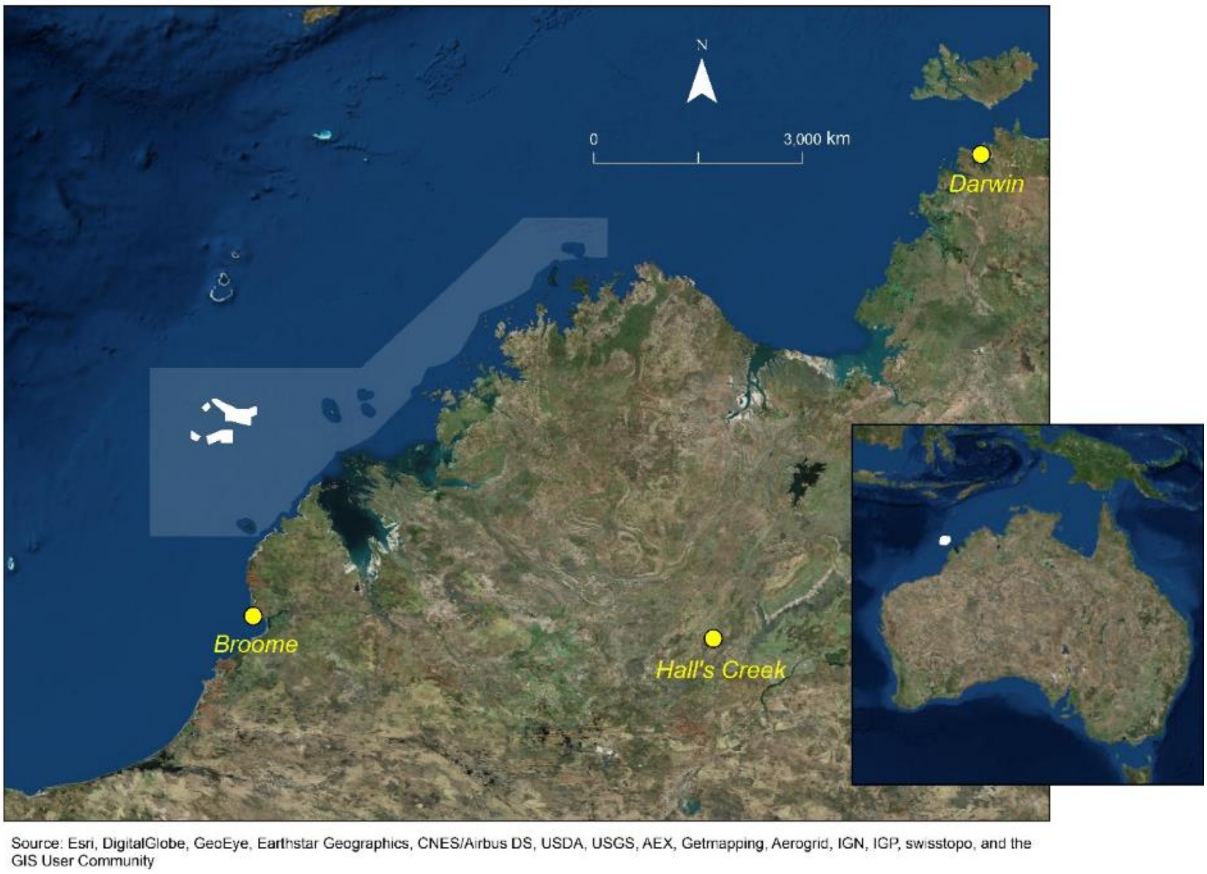

Figure 11. Location (solid white polygons) of recent benthic faunal surveys focussing on Lynher Bank in the Kimberley Marine Park.

In the Lynher Bank area, benthic cover was typically ~6% which is low compared with the inshore Kimberley at equivalent depths (which has ~10-15% benthic cover) (Heyward et al 2018b). From towed video observations, bryozoans are the most abundant benthic invertebrate group across the Lynher Bank study area, with sponges, soft corals, hard corals and “other” (which was predominantly crinoids) each representing <1% cover.

A recent assessment of data coverage for North and North-west Marine Parks showed that the Kimberley Marine Park was a potential candidate for benthic habitat modelling to predict the distribution of assemblages across the park (Miller et al 2016). However, recent benthic predictive modelling for the Lynher Bank area (Heyward et al 2018b) showed that due to the lack of seabed features, accuracy of models was low (even where there was high resolution multibeam bathymetry data ground-truthed with quantitative benthic data) and so would likely be uninformative for management at the whole-of-park scale based on existing data sets.

5.2.1 Corals

There are few records of corals (80 total) in the Atlas of Living Australia for the Kimberley Marine Park, and these include 46 species of hard coral and eight species of soft coral. Of the hard corals there is a mix of shallow water hermatypic species (32 species), and deeper water solitary corals (14 species), and although the latter is less diverse, the solitary corals represent the majority of records (52%), likely reflecting the dominance of soft-sediment and deep water habitats in the park. All hard coral species recorded from the Kimberley Marine Park are a subset of species found elsewhere in WA and are generally widespread and/or common species. The recent WAMSI surveys across Lynher Bank collected an additional 14 hard coral species, all representing new records for the Kimberley Marine Park and increased the total number of hard coral species recorded in the marine park to 60.

Soft corals from the Kimberley Marine Park reported in the Atlas of Living Australia are all species that have been recorded elsewhere in tropical Australia, and there are only 11 records overall. The recent WAMSI voyage to Lynher Bank collected 55 additional species of soft coral (increasing the known diversity to 63 species) and showed soft corals can be common in some areas of the park. Octocoral assemblages appear to be typical of Indo-Pacific fauna associated with soft sediment and turbid environments. Based on recent collections in the SW corner of the Kimberley Marine Park at Lynher Bank, it is reasonable to assume that the diversity of hard and soft corals is underestimated.

5.2.2 Sponges

Sponge communities within the Kimberley Marine Park are also typical of tropical areas, and representative of other areas in Western Australia (Figure 12). Forty-three species of sponge are recorded from the Kimberley Marine Park in the Atlas of Living Australia, many species which appear to be common (i.e. are recorded more than 30 times) and there is one species *Homaxinella ensifera,* that has only ever been recorded from the Kimberley Marine Park. Given the two-week WAMSI survey at Lynher Bank added 174 new species records for the Kimberley Marine Park (Heyward et al 2018b), it is likely that sponge diversity and distribution is still underestimated across the extent of the park and diversity of habitats.

Figure 12. Examples of sponge and soft coral communities within the Kimberley Marine Park. Image from AIMS Towed video surveys at Lynher Bank

5.2.3 Other benthic fauna

Generally the invertebrate fauna within the Kimberley Marine Park is typical of soft-sediment tropical regions with species representing a sub-set of taxa recorded across Western Australia or in the tropics. There are 25 species of polychaetes recorded in the park; all species that are widespread. The Crustacean fauna is representative of sandy habitats, although appear to be more diverse than inshore areas within state marine park waters (Heyward et al 2018b).

Ophiuroids formed a conspicuous component of the benthic fauna in some areas of Lynher Bank (Figure 13, Heyward et al 2018b). A total of 58 species of ophiuroid (brittlestar) have been recorded in the Kimberley Marine Park. Most of these species are widespread and found in other tropical and temperate parts of Australia. However, four species, *Amphiophiura confecta*, *Astroceras mammosum*, *Ophiothrix accedens* and *Ophiothrix crassispina* have been found only in the park to date. Species from other echinoderm groups (asteroids, echinoids etc.) appear to represent a subset of species known from tropical Australia.

Molluscs are among the most speciose groups in the Kimberley Marine Park, with 229 species listed in the Atlas of Living Australia from the park, with the fauna being typical of the Indo-west Pacific. Most records in ALA represent single observations, with those that are recorded more frequently representing common/widespread species. An additional 51 mollusc species were recorded in the Kimberley Marine Park during the recent WAMSI voyage to Lynher Bank, increasing the total number of species to 280. Of note, there were two new species of (large, conspicuous) gastropod collected at Lynher Bank that are currently being formally identified.

Figure 13. Crinoids and bryozoans in the Kimberley Marine Park. Images from AIMS Towed Video surveys at Lynher Bank.

REFERENCES

Allen GR, Swainston R (1988) The marine fishes of north-western Australia: a field guide for anglers and divers. Western Australian Museum

Allen G, Swainston R, Ruse J (1997) Marine fishes of the Great Barrier Reef and South-East Asia–a field guide for anglers and divers. West Aust Museum, Perth 292

Bahmanpour, M.H., Pattiaratchi, C., Wijeratne, E.M.S., Steinberg, C.R., & D'Adamo, N. (2016). Multi-Year Observation of Holloway Current along the Shelf Edge of North Western Australia. *Journal of Coastal Research, SI 75*, 517-521

Bamford M, Watkins D, Bancroft W, Tischler G, Wahl J (2008) Migratory shorebirds of the East Asian-Australasian flyway: Population estimates and internationally important sites. Wetlands International, Oceania Canberra

Bejder, M., Johnston, D. W., Smith, J., Friedlaender, A., & Bejder, L. (2016). Embracing conservation success of recovering humpback whale populations: evaluating the case for downlisting their conservation status in Australia. *Marine Policy*, *66*, 137-141.

Bender MG, Floeter SR, Mayer FP, Vila-Nova DA, Longo GO, Hanazaki N, Carvalho-Filho A, Ferreira CEL (2013) Biological attributes and major threats as predictors of the vulnerability of species: a case study with Brazilian reef fishes. Oryx 47:259–265

Blevin, J.E., Struckmeyer, H.I.M., Boreham, C.J., Cathro, D.L., Sayers, J. and Totterdell, J.M., (1998). Tectonostratigraphic framework and petroleum systems of the Browse Basin, North West Shelf. IN: Purcell, P.G. and Purcell, R.R. (Editors), The sedimentary basins of Western Australia 2: *Proceedings of the Petroleum Exploration Society of Australia* Symposium, Perth, 1998, 369-395

Brink, K.H., Bahr, F., & Shearman, R.K. (2007). Alongshore currents and mesoscale variability near the shelf edge off northwestern Australia. *Journal of Geophysical Research: Oceans*, 112, C05013.

Carrigan, A. D., & Puotinen, M. L. (2011). Assessing the potential for tropical cyclone induced sea surface cooling to reduce thermal stress on the world's coral reefs. *Geophysical Research Letters*, *38*(23).

Cetacean Specialist Group (1996) Balaenoptera musculus ssp. brevicauda. IUCN 2013 IUCN Red List of Threatened Species Version 20131.

Chenoweth SF, Hughes JM, Keenan CP, Lavery S (1998) When oceans meet: a teleost shows secondary intergradation at an Indian–Pacific interface. *Proc R Soc London B Biol Sci* 265:415–420

Commonwealth of Australia 2017. *Recovery Plan for Marine Turtles in Australia*.

Copping JP, Stewart BD, McClean CJ, Hancock J, Rees R. 2018. Does bathymetry drive coastal whale shark (Rhincodon typus) aggregations? *Peer J* 6:e4904 https://doi.org/10.7717/peerj.4904

D'Adamo, N., Fandry, C., Buchan, S., & Domingues, C. (2009). Northern Sources of the Leeuwin Current and the "Holloway Current" on the North West Shelf. *Journal of the Royal Society of Western Australia, 92*, 53-66

Depczynski M, Cure K, Holmes T, Moore G, Piggott C, Travers M, Wilson S, Oades D, McCarthy P (2017) Final report of Project 1.1.2a Key Ecological Processes in Kimberley Benthic Communities: Fish Recruitment, prepared for the Kimberley Marine Research Program, Western Australian Marine Science Institution, Perth, Western Australia, pp 35. Final Rep Proj 1:35

DEWHA (2008) Department of Environment, Water, Heritage and Arts. The North-West Marine Bioregional Plan. Bioregional Profile. A description of the ecosystems, conservation values and uses of the North-West marine region. Canberra

Double, M. C., Andrews-Goff, V., Jenner, K. C. S., Jenner, M. N., Laverick, S. M., Branch, T. A., & Gales, N. J. (2014). Migratory movements of pygmy blue whales (Balaenoptera musculus brevicauda) between Australia and Indonesia as revealed by satellite telemetry. *PLoS One*, *9*(4), e93578.

Dufois, F., Lowe, R.J., Branson, P., & Fearns, P. (2017). Tropical Cyclone-Driven Sediment Dynamics Over the Australian North West Shelf. *Journal of Geophysical Research: Oceans, 122*, 10225-10244

Ferreira LC, Thums M, Meeuwig JJ, Vianna GMS, Stevens J, McAuley R, et al. (2015) Crossing Latitudes—Long-Distance Tracking of an Apex Predator. *PLoS ONE* 10(2): e0116916. https://doi.org/10.1371/journal.pone.0116916

Fletcher WJ, Santoro K (2018) Status reports of the fisheries and aquatic resources of Western Australia 2016/17: The state of the fisheries. Perth, Australia

Geoscience Australia (2018). High-resolution depth model for Northern Australia – 30 m. https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search;jsessionid=C8F1FB890DD483EB4DD17513E7E433D3#/metadata/121620

Guzman, H. M., Gomez, C. G., Hearn, A., & Eckert, S. A. (2018). Longest recorded trans-Pacific migration of a whale shark (Rhincodon typus). *Marine Biodiversity Records*, 11(1), 8.

Heap, A.D. and Harris, P.T., (2008). Geomorphology of the Australian margin and adjacent seafloor. *Australian Journal of Earth Sciences*, 55(4), pp.555-585.

Heyward A, Miller K, Fromont J, Keesing J, Parnum I (EDS.) (2018b). Kimberley Seabed Biodiversity – Flatback turtle habitat assessment. WAMSI Project 1.1.1. Final Report to WAMSI.

Heyward A, Miller K, Fromont J, Keesing J, Parnum I (EDS.) (2018a). Kimberley Seabed Biodiversity, WAMSI Project 1.1.1. Final Report to WAMSI.

Hoese DF, Bray DJ, Paxton JR, Allen GR (2006) Zoological Catalogue of Australia. Australian Biological Resources Study & CSIRO Publishing: Collingwood. Number 35. 3 Vols. Part 1, pp. xxiv, 1-670; Part 2, 671-1472; Part 3, 1473-2178 pp.

Holloway, P.E. (1983). Internal Tides on the Australian North-West Shelf: A Preliminary Investigation. *Journal of Physical Oceanography, 13*, 1357-1370

Holloway, P.E. (2001). A regional model of the semidiurnal internal tide on the Australian North West shelf. *Journal of Geophysical Research: Oceans, 106*, 19625-19638

Holloway, P.E., & Nye, H.C. (1985). Leeuwin Current and wind distributions on the southern part of the Australian North-west Shelf between January 1982 and July 1983. Australian *Journal of Marine and Freshwater Research*, 36, 123-137.

Holloway, P.E., Chatwin, P.G., & Craig, P. (2001). Internal Tide Observations from the Australian North West Shelf in Summer 1995. *Journal of Physical Oceanography, 31*, 1182-1199

Howard, F.J.F., Nicholson, C., Bernardel, G., Carroll, A.G., Grosjean, E., Hackney, R., Lech, M., Melrose, R., Nichol, S.L., Picard, K., Radke, L.C., Rollet, N., Romeyn, R., Siwabessy, P.J.W and Trafford, J. (2016). A Marine Survey to Investigate Seal Integrity Between Potential CO2 Storage Reservoirs and Seafloor in the Caswell Sub-basin, Browse Basin, Western Australia: GA0345/GA0346/TAN1411 – Post-survey Report. Record 2016/05. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2016.005

Hughes, A. R., Williams, S. L., Duarte, C. M., Heck, K. L., & Waycott, M. (2009). Associations of concern: declining seagrasses and threatened dependent species. *Frontiers in Ecology and the Environment*, *7*(5), 242-246.

Human BA, McDonald JI (2009) Knowledge review and gap analysis: resource condition monitoring in the Pilbara and Kimberley regions of Western Australia. Coastal and Marine Resource Condition Monitoring—Scoping Project. Final NRM Report, Project 073007-Part 1. Fish Res Rep:192

Hutchins JB (1999) Biogeography of the nearshore marine fish fauna of the Kimberley, Western Australia. In*: Proceedings of the Fifth Indo-Pacific Fish Conference*, Noumea.p 99–108

Jackson G, Norriss J V, Mackie MC, Hall NG (2010) Spatial variation in life history characteristics of snapper (Pagrus auratus) within Shark Bay, Western Australia. New Zeal *J Mar Freshw Res* 44:1–15

James, N.P., Bone, Y., Kyser, T.K., Dix, G.R., Collins, L.B., (2004). The importance of changing oceanography in controlling late Quaternary carbonate sedimentation on a high energy, tropical, oceanic ramp: North-western Australia. *Sedimentology*, 51, 1179-1205

Le Nohaic, M., Ross, C.L., Cornwall, C.E., Comeau, S., Lowe, R., McCulloch, M.T., & Schoepf, V. (2017). Marine heatwave causes unprecedented regional mass bleaching of thermally resistant corals in northwestern Australia. *Scientific Reports, 7*, 14999

Lukoschek V, Waycott M, Marsh H (2007) Phylogeography of the olive sea snake, Aipysurus laevis (Hydrophiinae) indicates Pleistocene range expansion around northern Australia but low contemporary gene flow. *Mol Ecol* 16:3406–3422

Margvelashvili, N., Herzfeld, M., and Webster, I. (2006). Modelling of fine sediment transport in Fitzroy Estuary and Keppel Bay. CRC for the Coastal Zone, Estuary and Waterway Management. Technical Report No. 39.

Mahjabin, T., Bahmanpour, M.H., Pattiaratchi, C., Hetzel, Y., Wijeratne, E.M.S., Steinberg, C. (2016). Dense Shelf Water Cascades along the North-West Australian Continental Shelf. In the Proceedings of 20th Australasian Fluid Mechanics Conference, Perth Australia, 5-8 December 2016.

McLaughlin, M.J., Lourey, M.J., Hanson, C.E., Cherukuru, N., Thompson, P.A., Pattiaratchi, C.B. (2019). Biophysical characteristics of tidally-extreme waters of the southern Kimberley coast, Western Australia. *Continental Shelf Research* 173, 1-12.

Molony BW, Newman SJ, Joll L, Lenanton RCJ, Wise B (2011) Are Western Australian waters the least productive waters for finfish across two oceans? A review with a focus on finfish resources in the Kimberley region and North Coast Bioregion. *J R Soc West Aust* 94:323

Marsh, H., Eros, C., Corkeron, P., & Breen, B. (1999). A conservation strategy for dugongs: implications of Australian research. *Marine and Freshwater Research*, *50*(8), 979-990.

Meekan, Radford 2010. Migration Patterns of Whale Sharks: A summary of 15 satellite tag tracks from 2005 to 2008. Report to the Browse Joint Venture Partners. Australian Institute of Marine Science, Perth (21pp).

Miller K, Puotinen M, Przeslawski R, Huang Z, Bouchet P, Radford B, Li J, Kool J, Picard K, Thums M, Nichol, S (2016). Ecosystem Understanding to Support Sustainable Use, Management and Monitoring of Marine Assets in the North and North-West Regions: Final Report for NESP D1 2016e. Report to the National Environmental Science Program, Marine Biodiversity Hub. Australian Institute of Marine Science. 133pp.

Moore G, Morrison S, Hutchins JB, Allen GR, Sampey A (2014) Kimberley marine biota. Historical data: fishes. *Rec West Aust Museum Suppl* 84:161–206

Nanson, R.A. and Nichol, S. 2018. National Seafloor Geomorphology (NSGM) mapping workshop 29th October 2018 - Summary and Actions. Distributed 19th November 2018. 12 pages. www.ausseabed.gov.au/resources/publications

Newman SJ, Dunk IJ (2002) Growth, age validation, mortality, and other population characteristics of the red emperor snapper, Lutjanus sebae (Cuvier, 1828), off the Kimberley coast of north-western Australia. *Estuar Coast Shelf Sci* 55:67–80

Newman SJ, Smith KA, Skepper CL (2008) Northern demersal scalefish managed fishery. Department of Fisheries, Western Australian Fisheries & Marine Research Laboratories

Newman SJ, Young GC, Potter IC (2004) Characterisation of the inshore fish assemblages of the Pilbara and Kimberley coasts.

Nowara GB, Newman SJ (2001) A history of foreign fishing activities and fishery-independent surveys of the demersal finfish resources in the Kimberley region of Western Australia. Fisheries Western Australia

Patterson H, Noriega R, Georgeson L, Larcombe J, Curtotti R (2017) Fishery status reports 2017, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. ISBN 978-1-74323-355-9

Pepping M, Piersma T, Pearson G, Lavaleye M (1999) Intertidal sediments and benthic animals of Roebuck Bay, Western Australia.

Picard K., Nichol, S.L., Hashimoto, R., Carroll, A.G., Bernardel, G., Jones, L.E.A., Siwabessy, P.J.W., Radke, L.C., Nicholas, W.A., Carey, M.C., Stowar, M., Howard, F.J.F., Tran, M. & Potter, A., (2014). Seabed Environments and Shallow Geology of the Leveque Shelf, Browse Basin, Western Australia; GA0340/SOL5754 – Post-survey report. Record 2014/10. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2014.010

Piersma T, Pearson GB, Hickey R, Lavaleye MSS (2005) The long mud: benthos and shorebirds of the foreshore of Eighty-mile Beach, Western Australia. Report on the'Anna Plains Benthic Invertebrate and bird Mapping 1999'(ANNABIM-99).

Rayson, M.D., Ivey, G.N., Jones, N.L., Meuleners, M.J., & Wake, G.W. (2011). Internal tide dynamics in a topographically complex region: Browse Basin, Australian North West Shelf. *Journal of Geophysical Research: Oceans, 116*, C01016

Reynolds SD, Norman BM, Beger M, Franklin CE, Dwyer RG. Movement, distribution and marine reserve use by an endangered migratory giant. *Divers Distrib*. 2017;23:1268–1279.

Ridgway, K.R., & Godfrey, J.S. (2015). The source of the Leeuwin Current seasonality. *Journal of Geophysical Research: Oceans, 120*, 6843-6864

Rogers DI, Hassell CJ, Boyle A, Gosbell K, Minton C, Rogers KG, Clarke RH (2011) Shorebirds of the Kimberley Coast-Populations, key sites, trends and threats. *J R Soc West Aust* 94:377

Rosenbaum, H. C., Maxwell, S. M., Kershaw, F., & Mate, B. (2014). Long-range movement of humpback whales and their overlap with anthropogenic activity in the South Atlantic Ocean. *Conservation Biology*, *28*(2), 604-615.

Sainsbury KJ, Kailola PJ, Leyland GG (1985) Continental shelf fishes of northern and north-western Australia: an illustrated guide. Melbourne, Vic, CSIRO Australia

Shearman, P.K., & Brink, K.H. (2010). Evaporative dense water formation and cross-shelf exchange over the northwest Australian inner shelf. *Journal of Geophysical Research: Oceans, 115*, c06027

Simpfendorfer CA (2009) Galeocerdo cuvier. IUCN Red List Threat Species. Available: http://www.iucnredlist.org/details/39378/0. Accessed 2014 Jul 10.

Stephenson P, Jackson G (2005) Managing depleted snapper stocks in inner Shark Bay, Western Australia. Fish Assess Manag Data-limited Situations'(Eds GH Krus VF Gall Hay, RI Perry, RM Peterman, TC Shirley, PD Spencer, B Wilson D Woodby) pp:31–50

Thums M, Jenner C, Waples K, Salgado Kent C, Meekan M. (2018) Humpback whale use of the Kimberley; understanding and monitoring spatial distribution. Report of Project 1.2.1 prepared for the Kimberley Marine Research Program, Western Australian Marine Science Institution, Perth, Western Australia, 78pp.

Thums, M., Waayers, D., Huang, Z., Pattiaratchi, C., Bernus, J. and Meekan, M. (2017) Environmental predictors of foraging and transit behaviour in flatback turtles *Natator depressus*. Endangered Species Research 32, 333-349.

Tillett BJ, Meekan MG, Broderick D, Field IC, Cliff G, Ovenden JR (2012) Pleistocene isolation, secondary introgression and restricted contemporary gene flow in the pig-eye shark, Carcharhinus amboinensis across northern Australia. *Conserv Genet* 13:99–115

Tol SJ, Coles RG, Congdon BC. 2016. *Dugong dugon* feeding in tropical Australian seagrass meadows: implications for conservation planning. PeerJ 4:e2194 https://doi.org/10.7717/peerj.2194

Travers MJ, Potter IC, Clarke KR, Newman SJ, Hutchins JB (2010) The inshore fish faunas over soft substrates and reefs on the tropical west coast of Australia differ and change with latitude and bioregion. *J Biogeogr* 37:148–169

Van Gastel, P., Ivey, G.N., Meuleners, M., Antenucci, J.P., & Fringer, O. (2009). The variability of the large-amplitude internal wave field on the Australian North West Shelf. *Continental Shelf Research, 29*, 1373-1383

Wilson, B. (2014). Kimberley marine biota. History and environment. *Records of The Western Australian Museum, Supplement 84*, 1-18

Zhang, N., Feng, M., Hendon, H.H., Hobday, A.J., & Zinke, J. (2017). Opposite polarities of ENSO drive distinct patterns of coral bleaching potentials in the southeast Indian Ocean. *Scientific Reports, 7*, 2443

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