Vaavu Ruh Hurihuraa

An Ecological Assessment on Biodiversity and Management

2021

Enhancing Resilience of social-ecological coral reef systems in the Maldives

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Introduction

In light of the extent and scale of natural and anthropogenic impacts threatening marine and terrestrial 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 environment'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 Vaavu Ruh Hurihuraa 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 21,372km^2 (Naseer and 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 5km^2 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 (Saleem and Nileysha 2003, Dryden et al. 2020b). Fifteen species of mangroves are found across approximately 150 islands (Ministry of Environment and Energy 2015, Dryden et al. 2020a). Over 200 species of birds have been recorded in the Maldives consisting of seasonal migrants, breeding residents, and introduced birds (Ministry of Environment and Energy 2015, Anderson and Shimal 2020).

Coral reefs of the Maldives are the seventh largest reef system in the world, representing as much as 3.14% of the worlds' reef area. There are 2,041 individual reefs covering an area of 4,493.85km^2 (Naseer and 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 and 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 (Dryden et al. 2020b). 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 provide essential socio-economic services 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. The social and economic reliance on the environment, as well as the need to protect and conserve valuable and threatened habitats across the country means there is an immediate need for biodiversity assessments and management plans to ensure the sustainable use and effective management of these natural resources. Such approaches will play a key role in efforts to manage and monitor the resources in a co-managed concept.

Study Site

Ruh Hurihuraa is an uninhabited island in the Vaavu atoll lagoon, approximately 3.5 km from the southern edge of the atoll. The nearest inhabited island is Rakeedhoo, approximately 6 km to the south east. The island is about 200 m long with an area of 0.5 ha and a small extension of beach rock that stretches 80 m from the South of the island (Figure 1). There is low but dense vegetation growth throughout the island with some mangrove trees in the centre of the island. Sandy shoreline habitat is virtually absent, instead the island is surrounded by beach rock with vegetation growing right up to the water-line. The island can get inundated during high tides.

Ruh Hurihuraa island sits at the North East corner of a faro reef structure i.e. a ring shaped reef with reef flats near the surface and a central lagoon (Perry et al. 2013). The circumference of the outer reef and inner lagoon are approximately 3 km and 1.8 km respectively. The reef flat ranges from 280 m at its widest to 50 m at its narrowest. The lagoon is around 20 m at its deepest point. Isolated patches of coral, “coral bombies” are located throughout the lagoon area.

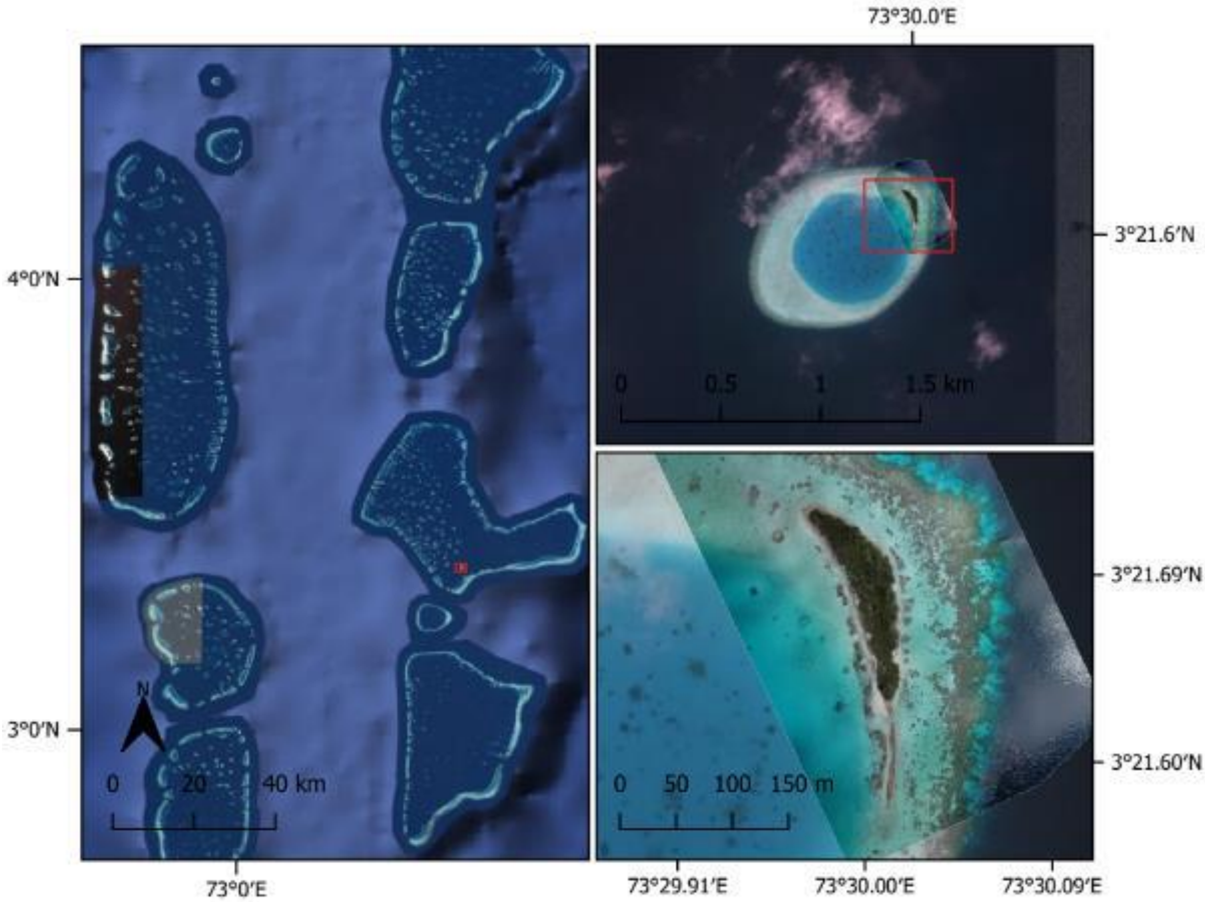

Figure 1. Vaavu Ruh Hurihuraa island and reef area

Methods

Terrestrial survey

The terrestrial survey area was divided into three zones: the coastal fringe, mangrove and inner island. Twenty-one 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 to navigate to the point. Vegetation was surveyed using a point survey approach (Dryden and Basheer 2020).Due to the small size of the island, it was not always possible to identify which habitat birds were observed in, therefore counts were made for the whole island.

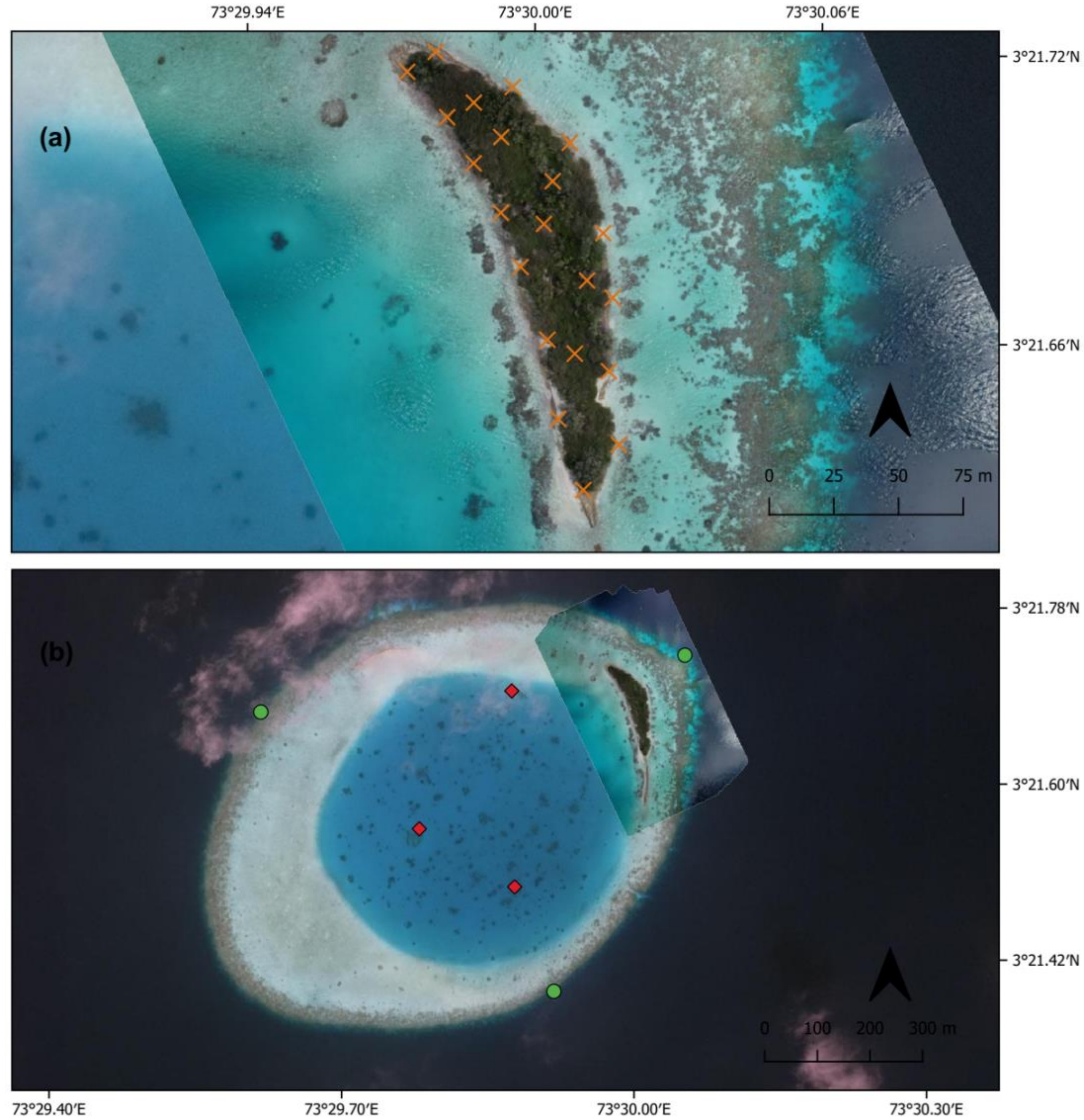

Figure 2. Location of (a) terrestrial and (b) marine survey sites. In (b) red diamonds indicate roaming surveys and green circles indicate transect survey sites

Aerial survey

Aerial surveys were conducted to create an accurate, high resolution map of Ruh Hurihuraa. 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 were 75% on front-lap and 75% on side-lap. Ground control points (GCPs) were used to ensure the map was as accurate as possible. To increase geo-location accuracy during post-processing, five GCPs were randomly distributed across the island and marked in open areas using natural markers painted red. Horizontal GPS locations of these markers were taken with Topcon GR-5 GPS and Base Station at a ± 10.0 mm or ± 1 cm accuracy using the RTK mode. The GCPs were taken before the mapping of the island. A total of 121 geo-referenced images were processed using the Agisoft Metashape Software© which generated a high-resolution geo-referenced Orthomosaic and detailed digital elevation models.

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

Marine survey

Marine surveys were performed using three methods. A manta tow was used to perform coarse-scale assessments of the Ruh Hurihuraa reef flat. SCUBA roaming surveys lasting 15 minutes were used assess fish and benthic communities on the reef slope were conducted at three large coral bombies within the lagoon. Transect surveys were conducted at three reef slope locations around the outer reef (Figure 2). 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 (Dryden and 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.

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

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

Results

Terrestrial

Two species of flora were identified during the terrestrial surveys, *Pemphis acidula* (Dhivehi name: Kuredhi) and the mangrove *Bruguiera cylindrica* (Dhivehi name: Kandoo) (Figure 4). Over 95 % of the total island vegetation was *P. acidula*. The *P. acidula* grew to the waterline along the shore, meaning there was no change in vegetation habitat between the coastal fringe and the inner island. The height of the tallest trees averaged 3.5 m (± 0.4 S.E.) in the coastal fringe, 4.6 (± 0.8 S.E.) in the inner island and 5 m (± 0.0 S.E.) in the mangrove. The tallest trees were *P. acidula* in the inner island that reached around 8 m in height (Figure 6). The soil type found throughout the inner island was a mixture of coarse sand and rubble and at the coastal fringe it was a mixture of larger rocks and rubble.

The mangrove area was the only part of the island where vegetation other than *P. acidula* was recorded. The only species found here was *B. cylindrica*. The trees were a mix of mature trees (> 2 m tall) and saplings (0.5 – 2 m tall). No seedlings were found at the site. The basin was approximately 136 m^2, 2.7 % of the total island area. The basin was submerged during high tide as water flowed through the porous rock. During low tide the water completely receded leaving a coarse sand and rubble bottom.

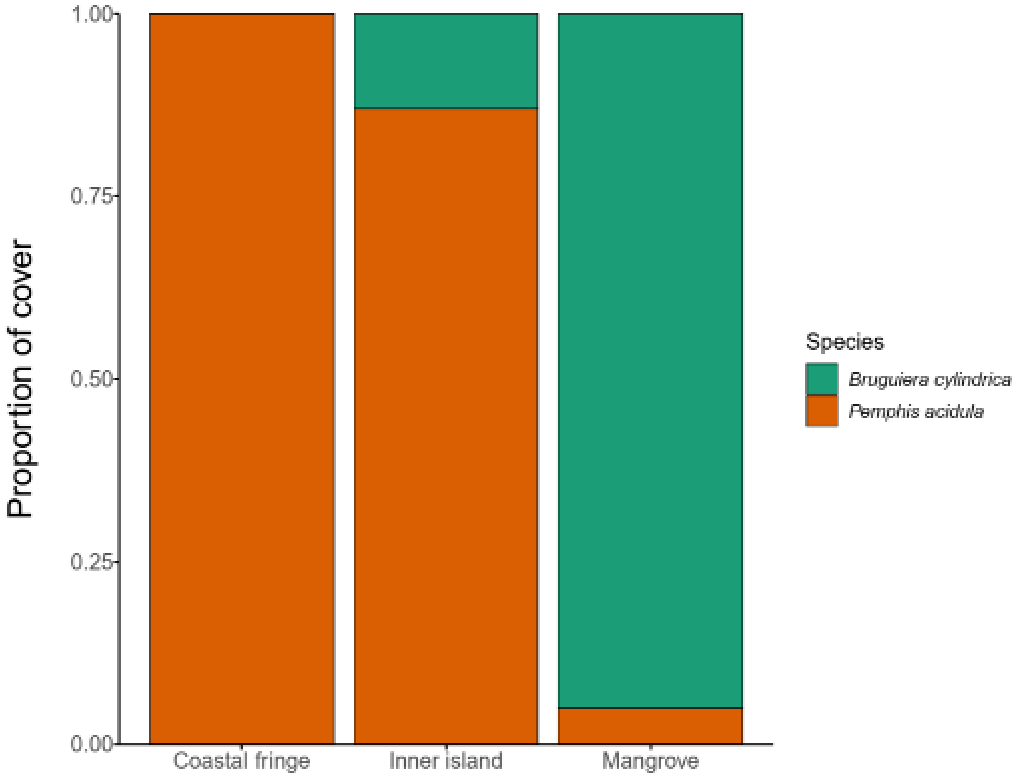

Figure 4. Percent cover of tree species in the three areas of vegetation

There were no man-made structures on the island and there was no evidence of pathways or picnic areas. There was a significant amount of rubbish across the inner island and mangrove areas (Figure 7). This was predominantly plastic water bottles, small broken bits of plastic and pieces of Styrofoam. The shoreline around the entire island was rocky shore habitat with no areas of sandy shoreline present. The beach rock extends in a line about 80 m from the southern tip of the island, providing additional rocky shore habitat. The shallow areas surrounding the island had high numbers of sea cucumbers (Holothuroidea) and small coral covered rocks.

Figure 5. Mangrove basin at the centre of Ruh Hurihuraa

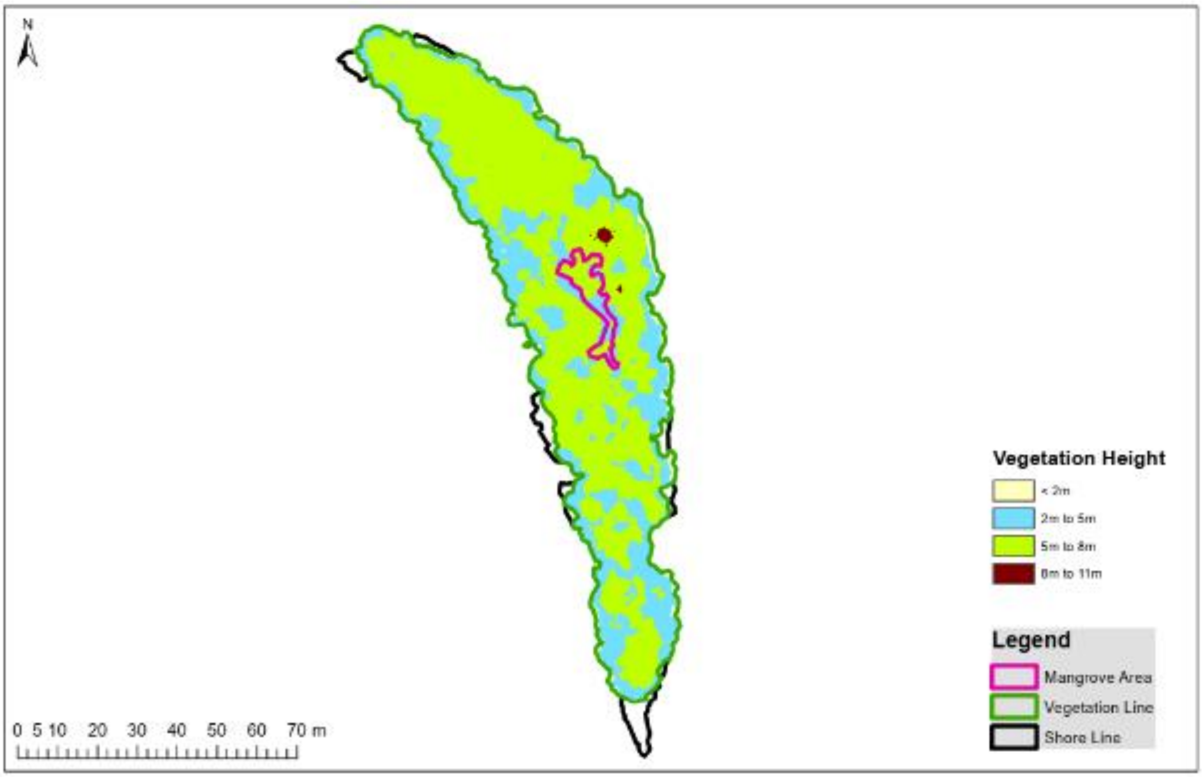

Figure 6. Digital elevation map of the vegetation height

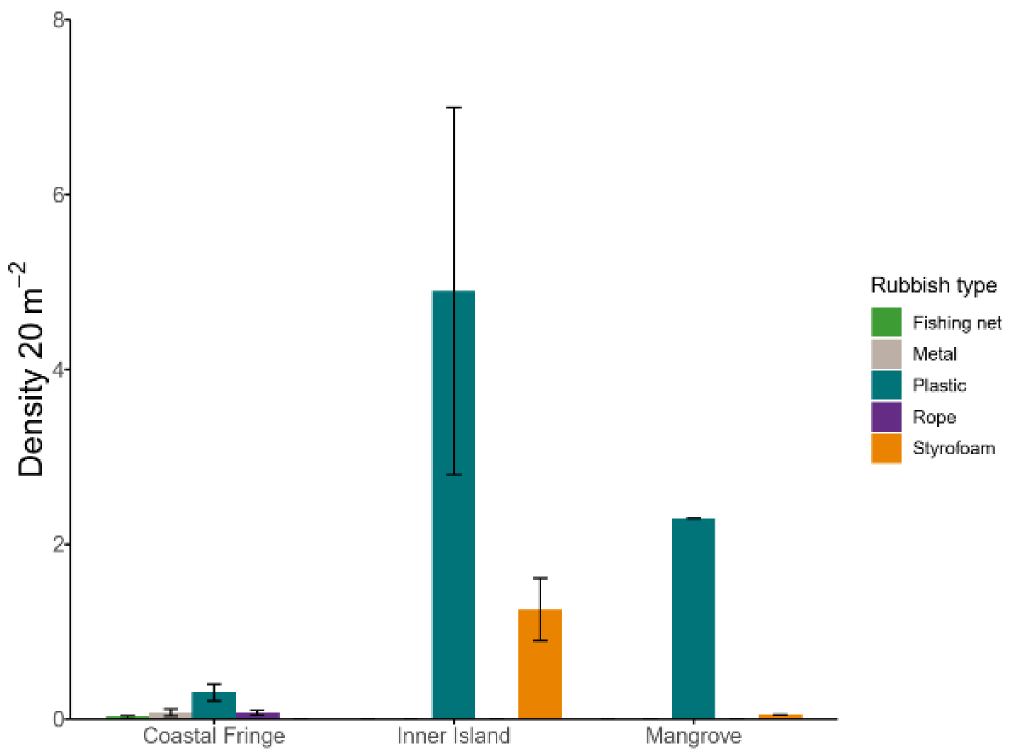

Figure 7. Mean density of items of refuse found in per 20 m^2 survey point in the three areas of vegetation

Marine

The manta tow identified rock as the dominant benthic cover around the reef flat/crest area, comprising 60.6 % (± 2.5 S.E.) of the substrate (Figure 8). Rubble was the second most common substrate type with 16.2 % (± 1.9 S.E.). The remaining substrate was sand 11.4 (± 2.2 S.E.), hard coral 10.4 (± 1.5 S.E.) and algae 0.7 (± 0.4 S.E.).

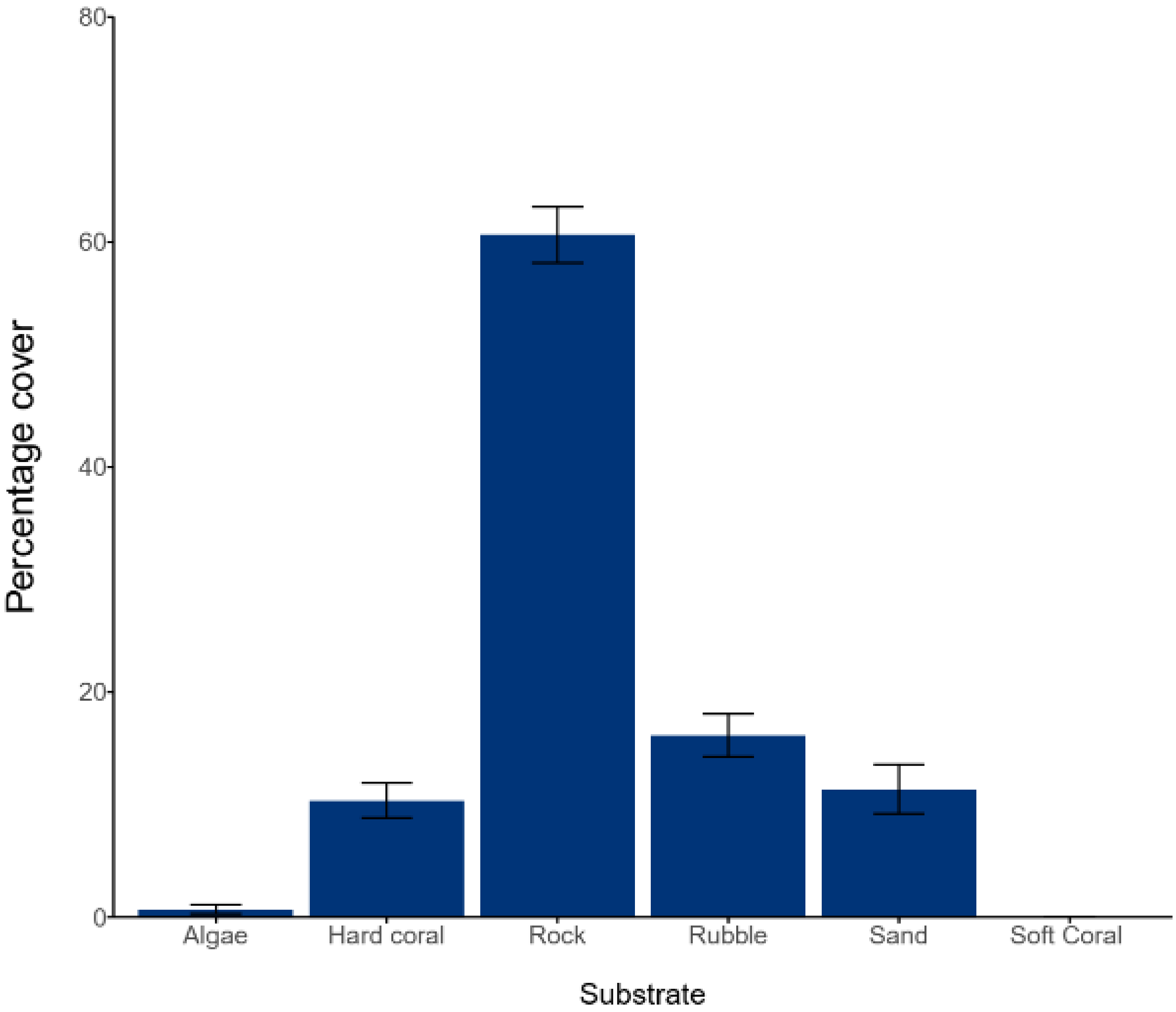

Figure 8. Mean percentage cover of six substrate categories recorded on manta tow survey.

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

Substrate	**East Side**		**North West Side**		**South Side**	
	Percentage cover	S.E.	Percentage cover	S.E.	Percentage cover	S.E.
Hard coral	11.5	5.3	1.5	0.3	4.0	0.9
Macroalgae	5.1	2.0	2.7	0.5	9.6	1.3
Rock	24.5	1.7	17.4	5.4	17.9	4.2
Rubble	29.8	2.9	58.8	7.7	42.6	4.8
Sand	21.2	5.6	15.1	1.8	21.1	1.9
Turf algae	3.2	0.8	1.8	0.7	1.7	1.0
Other Invertebrates	2.8	0.2	2.1	0.3	2.7	0.3
	1.9	0.6	0.6	0.2	0.5	0.0

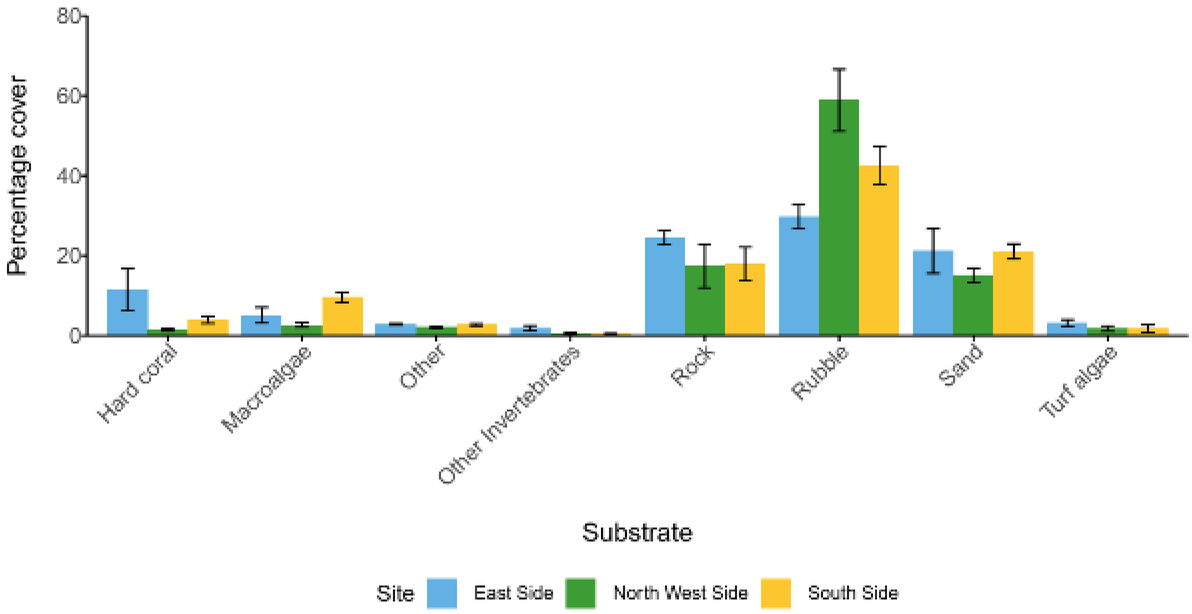

Figure 9. Mean percentage cover of substrate types at the three transect survey sites.

The reef around the outside of the faro was dominated by unconsolidated substrate (Table 2, Figure 9). Rubble was the most common substrate type at all three sites. Rock and sand were the second most common substrates and made up approximately equal proportions of the benthos at each site. The East Side survey site was the only location where hard coral cover was greater than 5 % and the only site where coral cover was greater than algae cover.

The eight most common coral families were Poritidae, Pocilloporidae, Acroporiidae, Merulinidae, Agariciidae and Mussidae (Figure 10). Poritidae (6.6 % cover) was the most common coral family at the East Side survey site, though it was highly variable across the three transects at the site. This was the only site where a single coral family made up more than 2 % of the substrate. The next most common family at this site was Acroporidae (1.1 % cover). At the North West site, total coral cover was 1.5 %. Porites made up 0.7 % of this and the cover of all other families was below 0.2 %. At the South Side site Acroporidae was the most common coral with 1.5 % cover.

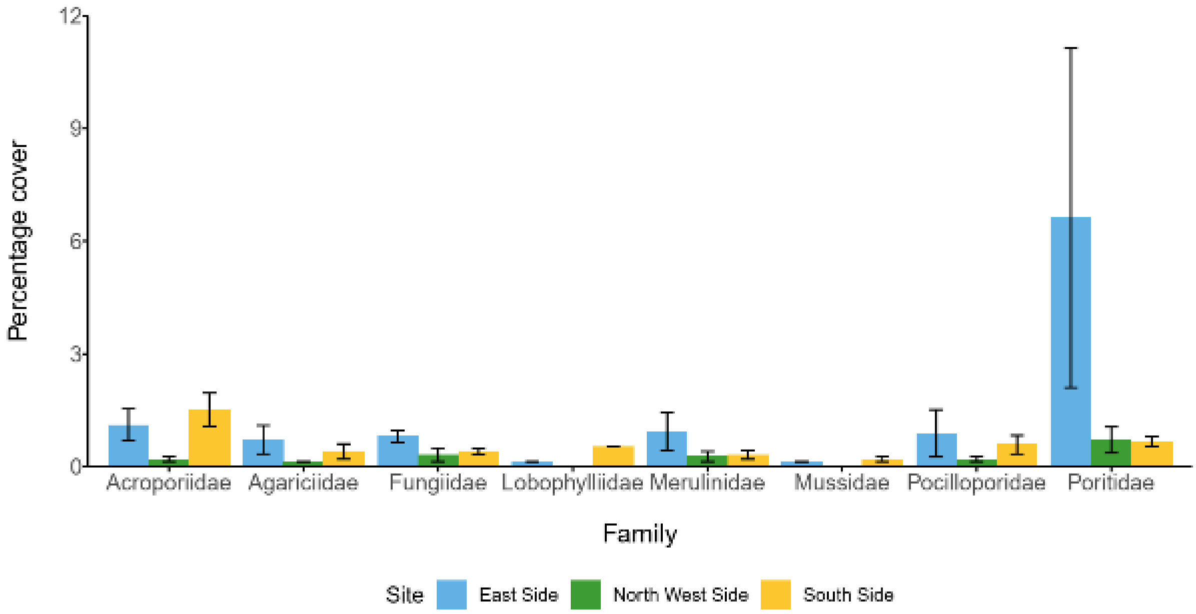

Figure 10. Percentage cover of the eight most commonly observed coral families recorded on transect surveys

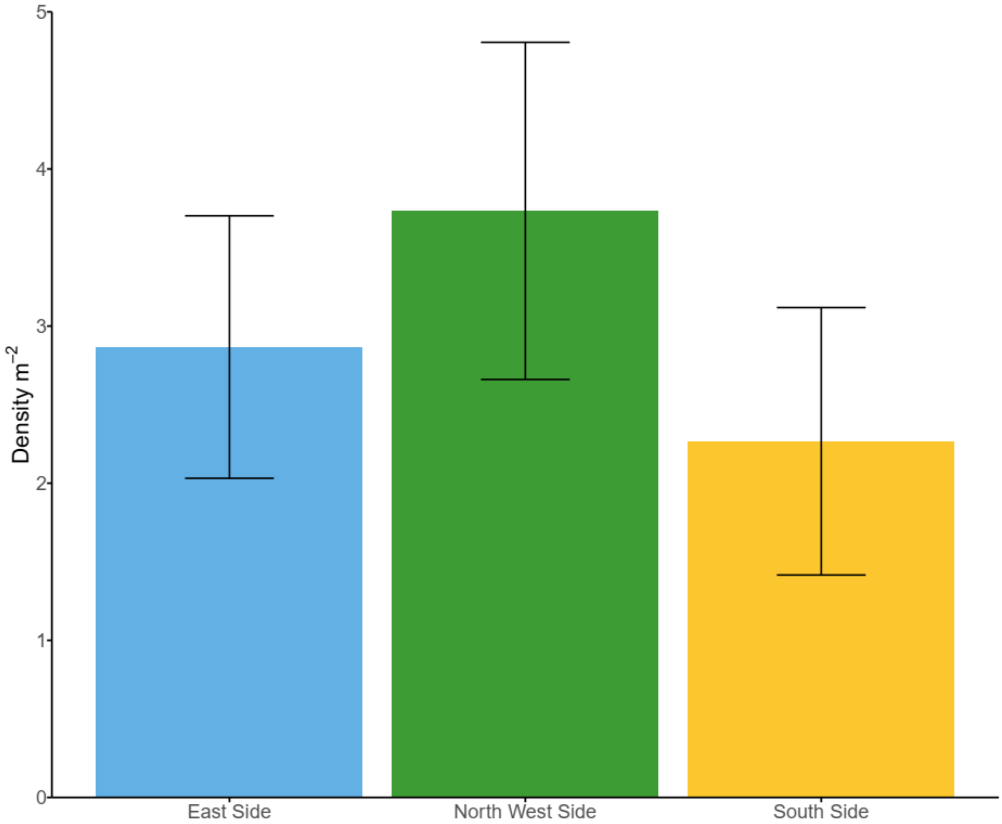

Figure 11. Density per m^2 of all coral recruits recorded on transect surveys

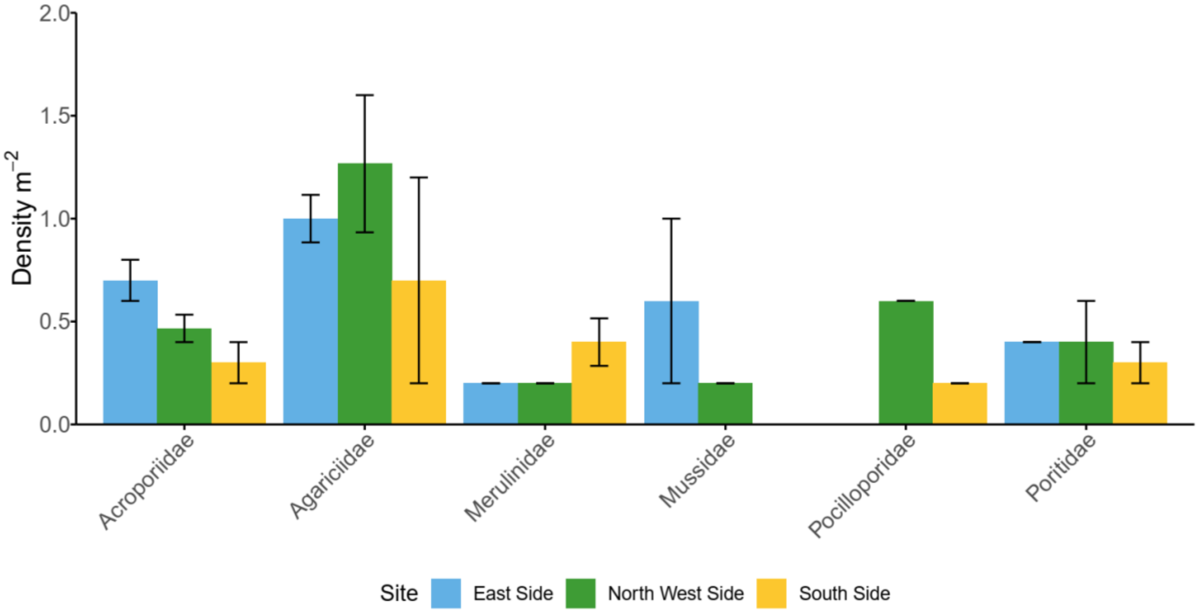

Figure 12. Density per m^2 of recruits from the six most commonly recruiting families.

Total recruit density was 2.8/ m^2 ± 1.6 at the East Side site, 3.7/ m^2 ± 1.9 at the North West Side site and 2.2/ m^2 ± 1.8 at the South Side site (Figure 11). Total density of recruits did not vary greatly between sites but did show large variation between transects within sites. Agariciidae was the most commonly recruiting coral family at both the East and North West Side sites (Figure 12). This family was dominated by recruits from the genus *Pavona*. Acroporids were the second most common family of recruits at the East Side site. Merulinidae was the only family that had its highest levels of recruitment at the South Side site.

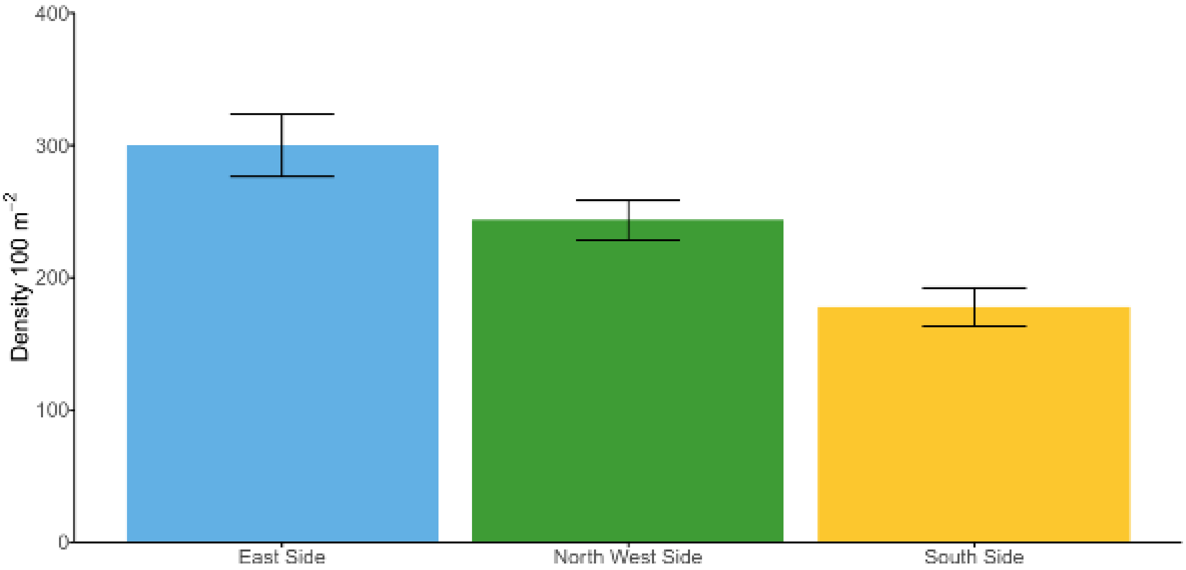

Figure 13. Average density of all fish per 100 m^2 recorded on transect surveys

Total fish density was highest at the East Side site (299.7/ m^2 ± 23.5) followed by the North West side site (243.3/ m^2 ± 15.0) and lowest at the South Side site (177.7/ m^2 ± 14.5). Fish species richness did not vary greatly between sites, ranging from 34.0 ± 1.7 at the South Side site to 30.7 ± 0.3 at the East Side site (Figure 14).

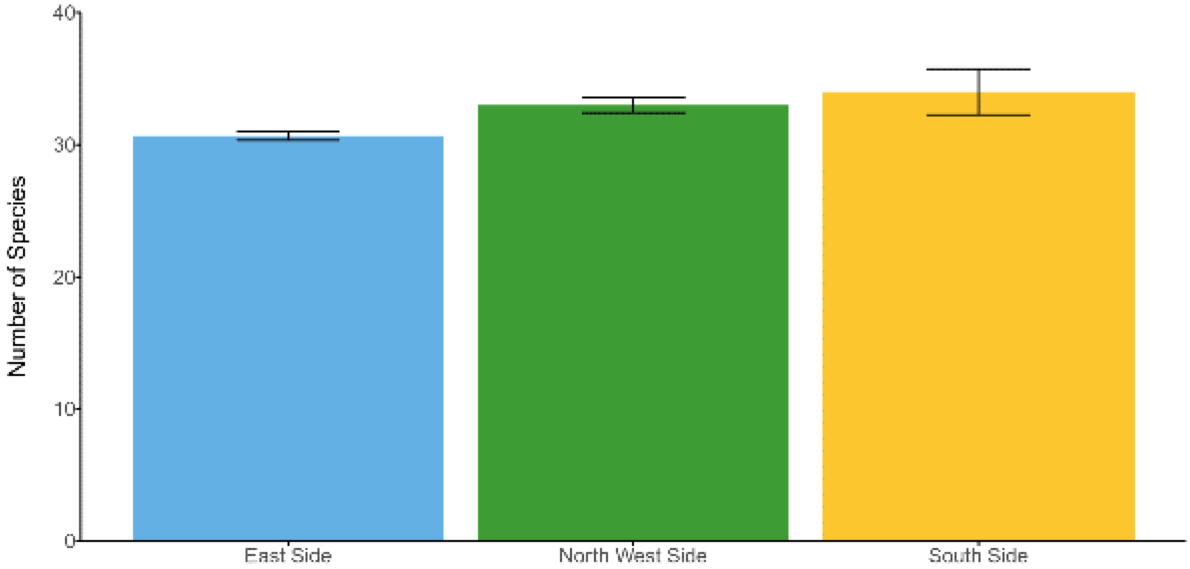

Figure 14. Average fish species richness recorded on transect surveys

Planktivores, including all Caesionids, *Chromis spp.* and *Acanthurus thompsoni* and *Odonus niger*, were the most abundant group of fish found the reefs. At the East Side site their density was 232.4/ 100 m^2 ± 20.6. This means they accounted for 77.5 % of all fish recorded at this site. There were fewer planktivores at both the North West Side (135.6/ 100m^2 ± 26.7) and South Side (74.9/ 100 m^2 ± 36.1) sites making up 55.7 % and 42.1 % respectively of the total fish density.

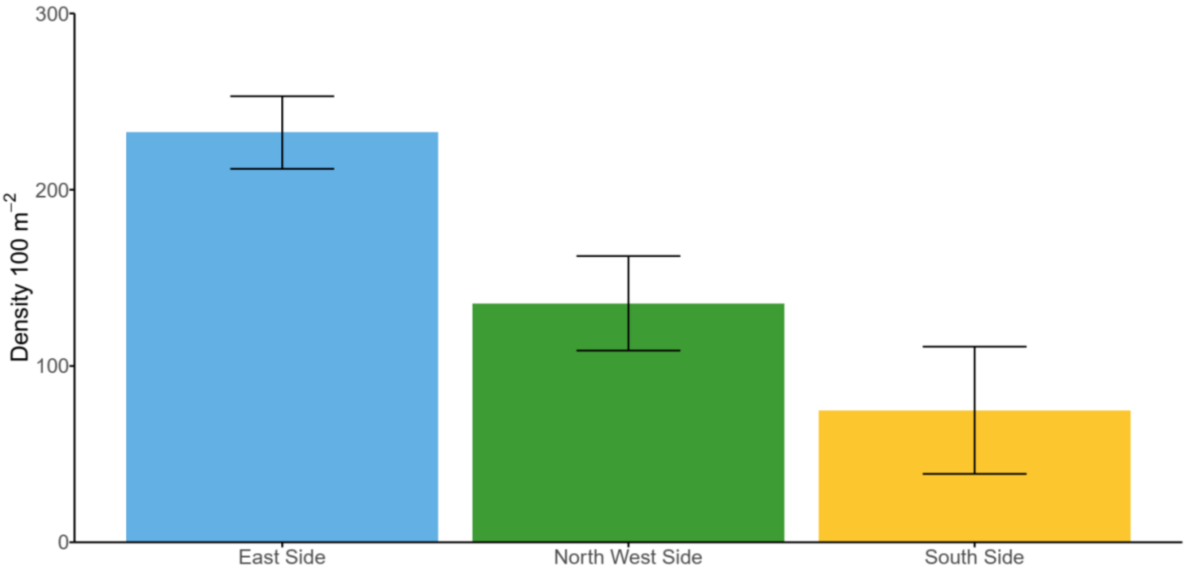

Figure 15. Average density of planktivores per 100 m^2 recorded on transect surveys

Biomass of the key herbivore families, Acanthuridae and Scaridae was low across all three sites (Figure 16 A & B). The South Side site had the highest biomass of both families (Acanthuridae: 0.87 kg/ 100m^2 ± 0.34, Scaridae: 1.04 kg/ 100m^2 ± 0.89), though Scarid biomass was highly variable between the transects. Acanthurid biomass was similar at both the East Side site (0.34 kg/ 100m^2 ± 0.13) and North West Side site (0.34 kg/ 100m^2 ± 0.22). Scarid biomass at the East Side site was extremely low (0.11 kg/ 100m^2 ± 0.09), and only slightly higher at the North West Side site (0.51 kg/ 100m^2 ± 0.21). Chaetodontidae biomass was highest at the East Side site (0.15 kg/ 100m^2 ± 0.08). At both the North West and South Side sites Chaetodontidae biomass was less than 0.05 kg/ 100m^2. The biomass of the carnivorous families Serranidae and Lutjanidae was low, with no site having greater than 0.8 kg/ 100m^2 (Figure 16 D & E). Biomass was also variable within sites.

Species richness was low for Acanthurids, on average less than 3 species were observed at each site (Figure 17 A) and only four species were observed during surveys (Table A2). Scarid species richness was highest at the North West Side (5.0 ± 1.0 species) and South Side (4.0 ± 1.1) sites and very low at the East Side site (1.6 ± 0.6). Chaetodontidae species richness was less than 3 for all sites and the average number of species did not differ from zero at the North West Side site. Serranid species richness was similar at the North West (4.0 ± 0.6) and South Side (3.0 ± 0.6) sites and lowest at the East Side site (1.0 ± 0.6) (Figure 17 D). Lutjanid species richness was less than 2 for all sites and only two species of Lutjanid, *Lutjanus bohar* and *Macolor macularis*, were observed during surveys.

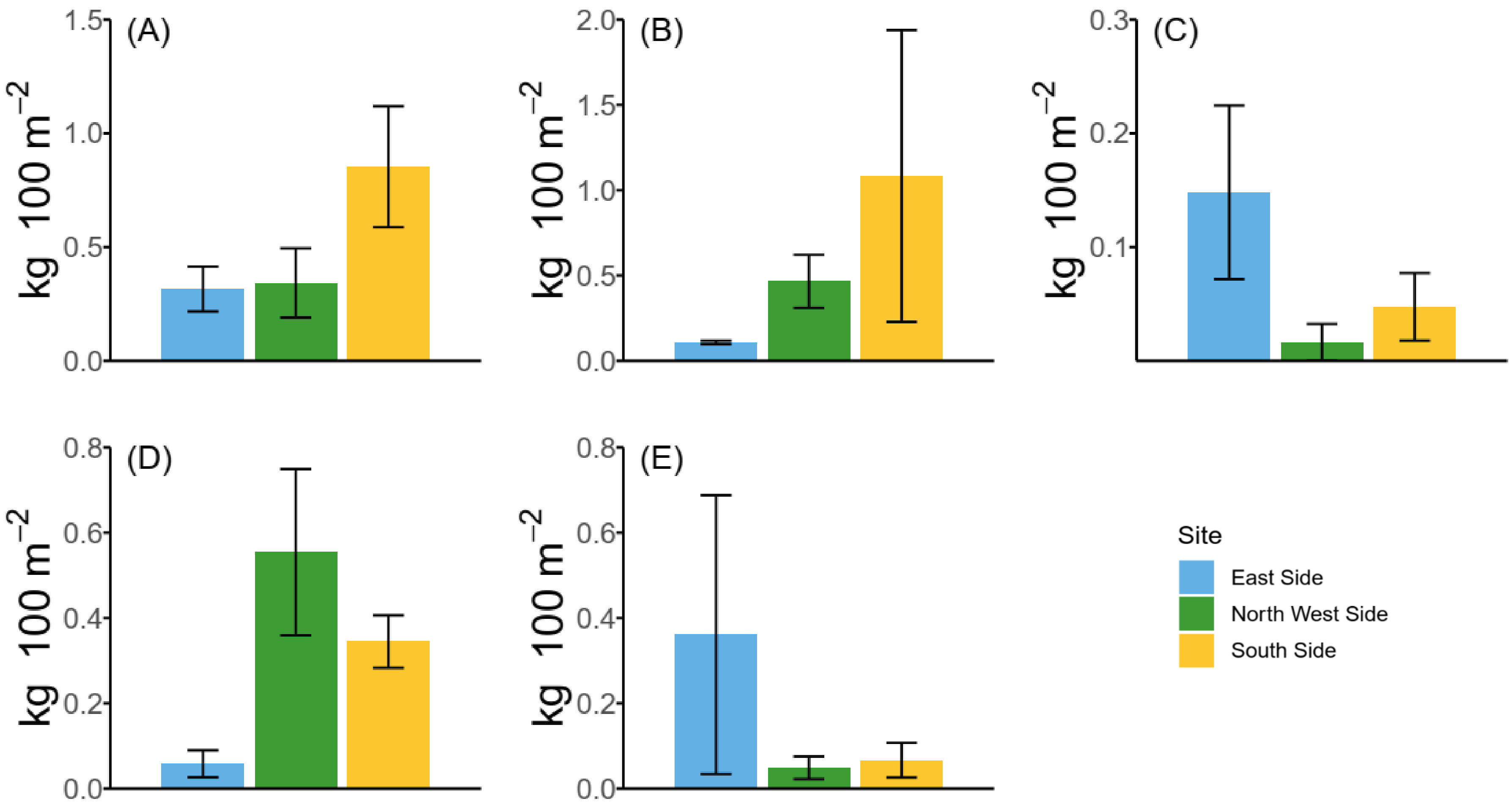

Figure 16. Biomass of the families (A) Acanthuridae, (B) Scaridae, (C) Chaetodontidae, (D) Serranidae (excluding Anthias) and (E) Lutjanidae recorded on transects

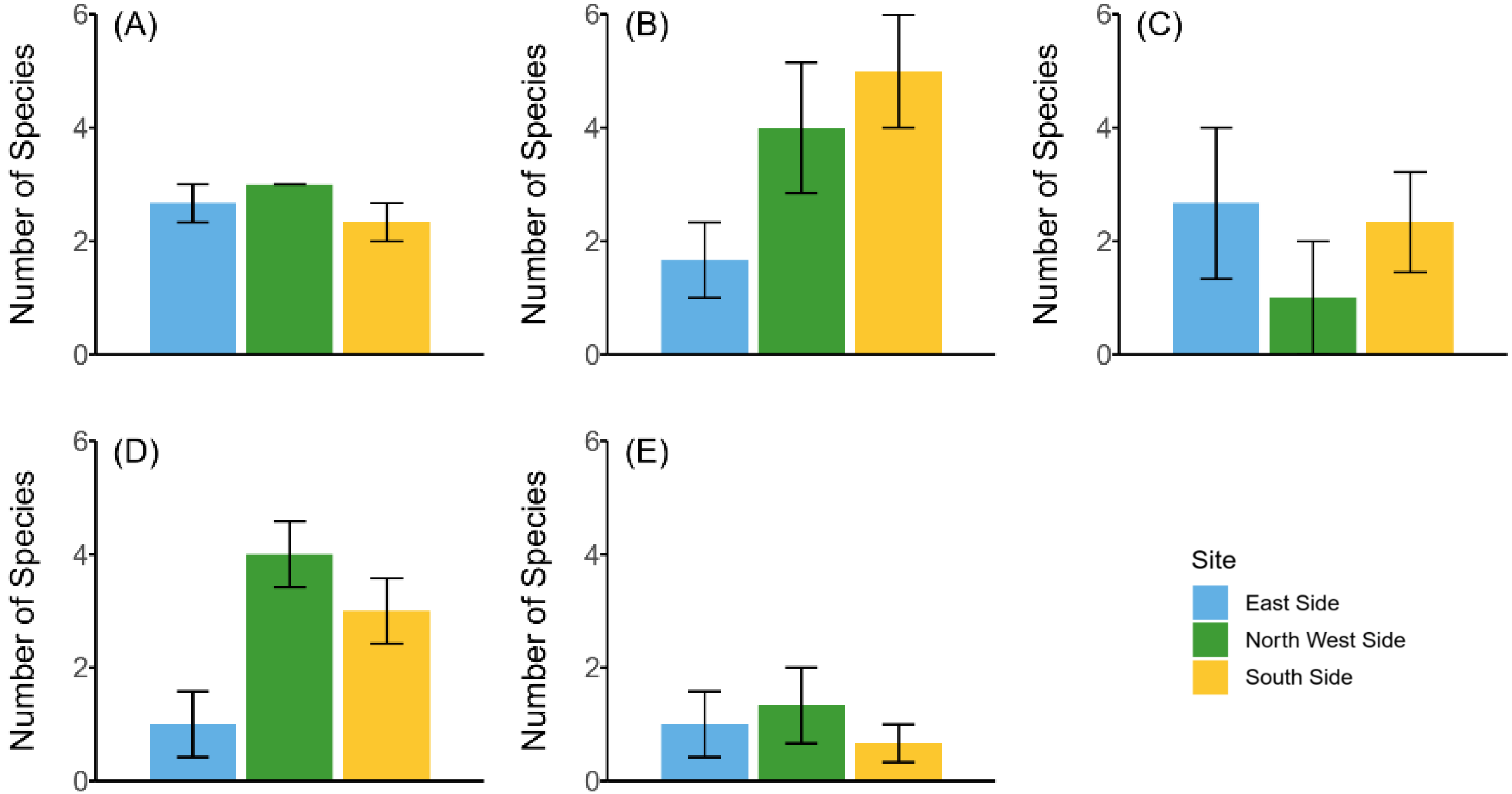

Figure 17. Species richness of the families (A) Acanthuridae, (B) Scaridae, (C) Chaetodontidae, (D) Serranidae (excluding Anthias) and (E) Lutjanidae recorded on transects

The roaming surveys of three large coral bombies in the lagoon revealed they are predominantly covered with hard corals and rock (Figure 18). Sand and rubble at the base of the coral bombies comprised the remaining substrate. The massive corals were the dominant coral growth form at all three bombies (Figure 19).

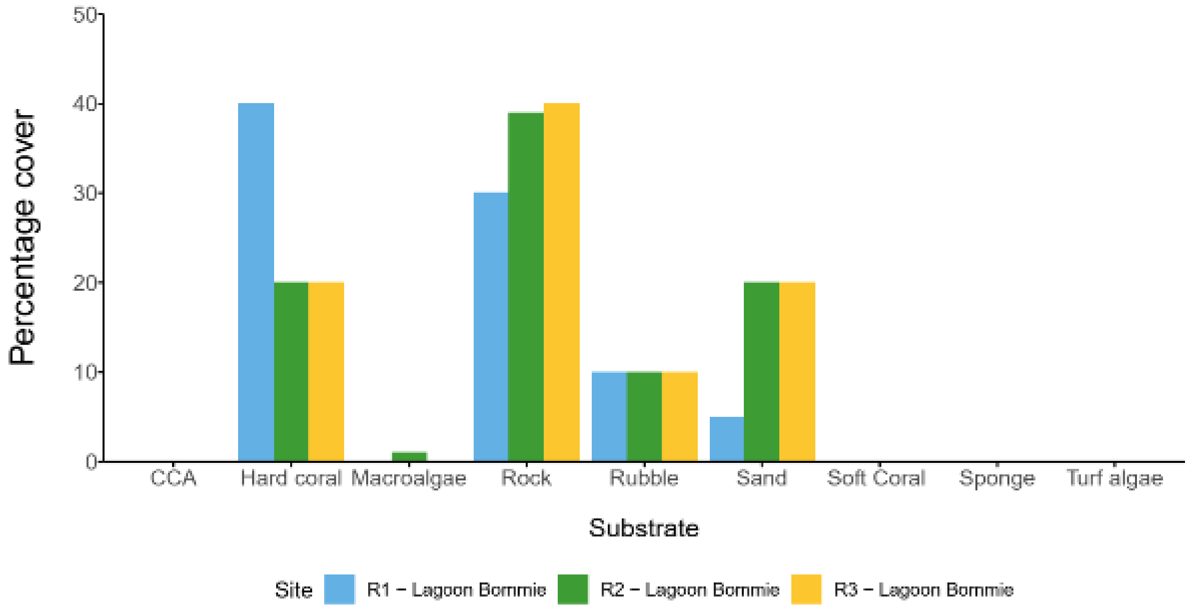

Figure 18. Estimated percentage cover of substrate cover at three large coral bombies in the lagoon area

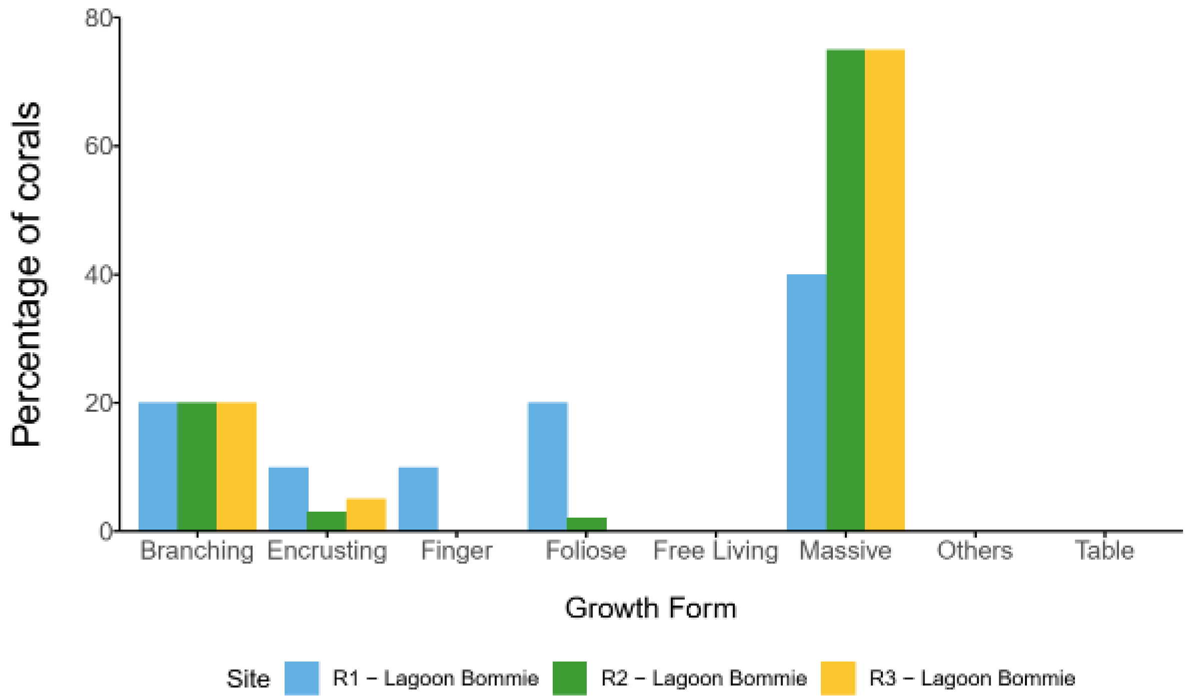

Figure 19. Percentage of coral cover in each growth form at three large coral bombies in the lagoon area

Red Listed species

No IUCN Red Listed species were recorded during the surveys at Ruh Hurihuraa.

Discussion

Ruh Hurihuraa is in many ways an unusual island in the Maldives. There was no sandy shoreline, the island is dominated by a single species of vegetation and there appears to be no use of the island by humans. Despite that, there were significant amounts of rubbish found across the island. The mangrove basin was a small area at the centre of the island where *B. cylindrica* dominated. The absence of sandy shoreline meant that there was no area for turtles to nest, or shorebirds to forage. The faro reef associated with the island was dominated by rubble, sand and rock and had a very low hard coral cover. The fish community was primarily made up of planktivores, particularly at the East Side site, and there was a low biomass of key indicator families including Acanthuridae, Scaridae, Chaetodontidae, Serranidae and Lutjanidae. No IUCN Red List species were observed during either terrestrial or marine surveys.

Terrestrial

The island is a relatively uniform habitat, the soil type is sand and rubble throughout and outside of the small mangrove basin the vegetation is a monospecific stand of *P. acidula*. Despite the island being named after coconut palms “Ruh” there were no palms present. 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. Given the mangrove basin floods during high tide 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, 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).

Figure 20. Images from the mangrove basin on Ruh Hurihuraa. These images also show the sand and rubble substrate present across the whole island.

Despite the island's small size and the absence of any standing water a small mangrove habitat is present (Figure 20). The mangrove habitat was a relatively well defined mangrove basin (Lugo and Snedaker 1974, Ewel et al. 1998). The area was a mix of mature and sapling *B. cylindrica* trees, with dense growths in some areas. The basin is closed off from the sea by the raised shoreline made of beach rock and rubble. Though there are similarities between this mangrove and the ones found on nearby Vattaru and Hulhidhoo, the dynamics of this area are somewhat different. Water completely floods the basin area at high tide, seeping in through the bedrock. The sand and rubble sediment in the area suggests there is little organic matter in the soil. Whereas the other islands had a muddy soil type where nutrients likely accumulate. Mangrove species are susceptible to changes in the surrounding environment and can be impacted by changing salinity, pH or the moisture content of the soil (Kathiresan and Bingham 2001). The mangroves in the area appeared to be in relatively good health. The fact the basin drains completely at low tide meant there was no aquatic life in the area.

The most likely source of the large rubbish deposits found throughout the island was being washed ashore by the waves and tides. The rubbish was almost entirely plastic water bottles and pieces of Styrofoam (Figure 21). 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.

Figure 21. Deposits of rubbish found throughout the Ruh Hurihuraa inner island and mangrove areas

Marine

The reef slope habitat was in a relatively poor condition. Rubble was the dominant substrate type at all transect survey sites. This was made up of branching *Acropora* coral skeletons. *Acropora* are among the most historically sensitive coral genera to coral bleaching (Baird and Marshall 2002, Mizerek et al. 2018) and the *Acropora* corals here likely died during the 2016 coral bleaching event, as recorded elsewhere around the country (Ibrahim et al. 2017, Dryden et al. 2020). Over time the skeleton has been eroded to form rubble and sand. Rubble can be suitable settlement surface for coral when it is relatively stable, especially when bound by CCA (Heyward and Negri 1999). However, the rubble present here was generally highly mobile on sand patches and often covered in a fine layer of sediment (Figure 22). As a result, the substrate was unstable and unconsolidated. 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 results in a decline in suitable settlement area for corals which may hinder reef recovery following bleaching events. Coverage of the substrate by sand and other particulate matter such as silt and sediment reduces the amount

Figure 22. Images of the reef slope. The upper images show the degraded rubble/sand reef slope. The lower images show coral growth on patches of rocky substrate.

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). Therefore it is possible that the low abundance of coral recruits on this reef is in part a result of higher levels of unconsolidated substrate following the bleaching event in 2016.

Where large patches of hard substrate were present there was coral recruitment and coral colony growth as seen in the bottom images of Figure 22. There was also an area just North of the transect surveys at the East Side site which had far higher coral cover than the areas captured by the transect surveys. However, this patch was less than 25 m^2 and appeared an anomaly given the condition of the rest of the reef area. The low cover of turf algae and macroalgae are also likely to be attributed to a lack of settlement surface, especially as herbivore numbers were low so it was not as a result of grazing pressure. Large coral bombies within the lagoon did have areas of high coral growth. These were dominated by massive forms of *Diploastrea* sp. and *Goniopora* sp. (Figure 23).

Figure 23. Images of large bombies in the lagoon

The fish community at all sites was dominated by planktivores. This group is made up of 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. Erosion of the reef structure following coral death results in loss of food and habitat for fish as well as shelter from predators (Graham et al., 2007). The low level of structural complexity on these reefs are likely to have contributed to the low biomass of key fish families recorded here. Biomass of the herbivores Acanthuridae and Scaridae was low and comparable to other areas of the country impacted by the 2016 bleaching event (Dryden et al. 2020). Herbivorous fish, are important 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). If the reef in this area is to recover, healthy herbivore communities will be essential. 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.

The reef around Ruh Hurihuraa is unlikely to be an important local fishing area as higher trophic level fish families including groupers and snappers were rare around the island. The absence 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.

Human activities over the past 150 years have caused approximately 1.09^{o}C of climate warming and it is likely that it will continue to warm by at least 1.5^{o}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 relatively little direct human interaction with the island, the indirect impacts of human activities are clear across the Ruh Hurihuraa area. The deposits of rubbish across the island and the effects of coral bleaching are clear from these surveys. These findings show how linked the Maldives natural ecosystem is to the behaviour of humans both within the country, and globally. Management efforts must be nationwide 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. These should also utilise strategies and action plans developed by local and national governments such as regional waste strategy and action plans (Ministry of Environment 2019), the reports on biodiversity (Ministry of Environment and Energy 2015), clean environment programs (Ministry of Environment 2016) and marine management (Sattar et al. 2014).

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. The high cover of unconsolidated sand and rubble substrate around the reef slope.
3. The low numbers of herbivorous fish species.

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.
- 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, fishing of herbivores on all reefs.
- 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:
    - Sand pumping for beach replenishment

    - Dredging of sand within atolls
    - 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

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

Family	Genus
Acroporiidae	*Acropora*
Acroporiidae	*Astreopora*
Acroporiidae	*Montipora*
Agariciidae	*Leptoseris*
Agariciidae	*Pavona*
Dendrophylliidae	*Turbinaria (coral)*
Euphylliidae	*Galaxea*
Fungiidae	*Ctenactis*
Fungiidae	*Fungia*
Fungiidae	*Halomitra*
Fungiidae	*Herpolitha*
Insertae sedis	*Physogyra*
Lobophylliidae	*Lobophyllia*
Merulinidae	*Cyphastrea*
Merulinidae	*Favites*
Mussidae	*Favia*
Pocilloporidae	*Pocillopora*
Poritidae	*Porites*
Unknown	NA

Table A2. All fish species observed on surveys in Ruh Hurihuraa

Family	Species	Common name
Acanthuridae	*Acanthurus thompsoni*	Night surgeonfish
Acanthuridae	*Ctenochaetus striatus*	Fine-lined bristletooth
Acanthuridae	*Ctenochaetus truncatus*	Gold-ring bristletooth
Acanthuridae	*Zebrasoma desjardinii*	Sailfin surgeonfish
Acanthuridae	*Zebrasoma scopas*	Brown Tang
Apogonidae	*Apogon angustatus*	Narrow striped cardinalfish
Apogonidae	*Cheilodipterus lineatus*	Tiger cardinalfish
Balistidae	*Balistapus undulatus*	Striped triggerfish
Balistidae	*Balistoides viridescens*	Titan triggerfish
Balistidae	*Odonus niger*	Blue triggerfish
Balistidae	*Pseudobalistes flavimarginatus*	Yellow-margin triggerfish
Blenniidae	*Ecsenius minutus*	Little combtooth blenny
Blenniidae	*Meiacanthus smithi*	Disco blenny
Caesionidae	*Caesio lunaris*	Moon fusilier
Caesionidae	*Caesio xanthonota*	Yellow-back fusilier
Caesionidae	*Pterocaesio trilineata*	Striped fusilier
Chaetodontidae	*Chaetodon auriga*	Threadfin butterflyfish
Chaetodontidae	*Chaetodon falcula*	Double-saddle butterflyfish
Chaetodontidae	*Chaetodon kleinii*	Brown butterflyfish
Chaetodontidae	*Chaetodon triangulum*	Triangular butterflyfish

Family	Species	Common name
Chaetodontidae	*Chaetodon trifasciatus*	Pinstriped butterflyfish
Chaetodontidae	*Forcipiger longirostris*	Very long-nose butterflyfish
Chaetodontidae	*Hemitaurichthys zoster*	Black pyramid butterflyfish
Gobiidae	*Eviota sp.*	Eviota species unkown
Gobiidae	*Koumansetta hectori*	Hector's goby
Holocentridae	*Myripristis murdjan*	Crimson soldierfish
Holocentridae	*Sargocentron spiniferum*	Sabre squirrelfish
Labridae	*Biochoeres cosmetus*	Adorned wrasse
Labridae	*Cheilinus fasciatus*	Banded Maori wrasse
Labridae	*Cheilinus trilobatus*	Triple-tail Maori wrasse
Labridae	*Epibulus insidiator*	Sling-jaw wrasse
Labridae	*Gomphosus caeruleus*	Bird wrasse
Labridae	*Halichoeres chrysotaenia*	Vrolik's wrasse
Labridae	*Halichoeres hortulanus*	Checkerboard wrasse
Labridae	*Hemitautoga scapularis*	Zigzag wrasse
Labridae	*Labroides bicolor*	Two-colour cleaner wrasse
Labridae	*Labroides dimidiatus*	Blue-streak cleaner wrasse
Labridae	*Labropsis xanthonota*	V-tail tubelip wrasse
Labridae	*Macropharyngodon bipartitus*	Splendid leopard wrasse
Labridae	*Oxycheilinus digramma*	Cheek-line Maori wrasse
Labridae	*Pseudocheilinus hexataenia*	Six-line wrasse
Labridae	*Stethojulis albovittata*	Blue-lined wrasse
Labridae	*Thalassoma hardwicke*	Six-bar wrasse
Labridae	*Thalassoma lunare*	Moon wrasse
Lethrinidae	*Lethrinus erythracanthus*	Orange-finned emperor
Lethrinidae	*Lethrinus xanthochilus*	Yellow-lip emperor
Lethrinidae	*Monotaxis grandoculis*	Large-eye bream
Lutjanidae	*Aphareus furca*	Small-tooth jobfish
Lutjanidae	*Lutjanus bohar*	Red bass
Lutjanidae	*Macolor macularis*	Midnight snapper
Microdesmidae	*Ptereleotris evides*	Arrow goby
Mullidae	*Parupeneus macronema*	Long-barbel goatfish
Nemipteridae	*Scolopsis bilineata*	Monocle bream
Pinguipedidae	*Parapercis hexophthalma*	Black-tail grubfish
Pomacanthidae	*Centropyge multispinis*	Many-spined angelfish
Pomacanthidae	*Pomacanthus imperator*	Emperor angelfish
Pomacanthidae	*Pygoplites diacanthus*	Regal angelfish
Pomacentridae	*Amblyglyphidodon batunai*	Green sergeant
Pomacentridae	*Chromis flavipectoralis*	White-finned puller
Pomacentridae	*Chromis lepidolepis*	Scaly chromis
Pomacentridae	*Chromis ternatensis*	Swallow-tail puller
Pomacentridae	*Chromis viridis*	Green puller
Pomacentridae	*Dascyllus aruanus*	Humbug damsel
Pomacentridae	*Dascyllus carneus*	Indian humbug
Pomacentridae	*Plectroglyphidodon dickii*	Narrowbar damsel
Pomacentridae	*Plectroglyphidodon lacrymatus*	Jewel damsel
Pomacentridae	*Pomacentrus caeruleus*	Blue-yellow damsel
Pomacentridae	*Pomacentrus indicus*	Indian damsel
Pomacentridae	*Pomacentrus philippinus*	Philippine damsel
Scaridae	*Cetoscarus bicolor*	Two-colour parrotfish
Scaridae	*Chlorurus sordidus*	Shabby parrotfish

Family	Species	Common name
Scaridae	*Chlorurus strongylocephalus*	Sheephead parrotfish
Scaridae	*Scarus caudofasciatus*	Bartail parrotfish
Scaridae	*Scarus frenatus*	Bridled parrotfish
Scaridae	*Scarus niger*	Dusky parrotfish
Scombridae	*Euthynnus affinis*	Kawaka
Scombridae	*Gymnosarda unicolor*	Dogtooth tuna
Serranidae	*Aethaloperca rogaa*	Red-flushed grouper
Serranidae	*Anyperodon leucogrammicus*	White-lined grouper
Serranidae	*Cephalopholis argus*	Peacock rock cod
Serranidae	*Cephalopholis leopardus*	Leopard rock cod
Serranidae	*Cephalopholis nigripinnis*	Blackfin rock cod
Serranidae	*Cephalopholis sonnerati*	Tomato rock cod
Serranidae	*Diploprion bifasciatum*	Yellow soapfish
Serranidae	*Plectropomus laevis*	Black-saddle coral grouper
Serranidae	*Plectropomus pessuliferus*	Indian coral grouper
Serranidae	*Variola louti*	Lunar-tailed grouper
Synodonitdae	*Saurida nebulosa*	Clouded lizardfish
Tetraodontidae	*Arothron meleagris*	Guineafowl pufferfish
Tetraodontidae	*Canthigaster valentini*	Saddled pufferfish

Table A 3. GPS coordinates for the terrestrial survey points

Zone	Latitude	Longitude
Coastal Fringe	3.361018	73.500043
Coastal Fringe	3.361270	73.499950
Coastal Fringe	3.361458	73.499881
Coastal Fringe	3.361629	73.499787
Coastal Fringe	3.361789	73.499694
Coastal Fringe	3.361947	73.499556
Coastal Fringe	3.362016	73.499654
Coastal Fringe	3.361894	73.499923
Coastal Fringe	3.361701	73.500121
Coastal Fringe	3.361387	73.500238
Coastal Fringe	3.361163	73.500270
Coastal Fringe	3.360908	73.500257
Coastal Fringe	3.360654	73.500292
Coastal Fringe	3.360497	73.500168
Coastal Fringe	3.360744	73.500080
Inner Island	3.360969	73.500139
Inner Island	3.361223	73.500181
Inner Island	3.361419	73.500031
Inner Island	3.361720	73.499883
Inner Island	3.361840	73.499787
Mangrove	3.361567	73.500062

Table A 4. GPS coordinates for the transect surveys

Site	Latitude	Longitude
East Side	3.36220	73.50087
North West Side	3.36123	73.49362
South Side	3.35647	73.49863

Table A 5. GPS coordinates for the lagoon bombie roaming surveys

Site	Latitude	Longitude
R1 - Lagoon Bommie	3.36159	73.49791
R2 - Lagoon Bommie	3.35924	73.49633
R3 - Lagoon Bommie	3.35825	73.49796