Shallow coral habitat distributions across the offshore Kimberley region

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WAMSI Kimberley Marine Research Program

Final Report

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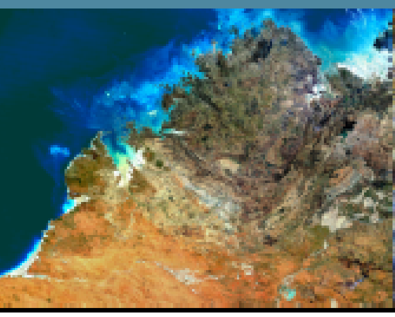
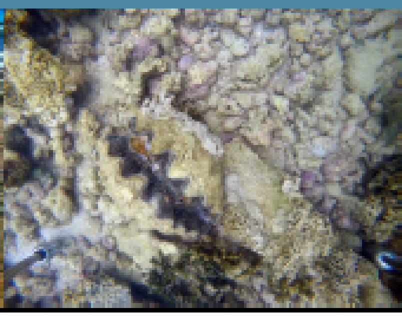
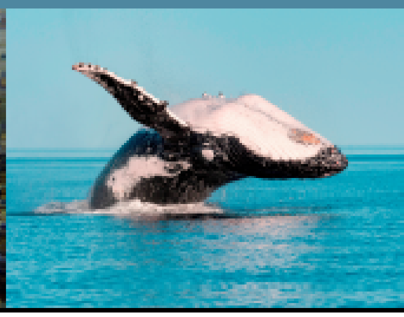
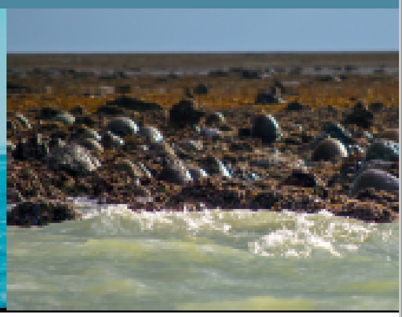

WAMSI Kimberley Marine Research Program

Initiated with the support of the State Government as part of the Kimberley Science and Conservation Strategy, the Kimberley Marine Research Program is co-invested by the WAMSI partners to provide regional understanding and baseline knowledge about the Kimberley marine environment. The program has been created in response to the extraordinary, unspoilt wilderness value of the Kimberley and increasing pressure for development in this region. The purpose is to provide science based information to support decision making in relation to the Kimberley marine park network, other conservation activities and future development proposals.

Front cover images (L-R)

Image 1: Satellite image of the Kimberley coastline (Image: Landgate)

Image 2: Live tridacnid clams on the inner- to mid- reef-flats in bays adjacent to Cape Bougainville. (Image: WAM)

Image 3: Humpback whale breaching (Image: Pam Osborn)

Image 4: Wildcat Reef exposed domal coral habitat (Image: WAM)

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Contents

Executive Summary

The Project's surveys, in combination with the results of recent work by the WA Museum and ongoing drop camera assessments along the coast by DBCA, indicate that Scleractinian corals are present as a component of benthic habitats throughout the Kimberley.

Coral reef habitats, some with species diversity equivalent to well recognised offshore coral reef ecosystems, have been observed in southern, central and northern locations across the region and have been best documented around outer coastal islands. While the Bonaparte Archipelago in the central region remains the location of maximum documented species diversity, historical records indicate locations of moderate to high diversity can also occur very near the mainland. Consequently it is reasonable to infer that coral habitats with moderate to high diversity exist throughout the region in WA coastal waters. While a number of larger coral reef type platforms are known, the presence of smaller patches of reef or coral-dominated habitat on rocky substrate is pervasive and may represent the majority of coral habitat in the region.

The surveys made during this Project suggest that corals are likely to be present on much of that rocky shoreline, if the elevation in relation to tidal heights is appropriate. The observations made from the Eclipse Archipelago to Camden Sound indicate that mid- and upper reef flat coral abundance is frequently <5-10%, with macroalgae the major habitat component. Both abundance and diversity rise when the corals are less exposed, which includes intertidal ponds and rock pools at all elevations. However the outer reef flat and crest region provide larger and more continuous areas of substrate that support the highest levels of diversity and coral cover. Observations on tidal exposure of the coral dominated habitats indicate that in many locations this rich coral zone tends to commence on the seaward margins where the substrate lies lower than 1m below LAT.

Very high coral diversity was observed at a few locations within the outer reef flat zone and from the reef crest to several meters below LAT. However the coral dominated habitat on the inshore fringing reef and rocky shelf areas surveyed in the current project did not extend beyond 10-15m depths, due to the absence of hard substrate at the base of the reef drop off and perhaps less favourable environmental parameters, including the marked attenuation of surface sunlight.

While corals were recorded to 30m, deeper than 10-15m below LAT, they were generally absent or contributed <1% to the biota. This suggests that management of benthic primary producers in the coastal waters of the Kimberley should focus on intertidal and subtidal waters <15m deep.

1 Introduction

Coral reefs of the Kimberley have been utilized by indigenous people for millennia (Woolagoodja , 2011; Wilson, 2014), with the cultural connection persisting during the Holocene sea level rise that flooded the coastal valleys and peneplains. The inundation formed the many long narrow inlets and enclosed gulfs observed today, which support extensive mangrove, mud and sand flat and coral reef habitat. Unlike other reef areas in Western Australia (WA), carbonate reefal development around many of the inner islands and mainland shores appears to comprise Holocene accretionary veneers of coralgal limestone (Wilson, 2009).

European expeditions in the early 1800s mention corals and coral reefs of the Kimberley coast, with a small number of species being collected (King, 1827 cited in Wilson, 2009). More modern regional assessments of biota in the Kimberley Bioregion (IMCRA, 1998 cited in DEC, 2008) identified the presence of coral reefs, in particular those associated with offshore islands. Subsequently, field based surveys at specific locations, including expeditions by the WA Museum developed a coral reference collection with has continued to expand from the 1880's to the present (see Richards et al, 2014). Since 2000 a number of more intensive surveys have been undertaken at selected locations, such as Inpex Ltd funded studies in the Bonaparte Archipelago between 2005-2008 (see Comrie-Greig & Abdo, 2014) and a regional assessment by the WA Museum, supported by Woodside Energy Ltd (http://museum.wa.gov.au/research/research-projects/websites/kimberley-woodside-collection-project-woodside-4). Those studies have identified the presence of thriving coral communities in a number of places (e.g. Rosser & Veron, 2011), with at least one location in the Bonaparte Archipelago supporting a diversity of coral species (Richards et al. 2015) that rivals those of the much better studied offshore atoll reef systems, such as the Rowley Shoals and Scott Reef (see McKinney, 2009)

The realisation that the Kimberley might represent one of the major reef coral regions of Australia, despite perceived unfavourable environmental conditions such as high turbidity, began to resonate with researchers around the time the Kimberley Marine Research Program Science Plan (Simpson, 2011) was being formulated. At the time the Seabed Biodiversity Project commenced the coral reefs of the Kimberley Bioregion remained some of the least known in Australia (Wilson, 2013). Consequently the Plan acknowledged the presence of coral reefs in the Kimberley bioregion as an important environmental attribute, noting that more knowledge of their extent, composition and ecology would benefit future management.

The ship-based surveys of seabed biodiversity described in the preceding chapters revealed a variety of habitats in the deeper waters, usually >15m deep, but also determined that little or no sunlight reached the seabed at those depths. Mostly organisms that could feed by filtration of the water or on sediments predominated. Yet the Kimberley coast clearly supports high levels of benthic primary production, with seagrass, algae and reef building corals noted across the region in shallow nearshore areas. There was a need to visit and survey seabed biota in those shallow areas. The project subsequently pursued collaborative field work between researchers and indigenous sea ranger groups and pursued additional collaborations with independent researchers at Curtin University and DPAA. These recent field based assessments, in combination with data from recent government and industry reports, have been used to synthesise information on the region's coral habitat distributions. This report presents data on shallow intertidal and subtidal habitats from inshore rocky shorelines and fringing reefs along the ria coast between the Anjo Peninsula and Camden Sound.

2 Methods

2.1 Main Expeditions

Ship time aboard the RV Solander was provided by AIMS and two joint voyages with indigenous Sea Rangers were organised in 2017. The focus of those expeditions was investigation of benthic habitats very near shorelines, using drop cameras to characterise intertidal and shallow subtidal environments. The first additional voyage took advantage of a vessel transit between Darwin and Broome in March, 2017, which meant the three day travel time normally associated with dedicated trips was already accounted for. AIMS cruise 6682, 16-23 March 2017, travelled from Darwin to Broome and provided AIMS researchers and representatives of the Wunambal Gaambera people an opportunity to visit inshore areas in their sea country. Shallow water surveys using drop cameras were undertaken using the 5.5m auxiliary vessels from RV Solander. Key areas visited were fringing reef areas along the western side of the Eclipse Archipelago (13°54'46.03"S, 126°18'34.56"E) the western coastline of the Cape Bougainville area (13°54'27.59"S, 126° 4'54.18"E), the west coast shallow bays near Cape Voltaire (14°16'1.41"S, 125°35'10.03"E) and small islands adjacent to the northeast side of Bigge Island (14°29'0.76"S, 125°14'39.76"E) (see Figure 10.1).

AIMS cruise 6710, 29 May – 6 June 2017 to and from Broome, provided AIMS researchers and representatives of the Dambimangari people an opportunity to visit inshore areas in their sea country at the northern end of Camden Sound. Shallow water habitat surveys using drop cameras were undertaken using the 5.5m auxiliary vessels from RV Solander. The particular focus of the cruise was the chain of reefs and islands at the northern end of the North Lalang-garram Marine Park. The intent was to visit nearshore fringing reef type areas from the furthest offshore location around Wildcat Reefs then progressively move east towards the mainland through the island archipelago (see Figure 2).

Figure 1. Locations visited during AIMS cruise 6682 shown with yellow markers and AIMS cruise 6710 with a green marker (see Figure 2 also).

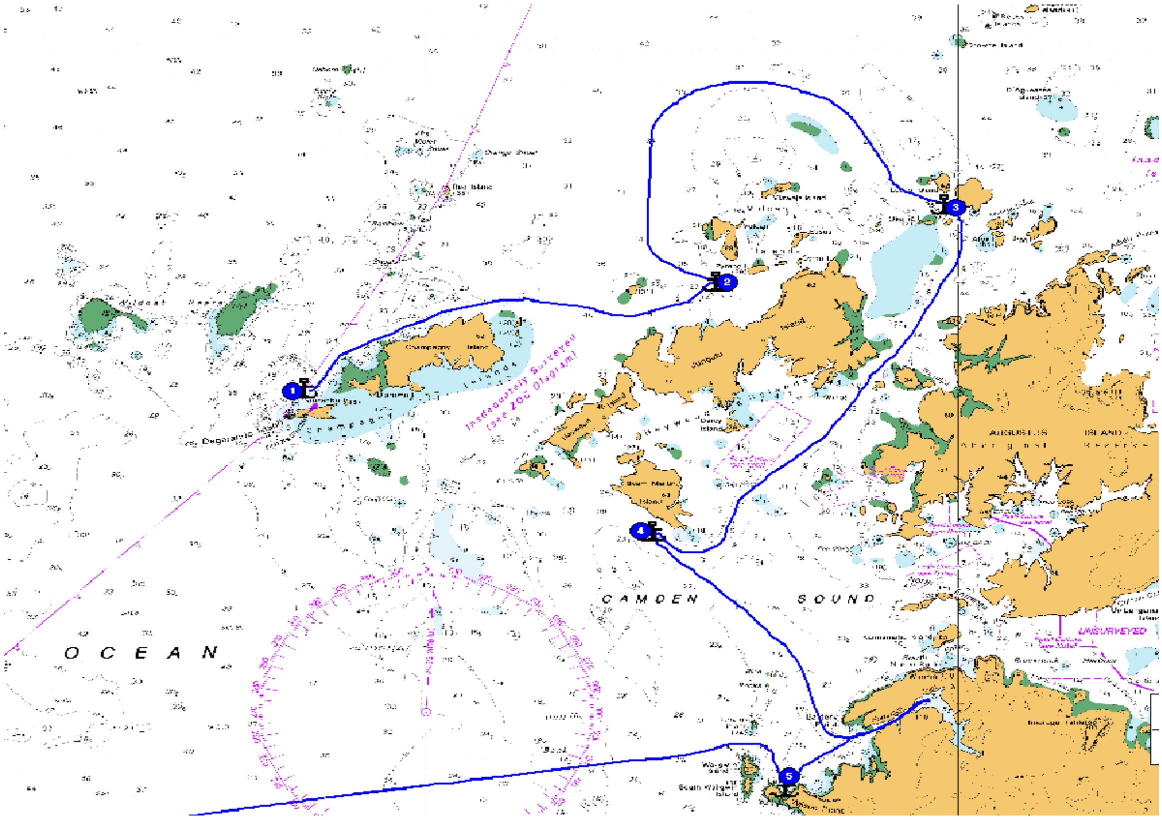

Figure 2. AIMS cruise 6710 - RV Solander route through the island areas in the North Lalang-Garram Marine Park, where surveys were conducted. Blue circles indicate the location of the vessel's anchorages, from which shallow water surveys were conducted within a radius of 3 nautical miles using the auxiliary vessels.

2.2 Additional field surveys.

The Project formed collaborative links with Dr Zoe Richards (WA Museum/Curtin University) and Dr Andrew Halford (DBCA -Department of Biodiversity, Conservation and Attractions), to support complementary but independent surveys of intertidal and shallow subtidal benthic habitats in the Project area of primary interest, between Cape Leveque and Cape Bougainville.

Field work around coastal islands in the central and southern RIA coast region was led by Dr Richards, accompanied by other WA Museum staff and participants from the Wunambal Gaambera Traditional Owners (see Appendix 5), during a one week expedition in September, 2016. Research focused on further assessments of intertidal and subtidal biodiversity in the Bonaparte Archipelago (central region). In October 2017 surveys of intertidal reef flats were conducted at four locations within the southern inshore Kimberley region (see Appendix 2), coinciding with spring tides occurring over the same period. Researchers focused on coral and intertidal sponge distributions. Locations included three fringing reef flat habitats (Adele Island, White Island and Bathurst-Irvine Reef) and a solitary reef system. Three sites were surveyed at Adele Island, two at Beagle Reef and one site each at White Island and Bathurst-Irvine Reef.

Collaboration with Dr Halford consisted of joint survey site planning, along with provision of drop camera equipment, to enable additional shallow benthic habitat data to be acquired during DBCA cruises at multiple inshore sites from Camden Sound northwards, with the new vessel PV Warndoon.

Additional drop camera trials were conducted in 2016 in the Buccaneer Archipelago area, at the southern end of Camden Sound, by Dambimangari sea rangers. The rangers used and evaluated the Project's equipment and draft Standard Operating Procedure for drop camera at multiple locations, including Whirlpool Pass, Talbot Island Turtle Island and Vickery Reef.

2.3 Methods

Drop camera techniques, originally developed during AIMS surveys of Kimberley shallow waters in 2009 (e.g. Heyward and Moore, 2009), were refined for the Project. It was discovered during the initial AIMS work that if a camera was supported on a stable frame that landed on the seabed, images of acceptable quality for interpreting the major biota present could be obtained without the need for auxiliary lighting. This had a number of advantages, particularly when water turbidity was elevated in the nearshore areas and paved the way for development of a simple and compact drop camera arrangement.

A quite heavy (11kg) stainless tripod mounted with a downward-facing camera was created by the AIMS workshop to provide a robust device that could be hand lowered from a vessel to the seabed. This drop camera provided a stable platform that, while resting on the seabed, maintained the camera at a fixed distance as photographs were taken every few seconds. A range of cameras were evaluated, with key criteria being a built in intervalometer, waterproof capability to a minimum of 30m, acceptable image quality, ease of use and affordability. The camera chosen for the Project was the GoPro 4s, which delivered against each criterion, albeit with only average image quality. A standard operating procedure (SOP) for drop camera surveys was initiated during the project, with field trials and improvements to the SOP documentation developed in collaboration between AIMS and representatives of the Dambimangari people (see Heyward, et al. 2016; Appendix 1). The same SOP was then provided to Dr Halford and used on the initial inshore assessments from the PV Warndoom.

At each field location, such as the Eclipse Archipelago, Cape Bougainville and Cape Voltaire, multiple drop camera transects were run perpendicular to the shoreline at medium to high tide over the submerged reef flat and rock ledge areas. Photos of the seabed were collected at five second intervals, allowing images of seabed habitat to be captured every few metres along each transect. A tract of each transect was logged on handheld GPS (see Heyward et al. 20160 and the resulting images georeferenced (http://geotag.sourceforge.net/) upon return to the laboratory. Images along each transect were then reviewed to determine the dominant benthic biota. Live coral abundance was estimated using categories for percent cover (see English et al, 1997), with a subset of images also selected for more detailed analysis of coral cover using 100 points overlaid on each image with CPCE software (Kohler and Gill, 2006).

Methods for the WA Museum's Kimberley intertidal and subtidal assessments are outlined in Bryce et al. (2018). Rationalisations concerning occupational health and safety limited survey work to locations away from nearshore coastal islands and river mouths where crocodile densities are highest and water turbidity a complicating factor. To some extent the drop camera work associated with the Project (AIMS, DBCA & Dambimangari) was able to compliment those spatial gaps, working closer inshore, as personnel were able to remain inside the small boats when surveying.

Intertidal survey transects undertaken on the offshore coastal islands of the southern region in 2017 included assessment of sponges by Abdul Wahab (see Abdul Wahab, 2018; Appendix 2). Transects were performed via reef walks oriented at a bearing perpendicular to the water's edge where possible, and in a haphazard manner in areas with high coral cover to minimise damage to the benthos.

3 Results

Drop camera assessments on the AIMS inshore cruises found reef building corals were present at all locations visited, although not always a dominant feature at all sampling sites in each area. Narrow bands of coral habitat were encountered along the western side of the Eclipse Islands and around small islands on the eastern side of Bigge Island. Along the mainland coast corals were encountered in broad intertidal and subtidal fringing reef type areas, but also on simple rocky shorelines of bays along the mainland coast in the Cape Bougainville and Cape Voltaire areas. Similarly, hard corals were a ubiquitous component of the benthos throughout the islands of the North Lalang garram Marine Park from offshore at the Wildcat Reefs to the mainland shore adjacent to Wilson Point. The Wildcat reefs habitat consisted of a low intertidal platform, with dense corals extending into the subtidal (Figure 5), whereas in inshore sheltered places, such as the southern side of Miata Island a broad zone of coral habitat was not observed, but represented by a very narrow band of low species diversity just along the outer edge of a fringing rocky shelf (e.g. Figure 18).

3.1 Outer coastal Islands reefs

The abundance and diversity of coral communities encountered varied within local regions as much as between, being strongly associated with the depth of the underlying reef or rock substrate, presumably indicative of intertidal exposure times, rather than distance from shore. Nonetheless, the best developed coral dominated habitats were observed at outer coastal island sites, including Holothuria Reef north of Cape Bougainville, the Maret Islands in the Central region (see Rosser and Veron, 2010) and various islands in the southern region, for example Beard Island (see Figures 3, & 4). The most diverse and best studied area remains the Bonaparte region in the central part of the ria coast (see Richards et al. 2015, 2018; Rosser & Veron, 2011), where at least 250 species have been recorded, from intertidal studies alone. Recent quantitative surveys, within coral dominated zones at those locales (Richards et al. 2018) indicate levels of coral cover equivalent to that measured on healthy coral reefs elsewhere in the country.

Figure 3. Exposed Acropora coral community at Holothuria Reef during the northern survey. Image taken during a morning low tide when the predicted tidal height at West Holothurian Reef (Port 63019, Hydrographic Service RAN) was 0.6m. Photo: K. Miller.

Figure 4. Exposed *Acropora* dominated coral community at Beagle Island in the southern region of the Project study area. Predicted tidal height at nearby Adele Island was approximately 0.3m.

These outer coastal island lower intertidal and subtidal habitats, demonstrate the presence of extensive and diverse coral communities across the entire study region of the Project. Species diversity is likely to be high, with the best studied area around the Maret Islands already documented to support a comparable number of reef building coral species to the region's offshore reef systems like the Rowley Shoals and Scott Reef.

The height of those outer island reef edge habitats, relative to lowest astronomical tide (LAT), appears be more than one metre above LAT. Figures 3 and 4 show the mixed *Acropora*-dominated habitats were well exposed at predicted tidal heights of 0.6m at Holothuria Reef and 0.3m at Beagle Island (inferred from predicted heights provided by the Australian Hydrographic Service for the nearest secondary ports, West Holothuria Reef - 63019 and Adele Island - 62890). The size of those reef habitats is likely dependent on the area of available underlying substrate within a suitable exposure range. The coral communities change in both directions away from the reef edges, with consolidated reef matrix beyond the reef crest frequently supporting a diverse mix of submassive, massive and encrusting coral species. In the other direction, shallower intertidal habitats, which can still be highly diverse, often supporting corals from numerous families in a mixed, medium density community dominated by domal brain corals (formerly Faviidae now family Merulinidae – various genera, including *Platygyra* and *Goniastrea*). Wilson (2013) has also noted these domal corals as a common habitat forming group on many intertidal reefs. The domal corals can persist as significant components of the intertidal assemblage all the way to the reef edge (see Figure 5), but frequently form a distinct band slightly shoreward of the high diversity outer reef flat community. Observation of exposure of this habitat during flooding tides (Figure 6), suggest this community may frequently be found at heights of 0.7-0.9m above LAT. As larger domed colonies can commonly exceed 30-40cm in height, many of these corals may continue to be partially exposed at tidal heights of 1.0m or more.

Figure 5. Wildcat Reef exposed domal coral habitat during the southern survey. Image taken during a morning low tide when the predicted tidal height at nearby Degerando island (Port 62930, Hydrographic Service RAN) was 0.9m.

Figure 6. South Maret Island – initial tidal inundation of the domal coral habit zone of the western reef flat. Image taken after the commencement of the flood tide when predicted tidal height at North Maret Island (Port 62990, Hydrographic Service RAN) was approximately 0.8m

3.2 Inshore Habitats

At each of the four main survey locations shown in Figure 1 the RV Solander auxiliary vessels were used to assess shallow water benthic habitats. Satellite images obtained from Google Earth were used for planning, with a particular objective to assess the nature of the seabed across what appeared to be shallow areas of varying colour, extending seawards from the shorelines. Despite the Kimberley coastal zone often being highly turbid, available Google Earth imagery shows extensive potential intertidal and shallow submerged habitat along most shorelines

3.3 Eclipse Archipelago

Surveys in this area, during March 2017, focused on fringing habitats along the western side of the archipelago (see Figure 7). A series of replicate drop camera transects were attempted at each of the three locations. Water clarity was poor and macroalgae frequently obscured the substrate, with the resulting images often difficult or impossible to interpret. However enough images of acceptable quality were obtained to provide an initial overview of habitat type and distributions.

Figure 7. Satellite view (Google Earth) of the Eclipse Archipelago (13°55'34.98"S, 126°17'44.90"E) showing the general location of initial drop camera surveys.

Much of the habitat featured coarse sand with little or no macrobenthos. Macroalgae, in particular the brown *Sargassum* spp. (Figure 8) were abundant across much of the shallow fringing area visible from satellite images. Scleractinian corals were widespread, but where present on mid- or inner reef flats, mostly covered <1-5% of any single image. Coral taxa detected increased at the included species in the Families Acroporidae, Mussidae, Occulinidae, Faviidae, Pectinidae and Poritidae.

Figure 8. Eclipse Archipelago. A - Macroalgae were abundant in many photos on the inner and mid-fringing reef area. B – Mixed coral, sponge and algal habit was found across the mid- and outer fringing reef area.

Figure 9. Central Eclipse Archipelago - satellite image showing the fringing reef area. Red marker indicates the location of the edge of the fringing reef and habitat shown in the image on the right. A very narrow band of more abundant and diverse corals was found at the very edge of the fringing reef system.

3.4 Cape Bougainville

Drop camera transects were undertaken in the first three bays running south for Cape Bougainville along the west coast of the peninsula (see Figures 11, 12). Australian chart AUS 728 does not provide names for these shallow bays. They were selected to allow investigation of the shallow fringing reef structure apparent in satellite images. The likelihood that fringing reef habitat, with corals and other associated biota, would be present, was reinforced when Traditional Owners on board, from the Wunambal Gaambera, passed on knowledge that giant clams had previously been observed there. This proved to still be the case (see Figure 10).

Figure 10. Live tridacnid clams were found during the survey on the inner- to mid- reef-flats in bays adjacent to Cape Bougainville.

Weather conditions on the 19th March were calm and water clarity over the fringing reefs at high tide was moderate to good, with the seabed visible in 2-3m depths. Replicate drop camera transects were completed in the three bays and in each bay at least one depth profile was recorded across the fringing reef at high tide using a single beam echo sounder (Lowrance Elite 7) fitted to one of the auxiliary vessels.

Figure 11. Cape Bougainville - satellite image (Google Earth), showing the location of two of the cross reef drop camera transects.

Figure 12. Cape Bougainville –drop camera transect #3 images overlayed on a Google Earth image, with locations marked for key habitat types and transition areas.

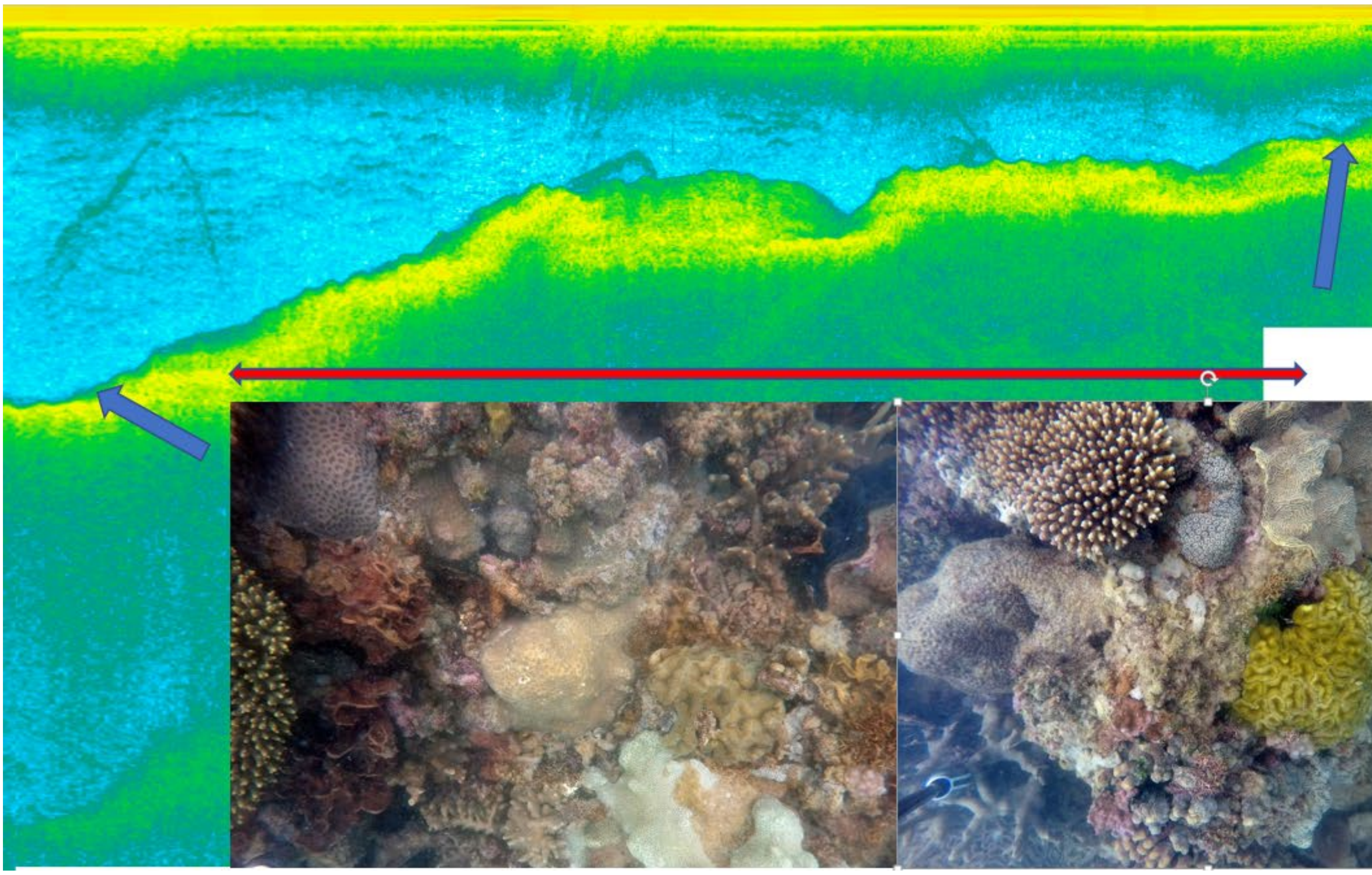

Figure 13. Cape Bougainville – depth profile of the outer fringing reef area on the lower transect shown in Figure 12 above, from the beginning of the rocky reef crest down to the base of the reef slope, bracketed by the two blue arrows. The width of the coral dominated zone, as indicated by the red arrow, is approximately 40m, with a total change in depth of around 5m, from 2.5-7.5m. Highly consolidated substrate in this habitat zone features a diverse and abundant hard coral community. Depth scale in metres on the right axis. Profile was run at mid tide, between 10:30-11:00 on 19 March 2017.

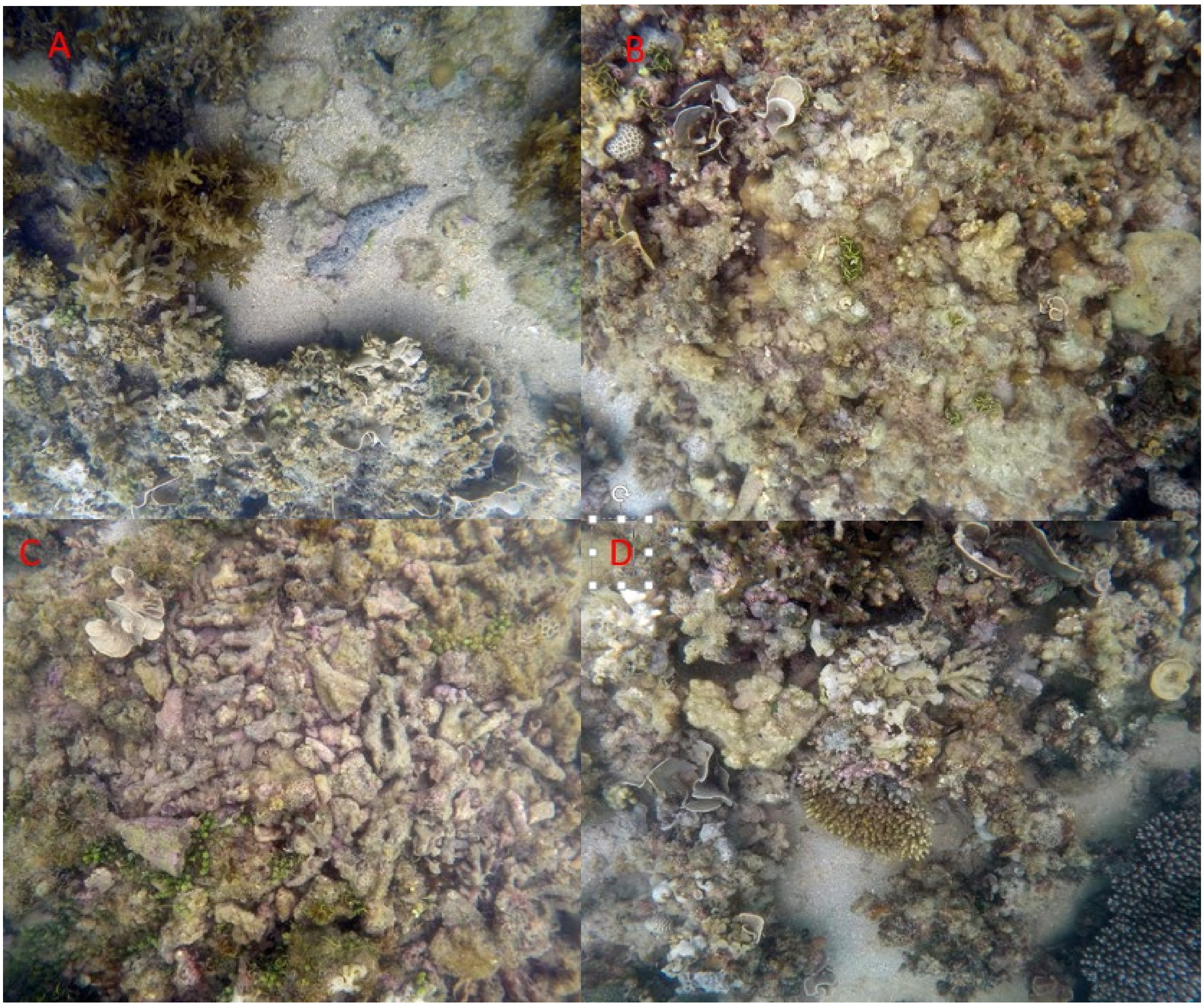

Figure 14. Cape Bougainville – drop camera photo quadrats on inner and mid-reef flat areas. A – Nearshore habitat features mixed sand and rocks, with occasional Holothuria and abundant macroalgae, including *Sargassum*. B – Mid reef flat habitats supported small corals, mostly Favids, and an increased diversity of other benthos including sponges and algae. C- Outer reef flat areas often contained patches with dense coral skeletal fragments, including branching and massive forms, suggesting previous disturbances such as storms can affect these habitats. D: outer edge reef flat habitats begin to transition to slightly deeper and topographically more complex habitats approaching the reef crest, with an increase in coral cover and diversity, including a variety of Acropora species.

3.5 Cape Voltaire drop camera transects

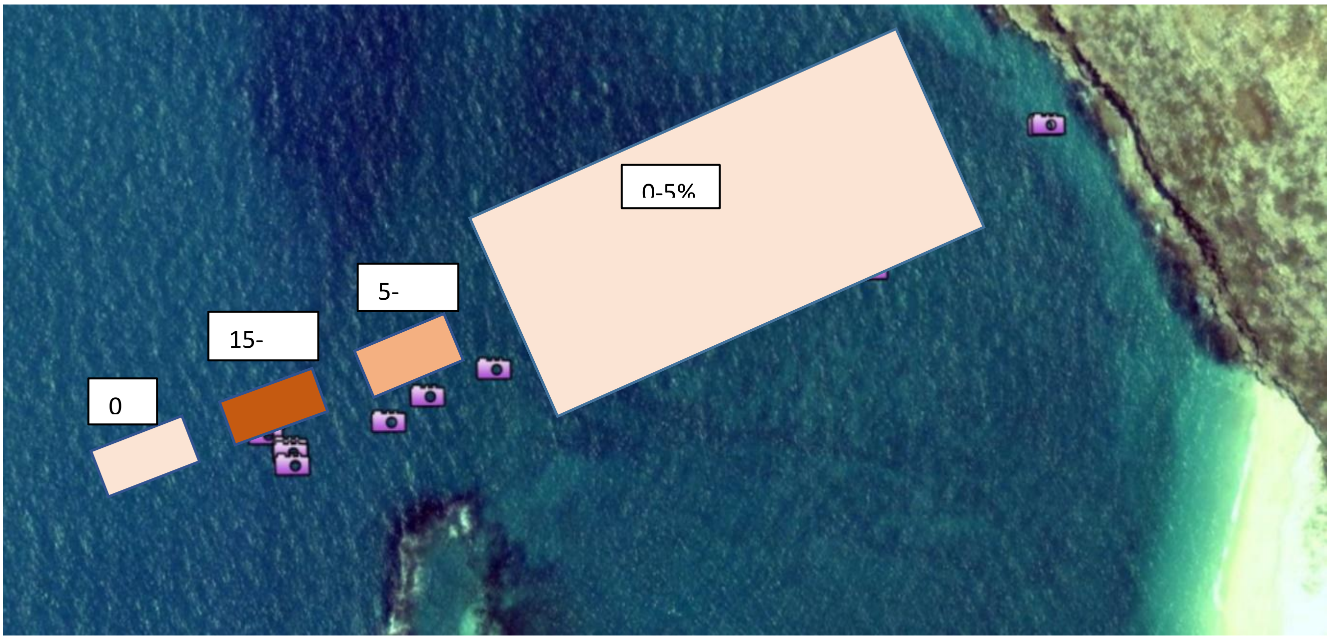

Figure 15: Cape Voltaire area, Transect A- relative hard coral cover, shown as percent cover ranges, along drop camera transect from the shore to fringing reef edge drop off area, overlaid on a Google Earth satellite image. Warmer colours along the transect line reflect higher coral cover.

The zonation of coral abundance and diversity observed in all areas typically showed very low coral presence (0-5%) across the majority of inner reef flat, representing the largest but shallowest portion of the fringing reef area (Figure 10.15). Coral species diversity was also low in this area, commonly represented by small Favid or Poritid species, but with occasional additional species, including small Acroporid colonies. Fleshy macroalgae were abundant, including algal turf complexes, *Sargassum*, *Padina*, *Halimeda* and *Caulerpa* species. Algae were the dominant epibenthic organisms across most areas of the mid- and inner intertidal zone. Greater coral abundance and species diversity occurred around the rocky edges of what would be small stranded pools at low tide. In the last 50-100m across the reef flat the substrate inflected slightly downwards, with depth increasing by 05.-1.0m at the reef crest. This slightly deepening outer area supported greater coral abundance (5-20% cover) and a rise in diversity, with small Acroporid corals and other family occurring more frequently. The reef crest and seaward slope featured abundant coral cover and high diversity of many of the major coral families, which persisted over a distance of approximately 60m on a three dimensionally complex, consolidated seabed. Some images suggested old spur and groove structure in parts of the rocky reef slope, which continued, with moderate to high coral cover down to depths of 15m. At the bottom of the rocky slope, corals became a very minor feature of the benthos, with a rubble and coarse sand seabed featuring filter feeders such as sponges becoming the dominant epibenthos. (see Figure 10.16).

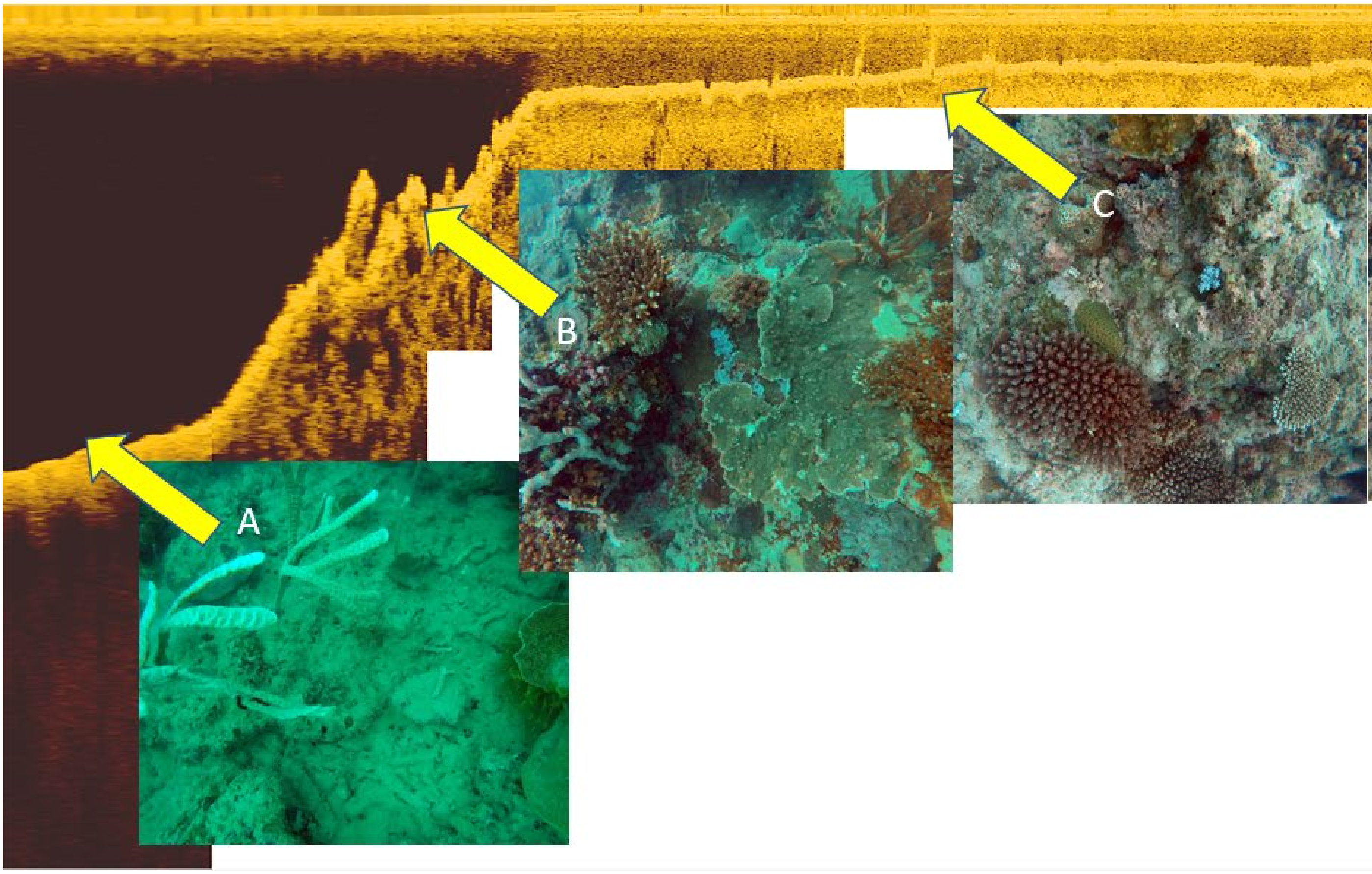

Figure 16. Cape Voltaire – cross reef depth profile for drop camera transect A (see Figure 15). Images labelled A,B,C & D are indicative of the different habitats at key transition points. At location C the slope of the reef increases and the reef deepens by approximately 1m over the next 100m to the reef crest, with a progressive increase in coral abundance and diversity. Predicted tidal heights at the time of the survey on 20 March, 2017, were in the range 4.6-5m (Port 63001, Hydrographic Office RAN).

3.6 North Lalang Garram Marine Park

The voyage departed Broome 29 May, 2017 and returned to Broome on 6 June, 2017. RV Solander steamed from approximately twenty hours directly to the northern study area, anchoring near Degerando Island, east of Wildcat Reefs, on 30th May. During the next 5 days the RV Solander moved progressively around the islands, supporting teams working from the two auxiliary boats. The daily track and each of the five anchorages used during the survey are shown in Figure 2.

While a previous cruise noted Wildcat Reef supported extensive fringing reef, with abundant corals in the lower intertidal zone (e.g Figure 5), the nearshore surveys confirmed that stony corals and fleshy brown algae (see Figure 17) occurred on shallow fringing reefs and rocky shores throughout the island archipelago and to the mainland. The corals were present at low to medium density, depending on substrate availability and depth in relation to tidal range. Generally, when the intertidal and shallow subtidal structures near any shoreline were wider than a few tens of metres, corals were not present right to the shore but began to increase in abundance and diversity on the outer third of reef flat areas and were most diverse and abundance just around the outer edges and drop off zones of reef flat.

Figure 17. Left - Brown algae *Sargassum* sp. near Byam Martin Island. Right - Mixed hard and soft coral community on the shallow reef platform east of Jungulu Island.

On rocky shores where no subtidal reef flat was apparent, corals were sometimes present in a very narrow band, in the order of 10m wide or less, just along the edge of the drop off (Figure 18). In places where hard substrate persisted at the base of shoreline rocky ledges, hard corals transitioned to filter feeding taxa such as sponges and sea fans, but frequently the base of the drop off ended in sand or mixed coarse sand and rubble, with little or no macro-epibenthos. In a previous AIMS survey, typically dense and diverse corals were found at the outer reef edge, but depths of around 12m between Slate Island and Wilson Point supported a filter feeder dominated habitat, although some hard corals were present as a minor component of the habitat (Figure 19).

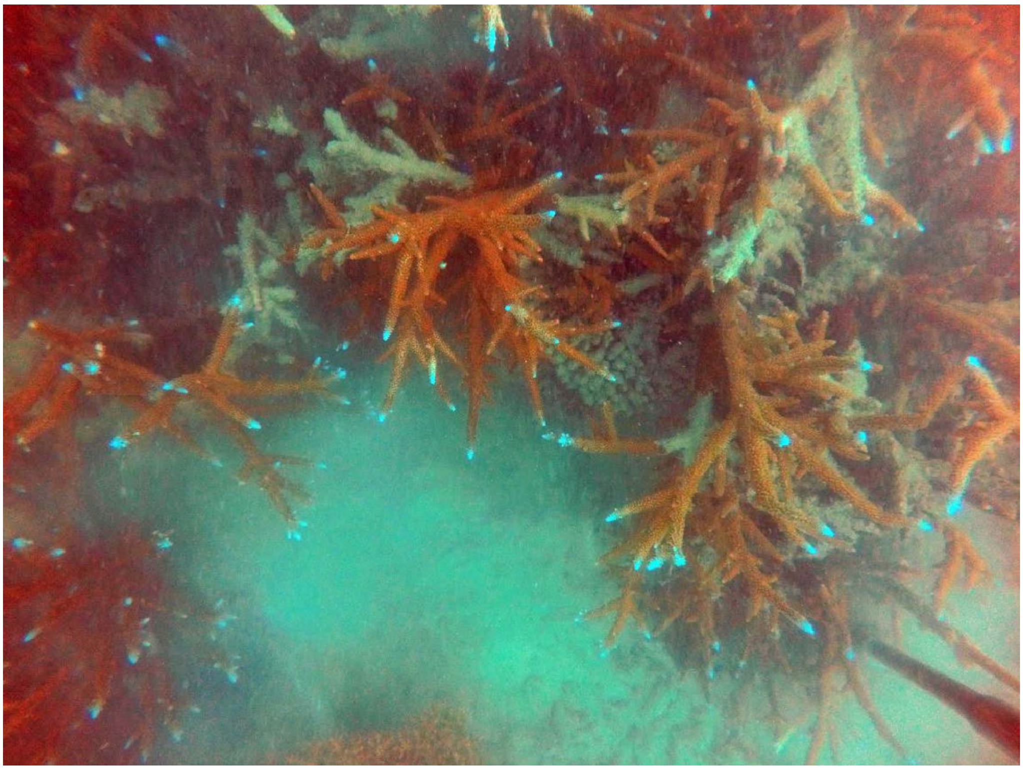

Figure 18. A thicket of staghorn corals located in a very narrow band along the drop off area of rocky shore on the southern side of Miawaja Island. The sandy and coral rubble substrate is visible at the base of the drop off.

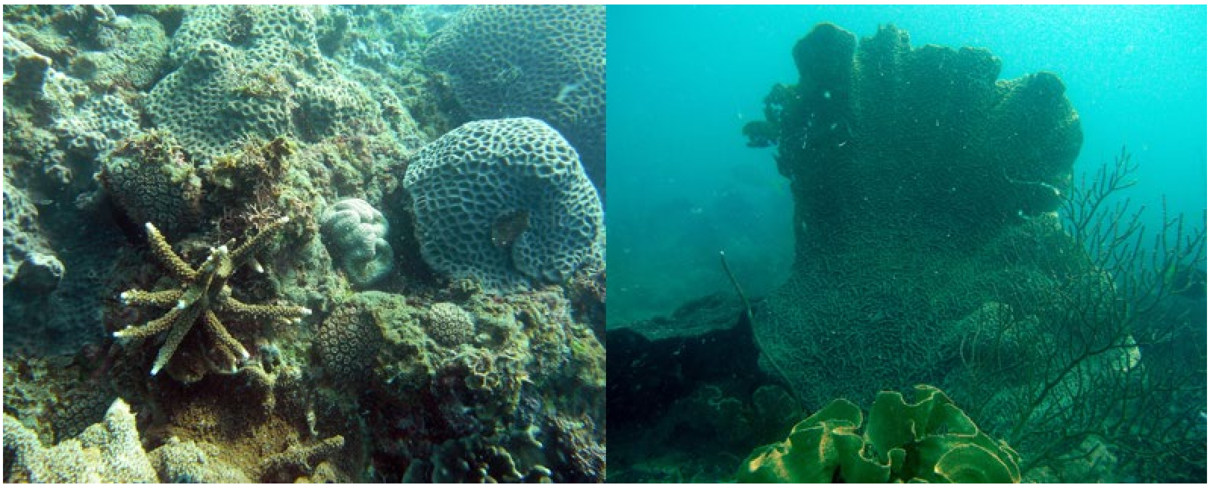

Figure 19. Wilson Point-Slate Islands (Wailgwin Islands), northern Camden Sound. Left – Diverse and moderately abundant hard coral just below the reef crest gives way to filter feeder dominated habitat (right image) at 12m depths in the channel. Photo – A. Heyward, AIMS, 2009.

The general observations from this voyage confirm the widespread presence of reef building corals throughout the area, from offshore to inshore, mainly as low to medium density communities rather than extensive, high abundance and diversity reefs.

A limited amount of sampling immediately adjacent to Wilson Point found evidence of *Acropora* coral thickets in place, but with the coral dead and the skeletons now covered in calcareous and turf algae. The mortality had not occurred within recent months, with the appearance of the encrusting algae suggesting an event 12 months or more prior. These patches of coral were previously seen alive by A. Heyward in 2009. As storm damage would likely have broken down the thickets, it may be that mortality occurred in 2016. These observations are consistent with other work in the southern Kimberley (Schoepf et al. 2015) where, despite their ability to adapt to the high temperatures, corals were nonetheless highly susceptible to heat stress and bleaching. In contrast to these qualitative observations, detailed surveys of the Bonaparte Archipelago in 2016 (Appendix 5) found no evidence of bleaching damage to those coral communities.

3.7 Additional surveys.

Corals of varying abundance and diversity appear to be an almost ubiquitous component of intertidal and subtidal platforms and rocky shelves along the Kimberley coast. Drop camera work in the North Kimberley by DBCA, supported by the Project, also uncovered numerous examples of healthy and diverse coral reef (A. Halford pers. comm. to A. Heyward). Researchers noted that the highly turbid environments typical of the Kimberley did not appear to have been an impediment to the development of coral habitats and reef systems in many locations.

Similarly, field surveys by Dambimangari sea rangers, using drop cameras, revealed the presence of branching and plate coral species, together with macroalgae and sponges at Vickery Reef (Figure 20).

Figure 20. Left -Location of Vickery Reef drop camera surveys undertaken by Dambimangari sea ranger. Right – Encrusting and foliaceous corals on Vickery Reef.

Perhaps the most unusual, but unpublished, coral survey in the region was undertaken in the Buccaneer Archipelago at Koolan Island (MScience, 2008). Open cut mining of iron ore on the island was conducted until 1993 when, as part of a rehabilitation program following cessation of mining, the mine pit was connected to the ocean by a channel cut through the seawall see Appendix 3, Figure 1). The pit was drained in 2008, allowing an assessment of biota remaining, which had developed over the intervening 15 years. Corals from Koolan Island mine pit were collected by MScience Pty Ltd as part of a series of studies for Koolan Iron Ore Limited. Sampling took place over 2 days at accessible locations on the pit wall, to the equivalent depth of -2m below LAT. Species were collected and lodged at AIMS for identification, which determined that approximately 100 Scleractinian coral species, representing 13 families, were sampled (see Appendix 3). Given the brief sampling period and limited depths below LAT sampled, it is very like this is an underestimate of coral species diversity present in the mine. Even so it is indicative of the potential diversity on surrounding reef areas.

4 Discussion

It is clear from the Project's surveys, in combination with the results of recent work by the WA Museum (see Richards et al. 2014, 2018; Appendix 5) and ongoing drop camera assessments along the coast by DBCA, that Scleractinian corals feature as a component of benthic habitats throughout the Kimberley. Coral reef habitats, some with species diversity equivalent to well recognised offshore coral reef ecosystems, have been observed in southern, central and northern locations across the region and have been best documented around outer coastal islands. While the Bonaparte Archipelago in the central region remains the location of maximum documented species diversity (see Appendix 5), the historical records indicate locations of moderate to high diversity can also occur very near the mainland (Figure 21). The documented diversity is influenced by sampling effort, with many of the locations shown in Figure 21 sampled during a single collecting event (Richard et al, 2014). Considering that 100 Scleractinian species were found in the flooded mine pit at Koolan Island and observations of diverse coral habitats tens of species at several locations along the coast during the Project, it is reasonable to infer that coral habitats with moderate to high diversity exist throughout the region's coastal waters.

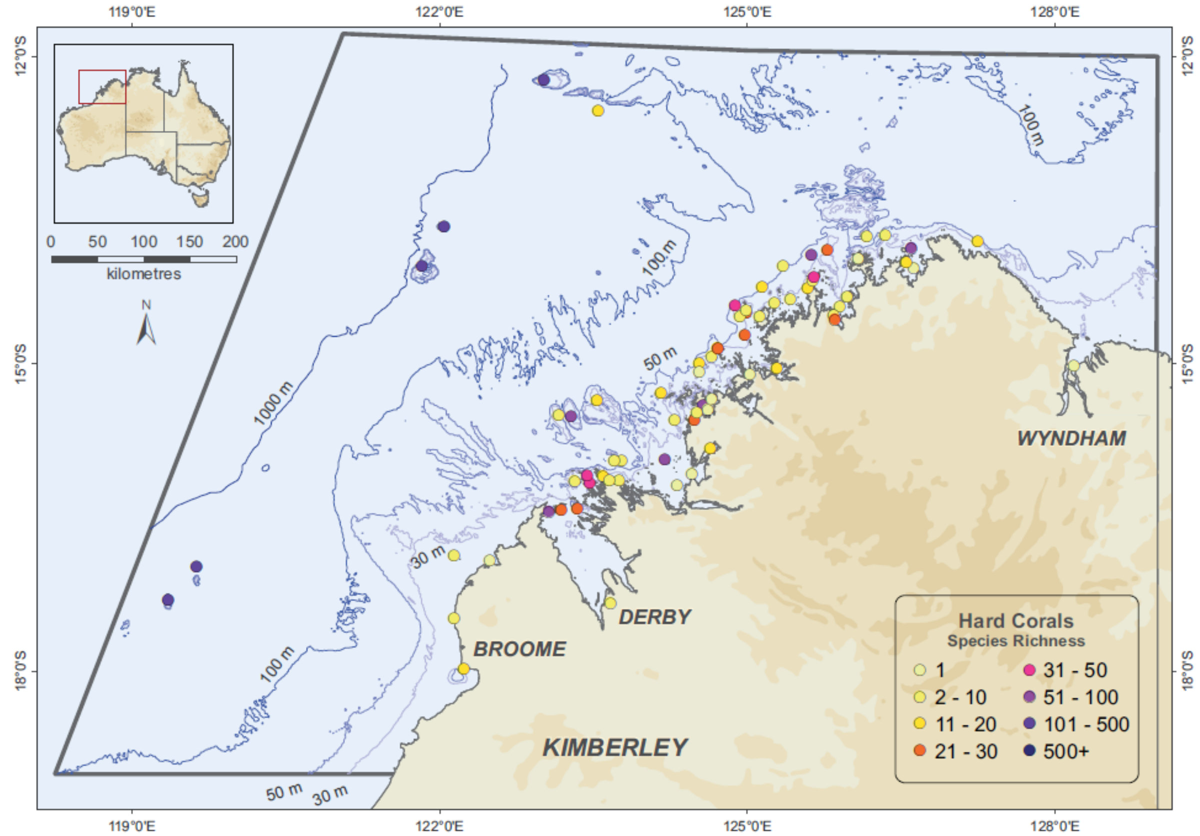

Figure 21. Species richness of hard corals based on historical WA Museum collection records up until 2009. From Richards et al. (2014), p117.

While a number of larger coral reef type platforms are known, the presence of smaller patches of reef or coral-dominated habitat on rocky substrate is pervasive and may represent the majority of coral habitat in the region. Short (2011) estimated the Kimberley coast to be 4,340 km long and dominated by usually steep rocky shores, which occupy over 80% of the open coast. The surveys made during this Project suggest that corals are likely to be present on much of that rocky shoreline, if the elevation in relation to tidal heights is appropriate. Intertidal habitats were found at all locations surveyed. In general, hard coral dominated habitats occupied areas at the edge of the reef flat and periphery to the low tide line, which then transitioned to consolidated rubble habitats having sparse coral cover further inshore. Further inshore and in the upper intertidal, habitats were dominated by macroalgae, often brown algal species in the Class Phaeophyceae. Where they occurred, foliose phyllospongiinid sponges were sparse in coral dominated habitats, and were found in highest abundance in consolidated rubble habitats having low cover of live hard corals. In the study of outer coastal island reef flats (Appendix 2) sponges were sparse in the upper intertidal macroalgae habitats.

The observations made from the Eclipse Archipelago to Camden Sound indicate that mid- and upper reef flat coral abundance is frequently <5-10%, with macroalgae the major habitat component. Both abundance and diversity rise when the corals are less exposed, which includes intertidal ponds and rock pools at all elevations, However the outer reef flat and crest region provide larger and more continuous areas of substrate that support the highest levels of diversity and coral cover.

Observations on tidal exposure of the coral dominated habitats indicate that in many locations this rich coral zone tends to commence on the seaward margins where the substrate lies lower than 1m above LAT. The actual demarcation of a more coral dominated habitat is sometimes associated with a slight change in seabed slope, with the reef flat inflecting downward a few degrees and sloping gently to the reef edge before sloping steeply. The actual species assemblages vary from place to place, although many species are widely distributed across the bioregion. Where broader reef flats exist at appropriate elevations, observed to be in the range 0.8-1.2m above LAT, domal corals can be a notable feature (see also Wilson, 2013), with more *Acropora* dominated habitats tending to proliferate towards the reef edge at elevations below 0.7m LAT. However a distinct band of domal corals is not always evident and in some locations, for example Montgomery Reef (Figure 22), the more obvious coral habitats may be a mix of species compressed into narrow reef edge zones, but some species feature more than others. Heyward and Moore (2009) found the coral communities on shallow areas of Montgomery Reef were characterised by submassive life forms (protruding and flattened), massive life forms, digitate *Acropora* and encrusting life forms. The more fragile tabulate *Acropora* and branching morphologies provided a very small contribution (<1%). Coral cover on the reef edge at scales of tens to hundreds of metres was typically in the range 15-25% and up to 43.6% at one location. This is consistent with more recent surveys that included Montgomery, a large number of coastal islands and the offshore shelf edge reefs such as the Rowley Shoals (Richards et al. 2018) which found a mean of hard coral at those locations of 23.6%. In regional terms this is slightly lower than the Great Barrier Reef, where pre-decline mean coral abundance was estimated at 28% in one study (De'ath et al. 2012).

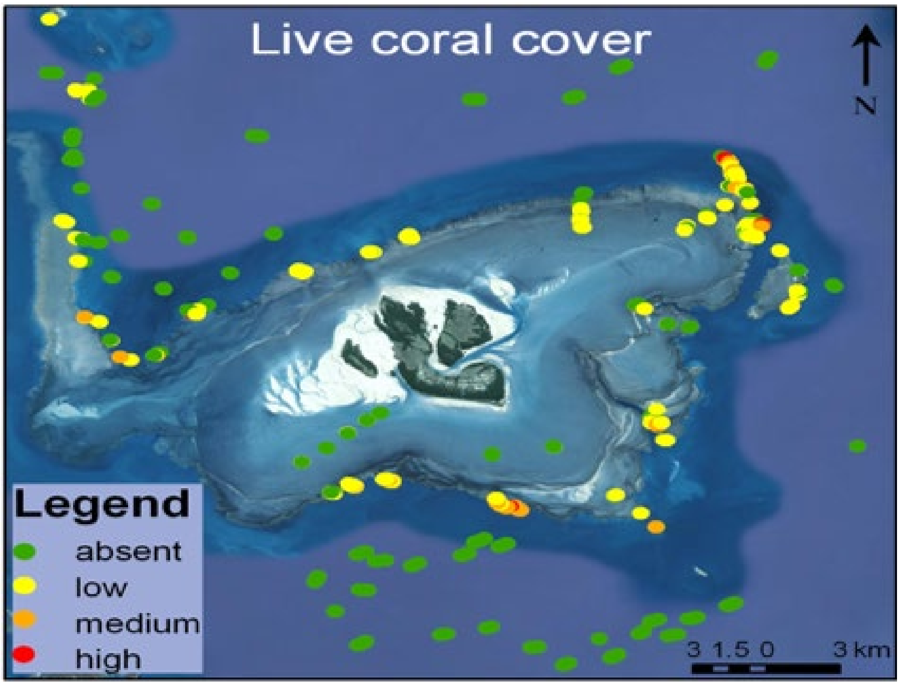

Figure 22. Montgomery Reef relative distribution of live coral abundance (from Heyward and Moore, 2009)

Very high coral diversity has been observed at a few locations within the outer reef flat zone and from the reef crest to several meters below LAT. However the coral dominated habitat on the inshore fringing reef and rocky shelf areas surveyed in the current project did not extend beyond 10-15m depths, due to the absence of hard substrate at the base of the reef drop off and perhaps less favourable environmental parameters, including the marked attenuation of surface sunlight.

Despite a tidal range of 11m in Camden Sound compared to around 4m at the northern end of the study area, light profiles from the surface to the seabed were on some days comparable between the north and the south (see 1.1.1.1 Chapter 3, Figure 4; Appendix 4, Figure 1). A single brief visit to the Cape Bougainville area nearshore habitats is unlikely to be representative of water quality. However it is noteworthy that a previous assessment of potential coral habitats in the northern region, around the Anjo Peninsula, reported that “underwater visibility was generally less than 0.5 m in deeper waters (approx. >7 m, increasing to 2-3 m in shallow protected inshore waters” (p9, DEC, 2008). While the range of turbidity each area might experience varies over neap and spring cycles, detail is lacking on how frequently corals and other benthic primary producers in the southern, central and northern regions are equally as turbid. The inshore coral habitat study and the offshore expeditions reported on in previous chapters, found that while corals were recorded to 30m in at least one sample, at below 10-15m they are often absent or contribute <1% to the biota. This suggests that management of benthic primary producers in the coastal waters of the Kimberley should focus on intertidal and subtidal waters <15m deep (Figure 23) for detailed study of specific locations

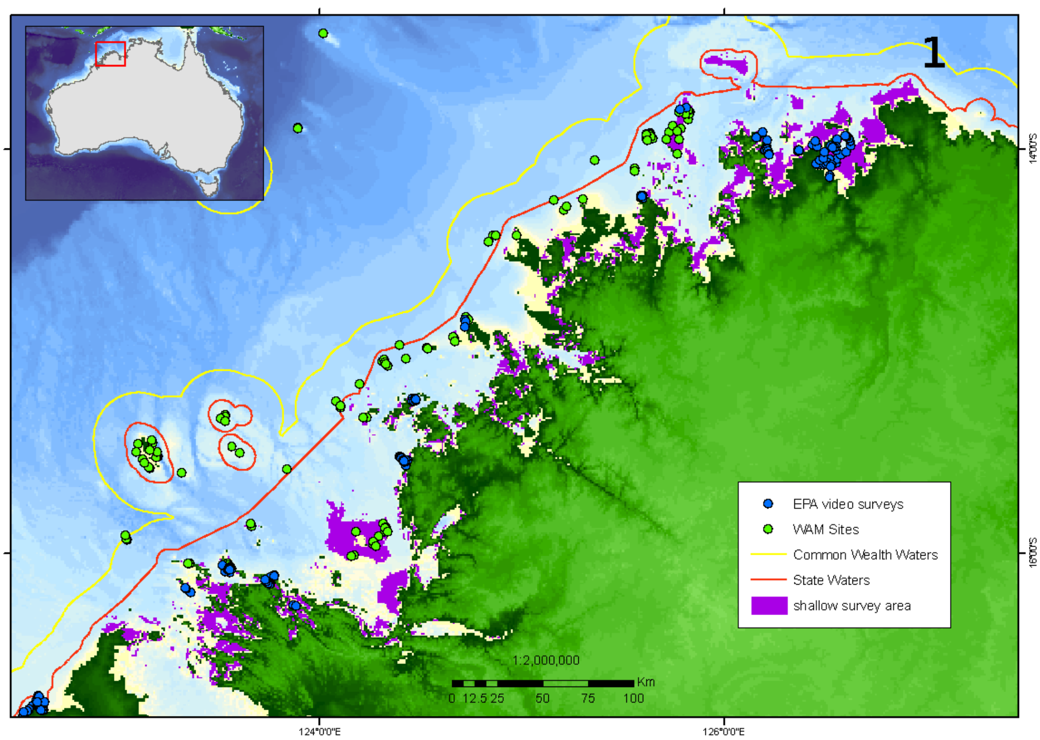

Figure 23. Map of coastal waters along the Kimberley. Shallow water areas most likely to support benthic primary producers, including hard corals, shown in purple.

The results of this and other recent complementary studies confirm the Kimberley coastal region as a significant coral province. A narrow band of coral exists on many of the intertidal and subtidal rocky shore areas, even along mainland shores, however the areal extent of coral habitat remains uncertain. The width of those coastal fringing habitats could be hundreds of meters, but habitat where coral cover exceeded 10-15%, was measured in this study to vary from 10m to 200m. This would suggest that, even if several thousand kilometres of rocky shore supports a dense lower intertidal and subtidal coral habitat, it is a diffuse element whose extent totals a few hundred square kilometres.

Hence, as a general rule, large areal extent of coral habitat is not a preeminent environmental value of the Kimberley reef systems. Rather, the key feature of inshore coral habitats there is the occurrence in a broad variety of sometimes unusual and largely undisturbed environmental settings, in addition to the more typical coral-reef like habitats observed on larger reef platforms around the coastal islands.

When considering representative examples of coral habitat within the proposed Greater Kimberley Marine Park area, it is clear that corals will be part of almost any spatial planning area selected for management and conservation. However there are regional and local differences in abundance and diversity, influenced by depth, underlying geomorphology, exposure to currents and waves and so forth (this study; Wilson, 2013). Richards et al (2018) reported distinct inshore-offshore, intertidal-subtidal and subregional patterns of community structure in their study of coastal islands and inshore reefs. Taken together these studies suggest conservation of areas that include inshore-offshore gradients and a variety of environmental settings, such as sheltered and exposed shorelines, should be effective in ensuring a representative sample of coral habitats and species, as well as genetic diversity between sites within the area. The recently declared North Lalang Garram Marine Park is one good example likely to meet those needs.

Nonetheless, additional marine park areas are likely to be needed at more local scales within the Greater Kimberley Marine Park. While many of the Kimberley coral species are widely distributed and form a subset of the broader Indo-Pacific coral taxa, genetic evidence from the recent WAMSI connectivity project (Berry et al, 2017) indicated corals typically exhibited localised population structure, with evidence for limitations to routine dispersal on scales of 10s of kilometres or less. Consequently they suggest conservation would be most effective with protected areas of similar scale (10–20 km). They also found evidence that King Sound, subject to strong tidal flows and seasonal salinity effects, could be a barrier to dispersal. While the presence of coral habitat on islands and submerged reefs is likely to provide important stepping stones for dispersal across this barrier over multiple generations, this finding raises the question of whether other large Sounds within the Greater Kimberley Marine Park, such as Prince Regent Sound, may form additional dispersal barriers. Conversely it is uncertain if the widespread occurrence of coral populations along rocky shorelines provides a mechanism to overcome them within ecological time scales. Answering that question will help demarcate functional coral habitat provinces of the Kimberley coast and aid in locating additional areas for protection.

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6 Appendices

Appendix 1 :

Drop camera procedures -SOP v 1.0, August 2016

Andrew Heyward, Jarrad Holmes and James Mansfield

Background

These procedures provide a guide to basic benthic photography using a camera lowered on a frame or tripod to rest on the seabed. It relies on using a camera that has a built in interval timer, which allows it to automatically take photos every few seconds, and a stable frame from which to suspend the camera so it is pointing down at the seabed. Any frame will do, provided the camera can be mounted pointing downwards, the frame is stable and the view of the seabed is not obstructed. Tripods with the camera mount inverted to hang down between the tripod legs can work well but usually need some weight on the legs to keep it stable. Metal or plastic frames will also work. Many cameras have interval timers and will work, provided they are protected in a waterproof housing of some sort. The quality of the photos depends on the camera and, the water clarity, amount of available light at the seabed and the stability of the camera on its frame. More expensive cameras tend to give better photos, particularly if water is a bit turbid, but even small sensor cameras like GoPros and various rugged tough cameras will produce useable images under most conditions.

This guide to drop camera procedures was originally developed by Andrew Heyward at AIMS, then refined in collaboration with Jarrad Holmes and James Mansfield of the Dambimangari, for use in the WAMSI Kimberley Seabed Biodiversity project. This version (V1.0) applies to use of GoPro 4 Silver cameras and a custom weighted tripod, documenting the initial approach used in the WAMSI Project. The SOP remains an open document and will be updated by Heyward as new methods and equipment are evaluated and adopted.

Equipment required for the field:

1. Tripod drop frame, including the bracket that will hold the camera itself. Make sure all nuts/bolts are present, and take a few spare.
2. Rope (suggest 8-10mm silver rope for depths to 15-20m)
3. Gloves - to protect hands from rope burn during lowering/raising of frame
4. Shackle to attach rope to tripod, include some small wire to mouse the shackle
5. A small shifter or spanner will be useful to help tighten shackle
6. Camera with interval setting (preference is GoPro4)
7. Water proof housing for camera
8. Cable ties or a cord to tether the camera housing to the rest of the frame is a useful safety idea.
9. Laptop and cables to download your GPS tracks and photos onto at end of each day
10. Camera batteries and chargers. Make sure batteries are charged.
11. Camera memory cards (check they are compatible with camera as older cameras may not recognise larger sized modern cards). Enough for a full day’s photos, plus spares.
12. SD adaptor card (if needed. It is for GoPro) so you can download your photos onto your laptop
13. Slate or whiteboard for site naming.
14. Handheld GPS (notes in this doc relate to Garmin GPSMAP64)
15. Take Notebook and/or print plenty of data sheets and pens to record information
16. PPE – Hat, sunscreen, water bottle

Before you leave for the field:

It is recommended to run through setting up the equipment and reviewing the SOP prior to going into the field. Once set up, the gear shouldn't need adjusting again for any future trips, but it is good to double check.

1: GoPro4 photo settings - Check that all of the standard settings are the same as outlined below. You can look at all the photo settings by going to the screen as if ready to start taking time lapse photos, then tap twice on the screen on bottom right corner, and it opens up the photo setting menu.

Mode:	Time lapse
Interval:	5 secs
Megapixels:	12mp/wide
Spot meter:	Off
Protune	On
White balance:	Auto
Color:	GoPro Color
ISO limit:	800
Sharpness:	HighEV Compression 0

For other cameras that aren't GoPro set the camera to auto exposure, flash off, and focus to macro.

2: GPS - GPS units can be used to automatically record locations as you move along a transect. This can be setup to record a track at either regular distance intervals or regular time intervals. For drop camera work either is OK but generally the track is set up to record every five seconds. To check this setting on the Garmin GPSMap64 use the 'page' button to scroll to 'main menu'. Then 'Setup'. Scroll down and then select 'tracks'. Scroll down and select 'recording interval'. Make sure that it is set at "00:00:05" which means the GPS will automatically take a waypoint every 5 seconds. Also check that the 'record method' is set to "time".

You will need to be familiar with software to manage your tracks when they get downloaded from the GPS in the field. 'Garmin Basecamp' is free software that can be downloaded from the web. 'Expert GPS' isn't free but it's quite cheap and very easy to use. You need to learn how to download tracks from the gps to your computer, then how to select and save the tracks as gpx files into folders. Learn to do this before you go out in the field.

3: Charged - Make sure everything is charged, and you have spare batteries and battery charges.

4: Be well planned and prepared - Prepare maps to take for where you are going and will be doing transects.

5: ***Tripod or other camera frame*** – check everything is secure, bolts and knots tight. Height of camera mount set to what is needed.

Doing a transect in the field:

17. Set up the frame and waterproof housing for the camera mount as per photos. The lens of the camera should be looking straight down.
18. Make sure the time on the GPS and on the camera are synchronised. You should do this once or twice a day when you are doing camera drops. To do this :
    a. Turn on GPS and let it acquire satellites. The GPS time can be seen on the 'map' homepage.
    b. For GoPro4 camera: Turn on. Press button on front of camera twice to get to 'setup'. Scroll down 'setup' until 'Date/time'. Select 'time'. Adjust the clock to one minute ahead of the GPS clock. Wait for the

GPS clock to catch up, then select ‘done’ on camera. This means that the camera and GPS should be now sync’d to the second and on the exact same time.

19. Follow all of the steps on the data sheet on the following pages.
20. For the camera drop itself, lower the camera gently to the seabed using 20m+ of 10mm rope. Once on the bottom give it a little slack and count to 10. If the current is too strong you may have to use the motor, sometimes in reverse works well, to keep the boat close to the camera, but if current is OK then just slowly drifting works well.
21. Pull the tripod up off the bottom. If the drift is very slow just pull it up a couple of meters then lower again. If deeper water and/or faster drift you may have to retrieve the tripod more, sometimes almost back to the boat, then lower again.
22. Repeat the process, counting to 10, retrieving and lowering as you move along the transect.
23. Don’t forget to complete all of the steps outlined on following data sheet.

CAMERA DROP DATA SHEET (2 pages)

On site but before you start using the camera

Site Name and general area description

Date

Who is doing the work

Record the setting for how high the camera lens is above the ground when frame is flush on ground (standard setting is 50cm for gopro).

Turn on GPS to give it some time to acquire satellites

Make sure the rope is secured to the tripod and the other end is tied to the boat. Lay out enough rope so you have heaps to reach the seabed.

Before camera is placed inside housing

Take a general site photo of the area (all photos taken should be done using the same Gopro that will be used underwater)

Take a photo of the time displayed on the GPS (the time is displayed on the 'map' page of the GPS)

Take photo of the slate/whiteboard (incl. site name, date, project name and people present)

Set camera to the 'timelapse' mode, press top button, now the indicator symbol should go red. When this symbol is red it is now taking a photo every 5 seconds.

Once camera is taking photos and is placed inside housing.

Put the camera in the housing on the tripod and check the viewfinder to see that it is taking photos (camera pic top left should be red) and is looking straight down.

Lower rope with frame and camera gently to sea floor and begin transect

Record waypoint location at start of transect (also mark wpt on GPS as well)

Depth at start of transect

Time at start of transect

Set GPS to "go to" "wpt" so it's easy to measure distance travelled away from start (You do this by going 'main menu', 'waypoint manager', select the waypoint you want, then 'go')

Waypoint location at end of transect

Depth at end of transect

Time at end of transect

How long was the transect (aim for between 150-250m from start wpt)

Save the track log on the GPS by "Track manager", "Current Track", "Save Track".

Any interesting notes or comments during the transect

At the end of the day:

It doesn't take long for the GPS and camera storage to become full. A standard GoPro battry may last for about 2000 photos if taken in one run, more or less if multiple stop and starts are involved,m but it should cover a solid amount of work without needing to open the housing. At the end of each day you should download all data and clear the devices and charge batteries for the next day.

1) Once you are ready to download, create new folders on the laptop for each of the days transects that describes the location and date.

For Camera:

2) Remove the data card from the side of the GoPro
3) Insert the data card into the larger adaptor, so it can be inserted into your laptop like any other SD card.
4) You can then select, cut and paste folders from the data card to your computer, the same as any other storage device (e.g. USB).
5) All photos from each individual transect (such as general shots, shots of GPS etc) should be put into the new folder.
6) Be aware that for some reason the gopro doesn't automatically order every photo sequentially, you might have to check this, to make sure you cut and paste all of the right photos into the right folders.
7) Check a few of the images after each session to make sure they seem OK. Many will be blurred or empty because they were taken on the drop or retrieve, but there should be one or two good ones each drop of the camera, taken when the camera was resting on the seabed.

For GPS:

8) Connect GPS to laptop using cable.
9) If using 'Garmin Basecamp' software onto laptop, after connecting device select 'receive data from device'. The tracks then show up in the window. Select the track you want, then go up to file and 'export' and save the gpx format file in the same folder as the photos from that site.

For both:

10) Make a backup on an external hard drive of the new folders containing the photos and track logs.
11) Clear photos and track logs from camera and GPS.
12) Charge up all batteries

Appendix 2:

Where are the phototrophic fans? Distribution of foliose sponge populations (Dictyoceratida: Thorectidae: Phyllospongiinae) in the Kimberley intertidal

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Introduction

Intertidal habitats are common features of the Kimberley, a region that is characterised by one of the largest macrotidal regimes in world (Wilson 2013). Here, sessile marine invertebrates occurring in littoral zones can be exposed to harsh environmental conditions during spring low tides, and are subjected to air exposure, UV irradiation and desiccation. Despite these stressful conditions, the intertidal invertebrate communities of the Kimberley are highly diverse and comprised taxa that are well adapted to "living on the edge" (Keesing et al. 2011, Fromont & Sampey 2014, Bryce et al. 2018).

Sponges (Phylum Porifera) are filter feeding organisms that rely on the flow and pumping of water, and thus immersion, for respiration, feeding and reproduction (Reiswig 1971, 1974). Surprisingly, some sponge taxa are able to survive, and in some cases thrive, in the intertidal. Foliose sponges in the sub-family Phyllospongiinae (Dictyoceratida: Thorectidae) are common on some coral reefs and can form up to 80% of total number and biomass of sponges (Wilkinson 1988). These sponges are phototrophic, and rely on light and primary production of their cyanobacterial symbionts to supplement up to 50% of their daily energetic requirements (Wilkinson 1983, 1987). Their distribution can be highly depth regulated and influenced by water clarity and hydrodynamics (Wilkinson & Evans 1989), and foliose phyllospongiinid sponge populations had been reported from the mesophotic (Bridge et al. 2011) to the intertidal (Abdul Wahab, de Nys, et al. 2014, Abdul Wahab, Fromont, et al. 2014). Importantly, it was recently reported that phyllospongiinid sponges can act as sensitive receptors to environmental degradation, in particular with respect to declining water clarity associated to coastal developments (e.g. dredging, Pineda et al. 2016, 2017).

This study aimed at quantifying the abundance and distribution of foliose phyllospongiinid sponge populations at four locations in the Kimberley. Photo survey transects of intertidal habitats were performed on reef flats and coincided with spring tides in October 2017.

Materials and methods

The field expedition was conducted onboard the MV Kingtide, a 16.5m live aboard charter vessel operating in the Kimberley region. Surveys of intertidal reef flats were conducted between 6th – 10th October 2017 at four locations within the inshore Kimberley region, coinciding with spring tides occurring over the same period (minimum low tide = 0.1 m datum on 8th October 2018). Survey locations included three fringing reef flat habitats (Adele Island, White Island and Bathurst-Irvine Reef) and a solitary reef system (Beagle Reef, Figure 1). Three sites were surveyed at Adele Island, two at Beagle Reef and one site each at White Island and Bathurst-Irvine Reef.

Surveys transects were performed via reef walks oriented at a bearing perpendicular to the water's edge where possible, and in a haphazard manner in areas with high coral cover to minimise damage to the benthos. Downward facing photographs were taken at approximately 1 m above the substrate (field of view of 2 × 1.5 m) at every 4 – 5 m horizontal distance intervals. Each transect lasted between 30 minutes to an hour depending on the time available at the site during low tide. The total number of foliose sponge individuals (including *Carteriospongia foliascens*, *C. flabellifera* and *Phyllospongia papyracea*) were collectively quantified for each photo, and their distribution and abundance mapped.

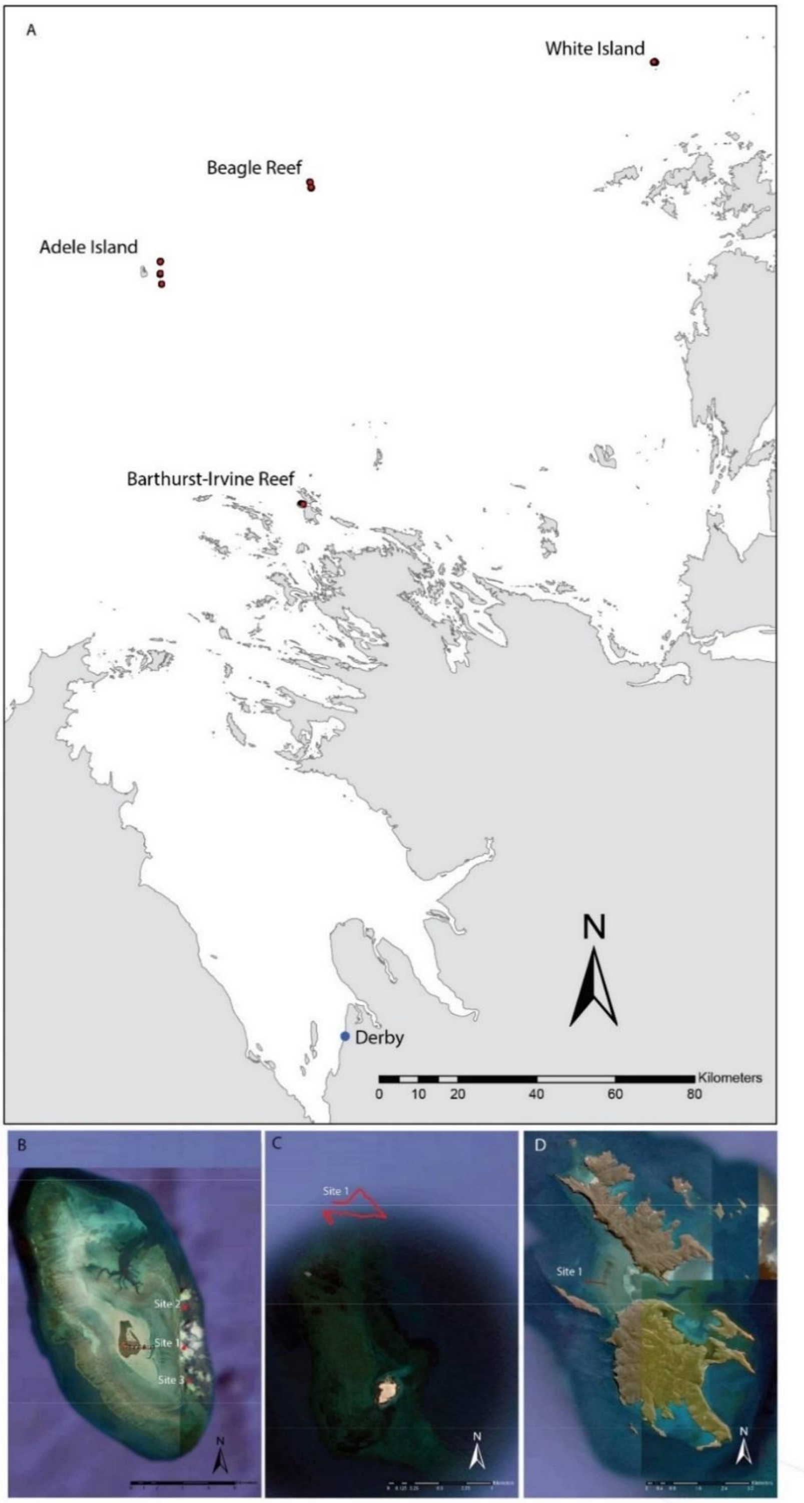

Figure 1: A) Overview of the study area showing the four surveyed locations including Adele Island, Beagle Reef, White Island and Bathurst-Irvine Reef. Red dots represent survey sites. Close up of survey locations, B) Adele Island with the three surveys sites on the eastern section of the reef flat, C) White Island with a single survey site at the northern section of the reef flat, and D) Bathurst-Irvine Reef with a single survey site located in between Bathurst Island to the north and Irvine Island to the south. No satellite imagery of Beagle Reef was available at the time of writing this report.

Results and discussion

Intertidal habitats were extensive at all locations surveyed (Figure 2). In general, hard coral habitats occupied areas at the edge of the reef flat and periphery to the low tide line, which then transitioned to consolidated rubble habitats having sparse coral cover as the transect moved inshore. Further inshore and in the upper intertidal, habitats were dominated by macroalgae, in particular in the Class Phaeophyceae. Where they occurred, foliose phyllospongiinid sponges were sparse in coral dominated habitats, and were found in highest abundance in consolidated rubble habitats having low cover of live hard corals. Sponges were sparse in the upper intertidal macroalgae habitats. These patterns are further discussed below for each of the locations (Figure 3 to 6).

Figure 2: Diversity of intertidal habitats in the Kimberley. A) Bathurst-Irvine Reef flat at low tide. The habitat had low rugosity compared to the other three locations, however had a moderately high abundance of foliose phyllospongiinid sponges, including *Carteriospongia foliascens*, *C. flabellifera* and *Phyllospongia papyracea*. B) Bathurst-Irvine Reef. Macroalgae dominated the benthos in the upper intertidal (shallower areas). C) Beagle Reef Site 2. Hard coral dominated the benthos at the lower intertidal to the edge of the reef flat (deeper areas) and can exhibit very high cover of the substrate.

There were clear differences in the abundance and distribution of sponges within and between locations (Table 1). The highest density of sponges was found at Adele Island Site 1, reaching 19 sponges/ photo, however sponge distribution was patchy within site and occurred within narrow zones (~ 50 m along surveyed transects) of consolidated rubble (Figure 3). No sponges were found in hard coral and macroalgae dominated habitats. The patchy distribution of sponges at the other Adele Island sites (Site 2 and 3) were similar to that observed at Site 1 as determined by the proportion images with sponges (22 – 32% of photos) and spatial distribution maps, however sponges were up to 6× less abundant at these sites.

Table 1: Patterns of sponge abundance and distribution within and between locations, for Adele Island, Beagle Reef and Bathurst-Irvine Reef. No sponges were found at White Island.

	Adele Island 1	Adele Island 2	Adele Island 3	Beagle Reef 1	Beagle Reef 2	Bathurst-Irvine Reef
Maximum number of sponges	19	3	7	1	2	6
Total number of images	152	181	91	50	373	235
Proportion image with sponges (%)	23.03	21.55	32.97	4.00	9.38	23.83

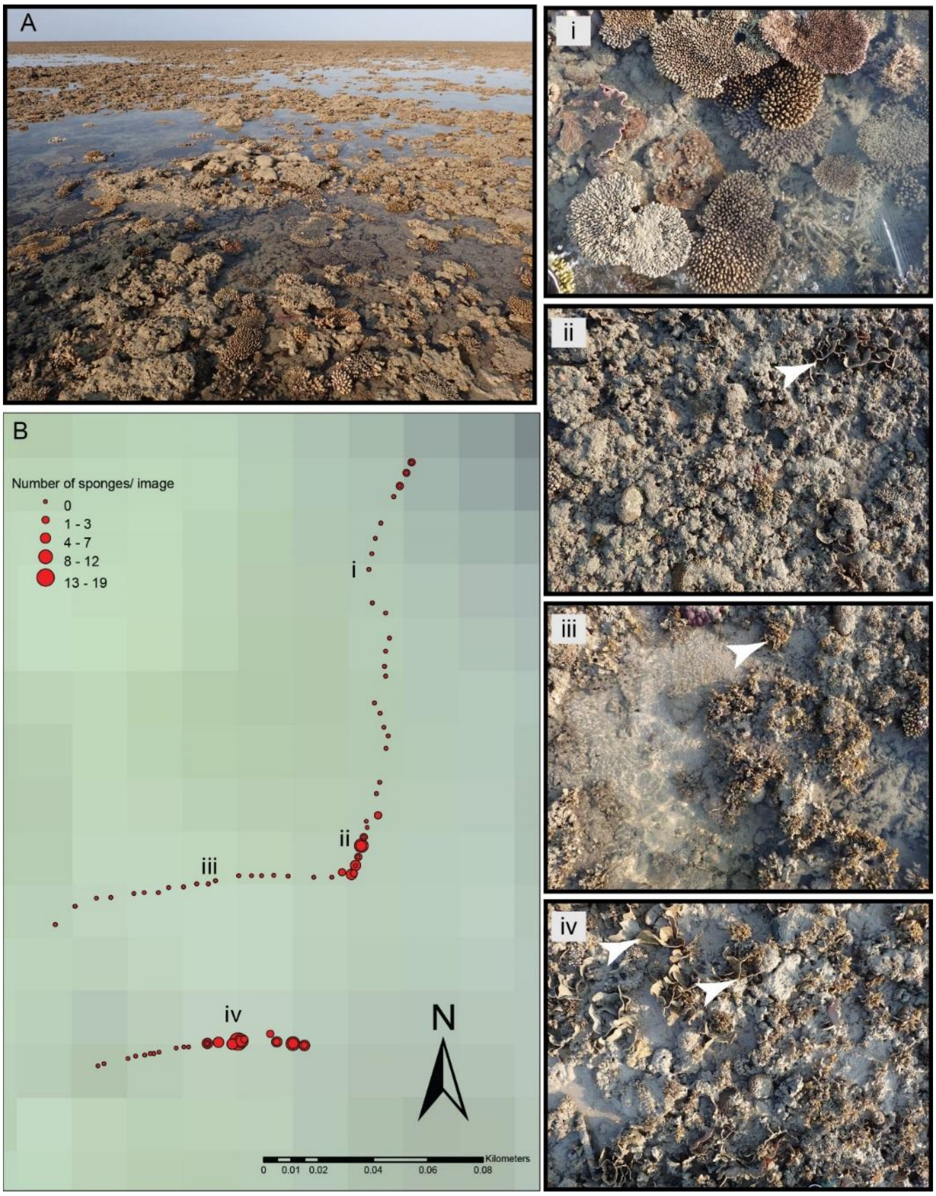

Figure 3: Adele Island Site 1, the edge of the reef flat edge is to the east (see Figure 1 for an overview of the area). A) A view of the reef flat at low tide, 6th October 2017, 0530h; showing consolidated reef habitat with sparse coral cover. B) Photo transect tracks with points indicating the locations where a 2 × 1.5 m field of view photos of the benthos were taken. The size of bubbles correspond to the abundance of sponges (counts). Insets on the right show images of the benthos where i) the benthos was dominated by hard corals closer to the edge of the reef, ii) there was moderate abundance of sponges (see arrow head for sponge), iii) the benthos was dominated by macroalgae (see arrowhead for macroalgae) and iv) there was high abundance of sponges (see arrowhead for sponges).

Sponges were found at low densities at Beagle Reef, with a maximum number of 1 to 2 sponges/ photo (Table 1). The low number and highly patchy distribution of sponges here (4 – 9% photos with sponges; Table 1), could be a result of the high cover of hard corals in the intertidal (up to 100% cover) which may have outcompeted sponges for substrate space (Figure 4A, inset ii). Where sponges were found, they occurred in bare spaces in between hard corals, and indicate a population distribution driven by opportunistic settlement and survival, in contrast to sponge populations seen at Adele Island Site 1 (Figure 3, inset iv) where they were allowed to proliferate in the absence of a space competitor.

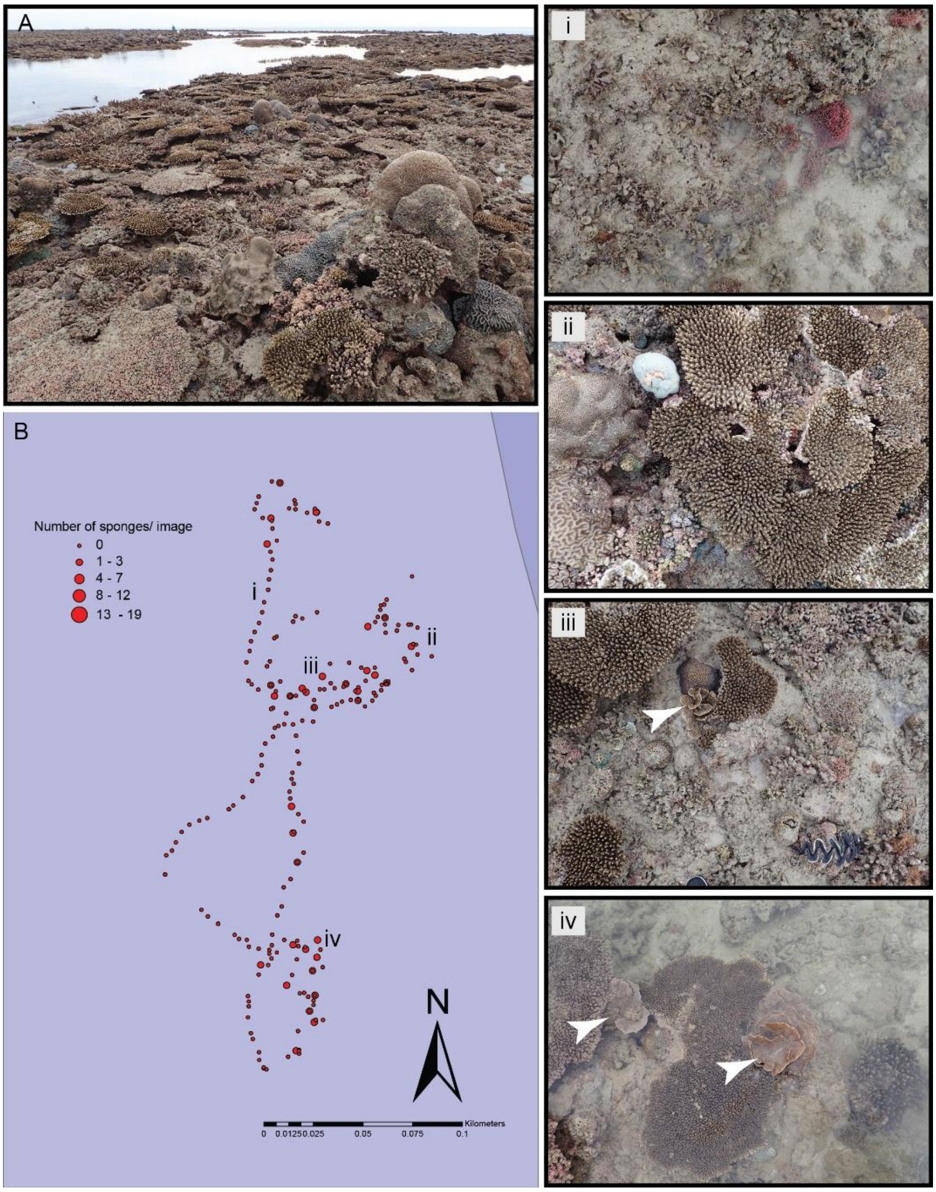

Figure 4: Beagle Reef Site 2, the edge of the reef flat is to the east. A) A view of the reef flat at low tide, 8th October 2017, 0550h; showing the high coral cover. B) Photo transect tracks with points indicating the locations where a 2 × 1.5 m field of view photos of the benthos were taken. The size of bubbles correspond to the abundance of sponges (counts). Insets on the right show images of the benthos where i) consolidated rubble habitat was dominated by macroalgae, ii) high coral cover (>90%; massive, branching and plating) near the edge of the reef flat, iii) area with sparse sponges occurring in between hard corals (see arrowhead for sponge) and iv) area having a similar sparse sponge distribution in a tidal pool (see arrowhead for sponges).

At Bathurst-Irvine Reef, the intertidal habitat comprised of extensive consolidated rubble substrate with sparse distribution of small massive hard coral that occupied a narrow band close to the reef flat edge (Figure 5A, inset i). Sponges were moderately abundant and patchy reaching densities of 6 individuals/ photo (Table 1, Figure 5B). Here, the survey transect was relatively unidirectional and followed a west-east direction. Sponges occurred within a zone of approximately 250 m on the transect (Figure 5, between inset ii and iii). Sponges did not occur in macroalgal dominated habitats further inshore within the upper intertidal.

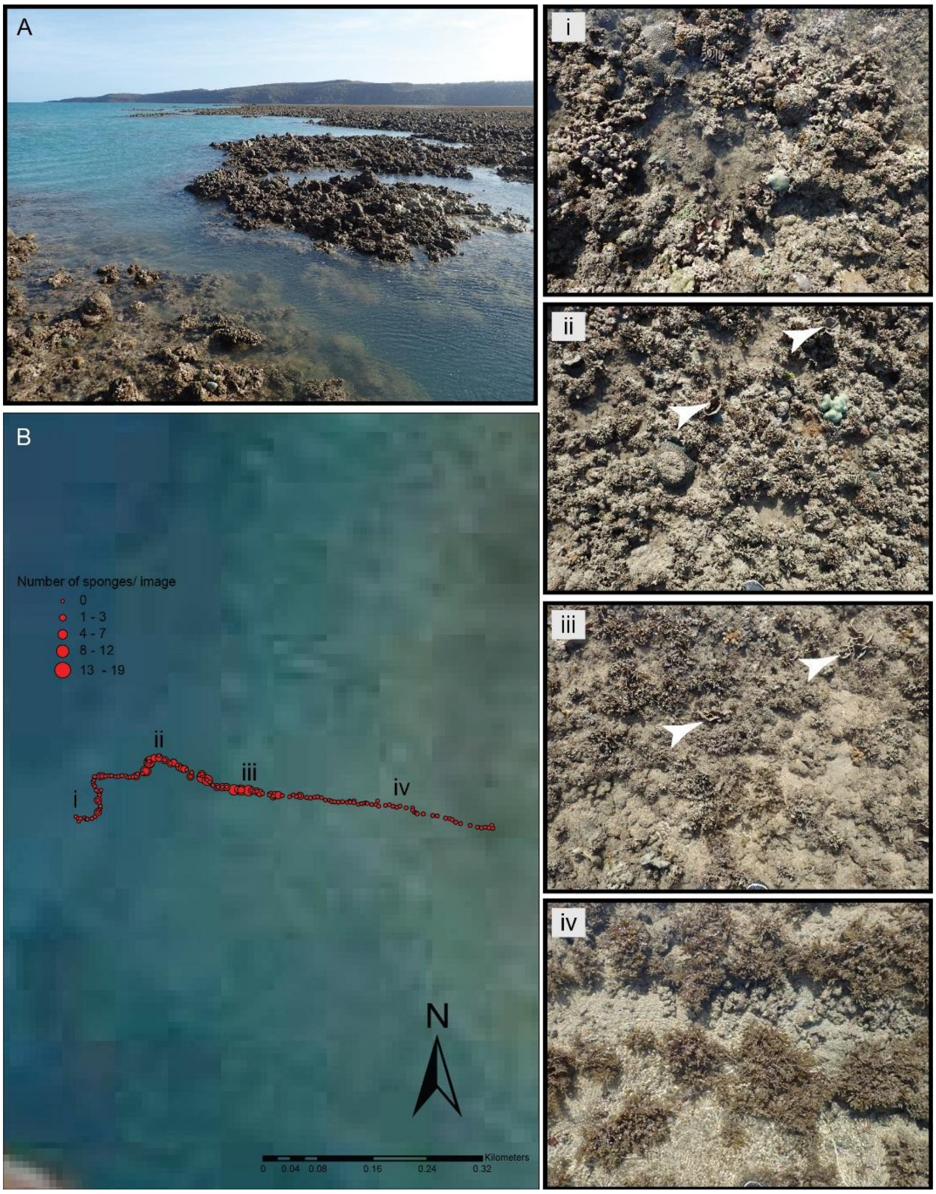

Figure 5: Bathurst-Irvine Reef, the edge of the reef flat is to the west (see Figure 1 for an overview of the area). A) A view of the edge of the reef flat at low tide, 10th October 2017, 0700h; showing the consolidated rubble habitat and low coral cover. B) Photo transect tracks with points indicating the locations where a 2 × 1.5 m photo of the benthos was taken. The size of bubbles correspond to the abundance of sponges (counts). Insets on the right show images of the benthos where i) consolidated rubble habitat with low coral cover (massive), ii) consolidated rubble habitat with sparse macroalgae and sponges (see arrowhead for sponges), iii) similar consolidated rubble habitat (see arrowhead for sponge) and iv) macroalgae dominated habitat with no sponges.

White Island was the only location out of the four surveyed where foliose phyllospongiinid sponges were completely absent (Figure 6). The intertidal habitat at the edge of the reef flat to the north comprised of mostly consolidated reef with sparse cover of massive and encrusting hard coral (Figure 6A, inset i). Towards the upper intertidal, the benthos was dominated by macroalgae which grew over low rugosity consolidated rubble habitat (Figure 6B, inset ii and iii). There were sections of the reef flat, within ~50 m of the reef edge, that were dominated by large mats of zooanthids (Figure 6B, inset iv). These large mats of zoonanthids were not observed at the other three locations surveyed. Why sponges were absent from White Island could not be determined from the present study, however detrimental effects such as that from recent heatwaves and turbulent hydrodynamics from storm or cyclonic events may have influenced benthic communities in this most northerly location. Some evidences of recent disturbances were observed, which included fields of unconsolidated coral rubble derived from branching corals, and the presence of a large boulder which appeared to have been displaced onto the upper intertidal potentially from a storm event (Figure 7). However, these evidences are inconclusive and further comparative work to previous surveys performed at the location, such as that performed by the Western Australian Museum in 2011, would be crucial in providing additional perspective on benthic community dynamics at White Island (Bryce et al. 2018).

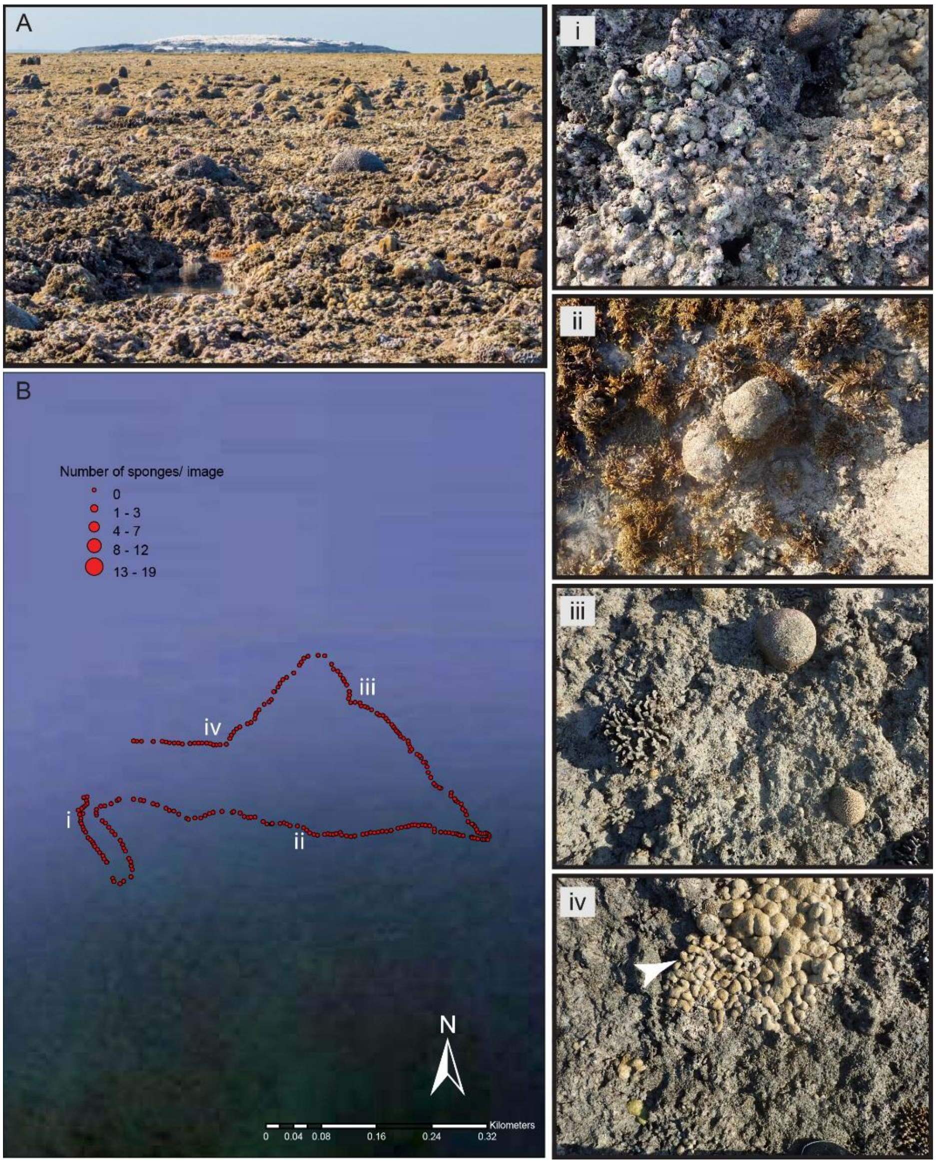

Figure 6: White Island, the edge of the reef flat is to the north (see Figure 1 for an overview of the area). A) A southern view from the edge of the reef flat with White Island in the background at low tide, 9th October 2017, 0545h; showing the sparse distribution of massive and encrusting hard corals. B) Photo transect tracks with points indicating the locations where a 2 × 1.5 m photo of the benthos was taken. No sponges were found at this location. Insets on the right show images of the benthos. i) consolidated reef substrate with sparse massive and encrusting hard corals near the edge of the reef flat, ii) macroalgae dominated habitat through the upper intertidal section of the reef flat, iii) low rugosity consolidated rubble habitat with sparse massive hard coral cover, and iv) section of the reef flat with high cover of zooanthid mats (see white arrowhead).

Figure 7: White Island, 9th October 2017, 0545h. A solitary, large granite boulder (~1.2 m high) resting on top of the reef flat in the upper intertidal, approximately 300 m away from the edge of the reef flat. The boulder was likely displaced from the granite outcrop in the background during a storm, as there were no other similar geological features in proximity. The boulder is relatively "clean" with very little epibenthic growth, except for the zooanthid mat visible at the top which seemed to suggest a recent displacement event.

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Appendix 3.

Initial list of Scleractinian coral taxa recovered from the drained open cut mine on Koolan Island. Based on analysis of skeletal morphology of specimens deposited with AIMS.

Family	Genus	Number of species
Acroporidae	*Acropora*	11
	Montipora	6
	Astreopora	4
Agariciidae	*Leptoseris*	3
	Pachyseris	1
	Pavona	1
Dendrophyllidae	*Turbinaria*	2
Euphyllidae	*Catalaphyllia*	1
Faviidae	*Caulastrea*	3
	Cyphastrea	2
	Echinopora	2
	Favia	8
	Favites	5
	Goniastrea	5
	Leptoria	2
	Montastrea	2
	Platygyra	3
Fungiidae	*Fungia*	1
	Podobacia	1
Merulinidae	*Hydnophora*	3
	Merulina	2
Oculinidae	*Galaxea*	2
Mussidae	*Acanthastrea*	2
	Cynarina	1
	Lobophyllia	4
	Symphyllia	1
Pectinidae	*Echinophyllia*	2
	Mycedium	2
	Oxypora	1
	Pectinia	3
Pocilloporidae	*Seriatopora*	2
	Stylophora	1
Poritidae	*Alveopora*	1
	Porities	8
Siderastreidae	*Psammocora*	1
	Pseudosammocora	1
13	36	100

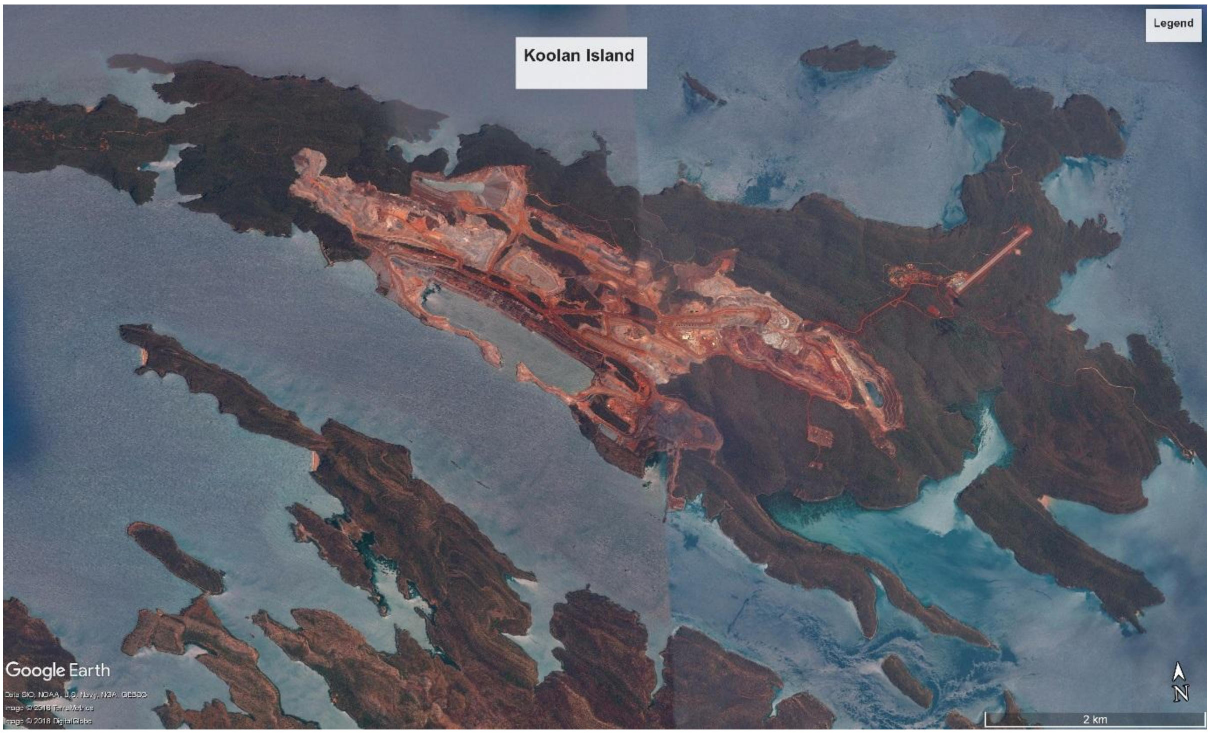

Figure 1: Satellite image (Google Earth) of Koolan Island with the seawall breached and the mine pit flooded

Appendix 4.

Water column light profile in the northern region

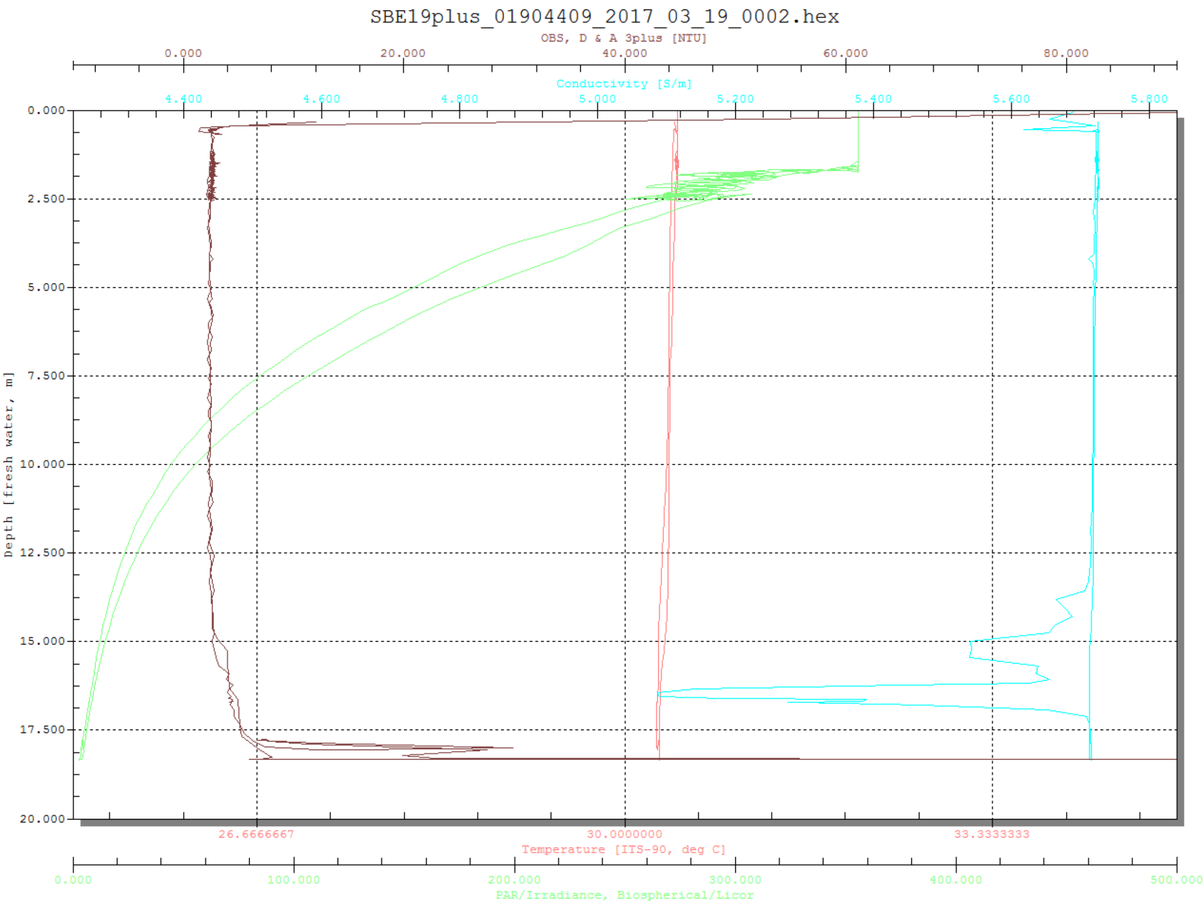

Figure 1. CTD+ PAR (photosynthetically active radiation) profile through the water column, inshore in the Cape Bougainville area during cruise 6672 in March 2017. The green line shows PAR, which declines to zero at less than 20m depth.