



Faafu Dhiguvaru



An Ecological Assessment on Biodiversity and Management

2021

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Introduction

In light of the extent and scale of natural and anthropogenic impacts threatening marine and island habitats across the Maldives, it is crucial that areas with potentially high ecological value are identified and assessed to formulate ecological management plans specific to these habitats. The long-term goal is to create a network of well-managed, conservation focused areas throughout the Maldives, increasing the habitat's resilience against future change. In collaboration with the Ministry of Environment and Project REGENERATE (a Government of Maldives project, implemented by IUCN and generously funded by USAID) a series of ecological assessments were conducted at various key marine and terrestrial sites. This report describes the findings of habitat assessments conducted at Faafu Dhiguvuru and presents elements that should be considered when developing management plans.

Natural environment of the Maldives

The Maldives is an archipelago of coralline islands located in the middle of Indian Ocean. Around 1192 islands are distributed across 25 natural atolls which are divided into 16 complex atolls, 5 oceanic faros, 4 oceanic platform reefs covering a total surface area of 21,372km² (Naseer & Hatcher, 2004). The islands are considered low-lying, with 80% of the country less than a meter above the sea level and most islands are less than 5km² in size (Ministry of Environment and Energy, 2015).

The terrestrial habitats present across the country includes: rocky and sandy shorelines, coastal shrublands, marshes, brackish ponds, mangroves and woodlands (Toor et al., 2021). There are at least 583 species of terrestrial flora, of which 323 are cultivated and 260 are natural. Mangrove ecosystems can be classified based on the system's exposure to the sea as either open or closed mangrove systems (C. S. Dryden et al., 2020; Saleem & Nileysha, 2003). Fifteen species of mangroves are found across approximately 150 islands (C. Dryden et al., 2020; Ministry of Environment and Energy, 2015). Over 200 species of birds have been

recorded in the Maldives consisting of seasonal migrants, breeding residents, and introduced birds (Anderson & Shimal, 2020; Ministry of Environment and Energy, 2015).

Coral reefs of the Maldives are the seventh largest reef system in the world, representing as much as 3.14% of the world's reef area. There are 2,041 individual reefs covering an area of 4,493.85km² (Naseer & Hatcher, 2004). Coral reefs and their resources are the key contributors to the economic industry of the Maldives. It is estimated that approximately 89 percent of the country's national Gross Development Product (GDP) comes from biodiversity-based sectors (Emerton et al., 2009). There are approximately 250 species of corals belonging to 57 genera (Pichon & Benzoni, 2007) and more than 1,090 species of fish recorded in the Maldives (Ministry of Environment and Energy, 2015).

The natural environment in the Maldives is threatened by many local and global scale factors (C. S. Dryden et al., 2020). Threats to the terrestrial biome include infrastructure development, human waste and land reclamation projects. Due to historical and continued undervaluation, many of these areas are not given the level of respect and protection they require. Many mangroves across the country have been reclaimed to pave the way for land and infrastructure development. The 2016 bleaching event impacted an estimated 75% of the coral reefs (Ibrahim et al., 2017), and has shown that even some of the most protected reef ecosystems could perish. Reefs are also at risk from local stressors such as overfishing, pollution and land reclamation (Burke et al., 2011). Despite these stressors, Maldivian reefs have previously shown resilience and recovery following such disturbances (Morri et al., 2015; Pisapia et al., 2016). The terrestrial and marine biota serve as a source of income, food, and socio-economic benefits to the community. Tourism and fishing industries depend directly on the natural resources, and the country's economy is primarily dependent on the profits around these industries. This highlights the significance of the natural environment to the Maldives as well as the need to protect and conserve valuable and threatened habitats across the country. Therefore, there is an immediate need for biodiversity assessments and management plans

to ensure successful management and sustainable use of these natural resources. Such approaches will play a key role in standardising the efforts to manage and monitor the resources in a co-managed concept.

Study Site

Dhiguvaru is a small uninhabited island on the Eastern outer rim of Faafu Atoll (Figure 1). The North of Faafu Atoll is sparsely populated, with four of the five inhabited islands at the southern edge of the atoll over 15 km away from Dhiguvaru. The nearest inhabited island is Feeali, approximately 3.5 km to the north. The island is 150 m long, with an area of approximately 0.75 ha. A small rocky platform that extends about 80 m eastward from the island. Rocky shoreline habitat is present along the exposed Northern and Eastern shorelines with sandy shoreline along the Southern and Western shorelines. There is coral growth in the shallow water up to the Eastern shoreline. Dense vegetation grows throughout the island, with some mangrove trees on the Western side of the island growing along a narrow strip towards the middle of the island (from West to East). The rocky platform on the Eastern side of the island has a small stand of trees. Parts of the island gets inundated during high tide. The island is used as a picnic island by locals from the neighbouring islands.

The island sits at the Northeast corner of a tear drop shaped faro reef structure i.e. a ring shaped reef with reef flats near the surface and a central lagoon (Perry et al. 2013). There is a long, exposed atoll edge reef on the Eastern side, channels to the North and South and a curved sheltered reef along the Western side. There is a large area of reef flat around the rim which reaches near the surface. The central lagoon is shallow and split in two by a stretch of reef that bridges the Northern and Southern reefs. The circumference of the outer reef and inner lagoon are approximately 6.5 km and 4.8 km respectively. The reef flat is 500 m at its

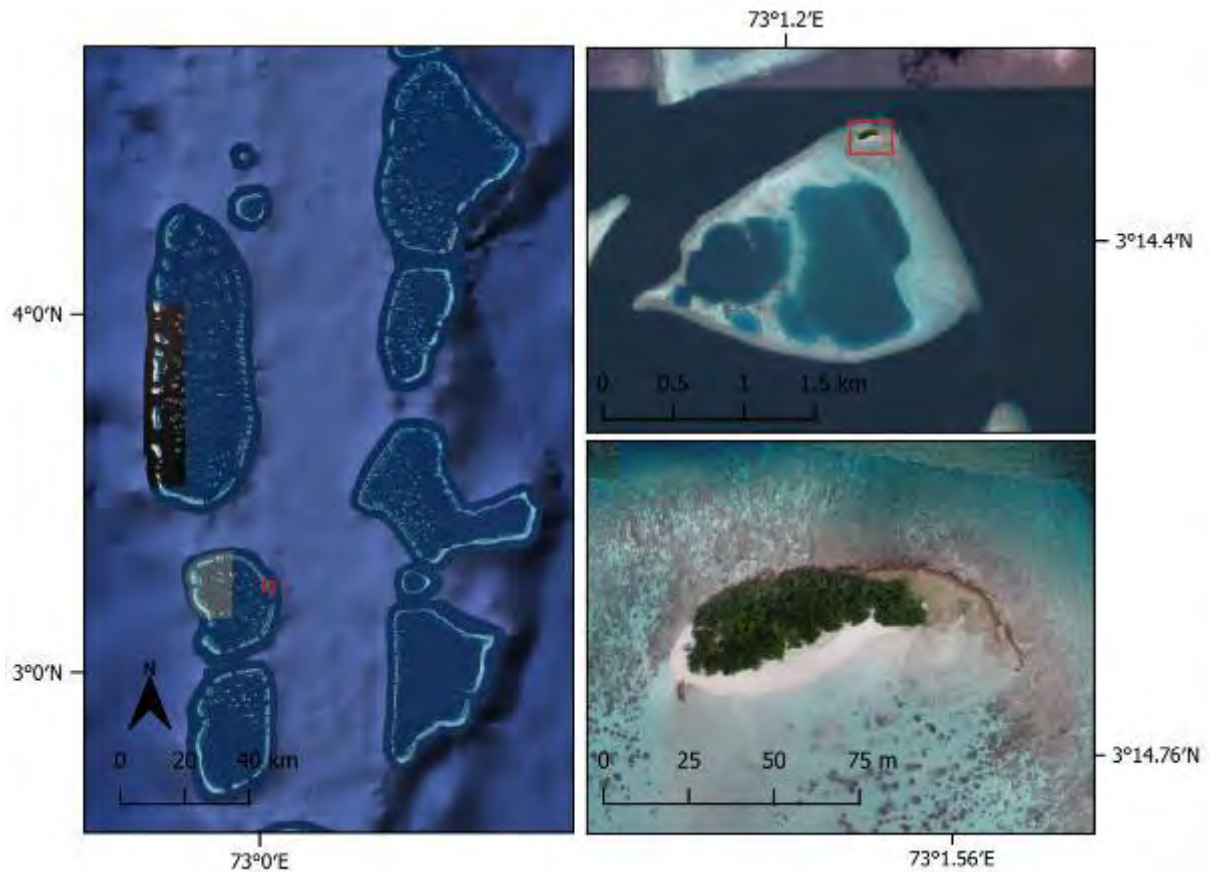


Figure 1. Faafu Dhiguvaru island and reef area

widest and 50 m at its narrowest. The lagoon is around 20 m at its deepest point. Isolated patches of coral, “coral bobbies” are located throughout the lagoon area.

Methods

Terrestrial survey

The terrestrial survey area was divided into three zones, the coastal fringe, mangrove and inner island and 18 Survey points were identified using a stratified sampling approach with sites selected around pond fringes and around the coastal fringe area (Figure 2). GPS coordinates were extracted from Google Earth© version 7.3.1 and entered into the android phone application SW Maps (©Softwell (P) Ltd. 2020) which was used for navigation to the point. Vegetation was surveyed using a point survey approach (C. Dryden & Basheer, 2020).

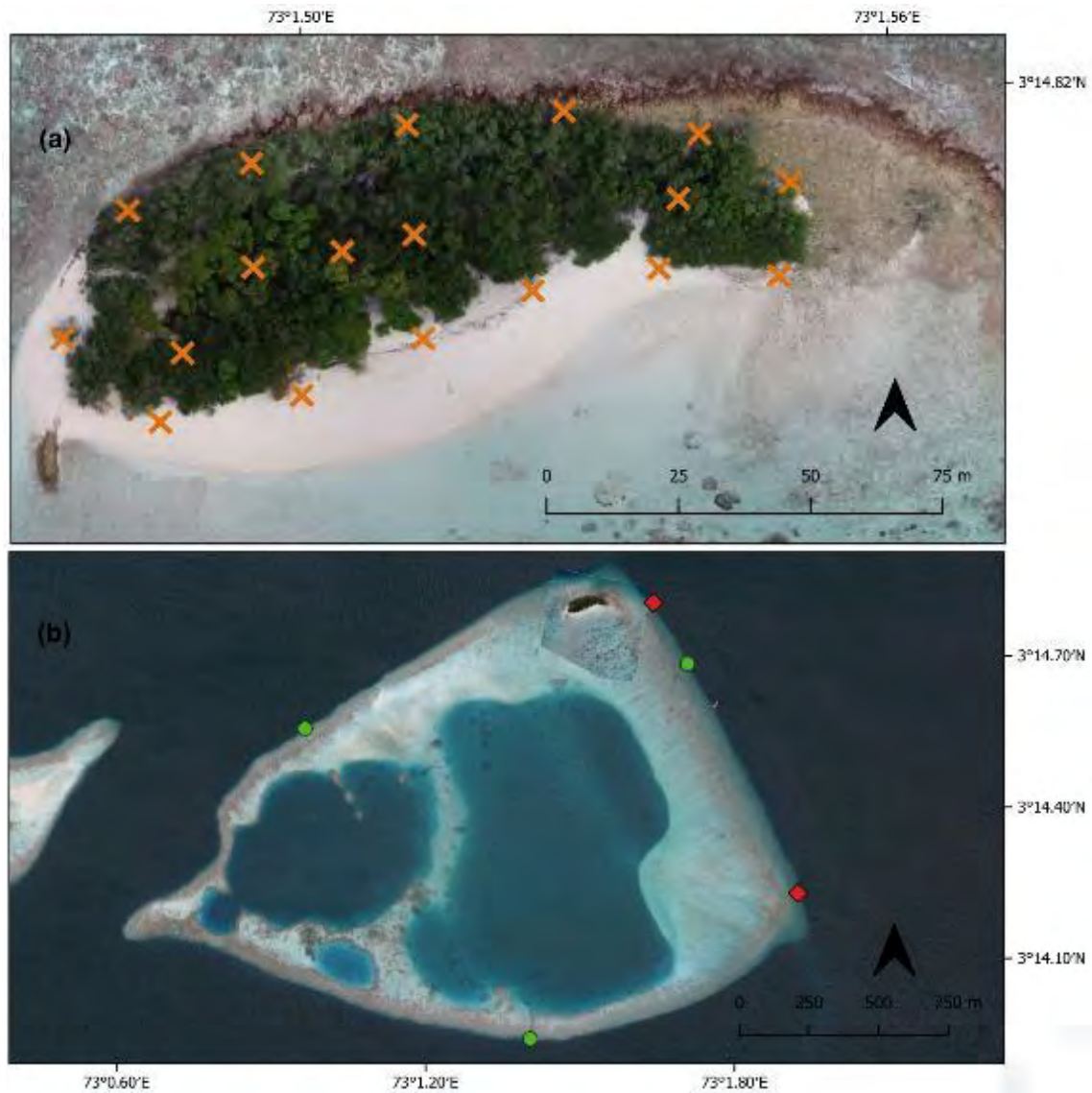


Figure 2. Location of (a) terrestrial and (b) marine survey sites. In (b) red diamonds indicate roaming surveys and green circles indicate transect survey sites

Aerial survey

Aerial surveys were conducted to create an accurate, high-resolution map of Dhiguvaru. Aerial imagery was collected using the DJI Phantom 4 Pro UAV with 1-inch 20 Mega Pixel CMOS sensor. The flight plans were created using DroneDeploy© Free Mobile App, with a height of 85 meters from ground level. At this height, with a small format camera it is possible to get a pixel size of less than 5 cm. The overlay of the pictures was 75% on front-lap and 75% on side-lap. Ground Control Points (GCPs) were used to ensure the map was as accurate as possible. A total of 101 geo-referenced images were processed using the Agisoft Metashape



Figure 3. Images from (top) terrestrial and (bottom) marine transect surveys

Software© this generated a high-resolution geo-referenced Orthomosaic and detailed digital elevation models.

Marine survey

Marine surveys were performed using three methods. A manta tow was used to perform coarse-scale assessments of the Hulhidhoo reef flat. SCUBA roaming surveys lasting 15 minutes were used assess fish and benthic communities on the reef slope were conducted at both the North and South channel areas. Transect surveys were conducted at three reef slope locations around the outer reef (Figure 2b). Three 50 m transects were set at a depth of 10 m, with a gap of at least 5 m between each transect to ensure independence of samples. Reef substrate was surveyed using photoquadrats taken every 2 m on alternating sides of the transect, a total of 75 photos per site. Mean percentage cover of each major benthic category,

the genera of coral, and other significant benthic life forms for each transect survey site was calculated using CoralNet (<https://coralnet.ucsd.edu/>) (Beijbom et al. 2015). To quantify coral recruitment a 25 x 25 cm quadrat was placed above and below the transect every 10 m along the transect. Fish communities were surveyed along the same transects as the benthic surveys. All fish species were identified, and their total length was estimated to the nearest 5cm. Pomacentrids and smaller Serranids (Anthias) were counted within a 2 m belt along each transect, and all other species were counted within a 5m belt along each transect. The biomass of fish species was calculated using length-weight conversion: $W = aL^b$, where a and b are constants, L is total length in cm and W is weight in grams. Constants vary by species and were gathered from FishBase (Froese and Pauly 2017). For a full description of the three marine survey methods see (C. Dryden & Basheer, 2020).

Endangered, vulnerable, or threatened species

The IUCN Red List of Threatened Species categories, critically endangered (CR) endangered (EN), vulnerable (VU), or near threatened (NT) were used to identify marine species globally at risk that were present. Roaming surveys were used to quantify the presence and abundance of these species as this method covers a large area, which increases the likelihood of encounter. Five pre-selected VU coral species were surveyed as they were easy to identify during the rapid surveys (

Table 1). All fish and marine reptile species (CR, EN, VU or NT) were counted and identified to species.

Species	Red category	List	CITES Appendix
<i>Galaxea astreata</i>	Vulnerable		II
<i>Pachyseris rugosa</i>	Vulnerable		II
<i>Pavona venosa</i>	Vulnerable		II
<i>Physogyra lichtensteini</i>	Vulnerable		II
<i>Turbinaria mesenterina</i>	Vulnerable		II

Table 1. Pre-selected coral species and their IUCN Red List category and CITES Appendix

Results

Terrestrial

Four species of flora were identified during the terrestrial surveys, *Pemphis acidula* (Dhivehi name: Kuredhi), *Guettarda speciosa* (Dhivehi name: Uni), *Scaevola taccada* (Dhivehi name: Magoo) and the mangrove *Bruguiera cylindrica* (Dhivehi name: Kandoo) (Figure 4). *P. acidula* accounted for 78.7 % of the total island vegetation cover and was the dominant vegetation type around the coastal fringe and inner island habitat. *S. taccada* and *G. speciosa* covered 3.9 % and 5.7 % respectively and were the only other non-mangrove species present. The dominance by *P. acidula* meant there was little change in the vegetation community along the gradient from the coast to the inner island.

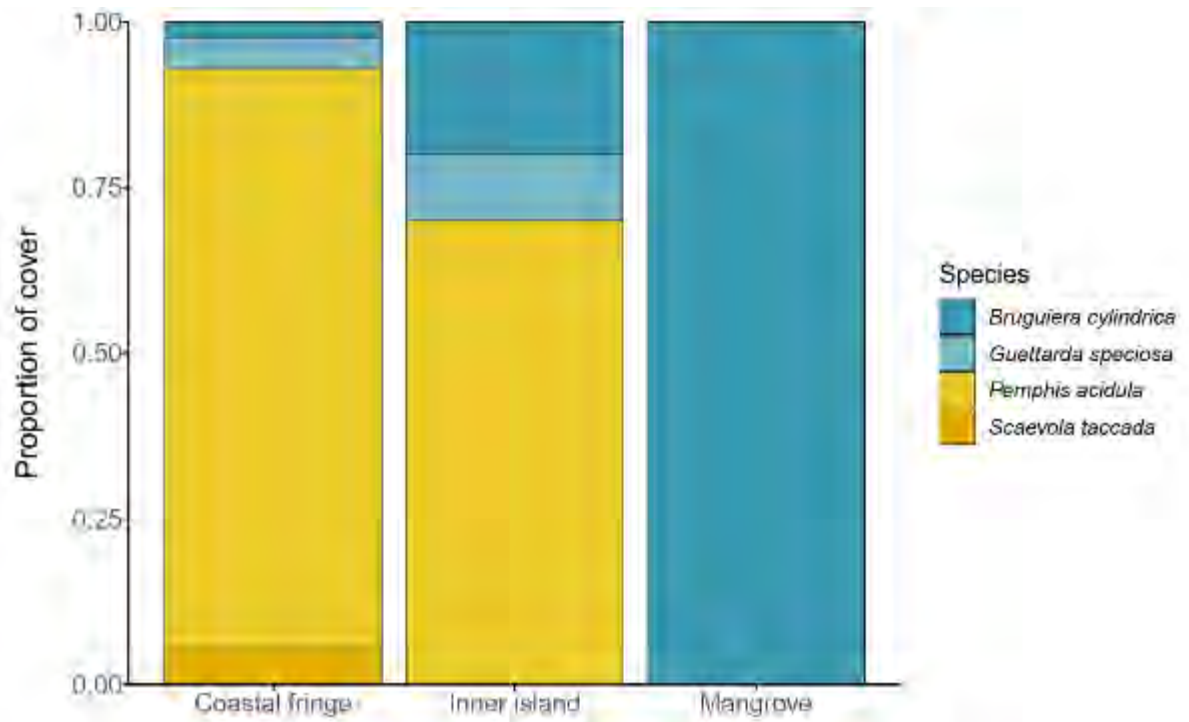


Figure 4. Percent cover of tree species in the three areas of vegetation

The soil type found throughout the inner island was a mixture of coarse sand and rubble. The soil type at the coastal fringe was a mixture of beach rock, and rubble along the North and East, and sand and rubble along the South and West. The height of the tallest trees in the

coastal fringe averaged 3.3 m (± 0.4 S.E.) and in the inner island averaged 4.0 m (± 0.4 S.E.) (Figure 6).

The mangrove habitat was a monospecific stand of *B. cylindrica* (Figure 5) that was approximately 670 m², 9 % of the total island area. These were almost exclusively mature trees and had an average height of 4.3 m (± 0.1 S.E.). The raised outer rim of the habitat had *B. cylindrica* trees growing spread out on coarse sand and rubble sediment and the centre of the habitat had trees growing more densely, with pronounced knee roots in a depression with shallow pools of water and a fine sediment and mud (Figure 7). The depth of the water in the basin fluctuated with tides as water flowed through the porous bedrock.

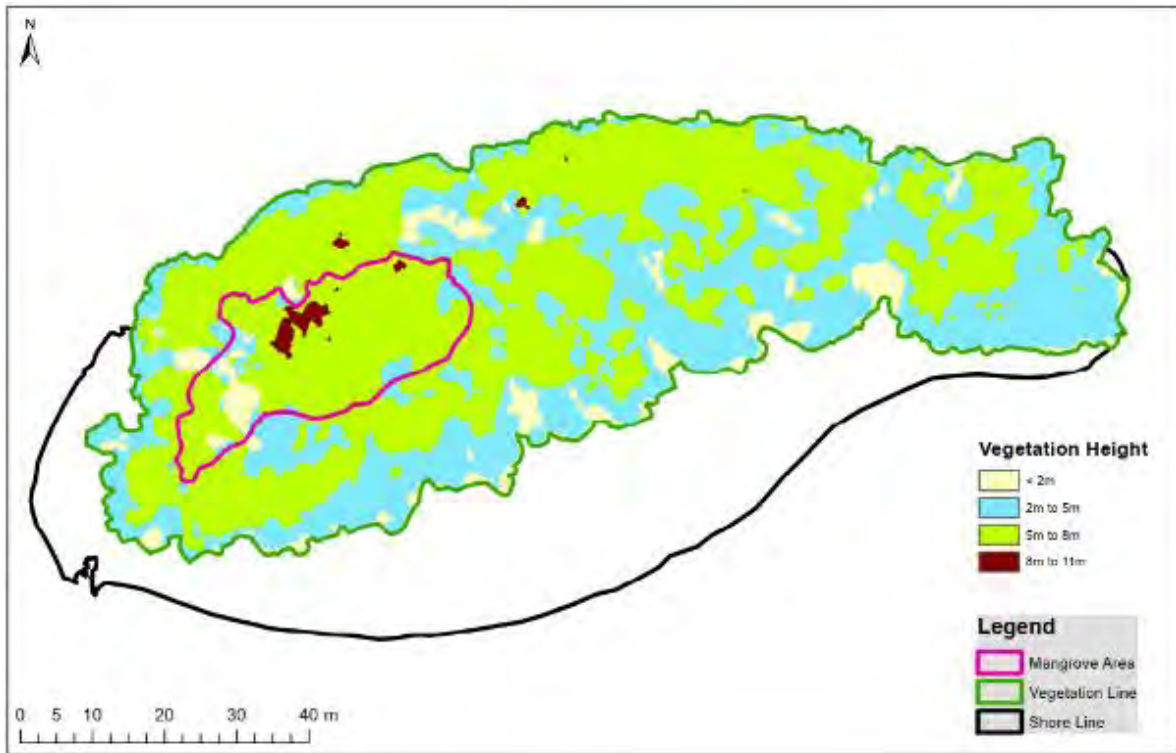


Figure 6. Digital elevation map of the vegetation height



Figure 5. Mangrove basin at the Western side of Dhiguvaru



Figure 7. Images of the mangrove habitat at Dhiguvaru. Images show clockwise from the top left: water filled centre of the mangrove basin, border between the water filled depression and the outer rim of the mangrove habitat, sparsely growing *B. cylindrica* trees in the outer rim of the habitat and *B. cylindrica* trees growing in rubble on edge of the shoreline

A significant amount of rubbish was found throughout the island, but particularly across the inner island area (Figure 8). The rubbish type was almost entirely plastic waste, mostly plastic bottles, with some pieces of metal and rope also found. There were no man-made structures on the island, however there was significant evidence of human island use. There were pathways leading through and around the island, trees had been cut down for timber and areas had been cleared as picnic spots. Much of the inner island rubbish could be attributed to picnickers.

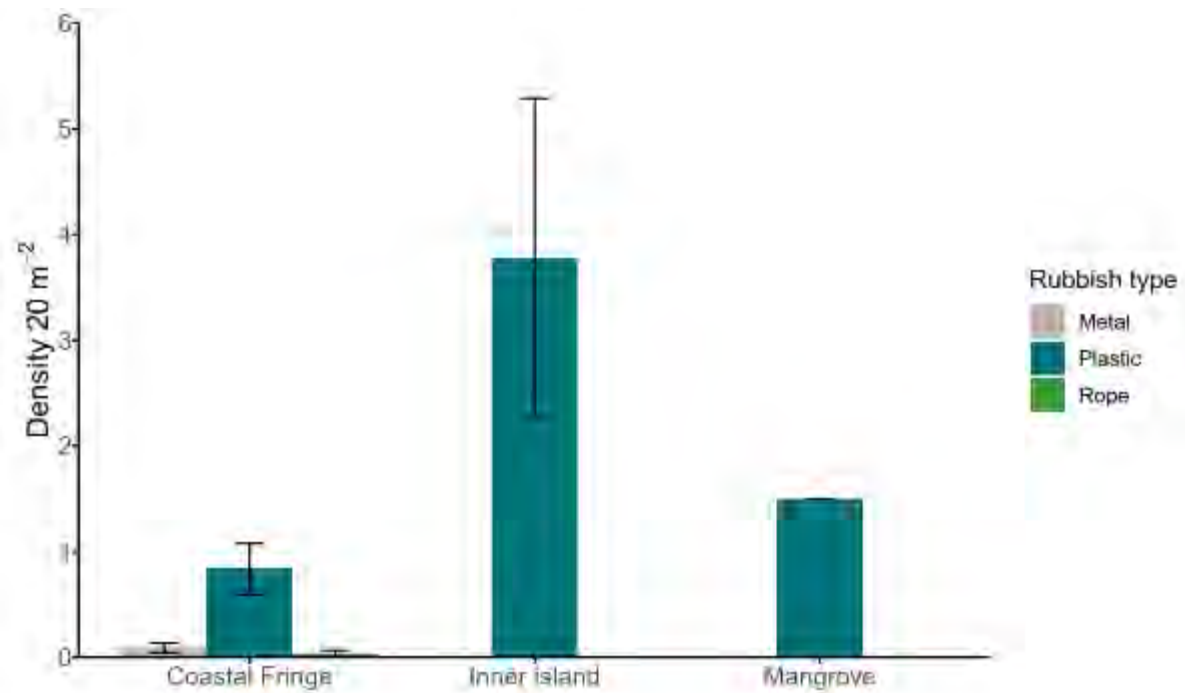


Figure 8. Mean density of items of refuse found in per 20 m² survey point in the three areas of vegetation

Rocky shoreline habitat around the North and East with a beach rock and rubble platform that extended 80 m eastward. On a small, raised section of the platform were three *P. acidula* trees. The South and West of the island had a relatively wide sandy shore with evidence of old turtle nests. The shallow areas surrounding the island had small coral covered rocks and patches of sand, rubble and rock.

Marine

The manta tow identified rock as the dominant benthic cover around the reef flat/crest area, comprising 55.0 % (± 2.0 S.E.) of the substrate (Figure 9). Hard coral was the second most common substrate type with 21.2 % (± 2.5 S.E.). The remaining substrate was rubble 13.8 (± 2.2 S.E.), sand 9.5 (± 1.7 S.E.) and algae 0.5 (± 0.2 S.E.).

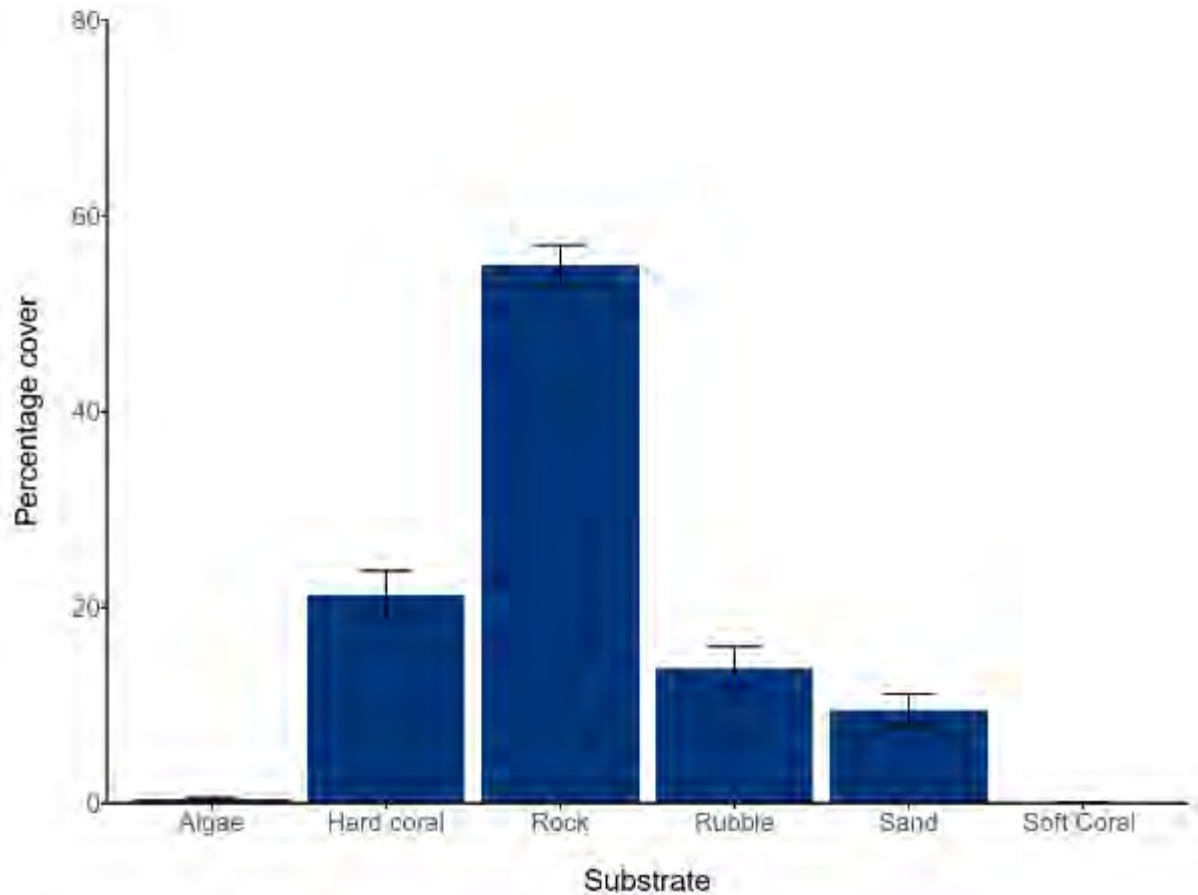


Figure 9. Mean percentage cover of six substrate categories recorded on manta tow survey.

Table 2. Mean percentage cover of substrate at the three transect survey sites

Substrate	East Side		North Side		South Side	
	Percentage cover	S.E.	Percentage cover	S.E.	Percentage cover	S.E.
Hard coral	15.9	3.8	14.3	1.1	5.9	0.9
Hard Substrate	51.8	12.7	53.4	4.3	37.6	9.3
Macroalgae	3.8	1.6	5.5	1.8	2.0	0.8
Turf algae	12.4	1.5	5.2	1.2	2.5	1.1
Rubble	1.9	0.9	14.6	6.7	38.4	10.7
Sand	5.3	4.5	3.7	0.9	9.9	1.9
Soft coral	0.0	0.0	0.3	0.0	0.0	0.0
Sponge	1.6	0.0	0.0	0.0	0.0	0.0
Other	2.8	1.6	1.7	0.1	2.0	0.3
Other Invertebrates	5.5	1.2	1.5	0.6	1.7	0.8

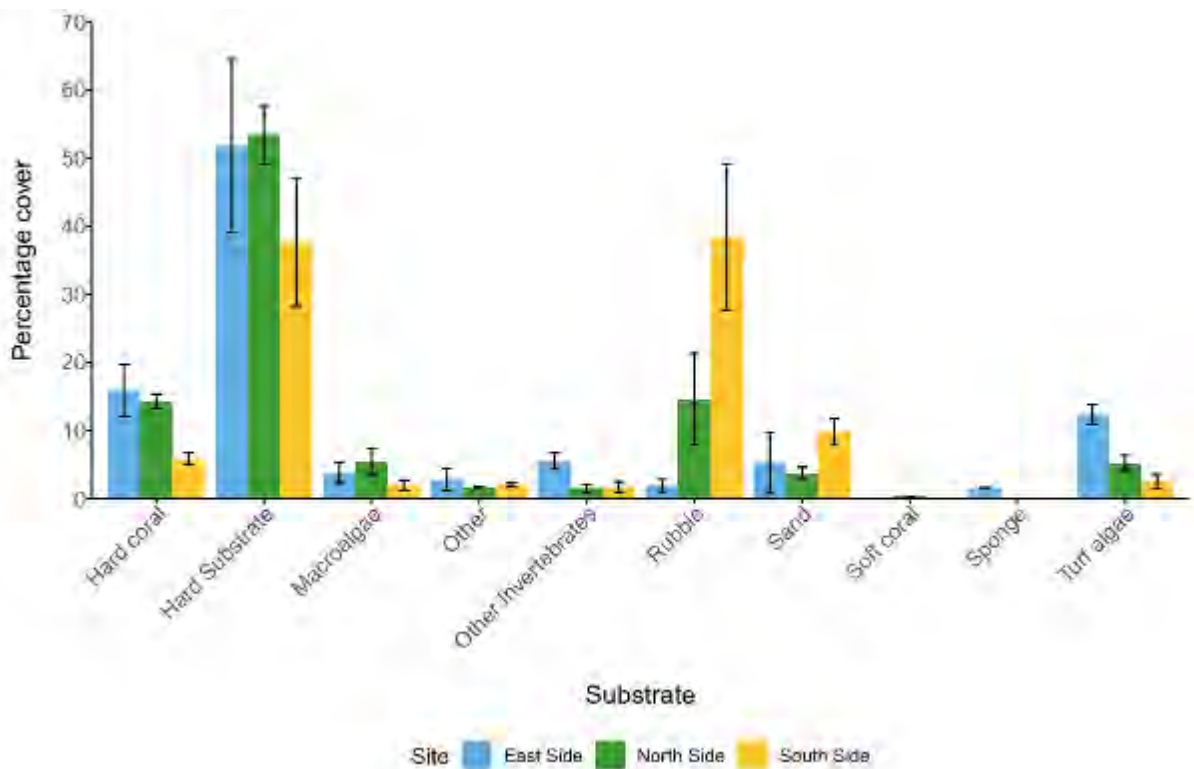


Figure 10. Mean percentage cover of substrate types at the three transect survey sites.

Hard substrate cover was the dominant substrate type at the East Side and North Side sites (Table 2, Figure 10). Hard substrate cover was lower at the South Side site where it was similar to rubble cover. At the East Side site hard coral and turf algae were the second and third most common substrate types, though there was little difference between the two. At the North Side site, rubble and hard coral were the second most common substrates and made up approximately equal proportions of the benthos. Hard coral cover was only 5.9 % at the South Side site, this was also the only site where sand cover was greater than 5 %.

The seven most common coral families were Poritidae, Acroporiidae, Merulinidae, Pocilloporidae, Agariciidae, Dendrophylliidae and Psammocoridae (Figure 11). The most common families at the East Side site were Poritidae (4.8 % cover), Merulinidae (3.3 % cover) and Pocilloporidae (3.2 % cover). The most common families at the North Side site were Acroporiidae (3.7 %) Poritidae (2.8 % cover), Merulinidae (2.5 % cover) and Pocilloporidae (1.8 % cover). The most common families at the South Side site were Poritidae (1.6 % cover), Acroporiidae (1.6) and Merulinidae (1.0 % cover). The cover of all coral families was lowest at the South Side site.

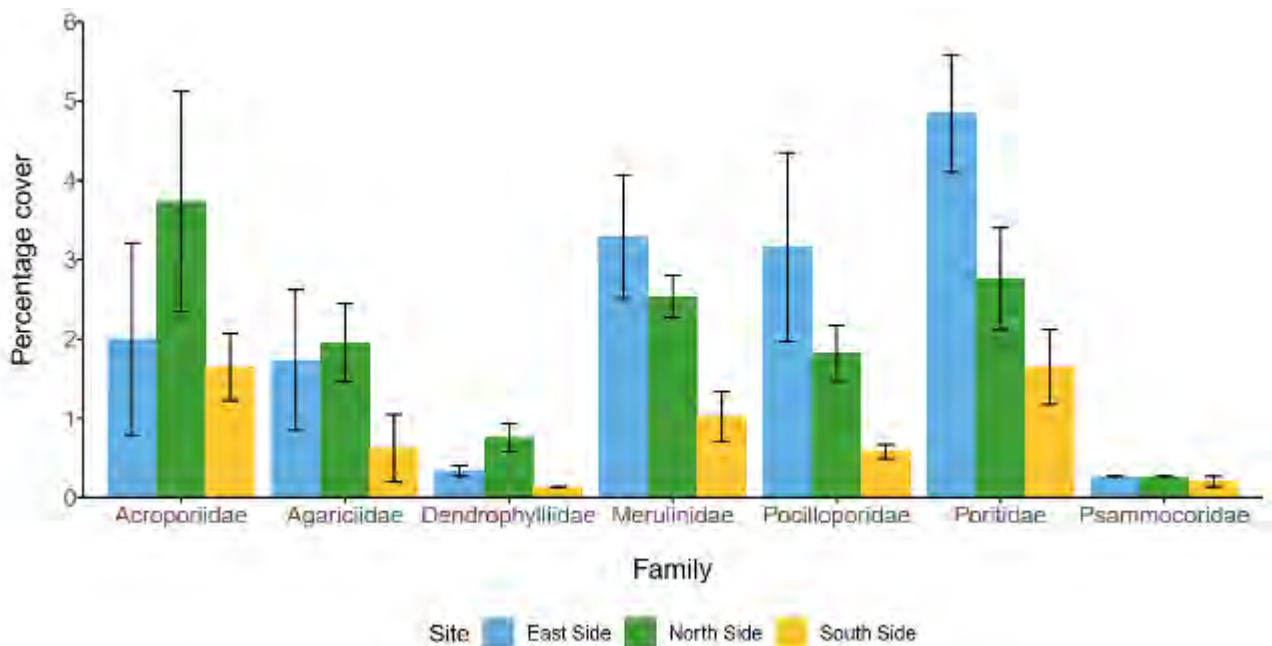


Figure 11. Percentage cover of the seven most commonly observed coral families recorded on transect surveys

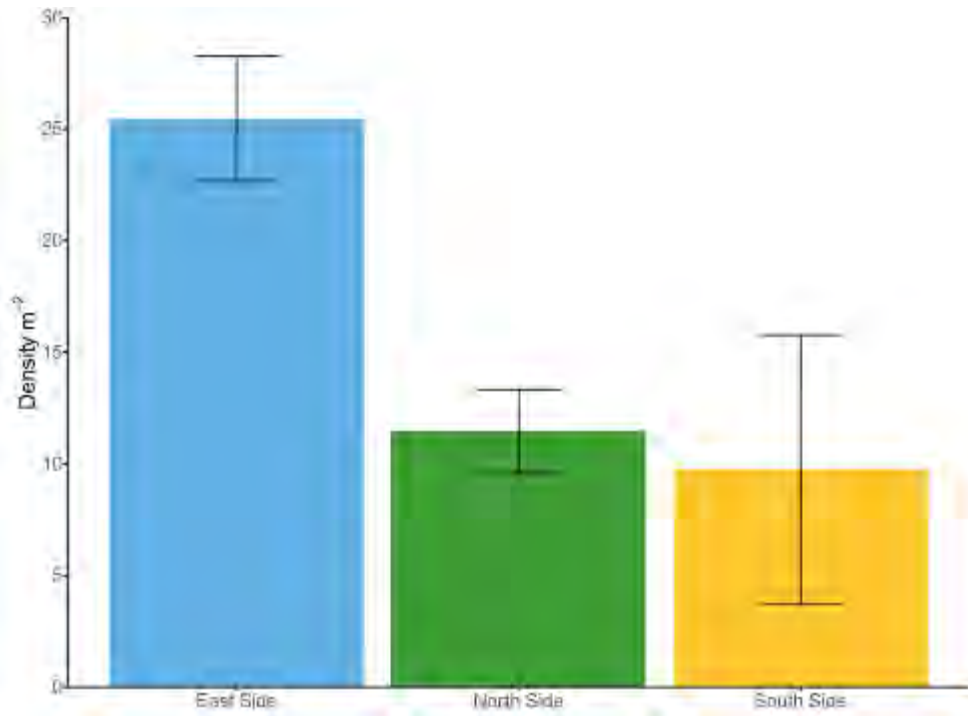


Figure 13. Density per m^2 of all coral recruits recorded on transect surveys

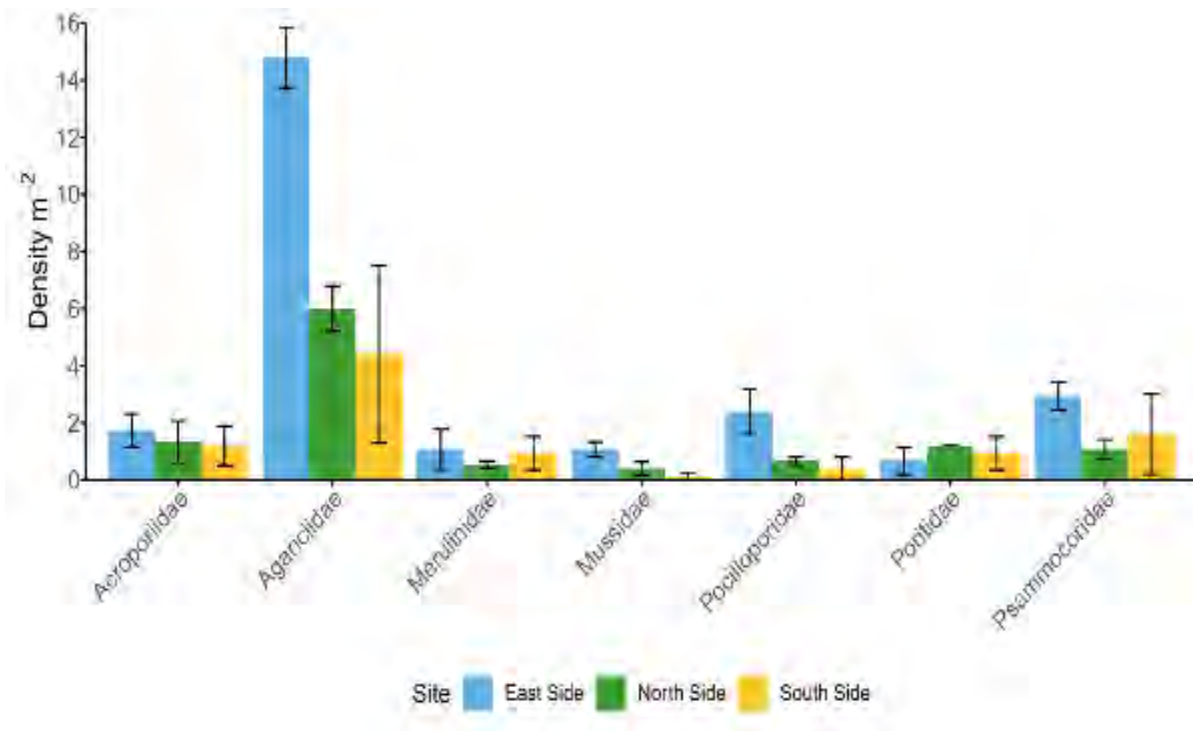


Figure 12. Density/ m^2 of recruits from the seven most common families observed.

Total recruit density was $25.4/ \text{m}^2 \pm 2.8$ at the East Side site, $11.5/ \text{m}^2 \pm 1.9$ at the North Side site and $9.7/ \text{m}^2 \pm 6.0$ at the South Side site (Figure 12). Total density of recruits was noticeably higher at the East Side site. Recruit density varied greatly between transects at the South Side site. Agariciidae was the most commonly recruiting coral family at all three sites (Figure 13). This family was dominated by recruits from the genus *Pavona*. Pocilloporidae and Psammocoridae were the second most common families of recruits at the East Side site. There was no notable difference between family level recruitment at the North and South Side sites.

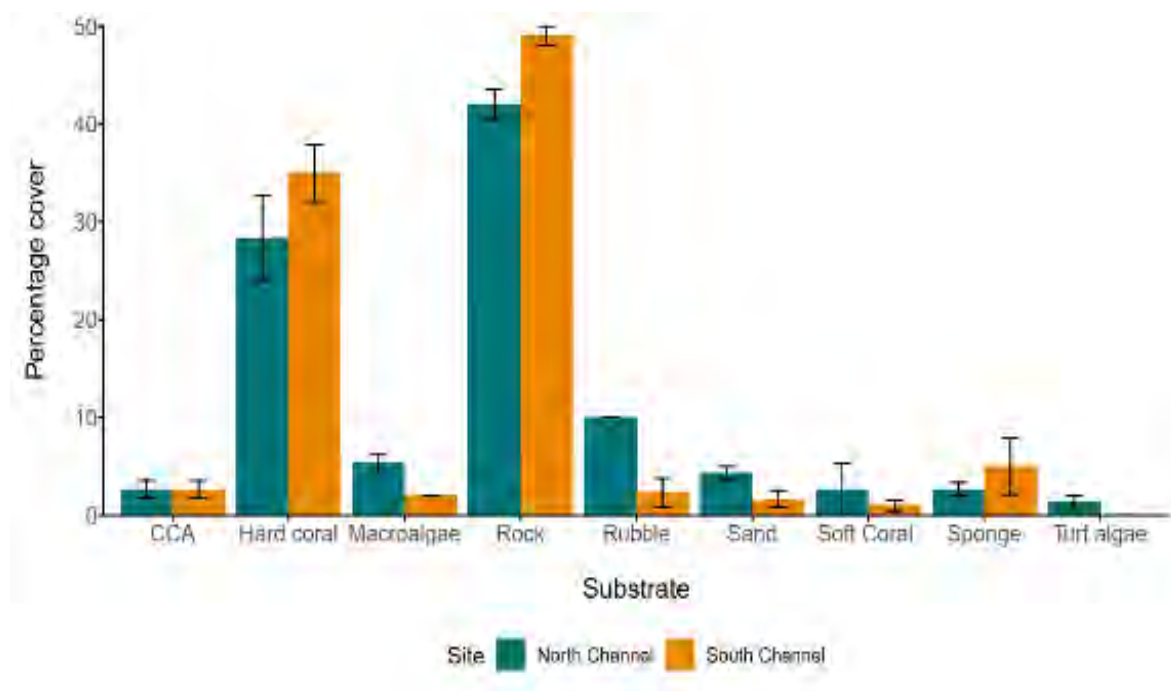


Figure 14. Estimated percentage cover of substrate cover at the North and South Channel survey areas

The roaming surveys of the channel habitats found rock and hard coral to be the dominant substrate types (Figure 14). Branching and massive corals were the most common coral

growth forms at both channels (Figure 15). The channel corners had high coral cover with branching and table corals abundant.

Total fish density was highest at the North Side site ($258.4/ \text{m}^2 \pm 69.1$) followed by the East Side site ($176.7/ \text{m}^2 \pm 8.4$) and lowest at the South Side site ($101.3/ \text{m}^2 \pm 12.1$) (Figure 16). A total of 100 fish species were recorded during the transect surveys. Fish species richness did not vary greatly between sites, ranging from 40.7 ± 6.6 at the North Side site to 38.7 ± 1.7 at the East Side site (Figure 15). The higher density at North Side site was driven by planktivorous species. This group includes all Caesionids, Anthias, *Chromis spp.* and *Acanthurus mata*, *A. thompsoni*, *Naso hexacanthus* and *Odonus niger*. At the North Side site density was $115.6/ 100 \text{ m}^2 \pm 24.5$ meaning planktivores accounted for 44.7 % of all fish recorded at this site. There were fewer planktivores at both the East Side ($39.7/ 100\text{m}^2 \pm 5.4$) and South Side ($10.7 100 \text{ m}^2 \pm 4.0$) sites making up 22.5 % and 10.5 % respectively of the total fish density.

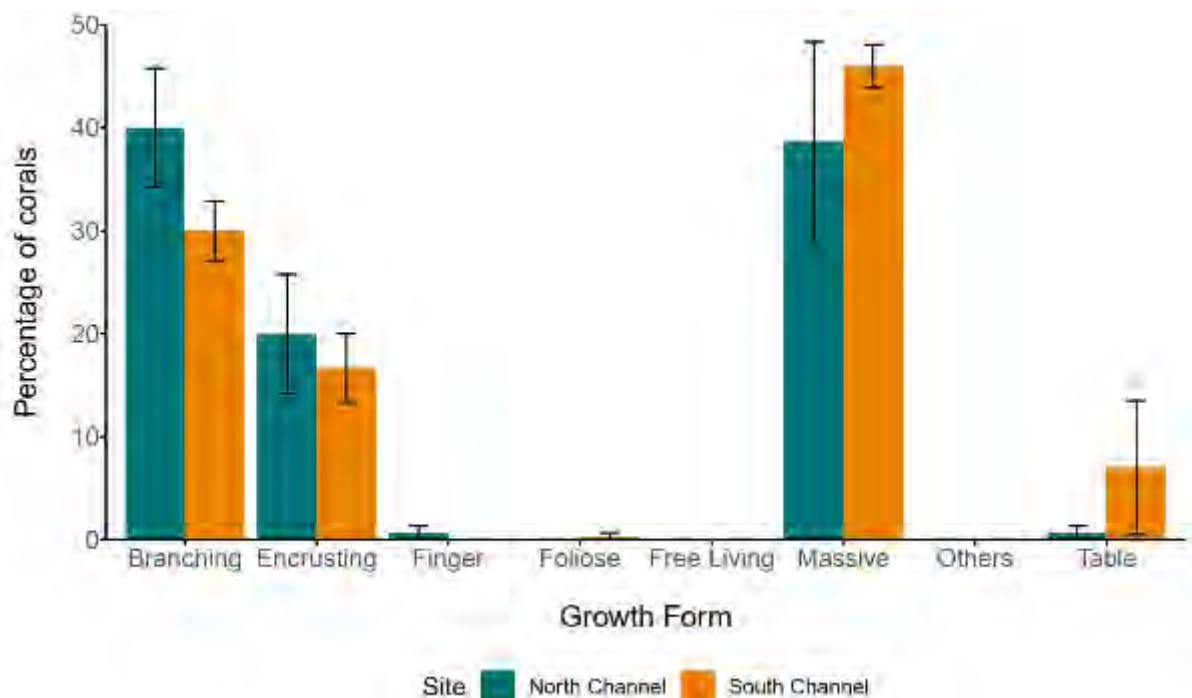


Figure 15. Percentage of coral cover in each growth form at the North and South Channel survey areas

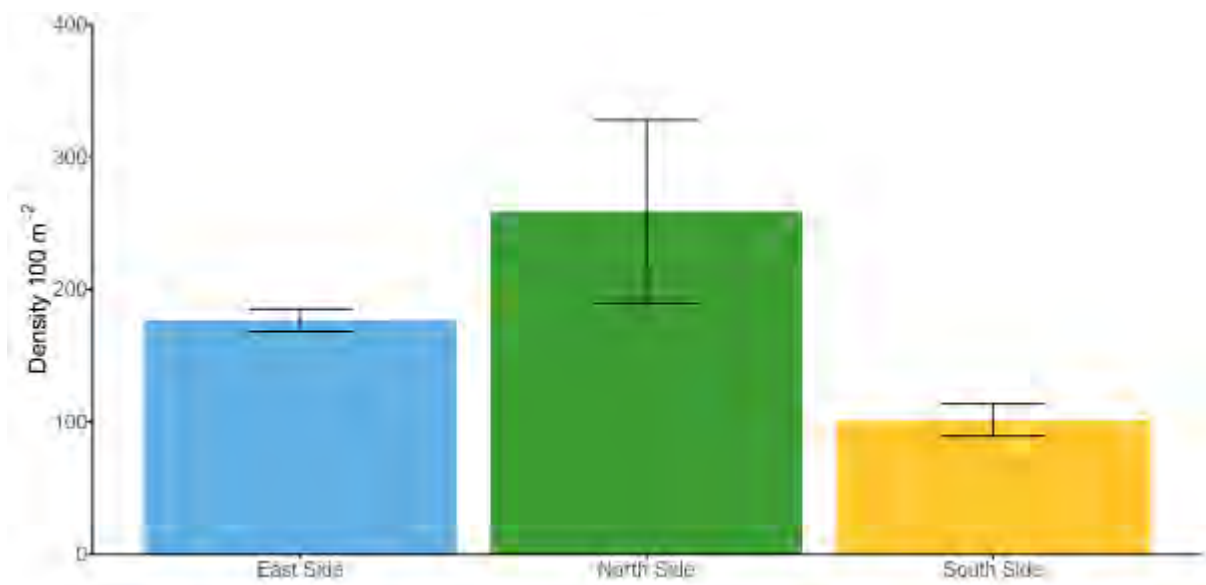


Figure 16. Average density of all fish per 100 m² recorded on transect surveys

Acanthuridae biomass was low across all three sites (Figure 17 A). Acanthurid biomass was marginally higher at the East Side site (1.9 kg/ 100m² ± 1.1) than the North Side (1.18 kg/ 100m² ± 0.52 S.E.) and South Side (1.09 kg/ 100m² ± 0.26 S.E.) sites, but high within site variability meant the sites did not differ from each other. The biomass of Acanthurids at each site was dominated by the planktivorous species *A. mata*, *A. thompsoni* and *N. hexacanthus* (Figure A2 1). At the East Side site *A. mata* biomass was 1.17 kg/ 100m² ± 0.89 S.E., which was 60 % of the total Acanthurid biomass at the site. The North Side *A. thompsoni* biomass was 0.65 kg/ 100m² ± 0.18 S.E. and *N. hexacanthus* biomass was 0.31 kg/ 100m² ± 0.31 S.E., making up 55 % and 26 % of Acanthurid biomass respectively. At the South Side *A. thompsoni* biomass was 0.67 kg/ 100m² ± 0.17 S.E. which was 61 % of the total Acanthurid biomass at the site.

Scaridae biomass was at the East Side site was extremely low (0.07 kg/ 100m² ± 0.05), and only slightly higher at the South Side site (0.15 kg/ 100m² ± 0.02). No Scarids were observed on any transects at the North Side site.

Chaetodontidae biomass was highest at the East Side site ($0.52 \text{ kg/ } 100\text{m}^2 \pm 0.37$), followed by the North Side site ($0.27 \text{ kg/ } 100\text{m}^2 \pm 0.10$), then the South Side site ($0.05 \text{ kg/ } 100\text{m}^2 \pm 0.05$). The high biomass of Chaetodontidae at the East Side Site was driven by a large school of *Hemitaurichthys zoster* on a single transect which had a biomass of $0.41 \text{ kg/ } 100\text{m}^2 \pm 0.41$ S.E. (Figure A2 2). This species is from the planktivorous bannerfish group of Chaetodontids.

The biomass of the carnivorous families Serranidae and Lutjanidae was low, with no site having greater than $0.8 \text{ kg/ } 100\text{m}^2$ (Figure 17 D & E). Serranid biomass at the North Side site and Lutjanid biomass at the East Side site did not differ significantly from zero. Biomass was generally variable within sites.

A total of six species of Acanthurids were recorded on transects (Table A2) (Figure 18). Acanthurid species richness was highest at the South Side site ($5.0 \text{ species} \pm 0.6$), followed by the East Side ($4.0 \text{ species} \pm 0.3$) then the North Side ($3.0 \text{ species} \pm 0.6$). Scaridae species richness was very low for the whole survey area, with only three species observed in total. Scarid species richness was highest at the South Side site ($1.6 \text{ species} \pm 0.3$), followed by the East Side ($1.0 \text{ species} \pm 0.0$) then the North Side ($0.0 \text{ species} \pm 0.0$). Chaetodontidae species richness was similar across all sites, with $5.3 \text{ species} \pm 1.2$ at the North Side, $5.0 \text{ species} \pm 0.6$ at the South Side and $3.7 \text{ species} \pm 0.8$ at the East Side site. Serranid species richness was similar at the East ($4.7 \text{ species} \pm 0.3$) and South Side (4.7 ± 0.9) sites but was marginally lower and highly variable between transects at the North Side ($3.7 \text{ species} \pm 1.9$). Lutjanid species richness was less than or equal to 1 for all sites and only two species of Lutjanid, *Lutjanus bohar* and *Macolor macularis*, were observed during surveys.

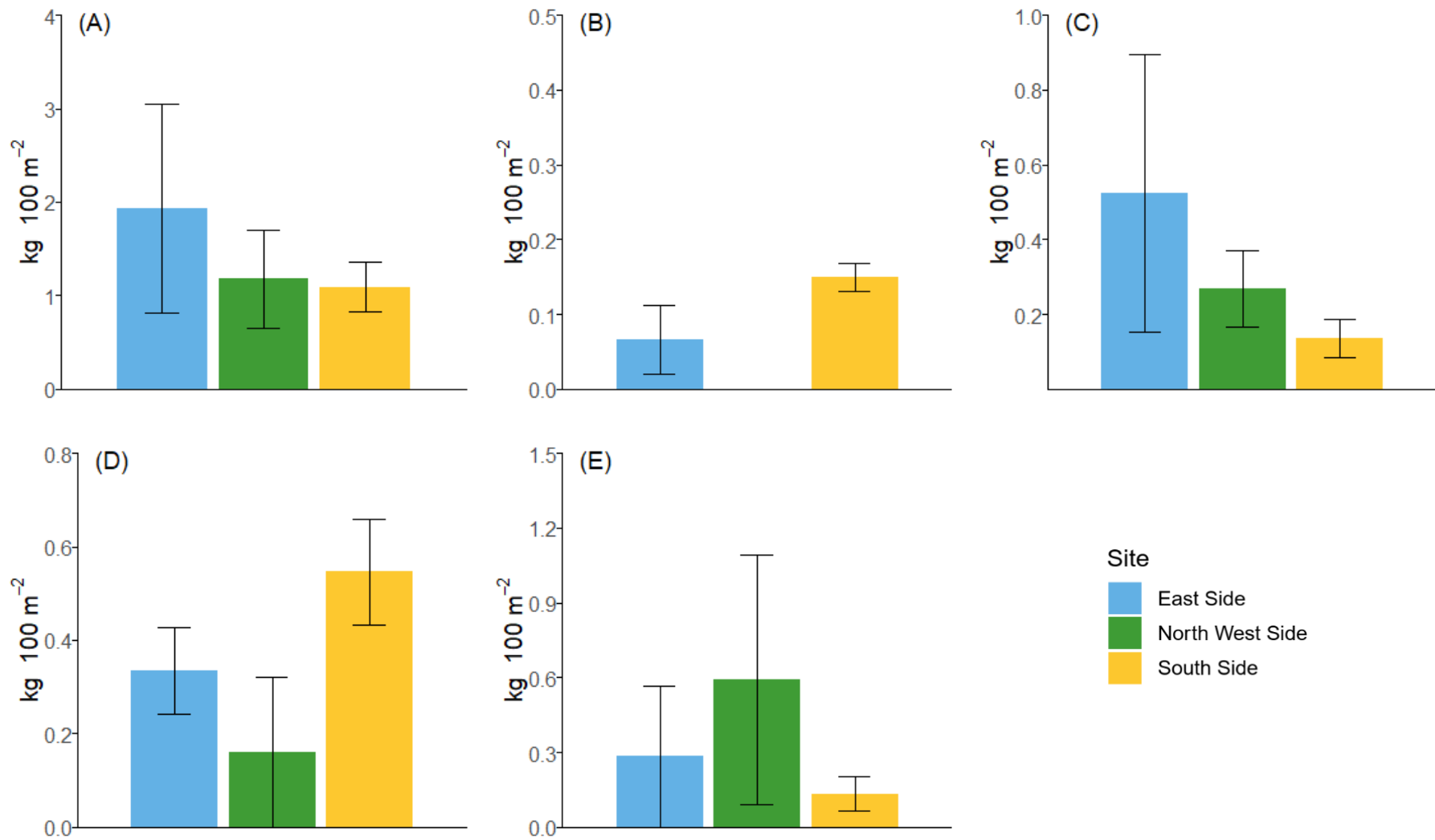


Figure 17. Biomass of the families (A) Acanthuridae, (B) Scaridae, (C) Chaetodontidae, (D) Serranidae (excluding Anthias) and (E) Lutjanidae recorded on transects

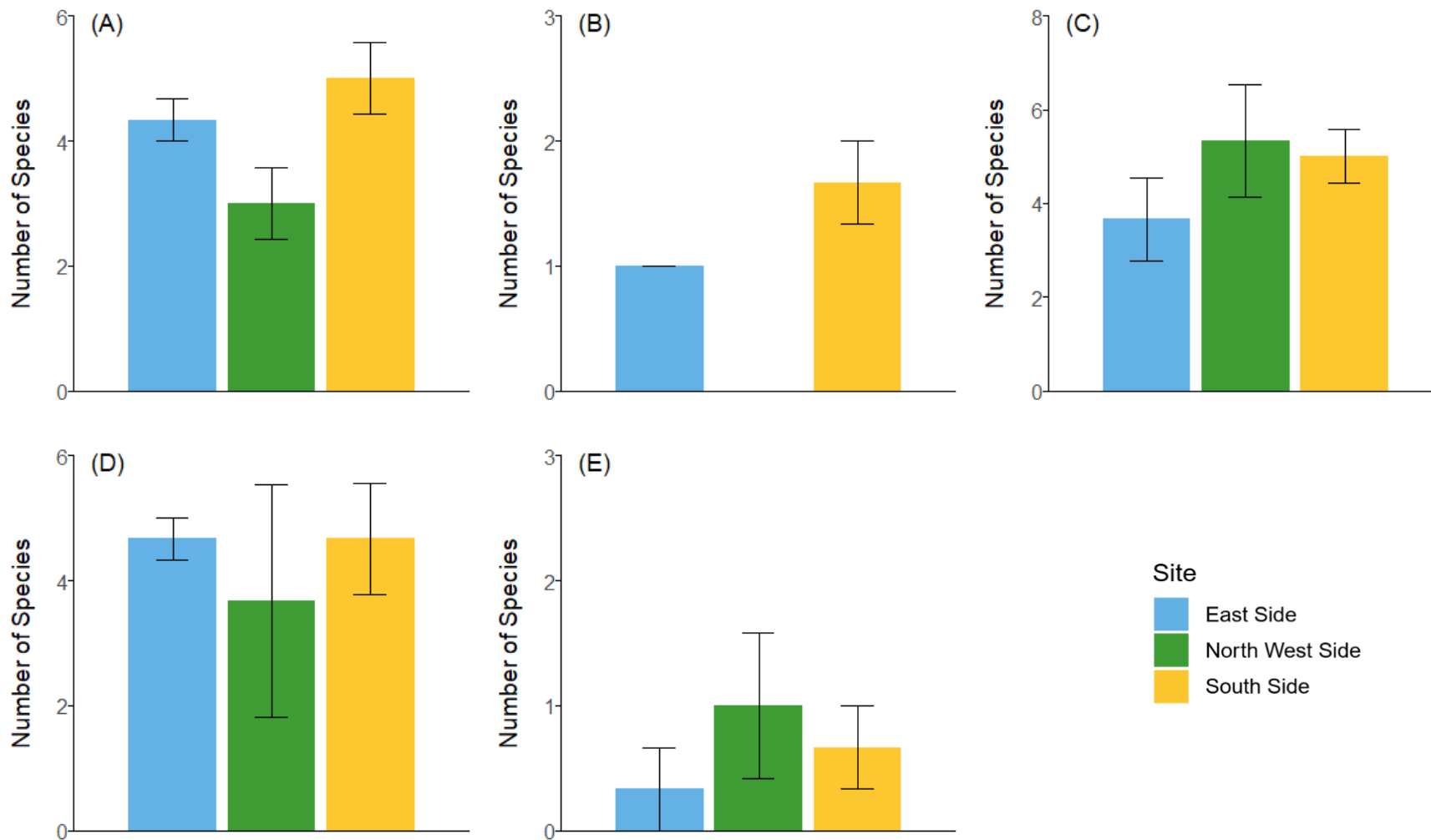


Figure 18. Number of species from the families (A) Acanthuridae, (B) Scaridae, (C) Chaetodontidae, (D) Serranidae (excluding Anthias) and (E) Lutjanidae recorded on transects

IUCN Red List species

IUCN Red List species were observed throughout the Dhiguvaru marine area. A total of 31 non-coral animals and 21 coral colonies were recorded (Table 3 & Table 4). The squaretail coral grouper (*Plectropomus areolatus*) was the most frequently observed species. Blacktip reef sharks and Whitetip reef sharks were the only species of sharks recorded. *Pachyseris rugosa* was the most commonly observed Red List coral species observed, *Pavona venosa* was the only pre-selected coral species not found on any surveys. Old turtle nests were observed on the sandy shore the around the Southern and Western sides of the island.

Table 3. Abundance of non-coral IUCN Red List marine species

Species	Common name	Abundance
<i>Carcharhinus melanopterus</i>	Blacktip reef shark	1
<i>Triaenodon obesus</i>	Whitetip reef shark	2
<i>Chaetodon trifascialis</i>	Chevron butterflyfish	6
<i>Cheilinus undulatus</i>	Napoleon wrasse	3
<i>Epinephelus fuscoguttatus</i>	Marble grouper	2
<i>Plectropomus areolatus</i>	Squaretail coral grouper	10
<i>Plectropomus laevis</i>	Black-saddle coral grouper	7

Table 4. Abundance of pre-selected IUCN Red List coral species

Species	Abundance
<i>Galaxea astreata</i>	4
<i>Pachyseris rugosa</i>	12
<i>Pavona venosa</i>	0
<i>Physogyra lichtensteini</i>	1
<i>Turbinaria mesenterina</i>	4

Discussion

Dhiguvaru island and the surrounding reef area represents a relatively common formation in the Maldives – a small island on an atoll edge ring reef. The island was dominated by a single species of vegetation in the coastal fringe and inner island areas. The mangrove basin was a small portion of the island at the Western side where *B. cylindrica* dominated. The rocky shoreline along the exposed Northern and Eastern created a habitat with rock pools coral rubble and rocks. This was particularly notable along the rocky platform that extended East towards the atoll edge. The sandy shoreline along the sheltered South and West had evidence of turtle nesting. The reef was dominated by hard rock substrate, however the corner areas of the North and South channels had high coral cover. The abundance of reef fish was generally low across all sites surveyed. There was a low biomass of key indicator families including Acanthuridae, Scaridae, Chaetodontidae, Serranidae and Lutjanidae. However, there was a notable number of IUCN Red List grouper species and of the chevron butterflyfish (*Chaetodon trifascialis*).

Terrestrial

The terrestrial realm contains four ecosystem functional groups (Toor and Murray *in progress*; appendix 3): rocky shoreline, sandy shoreline, coastal shrubland and grassland and intertidal forest and shrubland. The majority of the island consists of coastal shrubland. This habitat is a low productivity environment, with specialised plants, exposed to harsh conditions from the wind, sun and salt that grows on unstable sand and rubble substrate and a water deficit (Keith et al. 2020). *P. acidula* was the dominant vegetation across the whole island, with only three other species present in small numbers. The soil type likely makes this island uninhabitable for many plant species. The coarse nature of the sediment means the water drains rapidly through the ground, preventing any freshwater build-up. There was significant saltwater intrusion to the soil which alters the nutrients available in soils (Weissman and Tully 2020). There was no organic matter build-up on the ground and no humus accumulation. Therefore,



Figure 20. Image of the mangrove basin on Dhiguvaru. This image also shows the small area with muddy substrate and a shallow pool of water

the soil was likely to be very nutrient poor with a high pH due to the calcium carbonate sand. Erosion due to waves and blowouts by wind are key factors preventing humus accumulation and soil formation (McLachlan and Brown 2006).

Despite the island's small size, a small mangrove habitat is present (Figure 19). These habitats are structurally complex and productive ecosystems in the intertidal zone, composed of salt tolerant aquatic and terrestrial species (Bishop et al. 2020a). This area was a relatively well defined mangrove basin (Lugo and Snedaker 1974, Ewel et al. 1998) and was dominated by the mangrove *B. cylindrica*. The mangrove was separated from the sea by the rocky shoreline and coastal shrubland vegetation. Water moves between the sea and the wetland via groundwater seepage. The enclosed nature of the habitat means evaporation and precipitation cycles create a variable environment. The result is fluctuations in water and soil salinity, temperature and depth and areas will flood and dry based on tides and rainfall. Mangrove species are susceptible to changes in the surrounding environment and can be impacted by changing salinity, pH or the moisture content of muddy areas (Kathiresan and Bingham 2001). However, soil and water quality parameters were not measured during these surveys. Anchialine pools and mangrove basins elsewhere in the world are known to play important roles for birds, insects and invertebrates (Jarecki 1999, Gangemi 2003). Due to their

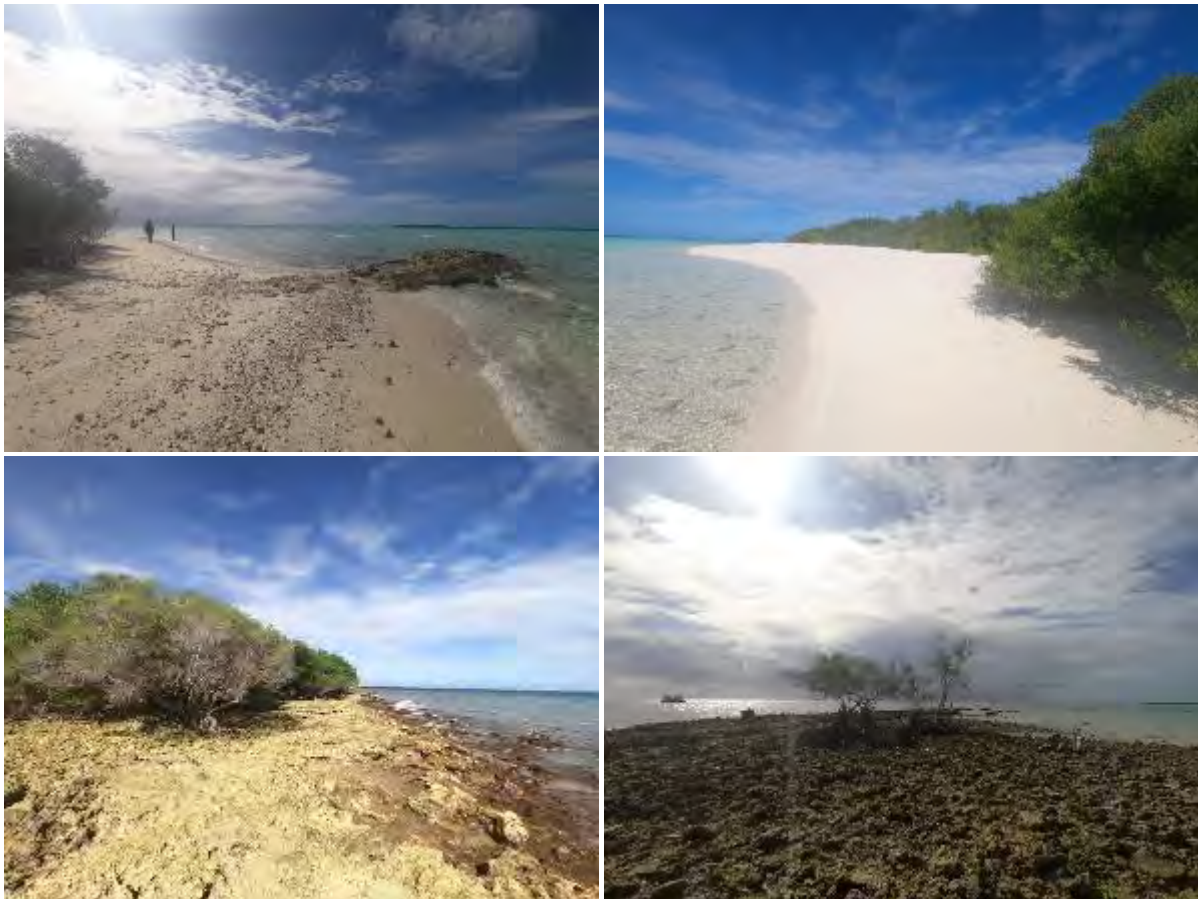


Figure 21. Images of sandy shoreline at West (top left) and South of the island (top right) and rocky shoreline at the North (bottom left) and East (bottom right).

low connectivity, mangrove basins are nutrient and carbon sinks (Ewel et al. 1998) and are therefore important for environmental balance. The shallow, possibly semi-permanent nature of the water meant there was no aquatic life in the area.

The shoreline around Dhiguvaru consisted of two ecosystem functional groups (Figure 20). The rocky shoreline habitat is a high energy intertidal benthic system regulated by waves, tides, and aerial exposure present on solid substrate (Bishop et al. 2020b). The shoreline along the north coastline consists of solid beach rock with *P. acidula* growth along the island fringe. On the East side of the island this habitat was present as a solid rocky platform with areas of loose rubble and small rocky outcrop with three *P. acidula* trees growing. The sandy shoreline is moderate to high-energy intertidal coastlines composed of unstable and shifting sediments with shoreline morphology determined by exposure to waves and tides (Bishop et



Figure 22. Deposits of rubbish found throughout the survey area

al. 2020c). Along the South this was a wide band of fine sediment that transitioned to sand and rubble at the Western side. Turtle nests were observed in this area.

Large patches of rubbish were found washed ashore by the waves and tides along the coastal fringe (Figure 21). The rubbish was almost entirely plastic water bottles. These items are buoyant and easily carried by the sea. Plastic debris can cause harm to the marine and coastal environment through a number of pathways including ingestion by seabirds, fish, turtles and marine mammals (Schuyler et al. 2014, Wilcox et al. 2015, 2016, Roman et al. 2021), increasing the temperature of beach sediments (Lavers et al. 2021) and entrapping marine invertebrates (Lavers et al. 2020). Waste management is a significant issue for the country, and it has been identified by the Maldivian government as a key issue for biodiversity management in their report to the UN on biological diversity (Ministry of Environment and Energy 2015). Regional waste strategy and action plans are being developed to identify and develop practical approaches for waste management (Ministry of Environment 2019). The recommendations in such plans should be incorporated in future management plans. As of 01/06/2021 a number of single use plastic items have been banned from imports. These include single use plastic drinking straws, plates, cutlery and cups less than 250 ml, plastic water bottles less than 500 ml and small single use plastic bags. This is an important step towards phasing out single use plastic in the Maldives by 2023 as stated in the Maldives Parliamentary Resolution of 2019 (1-ޖ /2019/EC).

Marine

The marine habitat surveyed was the photic coral reef ecosystem functional group (Polidoro et al. 2020a). Though they were not surveyed sub-tidal sand beds were present inside the shallow lagoon and epipelagic waters offshore from the coral reef edge. The reef crest and slope areas were dominated by hard rock substrate. Hard coral cover ranged from around 10 % on the South channel reef slope to around 35 % at the South channel corner (Figure 22). The North Side and East Side (outer atoll reef) were similar habitats with approximately 50 % rock and 15 % coral cover. The South Side reef slope was the least healthy reef area. Coral cover was around 5 % and there was a high cover of unconsolidated substrates. Unconsolidated substrate is making up a greater proportion of the reef substrate at other reefs in the country (Dryden et al. 2020) and may constitute a worrying sign for the Maldives as it suggests a decline in suitable settlement area for corals, which may hinder reef recovery following disturbances.



Figure 23. Images of the coral reef. The upper images show the North and South Channel corners with high coral cover. The lower images show the North and South Channel reef slopes with lower coral cover and more mixed substrate types

The channel corner habitats where the North and South channel reefs meet the outer reef were of particular interest at Dhiguvaru. The substrate was rich in complex branching and table coral growth colonies. Schools of snappers were also observed here. Channels exist between the contiguous coral reef structure around Maldivian atolls and are often popular dives sites due the high coral cover, abundance of fish and the potential for shark aggregations. Constant water movement through the area, flushing with oceanic water and depths usually > 20 m may also make these areas resistant to coral bleaching events. Some channels serve as grouper spawning sites and efforts have been made to survey channels as part of the grouper management plan (MMRI 2020). These surveys aside, channel corner habitats have received little survey attention and the factors influencing channel corner habitat condition are poorly understood.

Coral recruitment was particularly high along the Eastern outer reef survey site. This may indicate recovery following a disturbance, such as a bleaching event. The majority of recruits at all sites were *Pavona sp.* corals from the family Agariciidae. Pocilloporid coral recruits had a marginally greater density at the East Side site, though the density of all other families was similar across sites. The high variability in recruit numbers at the South Side site may be due to the high cover of unconsolidated substrate. Coverage of the substrate by sand and other particulate matter such as silt and sediment reduces the amount of substrate suitable for the recruitment of corals and other benthic organisms (Birrell et al. 2005, Arnold et al. 2010, Cameron et al. 2016, Speare et al. 2019).

Relatively few fish were observed on the reefs around Dhiguvaru. Particularly concerning was the low numbers of herbivores which were present in far lower numbers than elsewhere in the country (Dryden et al. 2019, 2020). Scarids, one the most important herbivore families were absent from the South Side reef. Herbivorous fish, play a key role in preventing coral reefs from becoming overgrown by algae following disturbances, providing a level of resilience to the reef habitat (Hughes et al. 2007, Mumby et al. 2007). Though algae cover appeared to be low across the survey area, without herbivores there is a greater risk of algae proliferation in

the future. There is no fishery targeting these species, however there is evidence that localised parrotfish fishing is occurring in some areas. It is therefore key management efforts include education on their importance to reef health.

At the East Side site where fish were more abundant, the community was dominated by planktivores. Across reefs at Dhiguvuru the biomass of the mostly herbivorous Acanthuridae family was dominated by planktivorous species. Planktivores are small to medium bodied fish that feed on plankton and detritus in the water column. Though they play an important role in the function of a healthy reef ecosystem they contribute little to reef resilience.

The reef around Dhiguvuru is unlikely to be an important local fishing area as higher trophic level fish families including groupers and snappers were rare, though some larger grouper species were observed during the channel surveys. Low numbers of these species is another indicator of unhealthy reefs (Graham et al. 2013). Additionally, few baitfish e.g. Apogonids or Anthias were observed around the reef.

The island and the reefs provide valuable habitat for a number of IUCN Red List species. Turtles use the beach for nesting, and there was evidence of turtle egg poaching, which has also been recorded on previous surveys (Dryden et al. 2019). This practice could threaten turtle populations around the country. Large IUCN Red List grouper species were observed during the roaming channel surveys. Many channels throughout the country are known to be areas where groupers aggregate for spawning. However, despite recent survey and management efforts many aggregation spots remain unidentified and unprotected (MMRI 2020).

Human activities over the past 150 years have caused approximately 1.09°C of climate warming and it is likely that it will continue to warm by at least 1.5°C between 2021 and 2040 (IPCC 2021). The impacts of climate change will pose a significant threat to both the people and the natural environment of the Maldives. Global mean sea level rise is predicted to be between 0.38 – 0.77 m by 2100 (IPCC 2021). This increases the risk of storm damage to

wetlands and ponds, as well human settlements and may result in eventual inundation of them by sea water. Healthy coastal vegetation, mangrove, seagrass and coral reef systems are predicted to act as a buffer against the impacts of sea level rise. They act as protection against storm damage and help fix and consolidate island sediments which may limit island erosion and may enable island growth to keep pace with any sea level change.

The warming climate will also lead to more frequent and severe coral bleaching events (Hoegh-Guldberg 2011). The Maldives archipelago is built up by millions of years of coral growth (Perry et al. 2013) and healthy coral reefs are essential to the survival of these small islands (Kench et al. 2005). Local factors can significantly affect the resilience of corals. Competition between algae and coral is often finely balanced and reefs and both are important for a healthy reef habitat, however, increases in nutrients from pollution or declines in certain herbivorous fish species can enable algae to proliferate and outcompete corals, especially following coral die-offs (Bellwood et al. 2004).

Management

Despite limited direct human interaction with the island, the impacts of human activities are apparent. There were deposits of rubbish across the island and evidence of poaching of turtle nests. The ecological management goal for Dhiguvuru is to provide a means to promote and ensure the long-term conservation and protection of the ecosystem. Management efforts must combine local and nationwide efforts to promote and ensure the long-term conservation and protection of the country's natural ecosystems. Local management efforts can be developed with this goal in mind. The aim should also be to utilise strategies and action plans local and national governments have developed such as the Regional Waste Management Strategy and Action Plan for Zone 6, Republic of Maldives (Ministry of Environment, 2019), the reports on biodiversity, Fifth national report to the United Nations convention on Biological Diversity (Ministry of Environment and Energy, 2015) and National Biodiversity Strategy and Action Plan 2016-2025 (Ministry of Environment and Energy 2015), Maldives Clean Environment Project Environmental and Social Assessment and Management Framework (ESAMF) &

Resettlement Policy Framework (RPF) (Ministry of Environment, 2016), and Current status of the reef fisheries of Maldives and recommendations for management (Sattar et al., 2014). and Maldives Grouper Fishery Management Plan (MMRI 2020).

The findings of this report and the data collected can be used as a baseline against which to measure the aim of conservation and protection. This aim can be broken down into two sub-goals:

- 1) to maintain the resilience of biological communities to stressors associated with anthropological change; and
- 2) to maintain populations of natural communities for social development, fishery enhancement and island health.

Future efforts should aim to monitor and manage the habitat to maintain overall system health and function (Flower et al. 2017, Lam et al. 2017).

In order to preserve the ecological resilience of the island and to protect its biodiversity for future generations, it is recommended that a management plan is developed.

Key findings from this report that should be addressed by management:

1. The identification of a small but healthy mangrove basin on the island.
2. High volume of plastic waste on the island.
3. Low coral cover around the reef slope.
4. Low numbers of herbivorous fish species.
5. Healthy reef corner habitats at the North and South channel mouths.

The management plan could consider the following elements:

- The development of a long-term monitoring programme for mangrove, and coral reef habitats in order to track ecological changes over time.
- The development of survey programme specifically for channel habitats.

- Island geographical and topographical monitoring programme to monitor and map the structural development of the island.
- Establish measures to stop local stresses to coral reefs (e.g. sedimentation from dredging, pollution, waste disposal, nutrient inputs to the marine environment).
- Protect herbivorous reef fish. This will strengthen natural controls by reef communities on the development of turf algae and macroalgae on reefs.
- Limit activities that cause or accelerate reef erosion, or that increase the presence of sand and particulate matter on reefs. Activities to consider include:
 - o Sand pumping for beach replenishment.
 - o Dredging of sand within atolls.
 - o Land reclamation and island building projects that require depositing sediment near reef areas.
- A plan for development and enforcement of regulations in the area.

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Appendix 1: Tables

Table A 1. All coral genera observed on transect surveys in Dhiguvaru

Family	Genus
Acroporiidae	<i>Acropora</i>
Acroporiidae	<i>Astreopora</i>
Acroporiidae	<i>Montipora</i>
Agariciidae	<i>Leptoseris</i>
Agariciidae	<i>Pachyseris</i>
Agariciidae	<i>Pavona</i>
Dendrophylliidae	<i>Tubastrea</i>
Dendrophylliidae	<i>Turbinaria</i>
Diploastreidae	<i>Diploastrea</i>
Euphylliidae	<i>Galaxea</i>
Fungiidae	<i>Fungia</i>
Lobophylliidae	<i>Echinophyllia</i>
Lobophylliidae	<i>Lobophyllia</i>
Lobophylliidae	<i>Symphyllia</i>
Merulinidae	<i>Cyphastrea</i>
Merulinidae	<i>Echinopora</i>
Merulinidae	<i>Favites</i>
Merulinidae	<i>Goniastrea</i>
Merulinidae	<i>Leptoria</i>
Merulinidae	<i>Merulina</i>
Merulinidae	<i>Platygyra</i>
Mussidae	<i>Favia</i>
Paramontastraea	<i>Montastraea</i>
Pocilloporidae	<i>Pocillopora</i>
Poritidae	<i>Porites</i>
Psammocoridae	<i>Psammocora</i>

Table A2. All fish species observed on surveys in Dhiguvaru

Family	Species	Common name
Acanthuridae	<i>Acanthurus mata</i>	Pale surgeonfish
Acanthuridae	<i>Acanthurus thompsoni</i>	Night surgeonfish
Acanthuridae	<i>Ctenochaetus striatus</i>	Fine-lined bristletooth
Acanthuridae	<i>Ctenochaetus truncatus</i>	Gold-ring bristletooth
Acanthuridae	<i>Naso hexacanthus</i>	Sleek unicornfish
Acanthuridae	<i>Zebrasoma scopas</i>	Brown Tang
Balistidae	<i>Balistapus undulatus</i>	Striped triggerfish
Balistidae	<i>Balistoides conspicillum</i>	Clow triggerfish
Balistidae	<i>Balistoides viridescens</i>	Titan triggerfish
Balistidae	<i>Melichthys indicus</i>	Indian triggerfish
Balistidae	<i>Odonus niger</i>	Blue triggerfish
Balistidae	<i>Sufflamen bursa</i>	Bommerang triggerfish
Blenniidae	<i>Meiacanthus smithi</i>	Disco blenny

Family	Species	Common name
Blenniidae	<i>Plagiotremus tapeinosoma</i>	Piano fangblenny
Caesionidae	<i>Pterocaesio tile</i>	Blue dash fusilier
Caesionidae	<i>Pterocaesio trilineata</i>	Striped fusilier
Carangidae	<i>Caranx melampygus</i>	Blue-fin jack
Carangidae	<i>Elegatis bipinnulata</i>	Rainbow runner
Carcharhinidae	<i>Carcharhinus melanopterus</i>	Blacktip reef shark
Chaetodontidae	<i>Chaetodon guttatissimus</i>	Spotted butterflyfish
Chaetodontidae	<i>Chaetodon kleinii</i>	Brown butterflyfish
Chaetodontidae	<i>Chaetodon madagaskariensis</i>	Madagascar butterflyfish
Chaetodontidae	<i>Chaetodon triangulum</i>	Triangular butterflyfish
Chaetodontidae	<i>Chaetodon trifasciatus</i>	Pinstriped butterflyfish
Chaetodontidae	<i>Chaetodon xanthocephalus</i>	Yellow-head butterflyfish
Chaetodontidae	<i>Forcipiger flavissimus</i>	Long-nose butterflyfish
Chaetodontidae	<i>Forcipiger longirostris</i>	Very long-nose butterflyfish
Chaetodontidae	<i>Hemitaurichthys zoster</i>	Black pyramid butterflyfish
Chaetodontidae	<i>Heniochus pleurotaenia</i>	Phantom bannerfish
Cirrhitidae	<i>Paracirrhites arcatus</i>	Ring eye hawkfish
Cirrhitidae	<i>Paracirrhites forsteri</i>	Forster's hawkfish
Gobiidae	<i>Eviota sp.</i>	Eviota species unknown
Holocentridae	<i>Myripristis murdjan</i>	Crimson soldierfish
Holocentridae	<i>Sargocentron caudimaculatum</i>	White-tail squirrelfish
Holocentridae	<i>Sargocentron spiniferum</i>	Sabre squirrelfish
Labridae	<i>Biochoeres cosmetus</i>	Adorned wrasse
Labridae	<i>Bodianus axillaris</i>	Coral hogfish
Labridae	<i>Bodianus diana</i>	Diana hogfish
Labridae	<i>Cheilinus fasciatus</i>	Banded Maori wrasse
Labridae	<i>Cheilinus oxycephalus</i>	Snooty wrasse
Labridae	<i>Cheilinus undulatus</i>	Napoleon wrasse
Labridae	<i>Cirrhilabrus exquisitus</i>	Exquisite wrasse
Labridae	<i>Epibulus insidiator</i>	Sling-jaw wrasse
Labridae	<i>Gomphosus caeruleus</i>	Bird wrasse
Labridae	<i>Halichoeres chrysoaenia</i>	Vrolik's wrasse
Labridae	<i>Halichoeres hortulanus</i>	Checkerboard wrasse
Labridae	<i>Labroides dimidiatus</i>	Blue-streak cleaner wrasse
Labridae	<i>Labropsis xanthonota</i>	V-tail tubelip wrasse
Labridae	<i>Oxycheilinus digramma</i>	Cheek-line Maori wrasse
Labridae	<i>Pseudocheilinus hexataenia</i>	Six-line wrasse
Labridae	<i>Stethojulis albovittata</i>	Blue-lined wrasse
Labridae	<i>Thalassoma amblycephalum</i>	Two-tone wrasse
Labridae	<i>Thalassoma lunare</i>	Moon wrasse
Lethrinidae	<i>Gnathodentex aureolineatus</i>	Gold-spot emperor
Lethrinidae	<i>Monotaxis grandoculis</i>	Large-eye bream
Lutjanidae	<i>Lutjanus bohar</i>	Red bass
Lutjanidae	<i>Macolor macularis</i>	Midnight snapper
Monacanthidae	<i>Oxymonacanthus longirostris</i>	Long-nose filefish
Mullidae	<i>Parupeneus macronema</i>	Long-barbel goatfish
Muraenidae	<i>Gymnothorax javanicus</i>	Giant moray
Nemipteridae	<i>Scolopsis bilineata</i>	Monocle bream
Ostraciidae	<i>Ostracion cubicus</i>	Yellow boxfish
Pomacanthidae	<i>Centropyge multispinis</i>	Many-spined angelfish
Pomacanthidae	<i>Pomacanthus imperator</i>	Emperor angelfish

Family	Species	Common name
Pomacanthidae	<i>Pygoplites diacanthus</i>	Regal angelfish
Pomacentridae	<i>Amblyglyphidodon batunai</i>	Green sergeant
Pomacentridae	<i>Chromis dimidiata</i>	Two-tone puller
Pomacentridae	<i>Chromis flavipectoralis</i>	White-finned puller
Pomacentridae	<i>Chromis lepidolepis</i>	Scaly chromis
Pomacentridae	<i>Chromis ternatensis</i>	Swallow-tail puller
Pomacentridae	<i>Chromis viridis</i>	Green puller
Pomacentridae	<i>Chromis weberi</i>	Weber's puller
Pomacentridae	<i>Chromis xutha</i>	Buff puller
Pomacentridae	<i>Dascyllus aruanus</i>	Humbug damsel
Pomacentridae	<i>Dascyllus carneus</i>	Indian humbug
Pomacentridae	<i>Dascyllus trimaculatus</i>	Three-spot Humbug
Pomacentridae	<i>Plectroglyphidodon dickii</i>	Narrowbar damsel
Pomacentridae	<i>Plectroglyphidodon lacrymatus</i>	Jewel damsel
Pomacentridae	<i>Pomacentrus indicus</i>	Indian damsel
Pomacentridae	<i>Pomacentrus philippinus</i>	Philippine damsel
Scaridae	<i>Chlorurus sordidus</i>	Shabby parrotfish
Scaridae	<i>Scarus frenatus</i>	Bridled parrotfish
Scaridae	<i>Scarus niger</i>	Dusky parrotfish
Scombridae	<i>Gymnosarda unicolor</i>	Dogtooth tuna
Scorpaenidae	<i>Pterois radiata</i>	White-lined lionfish
Serranidae	<i>Aethaloperca rogaa</i>	Red-flushed grouper
Serranidae	<i>Cephalopholis argus</i>	Peacock rock cod
Serranidae	<i>Cephalopholis leopardus</i>	Leopard rock cod
Serranidae	<i>Cephalopholis miniata</i>	Vermilion rock cod
Serranidae	<i>Cephalopholis nigripinnis</i>	Blackfin rock cod
Serranidae	<i>Diploprion bifasciatum</i>	Yellow soapfish
Serranidae	<i>Pseudanthias evansi</i>	Yellow-tail basslet
Serranidae	<i>Pseudanthias squamipinnis</i>	Orange basslet
Serranidae	<i>Variola louti</i>	Lunar-tailed grouper
Siganidae	<i>Siganus corallinus</i>	Coral rabbitfish
Siganidae	<i>Siganus laques</i>	Starry rabbitfish
Tetraodontidae	<i>Arothron meleagris</i>	Guineafowl pufferfish
Tetraodontidae	<i>Arothron nigropunctatus</i>	Black-spotted pufferfish
Tetraodontidae	<i>Canthigaster valentini</i>	Saddled pufferfish
Zanclidae	<i>Zanclus cornutus</i>	Moorish idol

Table A 3. GPS coordinates for the terrestrial survey points

Zone	Latitude	Longitude
Coastal Fringe	3.246826	73.025836
Coastal Fringe	3.246661	73.025815
Coastal Fringe	3.246674	73.025611
Coastal Fringe	3.246635	73.025396
Coastal Fringe	3.246551	73.025209
Coastal Fringe	3.246452	73.025002
Coastal Fringe	3.246405	73.024761
Coastal Fringe	3.246551	73.024594
Coastal Fringe	3.246776	73.024705
Coastal Fringe	3.246859	73.024916
Coastal Fringe	3.246926	73.025180
Coastal Fringe	3.246950	73.025449
Coastal Fringe	3.246910	73.025680
Inner Island	3.246796	73.025644
Inner Island	3.246733	73.025193
Inner Island	3.246704	73.025071
Inner Island	3.246526	73.024798
Mangrove	3.246676	73.024919

Table A 4. GPS coordinates for the transect surveys

Site	Latitude	Longitude
East Side	3.24475	73.02848
North Side	3.24260	73.01610
South Side	3.23234	73.02339

Table A 5. GPS coordinates for the channel roaming surveys

Site	Latitude Start	Longitude Start	Latitude End	Longitude End
North Channel	3.24677	73.02738	3.24745	73.02402
South Channel	3.23716	73.03206	3.23452	73.03036

Appendix 2: Figures

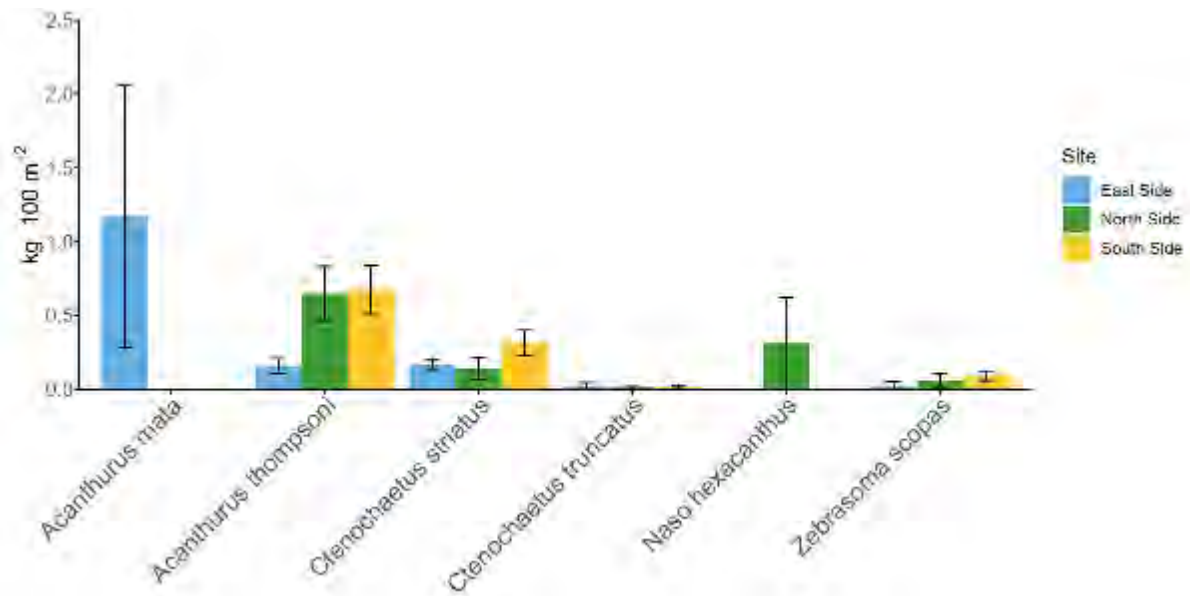


Figure A2 1. Biomass of individual Acanthurid species on transects at the three survey sites

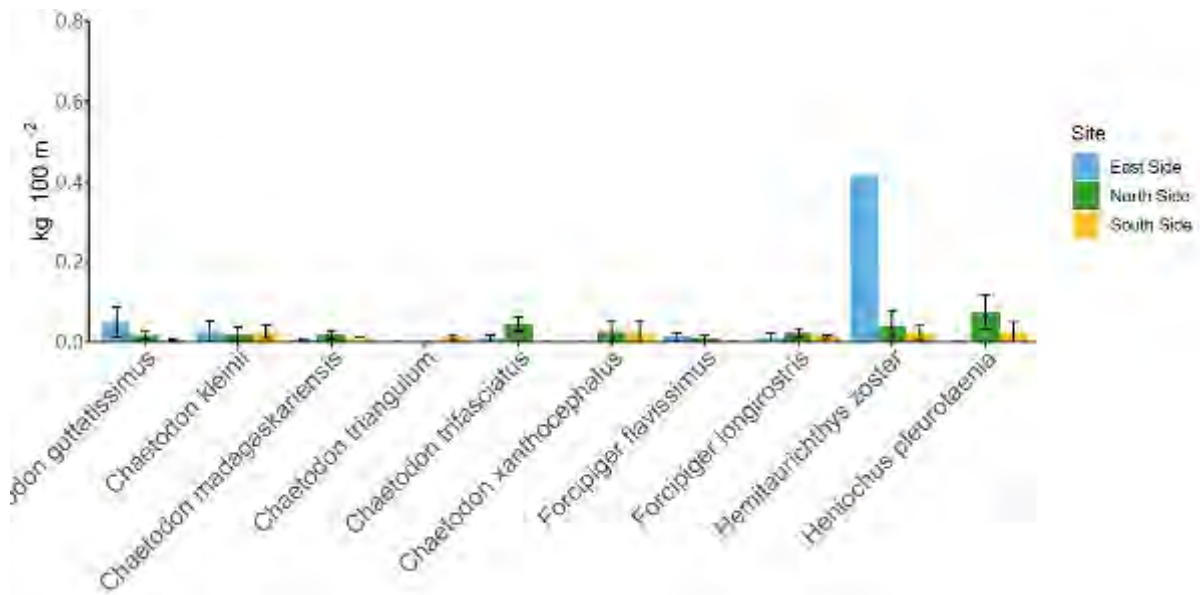


Figure A2 2. Biomass of individual Chaetodon species on transects at the three survey sites