Marine Biodiversity Hub

National Environmental Science Programme

An eco-narrative for banks and shoals within Arafura Marine park

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Project D3 – Implementing monitoring of Australian Marine parks and the status of marine biodiversity assets on the continental shelf

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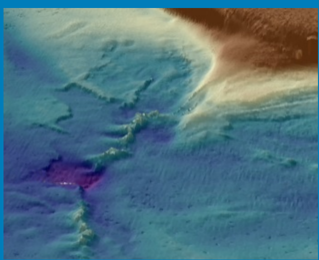

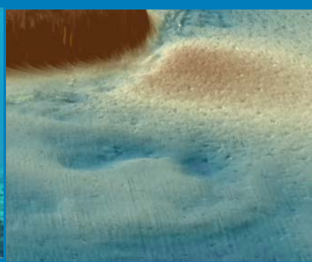


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We acknowledge the Traditional Owners of the sea country land on which the research took place, and pay our respects to Elders past, present and future. We honour their continuing culture, knowledge, beliefs and spiritual relationship and connection to country. We also recognise Aboriginal and Torres Strait Islander peoples as the Traditional Owners of the land and sea, and as Australia's first scientists. Yuwurrumu members of the Mandilarri-Ildugij, the Mangalara, the Murran, the Gadura-Minaga and the Ngaynjaharr clans have responsibilities for sea country in Arafura Marine Park, which they have been sustainably using and managing for tens of thousands of years.

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 Australian Marine Parks. These are intended to enable managers and researchers to ascertain the physical and ecological characteristics of each park, and to highlight knowledge gaps for future research focus. The information in this eco-narrative forms an initial characterisation of the physical, oceanographic and biological character of Arafura Marine Park, with a focus on results from a biodiversity and mapping survey undertaken by the Marine Biodiversity Hub in November 2020. This survey targeted two areas, Money Shoal as an example of shallow coral reef habitat, and Pillar Bank as an example of a deeper water outer shelf seabed environment.

Arafura Marine Park is characterised by a gently sloping broad shelf across the southern part of the park (Multiple Use Zone) that grades to a series of canyons (Arafura canyons) that connect the shelf to the deeper waters of the continental slope, reaching to depths of ~500 m (Special Purpose Zone (Trawl)). Areas of reef are very limited within the marine park, with Money Shoal the only substantial feature that supports a shallow water coral reef community. As an isolated feature, surrounded by an expanse of flat muddy seabed, Money Shoal is unique within the Arafura Sea shelf region. Rising from 60 m water depth to less than 10 m, the reef provides a stable substrate for a diverse assemblage of sponges, hard and soft corals that in turn attract an abundant and diverse population of demersal fish; ranging up to grouper, rays and sharks. Money Shoal fish and shark assemblages are characteristic of the broad community of the north-west region, with a clear separation of composition found on the flats and slopes compared to the deeper shelf. The benthos was predominantly algae, however a healthy and diverse hard and soft coral community was evident, as well as sponges and other marine invertebrates.

In contrast to Money Shoal, the deeper environments in the northern parts of Arafura Marine Park are characterised by a complex seabed of large and steep ridges, valleys and plains. Underwater imagery shows these environments are typically highly turbid, due to strong tidal currents, with a sparse seabed biota. These areas, such as Pillar Bank, are not barren, however, with localised concentrations of filter feeders such as sponges utilising the rocky outcrop on the steeper parts of ridges. These sites are also observed to support a range of demersal fish, although further analyses are required to fully characterise the fish community in these deeper areas of the marine park.

The oceanographic regime of the marine park is characterised by strong tidal flows and a connection to waters delivered by the Indonesian Throughflow and the South Equatorial Current. Nutrient levels are relatively low (oligotrophic) across most of the park, as indicated by low Chlorophyll-a levels on the sea surface. However, closer to the coast, higher nutrient levels occur due to input from rivers; but this is localised. The satellite record of sea-surface temperatures for the past 15 years shows a relatively stable ocean temperature record across the park. But the region does experience marine heat waves, with three closely spaced events occurring in 2015-2016. While these were classified as ‘moderate’ marine heat waves, the potential for coral bleaching of the shallow water corals on Money Shoal represents a risk to the future health of the reef. The additional impact of physical disturbance by tropical cyclones on Money Shoal emphasises the importance of continued monitoring of this regionally unique ecosystem.

1. INTRODUCTION

Arafura Marine Park is located 250 km to the northeast of Darwin within the North Network of Australian Marine Parks. The park extends across the continental shelf and upper continental slope of the Arafura Sea to the limit of Australia's exclusive economic zone, covering an area of 22,924 km^2 (Figure 1). Conservation values within the park include the tributary canyons that connect the deep offshore to the continental slope in the northern part of the park, and which are a pathway for upwelling of nutrient rich waters; plus a range of pelagic fauna including whale sharks, sawfish and turtles (Director of National Parks, 2018). Benthic biological communities within the marine park include sponges, hard and soft corals associated with Money Shoal and hard substrates within canyons, but information on these communities is limited (Edgar et al., 2017).

Arafura Marine Park is designated IUCN category VI, with three management zones, including: Multiple Use Zone (VI), a Special Purpose Zone (VI), and a Special Purpose Zone (Trawl) (VI). This eco-narrative presents an overview of the physical and oceanographic setting for Arafura Marine Park, then focuses on the results from a recent marine biodiversity survey within Arafura Marine Park that targeted two areas: (1) Money Shoal located within the Multiple Use Zone, as an example of a shallow water coral reef, and; (2) Pillar Bank located within the Special Purpose Zone (Trawl) on the outer shelf, as an example of a deeper water outer shelf seabed environments that characterise much of the northern part of the marine park (Figure 2).

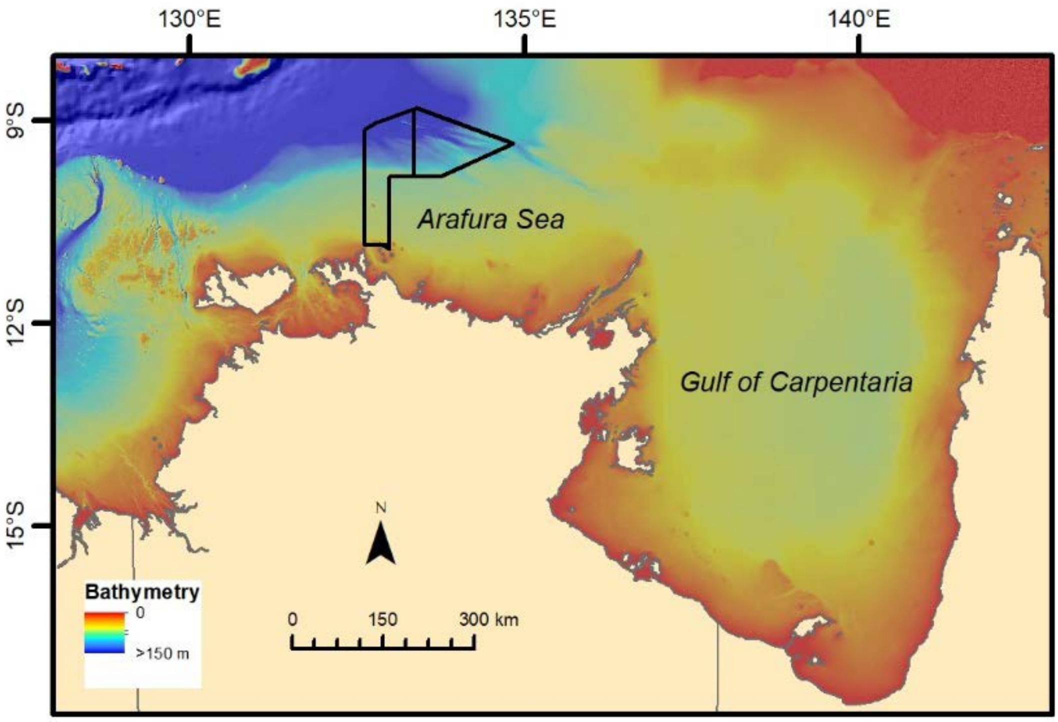


Figure 1. Location of Arafura Marine Park, showing regional bathymetry based on the 250 m national grid (Whiteway, 2009).

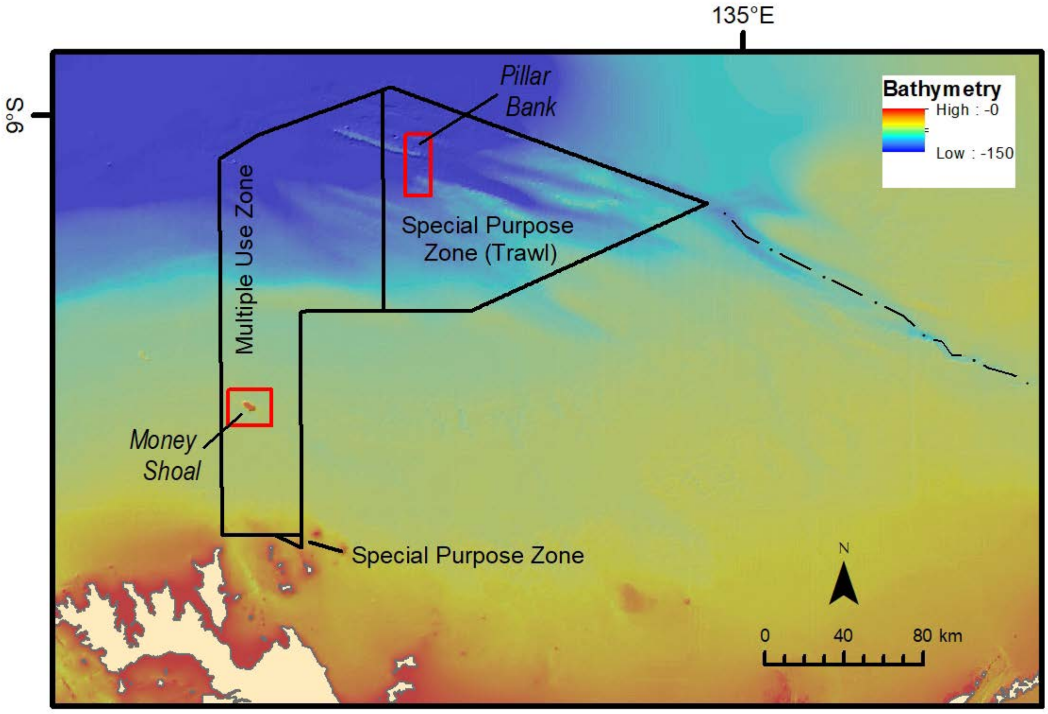


Figure 2. Arafura Marine Park, showing management zones and locations of Money Shoal and Pillar Bank survey areas (Picard et al., 2021). Dashed line indicates the path of the ancestral river system that connected the Gulf of Carpentaria to the Arafura canyons during periods of low sea level.

2. PHYSICAL SETTING

Arafura Marine Park extends across the broad, ~240 km wide, continental shelf to the upper continental slope of northern Australia. Water depths range from 3 m at Money Shoal in the south of the park, to over 500 m on the continental slope at the northern limit of the park. Seabed geomorphic features include extensive sediment plains across the shelf, the isolated pinnacle reef of Money Shoal, and a network of tributary canyons (Arafura canyons) and ridges (including Pillar Bank) that connect the continental shelf to the deeper waters of the Arafura Sea.

The Arafura Sea continental shelf and slope form the seabed expression of a succession of sedimentary rocks that formed over a protracted period of geological time, commencing sometime in the Neoproterozoic Era (1000 – 541 million years ago) and continuing over multiple phases to the Cenozoic Era (< 66 million years ago) (Struckmeyer, 2006). During this long time span, the region underwent four intervals of subsidence and deformation, resulting in a stratigraphic sequence of rocks of the Arafura Basin (Figure 3) that are up to 15 km thick and characterised by large-scale faults. Overlying the Arafura Basin is an additional 3 km of sediment that forms the Money Shoal Basin that was deposited during the Jurassic (201 – 145 million years) to Cretaceous Period (145 – 65 million years), with a final phase of deposition during the last 2 million years of the Quaternary Period (Struckmeyer, 2006). The deep faulting in the Arafura Basin appears to extend into these younger deposits (Logan et al., 2006); and it is possible that the large valleys of the Arafura canyons have formed in areas of weakness associated with this faulting, with more resistant areas forming ridges, such as Pillar Bank.

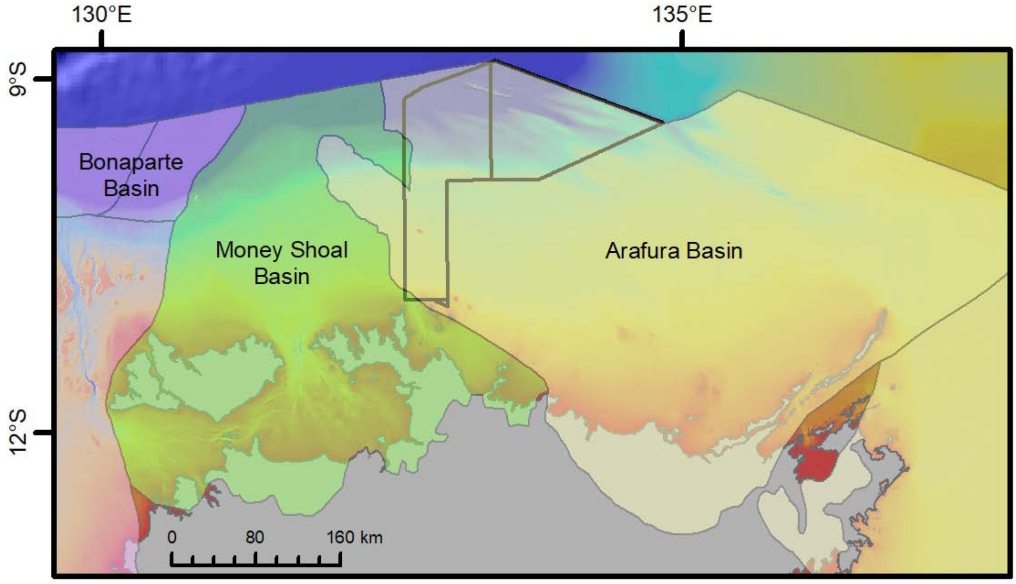


Figure 3. Structural geology of the Arafura Sea region, showing the spatial extent of Arafura Basin and Mondy Shoal Basin that underlie Arafura Marine Park (indicated).

During the Quaternary Period, the continental shelf to upper slope of the Arafura Sea was exposed as land multiple times in association with a series of global ice ages. During these times of low sea level, the deep submarine valleys (Arafura canyons) that extend toward the shelf were connected to large rivers that likely originated from the area now occupied by the Gulf of Carpentaria, to the east of the Arafura Sea (Figure 2; Chivas et al., 2001; Logan et al., 2006). In addition to transporting sediment from the Gulf, the rivers would have further incised the valleys now occupied by the Arafura canyons. Smaller rivers would have also extended across the shelf from the Arnhem Land region, delivering terrestrial sediment to floodplains and coastal lowlands in areas that were inundated by the sea during the Late Pleistocene to early Holocene epoch (~15,000 – 7,000 years ago). These areas now form the broad sediment plain that characterises much of the southern to central part of Arafura Marine Park.

Money Shoal is an isolated area of raised seabed located midway across the continental shelf. Its origin and age is unclear, but it is likely the product of successive periods of coral reef growth over multiple sea level cycles during the Quaternary Period (last ~1.8 million years). Similar isolated banks and pinnacles comprising reef carbonate material have formed across large areas of the Timor Sea continental shelf, within the Oceanic Shoals Marine Park to the west of Arafura Marine Park (Nichol et al., 2013).

3. OCEANOGRAPHY

The oceanography within the Arafura Sea region is not well understood due to a lack of long-term observation data. The available observation data and modelling studies indicate that the Arafura Marine Park is likely under the influence of the westward flowing South Equatorial Current that flows with a mean velocity of less than 0.5 m s^{-1} (Morrison and Delaney, 1996; Heap et al., 2004; Condie, 2011). Although without direct evidence, the waters within and around the marine park might also have some interaction with the eastern branch of the Indonesian Throughflow (Morrison and Delaney, 1996; Schiller, 2011; Sprintall et al., 2014). This interaction contributes to the net westerly flow of water across the Arafura Sea. Modelling studies of Condie (2011) and Kampf (2015) show that this westward flowing surface current affecting the marine park is strong during the Southeast Monsoon (April to November). The surface current becomes much weaker or even reverses its direction under the Northwest Monsoon (December to March) (Condie, 2011). In addition, Kampf (2015) reveals that, during the Southeast Monsoon, there is an eastward or northward under-current flowing through the Arafura Marine Park, potentially carrying nutrient-rich waters from the Banda Sea.

Tides in the Arafura Sea region are mainly semidiurnal, with tidal ranges of 2-4 m and tidal currents of ~0.5 m s^{-1} (Heap et al., 2004; Condie, 2011). The mean significant wave height is 1.25-1.5 m. Tropical cyclones pass through the Arafura Marine Park from time to time, which may have destructive impacts on the shallow water marine communities. In the last 50 years, 17 cyclones have crossed the marine park, the most recent of which was Tropical Cyclone Ann in May 2019.

Satellite-derived (MODIS) Sea Surface Temperature (SST) and Chlorophyll-a data were obtained from the Integrated Marine Observing System (IMOS; http://imos.org.au/) to analyse the SST and surface Chlorophyll-a characteristics of surface waters in the marine park. Sea surface temperatures show a clear seasonal pattern, with warmest conditions in December (monthly mean of 30.2°C) and slightly cooler waters in August (monthly mean of 26.1°C) (Figure 4a). There is also notable inter-annual variation in SST, but without a clear warming trend (Figure 12b). Over the last 16 years (2003 to 2018 inclusive), the highest annual mean SST (~ 29.0 °C) occurred in 2016; while the lowest annual mean SST (~ 27.3 °C) occurred in 2006 and 2011. The long-term average SST varies little spatially within the marine park (28.0±0.08 °C) (Figure 13a).

Analysis of surface Chlorophyll-a concentrations shows a clear seasonal pattern (Figure 12c). The highest surface Chlorophyll-a concentrations occur in late austral autumn and austral winter (May to July), with monthly means of 0.43-0.48 mg/m^3; while the lowest surface concentrations occur in austral spring and early summer, with values of 0.25-0.27 mg/m^3. The inter-annual variation of the surface Chlorophyll-a concentrations over the period 2003 to 2018 are substantial, but without any clear trend (Figure 12d). However, there is a clear spatial pattern across Arafura Marine Park in the long-term mean Chlorophyll-a concentrations (Figure 13b). Thus, relatively high surface Chlorophyll-a concentrations occur at the southern part of the marine park, with concentrations between 0.5-1.2 mg/m^3. This is likely due to terrestrial inputs from rivers and re-suspended seabed sediments under the influence of strong tidal currents (Morrison and Delaney, 1996; Condie, 2011). These higher nutrient levels decrease offshore toward Money Shoal where the long term mean Chlorophyll-a concentration is ~0.4 mg/m^3. Further offshore, the deeper waters of the central and northern part of the marine park are characterised by relatively uniform Chlorophyll-a concentrations of 0.2-0.3 mg/m^3.

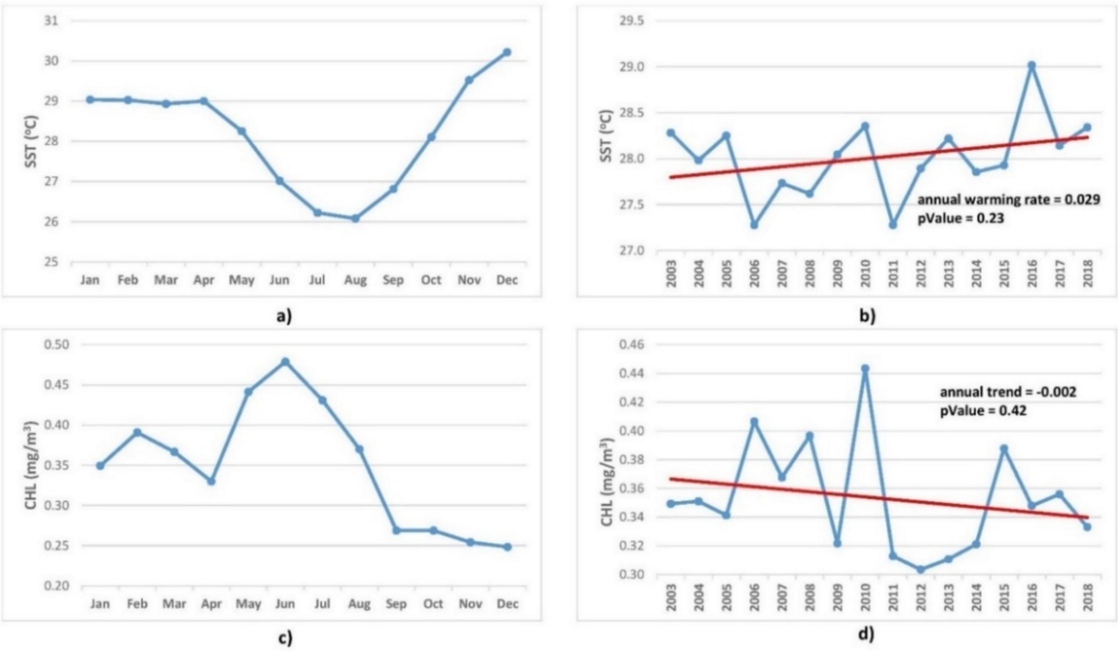


Figure 4. Sea Surface Temperature and surface Chlorophyll-a properties of the Arafura Marine Park, derived from daily MODIS satellite imagery (July 2002- July 2019); a) SST seasonal variation; b) SST inter-annual trend; c) Chlorophyll-a seasonal variation; d) Chlorophyll-a inter-annual trend.

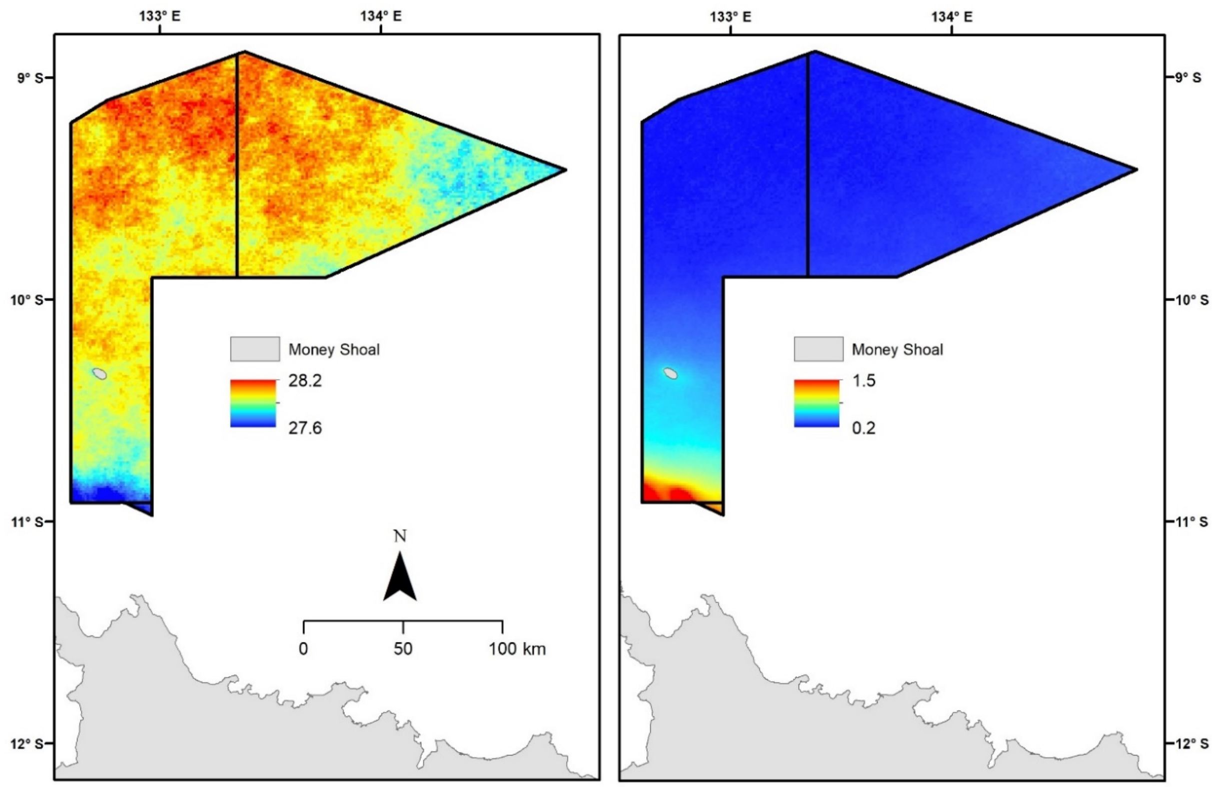


Figure 5 Long-term mean a) SST (°C) and b) Chlorophyll-a (mg/m3) over the Arafura Marine Park, derived from daily MODIS satellite imagery for the period 2003 to 2018 inclusive.

Despite the lack of a clear warming trend for the period of MODIS satellite data, the waters within Arafura Marine Park have been impacted by marine heatwaves (MHWs), following the definition of Hobday et al. (2016) for such events (Table 1). Between 2002 and 2019 a number of MHWs occurred within the marine reserve. In particular, during the three consecutive seasons of 2015-16 summer, 2016 autumn and 2016 winter, MHWs affected the entire tropical Australia, including the Arafura Marine Park (Benthuysen et al., 2018; Table 1). Using the daily Himawari-8 SST satellite data, which have much higher spatial coverage than the daily MODIS SST data, and the SSTAARS climatology (Wijffels et al., 2018), we were able to examine the spatial patterns of the MHWs during these three seasons (Figure 6). This also shows that MODIS SST data has under-estimated the duration of MHWs. According to the Himwari-8 SST data, in 2015-16 summer, 2016 autumn and 2016 winter, the marine park was affected by MHWs for a mean duration of 10 ± 5 days, 75 ± 5 days and 80 ± 12 days, respectively. For the 2015-16 summer event and the 2016 autumn event there isn't a notable spatial variation across Arafura Marine Park. Whereas, the 2016 winter event was ~40 days shorter in duration within the northwestern part of the marine park than the southern parts around Money Shoal (Figure 6). Prolonged MHW condition such as this could pose a threat to the health of shallow-water coral and other sessile communities around the Money Shoal. However, most of the MHWs identified in these seasons were classified as “moderate” according to the definition of Hobday et al. (2018).

Table 1. The seasonal MHWs statistics derived from daily MODIS SST data between July 2002 and June 2019

Season	Duration[1]	Mean Intensity[2]	Cumulative Intensity[3]	Season	Duration	Mean Intensity	Cumulative Intensity
2002-03 summer	10	1.06	10.57	**2009 spring**	6	0.63	3.80
2003 autumn	5	0.14	0.72	**2010 autumn**	7	0.40	2.82
2004 autumn	5	0.43	2.15	**2012-13 summer**	8	0.83	6.66
2004-05 summer	8	1.41	11.27	**2015-16 summer**	8	0.46	3.68
2005 autumn	8	0.36	2.90	**2016 autumn**	29	0.67	19.39
2005-06 summer	8	0.84	6.68	**2016 winter**	52	0.63	32.84
2007-08 summer	5	0.95	4.73	**2017 spring**	5	0.81	4.07
2009 autumn	5	0.27	1.36	**2018 autumn**	14	0.66	9.18

Note: 1. The duration indicates the total number of MHW days; 2. The mean intensity (ºC day^{-1}) indicates the averaged MHW intensity over all of the MHW days; 3. The cumulative intensity (ºC days) indicates the accumulated MHW intensity over all of the MHW days.

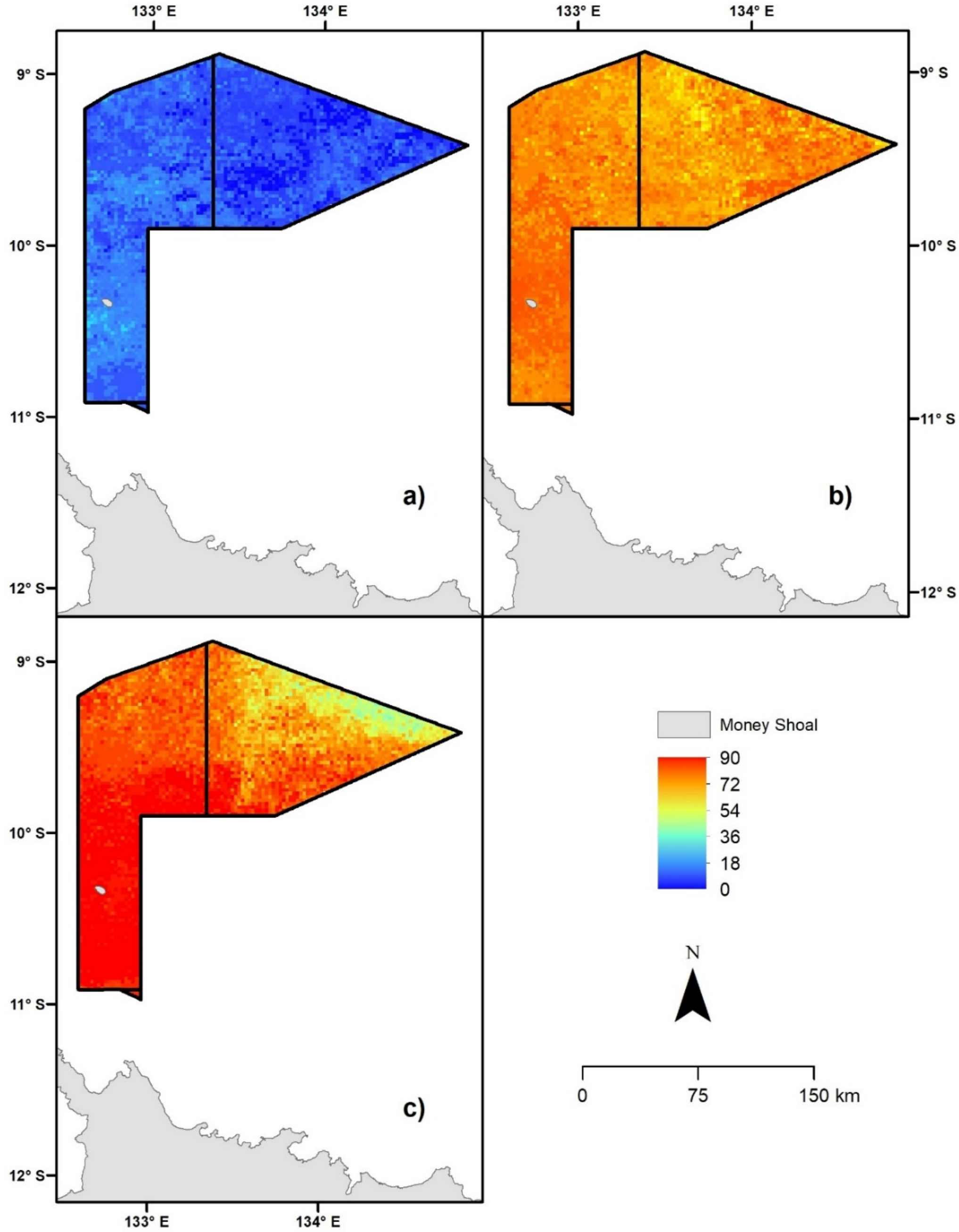


Figure 6. The spatial pattern of the number of marine heat wave days in Arafura Marine Park derived from Himawari-8 SST satellite data, showing; a) summer 2015-16 summer; b) autumn 2016; c) winter 2016.

In addition to the pressures imposed by MHWs, Arafura Marine Park falls within a zone of northern Australia that has historically been exposed to tropical cyclones capable of damaging shallow benthic habitats like coral reefs about once every 20 to 25 years (based on 1985-2020; Puotinen et al., 2020). While much uncertainty remains, global climate model projections suggest that these events could become more frequent as the climate continues to warm.

More frequent cyclone damage combined with marine heat waves could eventually threaten the ability of coral reefs like Money Shoal to maintain themselves as dominated by hard corals (Vercelloni et al., 2020).

4. GEOMORPHOLOGY AND POTENTIAL HABITATS

Seabed geomorphic features within Arafura Marine Park have been previously mapped at a coarse scale by Heap and Harris (2008) using the 250 m resolution bathymetry model for the Australian region (Whiteway, 2009). These features include low gradient plains, terraces and banks (including Money Shoal) on the continental shelf, ridges (including Pillar Bank) and canyons that incise across the continental slope, and an apron that forms a gently sloping sediment surface from the canyon mouths onto the lower continental slope (Figure 7). Of these, the shelf (plain) covers 50% of the park, with canyons occupying 30% (Table 2). Raised hardground features are less extensive, with banks and shoals covering 0.1% of the park and ridges approximately 3%. Some insight into the character of the ridges and canyons within the northern part of the marine park was provided by a seabed mapping and sampling survey undertaken in 2005 (Logan et al., 2006); however, the detailed character of these geomorphic features and their habitat potential for benthic communities has not been examined. This gap was addressed by a Marine Biodiversity Hub survey of Arafura Marine Park undertaken in 2020 that targeted Money Shoal and Pillar Bank as representative examples of the range of seabed habitats in the marine park. Details of that survey are reported in Picard et al. (2021) and are summarised below.

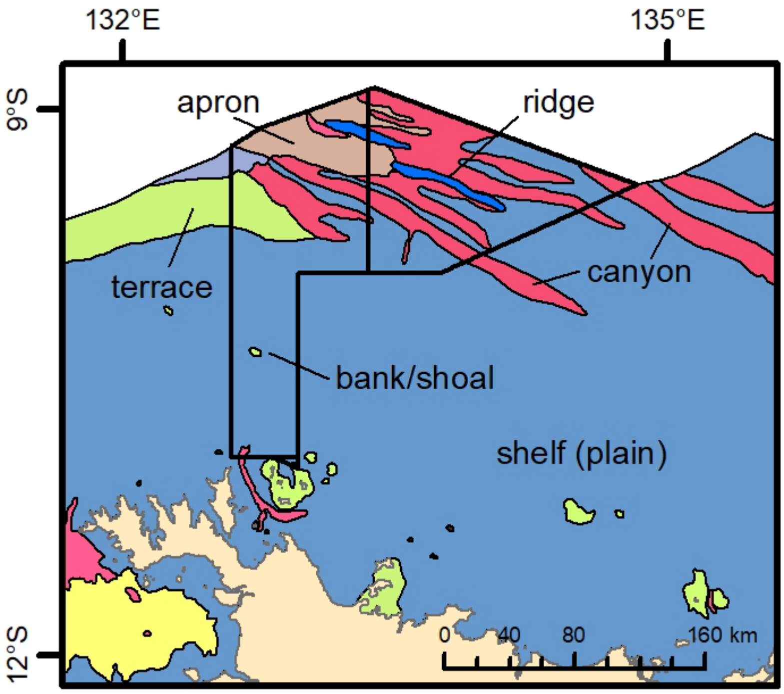


Figure 7. Seabed geomorphic features within Arafura Marine Park as mapped by Heap and Harris (2008), based on the national 250 m bathymetry grid (Whiteway, 2009).

Geomorphic feature	Area (km^2)	Proportion of Marine Park (%)
Apron	2,591	11.3
Bank/Shoal	31	0.1
Canyon	6,855	30.0
Ridge	681	2.9
Shelf (plain)	11,390	50.0
Terrace	1146	5.0

Table 2. Surface area and percent coverage of seabed geomorphic features within Arafura Marine Park (from Heap and Harris, 2008).

4.1 Money Shoal

Money Shoal is an oval-shaped reef (6.5 km x 3.3 km) surrounded by a mostly flat sediment plain (Figure 8). The base of the reef sits in ~60 m water depth and rises on a gradient of 10 degrees to ~3 m water depth on the reef platform. Gently sloping aprons of sediment extend up to 1.5 km from the northwest and southeast sides of the reef that are interpreted as the result of re-deposition of suspended sediments. The sediment plains around Money Shoal range in depth from 70 – 80 m and are mostly flat, with localised small depressions and channels. Seabed sediments on the plains comprise a mix of mud and carbonate sand and gravel, with higher concentrations of sand near the base of Money Shoal. The plains are also characterised by extensive fields of small pockmarks that form holes less than 1 m deep and 10 - 20 m wide. In places, the shape of the pockmark has been extended by tidal currents to form a linear scour mark. Pockmarks of this type were observed in the deeper areas of Arafura Marine Park in the 2005 survey (Logan et al., 2006) and elsewhere on the continental shelf of northern Australia (e.g. Oceanic Shoals Marine Park; Picard et al., 2018). In these settings, pockmarks are interpreted as the product of episodic fluid (gas) escape from sediments that have high organic content (Nicholas et al., 2014). As such, they may introduce an important food source for sessile organisms (filter feeders). Additionally, the shallow depression of a pockmark is also considered to provide shelter for demersal fish (Mueller, 2015).

A further assessment of the habitat potential of seabed features within the Money Shoal area is provided by an analysis of the gradient across the mapped area (Figure 9). This analysis classifies the seabed into three categories: (1) Planes, defined as seabed with less than 2° gradient; (2) Slopes, defined as areas with gradients of 2-10°, and; (3) Escarpments, areas steeper than 10°. For Money Shoal and surrounding seabed this classification shows that across the 192 km^2 mapped area, low gradient plain covers 91% (174 km^2) and slopes that form the basal to mid sections of the shoal and adjacent sediment aprons cover 8% (16 km^2). Escarpments, which form the steepest and most suitable substrate for sessile biota, cover <1% (1.3 km^2) and are restricted to the narrow perimeter of Money Shoal.

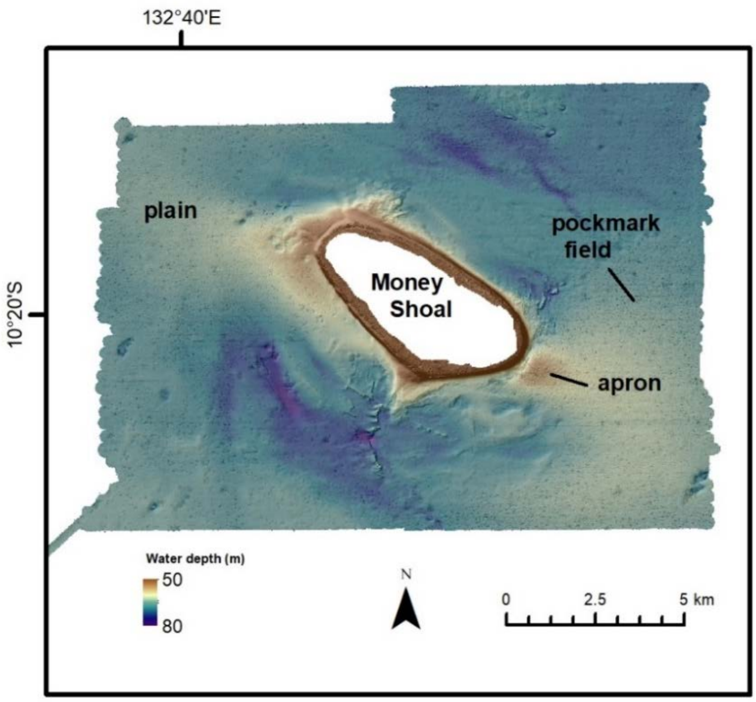


Figure 8. Money Shoal and surrounding seabed showing high-resolution multibeam bathymetry data gridded at 3 m.

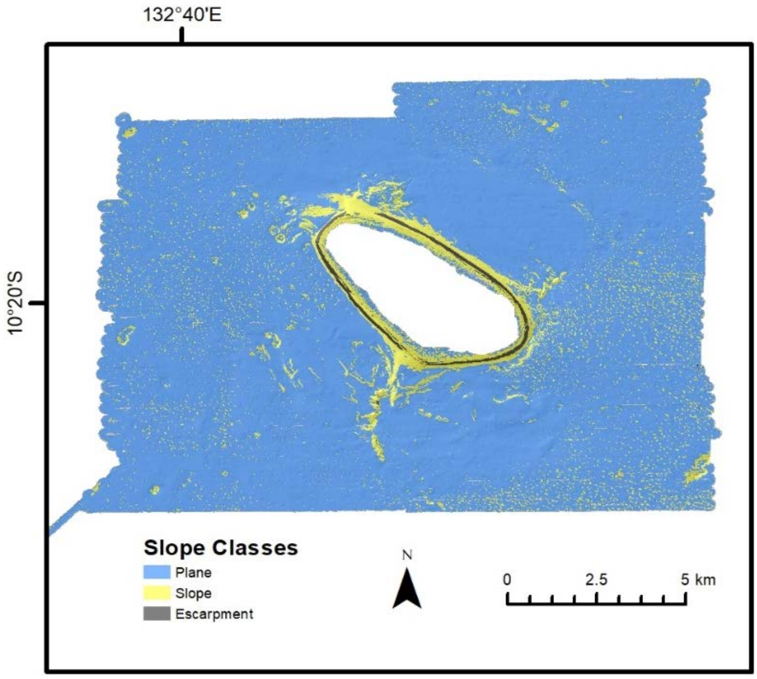


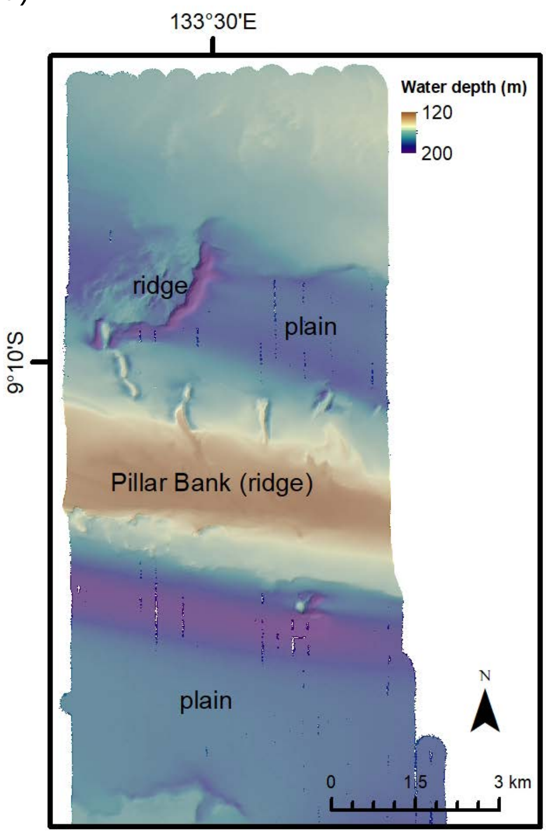
Figure 9. Seabed morphological features on Money Shoal and surrounding seabed within the Multiple Use Zone, Arafura Marine Park.

4.2 Pillar Bank

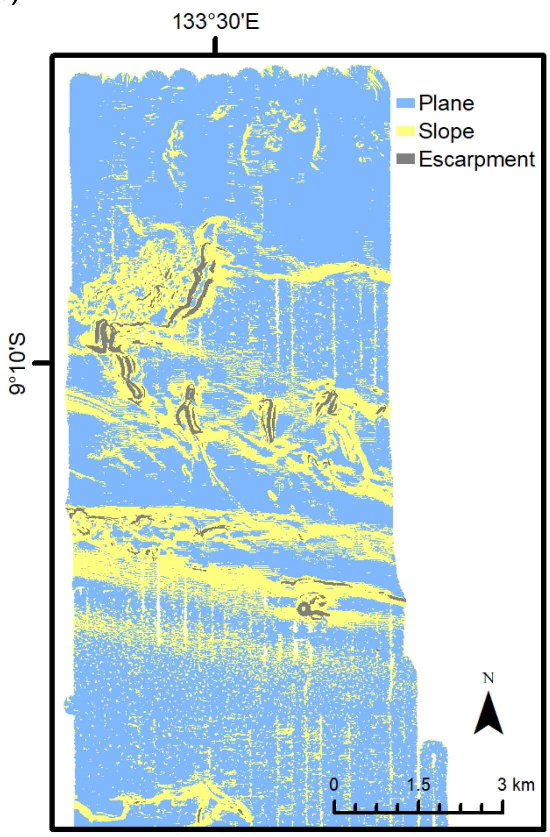
Pillar Bank is one of two large ridges that form areas of raised seabed that separate the canyons within the northern part of Arafura Marine Park (Figure 7). The area mapped by the Marine Biodiversity Hub survey extends across part of Pillar Bank and the second (unnamed) ridge to the south in water depths that range from 120 m to 200 m (Figure 10 a, c). This mapping reveals a range of seabed features, including smaller ridges, plains that define the floors of the canyons, and localised depressions and troughs located around the base of ridges. Pillar Bank is the largest ridge, with a height of 50 m; smaller ridges are 10 – 20 m high and incorporate areas of steeper escarpment that includes areas of exposed rock. In contrast, the plains are characterised by very soft sediment (silt) and extensive fields of pockmarks, as further evidence for fluid (gas) release from organic rich sediments.

The analysis of seabed slope categories for Pillar Bank and adjacent areas shows that across the 159 km^2 mapped area, low gradient plain covers 77% (123 km^2), slopes that form the ridges and banks cover 21% (34 km^2) and escarpments that define the steeper surfaces on larger ridges cover 1.5% (2.4 km^2) (Figure 10 b, d). These proportions are considered broadly representative of the seabed geomorphology across the northern part of Arafura Marine Park (Special Purpose Zone (Trawl)), with ridges and plains (canyon floors) extending east across the SPZ (Figure 7). Observations of the general seabed composition of these canyons also reported extensive areas of soft sediment plains with pockmark fields on the canyon floors (Logan et al., 2006).

a)



b)



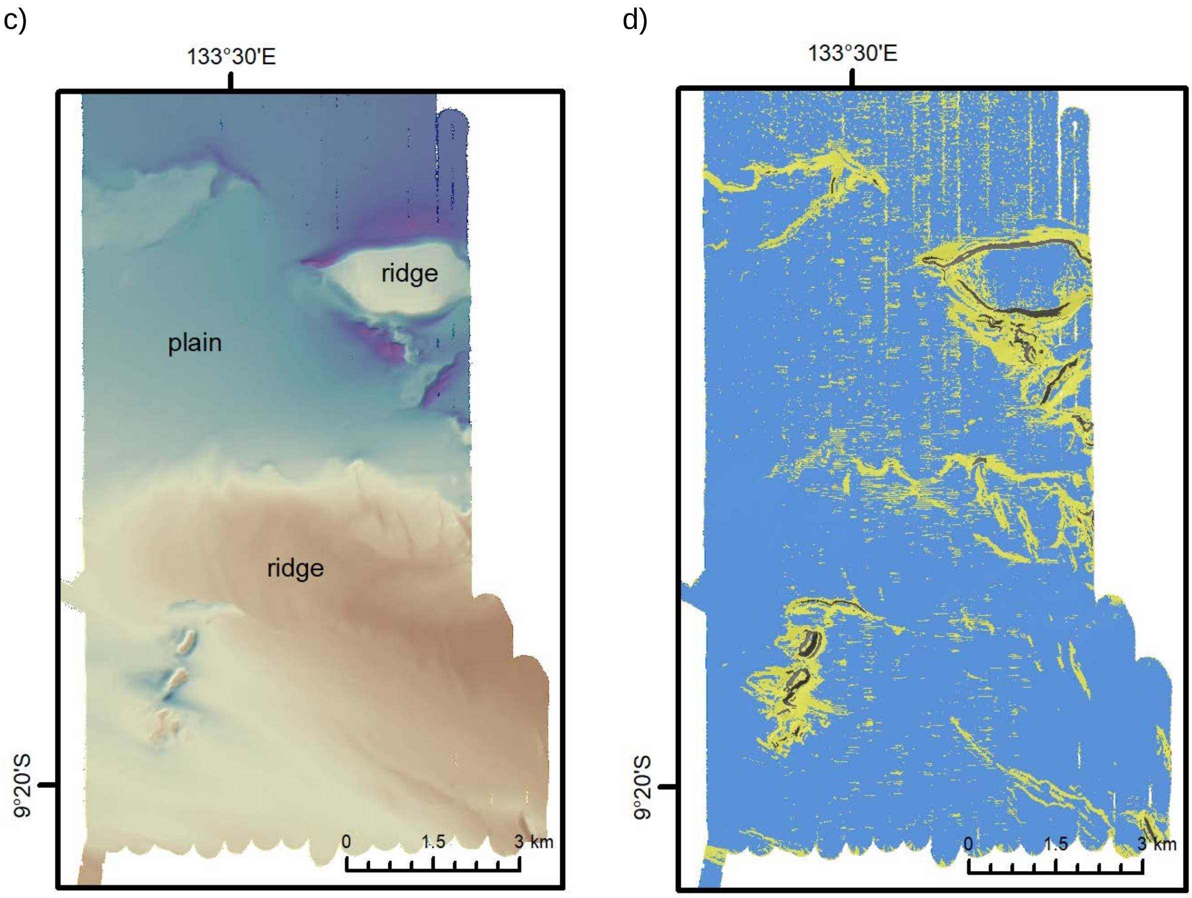


Figure 10 Seabed bathymetry (a, c) and morphological features (b, d) of the Pillar Bank mapping area (divided into northern and southern areas) within the Special Purpose Zone (Trawl), Arafura Marine Park.

5. THE ECOLOGICAL SIGNIFICANCE OF MONEY SHOAL AND PILLAR BANK

5.1 Marine megafauna

There is currently a paucity of information available for marine megafauna within the Arafura Marine Park, although some information exists for coastal and riverine systems in northern Australia that border this marine park. At the time of writing, a summary of inshore distribution and migration of megafauna in the North Marine Bioregion was in review for the NESP Marine Biodiversity Hub (Udyawer et al., 2021). It's likely that some of the species of megafauna identified in that review may also move into the Arafura Marine Park, such as dugongs. Furthermore, certain species of turtles have been tracked within the marine park (see section 5.1.1) (Udyawer et al., 2021). Whale sharks are also known to occur offshore from the Cobourg Peninsula (south-west of the marine park; http://www.ala.org.au. Accessed March 2021) and throughout the Arafura Sea, so it is likely they move through the Arafura Marine Park. There is scant information on seabirds across the northern region in general, although 17 species are known to occur in the Gulf of Carpentaria, including: the brown booby, crested tern, lesser frigatebird and roseate tern (Parks Australia 2018). Observed data sourced from the Atlas of Living Australia (https://www.ala.org.au/) as of 2018 suggests that seabirds are found throughout the Arafura Marine Park (see https://northwestatlas.org/node/1681?_ga=2.29082810.708504904.1615963905-774958671.1576484867).

5.1.1 Turtles

Of the seven species of marine turtles, six are found in the North Marine Region, and all are listed as endangered or vulnerable under the EPBC Act (DSEWPaC 2012). Within the Arafura Marine Park, two species are known to have critical habitat for inter-nesting (defined as 20 km seawards from nesting beaches – Commonwealth of Australia (2017)) and migration (transient movement between inter-nesting and foraging behaviour), which are the Green Turtle (*Chelonia mydas*) (Ferreira et al., 2021) and the Olive Ridley Turtle (*Lepidochelys olivacea*) (McMahon et al., 2007, Udyawer et al., 2021 – Figure 11). Critical habitat for turtles has also been identified along the southern section of the Arafura Marine Park (Conservation Values Atlas). Green turtles are currently listed as endangered by International Union for Conservation of Nature (IUCN) (Seminoff et al., 2008) and listed as vulnerable in Australia by the Environment Protection and Biodiversity Conservation (EPBC) Act 1999 (Ferreira et al., 2021). Whereas the Olive Ridley Turtle is listed as Vulnerable by the IUCN and Endangered by the EPBC.

Figure 11. Left panel is a tagged Green Turtle and right panel is a nesting Olive Ridley Turtle.

5.1.2 Fishes and sharks

To date, few studies have focussed on describing fish assemblages in offshore sites beyond the coastal zone of the Northern Territory (though see Edgar et al., 2017). The most recent survey (2020) describes fish and shark communities within the Arafura Marine Park itself, with its preliminary results (Picard et al., 2021) presented in this eco-narrative. A previous regional phylogenetic study of shark populations from northern Australia and southern Indonesia separated the Australian and Indonesian sequences into two well-supported clades (i.e. descended from a common ancestor) (Ovenden et al., 2009). In that study, only a single shark (spot-tail shark, *Carcharhinus sorrah*) sampled from Australian waters showed close genetic similarity to the Indonesian group, suggesting possible dispersal paths from Indonesia (Ovenden et al., 2009). The most recent study (2020) within the marine park (Picard et al., 2021) found that the shallow water shark fauna has similarities to that found in shallow coastal waters of the adjacent Cobourg Peninsula (Yon et al., 2020), with common species of reef sharks and rays observed in both inshore state waters and offshore national waters. Similarly, a genetic study on regional population structure of red snappers (*Lutjanus malabaricus* and *Lutjanus erythropterus*) found that all Australian samples collected from Timor Sea, Arafura Sea, Groote and Weipa were genetically homogeneous, while revealing a significant differentiation between Australian and Indonesian populations of these iconic species (Salini et al., 2006).

The shallow slopes of Money Shoal within Arafura Marine Park support a rich community of demersal fishes, including reef sharks from the Carcharhinidae family and several commercially valuable fish species such as Red emperor (*Lutjanus sebae*) and Goldband snapper (*Pristipomoides multidens*) (Figure 12). A recent fish survey of the shoal and its adjacent habitats using underwater baited cameras recorded species richness up to 3 times higher (maximum of 48 species vs. maximum of 14 species) on the top of the shoal slope than in the adjacent deployments on the shelf (Figure 12a). Similarly, the total abundance of species, calculated as a sum of the maximum number of individual species, was highest on the shoal (up to 162 individuals recorded in a camera deployment; Figure 13b). In contrast, some of the deployments on the shelf recorded up to 51 individuals in a single deployment (Figure 13b). Further analyses are underway to describe the spatial patterns in fish species richness and assemblage composition of Money Shoal in particular, and Arafura Marine Park in general.

Analysis of historic fish data collected on and in the vicinity of other oceanic shoals in the Arafura Sea and eastern Timor Sea region, and collated by AIMS, indicated that the fish assemblages of Money Shoal are characteristic of the broad fish community of the north-west region (Figure 14). A previous shallow-water survey of the Arafura Marine Park in 2015 identified this park as having the highest fish species richness of all parks across the North AMP Network, with the community being numerically dominated by planktivores, which is common to offshore reef fish assemblages (Edgar et al., 2017). A recent study of Money Shoal in 2020 found that the fish assemblage of shoal flats and slopes was different from the fish assemblage on a deeper shelf. It appears that the break between the shallow and the deep fish assemblages occurs around a water depth of 50 m, which could indicate the shallow edge of the mesophotic (or ‘middle light’) zone in this region. Baited camera data were collected at Pillar Bank during the November 2020 research voyage (Picard et al., 2021), however videos have yet to be fully analysed, and therefore a summary has not been included here.

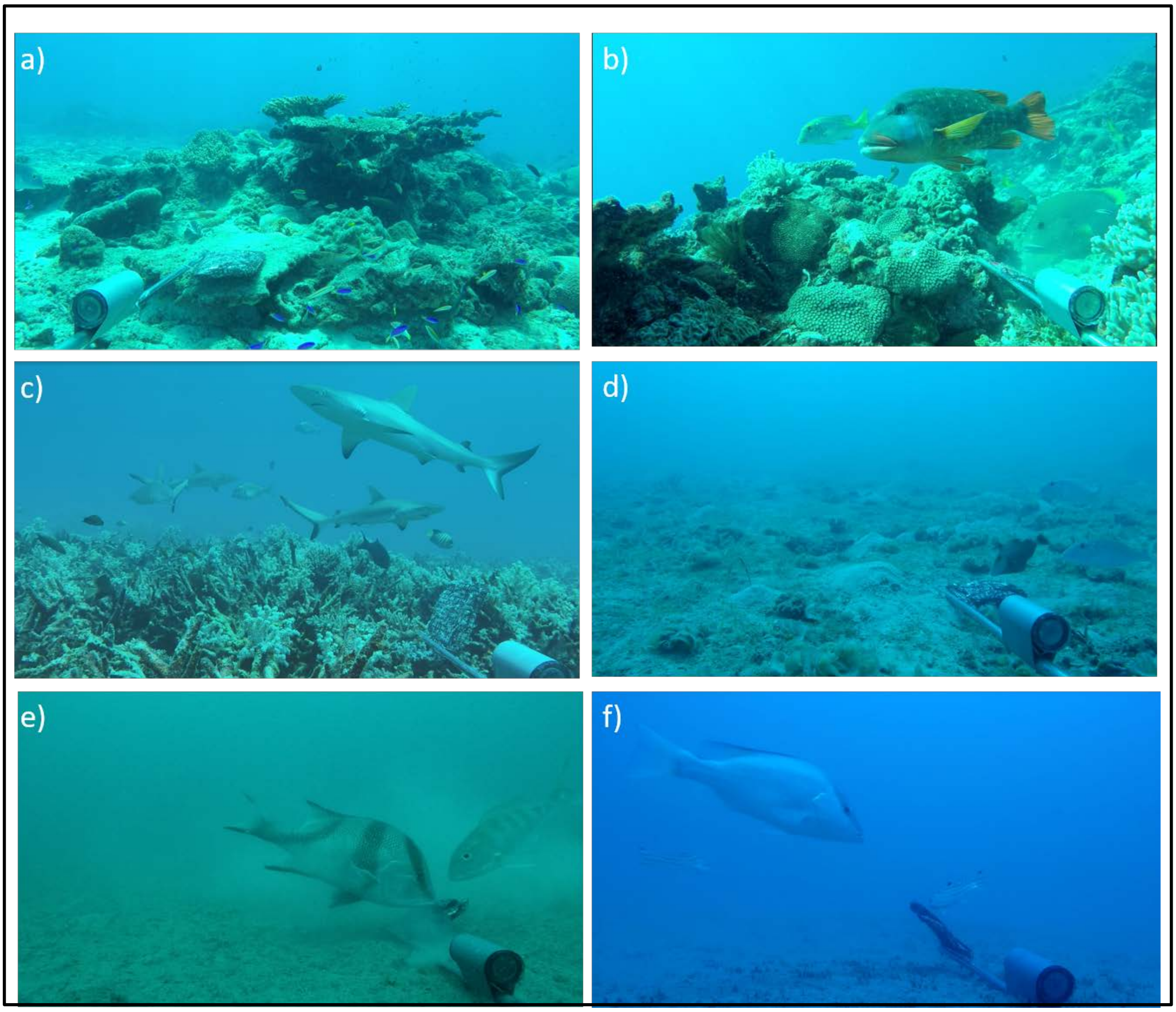


Figure 12. Examples of fish assemblages and associated habitat recorded in the stereo-BRUV survey at Money Shoal (November 2020): a-c on the slopes of Money Shoal, d-f on the surrounding shelf. a) Neon damselfish (*Pomacentrus coelestis*), Shoulder-spot wrasse (*Leptojulis cyanopleura*); b) Orangefin emperor (*Lethrinus erythracanthus*), Blubberlip snapper (*Lutjanus rivulatus*), Yellowtail emperor (*Lethrinus atkinsoni*); c) Grey reef shark (*Carcharhinus amblyrhynchos*); d) Bridled triggerfish (*Sufflamen fraenatum*), Drab emperor (*Lethrinus ravus*); e) Red emperor (*Lutjanus sebae*), Goldband snapper (*Pristipomoides multidens*); f) Saddletail snapper (*Lutjanus malabaricus*), Crescent grunter (*Terapon jarbua*).

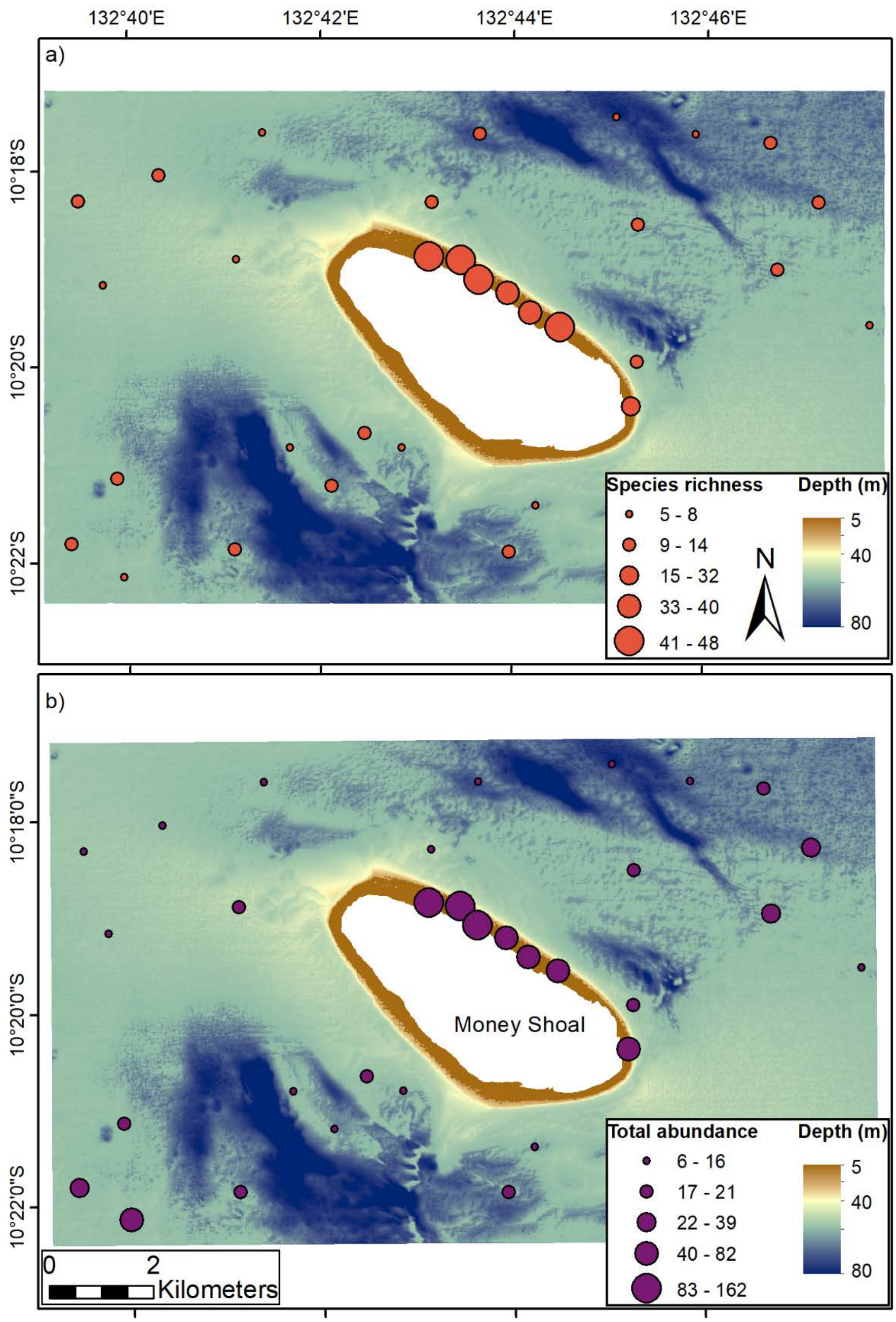


Figure 13. Fish species richness (a) and total abundance (sum of MaxN counts, b) of stereo-BRUVS deployments on Money Shoal and the surrounding shelf.

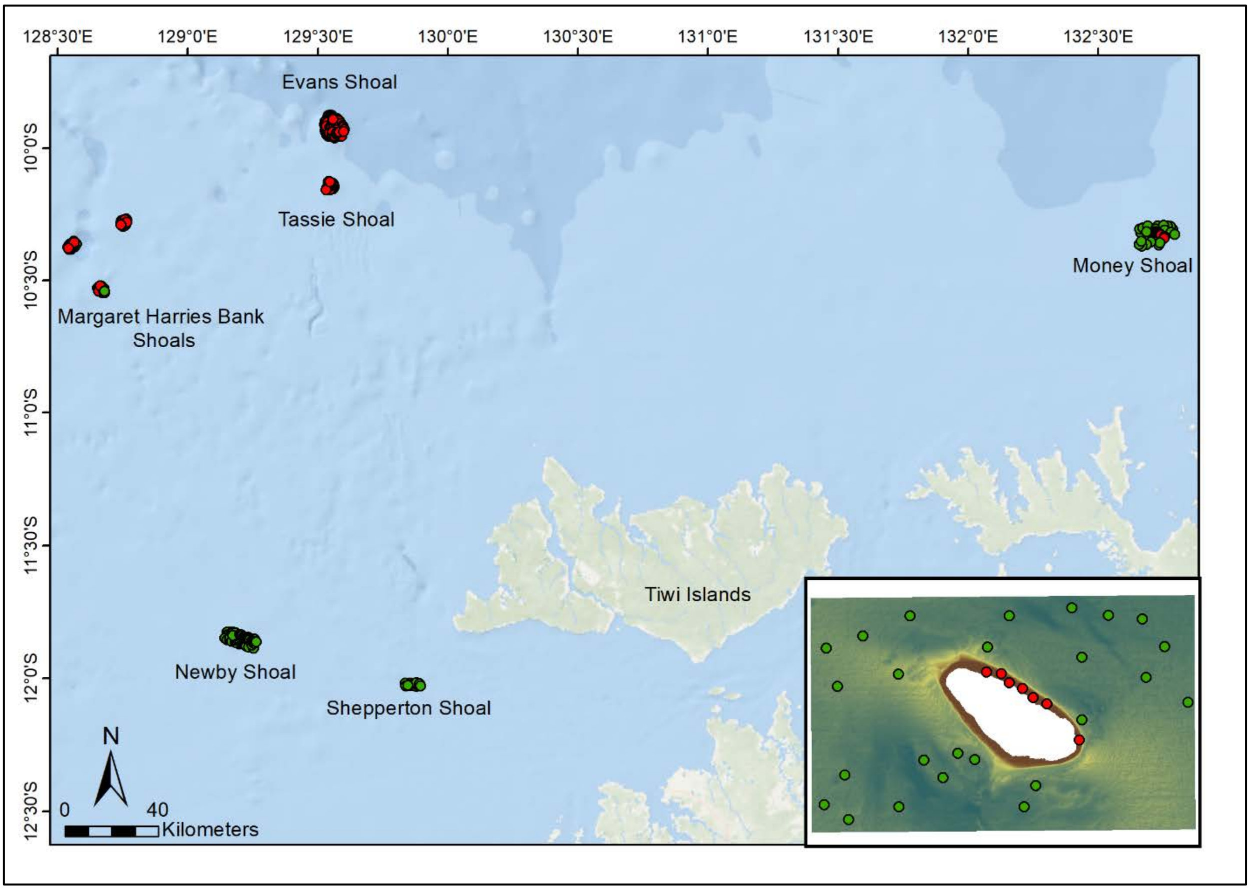


Figure 14. Regional comparison as a result of cluster analysis of fish assemblages from Money Shoal surveyed for the Marine Biodiversity Hub (Picard et al 2021) and other shoals surveyed by AIMS in this region. Red circles are shallow-water fish assemblages characteristic of shoal flat and slopes. Green circles are deep water fish assemblages characteristic of the deeper shelf habitat. Inset map represents the distribution of fish assemblages with depth on the Money Shoal. Depth range and colour scheme identical to the map presented in Figure 13 above.

5.2 Benthic fauna

Very few surveys have explored coral reefs and associated benthic communities in the far northern region of Australian waters, and even fewer in the deeper waters of most of the Arafura Marine Park. The marine park falls within the ‘Arnhem Coast to Gulf of Carpentaria’ bioregion, which field data from Reef Life Survey suggests that as a whole tends to be dominated by macro-algae and abiotic components, with some hard corals (Edgar et al. 2017a). This is similar to the ‘Bonaparte Coast’ bioregion directly to the west and the ‘Torres Strait Northern Great Barrier Reef’ bioregion to the east (Edgar et al., 2017b). Accordingly, benthic communities at reefs in the northern region as a whole tend to be more dominated by ‘turf algae’ than the Coral Sea, Great Barrier Reef (GBR), Indian Ocean, Indonesia or Western Australian regions. However, the hard coral cover across the northern region is similar to that of the GBR and Western Australia (Edgar et al., 2017b). Within this context, reefs within the

Arafura Marine Park tend to be dominated by live hard coral and turf, as is also the case for the Arnhem and Wessel Marine Parks (Edgar et al., 2017b). As of 2015, hard coral cover across reefs in the Arafura Marine Park was about 25% - similar to the Oceanic Shoals but higher than Arnhem and lower than Wessel Marine Park. Finally, the abundance and species richness of macroinvertebrates was highest in the Arafura Marine Park compared to the surrounding regions. Note that Reef Life Survey regularly surveys two shallow water sites within the Arafura Marine Park – Money Shoal and Bramble Rocks (located within the Multiple Use Zone at the southern end of the park;10.89º S, 132.78º E).

Footage from a recent towed video survey of Money Shoal and Pillar Bank for the Marine Biodiversity Hub (Picard et al., 2021) provides data to characterise benthic diversity and relative cover on these features, to add to the above regional context of benthic biodiversity.

5.2.1 Money Shoal

The 2020 survey towed video surveys found a mean cover of 68.3% for biotic and 31.70% for abiotic classes (Picard et al., 2021) surveying from 7.5 m to 85.2 m depth. The benthos was predominantly algae (57.58%), however a healthy and diverse hard and soft coral community was evident, particularly in shallower depths (3.19% and 1.59%, respectively; Figure 15). No corals were seen deeper than 69.8 m even though the surveys extended to 85 m water depth. This is similar to what was found in 2015 for both Money Shoal and Bramble Rocks by Reef Life Survey in shallow sites (Edgar et al., 2017b). Sponges (1.67%) and other unidentified marine invertebrates (3.47%) were also relatively abundant. The abiotic components were dominated by silt (26.99%), with relatively smaller contributions of sand (2.91%), rubble (1.87%) and shells (0.004%).

The mean coral cover measured in 2020 (3.19%) would be considered low on a typical shallow reef or shoal compared with other oceanic shoals of comparable size in the northwest and northern Australia. Coral cover was diverse, with corals recorded from 58 genera. The most dominant corals were from the genus *Porites* (0.49%), *Seritopora* (0.33%), *Diploastrea* (0.26%) and to a lesser extent *Goniastrea* (0.15%), *Montipora* (0.15%) and *Acropora* (1.18%). The majority of hard corals genera (55) were predictably present in shallow water depths between 7.5 m and 22 m, with the exceptions of *Echinopora* (~70 m), *Diaseris* (21.5-38 m), and from the family Dendrophylliidae (~70 m). These data only reflect coral cover observed from 7.7-69.8 m depth, and doesn’t include the top of Money Shoal where typically coral cover would be high. Indeed, the average coral cover for Arafura Marine Park recorded by Reef Life Survey at two reefs in shallow waters only was around 25% (Edgar et al., 2017b). Further shallow water surveys on the top and shallower parts of the shoal are needed to determine the full extent of coral and other benthic mean percent cover.

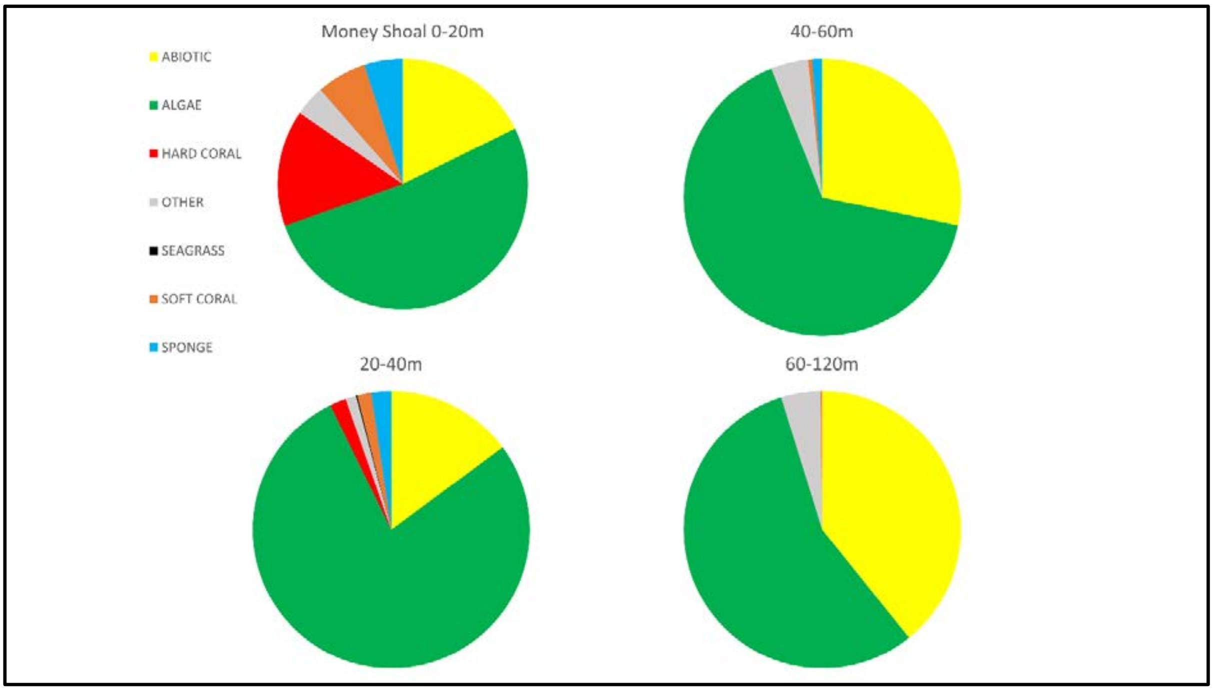


Figure 15. Percent cover of benthic categories from Money Shoal

Algae was the dominant benthos encountered during the 2020 survey at 57.58% cover. Turf algae on consolidated substates and sand was most prevalent (54.21%), however filamentous algae (1.32%), *Caulerpa* (0.62%) and *Padina* (0.44%), and other macroalgae (0.95%) made up a significant part of the algal community in the shallower depths. Marine algae and seagrasses are critical primary producers and the base of the food chain and constitute important habitat and resources for a wide community of herbivorous invertebrate, turtles, and fish species on reefs and shoals (Randall 1965, Ogden 1976, and Carpenter 1986). Some marine algae and seagrasses are considered ‘ecosystem engineers’ as they change the environment and diversity of marine life (Figueiredo, M.A.O. and Creed, J.C. 2009).

Seagrass (0.01%) was also present in small patches between 14.6 m and 30.6 m depth, dominated by the genus *Halophila* (0.01%). The green macroalgae, *Halimeda* was not recorded, an important reef building calcareous algal species and one of the foundation algae for *Halimeda* bioherms. It is difficult to speculate on *Halimeda’s* absence as the top of the shoal above 7.5 m was not surveyed.

Octocoral (soft coral) cover (1.59%) was most notable in the shallow water depths, however their presence was recorded as deep as 71.3 m. The most common octocoral was the encrusting genus *Lobophytum* (0.95%) and to a lesser extent arborescent soft coral from the family Nephtheidae (0.18%) and other unidentified soft corals (0.13%). Sponges were recorded from 7.8 m to 71.9 m depth (1.67% cover across surveyed area).

Other common marine invertebrates and fish (4.21%), were recorded when in the frame under the point score location, notably from the Phylum Ectoprocta (Bryozoan 0.40%) and Class Crinoidea (Crinoids 0.11%) which were abundant, but the largest percent mean cover was other unidentified invertebrates (3.47%).

Of note were the many large benthic foraminifera (LBF) present in some areas (Figure 16), which are an important part of tropical mesophotic environments (Renema 2019). However, they have been rarely observed in such high abundance on other reefs in the northern region.

Figure 16. Large benthic foraminifera observed on towed video at Money Shoal.

5.2.2 Pillar Bank

Pillar Bank is located 150 km north-west of Money Shoal. With depths ranging from 98 m to 208 m, Pillar Bank is significantly deeper than Money Shoal. The percent cover of biotic and abiotic components was quite different to Money Shoal, possibly due to Pillar Bank spanning a gradient from photic to aphotic zone given its greater maximum depth. Benthos was very sparse, with mean percent biotic cover at 28.22%. Abiotic (71.78%) components were overwhelmingly made up of abiotic silt (71.59%), with a very minor contribution of sand (0.15%) and rubble (0.03%) (Figure 17).

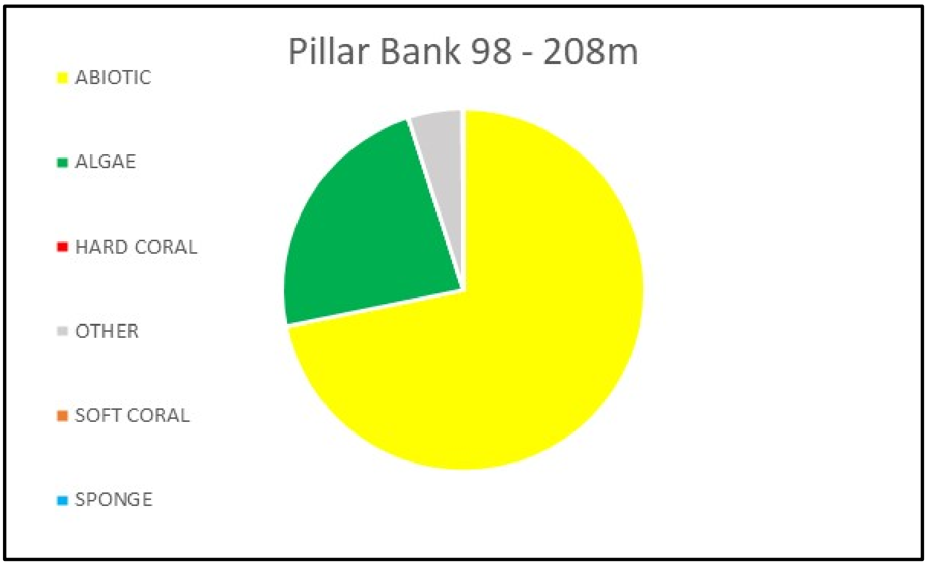


Figure 17. Percent cover of benthic categories from Pillar Bank

Algae was the main primary producer and the most abundant benthos recorded with the highest percent cover (23.25%), although that was only represented by turf algae on consolidated substrate (22.97%) and on sand (0.28%). No macroalgae was recorded at Pillar Bank. Sponges (0.05%) were the most common sessile macro benthos and are well suited to the aphotic depths. This is consistent with towed video surveys completed on Pillar Bank in 2005 that primarily found filter feeders, including sponges, octocorals and comatulacean crinoids (Wilson, 2006). A similar sparse biota dominated by filter feeders was observed off the Pilbara coast in similar depths at a series of five study areas along the 125-150 m depth contour that defines the ancient coastline, a Key Ecological Feature in the region (Wakeford et al., in review).

Hard coral was very rarely observed, with a percent cover of hard coral (0.004%) made up of only one species recorded from the family Dendrophylliidae, generally associated with deeper water and the aphotic zone. The percent cover of Octocorals (0.04%) was also very low and was represented by octocorals from the Family Nephtheidae (0.02%), Gorgoniidae (0.004%) and other unidentified octocorals species (0.01%). Other common marine invertebrates (4.88%), most notably from the Phylum Ectoprocta (Bryozoan) (0.008%) and Order Actiniaria (Anemone) (0.01%) that were present, but by far the largest percent cover were unidentified invertebrates (4.86%).

6. KEY KNOWLEDGE GAPS AND FUTURE RESEARCH

Our knowledge of shelf benthic habitats and associated biodiversity within Arafura Marine Park has been advanced by the high resolution mapping and sampling of Money Shoal and Pillar Bank. However, further work is required to fully document the fine scale spatial relationships between these seabed features and benthic communities. This will be achieved through predictive modelling that draws upon quantitative analysis of seabed imagery (benthos and fish) to derive measures of species abundance and diversity and seabed characteristics (substrate type, geomorphology derived from bathymetry and backscatter data). In turn, this modelling will provide insights to guide future research and monitoring, including areas to prioritise to revisit over time, and for selecting additional mapping and sampling sites. This could include areas near the shelf break within the Multiple Use Zone where reef habitat may be associated with the ancient coastline at 125 m depth. The shallow areas of the park, closer to the influence of coastal rivers, such as in the vicinity of Bramble Rocks would also warrant detailed mapping and sampling. With these additions, a representative baseline will be established for the ongoing monitoring of the range of shelf environments within Arafura Marine Park.

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