



A Rapid Assessment of Natural Environments in the Maldives: Supplementary Site Assessments





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INTRODUCTION

Natural environments in the Maldives are under threat from a range of natural and anthropogenic impacts. Climate change is causing increases in sea temperatures and sea levels, which present a significant threat to coral reefs and island habitats. Increasing population numbers and coastal development activities also threaten natural systems through the harvesting of natural populations and damaging pristine habitats. It is therefore crucial that areas with potentially high ecological value are identified and assessed to formulate ecological management plans specific to these habitats.

To help conserve these natural ecosystems, the nation has proposed to develop a network of Biosphere Reserves within the country for sustainable development. Biosphere Reserves are UNESCO designated "Science for Sustainability Support Sites" aimed at promoting conservation while also implementing sustainable management practices. UNESCO Biosphere Reserves help create a

framework to allow humans and the environment to interact in a more harmonious manner.

This publication is supplementary to the the Rapid Assessment of Natural Environment in the Maldives report. Here we present the results from surveys conducted in 37 locations across the country. These include 13 privately leased and managed resort house reef systems (Resort Reefs), 17 unmanaged reef systems representing a range of reef habitats (Marine Zones) and 7 island habitats, including mangrove bays (Terrestrial Zones).

The data gathered for this publication serves as a baseline dataset to make recommendations regarding the protection and management of the areas surveyed, as well as to understand the biodiversity within the area. Surveys were conducted using a mix of local knowledge, rapid ecological assessments and detailed visual census.

The surveys were conducted between in 2017, 2018 and 2019. The reports present average values

across all surveys within the zone, except for endangered animals, which are presented as total numbers observed. There is some variation in the presentation of the data and report layout between years as the objectives of the study changed over the course of the survey period. Surveys conducted in 2017 were rapid habitat assessments, whereas 2018 and 2019 were more comprehensive reports aimed at contributing to specific local management plans as well collecting detailed information for use in management plans. All resort reefs and marined zones were surveyed in 2017, except Orimas Thila (2018), Anemone Thila and Hatharufaru (both 2019). All terrestrial zones were surveyed in 2018 and 2019.

These reports contain the results for selected variables which are crucial to identify the condition, biodiversity and threats to the survey areas. Each report is kept as brief as possible to ensure the pertinent information is easily accessible to all stakeholders.

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BODULHAIMENDHOO

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 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 Bodhulaimendhoo in Noonu Atoll 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 scattered 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 and Hatcher 2004). Maldivian islands are known as low lying islands with 80% of the country being less than a meter above the sea level and the majority of islands being less than 5km² in size. (Ministry of Environment and Energy 2015). Studies to understand the atoll and island formation have suggested that the island reefs in the Maldives have been around 4000 yr. B.P (Kench et al. 2005, Perry et al. 2013).

The terrestrial fauna and flora have a rich biodiversity. The range of natural island habitats includes beaches, marshes, brackish ponds, mangroves and woodlands. There are 583 species of terrestrial flora found, of

which 323 are cultivated and 260 are natural. The farmed species are mostly used as a source of food and some for traditional medicine. Mangroves ecosystems can be classified based on the system's exposure to the sea as either "open mangrove systems" or "closed mangrove systems. These can then be further subdivided into four categories (Saleem and Nileysha 2003) (Table 1). In all but marsh-based mangroves, tree growth is limited to a narrow band around the water's edge. Around 15 species of mangroves are found across approximately 150 islands (Ministry of Environment and Energy 2015). Maldivian avifauna is made up of seasonal migrants, breeding residents and introduced birds. Over 167 species of birds have been recorded in the Maldives. Around 70 species of shorebirds are recorded, some of which are breeding residents while others are recorded as migrants. Migratory birds visit during certain seasons to breed or use the islands as a transit point to their breeding grounds (Ministry of Environment and Energy 2015).

Open mangrove systems	Coastal fringing mangroves	Exposed mangroves growing directly on the shoreline. Experience regular wave action. Uncommon mangrove system
	Embayment mangroves	Mangroves partly encircle a bay area. Experience daily tidal flushing. Common mangrove system
Closed mangrove systems	Pond-based mangroves	Mangroves encircle a brackish water pond. Possible water exchange through bedrock or overwash. Common mangrove system
	Marsh-based mangrove	Mangrove found on muddy substrate with no standing water. Dampness of mud may come from flow through the bedrock or overwash. Uncommon mangrove system

Table 1: Description of the four types of mangrove ecosystems found in the Maldives. From Saleem and Nileysha (2003)

Coral reefs of the Maldives are considered to be 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 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) is contributed by 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 whole Maldivian coral reef ecosystem has been under threat after series of catastrophic events such as mass coral bleaching and outbreaks of crown of thorns starfish (*Acanthaster planci*). Following the 2016 bleaching event, which damaged an estimated 75% of the coral reefs (Ibrahim et al. 2017), scientists have been alerted as the impact of the event has shown that even some of the most protected reef ecosystems could perish. However, the Reefs at Risk 2016 report indicates that a significant proportion of reef degradation is due to local stressors (Burke et al. 2011), such as, overfishing, pollution, land reclamation. Despite these global and anthropogenic stressors, the Maldivian reefs have previously shown resilience and recovery following these disturbances (Morri et al. 2015, Pisapia et al. 2016).

Terrestrial habitats are threatened by many local scale factors including infrastructure development, human waste and land reclamation projects. Similar to the marine environment, habitats such as mangrove areas are known for their ecological significance and diversity, providing habitats and services to animal and human communities (Kuenzer et al. 2011). However, due to historical and continued undervaluation, most 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 infrastructure development. Refuse dumping has had a major impact on the terrestrial and marine environment. Around 1.7kg of waste is generated per capita in Male' alone (Ministry of Environment and Energy 2015). This highlights the need for proper waste management in the Maldives. At present, 128 waste management centres are established across Maldives, and regional waste management centres are planned for major populated areas such as Addu City. The government has increased their efforts to manage the waste issue by incorporating the 3Rs (Reduce, Reuse, Recycle) concept into policy and investing on local waste management centres. However, many populated islands are far away from regional waste management centres making dumping waste on land or in the sea the most convenient disposal option for a large proportion of the population.

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 dependent on the profits around these industries. This highlights the significance of the natural environment to the Maldives and 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 the sustainable use and management of these natural resources within communities. Such approaches will play a key role in standardizing the efforts to manage and monitor the resources in a co-managed concept.

Considering the extent and scale of 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. Ultimately this will create a network of well managed 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 presents the findings of habitat assessments conducted at Bodulhaimendhoo in Noonu Atoll.



Figure 1: Map of Bodulhaimendhoo survey areas. Terrestrial survey areas are (A) Central pond, (B) NW pond, (C) NE pond and the coastal fringe area which runs around the island perimeter. Black diamonds indicate the start and end points of the coral reef surveys

Study site

Noonu Atoll is the southern administrative division of the large Miladhunmadulu Atoll, in the north of the Maldives. Partly because of its location in the far north of the country and generally low population, the atoll is under surveyed and currently has no marine protected areas or sustainable management plans for any of the inhabited islands.

Bodulhaimendhoo is a small, roughly circular island approximately 39 ha in size and with a perimeter is approximately 2.4 km. It is part of a short chain of similar islands that run along the outer edge of the atoll. Each of these islands appear to be a different stages of island development, ranging from fully developed with thick inland vegetation to ones that are a thin strip of sand with small scrub vegetation growth. Bodulhaimendhoo has a ring of vegetation around the perimeter which separates the shore from a large brackish water pond in the center. The vegetation is wide and dense in the north and narrow in the south. The large central pond is approximately 17 ha in size, making up almost half of the total island area. The island is uninhabited and has no history of agricultural use.

The island is surrounded by a shallow fringing reef that drops off steeply to 40 m. The outer atoll edge is exposed to the Indian Ocean and is subject to significant wave action. The reefs running along the north and south of the island form part of a channel system that connects in inner atoll with the open ocean, strong currents form here as the water moves between the two.



Figure 2: Recording data at a terrestrial survey point

Methods

The terrestrial survey area was the divided into four habitats: the coastal fringe, centre pond fringe, north east pond fringe and north west pond fringe. Survey points were identified using a stratified sampling approach with sites selected around pond fringes and around the coastal fringe area. GPS coordinates were extracted from Google Earth© version 7.3.1 and entered into a handheld GPS (either Garmin etrex 20x or Garmin GPS maps 64s) for navigation to the point (Figure 2). At a survey point a 2.5 m radius circle was estimated and the dominant and secondary flora within the area were identified to species and their respective percent covers were estimated. The height of the dominant species was estimated to the nearest metre. Substrate type was recorded and counts of crab burrows and rubbish were conducted. The number of survey points for each zone was dependent on zone size and accessed on foot or by kayak. If identified points were inaccessible a new point was taken as close as possible to the original and the survey was performed here. Wetland bird and fish surveys were conducted concurrent with terrestrial habitat surveys. All birds observed were identified to species.



Figure 3: Recording ecological data during roaming surveys

Fish were identified to family and their abundance was estimated. Due to the close proximity of the four survey habitats it was not possible to clearly identify which habitat birds were observed in therefore counts were made for the whole island.

Marine surveys were performed using a roaming survey approach. Six surveys were conducted along the northern reef, however due to challenging survey conditions it was only possible to conduct three surveys on the southern reef. Each survey

lasted 15 minutes with start and finish times, survey location (GPS of start/finish or entry/exit), reef type (wall, slope, channel), estimated average depth and visibility recorded. The percent was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and crustose coralline algae (CCA). Reef structural complexity was estimated on a scale of 0 – 5, where 0 was considered completely flat and 5 very complex with a high number of holes and refuges, complex coral structure and tall coral

or rock structures. Fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were. All surveys were conducted using SCUBA and were between 10 m and 25 m deep (Figure 3).

Results

Island survey

Twelve species of flora were identified on the vegetation surveys (Table A2), which include a single mangrove tree species *Rhizophora apiculata*. The most diverse survey area was the coastal fringe (Figure 4). The pond habitats had relatively few species. The large central pond was the only habitat which contained the mangrove trees, where it was the most abundant species. The bottom of the central pond was covered in very fine, deep sediment. The two small ponds were shallow with very warm water, seawater occasionally entered through overwash. Erosion of the beach area was noted along the north coast.

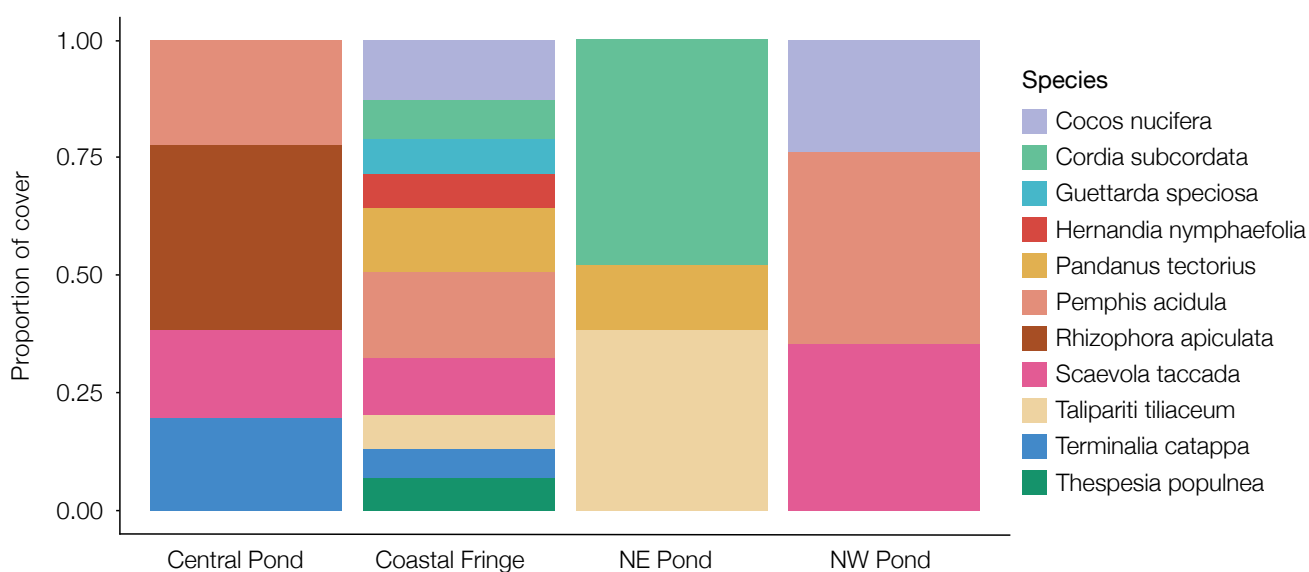


Figure 4: Percent cover of tree species at the four areas of vegetation surveyed on Bodulhaimendhoo

All terrestrial survey areas had refuse present. Plastic was the dominant type of waste observed followed by polystyrene foam, rubber, metal cans and glass. The amount of refuse found around the coastal fringe area was significantly greater than at the other three areas (Figure 5). All refuse items found were less than 50 cm².

Coral reef survey

The reef type around Bodulhaimendhoo was predominantly steep rocky wall, stretching from about 3 – 35 m deep. Both the north and south reef walls had numerous cave and fissures, however they were more abundant on the southern reef

wall. The more sheltered inner reef was the only area of reef slope. This area had little coral growth and was predominantly rubble and sand. Rock was the dominant abiotic substrate type on the northern reef, however rock sand made up approximately the same amount of the substrate at the southern site (Figure 5). Hard coral, CCA, soft coral and sponge combined to give a live reef cover of 40.5% and 49% on the north and south sites respectively (Figure 6). Turf algae was virtually absent from the surveys and macroalgae was absent from the south site and had less than 2% cover across the northern site.

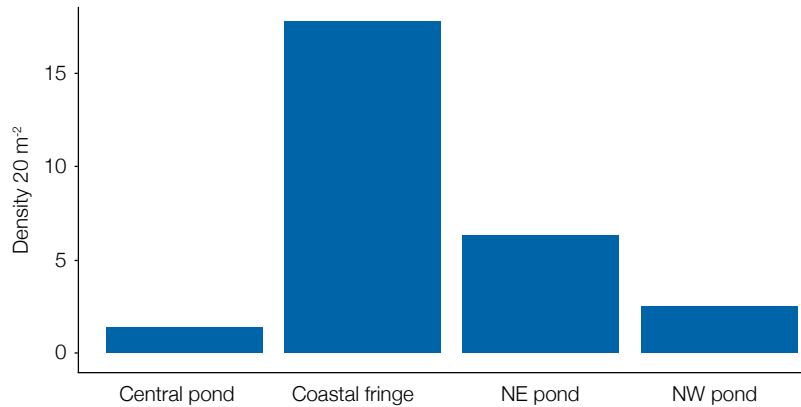


Figure 5: Mean number of items of refuse found in per 20 m² survey point in the four areas of vegetation surveyed on Bodulhaimendhoo

Birds were observed across all island habitats (Table 2). Fish were only observed in the large central pond (Table 3). There were some gastropods observed in the smaller ponds however. A high number of a turtle nests were observed on the beach area along the west and south of the island, though none appeared to contain eggs at the time of surveys.

Species	Common Name	Dhivehi Name	Abundance
<i>Numenius phaeopus</i>	Whimbrel	Bulhithunbi	3
<i>Eudynamis scolopacea</i>	Asian Koel	Dhivehi Koveli	5
<i>Nycticorax nycticorax</i>	Black-crowned Night Heron	Raabondhi	3
<i>Casmerodius albus</i>	Great Egret	Laganaa	1
<i>Ardea cinerea</i>	Grey Heron	Alhi Maakanaa	1
<i>Pluvialis dominica</i>	Lesser Golden Plover	Funamaa Dhushin	2
<i>Actitis hypoleucos</i>	Common Sandpiper	Fin'dhana	5

Table 2: Bird species observed during the terrestrial surveys at Bodulhaimendhoo

Zone	Family	Common Name
Central pond	Poeciliidae	Molly
Central pond	Unidentified	

Table 3: Fish families observed in water bodies on Bodulhaimendhoo

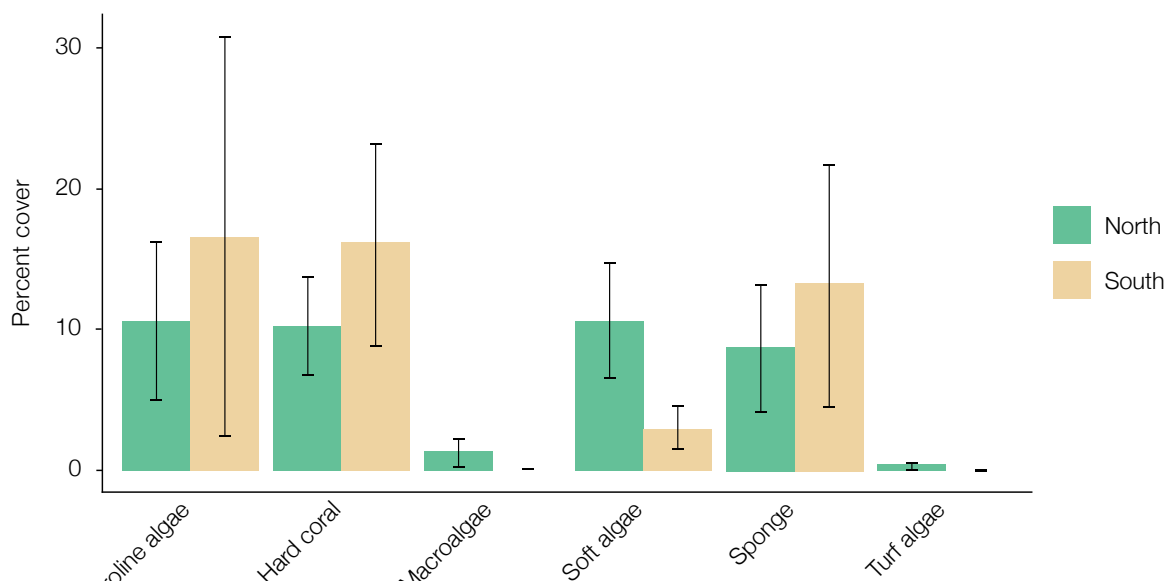


Figure 6: Percent cover of biotic substrate at the two Bodulhaimendhoo reef survey sites.

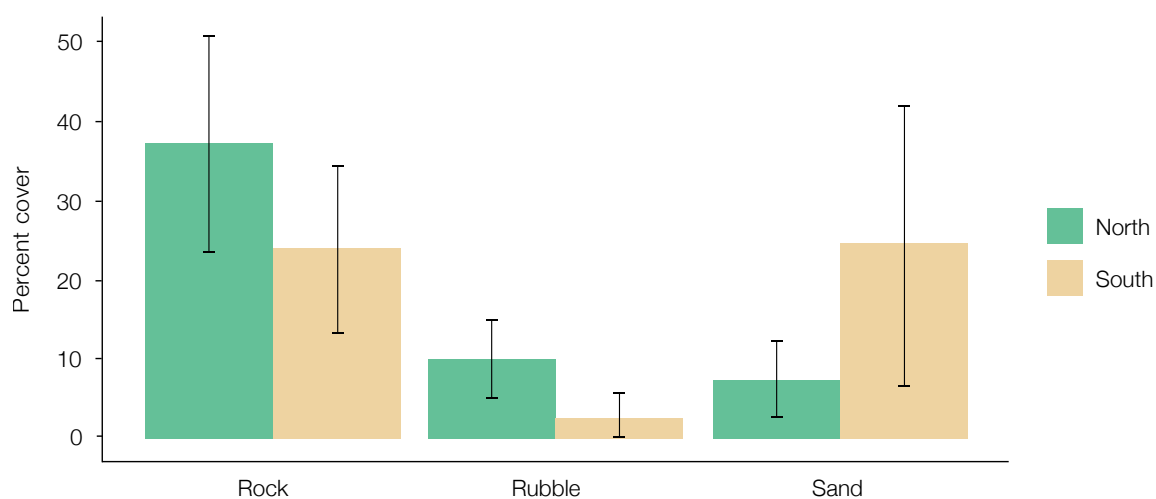


Figure 7: Percent cover of abiotic substrate at the two Bodulhaimendhoo reef survey sites.

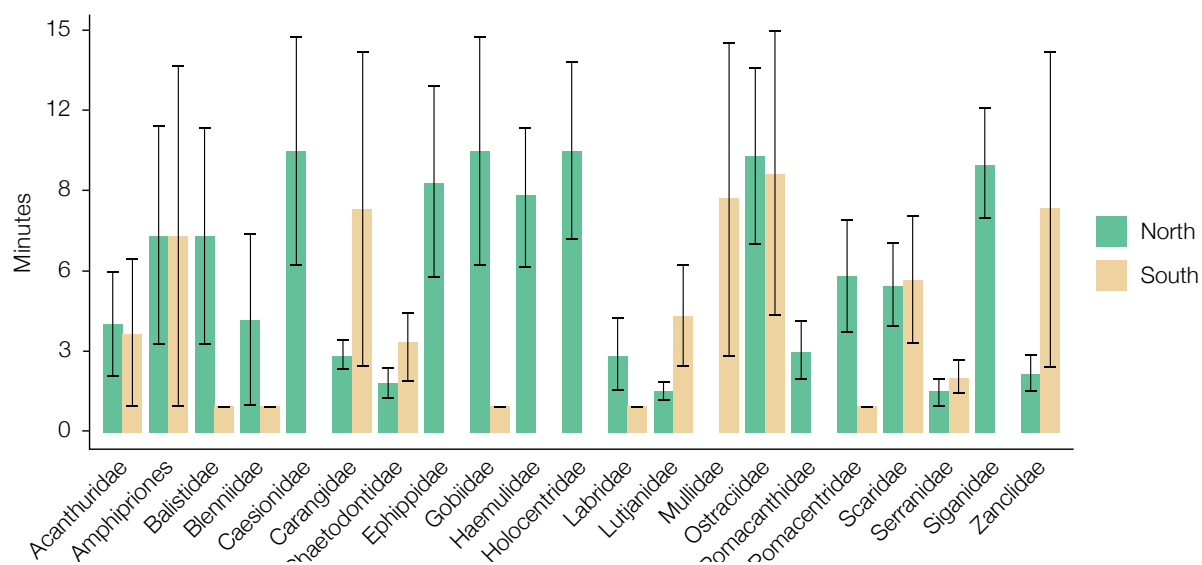


Figure 8: Mean time to first observation of fish families. Only families observed on a minimum of 5 surveys were included. Where values are equal to zero the family was absent from that site.

A total of 37 families of reef associated fish were observed during surveys (Table A1). Only *Acanthuridae*, *Chaetodontidae*, Labridae, Lutjanidae, Pomacentridae, *Scaridae* and *Serranidae* were observed on all surveys. Six families were recorded only at the north reef site (Figure 8). The herbivorous families *Acanthuridae* and *Scaridae* were observed within the first six minutes of all surveys. Lutjanidae were observed in less than 8 minutes on all surveys and in less than 3 minutes northern reef surveys. *Chaetodontidae* were rapidly observed across all surveys.

variation in age from the older, denser habitat in the north to the younger, less-developed area in the south and south-west. The position of the island means the reefs are exposed to waves and strong currents. There is limited coral development on the narrow, shallow reef flat as a result of this exposure. The steep reef walls had a significant amount of CCA and hard coral growth on both the north and south sides. The reef walls had numerous caves and large overhangs, inside which were large areas of soft coral and sponge growth.

The exposed position of the island and strong currents would make it a challenging fishing location which might explain the absence of any obvious impacts.

Mangrove growth was limited to the large central pond, and to just a single species *Rhizophora apiculata*. This genus is characterised by large prop roots which intertwine to create a complex habitat above and below the water and is important for many fish, bird and insect species. However, due to poor water visibility and difficulty surveying the large, soft

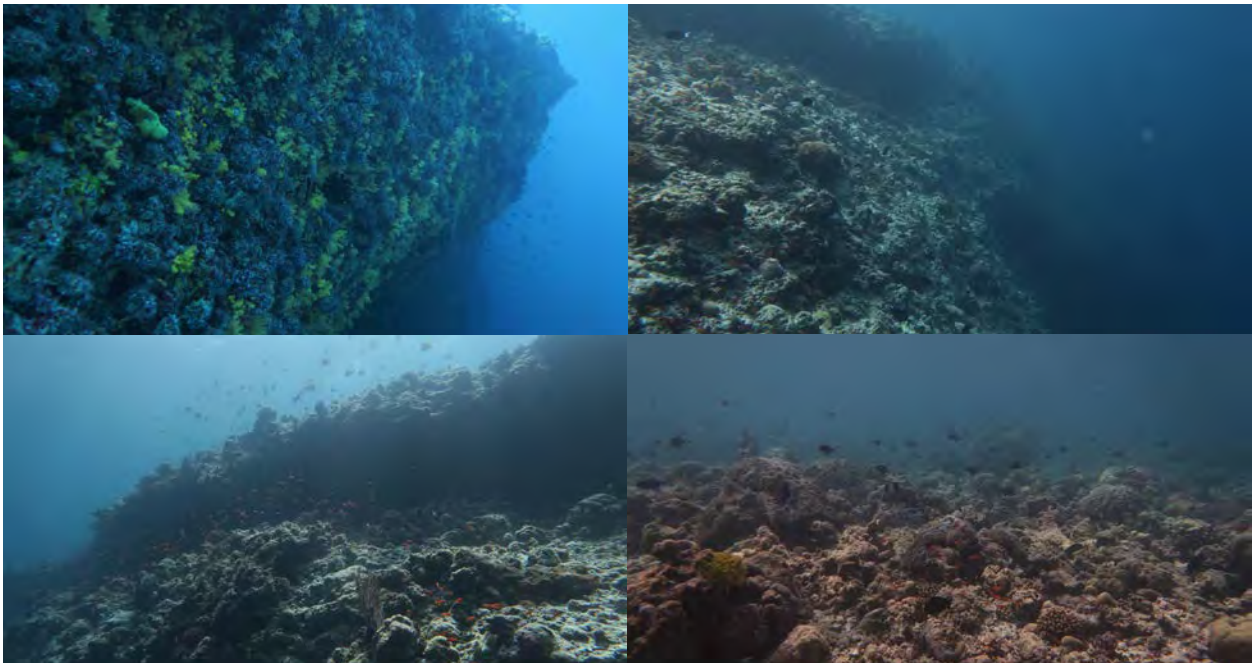


Figure 9: Images of the coral reef around Bodulhaimendhoo

Discussion

Bodulhaimendhoo is an unusual island habitat for the Maldives. It is more common across the country for the central area to remain open to the sea, creating a shallow sheltered bay area, rather than a closed pond habitat. However, here thick scrub vegetation around the south of the island has closed off the pond and created a consolidated beach habitat. The vegetation varies across the habitats, the coastal fringe has a diverse range of species and is not dominated by any one species this may be due to a

The island environment does not appear to be subject to much direct human impact. The refuse was predominantly found in the coastal fringe area and consisted of marine debris likely washed ashore from inhabited islands or boats rather than dumped there. There was no suggestion that the island was used as a picnic island for locals. There was no evidence of any timber harvesting on the island. The fish community also showed few signs of fishing impacts. Lutjanidae and *Serranidae*, the two most common reef fishery families were rapidly observed on all surveys, with large schools occasionally observed.

sediment bottom pond very few fish were identified in the pond. Mangrove species are susceptible to changes in the surrounding environment and can be impacted by changing water salinity and pH or the moisture content of muddy areas (Kathiresan and Bingham 2001). The closure of the pond from the sea has created a more uniform habitat and may have resulted in a reduction in the number of mangrove species present.

Islands in the Maldives are dynamic, constantly changing in shape and size (Kench and Brander 2006). Mangroves and coastal vegetation play a key role in

this process by binding and stabilising sediments around the shoreline and are considered to act as a natural barrier against ocean dynamics. They can protect the shore and inland areas from natural disasters such as tsunamis (Alongi 2008). They can break the force of waves and help to prevent coastal-erosion processes (Mazda et al. 2002). Island instability and increasing human populations have led to the reliance on engineered structures to combat erosion and maintain island shorelines. The introduction of such structures can result in a range of negative environmental impacts, including accelerated erosion and reef degradation (Maragos 1993). An examination of the efficacy of these engineered structures has proposed the revaluation of islands as “static landforms” with one that recognises the natural dynamism of the islands and emphasises the management of natural geomorphic processes (Kench 2012).

Herbivore populations at the two outer reef survey sites were greater than the average numbers found during a 2017 – 2018 nationwide survey (IUCN, in press). Herbivorous fish, such as parrotfish and surgeonfish are important in preventing coral reefs from becoming overgrown by algae following disturbances (Hughes et al. 2007, Mumby et al. 2007). The numbers found at surveys across the country, and here are likely to confer a level of resilience to Maldivian reefs. Herbivores can experience short- to medium-term benefits following reductions in coral cover (Wilson et al. 2006, 2009). There is no fishery targeting these species meaning there is no reason their numbers should decline in the near-future, however there is evidence that localised parrotfish is occurring in some areas. It is therefore key management efforts include education on their importance to reef health. Parrotfish have also been found to play an important role in sediment creation and island development and maintenance (Morgan and Kench 2016). With future sea level change threatening to impact the low-lying islands of the Maldives healthy

parrotfish populations will be important in maintaining island growth at the rates of any change in sea level.

Compared the benthic community found during a wide-ranging survey in 2017 – 2018 (IUCN, in press) the substrate in Bodulhaimendhoo was close to the national averages. Coral cover slightly below the national average and algae cover was significantly lower. However, due to the reef types surveyed here a direct comparison cannot be made to many of the country's reefs. The steep walls and caves present typically have lower live coral cover than reef flats. There is an increasing demand for land area in the Maldives, mainly for agricultural expansion, industrial growth and for housing (Thupalli 2009). Population growth is creating demands on the land area for food production and housing. Furthermore, expansion of the tourist industry may threaten habitats on uninhabited islands and shallow coral reefs, as plans for new airports and resorts require land reclamation and redevelopment of these sensitive areas.

Human activities over the past 150 years have caused approximately 0.85°C of climate warming (IPCC 2014) and it is likely that it will continue to warm by at least 1.5°C between 2030 and 2052 (IPCC 2018). The impacts of climate change will pose a significant threat to both the people and the natural environment of Kendhikulhudhoo.

Increases in ocean temperatures will lead to more frequent and severe coral bleaching events (Hoegh-Guldberg 2011), similar to 2016 which had led to widespread coral mortality (Ibrahim et al. 2017). 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). However, when the opposite is true, and corals have less competition for space on reefs colonies are able to expand and coral larvae are able to settle and grow more successfully (Johns et al. 2018). This increases a coral reef's chances of recovery following disturbances.

Human activities over the past 150 years have caused approximately 0.85°C of climate warming (IPCC 2014) and it is likely that it will continue to warm by at least 1.5°C between 2030 and 2052 (IPCC 2018). 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 0.26 – 0.77 m by 2100 (IPCC 2018). Depending on the actual level and the rate of change 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 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 will limit island erosion and may enable island growth to keep pace with any sea level change.

Bodulhaimendhoo has benefitted from having few resources for local people. Fishing the reef area is made challenging by its exposed location and strong currents. Narrow beaches that have no shelter means it is not a popular picnic spot. The terrestrial area of the island is relatively small and is covered by dense vegetation, making agricultural development difficult. The large central pond is unsuited to aquaculture due to the soft sediment and stagnant water, which has little exchange with the sea. Despite these features the island is not fully protected from future human impacts. It is therefore necessary to put in place

management measures that will prevent such impacts from damaging this valuable habitat.

Management

The ecological management goal for Kendhikulhudhoo is to provide a means to promote and ensure the long-term conservation and protection of the island's ecosystem. Existing local management efforts should be coordinated and developed further with this goal in mind. The aim should also be to utilise strategies and action plans local and national governments have developed 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 this goal. The main goal is broken down into two sub-goals: 1) to maintain the resilience of biological communities to stressors associated with climate change and 2) to maintain populations of unharvested species for social development, fishery enhancement and island health. Future efforts should aim to monitor and manage for resilience (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. The management plan could consider the following elements:

- The development of a long-term monitoring programme for pond, 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.
- A plan for development and enforcement of regulations in the area.

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Appendix

Family	Common Name	Number of surveys	Family	Common Name	Number of surveys
<i>Acanthuridae</i>	Surgeonfish	9	<i>Lutjanidae</i>	Snapper	9
<i>Apogonidae</i>	Cardinalfish	3	<i>Malacanthidae</i>	Tilefish	1
<i>Aulostomidae</i>	Trumpetfish	1	<i>Microdesmidae</i>	Dart Goby	3
<i>Balistidae</i>	Triggerfish	7	<i>Mullidae</i>	Goatfish	5
<i>Blenniidae</i>	Blenny	8	<i>Muraenidae</i>	Moray Eel	2
<i>Caesionidae</i>	Fusilier	3	<i>Nemipteridae</i>	Spinecheek	1
<i>Carangidae</i>	Jack	8	<i>Ostraciidae</i>	Boxfish	6
<i>Carcharhinidae</i>	Requiem Shark	2	<i>Pinguipedidae</i>	Grubfish	1
<i>Chaetodontidae</i>	Butterflyfish	9	<i>Pomacanthidae</i>	Angelfish	8
<i>Cirritidae</i>	Hawkfish	3	<i>Pomacentridae</i>	Anemonefish	9
<i>Dasyatidae</i>	Stingray	1	<i>Pomacentridae</i>	Chromis	4
<i>Diodontidae</i>	Porcupinefish	1	<i>Pomacentridae</i>	Damselfish	2
<i>Ephippidae</i>	Batfish	4	<i>Scaridae</i>	Parrotfish	9
<i>Fistulariidae</i>	Flutemouth	1	<i>Scombridae</i>	Tuna	2
<i>Gobiidae</i>	Goby	6	<i>Scorpaenidae</i>	Lionfish	1
<i>Haemulidae</i>	Sweetlips	5	<i>Serranidae</i>	Basslet	9
<i>Holocentridae</i>	Squirrelfish	5	<i>Serranidae</i>	Grouper	6
<i>Kyphosidae</i>	Rudderfish	1	<i>Siganidae</i>	Rabbitfish	6
<i>Labridae</i>	Wrasse	9	<i>Tetraodontidae</i>	Pufferfish	6
<i>Lethrinidae</i>	Emperor	4	<i>Zanclidae</i>	Moorish idol	8

Table A 1: All fish families observed on surveys in Bodulhaimendhoo

Species	Common name	Dhivehi name	Mangrove species
<i>Cocos nucifera</i>	Coconut palm	Dhivehi ruh	No
<i>Cordia subcordata</i>	Sea trumpet	Kaani	No
<i>Guettarda speciosa</i>	Beach gardenia	Uni	No
<i>Hernandia nymphaeifolia</i>	Hernandia	Kandhu	No
<i>Pandanus tectorius</i>	Screw pine	Boa Kashikeyo	No
<i>Pandanus tectorius</i>	Screw pine	Boa Kashikeyo	No
<i>Pemphis acidula</i>	Iron wood	Kuredhi	No
<i>Rhizophora apiculata</i>	Tall-stilted mangrove	Thakafathi	Yes
<i>Scaevola taccada</i>	Sea lettuce	Magoo	No
<i>Talipariti tiliaceum</i>	Sea hibiscus	Dhigga	No
<i>Terminalia catappa</i>	Indian almond	Midhili	No
<i>Thespesia populnea</i>	Thespesia	Hirun'dhu	No

Table A 2: All vegetation species observed on surveys in Bodulhaimendhoo



DHIFFUSHIMAADHOO

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 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 Dhiffushi Maadhoo in Lhavyani Atoll 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 scattered 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 and Hatcher 2004). Maldivian islands are known as low lying islands with 80% of the country being less than a meter above the sea level and the majority of islands being less than 5km² in size. (Ministry of Environment and Energy 2015). Studies to understand the atoll and island formation have suggested that the island reefs in the Maldives have been around 4000 yr. B.P (Kench et al. 2005, Perry et al. 2013).

The terrestrial fauna and flora have a rich biodiversity. The range of natural island habitats includes beaches, marshes, brackish ponds, mangroves and woodlands. There are 583 species of terrestrial flora found, of which 323 are cultivated and 260 are natural. The farmed species are mostly used as a source of food and some for traditional medicine. Mangroves

ecosystems can be classified based on the system's exposure to the sea as either "open mangrove systems" or "closed mangrove systems. These can then be further subdivided into four categories (Saleem and Nileysa 2003) (Table 1). In all but marsh-based mangroves, tree growth is limited to a narrow band around the water's edge. Around 15 species of mangroves are found across approximately 150 islands (Ministry of Environment and Energy 2015). Maldivian avifauna is made up of seasonal migrants, breeding residents and introduced birds. Over 167 species of birds have been recorded in the Maldives. Around 70 species of shorebirds are recorded, some of which are breeding residents while others are recorded as migrants. Migratory birds visit during certain seasons to breed or use the islands as a transit point to their breeding grounds (Ministry of Environment and Energy 2015).

Open mangrove systems	Coastal fringing mangroves	Exposed mangroves growing directly on the shoreline. Experience regular wave action. Uncommon mangrove system
	Embayment mangroves	Mangroves partly encircle a bay area. Experience daily tidal flushing. Common mangrove system
Closed mangrove systems	Pond-based mangroves	Mangroves encircle a brackish water pond. Possible water exchange through bedrock or overwash. Common mangrove system
	Marsh-based mangrove	Mangrove found on muddy substrate with no standing water. Dampness of mud may come from flow through the bedrock or overwash. Uncommon mangrove system

Table 1: Description of the four types of mangrove ecosystems found in the Maldives. From Saleem and Nileysa (2003)

Terrestrial habitats are threatened by many local scale factors including infrastructure development, human waste and land reclamation projects. Similar to the marine environment, habitats such as mangrove areas are known for their ecological significance and diversity, providing habitats and services to animal and human communities (Kuenzer et al. 2011). However, due to historical and continued undervaluation, most 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 infrastructure development. Refuse dumping has had a major impact on the terrestrial and marine environment. Around 1.7kg of waste is generated per capita in Male' alone (Ministry of Environment and Energy

2015). This highlights the need for proper waste management in the Maldives. At present, 128 waste management centres are established across Maldives, and regional waste management centres are planned for major populated areas such as Addu City. The government has increased their efforts to manage the waste issue by incorporating the 3Rs (Reduce, Reuse, Recycle) concept into policy and investing on local waste management centres. However, many populated islands are far away from regional waste management centres making dumping waste on land or in the sea the most convenient disposal option for a large proportion of the population.

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 dependent on the profits around these industries. This highlights the significance of the natural environment to the Maldives and 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 the sustainable use and management of these natural resources within communities. Such approaches will play a key role in standardizing the efforts to manage and monitor the resources in a co-managed concept.

Study site

Dhiffushi Maadhoo island is located on Faadhippolhu (Lhaviyani) atoll. Lhaviyani is one of the 16 complex atoll systems in the Maldives. The atoll comprises of 81 islands (5 community islands, 7 resorts and 69 uninhabited islands). There are 84 individual reef systems within the atoll (Ministry of Environment and Energy 2015). The total human population of the atoll is 12,674 (National Bureau of Statistics, 2014). The main economy of the atoll like much of the country is based on pelagic fishery and tourism activity. In particular, tourism on community islands appears to be growing rapidly with the increase in number of guest houses and the provision of tourism related activities on these islands across the atoll.

Dhiffushi Maadhoo is an uninhabited island on the eastern side of Lhaviyani atoll. It is the northern most island of a long reef area that extends for approximately 30 km around the south east corner of Lhaviyani atoll. It shares this reef area with eight other islands. Hudhufushi, the island next to Dhiffushi Maadhoo on the reef also has an embayment. The nearest community island is Olhuvelifushi, approximately 15 km south on the same stretch of reef. This survey focused on the northern area of Dhiffushi Maadhoo from (5.415 degrees) north. This section of the island is separated longitudinally into two halves by a long shallow bay. The southern end of the bay is open to the ocean. The northern enclosed edge has been reported to be drying up, resulting in a shallow and muddy area.'



Figure 1: Map of Dhiffushi Maadhoo survey areas. Yellow polygons indicate terrestrial survey areas, ©Google Earth 2019

Methods

The terrestrial survey area on Dhiffushi Maadhoo was identified as the habitat at the north end of the island and focused on the coastal fringe and mangrove bay areas. Survey points were identified using a stratified sampling approach with sites selected around pond fringes and throughout the wetland areas. GPS coordinates were extracted from Google Earth© version 7.3.1 and entered into a handheld GPS (either Garmin etrex 20x or Garmin GPS maps 64s) for navigation to the point (Figure 2). At a survey point, a 2.5 m radius circle was estimated and the dominant and secondary flora within the area were identified to species and their respective percent covers were estimated. The height of the dominant species was estimated to the nearest metre. Substrate type was recorded and counts of crab burrows and rubbish were conducted. The number

of survey points for each zone was dependent on zone size and accessed on foot. If identified points were inaccessible, a new point was taken as close as possible to the original point and the survey was performed here.

Wetland bird and fish surveys were conducted concurrently with terrestrial habitat surveys. All birds observed were identified to species. Fish were identified to family and their abundance was estimated.



Figure 2: Recording data at a terrestrial survey point

Results

Nine species of flora were identified during the surveys (Table 2), including a single species of mangrove. *Pemphis acidula* was the dominant vegetation in both survey areas. In the coastal fringe and mangrove bay it made up over 65% and 95% respectively of the total vegetation recorded (Figure 1). Both habitats had a similar mix of species. The mangrove species recorded was *Heritiera littoralis*. A single adult tree was found surround by many juvenile trees.

Emperors (*Lethrinus harak*), Mangrove Whipray (*Himantura granulata*) and Blacktip reef Sharks (*Carcharhinus melanoptera*).

Discussion

The bay at Dhiffushi Maadhoo appears to be an important area for marine and avifauna. Many juvenile reef fish were observed as well as a high number of prey fish species. The number of juvenile blacktip reef sharks suggests

shrub vegetation found throughout the Maldives and grows well in the sandy calcareous soils. It generally dominates the vegetation on exposed and rocky shores. However, *P. acidula* is not a mangrove species and provides few of the ecosystem services that mangrove trees are known to (Mumby et al. 2004, Nagelkerken et al. 2008). In embayments in the Maldives it is more common for mangrove trees to form a significant part of the flora e.g. Farukolhu. Sh and Dhigulaabadhoo GDh (IUCN, in press). The bay area

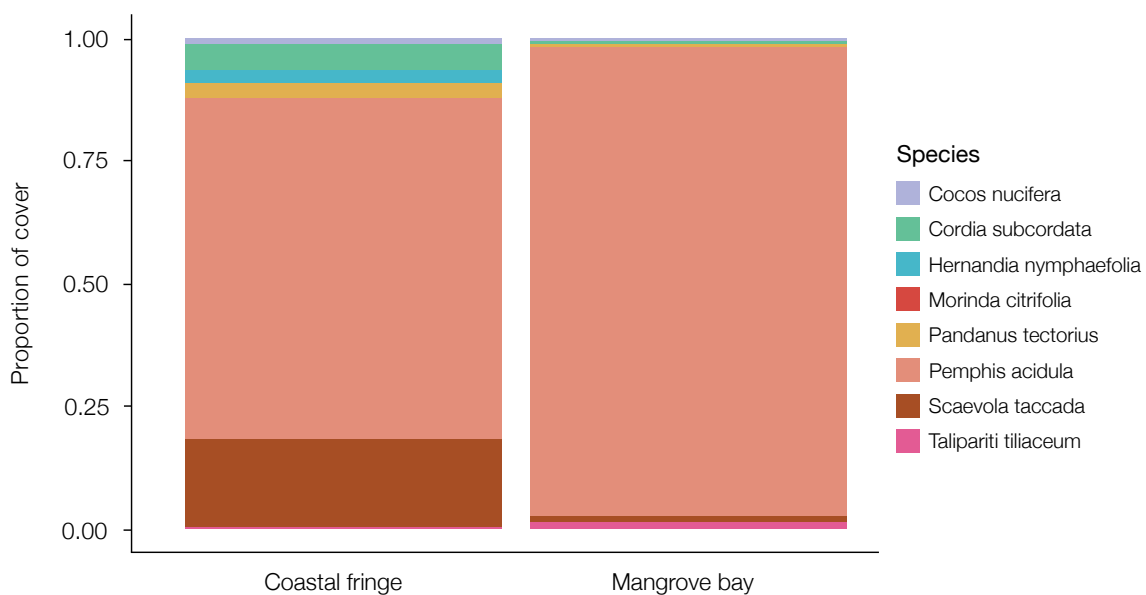


Figure 3: Proportion of cover of tree species at the two vegetation areas surveyed

Both terrestrial survey areas had refuse throughout, however the density of waste along the coastal fringe was much greater (Figure 3). Plastic was the dominant type of refuse observed followed by polystyrene foam, metal cans, rope, rubber and glass. Several large fishing nets were also found washed up on the shore.

A range of bird species were observed throughout the mangrove bay area (Table 2). A solitary nest was recorded in one of the trees in this area. The bay had an abundant population of mojarra (Table 3). Many juvenile species of fish were also observed in the bay including Mangrove Jacks (*Lutjanus argentimaculatus*), Black-blotch

the bay is important pupping area for these sharks. This is also likely to be true for the embayment on Hudhufushi just south of Dhiffushi Maadhoo. Birds nests were observed in the trees around the bay area, indicating there is a resident bird population here. The large beach area and fish species observed in the bay also make this island a potential foraging ground for a range of bird species. Turtle nests were found on the beach along the western side of the island. At least one of these had track marks from hatchlings emerging from the nest.

The vegetation around both the bay and coastal fringe was dominated by *Pemphis acidula*. This is a common

here however, had a solitary adult *H. littoralis* mangrove tree, though this was surrounded at its base by a high number of juvenile trees. The relative absence of mangrove trees might indicate a disturbance event shifting the dynamics of the bay away from conditions favourable for mangroves. The desiccation of the area at the north east of the pond may be further indication of this change in condition. Potentially an increased deposition of sediment at the mouth of the bay may be impacting water flow, however without a time series of images or data it is not possible to determine the cause.

There is an increasing demand for land area in the Maldives, mainly for agricultural expansion, industrial growth and for housing (Thupalli 2009). Population growth is creating demands on the land area for food production and housing. Furthermore, expansion of the tourist industry may threaten habitats on uninhabited islands and shallow coral reefs, as plans for new airports and resorts require land reclamation and redevelopment of these sensitive areas. It is important for the ecological health and diversity of the country that islands such Dhiffushi Maadhoo, which have not yet been significantly impacted by coastal development remain untouched.

Islands in the Maldives are dynamic, constantly changing in shape and size (Kench and Brander 2006). Mangroves and coastal vegetation play a key role in this process by binding and stabilising sediments around the shoreline and are considered to act as a natural barrier against ocean dynamics. They can protect the shore and inland areas from natural disasters such as tsunamis (Alongi 2008). They can break the force of waves and help to prevent coastal-erosion processes (Mazda et al. 2002). Island instability and increasing human populations have led to the reliance on engineered structures to combat erosion and maintain island shorelines. The introduction of such structures can result in a range of negative environmental impacts, including accelerated erosion and reef degradation (Maragos 1993). An examination of the efficacy of these engineered structures has proposed the revaluation of islands as “static landforms” with one that recognises the natural dynamism of the islands and emphasises the management of natural geomorphic processes (Kench 2012).

Though the island is uninhabited it is not free from human waste. The shoreline had a very high volume of refuse on the beach and entangled in the vegetation. Waste management is clearly 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). Of particular significance here were the many fishing nets found. These can do significant damage to marine life whilst in the water (Matsuoka et al. 2005) and the number found here indicate there are likely to be many more still drifting in the sea. Regional waste strategy and action plans are being developed (Ministry of Environment 2019) to identify and develop practical approaches for waste management. The recommendations in such plans should be incorporated in future management plans. Campaigns, such as the “National campaign to reduce plastic bottles” provide publicity and education on the need for waste reduction, particularly on single use plastics. However, many small islands have no clean safe drinking water to refill their water bottles.

Human activities over the past 150 years have caused approximately 0.85°C of climate warming (IPCC 2014) and it is likely that it will continue to warm by at least 1.5°C between 2030 and 2052 (IPCC 2018). 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 0.26 – 0.77 m by 2100 (IPCC 2018). Depending on the actual level and the rate of change this increases the risk of storm damage to wetlands and ponds, as well as human settlements and may result in eventual inundation of them by sea water. Healthy 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 will limit island erosion and may enable island growth to keep pace with any sea level change.

Management

The ecological management goal for Dhiffushi Maadhoo is to provide a means to promote and ensure the long-term conservation and protection of the island's ecosystem. Existing local management efforts should be coordinated and developed further with this goal in mind. The aim should also be to utilise strategies and action plans local and national governments have developed 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 this goal. The main goal is broken down into two sub-goals: 1) to maintain the resilience of biological communities to stressors associated with climate change and 2) to maintain populations of unharvested species for social development, fishery enhancement and island health. Future efforts should aim to monitor and manage for resilience (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. The management plan could consider the following elements:

- The development of a long-term monitoring programme for the bay habitat in order to track ecological changes over time.
- Island geographical and topographical monitoring programme to monitor and map the structural development of the island.
- A plan for development and enforcement of regulations in the area.
- Active management of the bay area to promote mangrove growth. This may include:
 - + Planting of juvenile mangroves
 - + Managing water flow into the bay

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Appendix

Species	Common name	Dhivehi name
<i>Ardea cinerea</i>	Grey heron	Maakana
<i>Numenius phaeopus</i>	Whimbrel	Bulhi Thunbi
<i>Charadrius mongolus</i>	Lesser Sand-plover	Bondana
<i>Actitis hypoleucos</i>	Common Sandpiper	Findhana
<i>Arenaria interpres</i>	Ruddy Turnstone	Rathafa
<i>Phaethon lepturus</i>	White-Tailed Tropic Bird	Dhandifulhu Dhooni
<i>Amauromis phoenicurus</i>	White-breasted Waterhen	Kanbili
<i>Nycticorax nycticorax</i>	Black-crowned Night Heron	Raabondhi
<i>Corvus corax</i>	Crows	Kaalhu

Table A 1: Bird species observed in the mangrove bay area

Species	Common name	Abundance
<i>Gerres oyena</i>	Blacktip pursemouth	1000
<i>Lethrinus harak</i>	Blackspot emperor	30
<i>Ostracion cubicus</i>	Yellow boxfish	2
<i>Lutjanus argentimaculatus</i>	Mangrove red snapper	5
<i>Caranx melampygus</i>	Blacktip reef shark	8
<i>Corythoichthys haematopterus</i>	Pipefish	3
<i>Chromis viridis</i>	Blue-green chromis	6

Table A 2: Fish species observed in the mangrove bay area



DHIGULAABADHOO

Introduction

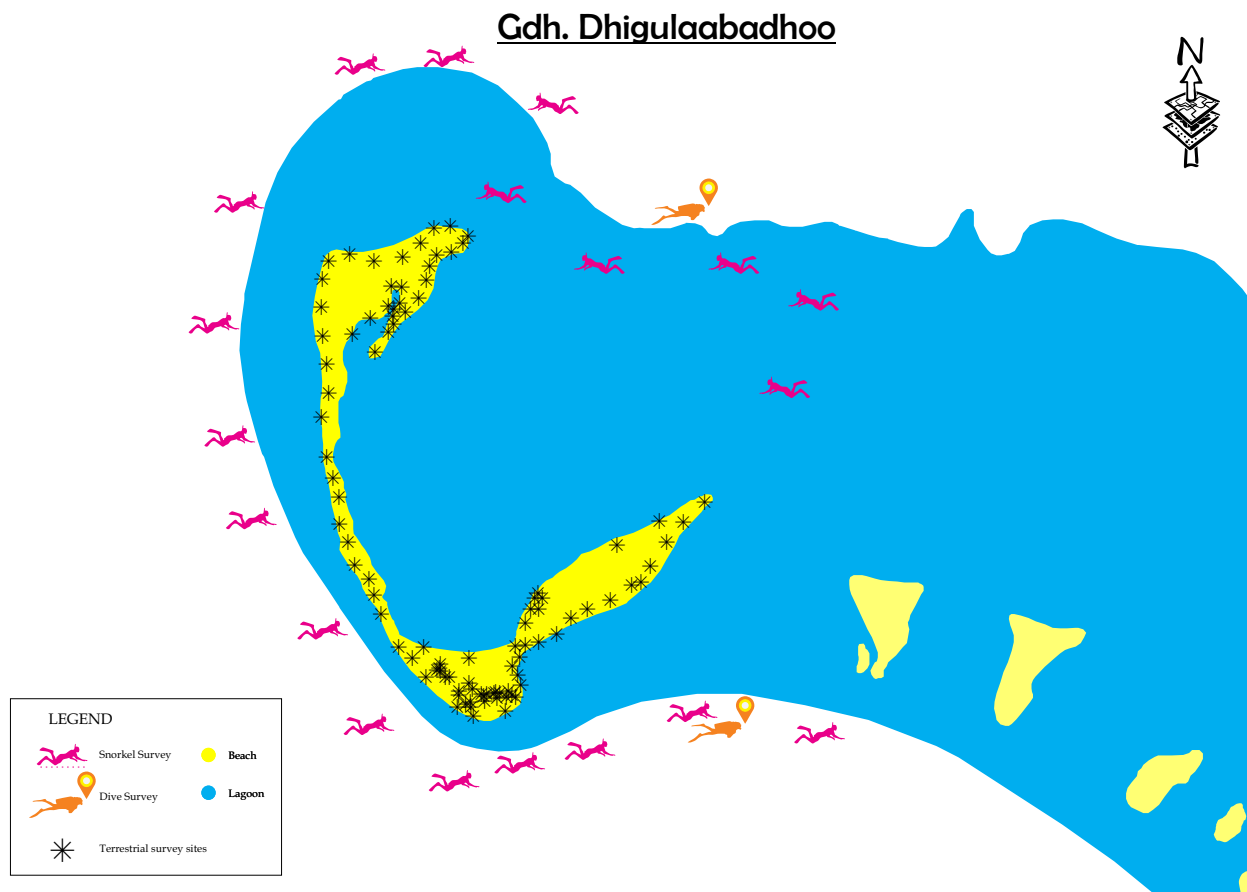
Dhigulaabadhoo is an uninhabited U-shaped island at the southern edge of one of the largest inhabited atolls in the world. The perimeter of the island had coastal scrub vegetation typical of the region. The northern section of the island had a dense wooded area inland. The southern section had several small brackish ponds, likely formed by the collection of the

rainwater in depressions. There was also an area of coconut grove that is regularly harvested. Pond vegetation was made up of the same species as the coastal scrub communities, with no true mangrove species present. Ponds contained small fish and gastropods and several bird species were observed in the surrounding vegetation. There was a large bay area with a smaller mangrove bay in the north. Many juvenile sharks and rays were observed throughout the mangrove bay, as well juvenile reef fish and birds.

There were several large patch reefs extending from the bay area to the outer reef. These had high coral cover of resilient *Porites* corals and had high numbers of juvenile reef fish. A fringing reef was present around the outside of the island. The outer atoll facing reef had many small branching and table corals. The inner atoll facing reef and channel reef area had some large patches of dead coral.

Site	Latitude	Longitude
1	0.22140	73.16577
2	0.20492	73.16527

Table 1. Latitude and longitude of the quantitative survey sites



Coral Reef Benthos



Figure 1. Branching and Tabular corals complementing the complexity of the reef found in Laabadhoo



Figure 2. Massive coral boulders found inside the lagoon of Laabadhoo

Two sites were surveyed using quantitative transect methods (Table 1). The mean coral cover of 28% was amongst the highest observed during the ecological surveys. High covers of both rock and CCA indicate good settlement conditions for potential coral recruits. Macro algal cover was

relatively high which and this should be monitored to ensure areas of reef to do not become algal dominated. The highest coral cover was found on the outer reef (36%). Structural complexity was high at survey sites with a mean of 3.7 for the reefs.

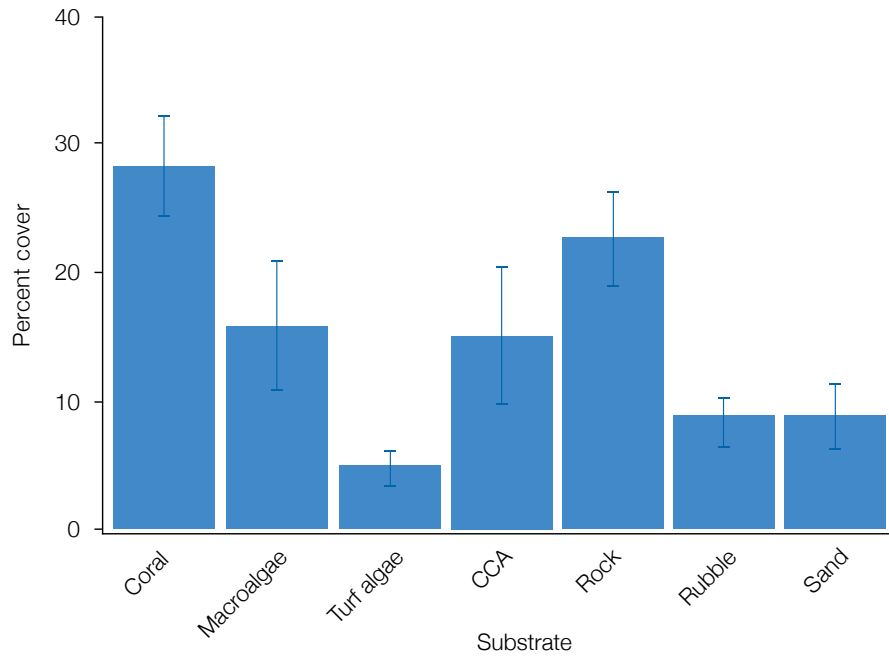


Figure 3. Mean percentage cover of substrate categories across all surveys on Dhigulaabadhoo

Site	Complexity	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	4.0	19.0	27.5	5.8	25.6	5.8	8.6	2.0	2.6	2.6
2	3.3	35.3	3.4	0.0	17.4	9.1	1.9	29.8	0.0	3.0

Table 2. Location, mean complexity and mean substrate cover of the quantitative surveys.

Fish community:

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy

reef areas. 51 reef associated fish families were observed across the country, 28 of which were found on Dhigulaabadhoo. Densities of the key herbivores, surgeonfish and parrotfish were high. Herbivores are a functionally important group on coral reefs They play a key role in keeping algae levels low enough for corals to thrive (Mumby

et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country. It is important that preservation of these herbivores is part of any future management plan.

Site	Total number of families	Mean number of families
Dhigulaabadhoo	28	16.1
1	27	16.0
2	25	16.2

Table 3. Location, total number of fish families and mean number of fish families per transect observed across all sites and at individual survey sites

Site	Total number of grouper species	Mean number of grouper species	Mean grouper density /100m ²	Total number of butterflyfish species	Mean number of butterflyfish species	Mean butterflyfish density /100m ²
Dhigulaabadhoo	9	3.4	4.0	8	2.3	2.4
1	8	3.3	3.8	6	2.3	3.3
2	4	3.0	4.3	4	1.2	1.7

Table 4. Location, total number of species, mean number of species and mean density per transect observed for grouper and butterflyfish across all sites and at individual survey sites

Site	Total number of parrotfish species	Mean number of parrotfish species	Mean parrotfish density /100m ²	Total number of surgeonfish species	Mean number of surgeonfish species	Mean surgeonfish density /100m ²
Dhigulaabadhoo	7	3.3	23.3	5	3.7	29.7
1	6	6.0	14.6	5	4.5	18.8
2	4	4.4	33.8	3	7.5	40.6

Table 5. Location, total number of species, mean number of species and mean density per transect observed for parrotfish and surgeonfish across all sites and at individual survey sites

Number of Endangered Animals

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks

and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives; however, their populations are at risk from a decline in available nesting sites and the declining health of coral reefs. Evidence of turtle poaching was found along the beach of Dhigulaabadhoo.



Figure 4. Blacktip Reef Shark cruising in the reef



Figure 5. Turtle skeleton found buried in the island

Latitude	Longitude	Carcharhinus melanopterus	Cheilinus undulatus	Eretmochelys imbricata	Plectropomus areolatus	Plectropomus laevis	Stegostoma fasciatum	Triaenodon obesus	Tridacna sp.
0.20416	73.16131	1	1	1				1	
0.20495	73.16052		3	1		2			
0.21873	73.15098		1			1	1		
0.22131	73.15145		5			3			
0.22596	73.15537					3			2
0.22620	73.15806		1		1				

Table 6. Location and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed during rapid surveys.

Vegetation

The coastal fringe facing the outer atoll was dominated by *Scaevola taccada*, *Talipariti tiliaceum* and *Guettarda speciosa*. Here the vegetation line is far from the high-water line. *Pemphis scidula* dominated on the bay fringe where the high-water line reached the vegetation edge. The pond fringe areas were also dominated by these species,

though there were also patches of *Pandanus tectorius*. Ponds had no evidence of any mangrove vegetation. The mangrove bay was dominated by *Cerriops tegal*, with few stands of *Rhizophora mucronata*. The width of mangrove growth was very narrow, usually only a single tree deep. Though seedling density was not recorded, there was evidence of juvenile growth, an indicator of a healthy community.



Figure 6. Vegetation found in the island.



Figure 7. Mangrove trees found at the bay area of Laabaadhoo.

Scientific name	Common name	Dhivehi name	Zone		
			Coastal fringe	Pond fringe	Mangrove bay fringe
<i>Cocos nucifera</i>	Coconut palm	Dhivehi ruh	8.1		
<i>Cordia subcordata</i>	Sea trumpet	Kaani		14.4	
<i>Guettarda speciosa</i>	Beach gardenia	Uni	17.3		
<i>Ochrosia oppositifolia</i>	Cork wood tree	Dhun'buri	1.7		
<i>Pandanus tectorius</i>	Screw pine	Boa Kashikeyo	4.4		
<i>Pemphis scidula</i>	Iron wood	Kuredhi	23.4	39.9	11.2
<i>Scaevola taccada</i>	Sea lettuce	Magoo	33.3		
<i>Talipariti tiliaceum</i>	Sea hibiscus	Dhigga	11.7	45.7	
<i>Ceriops tagal</i>	Yellow mangrove	Karamana			66.3
<i>Rhizophora mucronata</i>	Red mangrove	Ran'doo			22.5

Table 7. Percent cover of plant species in the three vegetation zones surveyed.

Birds

A high number of birds were observed across the island. The bird species observed differed between survey zones. Birds were most abundant in the bay area. This might be due to the abundance of potential prey, including gastropods and small fish. Surveys were limited to daylight hours so no roosting was observed and we were unable to determine the location of any nesting sites.

Scientific name	Dhivehi name	Zone		
		Coastal fringe	Pond	Bay area
<i>Ardea cinerea</i>	Maakanaa	4		
<i>Ardeola grayii phillipsi</i>	Huvadho Raabondhi	3	2	
<i>Tringa hypoleucos</i>	Findhana	3		
<i>Casmerodius albus</i>	Lagana			2
<i>Nycticorax nycticorax</i>	Raabondhi			5
<i>Arenaria interpres</i>	Rathafai			2
<i>Numenius phaeopus</i>	Bulhithun'bi			2
<i>Tringa hypoleucos</i>	Findhana			3
<i>Amauromis phoenicurus maldivus</i>	Dhivehi Kambili		1	

Table 8. Abundance of bird species observed in the three zones surveyed

Mangrove Fish Community



Figure 8. Juvenile Blacktip Reefshark found in the Mangrove bay area of Laabaadhoo



Figure 9. Juvenile fish species found in the Mangrove bay area of Laabaadhoo



Figure 10. Juvenile fish species found in the Mangrove bay area of Laabaadhoo

The mangrove bay had an abundant and diverse fish community sheltering or hunting amongst the mangrove roots. A high number of juvenile sharks and rays were found, indicating this habitat is an important nursery ground. There were also juveniles of

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process.

every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Species	Common Name	Abundance
<i>Abudefduf septemfasciatus</i>	Nine-band sergeant	30
<i>Caranx melampygus</i>	Blue-fin jack	2
<i>Carcharhinus melanopterus</i>	Blacktip reef shark	5
<i>Corythoichthys haematopterus</i>	Reef-top pipefish	1
<i>Epinephelus caeruleopunctatus</i>	Small-spotted grouper	1
<i>Gerres oyena</i>	Black-tip pursemouth	189
<i>Lutjanus argentimaculatus</i>	Mangrove jack	1
<i>Lutjanus fulvus</i>	Blacktail snapper	3
<i>Lutjanus monostigma</i>	One-spot snapper	35
<i>Pastinachus sephen</i>	Cowtail stingray	7
<i>Siderea picta</i>	Peppered moray	6
<i>Sphyaena barracuda</i>	Great Barracuda	1

Table 8. Abundance of fish species observed in the mangrove bay

commercially important fish species such as blue-fin jacks, and snapper and groupers. The importance of mangrove bays as nursery habitats is undervalued across the country and a proper evaluation of the goods and services provided by the different mangrove, sea grass and wetland habitats needs to be conducted.

Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape

Island vegetation areas were classified into five vegetation zones based on location: coastal fringe, pond fringe, mangrove bay fringe, mangrove forest and inland forest. Survey points were identified within each zone using a stratified sampling approach and the GPS coordinates were extracted from Google Earth© version 7.3.1 and entered into a handheld GPS (Garmin etrex 20x) for navigation to the point. At a survey point a 2.5 m radius circle was estimated and the dominant and secondary flora within the area were identified to species and their respective percent covers were estimated. The height of the dominant species was estimated

to the nearest metre. Bird surveys were conducted concurrent with terrestrial habitat surveys. All birds observed were counted and identified to species. Mangrove fish surveys were conducted first during high tide when the bay was sufficiently deep, surveys were conducted from a boat, and then during low tide surveys were conducted on foot. All fish were counted and identified to family and where possible to species.

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- Secretariat of the South Huvadhu Atoll Council
- Small Island Research Group in Fares Maathodaa

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Annex

Fish families observed at Dhigulaabadhoo

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Surgeonfish	<i>Acanthuridae</i>	Sweetlips	<i>Haemulidae</i>	Rabbitfish	<i>Siganidae</i>
Cardinalfish	<i>Apogonidae</i>	Soldierfish	<i>Holocentridae</i>	Lizardfish	<i>Synodontidae</i>
Trumpetfish	<i>Aulostomidae</i>	Squirrelfish	<i>Holocentridae</i>	Pufferfish	<i>Tetraodontidae</i>
Triggerfish	<i>Balistidae</i>	Rudderfish	<i>Kyphosidae</i>	Triplefin	<i>Tripterygiidae</i>
Blenny	<i>Blenniidae</i>	Wrasse	<i>Labridae</i>	Moorish idol	<i>Zanclidae</i>
Fusilier	<i>Caesionidae</i>	Emperor	<i>Lethrinidae</i>	Surgeonfish	<i>Acanthuridae</i>
Jack	<i>Carangidae</i>	Goatfish	<i>Mullidae</i>	Cardinalfish	<i>Apogonidae</i>
Butterflyfish	<i>Chaetodontidae</i>	Boxfish	<i>Ostraciidae</i>	Trumpetfish	<i>Aulostomidae</i>
Hawkfish	<i>Cirrhidae</i>	Angelfish	<i>Pomacanthidae</i>	Triggerfish	<i>Balistidae</i>
Porcupinefish	<i>Diodontidae</i>	Damselfish	<i>Pomacentridae</i>	Blenny	<i>Blenniidae</i>
Flutemouth	<i>Fistulariidae</i>	Parrotfish	<i>Scaridae</i>		
Goby	<i>Gobiidae</i>	Grouper	<i>Serranidae</i>		

Table A1. All fish families recorded

Grouper and butterflyfish species observed at Dhigulaabadhoo

Common name	Scientific name
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Honeycomb grouper	<i>Epinephelus merra</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>
Peacock rock cod	<i>Cephalopholis argus</i>
Red-flushed grouper	<i>Aethaloperca rogae</i>
Vermilion rock cod	<i>Cephalopholis miniata</i>
White-lined grouper	<i>Anyperodon leucogrammicus</i>
White-square grouper	<i>Gracila albomarginata</i>

Table A2. All grouper species recorded across detailed underwater

Common name	Scientific name	Common name	Scientific name
Chevron butterflyfish	<i>Chaetodon trifascialis</i>	Triangular butterflyfish	<i>Chaetodon triangulum</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>	Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>	Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>	Double-saddle butterflyfish	<i>Chaetodon falcula</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>	Long-nose butterflyfish	<i>Forcipiger flavissimus</i>
Threadfin butterflyfish	<i>Chaetodon auriga</i>		

Table A3. All butterflyfish species recorded across detailed underwater visual census around Dhigulaabadhoo



FARUKOLHU

Introduction

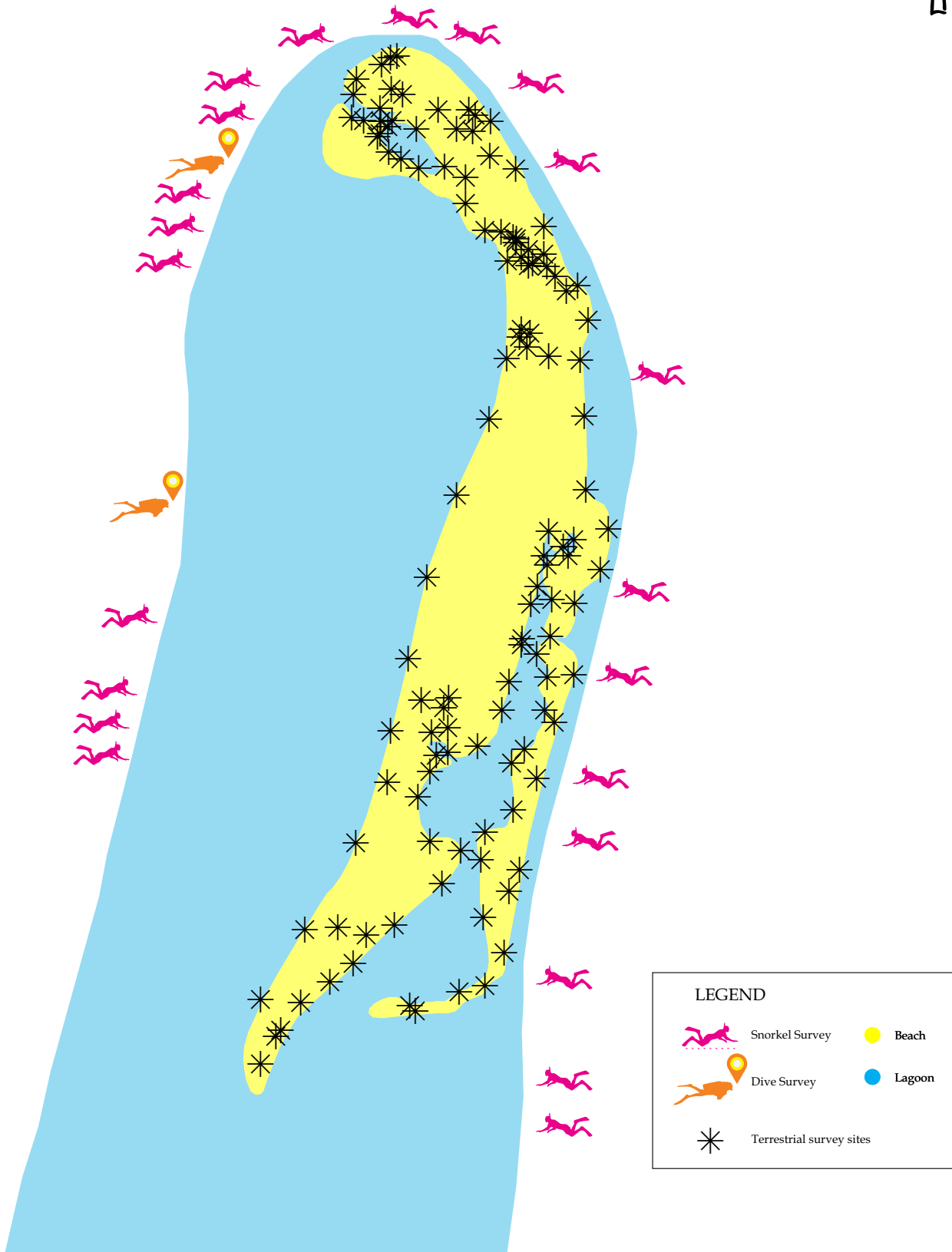
Farukolhu is a long, narrow uninhabited island on the eastern edge of the Shavyani atoll. The southern half of the island is split in two lengthways by a long mangrove bay. The northern end has several brackish water ponds, many of which are connected by narrow channels. The island's vegetation was made up primarily of coastal scrub vegetation typical of the region. *Scaevola taccada* and *Talipariti tiliaceum* dominated on the sheltered inner atoll facing shore and *Pemphis scidula* on the exposed outer atoll edge. The vegetation around the ponds was primarily made up of these species. Ponds may have been formed by seawater flowing through channels which have now closed or filled by rainwater or water transported through the porous underlying rocks. Only two of these ponds had mangrove trees present, and in both cases the trees appeared to be dying. There was also an area of coconut grove in the centre of the island that is regularly harvested. The mangrove bay was dominated by *Cerriops tagal* though much of the outer bay was *P. scidula*. *Rhizophora*

mucronata was also present. Many juvenile sharks and rays were observed throughout the bay, as well juvenile reef fish and birds. Juvenile sicklefin lemon sharks (*Negaprion acutidens*), a vulnerable (IUCN Redlist) species, were observed in high numbers. A fringing reef is present around the outside of the island. The outer atoll facing reef had many small branching and table corals. The inner reef slope was generally rubble with small rocky patches of coral growth.

Site	Latitude	Longitude
1	6.2007	73.29252
2	6.1913	73.29028

Table 1. Latitude and longitude of the quantitative survey sites

Sh. Farukolhu



Coral Reef Benthos



Figure 1. A sting ray hovering on top of the benthic habitat of Farukolhu

Two sites were surveyed using quantitative transect methods (Table 1). The substrate of the reefs surveyed was predominantly rock, rubble and sand. This characterised the inner and northern fringing reef. However, environmental conditions prevented detailed surveys of the outer reef which rapid surveys indicated had

higher coral cover than those reported here. The mean coral cover of 14% was below the average observed during the ecological surveys. Algal cover was very low. The highest coral cover was found on the northern channel reef (16.7%). Structural complexity was low at survey sites with a mean of 1.2 for the reefs.

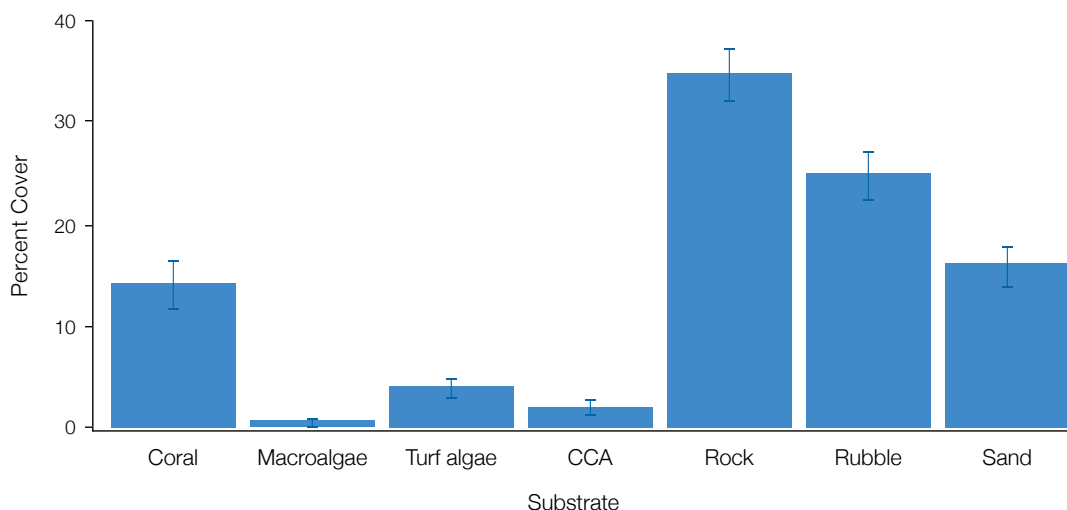


Figure 2. Mean percentage cover of substrate categories across all surveys on Farukolhu

Site	Complexity	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	1.3	16.7	1.7	5.7	33.5	24.3	13.5	2.5	0.0	1.8
2	1.0	9.9	2.9	3.7	34.1	23.7	16.7	4.0	2.4	1.8

Table 2. Location, mean complexity and mean substrate cover of the quantitative surveys.

Fish Community

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 31 of which were found on Farukolhu. Densities of the key herbivores, surgeonfish and parrotfish were not as high as observed elsewhere and their density was low. Herbivores are a functionally important group on coral reefs They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). These results suggest the reefs here could be of algal overgrowth due to low herbivore numbers. It is important that preservation of these herbivores is part of any future management plan.

Site	Total number of families	Mean number of families
Farukolhu	31	14.9
1	25	15.2
2	28	14.7

Table 3. Location, total number of fish families and mean number of fish families per transect observed across all sites and at individual survey sites

Site	Total number of grouper species	Mean number of grouper species	Mean grouper density /100m ²	Total number of butterflyfish species	Mean number of butterflyfish species	Mean butterflyfish density /100m ²
Farukolhu	5	3.2	3.1	11	3.4	4.0
1	4	2.7	2.9	8	3.0	4.2
2	4	3.0	3.2	10	2.5	3.9

Table 4. Location, total number of species, mean number of species and mean density per transect observed for grouper and butterflyfish across all sites and at individual survey sites

Site	Total number of parrotfish species	Mean number of parrotfish species	Mean parrotfish density /100m ²	Total number of surgeonfish species	Mean number of surgeonfish species	Mean surgeonfish density /100m ²
Farukolhu	3	2.0	4.9	8	4.4	9.6
1	3	2.5	6.0	7	5.0	8.2
2	2	2.3	2.8	7	5.8	11.0

Table 5. Location, total number of species, mean number of species and mean density per transect observed for parrotfish and surgeonfish across all sites and at individual survey sites

Number of Endangered Animals



Figure 3. An Endangered hawksbill turtle laying on the benthos in Farukolhu

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives; however, their populations are at risk from a decline in available nesting sites and the declining health of coral reefs.

Latitude	Longitude	Cheilinus undulatus	Chelonia mydas	Epinephelus fuscoguttatus	Eretmochelys imbricata	Plectropomus areolatus	Plectropomus laevis	Tridacna sp.
6.17356	73.29979				3			3
6.18492	73.30095				1		1	
6.18539	73.30095	1						
6.19030	73.29019						1	
6.20160	73.29305				1			
6.20493	73.29789		1	5	1	6		

Table 6. Location and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed during rapid surveys.

Vegetation



Figure 4. Shoreline vegetation of Farukolhu



Figure 5. Island vegetation



Figure 6. Mangrove vegetation



Figure 7. Bruguier sp.

The coastal fringe facing the inner atoll was dominated by *S. taccada*, *T. tillaceum* and *Guettarda speciosa*. Here the vegetation line is far from the high-water line, behind a sandy beach. *P. scidula* dominated on outer edge where there was a rocky shore and the high-water line reached the vegetation

edge. The pond fringe areas were also dominated by these species, though there were also patches of *Pandanus tectorius*. The ponds in the north which were connected to the sea by channels at high tide had stands of *R. mucronata*. The mangrove bay was dominated by *C. tegal*, with stands of

R. mucronata. The width of mangrove growth was very narrow, usually only a single tree deep. Though seedling density was not recorded, there was evidence of significant juvenile growth, an indicator of a healthy community.

Scientific name	Common name	Dhivehi name	Zone			
			Coastal fringe	Pond fringe	Mangrove bay fringe	Inland forest
<i>Cocos nucifera</i>	Coconut palm	Dhivehi ruh		5.3		6.0
<i>Guettarda speciosa</i>	Beach gardenia	Uni	8.1		7.7	0.0
<i>Pandanus tectorius</i>	Screw pine	Boa Kashikeyo	13.1	10.5	13.2	
<i>Pemphis scidula</i>	Iron wood	Kuredhi	52.2	36.8		18.1
<i>Scaevola taccada</i>	Sea lettuce	Magoo	23.7	13.2	42.3	14.9
<i>Talipariti tillaceum</i>	Sea hibiscus	Dhigga	2.8	21.1	2.5	30.2
<i>Thespesia populnea</i>	Thespesia	Hirun'dhu		2.6		
<i>Ochrosia oppositifolia</i>	Cork wood tree	Dhun'buri				30.9
<i>Brugeira cylindrica</i>	Small-leafed orange mangrove	Kandoo		2.6		
<i>Ceriops tegal</i>	Yellow mangrove	Karamana		2.6	34.3	

Table 7. Percent cover of plant species in the three vegetation zones surveyed.

Birds



Figure 9. A Grey Heron flying on top of the mangrove trees



Figure 8. A flock of black Naoed Tern

A high number of birds were observed across the island. The bird species observed differed between survey zones. Birds were most abundant in the mangrove bay habitat. This might be due to the abundance of potential prey, including gastropods and small fish. Surveys were limited to daylight hours, so no roosting was observed, and we were unable to determine the location of any nesting sites.

Mangrove Fish Community

The mangrove bay had an abundant and diverse fish community sheltering or hunting amongst the mangrove roots. A high number of juvenile sharks and rays were found at indicating this habitat is an important nursery ground. Notably, juvenile sicklefin lemon sharks (*Negaprion acutidens*), a rare and vulnerable (IUCN

Redlist) species, were observed in high numbers. There were also juveniles of commercially important fish species such as blue-fin jacks, and snapper and groupers. The importance of these Mangrove Bays as nursery habitats is undervalued across the country and a proper evaluation of the goods and services provided by the different mangrove, sea grass and wetland habitats needs to be conducted.

		Zone		
		Inland	Pond	Mangrove bay
<i>Corvus splendens</i>	Kaalhu	14		
<i>Eudynamys scolopaceus</i>	Koel	12		
<i>Ardea cinerea</i>	Maakanaa		2	5
<i>Ardeola grayii phillipsi</i>	Huvadhoo Raabondhi		2	
<i>Casmerodius albus</i>	Lagana		1	2
<i>Charadrius mongolus</i>	Kuda Bondana		2	
<i>Nycticorax nycticorax</i>	Raabondhi			3
<i>Arenaria interpres</i>	Rathafai			2
<i>Numenius phaeopus</i>	Bulhithun'bi			1
<i>Tringa hypoleucos</i>	Findhana			4

Table 8. Abundance of bird species observed in the three zones surveyed

Species/Family	Common Name	Abundance
<i>Caranx melampygus</i>	Blue-fin jack	2
<i>Carcharhinus melanopterus</i>	Blacktip reef shark	23
<i>Chaetodon auriga</i>	Threadfin butterflyfish	6
<i>Chaetodon lunula</i>	Raccoon butterflyfish	6
<i>Chanos</i>	Milkfish	30
<i>Gerres oyena</i>	Black-tip pursemouth	66
<i>Himantura granulata</i>	Mangrove whipray	69
Lethrinidae	Emperor	3
<i>Lutjanus monostigma</i>	One-spot snapper	7
Mullidae	Goatfish	13
<i>Negaprion acutidens</i>	Sicklefin lemon shark	9
Ostraciidae	Pufferfish	1
<i>Pastinachus sephen</i>	Cowtail stingray	63
<i>Urogymnus asperrimus</i>	Porcupine ray	2

Table 8. Abundance of fish species observed in the mangrove bay

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Island vegetation areas were classified into five vegetation zones based on location: coastal fringe, pond fringe, mangrove bay fringe, mangrove forest and inland forest. Survey points were identified within each zone using a stratified sampling approach and the GPS coordinates were extracted from Google Earth© version 7.3.1 and entered into a handheld GPS (Garmin etrex 20x) for navigation to the point. At a survey point a 2.5 m radius circle was estimated and the dominant and secondary flora within the area were identified to species and their respective percent covers were estimated. The height of the

dominant species was estimated to the nearest metre. Bird surveys were conducted concurrent with terrestrial habitat surveys. All birds observed were counted and identified to species. Mangrove fish surveys were conducted first during high tide when the bay was sufficiently deep, surveys were conducted from a boat, and then during low tide surveys were conducted on foot. All fish were counted and identified to family and where possible to species.

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Annex

Fish families observed at Farukolhu

Common Family	Family	Common Family	Family
Surgeonfish	<i>Acanthuridae</i>	Tilefish	Malacanthidae
Cardinalfish	Apogonidae	Dart Goby	Microdesmidae
Trumpetfish	Aulostomidae	Goatfish	Mullidae
Triggerfish	Balistidae	Moray Eel	Muraenidae
Blenny	Blenniidae	Eagle ray	Myliobatidae
Fusilier	Caesionidae	Spinecheek	Nemipteridae
Jack	Carangidae	Boxfish	Ostraciidae
Requiem Shark	Carcharhinidae	Grubfish	Pinguipedidae
Butterflyfish	<i>Chaetodontidae</i>	Angelfish	Pomacanthidae
Hawkfish	Cirrihitidae	Damselfish	Pomacentridae
Garden eel	Congridae	Parrotfish	<i>Scaridae</i>
Stingray	Dasyatidae	Tuna	Scombridae
Batfish	Ephippidae	Scorpionfish	Scorpaenidae
Goby	Gobiidae	Grouper	<i>Serranidae</i>
Sweetlips	Haemulidae	Rabbitfish	Siganidae
Squirrelfish	Holocentridae	Barracuda	Sphyraenidae
Rudderfish	Kyphosidae	Pufferfish	Tetraodontidae
Wrasse	Labridae	Triplefin	Tripterygiidae
Emperor	Lethrinidae	Moorish idol	Zanclidae
Snapper	Lutjanidae		

Table A1. All fish families recorded

Grouper, butterflyfish, parrotfish and surgeonfish species observed at Farukolhu

Common name	Scientific name
Red-flushed grouper	<i>Aethaloperca rogae</i>
Peacock rock cod	<i>Cephalopholis argus</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>
Honeycomb grouper	<i>Epinephelus merra</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Squaretail coral grouper	<i>Plectropomus areolatus</i>
Black-saddle coral grouper	<i>Plectropomus laevis</i>

Table A2. All grouper species recorded across detailed underwater visual census

Common name	Scientific name
Shabby parrotfish	<i>Chlorurus sordidus</i>
Five-saddle parrotfish	<i>Scarus scaber</i>
Three-colour parrotfish	<i>Scarus tricolor</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census

Common name	Scientific name
Ring-tail surgeonfish	<i>Acanthurus auranticavus</i>
Powder-blue surgeonfish	<i>Acanthurus leucosternon</i>
Eye-line surgeonfish	<i>Acanthurus nigricauda</i>
Dusky surgeonfish	<i>Acanthurus nigrofuscus</i>
Two-spot bristletooth	<i>Ctenochaetus binotatus</i>
Fine-lined bristletooth	<i>Ctenochaetus striatus</i>
Gold-ring bristletooth	<i>Ctenochaetus truncatus</i>
Brown Tang	<i>Zebrasoma scopas</i>

Table A4. All parrotfish species recorded across detailed underwater visual census

Common name	Scientific name
Threadfin butterflyfish	<i>Chaetodon auriga</i>
Head-band butterflyfish	<i>Chaetodon collare</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>
Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>
Madagascar butterflyfish	<i>Chaetodon madagaskariensis</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>
Triangular butterflyfish	<i>Chaetodon triangulum</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>

Table A5. All surgeonfish species recorded across detailed underwater visual census

Point #	Latitude	Longitude	Point #	Latitude	Longitude	Point #	Latitude	Longitude
1	6.177853	73.291939	38	6.186941	73.295964	75	6.196300	73.298980
2	6.179033	73.292897	39	6.187026	73.297318	76	6.196378	73.299230
3	6.179689	73.293272	40	6.187162	73.299847	77	6.196477	73.299019
4	6.179848	73.293372	41	6.187438	73.299599	78	6.196701	73.300606
5	6.180306	73.296577	42	6.187445	73.298599	79	6.197396	73.300086
6	6.180419	73.296433	43	6.187487	73.297216	80	6.197500	73.300358
7	6.180487	73.293856	44	6.187678	73.296672	81	6.197727	73.299828
8	6.180563	73.292905	45	6.187731	73.297325	82	6.197966	73.299624
9	6.180755	73.297609	46	6.188118	73.298773	83	6.197975	73.299197
10	6.180910	73.298217	47	6.188221	73.299653	84	6.198048	73.299278
11	6.180990	73.294537	48	6.188288	73.300290	85	6.198088	73.298692
12	6.181439	73.295096	49	6.188644	73.296380	86	6.198192	73.299009
13	6.181687	73.298667	50	6.188772	73.299409	87	6.198248	73.299553
14	6.182106	73.295391	51	6.188988	73.299041	88	6.198358	73.299183
15	6.182211	73.293939	52	6.189146	73.299070	89	6.198540	73.298880
16	6.182279	73.294731	53	6.189209	73.299732	90	6.198610	73.298910
17	6.182344	73.296062	54	6.189959	73.299276	91	6.198660	73.298820
18	6.182527	73.298164	55	6.189995	73.300314	92	6.198790	73.298530
19	6.183145	73.298776	56	6.190065	73.299765	93	6.198818	73.298150
20	6.183318	73.297200	57	6.190393	73.299426	94	6.198914	73.299550
21	6.183658	73.299022	58	6.190581	73.296813	95	6.199458	73.297691
22	6.183890	73.298110	59	6.190765	73.300922	96	6.200075	73.297685
23	6.184100	73.297634	60	6.190876	73.299645	97	6.200287	73.298885
24	6.184294	73.295145	61	6.191114	73.300152	98	6.200290	73.296590
25	6.184336	73.296896	62	6.191118	73.299576	99	6.200332	73.297189
26	6.184546	73.298200	63	6.191329	73.300039	100	6.200496	73.296168
27	6.185079	73.298863	64	6.191493	73.300281	101	6.200573	73.298266
28	6.185382	73.296620	65	6.191682	73.299697	102	6.200665	73.295867
29	6.185725	73.295882	66	6.191752	73.301103	103	6.201029	73.295599
30	6.185827	73.299429	67	6.192545	73.297502	104	6.201109	73.295655
31	6.185975	73.296901	68	6.192672	73.300573	105	6.201153	73.297852
32	6.186189	73.298832	69	6.194341	73.298257	106	6.201203	73.296524
33	6.186358	73.297053	70	6.194429	73.300521	107	6.201203	73.297480
34	6.186430	73.297323	71	6.195756	73.300421	108	6.201261	73.295856
35	6.186515	73.299137	72	6.195779	73.298690	109	6.201387	73.295684
36	6.186584	73.298021	73	6.195840	73.299680	110	6.201404	73.298282
37	6.186919	73.296928	74	6.196050	73.299150	111	6.201405	73.295287

Point #	Latitude	Longitude
112	6.201412	73.295957
113	6.201490	73.295001
114	6.201540	73.297910
115	6.201668	73.297044
116	6.201677	73.297769
117	6.201706	73.295670
118	6.202021	73.295027
119	6.202031	73.296190
120	6.202161	73.295929
121	6.202385	73.295099
122	6.202734	73.295695
123	6.202917	73.295896
124	6.202957	73.296062

Table A6. Latitude and longitude of the terrestrial surveys



KENDHIKULHUDHOO

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 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 Kendhikulhudhoo in Noonu Atoll 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 scattered 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 and Hatcher 2004). Maldivian islands are known as low lying islands with 80% of the country being less than a meter above the sea level and the majority of islands being less than 5km² in size. (Ministry of Environment and Energy 2015). Studies to understand the atoll and island formation have suggested that the island reefs in the Maldives have been around 4000 yr. B.P (Kench et al. 2005, Perry et al. 2013).

The terrestrial fauna and flora have a rich biodiversity. The range of natural island habitats includes beaches, marshes, brackish ponds, mangroves and woodlands. There are 583 species of terrestrial flora found, of which 323 are cultivated and 260 are natural. The farmed species are mostly used as a source of food and some for traditional medicine. Mangroves

ecosystems can be classified based on the system's exposure to the sea as either "open mangrove systems" or "closed mangrove systems. These can then be further subdivided into four categories (Saleem and Nileysha 2003) (Table 1). In all but marsh-based mangroves, tree growth is limited to a narrow band around the water's edge. Around 15 species of mangroves are found across approximately 150 islands (Ministry of Environment and Energy 2015). Maldivian avifauna is made up of seasonal migrants, breeding residents and introduced birds. Over 167 species of birds have been recorded in the Maldives. Around 70 species of shorebirds are recorded, some of which are breeding residents while others are recorded as migrants. Migratory birds visit during certain seasons to breed or use the islands as a transit point to their breeding grounds (Ministry of Environment and Energy 2015).

Coral reefs of the Maldives are considered to be 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 and Hatcher 2004). Coral

Open mangrove systems	Coastal fringing mangroves	Exposed mangroves growing directly on the shoreline. Experience regular wave action. Uncommon mangrove system
	Embayment mangroves	Mangroves partly encircle a bay area. Experience daily tidal flushing. Common mangrove system
Closed mangrove systems	Pond-based mangroves	Mangroves encircle a brackish water pond. Possible water exchange through bedrock or overwash. Common mangrove system
	Marsh-based mangrove	Mangrove found on muddy substrate with no standing water. Dampness of mud may come from flow through the bedrock or overwash. Uncommon mangrove system

Table 1: Description of the four types of mangrove ecosystems found in the Maldives. From Saleem and Nileysha (2003)

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) is contributed by 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 Maldivian coral reef ecosystem has come under threat from catastrophic events such as mass coral bleaching and outbreaks of crown of thorns starfish (*Acanthaster planci*). Following the 2016 bleaching event, which damaged an estimated 75% of the coral reefs (Ibrahim et al. 2017), scientists have been alerted as the impact of the event has shown that even some of the most protected reef ecosystems could perish. However, the Reefs at Risk 2016 report indicates that a significant proportion of reef degradation is due to local stressors (Burke et al. 2011), such as, overfishing, pollution, land

reclamation. Despite these global and anthropogenic stressors, the Maldivian reefs have previously shown resilience and recovery following these disturbances (Morri et al. 2015, Pisapia et al. 2016).

Terrestrial habitats are threatened by many local scale factors including infrastructure development, human waste and land reclamation projects. Similar to the marine environment, habitats such as mangrove areas are known for their ecological significance and diversity, providing habitats and services to animal and human communities (Kuenzer et al. 2011). However, due to historical and continued undervaluation, most 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 infrastructure development. Refuse dumping has had a major impact on the terrestrial and marine environment. Around 1.7kg of waste is generated per capita in Male' alone (Ministry of Environment and Energy 2015). This highlights the need for proper waste management in the Maldives. At present, 128 waste

management centres are established across Maldives, and regional waste management centres are planned for major populated areas such as Addu City. The government has increased their efforts to manage the waste issue by incorporating the 3Rs (Reduce, Reuse, Recycle) concept into policy and investing on local waste management centres. However, many populated islands are far away from regional waste management centres making dumping waste on land or in the sea the most convenient disposal option for a large proportion of the population.

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 dependent on the profits around these industries. This highlights the significance of the natural environment to the Maldives and 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 the sustainable use and management of these natural resources within communities. Such approaches will play a key role in standardizing the efforts to manage and monitor the resources in a co-managed concept.

Study site

Noonu Atoll is the southern administrative division of Miladhunmadulu Atoll, in the north of the Maldives. Partly because of its location in the far north of the country and low population, the atoll is under studied and currently has only 1 marine protected area and no sustainable management plans for any of the inhabited islands.

Kendhikulhudhoo is a long narrow island located on the eastern edge of the atoll. The island has a population of 1326 people (National Bureau of Statistics, 2014). An interconnected

mangrove network runs along the whole eastern edge of the island. This includes small ponds with thick *Bruguiera* spp. and *Rhizophora* spp. growths in the south which are joined by small channels that lead up to two long narrow ponds and finally into a wetland area covering the north of the island. The two large ponds used to be a single water body but were separated by the local community. A number of efforts have been undertaken to establish aquaculture activities in the two large ponds including sea cucumber farming and some fish farming. Small channels have been created between the ponds and the ocean in an effort to create water flow for aquaculture. However, to date, no significant aquaculture activities are in place. The island doesn't have any waste management system and mangrove ponds throughout the island have become dumping grounds for the island's waste.

The island is surrounded by a fringing coral reef. The outer atoll edge at the eastern side of the island is exposed to the open ocean and is subject to significant wave action. The reef inside the atoll is sheltered from the wave action, however the water is more turbid due to the low water movement. The short distance and close link between mangrove and reef habitats in the area means that impacts on one habitat are likely to have effects on the other.

Methods

Island survey

The terrestrial survey area on Kendhikulhudhoo was identified as the habitat in the south east of the island, the two large ponds along the eastern edge and wetland area at the north (Figure 1). Survey points were identified using a stratified sampling

approach with sites selected around pond fringes and throughout the wetland areas. GPS coordinates were extracted from Google Earth© version 7.3.1 and entered into a handheld GPS (either Garmin etrex 20x or Garmin GPS maps 64s) for navigation to the point. At a survey point, a 2.5 m radius circle was estimated and the dominant and secondary flora within the area were identified to species and their respective percent covers were estimated. The height of the dominant species was estimated to the nearest metre. Substrate type was recorded and counts of crab burrows and rubbish were conducted. The number of survey points for each zone was dependent on zone size and accessed on foot or by kayak. If identified points were inaccessible, a new point was taken as close as possible to the original point and the survey was performed here. Wetland bird and fish surveys were conducted concurrently with terrestrial habitat surveys. All birds observed were identified to species. Fish were identified to family and their abundance was estimated (Figure 2).



Figure 1: Map of Kendhikulhudhoo survey areas. Yellow polygons indicate terrestrial survey areas, A) northern wetland, B) north pond, C) south pond and D) southern wetland. Black diamonds indicate the coral reef survey sites. ©Google Earth 2019



Figure 2: Recording data at a terrestrial survey point

Coral reef survey

Three sites were selected for the coral reef survey. Two sites on the outer reef and one on the inside to examine both the exposed outer atoll reef and the sheltered inner reef. One outer reef site was in front of the large mangrove ponds at the centre of the island and the second in front of the wetland area at the south of the island. This allowed us to compare the two sites to examine whether pollution or aquaculture in the large ponds has impacted the reef immediately adjacent to this area.

The coral reef habitat was surveyed using transects SCUBA at a depth of 10 m. Six transects were conducted at each site and a gap of at least 5

m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral (identified to genus and growth form), dead coral (growth form), sponge (growth form), algae (turf and underlying growth form or macroalgae), rock, rubble, sand and Crustose Coralline Algae (CCA) (Figure 3 (A)).

Fish communities were also surveyed on six 5 x 30 m transects using the same transects as the benthos surveys. The presence of all fish

families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm. Battfish (*Ephippidae*), rabbitfish (*Siganidae*), snappers (*Lutjanidae*) and jacks (*Carangidae*) were counted and identified to family and their total length was estimated in 5 cm size classes (Figure 3 (A)). 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).

Specific metrics that have been shown to indicate the resilience of coral reef habitats were collected. Juvenile coral recruitment was quantified on the transects. A 25 x 25 cm quadrat was placed above and below the transect every 5 m along the transect. The number of coral recruits (colonies < 5 cm diameter) within each quadrat were counted and identified to genus where possible. Recruit density was then calculated as the number of recruits per m². Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007) for the length of each transect. Biomass of key herbivorous fish species was calculated on transects following the method described above.

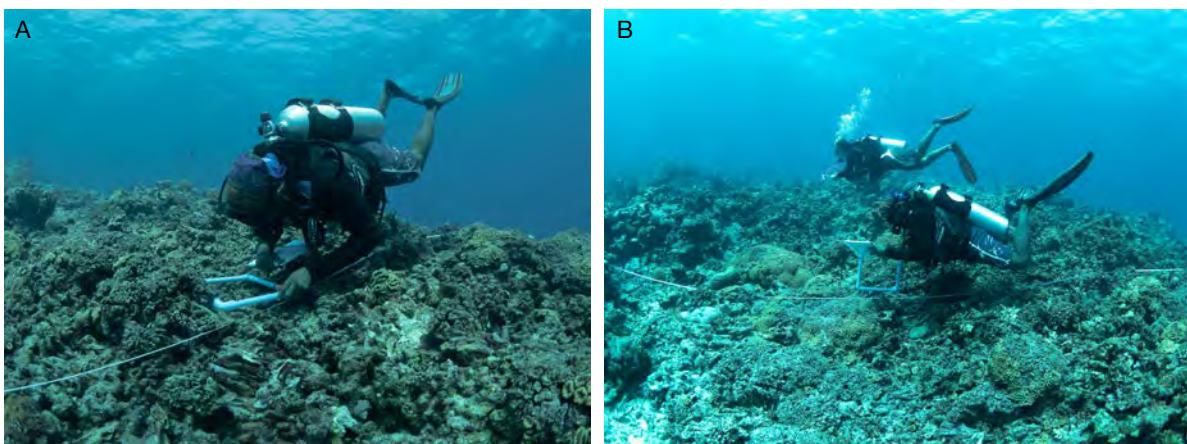


Figure 3: Surveyors carrying out marine surveys. (A) fish and benthic survey (B) coral recruitment survey

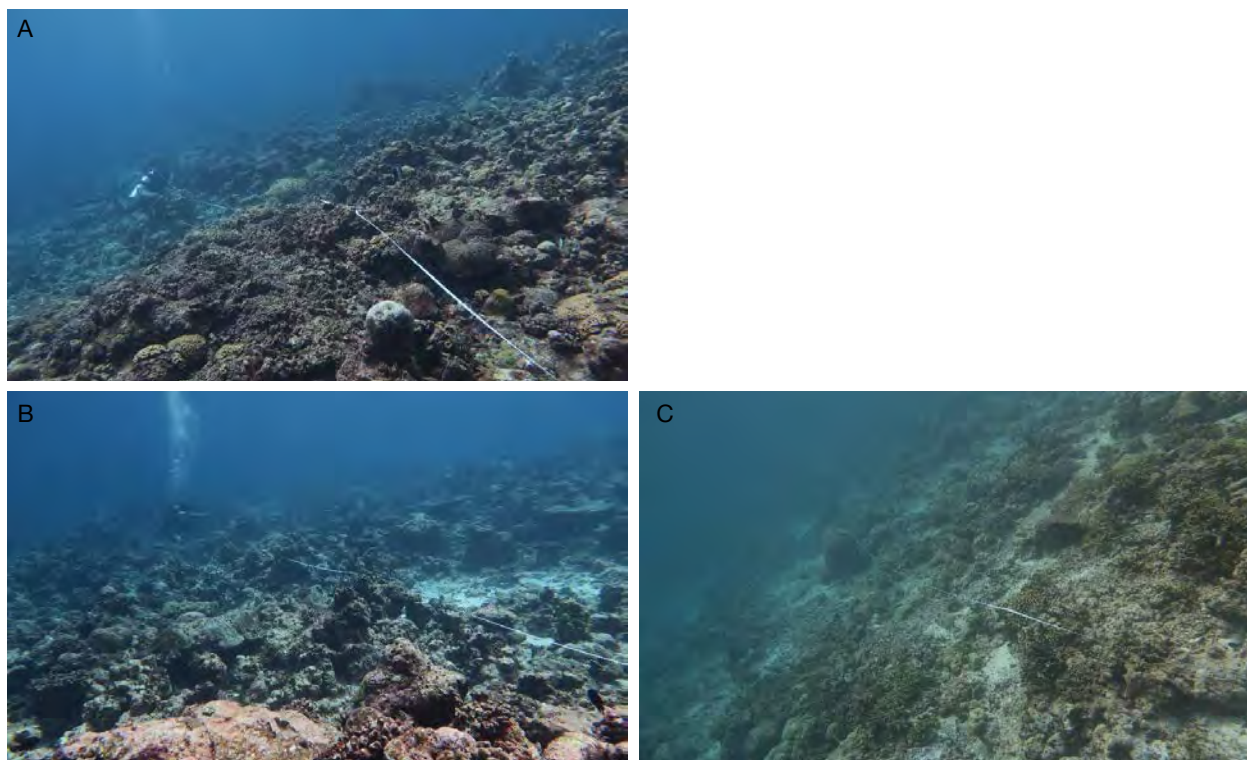


Figure 4: Images of the coral reef surveys at the. (A) south, (B) North and (C) Inside reef survey sites.

Results

Island survey

Sixteen species of flora were identified on the island surveys (Table A5),

including five species of mangrove trees. The most diverse survey area was the vegetation fringe around the north pond (Figure 5). The pond habitats had a relatively even mixture of species. The south pond fringe had the

fewest number of species. Mangrove tree species were dominant around the pond fringes and southern wetland area. The northern wetland area had a greater number of non-mangrove species.

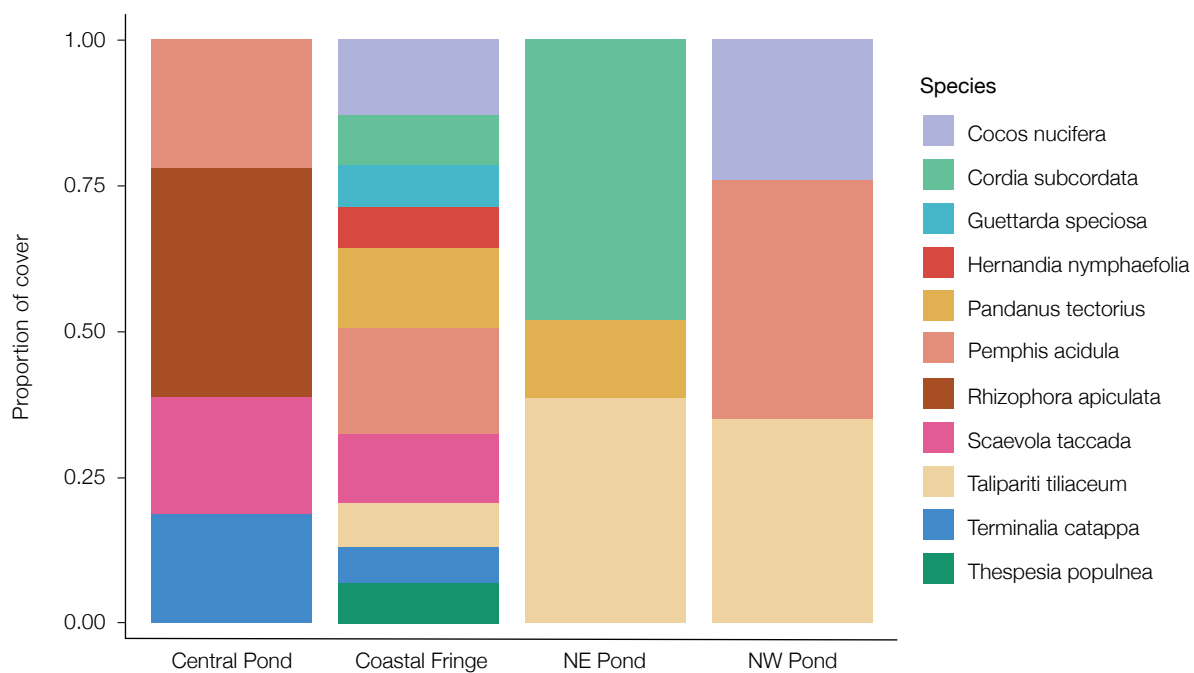


Figure 5: Percent cover of tree species at the four areas of vegetation surveyed on Kendhikulhudhoo.



Figure 4: Images of the coral reef surveys at the (A) south, (B) North and (C) Inside reef survey sites

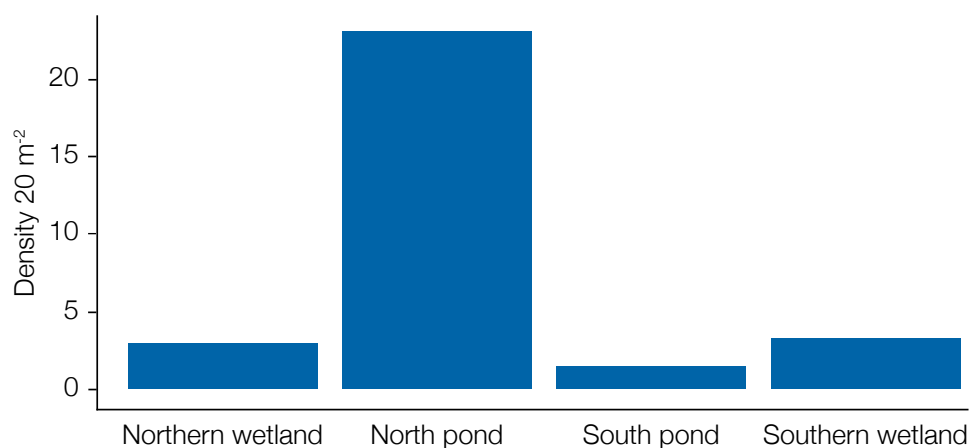


Figure 7: Mean number of items of refuse found in per 2.5m radius survey point in the four areas of vegetation surveyed on Kendhikulhudhoo

All terrestrial survey areas had significant amounts of refuse. Plastic was the dominant type of refuse observed followed by polystyrene foam, metal cans, glass and synthetic fiber gunny sacks. Some large items were also found dumped including a fridge, fishing nets and a washing machine. The north pond had an average of 23 pieces of rubbish per 20 m² survey area (*Figure 7*).



Figure 8: (A) Waste dumped in pond area (B) dried up marsh-based mangrove area

Zone	Species	Common Name	Dhivehi Name
Northern wetland	<i>Ardea cinerea</i>	Grey Heron	Maakana
Northern wetland	<i>Casmerodius albus</i>	Great Egret	Laganaa
Northern wetland	<i>Bubulcus ibis</i>	Cattle Egret	Iruvaahudhu
Northern wetland	<i>Actitis hypoleucos</i>	Common Sandpiper	Findhana
Northern wetland	<i>Numerius phaeopus</i>	Whimbrel	Bulhithumbi
North pond	<i>Bubulcus ibis</i>	Cattle Egret	Iruvaahudhu
North pond	<i>Amaurornis phoenicurus</i>	White-breasted Waterhen	Kanbili
North pond	<i>Ardea cinerea</i>	Grey Heron	Maakana
South pond	<i>Actitis hypoleucos</i>	Common Sandpiper	Findhana
South pond	<i>Ardeola grayii phillipsi</i>	Maldivian Pond Heron	Huvadhu Raabondhi
South pond	<i>Ardea cinerea</i>	Grey Heron	Maakana
South pond	<i>Casmerodius albus</i>	Great Egret	Laganaa
Southern wetland	<i>Corvus corax</i>	Crow	Kaalhu
Southern wetland	<i>Ardeola grayii phillipsi</i>	Maldivian Pond Heron	Huvadhu Raabondhi
Southern wetland	<i>Eudynamis scolopacea</i>	Asian Koel	Dhivehi Koveli
Southern wetland	<i>Ardeola grayii phillipsi</i>	Maldivian Pond Heron	Huvadhu Raabondhi

Table 2: Bird species observed in each of the four areas of vegetation surveyed on Kendhikulhudhoo

Zone	Family	Common Name
Southern wetland	Cichlidae	Tilapia
Southern wetland	Gobiidae	Goby
Southern wetland	Poeciliidae	Molly
Southern wetland	Shrimp	Shrimp
Southern wetland	Congridae	Conger
Southern wetland	Poeciliidae	Guppy
South pond	Congridae	Conger
South pond	Chanidae	Milk Fish
South pond	Sphyraenidae	Barracuda
South pond	Cichlid	Tilapia
North pond	Poeciliidae	Guppy
Northern wetland	Chanidae	Milk fish
Northern wetland	Poeciliidae	Molly

Table 3: Fish families observed in water bodies each of the four areas of vegetation surveyed on Kendhikulhudhoo

Coral reef survey

Abiotic substrates were the dominant benthic cover at all three sites making up 67.8% (Inside), 53.6% (South) and 66.1% (North) (Figure 10). Rock was the predominant substrate at both outside reefs, however no substrate dominated on the inside reef, with rock, rubble and sand making up approximately equal parts of the

substrate. Coral dominated the biotic substrate at all three sites (Figure 9) and had a mean cover of 23.5%. Cover was lower at the outside north site. Coralline algae made up a significant proportion of the substrate at the outer reef sites but was absent from the inside reef. There was no difference in turf algae cover between the three sites, however macroalgae cover was greater at the inside reef site.

Acanthuridae was the dominant surveyed family at all three sites (Figure 11). However, their biomass varied greatly between sites. The biomass of *Scaridae* at the two outer atoll survey sites was double that of the inside site. The biomass of *Acanthuridae* families was also significantly lower at the lagoonward site. A large school of *Macolor macularis* (midnight snapper) was present on

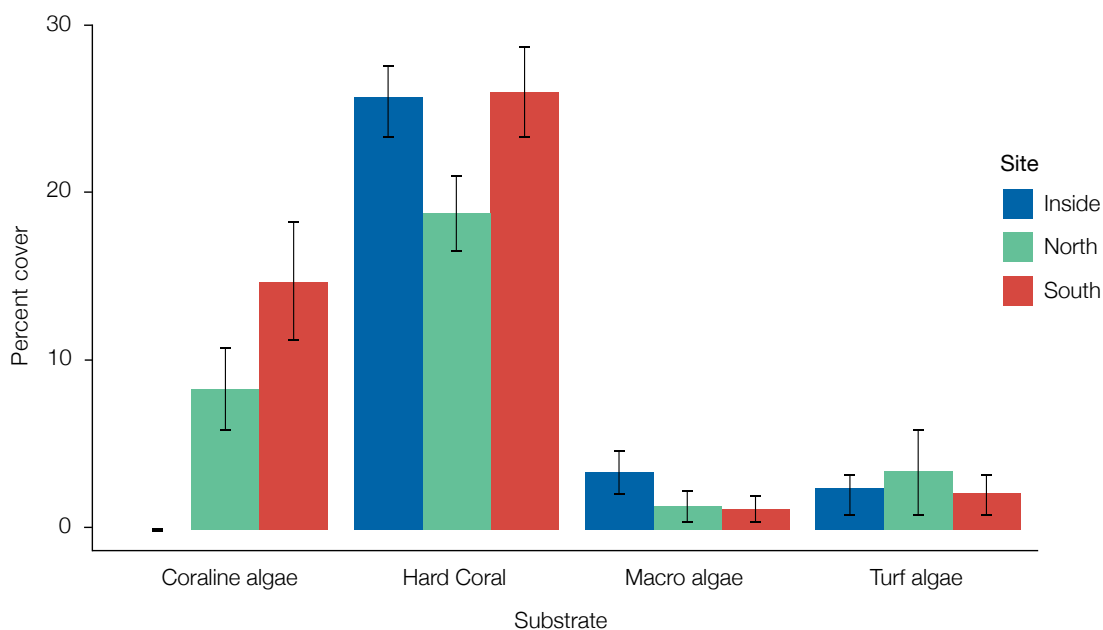


Figure 9: Percent cover of biotic substrate at the three Kendhikulhudhoo reef survey sites.

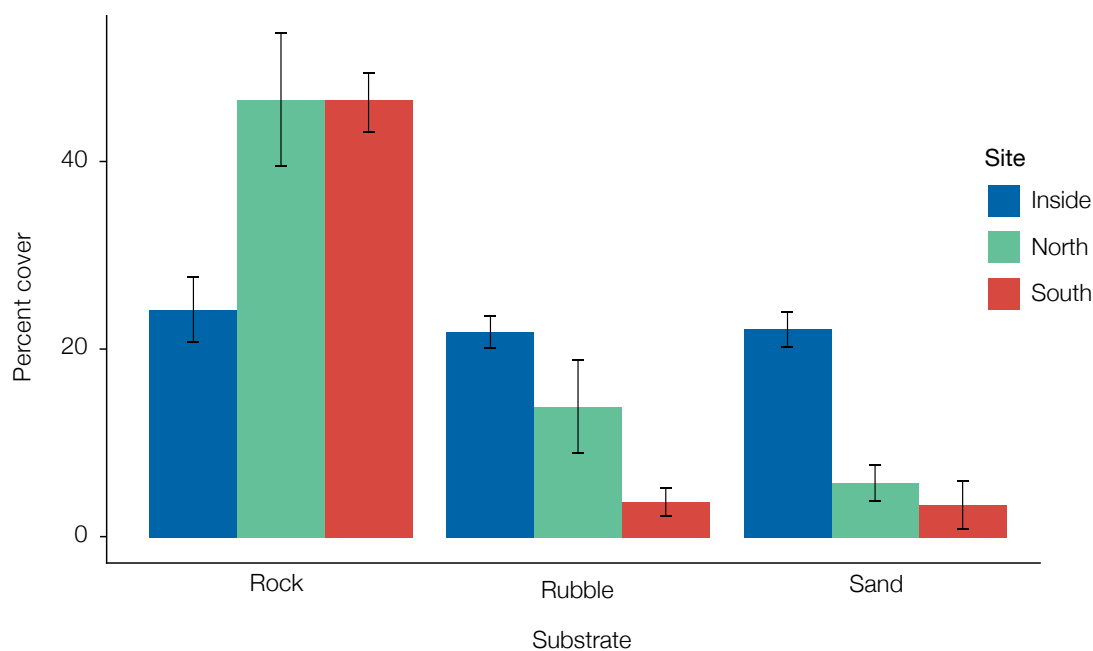


Figure 10: Percent cover of abiotic substrate at the three Kendhikulhudhoo reef survey sites.

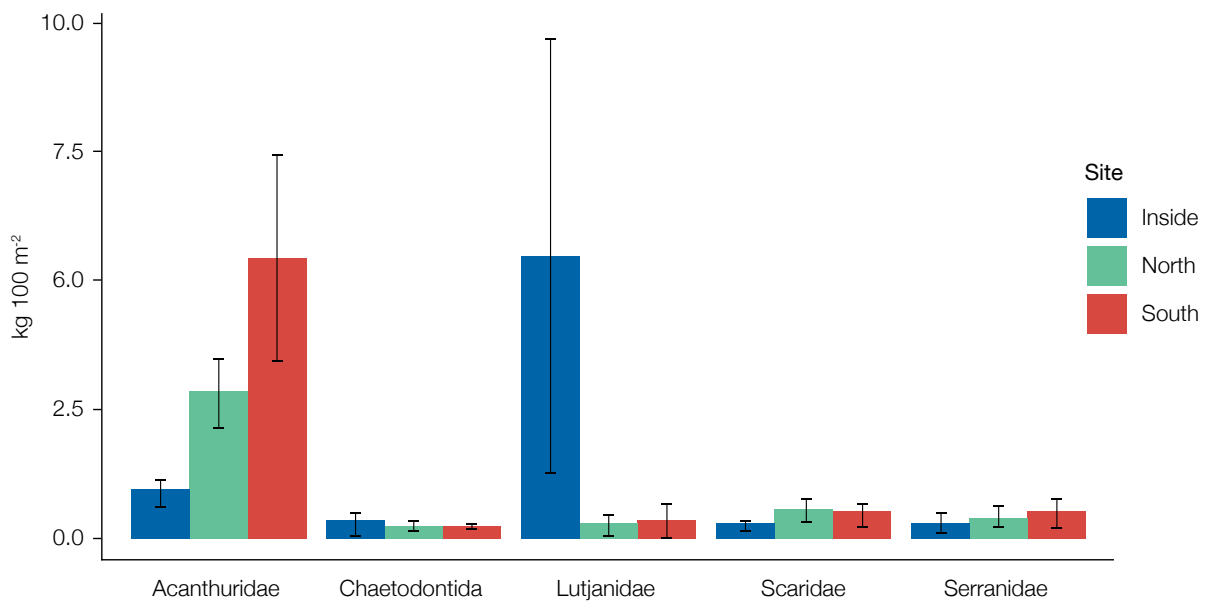


Figure 11: Biomass kg 100 m⁻² at the three Kendhikulhudhoo reef survey sites

one transect at the lagoonward site resulting in a significantly greater mean biomass of Lutjanidae at this site, but with high variability. There was no significant difference in the biomass of *Chaetodontidae* and *Serranidae* between sites. Ehippidae, Siganidae and Carangidae were present in relatively low numbers across all three sites.

Recruits

The mean density of recruits across all sites was 4.8/ m². It ranged between 4.2/ m² at the lagoonward site to 5.5/ m² at the northern outside reef site. Agariciidae was the most common family of recruits across the three sites (Figure 12). The greatest density of Agariciidae was found at the northern

oceanward reef site. Coral recruits from families that typically have a more complex structure, such as Acroporidae and Pocilloporidae were

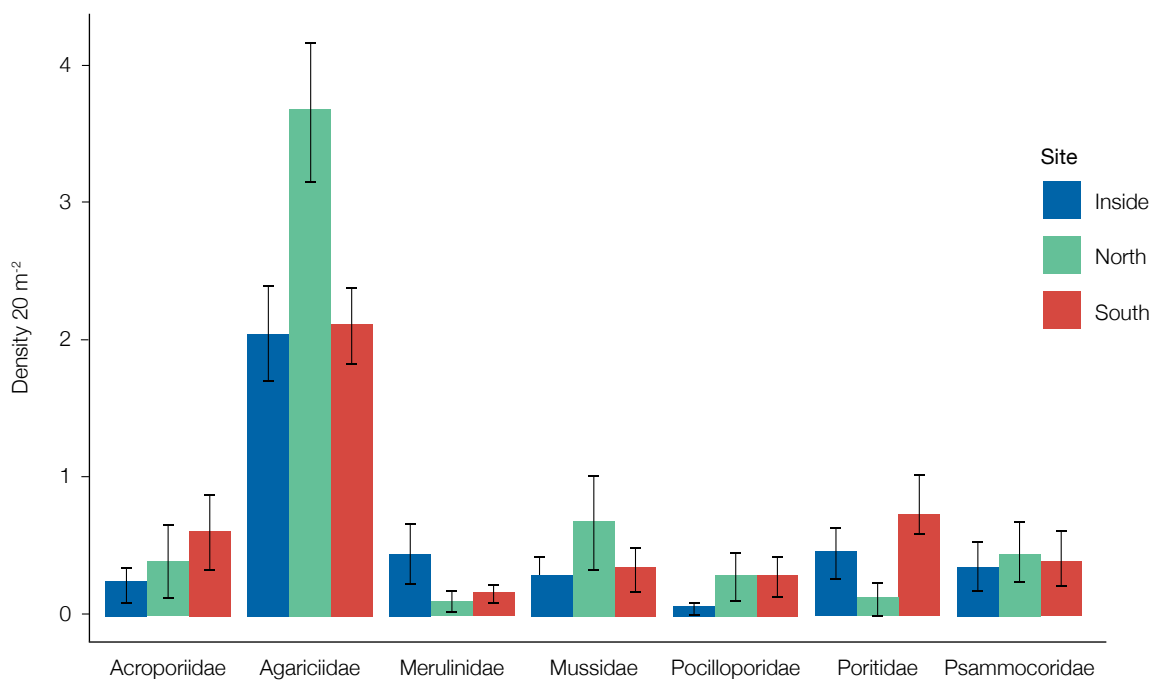


Figure 12: Density of the seven most common coral recruits per m² by family at the three Kendhikulhudhoo reef survey sites.

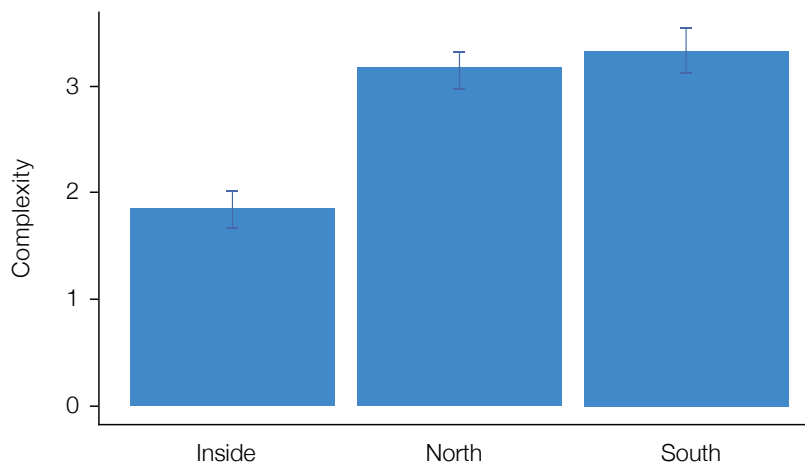


Figure 13: Mean visual complexity at the three Kendhikulhudhoo reef survey sites.

more common on the oceanward reef sites.

Mean reef complexity across all sites was 2.7, however, it was significantly lower at the lagoonward reef site, which had a complexity less than or equal to 2 across all transects, whereas all transects at both outer reefs had complexities of 3 or higher (Figure 13).

Discussion

The natural environment around Kendhikulhudhoo showed clear signs of human impact. Significant amounts of refuse had been dumped throughout the wetland and pond habitats. This was particularly severe in the north pond, where large areas were clearly being used as refuse

dumps for the island. In addition to the waste, attempts at managing waterflow through the ponds are apparent. In the southern wetland area this has resulted in the drying out of at least one pond and is likely to be the cause of drying of a nearby muddy mangrove area.

The mangrove system runs the whole length of the island's east coast, with narrow channels connecting the small ponds and wetland area in the south with the large ponds in the middle of the island and all the way up to the wetland area in the north. In the southern wetland area, the vegetation around pond fringes and channels was dominated by mangrove trees from the genus *Rhizophora*. This genus is characterised by large prop roots which intertwine to create a complex habitat above and below the water and is

important for many fish, bird and insect species. *Bruguiera* spp. mangrove trees were more abundant in shallow water or muddy areas such as those found in the northern and southern wetlands.

Mangrove species are susceptible to changes in the surrounding environment and can be impacted by changing water salinity and pH or the moisture content of muddy areas (Kathiresan and Bingham 2001). Attempts have clearly been made to manage water flow between the sea and pond or wetland areas wetland areas by creating channels. Nearly all of these manmade channels are blocked due to accumulation of sediment, rock and rubble. There was one area of the southern wetland habitat at 5.940180 latitude, 73.426790 longitude where channel has been created and trees removed to create a recreational and picnic area. This has led to significant deposition of sand potentially causing the drying up of at least one pond. There was an area just inland of this where the mud was drying out and the trees were mostly dead or dying which may have been caused by this attempt at management. There is a similar area drying out in the northern wetland that may be due to a loss of connectivity between waterbodies brought about by management or natural changes from sediment deposition during storms or high tides.



Figure 14: Sustainable and eco-friendly uses of the mangrove in Kendhikulhudhoo. (A) local woman in the process of extracting coir fibres from coconut husks soaked in mangrove ponds. (B) local café built into the mangroves.

There are existing examples of sustainable use of the mangrove habitat on the island. Ponds are used for soaking coconut husks. The fibres of the coconut, known as coir are then used to manufacture a range of products including brush bristles, woven mats and coir rope. However, the synthetic fibre gunny sacks commonly used for holding the husks during soaking break down easily into microplastics, becoming a significant source of pollution to the mangrove area. A café has also been built on the shore of the large ponds. This is an eco-friendly management concept bringing the beauty of the mangrove area to the locals and visitors.

Waste management is clearly a significant issue in Kendhikulhudhoo, as it is on many of the small community islands around 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). It was apparent that areas of the mangroves were being used as refuse dumps. The presence of large piles of refuse and big household items including a washing machine and a refrigerator suggest that there is either no location available to dispose of such items or that there is a lack of education or awareness as to the environmental damage such behaviour can have. Regional waste strategy and action plans are being developed (Ministry of Environment 2019) to identify and develop practical approaches for waste management. The recommendations in such plans should be incorporated in future management plans. Campaigns, such as the “National campaign to reduce plastic bottles” provide publicity and education on the need for waste reduction, particularly on single use plastics. However, many small islands have no clean safe drinking water to refill their water bottles.

There is an increasing demand for land area in the Maldives, mainly for agricultural expansion, industrial growth and for housing (Thupalli

2009). Population growth is creating demands on the land area for food production and housing. Furthermore, expansion of the tourist industry may threaten habitats on uninhabited islands and shallow coral reefs, as plans for new airports and resorts require land reclamation and redevelopment of these sensitive areas.

Islands in the Maldives are dynamic, constantly changing in shape and size (Kench and Brander 2006). Mangroves and coastal vegetation play a key role in this process by binding and stabilising sediments around the shoreline and are considered to act as a natural barrier against ocean dynamics. They can protect the shore and inland areas from natural disasters such as tsunamis (Alongi 2008). They can break the force of waves and help to prevent coastal-erosion processes (Mazda et al. 2002). Island instability and increasing human populations have led to the reliance on engineered structures to combat erosion and maintain island shorelines. The introduction of such structures can result in a range of negative environmental impacts, including accelerated erosion and reef degradation (Maragos 1993). An examination of the efficacy of these engineered structures has proposed the revaluation of islands as “static landforms” with one that recognises the

natural dynamism of the islands and emphasises the management of natural geomorphic processes (Kench 2012).

Coral cover on the island’s reefs is significantly below the historical average for the country (Pisapia et al. 2016). The 2016 mass coral bleaching event is the most likely cause (Ibrahim et al. 2017), though it may also be due to local conditions. However, there is little evidence of the direct local impacts of pollution or waste dumping from the island such as increased algae cover, turbid water or waste items on the reef.

Herbivore populations at the two outer reef survey sites were greater than the average numbers found during a 2017 – 2018 nationwide survey (IUCN, in press). Herbivorous fish, such as parrotfish and surgeonfish are important in preventing coral reefs from becoming overgrown by algae following disturbances (Hughes et al. 2007, Mumby et al. 2007). The numbers found at surveys across the country, and here are likely to confer a level of resilience to Maldivian reefs. Herbivores can experience short-to medium-term benefits following reductions in coral cover (Wilson et al. 2006, 2009). Historically there has not been a fishery targeting these species, however there is evidence that

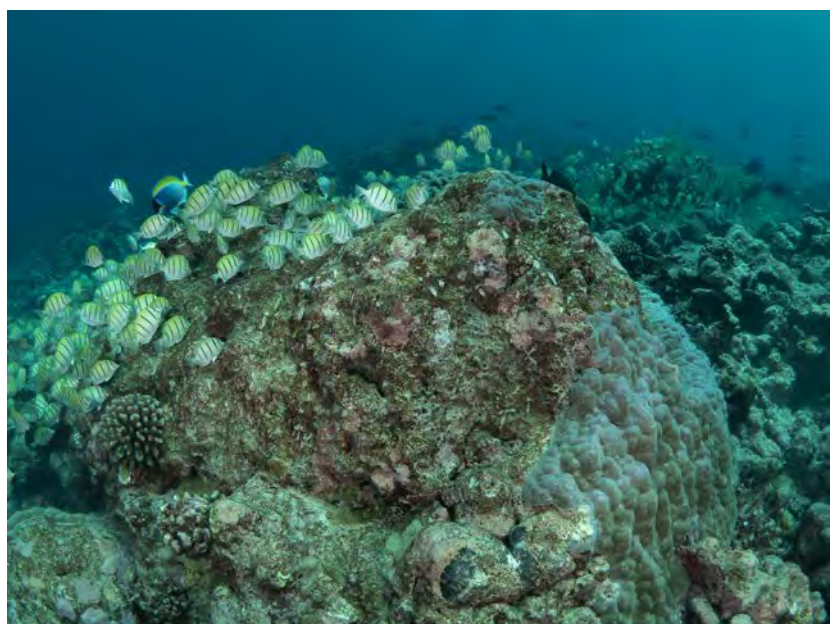


Figure 15: School of convict surgeon fish grazing off the algae on a rock



Figure 16: Massive boulder corals found in the outer reef in Kendhikulhudhoo

localised parrotfish is occurring in some areas. It is therefore key management efforts include education on their importance to reef health and prevents an expansion of this fishery. Parrotfish have also been found to play an important role in sediment creation and island development and maintenance (Morgan and Kench 2016). With future sea level change threatening to impact the low-lying islands of the Maldives healthy parrotfish populations will be important in maintaining island growth at the rates of any change in sea level.

Compared the benthic community found during a wide-ranging survey in 2017 – 2018 (IUCN, in press) the substrate in Kendhikulhudhoo was close to the national averages. Coral cover was slightly greater the national average and algae cover was significantly lower. Structural complexity of the reefs was identical to the national average. Juvenile coral recruitment was below the national average but was still greater than found at many reef sites. This suggests that the reefs around Kendhikulhudhoo were impacted on a similar level to much of the country by the 2016 bleaching. It may also indicate that the recovery of the reef will follow a similar trajectory reefs across the country. However, this is likely to be strongly dependent on local factors which can act to prevent or promote

coral recovery.

Increases in ocean temperatures will lead to more frequent and severe coral bleaching events (Hoegh-Guldberg 2011), similar to 2016 which had led to widespread coral mortality (Ibrahim et al. 2017). 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). However, when the opposite is true, and corals have less competition for space on reefs colonies are able to expand and coral larvae are able to settle and grow more successfully (Johns et al. 2018). This increases a coral reef's chances of recovery following disturbances.

Human activities over the past 150 years have caused approximately 0.85°C of climate warming (IPCC 2014) and it is likely that it will continue to warm by at least 1.5°C between

2030 and 2052 (IPCC 2018). 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 0.26 – 0.77 m by 2100 (IPCC 2018). Depending and the actual level and the rate of change 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 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 will limit island erosion and may enable island growth to keep pace with any sea level change.

Management

The ecological management goal for Kendhikulhudhoo is to provide a means to promote and ensure the long-term conservation and protection of the island's ecosystem. Existing local management efforts should be coordinated and developed further with this goal in mind. The aim should also be to utilise strategies and action plans local and national governments have developed 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 this goal. The main goal is broken down into two sub-goals: 1) to maintain the resilience of biological communities to stressors associated with climate change and 2) to maintain populations of unharvested species for social development, fishery enhancement and island health. Future efforts should aim to monitor and manage for resilience (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. The management plan could consider the following elements:

- The development of a long-term monitoring programme for pond, wetland, coral reef and seagrass habitats in order to track ecological and social changes over time,
- A plan for development and enforcement of regulations in the area which will include a plan for inclusion of the local community in management and enforcement.
- Detailed regulations for activities in the key areas, especially aquaculture developments in the ponds, timber harvesting and interactions with vulnerable or endangered species.
- Implementation of the waste management strategies outlined in the Fifth national report to the United Nations convention on Biological Diversity (Ministry of Environment and Energy 2015) specifically:
 - + The development of an island waste management plan
 - + The development of island waste management infrastructure
 - + The creation of a high capacity regional waste management facility
- Key areas of management or future protection should include:
 - + The southern and northern wetland areas, which are relatively unimpacted by human activities, but is potentially susceptible to changes in water flow or timber harvesting
 - + The reefs surrounding the island
 - + The seagrass area inside the island's lagoon, a habitat largely undervalued across the country
 - + The large ponds in the centre of the island which have been impacted by waste dumping and attempts at aquaculture development
- A plan for benefit-sharing for the area, so that benefits from the management have a positive impact on the wider community and can be used to empower and support the development of those who depend on the area for natural resources.
- Any management of the island's shoreline should make every effort to protect or enhance the intrinsic geomorphic resilience of the island and the use of engineering solutions should be adopted with extreme caution and only be used where they do not compromise natural geomorphic processes.

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Appendix

Species	Common name	Family
<i>Acanthurus lineatus</i>	Lined-surgeonfish	<i>Acanthuridae</i>
<i>Acanthurus maculiceps</i>	Spot-face surgeonfish	<i>Acanthuridae</i>
<i>Acanthurus nigricauda</i>	Eye-line surgeonfish	<i>Acanthuridae</i>
<i>Acanthurus nigrofuscus</i>	Dusky surgeonfish	<i>Acanthuridae</i>
<i>Zebbrasoma scopas</i>	Brown Tang	<i>Acanthuridae</i>
<i>Acanthurus leucosternon</i>	Powder-blue surgeonfish	<i>Acanthuridae</i>
<i>Ctenochaetus binotatus</i>	Two-spot bristletooth	<i>Acanthuridae</i>
<i>Ctenochaetus truncatus</i>	Gold-ring bristletooth	<i>Acanthuridae</i>
<i>Ctenochaetus striatus</i>	Fine-lined bristletooth	<i>Acanthuridae</i>
<i>Naso elegans</i>	Orange-spine unicornfish	<i>Acanthuridae</i>
<i>Heniochus diphreutes</i>	Schooling bannerfish	<i>Chaetodontidae</i>
<i>Chaetodon trifasciatus</i>	Pinstriped butterflyfish	<i>Chaetodontidae</i>
<i>Heniochus pleurotaenia</i>	Phantom bannerfish	<i>Chaetodontidae</i>
<i>Forcipiger flavissimus</i>	Long-nose butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon falcula</i>	Double-saddle butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon triangulum</i>	Triangular butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon auriga</i>	Threadfin butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon meyeri</i>	Meyers butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon guttatisimus</i>	Spotted butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon collare</i>	Head-band butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon xanthocephalus</i>	Yellow-head butterflyfish	<i>Chaetodontidae</i>
<i>Hemitaenichthys zoster</i>	Black pyramid butterflyfish	<i>Chaetodontidae</i>
<i>Sargocentron tiere</i>	Blue-lined squirrelfish	<i>Holocentridae</i>
<i>Myripristis berndti</i>	Blotcheye soldierfish	<i>Holocentridae</i>
<i>Myripristis kuntee</i>	Epaulette soldierfish	<i>Holocentridae</i>
<i>Myripristis murdjan</i>	Crimson soldierfish	<i>Holocentridae</i>
<i>Myripristis pralinia</i>	Big-eye soldierfish	<i>Holocentridae</i>
<i>Neoniphon sammara</i>	Spotfin squirrelfish	<i>Holocentridae</i>
<i>Sargocentron caudimaculatum</i>	White-tail squirrelfish	<i>Holocentridae</i>
<i>Lethrinus obsoletus</i>	Orange-stripe emperor	<i>Lethrinidae</i>
<i>Lutjanus biguttatus</i>	Two-spot snapper	<i>Lutjanidae</i>
<i>Lutjanus gibbus</i>	Humpback snapper	<i>Lutjanidae</i>
<i>Macolor macularis</i>	Midnight snapper	<i>Lutjanidae</i>
<i>Centropyge multispinis</i>	Many-spined angelfish	<i>Pomacanthidae</i>
<i>Pomacanthus imperator</i>	Emperor angelfish	<i>Pomacanthidae</i>
<i>Pygoplites diacanthus</i>	Regal angelfish	<i>Pomacanthidae</i>

Species	Common name	Family
<i>Pomacentrus nagasakiensis</i>	Scribbled damsel	Pomacentridae
<i>Pomacentrus philippinus</i>	Philippine damsel	Pomacentridae
<i>Chromis dimidiata</i>	Two-tone puller	Pomacentridae
<i>Chromis tematensis</i>	Swallow-tail puller	Pomacentridae
<i>Calotomus carolinus</i>	Starry-eye parrotfish	Scaridae
<i>Scarus tricolor</i>	Three-colour parrotfish	Scaridae
<i>Scarus rubroviolaceus</i>	Ember parrotfish	Scaridae
<i>Scarus psittacus</i>	Rosy-cheek parrotfish	Scaridae
<i>Scarus prasiognathos</i>	Green-face parrotfish	Scaridae
<i>Scarus scaber</i>	Five-saddle parrotfish	Scaridae
<i>Scarus frenatus</i>	Bridled parrotfish	Scaridae
<i>Chlorurus sordidus</i>	Shabby parrotfish	Scaridae
<i>Chlorurus strongylocephalus</i>	Sheephead parrotfish	Scaridae
<i>Scarus niger</i>	Dusky parrotfish	Scaridae
<i>Cephalopholis argus</i>	Peacock rock cod	Serranidae
<i>Cephalopholis leopardus</i>	Leopard rock cod	Serranidae
<i>Anypiperodon leucogrammicus</i>	White-lined grouper	Serranidae
<i>Aethaloperca rogaa</i>	Red-flushed grouper	Serranidae
<i>Epinephelus merra</i>	Honeycomb grouper	Serranidae

Table A 1: All species of *Acanthuridae*, *Chaetodontidae*, *Holocentridae*, *Lethrinidae*, *Lutjanidae*, *Pomacanthidae*, *Scaridae* and *Serranidae* observed on transects in Kendhikulhudhoo

Family	Common name	Family	Common name	Family	Common name
<i>Acanthuridae</i>	Surgeonfish	Holocentridae	Squirrelfish	Pomacentridae	Damselfish
Apogonidae	Cardinalfish	Kyphosidae	Rudderfish	Priacanthidae	Bigeye
Balistidae	Triggerfish	Labridae	Wrasse	Scaridae	Parrotfish
Blenniidae	Blenny	Lethrinidae	Emperor	Serranidae	Grouper
Caesionidae	Fusilier	Lutjanidae	Snapper	Siganidae	Rabbitfish
<i>Chaetodontidae</i>	Butterflyfish	Microdesmidae	Dart Goby	Synodontidae	Lizardfish
Cirrhitidae	Hawkfish	Mullidae	Goatfish	Tetraodontidae	Pufferfish
Ephippidae	Battfish	Muraenidae	Moray Eel	Tripterygiidae	Triplefin
Gobiidae	Goby	Pempheridae	Bullseye	Zanclidae	Moorish idol
Haemulidae	Sweetlips	Pinguipedidae	Grubfish		
Holocentridae	Soldierfish	Pomacanthidae	Angelfish		

Table A 2: All fish families observed on transects in Kendhikulhudhoo

Genus	Family	Genus	Family
Acropora	Acroporidae	Leptoseris	Agariciidae
Astreopora	Acroporidae	Lobophyllia	Lobophylliidae
Coscinaraea	Coscinaraea	Montastrea	Paramonastreae
Echinopora	Merulinidae	Montipora	Acroporidae
Favia	Mussidae	Pavona	Agariciidae
Favites	Merulinidae	Platygyra	Merulinidae
Fungia	Fungiidae	Pocillopora	Pocilloporidae
Galaxea	Euphylliidae	Porites	Poritidae
Goniastrea	Merulinidae	Psammocora	Psammocoridae
Heliopora	Helioporidae	Sacrophyton	Alcyoniidae
		Symphyllia	Lobophylliidae

Table A 3: All coral genera observed on transects in Kendhikulhudhoo

Genus	Family
Acropora	Acroporidae
Astreopora	Acroporidae
Favia	Mussidae
Favites	Merulinidae
Fungia	Fungiidae
Galaxea	Euphylliidae
Goniastrea	Merulinidae
Leptastrea	Insertae sedis
Leptoseris	Agariciidae
Lobophyllia	Lobophylliidae
Montastrea	Paramonastreae
Pavona	Agariciidae
Pocillopora	Pocilloporidae
Porites	Poritidae
Psammocora	Psammocoridae

Table A 4: All coral recruit genera observed on transects in Kendhikulhudhoo

Species	Common name	Dhivehi name	Mangrove species
<i>Bruguiera cylindrica</i>	Small-leafed orange mangrove	Kandoo	Yes
<i>Bruguiera gymnorrhiza</i>	Large-leafed orange mangrove	Bodavaki	Yes
<i>Cocos nucifera</i>	Coconut palm	Dhivehi ruh	No
<i>Cordia subcordata</i>	Sea trumpet	Kaani	No
<i>Cyperus sp.</i>	Sedge grass		No
<i>Excoecaria agallocha</i>	Blind-your-eye mangrove	Thela	Yes
<i>Lumnitzera racemosa</i>	Black mangrove	Burevi	Yes
<i>Pandanus odorifer</i>	Screw pine	Maa Kashikeyo	No
<i>Pandanus tectorius</i>	Screw pine	Boa Kashikeyo	No
<i>Pemphis acidula</i>	Iron wood	Kuredhi	No
<i>Rhizophora apiculata</i>	Tall-stilted mangrove	Thakafathi	Yes
<i>Rhizophora mucronata</i>	Red mangrove	Ran'doo	Yes
<i>Scaevola taccada</i>	Sea lettuce	Magoo	No
<i>Sonneratia caseolaris</i>	Mangrove apple	Kulhlhava	Yes
<i>Talipariti tiliaceum</i>	Sea hibiscus	Dhigga	No
<i>Thespesia populnea</i>	Thespesia	Hirun'dhu	No

Table A 5: All vegetation species observed on surveys in Kendhikulhudhoo



KEYLAKUNU

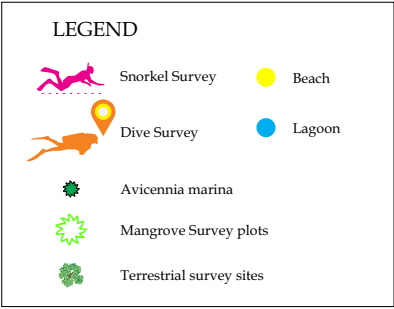
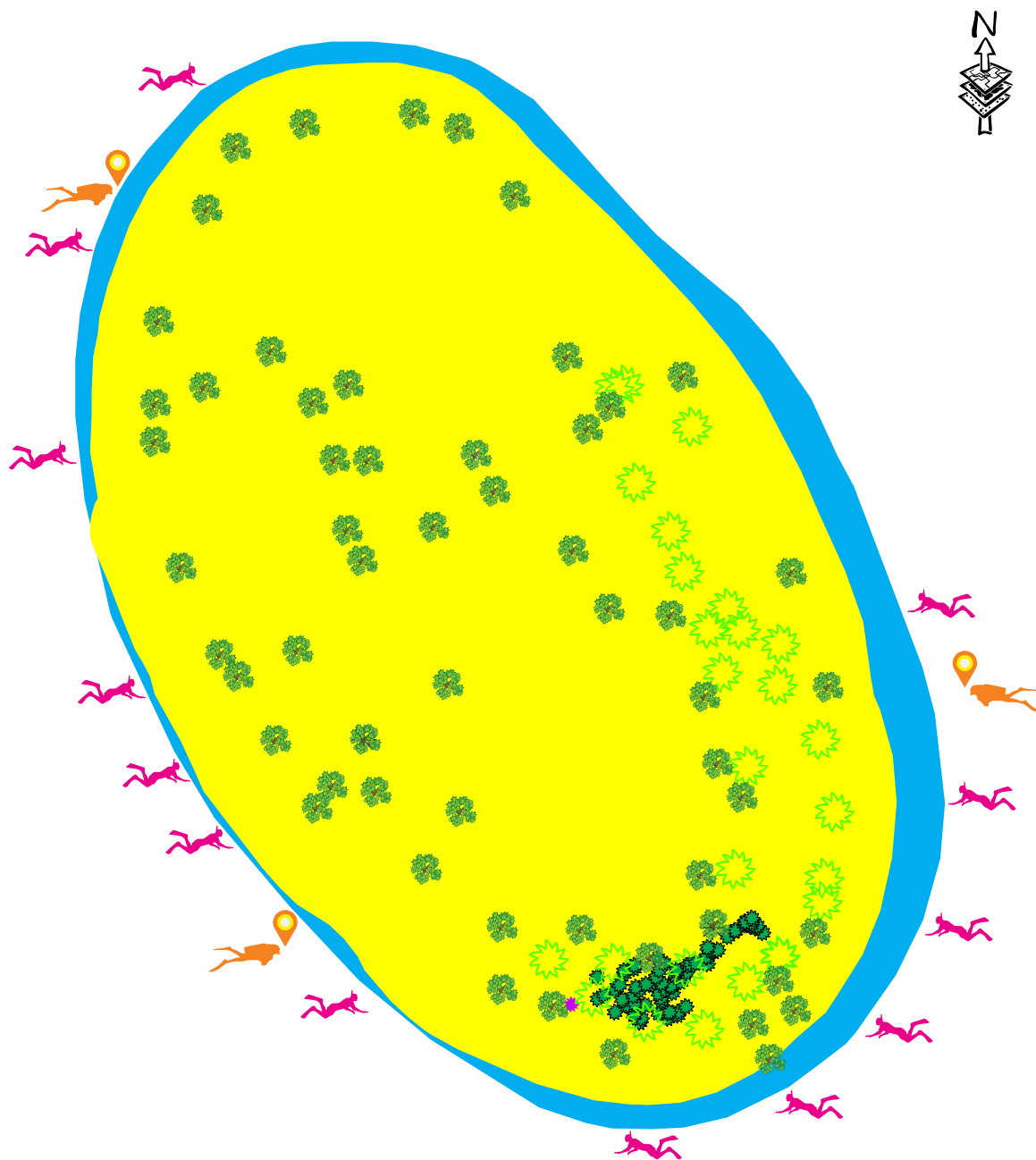
Introduction

Keylakunu is an oval-shaped uninhabited island located in the centre of Haa Dhaal atoll. The eastern side of the island is characterised by a mangrove wetland created by a large depression in the island which seawater flows into through the porous coral rock. Much of the rest of the island has thick forest growth with large trees growing greater than 30m tall. The sediment is more soil-like and is likely to be more nutrient rich than on the other islands. There are also agricultural plots on Keylakunu. The mangrove forest in Keylakunu is a special habitat. The combination of dense large, *Bruguiera cylindrica* areas with defined layers of mature, immature and juvenile growth, *Rhizophora mucronata* with complex tap root networks surrounding ponds and large *Avicennia marina* trees spread throughout make this a unique habitat. The stable nature of the area also means it is likely to be a significant carbon sink. Such mangrove habitats should be the subject of future research to shed greater light on to the value of these systems to the Maldives. There were many smaller depressions

with *B. cylindrica* growth around this side of the island. There was a solitary *Sonneratia caseolaris* in an isolated area to the north of the wetland. The charismatic white-tailed tropical bird (*Phaethon lepturus*) was observed in high numbers across the island. The beaches had a high number of turtle nests, however all had evidence of human disturbance, indicating illegal egg collection. A fringing reef wrapped around the outside of the island, with no lagoon area between the island and the reef. The shallow reef habitat was in a spur and groove formation, indicating high wave action around the island. The reef had low coral cover, though there was high structural complexity created by remnant table and branching coral skeleton.

Table 1. Latitude and longitude of the quantitative survey sites

Site	Latitude	Longitude
1	6.59857	73.00671
2	6.60150	73.01447
3	6.60746	73.00415



Coral Reef Benthos



Figure 1. Groove formation on the reef of Keylakunu

Three sites were surveyed using quantitative transect methods (Table 1). The reef was highly complex, made up of remnant table and branching coral structures on the reef flat/slope and spur and grooves in the shallow areas. The reef cover was predominantly

bare rock with little live growth of either coral or algae. The mean coral cover of 12.5% was below the average observed during the ecological surveys. Algal cover was low. The 3.8 mean structural complexity was amongst the highest observed.

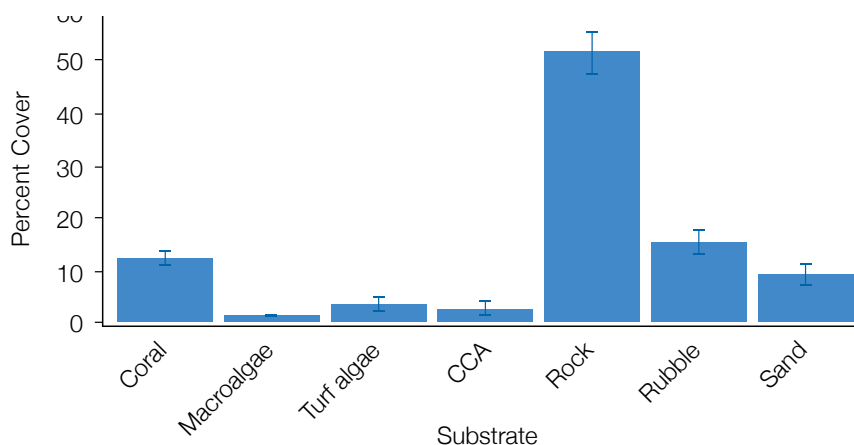


Figure 2. Mean percentage cover of substrate categories across all surveys on Keylakunu

Site	Complexity	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	3.3	9.5	0.8	3.4	47.0	17.8	14.6	3.7	0.0	2.0
2	4.3	14.6	1.9	3.6	54.7	15.0	1.9	2.3	2.3	2.0
3	3.7	13.3	0.9	4.2	52.6	13.1	10.8	2.0	0.0	2.0

Table 2. Location, mean complexity and mean substrate cover of the quantitative surveys.

Fish Community

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy

reef areas and the species richness here was high. 51 reef associated fish families were observed across the country, 32 of which were found on Keylakunu. The density of the key herbivores, surgeonfish and parrotfish was low, though the species richness was high. Herbivores are a functionally important group on coral reefs They

play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). These results suggest the reefs here could be at risk of algal overgrowth due to low herbivore numbers. It is important that preservation of these herbivores is part of any future management plan.

Site	Total number of families	Mean number of families
Keylakunu	32	17.4
1	28	17.7
2	27	17.7
3	24	17.0

Table 3. Location, total number of fish families and mean number of fish families per transect observed across all sites and at individual survey sites

Site	Total number of grouper species	Mean number of grouper species	Mean grouper density /100 m ²	Total number of butterflyfish species	Mean number of butterflyfish species	Mean butterflyfish density /100 m ²
Keylakunu	10	2.9	2.5	13	3.9	14.5
1	6	2.3	2.6	9	3.8	8.3
2	5	2.2	2.1	9	2.8	23.5
3	9	2.8	2.7	10	3.8	9.7

Table 4. Location, total number of species, mean number of species and mean density per transect observed for grouper and butterflyfish across all sites and at individual survey sites

Site	Total number of parrotfish species	Mean number of parrotfish species	Mean parrotfish density /100 m ²	Total number of surgeonfish species	Mean number of surgeonfish species	Mean surgeonfish density /100 m ²
Keylakunu	11	3.8	8.6	8	4.8	29.2
1	6	4.3	6.3	8	6.8	28.3
2	7	6.0	9.6	6	7.3	32.2
3	9	6.3	9.9	6	6.7	26.9

Table 5. Location, total number of species, mean number of species and mean density per transect observed for parrotfish and surgeonfish across all sites and at individual survey sites

Number of Endangered Animals

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large

groupers. Endangered hawksbill turtles are relatively common in the Maldives; however, their populations are at risk from a decline in available nesting sites, the declining health of coral reefs and illegal collection of eggs. Evidence of turtle egg poaching was found along the beach of Keylakunu.

Latitude	Longitude	<i>Cheilinus undulatus</i>	<i>Eretmochelys imbricata</i>	<i>Triaenodon obesus</i>
6.59777	73.00764	1	2	
6.60454	73.00391		3	1
6.60150	73.01447		1	1

Table 6. Location and number of IUCN Redlistd (endangered, vulnerable and least concern) species observed during rapid surveys.

Vegetation



Figure 3. *Rhizophora* sp.



Figure 4. *Rhizophora* sp.



Figure 5. Abundance of mangrove trees in Keylakunu



Figure 6. One of the many *Avicennia marina* trees in Keylakunu

The coastal fringe vegetation was dominated by *Scaevola taccada*, *Talipariti tiliaceum*, *Pandanus tectorius* and *Guettarda speciosa*. The inland forest habitat was unique among islands surveyed. Large trees such as banyan (*Ficus benghalensis*) and Indian almond (*Terminalia procera*) trees grow in the centre of the island and reached heights greater than 30 m. The sediment is more soil-like and is likely to be more nutrient rich than on the other islands allowing for this forest development. The ground had a thick cover of leaf litter. The mangrove area had thick *B. cylindrica* growth with an especially high density of young growth. There was a clearly defined area of *R. mucronata* in the south-eastern part of the mangrove. This was limited to the site where water was flowing into the depression through the bedrock and the water depth was greater. Spread throughout the area

were large *A. marina* trees. The largest of these trees was over 15 m tall with a DBH of 2.4 m. The main mangrove depression had been split in two by a man-made path. This may have cut off some of the water flow to the northern section and the *B. cylindrica* trees here appeared less healthy. Outside the main mangrove area were small depressions with mangrove growth. The majority of these consisted of 1 – 5 *B. cylindrica* trees with many seedlings at the base. There was a single *Sonneratia caseolaris* tree growing at the northern end of the mangrove area.

Birds

A high number of birds were observed across the island. The bird species observed differed between survey zones. Birds were most abundant in the inland habitat. This was the only

island where the charismatic white-tailed tropical bird (*Phaethon lepturu*) was observed. This is a ground nesting bird species which requires specific habitat characteristics for nesting. Rats and cats were observed on the island which is a concern as *P. lepturu* nests are at high risk from these. Surveys were limited to daylight hours so no roosting was observed and we were unable to determine the location of any nesting sites.

Scientific name	Common name	Dhivehi name	Zone		
			Coastal fringe	Inland forest	Mangrove forest
<i>Adenanthera gersenii</i>	Coral wood	Madhoshi	2.4		
<i>Calophyllum inophyllum</i>	Alexander Laurel wood	Funa	2.9		
<i>Cocos nucifera</i>	Coconut palm	Dhivehi ruh		3.3	
<i>Cordia subcordata</i>	Sea trumpet	Kaani		3.3	
<i>Ficus benghalensis</i>	Banyan tree	Nika		3.1	
<i>Guettarda speciosa</i>	Beach gardenia	Uni	12.0	16.0	
<i>Hernandia nymphaeifolia</i>	Hernandia	Kandhu	4.8		
<i>Ochrosia oppositifolia</i>	Cork wood tree	Dhun'buri	4.6	19.1	
<i>Pandanus odorifer</i>	Screw pine	Maa Kashikeyo		24.3	
<i>Pandanus tectorius</i>	Screw pine	Boa Kashikeyo	16.1		
<i>Pemphis scidula</i>	Iron wood	Kuredhi	2.0		
<i>Scaevola taccada</i>	Sea lettuce	Magoo	28.0	27.9	
<i>Talipariti tiliaceum</i>	Sea hibiscus	Dhigga	22.3		
<i>Terminalia catappa</i>	Indian almond	Midhili	3.4	2.9	
<i>Avicennia marina</i>	Grey mangrove	Baru			7.3
<i>Bruguiera cylindrica</i>	Small-leafed orange mangrove	Kandoo	1.7		76.4
<i>Rhizophora mucronata</i>	Red mangrove	Ran'doo			16.3

Table 7. Percent cover of plant species in the three vegetation zones surveyed.

Scientific name	Dhivehi name	Zone		
		Coastal fringe	Inland	Mangrove
<i>Corvus splendens</i>	Kaalhu	13		
<i>Amauromis phoenicurus maldivus</i>	Dhivehi Kambili			1
<i>Ardea cinerea</i>	Maakanaa	3	3	
<i>Ardeola grayii phillipsi</i>	Huvadhoo Raabondhi		2	
<i>Casmerodius albus</i>	Lagana		4	
<i>Charadrius mongolus</i>	Kuda Bondana		2	
<i>Elanus caeruleus</i>	Fiyakalhu Baazu		1	
<i>Eudynamis scolopaceus</i>	Koel	19		
<i>Numenius phaeopus</i>	Bulhithun'bi		5	2
<i>Nycticorax nycticorax</i>	Raabondhi		2	
<i>Phaethon lepturus</i>	Dhan'dhifulhu	4	7	

Table 8. Abundance of bird species observed in the three zones surveyed

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families

was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Island vegetation areas were classified into five vegetation zones based on location: coastal fringe, pond fringe, mangrove bay fringe, mangrove forest and inland forest. Survey points were identified within each zone using a stratified sampling approach and the GPS coordinates were extracted from Google Earth© version 7.3.1 and entered into a handheld GPS (Garmin etrex 20x) for navigation to the point. At a survey point a 2.5 m radius circle was estimated and the dominant and secondary flora within the area were identified to species and their respective percent covers were estimated. The height of the dominant species was estimated to the nearest metre. Bird surveys were conducted concurrent with terrestrial habitat surveys. All birds observed were counted and identified to species. Mangrove fish surveys were conducted first during high tide when the bay was sufficiently deep, surveys were conducted from a boat,

and then during low tide surveys were conducted on foot. All fish were counted and identified to family and where possible to species.

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Annex

Fish families observed at Keylakunu

Common family	Family	Common family	Family	Common family	Family
Surgeonfish	<i>Acanthuridae</i>	Flutemouth	Fistulariidae	Angelfish	Pomacanthidae
Cardinalfish	Apogonidae	Goby	Gobiidae	Damselfish	Pomacentridae
Triggerfish	Balistidae	Sweetlips	Haemulidae	Bigeye	Priacanthidae
Blenny	Blenniidae	Squirrelfish	Holocentridae	Parrotfish	<i>Scaridae</i>
Fusilier	Caesionidae	Rudderfish	Kyphosidae	Grouper	<i>Serranidae</i>
Jack	Carangidae	Wrasse	Labridae	Rabbitfish	Siganidae
Requiem Shark	Carcharhinidae	Emperor	Lethrinidae	Pufferfish	Tetraodontidae
Butterflyfish	<i>Chaetodontidae</i>	Snapper	Lutjanidae	Triplefin	Tripterygiidae
Hawkfish	Cirrihitidae	Tilefish	Malacanthidae	Moorish idol	Zanclidae
Porcupinefish	Diodontidae	Filefish	Monacanthidae		
Battfish	Ephippidae	Goatfish	Mullidae		

Table A1. All fish families recorded

Grouper, butterflyfish, parrotfish and surgeonfish species observed at Keylakunu

Scientific name	Common name
<i>Aethaloperca rogaa</i>	Red-flushed grouper
<i>Anyperodon leucogrammicus</i>	White-lined grouper
<i>Cephalopholis argus</i>	Peacock rock cod
<i>Cephalopholis leopardus</i>	Leopard rock cod
<i>Cephalopholis miniata</i>	Vermilion rock cod
<i>Cephalopholis nigripinnis</i>	Blackfin rock cod
<i>Epinephelus coeruleopunctatus</i>	Small-spotted grouper
<i>Epinephelus merra</i>	Honeycomb grouper
<i>Epinephelus spilotoceps</i>	Foursaddle grouper
<i>Variola louti</i>	Lunar-tailed grouper

Table A2. All grouper species recorded across detailed underwater visual census

Scientific name	Common name
<i>Chaetodon auriga</i>	Threadfin butterflyfish
<i>Chaetodon collare</i>	Head-band butterflyfish
<i>Chaetodon falcula</i>	Double-saddle butterflyfish
<i>Chaetodon guttatissimus</i>	Spotted butterflyfish
<i>Chaetodon kleinii</i>	Brown butterflyfish
<i>Chaetodon lunula</i>	Raccoon butterflyfish
<i>Chaetodon meyeri</i>	Meyers butterflyfish
<i>Chaetodon triangulum</i>	Triangular butterflyfish
<i>Chaetodon trifasciatus</i>	Pinstriped butterflyfish
<i>Chaetodon xanthocephalus</i>	Yellow-head butterflyfish
<i>Forcipiger flavissimus</i>	Long-nose butterflyfish
<i>Forcipiger longirostris</i>	Very long-nose butterflyfish
<i>Hemitaurichthys zoster</i>	Black pyramid butterflyfish

Table A3. All butterflyfish species recorded across detailed underwater visual census

Scientific name	Common name
<i>Chlorurus sordidus</i>	Shabby parrotfish
<i>Chlorurus strongylocephalus</i>	Sheephead parrotfish
<i>Scarus festivus</i>	Happy parrotfish
<i>Scarus frenatus</i>	Bridled parrotfish
<i>Scarus niger</i>	Dusky parrotfish
<i>Scarus prasiognathos</i>	Green-face parrotfish
<i>Scarus rubroviolaceus</i>	Ember parrotfish
<i>Scarus russelli</i>	Eclipse parrotfish
<i>Scarus scaber</i>	Five-saddle parrotfish
<i>Scarus tricolor</i>	Three-colour parrotfish
<i>Scarus viridifucatus</i>	Green-snout parrotfish

Table A4. All parrotfish species recorded across detailed underwater visual census

Scientific name	Common name
<i>Acanthurus auranticavus</i>	Ring-tail surgeonfish
<i>Acanthurus leucostemon</i>	Powder-blue surgeonfish
<i>Acanthurus nigricauda</i>	Eye-line surgeonfish
<i>Acanthurus nigrofuscus</i>	Dusky surgeonfish
<i>Ctenochaetus binotatus</i>	Two-spot bristletooth
<i>Ctenochaetus striatus</i>	Fine-lined bristletooth
<i>Ctenochaetus truncatus</i>	Gold-ring bristletooth
<i>Zebrasoma scopas</i>	Brown Tang

Table A5. All surgeonfish species recorded across detailed underwater visual census



MAAKAN'DOODHOO

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 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 Maakan'doodhoo in Shaviyani Atoll 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 scattered 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 and Hatcher 2004). Maldivian islands are known as low lying islands with 80% of the country being less than a meter above the sea level and the majority of islands being less than 5 km² in size. (Ministry of Environment and Energy 2015). Studies to understand the atoll and island formation have suggested that the island reefs in the Maldives have been around 4000 yr. B.P (Kench et al. 2005, Perry et al. 2013).

The terrestrial fauna and flora have a rich biodiversity. The range of natural island habitats includes beaches, marshes, brackish ponds, mangroves and woodlands. There are 583 species of terrestrial flora found, of which 323 are cultivated and 260 are natural. The farmed species are mostly used as a source of food and some for traditional medicine. Mangroves ecosystems can be classified based on the system's exposure to the sea as either "open mangrove systems" or "closed mangrove systems. These can then be further subdivided into four categories (Saleem and Nileysha 2003) (Table 1). In all but marsh-based

mangroves, tree growth is limited to a narrow band around the water's edge. Around 15 species of mangroves are found across approximately 150 islands (Ministry of Environment and Energy 2015). Maldivian avifauna is made up of seasonal migrants, breeding residents and introduced birds. Over 167 species of birds have been recorded in the Maldives. Around 70 species of shorebirds are recorded, some of which are breeding residents while others are recorded as migrants. Migratory birds visit during certain seasons to breed or use the islands as a transit point to their breeding grounds (Ministry of Environment and Energy 2015).

Terrestrial habitats are threatened by many local scale factors including

Open mangrove systems	Coastal fringing mangroves	Exposed mangroves growing directly on the shoreline. Experience regular wave action. Uncommon mangrove system
	Embayment mangroves	Mangroves partly encircle a bay area. Experience daily tidal flushing. Common mangrove system
Closed mangrove systems	Pond-based mangroves	Mangroves encircle a brackish water pond. Possible water exchange through bedrock or overwash. Common mangrove system
	Marsh-based mangrove	Mangrove found on muddy substrate with no standing water. Dampness of mud may come from flow through the bedrock or overwash. Uncommon mangrove system

Table 1: Description of the four types of mangrove ecosystems found in the Maldives. From Saleem and Nileysha (2003)

infrastructure development, human waste and land reclamation projects. Similar to the marine environment, habitats such as mangrove areas are known for their ecological significance and diversity, providing habitats and services to animal and human communities (Kuenzer et al. 2011). However, due to historical and continued undervaluation, most 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 infrastructure development. Refuse dumping has had a major impact on the terrestrial and marine environment. Around 1.7 kg of waste is generated per capita in Male' alone (Ministry of Environment and Energy 2015). This highlights the need for proper waste management in the Maldives. At present, 128 waste management centres are established across Maldives, and regional waste management centres are planned for major populated areas such as Addu City. The government has increased their efforts to manage the waste issue by incorporating the 3Rs (Reduce, Reuse, Recycle) concept into policy and investing on local waste management centres. However, many populated islands are far away from regional waste management centres making dumping waste on land or in the sea the most convenient disposal option for a large proportion of the population.

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 dependent

on the profits around these industries. This highlights the significance of the natural environment to the Maldives and 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 the sustainable use and management of these natural resources within communities. Such approaches will play a key role in standardizing the efforts to manage and monitor the resources in a co-managed concept.

Study site

Maakan'doodhoo is an uninhabited island in Shaviyani Atoll. The island is located at 6°14'5" N and 73°16'2" E. Shaviyani atoll is known as Northern Miladhunmadulu atoll or Miladhunmadulu Uthuruburi. This is an administrative division of the Maldives and it corresponds to the northern section of the natural Miladhunmadulu atoll. The atoll is 37 miles long and it is the third atoll from the northern edge of the country. It comprises 51 islands of which 16 are inhabited. The atoll's population is 12,636 (National Bureau of Statistics, 2014) (Godfrey, 2004). The main livelihood in the atoll is pelagic and reef fishing, however tourism is growing in the atoll with two newly opened resorts.

Maakan'doodhoo used to be inhabited however the damage caused by the 2004 Tsunami left the island uninhabitable and the population was relocated to other islands. Currently the island is leased for agricultural purpose. The island has a sandy beach that runs around all but the north east area which is covered in beach rocks. The

island has a large central pond and two smaller pond areas to the north. The central pond is approximately 430 m long and 285 m wide.



Figure 1: Abounded houses found in the island (A & B) Methods

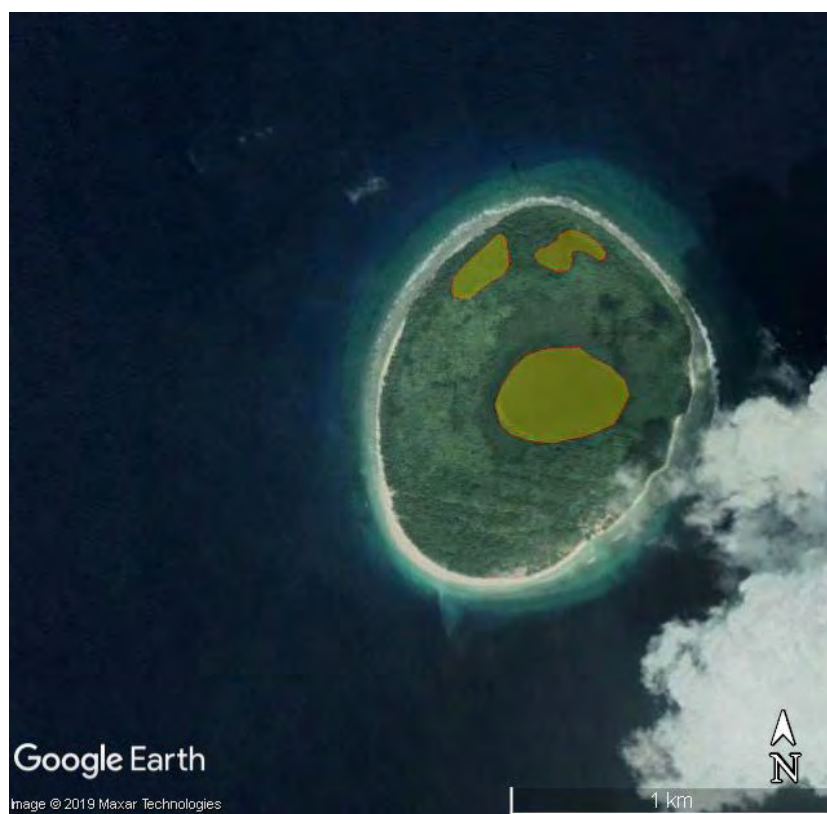


Figure 2: Map of Maakan'doodhoo survey areas. Yellow polygons indicate terrestrial survey areas, A) Central pond, B) North pond and C) Wetland. ©Google Earth 2019

Methods

The terrestrial survey area on Maakan'doodhoo was identified as the large central pond and the small pond and wetland areas at the north of the island. Survey points were identified using a stratified sampling approach with sites selected around pond fringes and throughout the wetland areas. GPS coordinates were extracted from Google Earth© version 7.3.1 and entered into a handheld GPS (either Garmin etrex 20x or Garmin GPS maps 64s) for navigation to the point (Figure 4). At a survey point, a 2.5 m radius circle was estimated and the dominant and secondary flora within the area were identified to species and their respective percent covers were estimated. The height of the dominant species was estimated to the nearest metre. Substrate type was recorded and counts of crab burrows and rubbish were conducted. The number of survey points for each zone was dependent on zone size and accessed on foot. If identified points were inaccessible, a new point was taken as close as possible to the original point and the survey was performed here. Wetland bird and fish surveys were conducted concurrently with terrestrial habitat surveys. All birds observed were identified to species. Fish were identified to family and their abundance was estimated.



Figure 4: Recording data at a terrestrial survey point

Results

Six species of flora were identified around the ponds and wetland areas on Maakan'doodhoo (Table A1). The mangrove species *Lumnitzera racemosa* was the dominant species at both the central pond and north pond area. The wetland area had a

more even mix of species but was much of the vegetation was made up of *Bruguiera cylindrica* and *L. racemosa* (Figure 5). The mangrove community in the wetland area and north pond were less healthy than those found in the central pond. Human waste was absent from both central and

north ponds and was present only in relatively small numbers in the wetland area (Figure 7). A diverse range of bird species was found throughout the survey areas (Table A2). The wetland area did not have any aquatic species; however the two ponds had several species (Table A3).

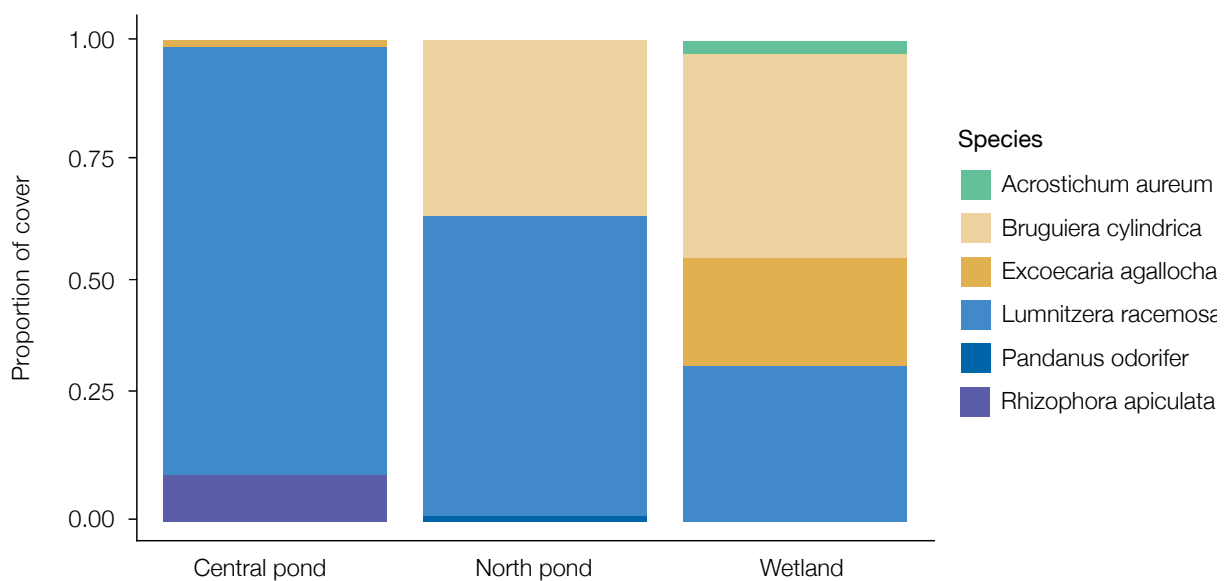


Figure 5: Proportion of cover of tree species at the three vegetation areas surveyed



Figure 6: Some Species of Mangrove trees found in Maakan'doodho

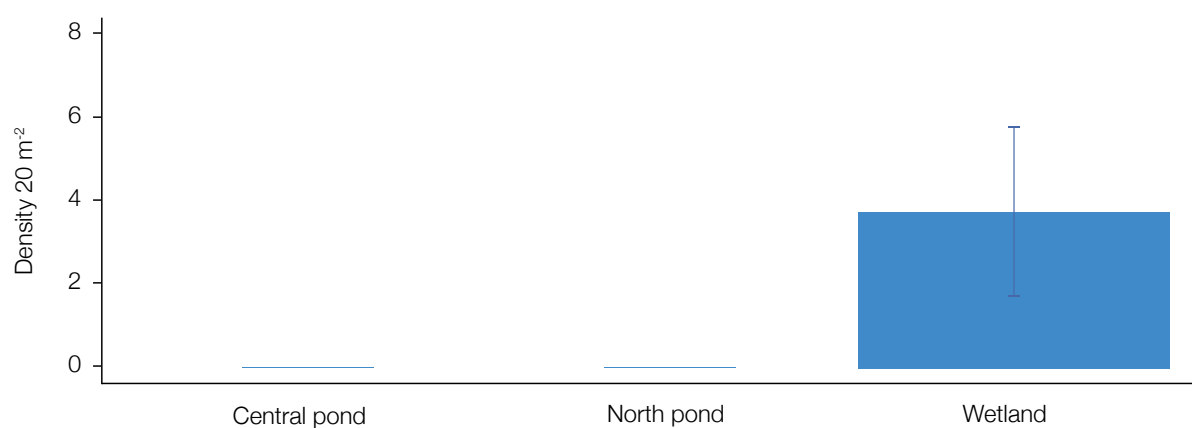


Figure 7: The mean number of refuse items found per 2.5 m radius survey point in the three areas of vegetation surveyed.



Figure 8: Some refuse found in pond C

Discussion

Maakandoodhoo island appears to have a relatively high diversity of mangrove species. Vegetation around at three areas was dominated by mangrove, though each had a different mix of species. There was no direct connection between the sea and any of the pond or wetland areas. The ponds were all connected by marshy soil which may indicate a high island water table. There was an abundant fish community in the large central pond which would have benefitted from the complex root structure provided by the *Rhizophora apiculata* that provides a structurally complex habitat. Many birds were observed hunting around the pond fringe, relying on this abundant fish community for food. Turtle nests were found on the beach and one of these had track marks from hatchlings emerging from the nest.

Mangrove species provide a range of ecosystem services (Mumby et al. 2004, Nagelkerken et al. 2008). Having a diverse mangrove community increases the number of habitat types available for the island's fauna and

the resilience of the system. Though enclosed ponds (locally called kulhi) such as those found here, are a common feature of many Maldivian islands the dynamics of their formation, and vegetation development are poorly understood. Given their abundance throughout the country developing a greater understanding of their dynamics and ecological role should be a priority.

Islands in the Maldives are dynamic, constantly changing in shape and size (Kench and Brander 2006). Mangroves and coastal vegetation play a key role in this process by binding and stabilising sediments around the shoreline and are considered to act as a natural barrier against ocean dynamics. They can protect the shore and inland areas from natural disasters such as tsunamis (Alongi 2008). They can break the force of waves and help to prevent coastal-erosion processes (Mazda et al. 2002).

Though the island is used primarily for agricultural purposes it is not free from human waste. However, the pond areas had very little refuse present as they are not connected to the sea and are visited by neighbouring islands

to collect dried coconut palm leaves. Though it was not part of the specified survey area it was observed that the shoreline had a very high volume of refuse on the beach and entangled in the vegetation. Waste management is clearly 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 (Ministry of Environment 2019) to identify and develop practical approaches for waste management. The recommendations in such plans should be incorporated in future management plans. Campaigns, such as the "National campaign to reduce plastic bottles" provide publicity and education on the need for waste reduction, particularly on single use plastics. However, many small islands have no clean safe drinking water to refill their water bottles.

There is an increasing demand for land area in the Maldives, mainly

for agricultural expansion, industrial growth and for housing (Thupalli 2009). Population growth is creating demands on the land area for food production and housing. Furthermore, expansion of the tourist industry may threaten habitats on uninhabited islands and shallow coral reefs, as plans for new airports and resorts require land reclamation and redevelopment of these sensitive areas. It is important for the ecological health and diversity of the country that islands such as Maakan'doodhoo, which have not yet been significantly impacted by coastal development remain this way. There is a risk agricultural expansion on the island may encroach on the ecologically valuable pond habitats.

Human activities over the past 150 years have caused approximately 0.85°C of climate warming (IPCC 2014) and it is likely that it will continue to warm by at least 1.5°C between 2030 and 2052 (IPCC 2018). 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 0.26 – 0.77 m by 2100 (IPCC 2018). Depending on the actual level and the rate of change this increases the risk of storm damage to wetlands and ponds, as well as human settlements and may result in eventual inundation of them by sea water. Healthy 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 will limit island erosion and may enable island growth to keep pace with any sea level change.

Management

The ecological management goal for Maakan'doodhoo is to provide a means to promote and ensure the long-term conservation and protection of the island's ecosystem. Existing local management efforts should be coordinated and developed further with this goal in mind. The aim should also be to utilise strategies and action plans local and national governments have developed 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 this goal. The main goal is broken down into two sub-goals: 1) to maintain the resilience of biological communities to stressors associated with climate change and 2) to maintain populations of unharvested species for social development, and island health. Future efforts should aim to monitor and manage for resilience (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. The management plan could consider the following elements:

- The development of a long-term monitoring programme for the pond and wetland habitats in order to track ecological changes over time.
- A research programme to examine the ecological value of inland ponds (kuhli's) here and across the Maldives.
- Island geographical and topographical monitoring programme to monitor and map the structural development of the island.
- Spatial planning for agriculture on the island that should be designed at preventing expansion towards the pond and wetland areas.

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Appendix

Species	Common name	Dhivehi name	Mangrove species
<i>Bruguiera cylindrica</i>	Small-leaved orange mangrove	Kandoo	Yes
<i>Excoecaria agallocha</i>	Blind-your-eye mangrove	Thela	Yes
<i>Lumnitzera racemosa</i>	Black mangrove	Burevi	Yes
<i>Rhizophora apiculata</i>	Tall-stilted mangrove	Thakafathi	Yes
<i>Acrostichum aureum</i>	Mangrove fern	Maakeha	No
<i>Pandanus odorifer</i>	Screw pine	Maa Kashikeyo	No

Table A 1: All vegetation species recorded during the pond fringe survey

Survey area	Species	Common name	Dhivehi name
Central pond	<i>Tringa nebularia</i>	Common greenshank	Chon Chon Ilolhi
Central pond	<i>Nycticorax nycticorax</i>	Black-crowned Night Heron	Raabondhi
Central pond	<i>Casmerodius albus</i>	Great Egret	Laganaa
Central pond	<i>Actitis hypoleucos</i>	Common Sandpiper	Fin'dhana
Central pond	<i>Numenius phaeopus</i>	Whimbrel	Bulhithunbi
Central pond	<i>Corvus corax</i>	Crow	Kaalhu
Central pond	<i>Ardea cinerea</i>	Grey heron	Maakana
Central pond	<i>Charadrius mongolus</i>	Lesser Sand-plover	Bon'dana
North Pond	<i>Ardea cinerea</i>	Grey Heron	Maakana
North Pond	<i>Haematopus ostralegus</i>	Oyster Catcher	
North Pond	<i>Numenius phaeopus</i>	Whimbrel	Bulhithumbi
North Pond	<i>Amauromis phoenicurus</i>	White-breasted Waterhen	Kan'bili
North Pond	<i>Actitis hypoleucos</i>	Common Sandpiper	Fin'dhana
North Pond	<i>Charadrius mongolus</i>	Lesser Sand-plover	Bon'dana
North Pond	<i>Anas clypeata</i>	Northern Shovler	Reyru
Wetland	<i>Numenius phaeopus</i>	Whimbrel	Bulhithunbi
Wetland	<i>Charadrius mongolus</i>	Lesser Sand-plover	Bon'dana
Wetland	<i>Actitis hypoleucos</i>	Common Sandpiper	Fin'dhana
Wetland	<i>Amauromis phoenicurus</i>	White-breasted Waterhen	Kan'bili
Wetland	<i>Himantopus himantopus</i>	Black-tailed Godwit	Theyravaallohi

Table A 2: Bird species observed in the three survey areas

Species	Common name
<i>Poeciliidae</i>	Molly
<i>Cichlidae</i>	Tilapia
<i>Shrimp sp.</i>	Shrimp
<i>Chanos chanos</i>	Milk fish

Table A 3: Fish observed in the ponds



MAAKOA

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 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 Maakoa in Lhavyani Atoll 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 scattered 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 and Hatcher 2004). Maldivian islands are known as low lying islands with 80% of the country being less than a meter above the sea level and the majority of islands being less than 5km² in size. (Ministry of Environment and Energy 2015). Studies to understand the atoll and island formation have suggested that the island reefs in the Maldives have been around 4000 yr. B.P (Kench et al. 2005, Perry et al. 2013).

The terrestrial fauna and flora have a rich biodiversity. The range of natural island habitats includes beaches, marshes, brackish ponds, mangroves and woodlands. There are 583 species of terrestrial flora found, of which 323 are cultivated and 260 are natural. The farmed species are mostly used as a source of food and some for traditional medicine. Mangroves

ecosystems can be classified based on the system's exposure to the sea as either "open mangrove systems" or "closed mangrove systems. These can then be further subdivided into four categories (Saleem and Nileysa 2003) (Table 1). In all but marsh-based mangroves, tree growth is limited to a narrow band around the water's edge. Around 15 species of mangroves are found across approximately 150 islands (Ministry of Environment and Energy 2015). Maldivian avifauna is made up of seasonal migrants, breeding residents and introduced birds. Over 167 species of birds have been recorded in the Maldives. Around 70 species of shorebirds are recorded, some of which are breeding residents while others are recorded as migrants. Migratory birds visit during certain seasons to breed or use the islands as a transit point to their breeding grounds (Ministry of Environment and Energy 2015).

Terrestrial habitats are threatened by many local scale factors including infrastructure development, human waste and land reclamation projects. Similar to the marine environment, habitats such as mangrove areas are known for their ecological significance and diversity, providing

Open mangrove systems	Coastal fringing mangroves	Exposed mangroves growing directly on the shoreline. Experience regular wave action. Uncommon mangrove system
	Embayment mangroves	Mangroves partly encircle a bay area. Experience daily tidal flushing. Common mangrove system
Closed mangrove systems	Pond-based mangroves	Mangroves encircle a brackish water pond. Possible water exchange through bedrock or overwash. Common mangrove system
	Marsh-based mangrove	Mangrove found on muddy substrate with no standing water. Dampness of mud may come from flow through the bedrock or overwash. Uncommon mangrove system

Table 1: Description of the four types of mangrove ecosystems found in the Maldives. From Saleem and Nileysha (2003)

habitats and services to animal and human communities (Kuenzer et al. 2011). However, due to historical and continued undervaluation, most 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 infrastructure development. Refuse dumping has had a major impact on the terrestrial and marine environment. Around 1.7kg of waste is generated per capita in Male' alone (Ministry of Environment and Energy 2015). This highlights the need for proper waste management in the Maldives. At present, 128 waste management centres are established across Maldives, and regional waste management centres are planned for major populated areas such as Addu City. The government has increased their efforts to manage the waste issue by incorporating the 3Rs (Reduce, Reuse, Recycle) concept into policy and investing on local waste management centres. However, many

populated islands are far away from regional waste management centres making dumping waste on land or in the sea the most convenient disposal option for a large proportion of the population.

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 dependent on the profits around these industries. This highlights the significance of the natural environment to the Maldives and 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 the sustainable use and management of these natural resources within communities. Such approaches will play a key role in standardizing the efforts to manage and monitor the resources in a co-managed concept.

Study site

Maakoa island is located in the centre of Faadhippolhu (Lhaviyani) atoll. Faadhippolhu is one of the 16 complex atoll systems in the Maldives. The atoll comprises of 81 islands (5 inhabited, 7 resorts and 69 uninhabited islands). There are 84 individual reef systems within the atoll (Ministry of Environment and Energy 2015). The total human population of the atoll is 12,674 (National Bureau of Statistics, 2014). Maakoa is uninhabited but is located in the same lagoon as Maafilaafushi. Maafilaafushi is the northern military base of the Maldives National Defense Force (MNDF) and is permanently staffed. The two islands are separated by a 100 m wide lagoon. Due to the proximity to the military base Maakoa is under direct jurisdiction of MNDF. The island has a very small sandy beach area only on the south eastern side and the rest of the island is covered in beach rock. Maakoa island has one large pond which is 328 m long and 167 m wide at the widest point and covers much of the north west of the island. This pond was the only area surveyed during this study.



Figure 1: Map of Maakoa survey areas. Yellow polygon indicate terrestrial survey area ©Google Earth 2019

entered into a handheld GPS (either Garmin etrex 20x or Garmin GPS maps 64s) for navigation to the point (Figure 2). At a survey point, a 2.5 m radius circle was estimated and the dominant and secondary flora within the area were identified to species and their respective percent covers were estimated. The height of the dominant species was estimated to the nearest metre. Substrate type was recorded and counts of crab burrows and rubbish were conducted. The number of survey points for each zone was dependent on zone size and accessed on foot. If identified points were inaccessible, a new point was taken as close as possible to the original point and the survey was performed here. Wetland bird and fish surveys were conducted concurrently with terrestrial habitat surveys. All birds observed were identified to species. Fish were identified to family and their abundance was estimated.

Methods

Terrestrial survey area on Maakoa was identified solely as the large central pond. Survey points were identified using a stratified sampling approach

with sites selected around pond fringes and throughout the wetland areas. GPS coordinates were extracted from Google Earth© version 7.3.1 and



Figure 2: Recording data at a terrestrial survey point

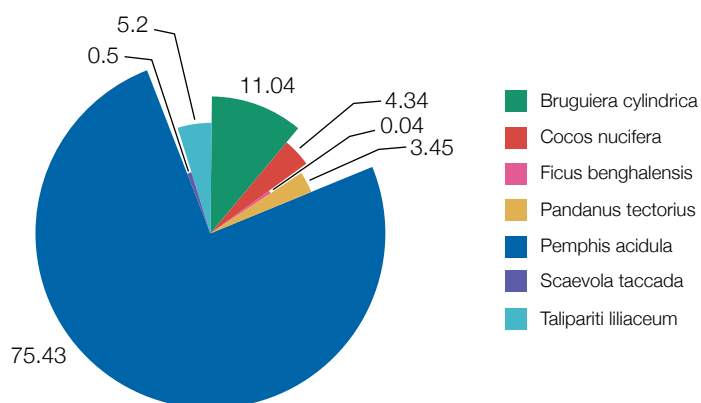


Figure 3: Proportion of cover of plant species at the pond fringe area

Results

Seven species of flora were identified during the surveys (Table 2), including a single species of mangrove. Pemphis acidula was the dominant vegetation, making up over three quarters of the vegetation cover. Bruguiera cylindrica was the only species of mangrove

present around the pond fringe. Birds were highly abundant throughout the pond area (Table 3). Four nests were observed in the trees. The pond was home to a high number of Chanos chanos (milkfish). Pathways had been built across the pond to allow access



Figure 4: Images of some species of vegetations found in Maakoa

to all parts of the island. Only seven items of waste were found around the pond fringe, these were all pieces of plastic.

Discussion

The vegetation around the pond was dominated by Pemphis acidula, which made up over three quarters of the flora. This is common shrub vegetation found throughout the Maldives and grows well in the sandy calcareous soils. It generally dominates the vegetation on exposed and rocky shores and around many closed ponds. However, P. acidula is not a mangrove species and provides few of the ecosystem services that mangrove trees are known to (Mumby et al. 2004, Nagelkerken et al. 2008). Bruguiera cylindrica was the only true mangrove species present around the pond and made up just over 10 % of the pond fringe vegetation. Though these enclosed ponds, known locally as kulhi, are a common feature of many islands the dynamics of their formation, and vegetation development are poorly understood. Given their abundance throughout the country developing a greater understanding of their dynamics and ecological role should be a priority.

The pond had a large area of desiccation at the north eastern side. This may indicate that the pond is beginning to dry out due to limited water exchange with the sea. There were no obvious pathways for water flow, however different weather patterns



Figure 5: Dried muddy area of the pond

during the two monsoon seasons may result in fluctuations in water flow from overflow or rainfall. The pond had a large number of *Chanos chanos*. The island had an abundant bird life. Two species of resident birds and eleven species of migratory birds were found in the pond. There was some evidence of pond management as pathways were made to allow access around the island. This may also have impacted the pond dynamics.

There is an increasing demand for land area in the Maldives, mainly for agricultural expansion, industrial growth and for housing (Thupalli 2009). Population growth is creating demands on the land area for food production and housing. Furthermore, expansion of the tourist industry may threaten habitats on uninhabited islands and shallow coral reefs, as plans for new airports and resorts require land reclamation and redevelopment of these sensitive areas. It is important for the ecological health and diversity of the country that islands such as Maakoa, which have not yet been significantly impacted by coastal development remain untouched.

Human activities over the past 150 years have caused approximately 0.85°C of climate warming (IPCC 2014) and it is likely that it will continue to warm by at least 1.5°C between 2030 and 2052 (IPCC 2018). 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 0.26 – 0.77 m by 2100 (IPCC 2018). Depending on the actual level and the rate of change this increases the risk of storm damage to wetlands and ponds, as well as human settlements and may result in eventual inundation of them by sea water. Healthy 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 will limit island erosion and may enable island growth to keep pace with any sea level change.

Management

The ecological management goal for Maakoa is to provide a means to promote and ensure the long-term conservation and protection of the island's ecosystem. Existing local management efforts should be coordinated and developed further with this goal in mind. The aim should also be to utilise strategies and action plans local and national governments have developed 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 this goal. The main goal is broken down into two sub-goals: 1) to maintain the resilience of biological communities to stressors associated with climate change and 2) to maintain populations of unharvested species for social development and island health. Future efforts should aim to monitor and manage for resilience (Flower et al. 2017, Lam et al. 2017).



Figure 6: Signs placed throughout the island and near the pond area restricting garbage disposal

In order to preserve the ecological resilience of the island and to protect its biodiversity for future generations, it is recommended that a comprehensive management plan is developed. The management plan could consider the following elements:

- The development of a long-term monitoring programme for the pond habitat in order to track ecological changes over time.
- Island geographical and topographical monitoring programme to monitor and map the structural development of the island.
- A plan for development and enforcement of regulations in the area.
- Active management of the pond area to promote mangrove growth. This may include:
 - + Planting of juvenile mangroves
 - + Managing water flow into the pond

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Appendix

Species	Common name	Dhivehi name	Mangrove species
<i>Bruguiera cylindrica</i>	Small-leafed orange mangrove	Kandoo	Yes
<i>Cocos nucifera</i>	Coconut palm	Dhivehi ruh	No
<i>Ficus benghalensis</i>	Banyan tree	Nika	No
<i>Pandanus tectorius</i>	Screw pine	Boa Kashikeyo	No
<i>Pemphis acidula</i>	Iron wood	Kuredhi	No
<i>Scaevola taccada</i>	Sea lettuce	Magoo	No
<i>Talipariti tiliaceum</i>	Sea hibiscus	Dhigga	No

Table A 1: All vegetation species recorded during the pond fringe survey

Species	Common name	Dhivehi name	Abundance
<i>Tringa nebularia</i>	Common Greenshank	Chon chon ilohi	3
<i>Tringa totanus</i>	Common Redshank		1
<i>Calidris minutilla</i>	Least Sandpiper	Feemaru ilohi	17
<i>Calidris ferruginea</i>	Curllew Sanspiper	Bondane ilohi	16
<i>Egretta gularis</i>	Western Reef Egret		1
<i>Ardea cinerea</i>	Grey heron	Maakana	1
<i>Numenius phaeopus</i>	Whimbrel	Bulhi Thunbi	2
<i>Charadrius mongolus</i>	Lesser Sand-plover	Bondana	17
<i>Actitis hypoleucos</i>	Common Sandpiper	Findhana	1
<i>Amauromis phoenicurus</i>	White-breasted Waterhen	Kanbili	1
<i>Himantopus himantopus</i>	Black-tailed Godwit	Theyravaa ilohi	1
<i>Arenaria interpres</i>	Ruddy Turnstone	Rathafa	18
<i>Pluvialis fulva</i>	Pacific Golden Plover	Maline Dhushine	2

Table A 2: Species and abundance of birds observed in the pond area

MARINE ZONE

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ANEMONE THILA

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 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 Anemone Thila in Lhavyani Atoll 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 scattered 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 and Hatcher 2004). Maldivian islands are known as low lying islands with 80% of the country being less than a meter above the sea level and the majority of islands being less than 5km² in size. (Ministry of Environment and Energy 2015). Studies to understand the atoll and island formation have suggested that the island reefs in the Maldives have been around 4000 yr. B.P (Kench et al. 2005, Perry et al. 2013).

Coral reefs of the Maldives are considered to be 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 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) is contributed by 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 Maldivian coral reef ecosystem has come under threat from catastrophic events such as mass coral bleaching and outbreaks of crown of thorns starfish (*Acanthaster planci*). Following

the 2016 bleaching event, which damaged an estimated 75% of the coral reefs (Ibrahim et al. 2017), scientists have been alerted as the impact of the event has shown that even some of the most protected reef ecosystems could perish. However, the Reefs at Risk 2016 report indicates that a significant proportion of reef degradation is due to local stressors (Burke et al. 2011), such as, overfishing, pollution, land reclamation. Despite these global and anthropogenic stressors, the Maldivian reefs have previously shown resilience and recovery following these disturbances (Morri et al. 2015, Pisapia et al. 2016).

Tourism and fishing industries depend directly on the nature. This highlights the significance of the natural environment to the Maldives and 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 the sustainable use and management of these natural resources within communities. Such approaches will play a key role in standardizing the efforts to manage and monitor the resources in a co-managed concept.

Study site

Anemone Thila is a rocky pinnacle (locally known as Thila) located in the centre of Faadhippolhu (Lhaviyani) atoll. Lhaviyani is one of the 16 complex atoll systems in the Maldives. The atoll comprises of 81 islands (5 community islands, 7 resorts and 69 uninhabited islands). There are 84 individual reef systems within the atoll (Ministry of Environment and Energy 2015). The total human population of the atoll is 12,674 (National Bureau of Statistics, 2014). The main economy of the atoll like much of the country is a combination of pelagic fishery and tourism activity. In particular, tourism appears to be growing rapidly with the increase in number of guest houses on community islands and the provision of tourism related activities on these islands across the atoll.

Anemone Thila is located at 5.44194 N, 73.49722W in Lhaviyani atoll. The thila is approximately 6 km from the nearest resort island and 10 km from the nearest community island. Anemone Thila is around 60m in diameter and the depth of the top reefs ranges from 10 – 12 m. Despite the thila's relatively small size it is rich in fish life. The thila is known for the high

number of sea anemones covering the surface. These provide habitat for clownfish (*Amphiprion*) and the complex and sheltered rock and coral formations create habitat for high numbers of cardinalfishes (*Apogonids*). The abundance of these prey species means that small and medium sized groupers are common here. However, cardinalfishes are also a popular baitfish for the tuna fishery meaning extractive activities like bait fishing are common at this site which has created some conflicts over area use.

Methods

Surveys were performed using a roaming survey approach. Due to the relatively small size of the thila three surveys were conducted, one along the northern side of the reef, one on the southern side and one over the thila top reef. Each survey lasted 15 minutes with start and finish times, survey location (GPS of start/finish or entry/exit), reef type (wall, slope, channel), estimated average depth and visibility recorded (*Figure 1*). The percent was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and crustose



Figure 1: Recording ecological data during roaming surveys

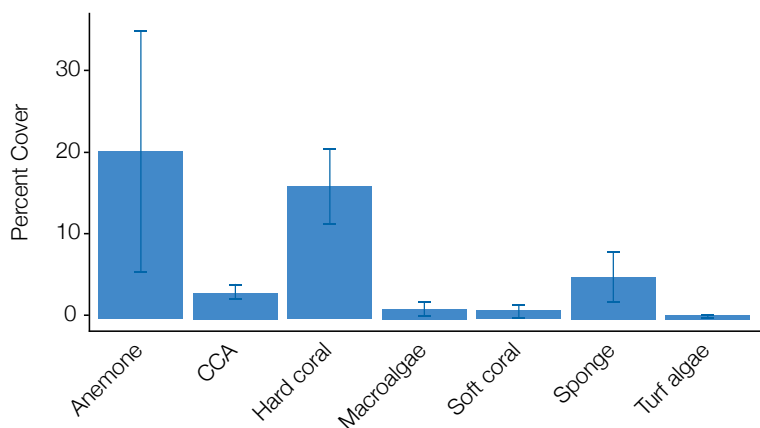


Figure 2: Percent cover of biotic substrate

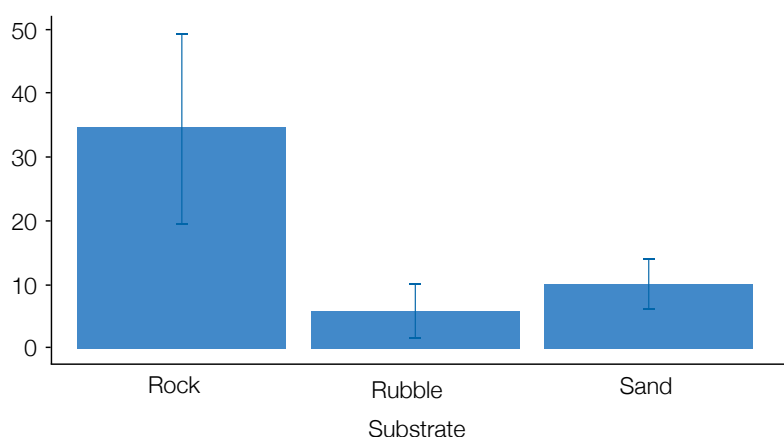


Figure 3: Percent cover of abiotic substrate



Figure 4: Anemones on the top reef of the thila

coralline algae (CCA). Reef structural complexity was estimated on a scale of 0 – 5, where 0 was considered completely flat and 5 very complex with a high number of holes and refuges, complex coral structure and tall coral or rock structures. Fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence

and time of first observation for each fish family was recorded. The family *Pomacentridae* was split into sub groups *pomacentrids*, *amphipriones* (clownfish) and chromis. This provides a representation of how common these families were. All surveys were conducted using SCUBA and were between 10 m and 25 m deep.

Results

The thila itself was similar in structure to many others across the country. It had steep sloping sides down to about 30 m with a relatively flat top about 13 m deep. The North side of the Thila had a small plateau around 20m deep with small overhangs. The reef slopes were predominantly rock and rubble. The top reef had a high density of sea anemone colonies with a diversity of sizes and species and very little bare rock. Averaged across the three surveys the dominant biotic substrate cover was anemones (Figure 2). They had a very high variability in cover, across the thila, ranging from 3 to 50 %. Hard coral was present along the reef slope, though few colonies were observed on the reef top. Macroalgae and turf algae cover was low throughout the thila.

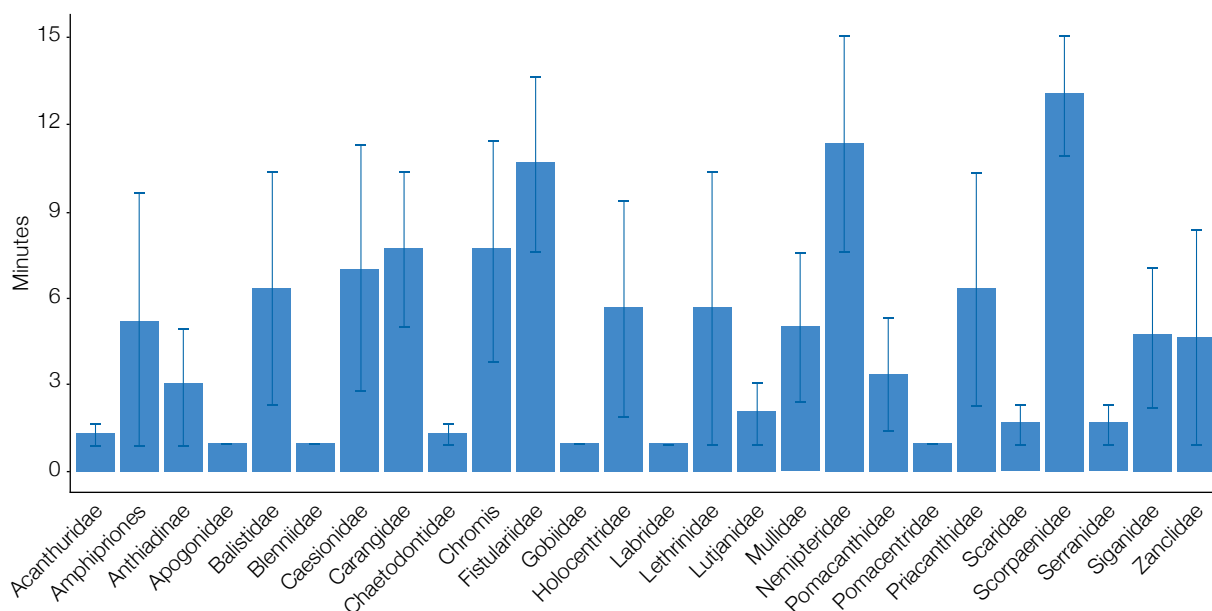


Figure 5: Mean time to first observation of fish families. Only fish families observed on all three surveys were included

The east side of the thila had a slope going down from top reef to approximately 25 m. Rock was the dominant cover on the reef (Figure 3) walls and slopes, but only 5 % of the substrate on the top reef was rock. Unconsolidated substrates such as sand and rubble made up a small proportion of the substrate. Structural complexity was $2.3 (\pm 0.3 \text{ s.e.})$.

A total of 27 families of reef associated fish were observed during surveys (Table A1). The herbivorous families *Acanthuridae* and *Scaridae* were observed within the first four minutes of all surveys. Apogonids and Anthias were rapidly observed during all surveys (Figure 5.). Large schools of Lutjanidae and Carangidae were observed around the thila crest. *Serranidae* were observed within the first five minutes of all surveys, high numbers of juvenile and small bodied serranids were observed throughout the surveys. Other generally less frequently observed families, such as *Fistulariidae* and *Scorpaenidae* were recorded on all three surveys.

Discussion

Anemone Thila is a usual thila habitat for the Maldives. Many such reefs are dominated by hard or soft corals, whereas the top reef of this thila is dominated by sea anemones. This has created a habitat which is not highly complex in its solid structure but still provides refuge for a range of small fish species including Pomacentrids, Apogonids and Anthias. Additional structure around the crest of the reef and small overhangs along the reef slopes created further refuge for these small species. The presence of these prey fish species has in turn led to an abundance of mesopredators such as small and medium – bodied Serranids and Lutjanids. Lionfish (family *Scorpaenidae*) and *Fistularids* were also present in higher numbers than usually observed elsewhere.

The tuna fishery is the most important fishery in the Maldives and provides a major source of employment as well being the preferred source of animal protein throughout the country. The fishery is heavily reliant on the use of baitfish to attract schools of tuna enabling the use of a pole-and-line approach. Almost all bait

is currently obtained at night, using powerful lights to attract the baitfish to their nets. Apogonids, Caesionids and Chromis sp. all make up a significant proportion of the baitfish used (Jauharee et al. 2015). Due to their abundance at Anemone Thila it has become a popular baitfishing location. A review of baitfishery catch from self-reported logbooks between 2011 – 2015 suggested that baitfishing is conducted at a sustainable level (Jauharee et al. 2015) and that there were no significant declines in baitfish abundance across the country. The high abundance of baitfish species at Anemone Thila appears to support the conclusion that this fishery has not significantly impacted the fish community, at least at this location. However, it should be noted that this is a snapshot of the fish community and these species are highly variable in their abundance and there are known to be considerable fluctuations in bait availability between years (Anderson and Saleem 1995).

The characteristic features of Anemone Thila have also made it a popular dive and night fishing site for resorts and tourists from guesthouses on community islands. The tourism industry is the largest single contributor to Maldivian GDP (Ministry of Tourism 2016) and the industry is growing all the time as local communities build

more guesthouses. This may lead to conflict between resource users. It is therefore necessary to put in place management measures that will prevent degradation of the habitat and ensure multiple groups can utilise the site without conflict.

Management

The ecological management goal for Anemone Thila is to provide a means to promote and ensure the long-term conservation and protection of the reef's ecosystem. Existing local management efforts should be coordinated and developed further 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 reports on biodiversity (Ministry of Environment and Energy 2015), 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 this goal. The main goal is broken down into two sub-goals:

1. to maintain the resilience of biological communities to stressors associated with climate change and;
2. to maintain populations of species for social development, fishery enhancement and reef health. Future efforts should aim to monitor and manage for resilience (Flower et al. 2017, Lam et al. 2017).

In order to preserve the ecological resilience of the reef and to protect the resource and biodiversity for future generations, it is recommended that a management plan is developed. The management plan should consider the following elements:

- The development of a long-term monitoring programme to track ecological changes over time. This should focus on:
 - Populations of baitfish species
 - Populations of reef fishery species
- The abundance and diversity of anemones
- The health of hard corals
 - + A plan for development and enforcement of regulations in the area through consultation with multiple communities and stakeholders.
 - + A focus on education of fishers regarding the potential for and impacts of overfishing.

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Appendix

Family	Common name	Family	Common name	Family	Common name
<i>Acanthuridae</i>	Surgeonfish	Holocentridae	Squirrelfish	Pomacentridae	Anemonefish
Apogonidae	Cardinalfish	Labridae	Wrasse	Pomacentridae	Chromis
Balistidae	Triggerfish	Lethrinidae	Emperor	Priacanthidae	Bigeye
Blenniidae	Blenny	Lutjanidae	Snapper	<i>Scaridae</i>	Parrotfish
Caesionidae	Fusilier	Mullidae	Goatfish	Scorpaenidae	Lionfish
Carangidae	Jack	Muraenidae	Moray Eel	<i>Serranidae</i>	Basslet
<i>Chaetodontidae</i>	Butterflyfish	Nemipteridae	Spinecheek	<i>Serranidae</i>	Grouper
Fistulariidae	Flutemouth	Ostraciidae	Boxfish	Siganidae	Rabbitfish
Gobiidae	Goby	Pomacanthidae	Angelfish	Tetraodontidae	Pufferfish
Haemulidae	Sweetlips	Pomacentridae	Damselfish	Zanclidae	Moorish idol

Table A 1: All fish families observed at Anemone Thila

BANANA REEF ZONE

Area type: rocky Pinnacle

Location: North Malé Atoll

Zone description

Banana reef is a large rocky pinnacle, locally called a thila, in the south-eastern corner of North Malé Atoll. It is amongst the oldest dive sites in the country which led to it being designated as one of the first marine protected areas. The pinnacle has steep sides and a flat top. There are several large caves and overhangs

along the rock face creating a mix of highly complex cave areas and flatter walls. There was a high cover of sand and silt, indicating the reef has suffered from high sedimentation due to its proximity to the Hulhumalé island development. The fish community was abundant and diverse with numerous schools observed during the surveys.

"51 reef associated fish families were observed across the country, 33 of which were found on banana reef."

Site	Total number of families	Mean number of families
Banana Reef combined	33	18
Dive 1	27	17.5
Dive 2	30	18.5

Table 1. Start and end GPS point Latitude and longitude of the dive survey

Coral reef benthos:

Mean coral cover was 13%. The high cover of sand, particularly at shallow sites, is a concern as this can smother living corals and prevent settlement of new recruits. High sponge and soft coral cover was found inside the numerous caves and overhangs found around the zone. Structural complexity ranged from flat on walls and top of the thila to highly complex around the cave and overhang areas.

Survey number	1	2	3	4	5	6	7	8
Depth	10	15	10	3	2	15	20	2
Complexity	2	1	1	3	2	3	1	3
CCA	2	6	2	4	0	4	2	1
Hard Coral	12	8	5	10	5	18	10	5
Macro algae	5	4	2	16	5	3	1	4
Rock	25	5	10	30	10	26	15	5
Rubble	5	5	0	5	30	5	25	15
Sand	1	3	40	0	40	1	28	50
Soft Coral	15	20	4	5	2	8	4	3
Sponge	25	30	30	5	2	29	15	2
Turf algae	3	0	0	0	0	3	0	0
Others	7	19	7	25	6	3	0	15

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish diversity:

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 33 of which were found on banana

reef. Groupers and butterflyfish are indicators of unfished and healthy reef areas and were observed within the first two minutes of all surveys. The key herbivores, surgeonfish and parrotfish were also observed within the first two minutes of all surveys. Herbivores are a functionally important group on coral

reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

	Dive 1		Dive 2	
	Entrance	Exit	Entrance	Exit
Latitude	4.24008	4.23819	4.23981	4.23936
Longitude	73.53297	73.53122	73.53375	73.53086

Table 3. Location, total number of fish families and mean number of fish families observed across all sites and during survey dives

Number of Endangered Animals:

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers.

Survey number	Napoleon wrasse	Black-saddle coral grouper
1	1	2
2		1

Table 4. Location and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed during rapid surveys.

METHODS

Eight rapid surveys were performed on banana reef during two SCUBA dives. During the first dive, divers swam clockwise from the north point of the reef and during the second dive surveyors swam anti-clockwise. Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst or SCUBA diving. Each survey lasted

15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting,

finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Fish families observed at Banana reef

Scientific name	Common name	Scientific name	Common name	Scientific name	Common name
<i>Acanthuridae</i>	Surgeonfish	<i>Haemulidae</i>	Sweetlips	<i>Pomacentridae</i>	Damselfish
<i>Apogonidae</i>	Cardinalfish	<i>Holocentridae</i>	Squirrelfish	<i>Scaridae</i>	Parrotfish
<i>Aulostomidae</i>	Trumpetfish	<i>Labridae</i>	Wrasse	<i>Scombridae</i>	Tuna
<i>Balistidae</i>	Triggerfish	<i>Lethrinidae</i>	Emperor	<i>Scorpaenidae</i>	Lionfish
<i>Caesionidae</i>	Fusilier	<i>Lutjanidae</i>	Snapper	<i>Serranidae</i>	Basslet
<i>Carangidae</i>	Jack	<i>Malacanthidae</i>	Tilefish	<i>Serranidae</i>	Grouper
<i>Carcharhinidae</i>	Requiem Shark	<i>Mullidae</i>	Goatfish	<i>Siganidae</i>	Rabbitfish
<i>Chaetodontidae</i>	Butterflyfish	<i>Muraenidae</i>	Moray Eel	<i>Tetraodontidae</i>	Pufferfish
<i>Cirrhitidae</i>	Hawkfish	<i>Nemipteridae</i>	Spinecheek	<i>Zanclidae</i>	Moorish idol
<i>Diodontidae</i>	Porcupinefish	<i>Ostraciidae</i>	Boxfish		
<i>Fistulariidae</i>	Flutemouth	<i>Pomacanthidae</i>	Angelfish		

Table A1. All fish families recorded at banana reef

EMBUDHOO KANDU ZONE

Area type: Channel

Location: South Malé Atoll

Zone description

Embudhoo Kanduu, otherwise known as Embudhoo express is a channel that connects the Indian ocean with the inner atoll waters of South Malé atoll. It is subject to strong currents as the water runs into or flushes out of the atoll depending on the tides. Its proximity to the capital Malé and several resorts has made it a popular dive site. It is known for aggregation of sharks at the channel's outer corners. The channel also has a small pinnacle (thila) in the centre.

	Dive 1		Dive 2	
	Entrance	Exit	Entrance	Exit
Latitude	4.08283	4.08289	4.07981	4.07986
Longitude	73.53842	73.53847	73.51500	73.51506

Table 1. Latitude and longitude of the entrance and exit points of the two survey dives in Embudhoo Kanduu

"Mean coral cover was 20%. The outer corner of the channel had many ledges and overhangs with soft coral growth inside."



Coral reef benthos:

Mean coral cover was 20% (Table 2). The substrate was predominantly rock with patches of sand and hard coral growth covering areas. The outer corner of the channel had many ledges and overhangs with soft coral growth inside. Other than these ledges the reef area was flat and Tubastrea corals and small rocks provided the only structure. Inside the channel the reef had a higher proportion of rubble.

Survey number	1	2	3	4	5	6	7	8
Depth	30	15	15	30	23	10	25	28
Complexity	1	2	2	2	2	3	3	3
CCA	3	5	9	0	0	0	0	0
Hard Coral	20	18	15	35	20	30	10	10
Macro algae	2	4	1	10	5	10	0	0
Rock	30	25	30	45	30	20	50	50
Rubble	1	5	5	0	15	10	10	15
Sand	26	26	20	0	20	20	5	5
Soft Coral	1	2	0	0	2	0	0	0
Sponge	12	10	10	5	3	5	0	0
Turf algae	0	0	0	0	0	0	0	0
Others	5	5	10	5	5	5	25	20

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish community:

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 33 of which were found in Embudhoo

Kandu. Groupers and butterflyfish are indicators of unfished and healthy reef areas and were observed within the first five minutes of all but one surveys. The key herbivores, surgeonfish and parrotfish were also observed within the first five minutes of all surveys. Herbivores are a functionally important

group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Site	Total number of families	Mean number of families
Embudhoo Kandu combined	33	18.13
Dive 1	30	20.00
Dive 2	26	16.25

Table 3. Location, total number of fish families and mean number of fish families observed across all sites and during survey dives

Number of Endangered Animals:

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks

and provide shelter spaces for large groupers. Channel corners where strong currents are present serve as shark aggregation areas for species such as grey reef (*Carcharhinus*

amblyrhynchos) and silvertip (*Carcharhinus albimarginatus*) sharks, though none were observed during these surveys.

	Chaetodon trifascialis	Eretmochelys imbricata	Plectropomus areolatus	Plectropomus laevis	Triacodon obesus
Dive 1	1	1			
Dive 2			2	2	3

Table 4. Location and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed during rapid surveys.

METHODS

Eight rapid surveys were performed in Embudhoo Kanduu during two SCUBA dives (*Table 1*). During the first dive, divers began to the south of the channel, swam up the outer reef and drifted in along the southern edge of the channel. During the second dive surveyors were dropped on to the thila and drifted back through the channel. Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming

surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting,

finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Fish families observed at Embudhoo Kanduu

Common family	Family	Common family	Family	Common family	Family
Surgeonfish	<i>Acanthuridae</i>	Squirrelfish	Holocentridae	Boxfish	Ostraciidae
Triggerfish	Balistidae	Sailfish	Istiophoridae	Grubfish	Pinguipedidae
Fusilier	Caesionidae	Wrasse	Labridae	Angelfish	Pomacanthidae
Jack	Carangidae	Emperor	Lethrinidae	Damselfish	Pomacentridae
Requiem Shark	Carcharhinidae	Snapper	Lutjanidae	Parrotfish	<i>Scaridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Tilefish	Malacanthidae	Tuna	Scombridae
Hawkfish	Cirrhitidae	Dart Goby	Microdesmidae	Basslet	<i>Serranidae</i>
Stingray	Dasyatidae	Filefish	Monacanthidae	Grouper	<i>Serranidae</i>
Porcupinefish	Diodontidae	Goatfish	Mullidae	Rabbitfish	Siganidae
Flutemouth	Fistulariidae	Eagle ray	Myliobatidae	Pufferfish	Tetraodontidae
Sweetlips	Haemulidae	Spinecheek	Nemipteridae	Moorish idol	Zanclidae

Table A1. All fish families recorded at banana reef

FUSHI FARU KANDU ZONE

Area type: Channel

Location: Lhavyani atoll

Zone description

Fushi Faru Kandu is a channel that connects the Indian ocean with the inner atoll waters of Lhavyani atoll. It is subject to strong currents as the water runs into or flushes out of the atoll depending on the tides. During times of strong currents, it is a well-known

shark aggregation area. Grey reef (*Carcharhinus amblyrhynchos*) sharks are commonly observed and less frequently silvertip sharks (*Carcharhinus albimarginatus*). This has made this a popular dive site for resorts.

	Dive entrance	Dive exit
Latitude	5.49817	5.48928
Longitude	73.52219	73.52011

Table 1. Latitude and longitude of the entrance and exit points of the dive survey in Fushi Faru Kandu

"Groupers and butterflyfish are indicators of unfished and healthy reef areas and were observed within the first five minutes of all surveys."

Coral reef benthos:

Mean coral cover in Fushi Faru Kandu was 11.25%. The deeper outer reef area had little coral or structural development and the substrate was predominantly bare limestone rock and rubble. The corner of the channel had

some ledges which created structure and shelter for fish. Inside the channel there was a small thila with coral growth and high structural complexity. CCA covered significant portions of the reef within the channel area.

Survey number	1	2	3	4
Depth	25	20	26	11
Complexity	1	3	2	2
CCA	8	4	28	10
Hard Coral	12	15	8	10
Macro algae	4	1	2	0
Rock	23	29	10	37
Rubble	30	15	20	30
Sand	18	8	20	0
Soft Coral	0	3	1	0
Sponge	5	15	1	3
Turf algae	0	0	0	0
Others	0	10	10	10

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish community:

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 26 of which were found in Fushi Faru Kandu. Groupers and butterflyfish are

indicators of unfished and healthy reef areas and were observed within the first five minutes of all surveys. The key herbivores, surgeonfish and parrotfish were also observed within the first five minutes of all surveys. Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to

thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country. Giant trevallies (*Caranx ignobilis*) were also present.

Site	Total number of families	Mean number of families
Fushi Faru Kandu combined	26	18.75

Table 3. Location, total number of fish families and mean number of fish families observed across all survey dives

Number of Endangered Animals:

These species are under threat and identifying and protecting habitat where they are found is key to their survival. High numbers of grey reef sharks

were recorded during the survey, predominantly on the outer atoll edge and channel corner. Large grouper species were also abundant. These

species shelter in the in complex reef habitats and form aggregations in channel areas to spawn (Robinson et al. 2008).

Survey number	<i>Carcharhinus amblyrhynchos</i>	<i>Cheilinus undulatus</i>	<i>Epinephelus fuscoguttatus</i>	<i>Eretmochelys imbricata</i>	<i>Plectropomus areolatus</i>	<i>Plectropomus laevis</i>
1	4		1			2
2	2			1		1
3	2	1		1	2	3
4			4			4

Table 4. Survey number and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed.

METHODS

Four roaming surveys were performed in Fushi Faru Kandu during one SCUBA dive (*Table 1*). Surveyors began on the outer atoll reef and swam south to the channel entrance into the channel and drifted through the middle of into the atoll. Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted

15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural

complexity of the reef was estimated on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Fish families observed at Fushi Faru Kandu

Common name	Family name	Common name	Family name	Common name	Family name
Angelfish	Pomacanthidae	Jack	Carangidae	Stingray	Dasyatidae
Basslet	<i>Serranidae</i>	Lionfish	Scorpaenidae	Surgeonfish	<i>Acanthuridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Parrotfish	<i>Scaridae</i>	Sweetlips	Haemulidae
Damselfish	Pomacentridae	Pufferfish	Tetraodontidae	Tilefish	Malacanthidae
Emperor	Lethrinidae	Rabbitfish	Siganidae	Triggerfish	Balistidae
Flutemouth	Fistulariidae	Requiem Shark	Carcharhinidae	Tuna	Scombridae
Fusilier	Caesionidae	Snapper	Lutjanidae	Wrasse	Labridae
Goatfish	Mullidae	Spinecheek	Nemipteridae	Moorish idol	Zanclidae
Grouper	<i>Serranidae</i>	Squirrelfish	Holocentridae		

Table A1. All fish families recorded at Fushi Faru Kandu

FUSHI KANDU ZONE

Area type: Channel

Location: Dhaalu Atoll

Zone description

Fushi Kanduu, is a channel that connects the Indian ocean with the inner atoll waters of Dhaalu atoll. It is subject to strong currents as the water runs into or flushes out of the atoll depending on the tides. The channel has a series of rocky ridges and grooves that run perpendicular to

the channel mouth and extend across the channel. These ridges had a high cover of branching corals and acted as aggregation points for schools of snappers and jacks. Large groupers were observed sheltering within the overhangs along these ridges.

	Dive entrance	Dive exit
Latitude	3.00091	2.99961
Longitude	72.93222	72.94614

Table 1. Latitude and longitude of the entrance and exit points of the dive survey in Fushi Kanduu

Coral cover in Fushi Kanduu was 35% which was the highest recorded in a channel zone and amongst the highest recorded in the whole country.

Coral reef benthos:

Coral cover in Fushi Kandu was 35% which was the highest recorded in a channel zone and amongst the highest recorded in the whole country. Large colonies of tabular *Acropora* covered large ridges that ran perpendicular to the channel opening. High water-flow may confer some resilience to temperature increases (Nakamura and

Van Woesik 2001) which might explain the high coral cover. CCA covered much of the remaining structure with little bare rock or algae cover. The structural complexity was high in these areas with many ledges and vertical relief. The ridges were separated by flat grooves of rock/sand.

Survey number	1	2	3	4	5	6
Depth	20	25	15	13	16	16
Complexity	4	4	3	3	3	3
CCA	25	24	20	15	20	30
Hard Coral	30	35	32	35	35	40
Macro algae	0	0	0	0	0	0
Rock	15	15	20	10	20	20
Rubble	0	3	2	3	0	0
Sand	15	5	5	35	20	10
Soft Coral	5	8	10	0	2	0
Sponge	6	6	8	0	0	0
Turf algae	0	0	0	0	0	0
Others	4	3	3	2	3	0

Table 1. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish diversity:

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 28 of which were found in Fushi Kandu. Groupers and butterflyfish are indicators

of un-fished and healthy reef areas and were observed within the first five minutes of all surveys. *Acropora* corals provide food for butterflyfish and the high complexity created shelter for groupers. The key herbivores, surgeonfish and parrotfish were also observed within the first five minutes of all surveys. Herbivores are a functionally

important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Site	Total number of families	Mean number of families
Fushi Kandu combined	28	17.1

Table 2. Location, total number of fish families and mean number of fish families observed across all survey dives

Number of Endangered Animals:

These species are under threat and identifying and protecting habitat where they are found is key to their survival. The Exceptionally high numbers of the IUCN Red Listed Chevroned

butterflyfish (*Chaetodon trifascialis*) were due to the high cover of tabular Acropora corals and this is area is clearly an important habitat for this species. High numbers of two Red

Listed grouper species were also recorded. These species shelter in the in complex reef habitats and form aggregations in channel areas to spawn (Robinson et al. 2008).

	Chaetodon trifascialis	Plectropomus areolatus	Plectropomus laevis	Triadenodon obesus	Tridacna sp.
Fushi Kandu	49	6	6	1	1

Table 3. Location and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed during rapid surveys.

METHODS

Six roaming surveys were performed in Fushi Kandu during one SCUBA dive (*Table 1*). Surveyors began on the outer corner of the eastern channel edge, swam west across the channel mouth into the channel and back towards the inner eastern corner. Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst

SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting,

finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Fish families observed at Fushi Kandu

Common family	Family	Common family	Family	Common family	Family
Surgeonfish	<i>Acanthuridae</i>	Emperor	Lethrinidae	Tuna	Scombridae
Triggerfish	Balistidae	Snapper	Lutjanidae	Grouper	<i>Serranidae</i>
Fusilier	Caesionidae	Tilefish	Malacanthidae	Rabbitfish	Siganidae
Jack	Carangidae	Filefish	Monacanthidae	Moorish idol	Zanclidae
Requiem Shark	Carcharhinidae	Goatfish	Mullidae	Surgeonfish	<i>Acanthuridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Spinecheek	Nemipteridae	Triggerfish	Balistidae
Hawkfish	Cirrhitidae	Boxfish	Ostraciidae	Fusilier	Caesionidae
Stingray	Dasyatidae	Grubfish	Pinguipedidae	Jack	Carangidae
Sweetlips	Haemulidae	Angelfish	Pomacanthidae	Requiem Shark	Carcharhinidae
Squirrelfish	Holocentridae	Damselfish	Pomacentridae	Butterflyfish	<i>Chaetodontidae</i>
Wrasse	Labridae	Parrotfish	<i>Scaridae</i>	Hawkfish	Cirrhitidae

Table A1. All fish families recorded at Fushi Kandu



HATHARUFARU

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 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 Hatharufaru in Meemu Atoll 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 scattered 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 and Hatcher 2004). Maldivian islands are known as low lying islands with 80% of the country being less than a meter above the sea level and the majority of islands being less than 5km² in size. (Ministry of Environment and Energy 2015). Studies to understand the atoll and island formation have suggested that the island reefs in the Maldives have been around 4000 yr. B.P (Kench et al. 2005, Perry et al. 2013).

The Maldivian coral reef ecosystem has come under threat from catastrophic events such as mass coral bleaching and outbreaks of crown of thorns starfish (*Acanthaster planci*). Following the 2016 bleaching event, which damaged an estimated 75% of the coral reefs (Ibrahim et al. 2017), scientists have been alerted as the impact of the event has shown that even some of the most protected

reef ecosystems could perish. However, the Reefs at Risk 2016 report indicates that a significant proportion of reef degradation is due to local stressors (Burke et al. 2011), such as, overfishing, pollution, land reclamation. Despite these global and anthropogenic stressors, the Maldivian reefs have previously shown resilience and recovery following these 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 dependent on the profits around these industries. This highlights the significance of the natural environment to the Maldives and 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 the sustainable use and management of these natural resources within communities. Such approaches will play a key role in standardizing the efforts to manage and monitor the resources in a co-managed concept.

Study site

Hatharufaru is a line of four reefs at the southwest of Meemu atoll. All four are faro reefs, ring-shaped coral reefs, rare across the rest of the world but common in the Maldives (Kench 2011). Each faro is like a mini atoll with a small lagoon or velu as it is known locally, at the centre. All four reefs feature an elongated outer reef edge with a wide reef flat. The reef flat area narrows, and the reef becomes more ovoid on their inner atoll side. None of the reefs have significant island development, however one does have a large coral rubble mound which does house nesting sea birds, though there is no vegetation growth. The reefs are separated by channels 30 m – 50 m deep and 500 – 800 m wide. These experience strong currents as water flows between the inner atoll and the Indian Ocean.

Methods

The coral reef habitat on the outer atoll edge of each reef was surveyed using transects at a depth of 10 m.

Six transects were conducted at each site and a gap of at least 5 m was left between each to ensure independence of samples. The cover of different substrate categories was collected using a point intercept approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral (identified to genus), dead coral, sponge, algae (turf or macroalgae), rock, rubble, sand and crustose coralline algae (CCA) (Fig 1A).

Juvenile coral recruitment was quantified on the transects. A 25 x 25 cm quadrat was placed above and below the transect every 5 m along the transect. The number of coral recruits (colonies < 5 cm diameter) within each quadrat were counted and identified to genus where possible. Recruit density was then calculated as the number of recruits per m² (Fig 1B). Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007) for the length of each transect.

Fish communities were also surveyed on six 5 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), snappers (*Lutjanidae*), jacks (*Carangidae*) sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm (Fig 1A). 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).

Due to conditions the channels between reefs and the inner atoll reefs were surveyed using a roaming survey approach. Four surveys were conducted on the north and south channels of each reef area and two surveys on the inner reef area. Each survey lasted 15 minutes with start and finish times, survey location

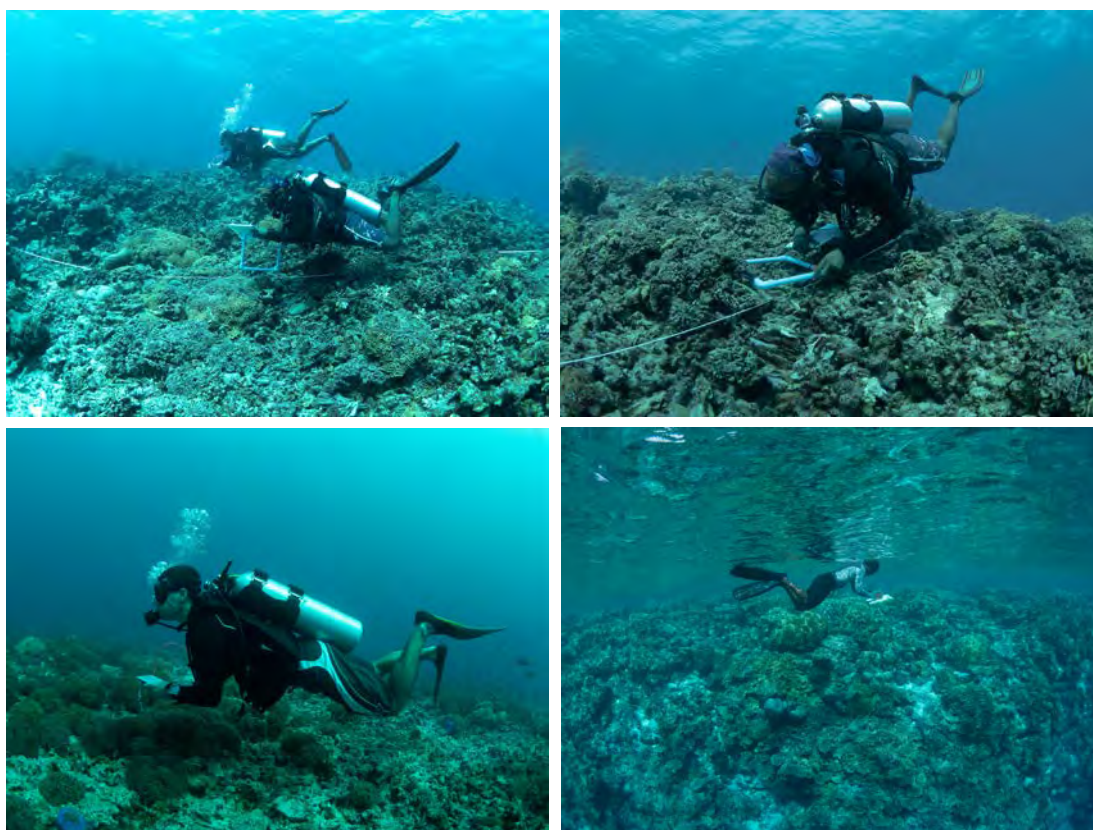


Figure 1: Different methodologies used in the survey

(GPS of start/finish or entry/exit), reef type (wall, slope, channel), estimated average depth and visibility recorded. The percent was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and crustose coralline algae (CCA). Reef structural complexity was estimated on a scale of 0 – 5, where 0 was considered completely flat and 5 very complex with a high number of holes and refuges, complex coral structure and tall coral or rock structures. Fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were. Channel surveys were conducted using SCUBA and were between 10 m and 25 m deep (Fig 1C). Inner reef surveys were conducted whilst snorkelling and were between 3 m and 10 m deep (Fig 1D).

Results

Hatharufaru reef area had a mean coral cover of 21.3 % (± 3.8 s.e.). Coral cover on the outer reefs was similar across the four sites (Figure 2a). The coral cover on the inside and channel reefs varied significantly (ANOVA, $p < 0.01$) (Figure 2b). The inside reef at Hatharufaru 4 had the highest coral cover observed in the area. Algae cover was generally low across these reefs, though there were some sites, such as Hatharufaru 3 outer reef and Hatharufaru 2 South where turf and macroalgae was a significant proportion of the substrate. Sponge cover was relatively high in many of the channel sites. Rock was the predominant abiotic substrate across the majority of the sites (Figure 3a & b). The channel and inner reef sites typically had a more even mix of abiotic substrate, though all sites at the most northern reef, Hatharufaru 1, were dominated by rock.

All three reef types, channel, inside and outside were dominated by rocky coral substrate (Figure 4). Outside reefs had the highest coral cover. The coral cover of the inside reefs was highly variable, the southern two inside sites had high coral cover, whereas the northern two were dominated by dead coral skeleton. Sand cover was relatively high in the channel areas. Algae cover was relatively low across all areas.

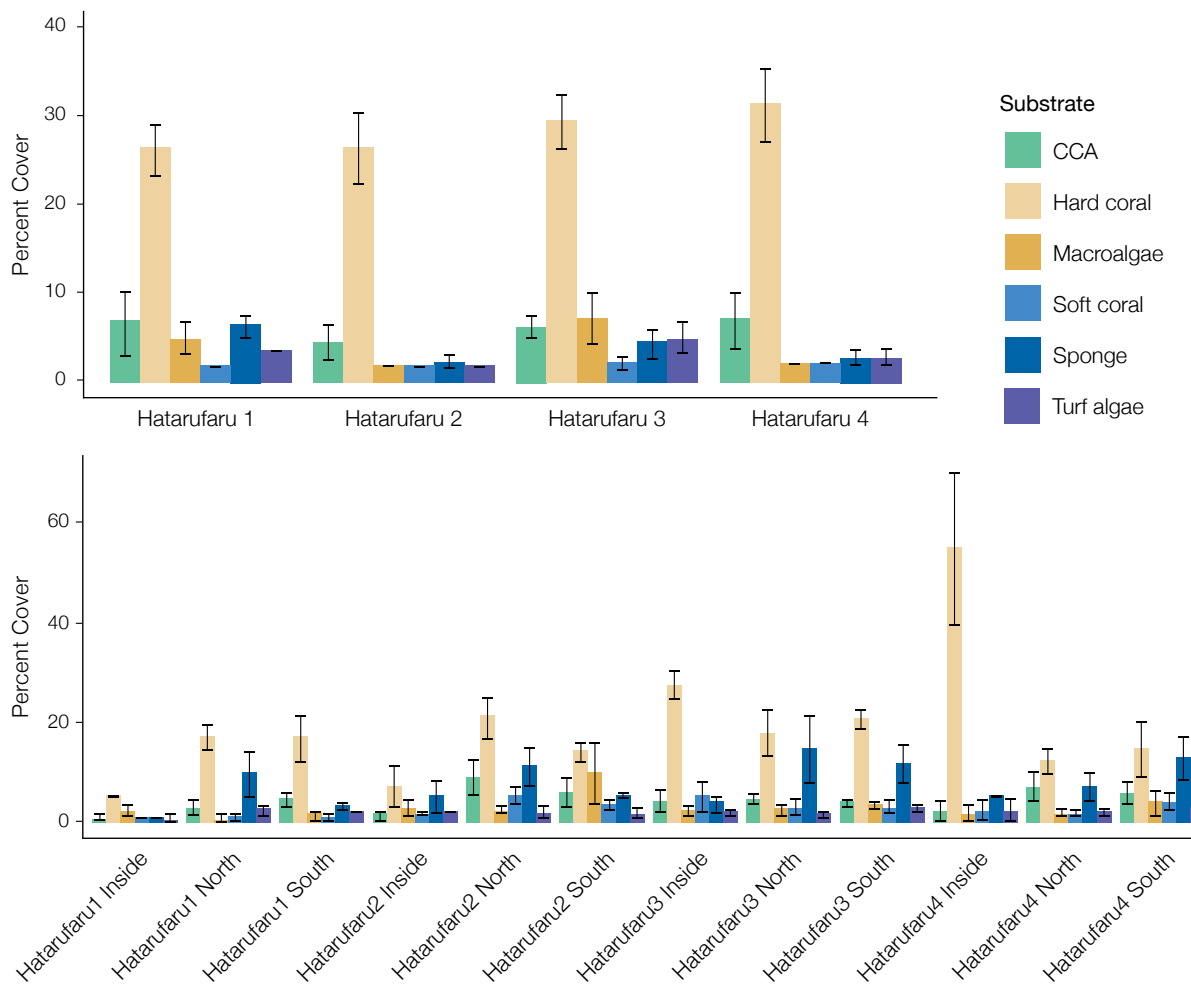


Figure 2: The percent cover of biotic substrate at (a) the four outer atoll sites surveyed using transects and (b) channel and inner atoll reef sites surveyed using the roaming survey method.

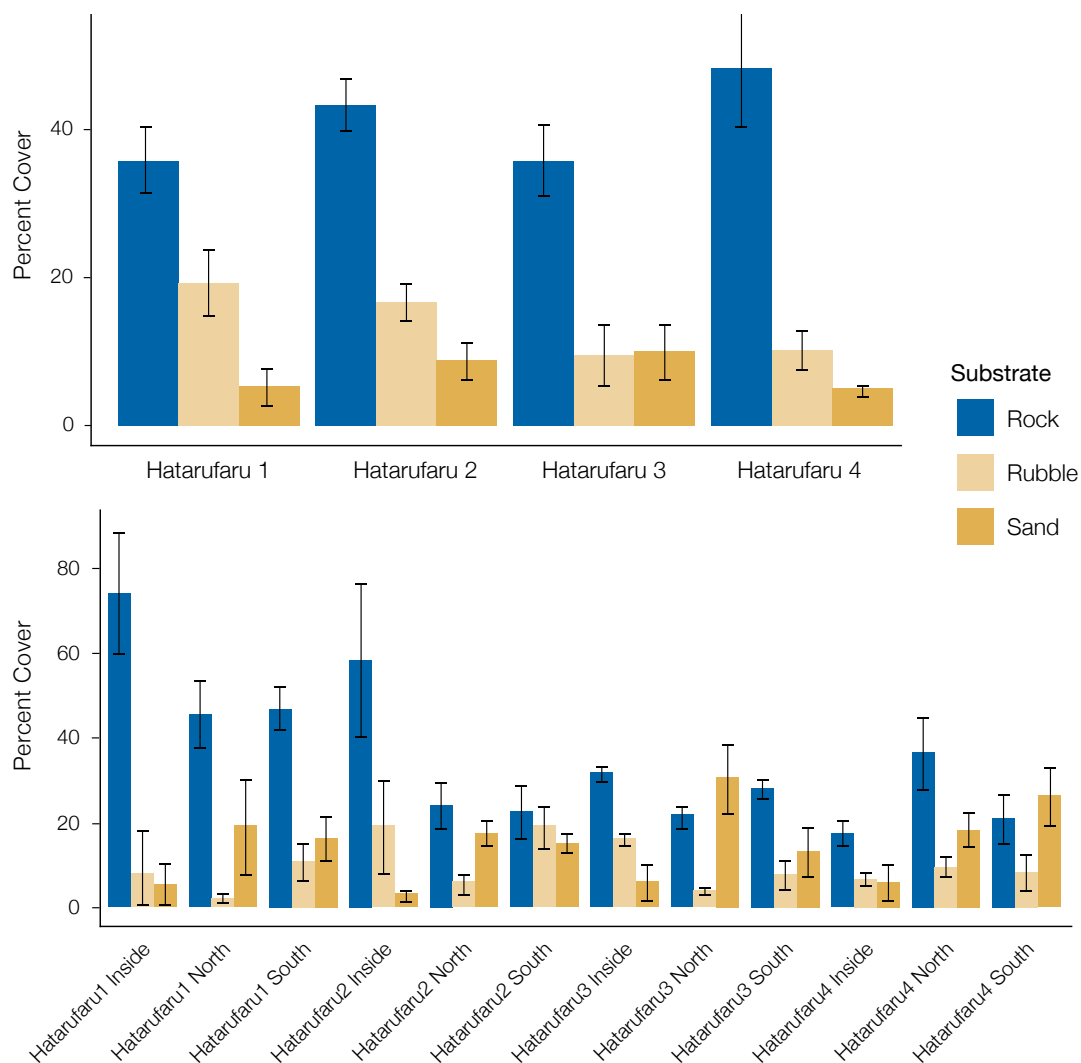


Figure 3: The percent cover of abiotic substrate at (a) the four outer atoll sites surveyed using transects and (b) channel and inner atoll reef sites surveyed using the roaming survey method.

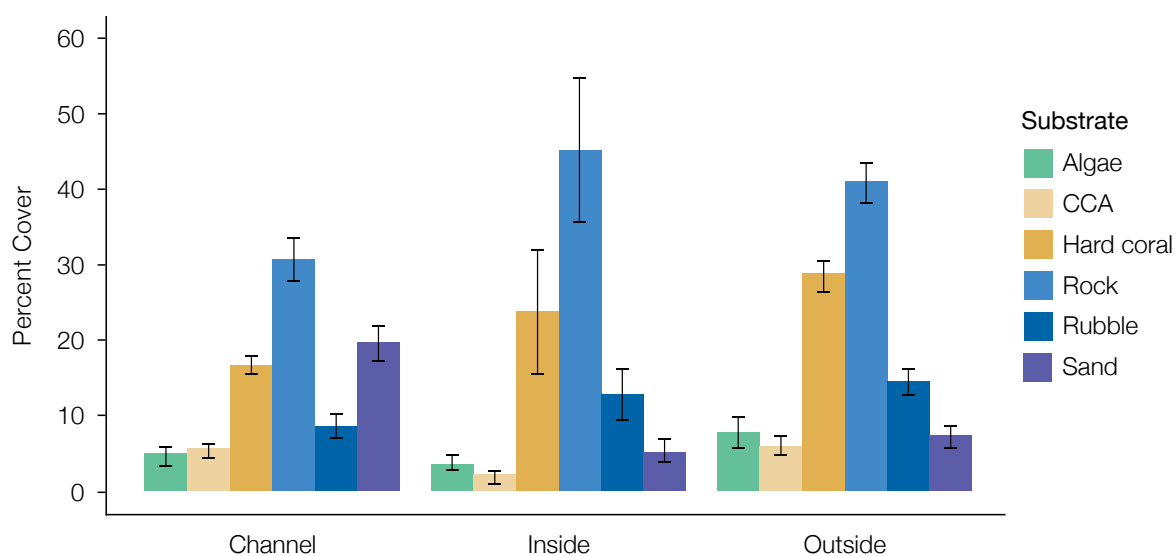


Figure 4: The mean percent cover of substrate by the three reef types surveyed

The mean density of recruits across all outside reefs was 5.0/ m². It ranged between 3.4/ m² at Hatarufaru 2 to 6.0/ m² at Hatarufaru 1, but total density of recruits did not vary significantly between sites (ANOVA, $p > 0.05$). Agariciidae was the most common family of recruits across the four sites (Figure 5). Coral recruits from families that typically have a more complex structure, such as Acroporidae and Pocilloporidae were also common across reef sites. Sites had similar patterns of recruitment, with the same families present across all sites, though their densities did vary somewhat between sites.

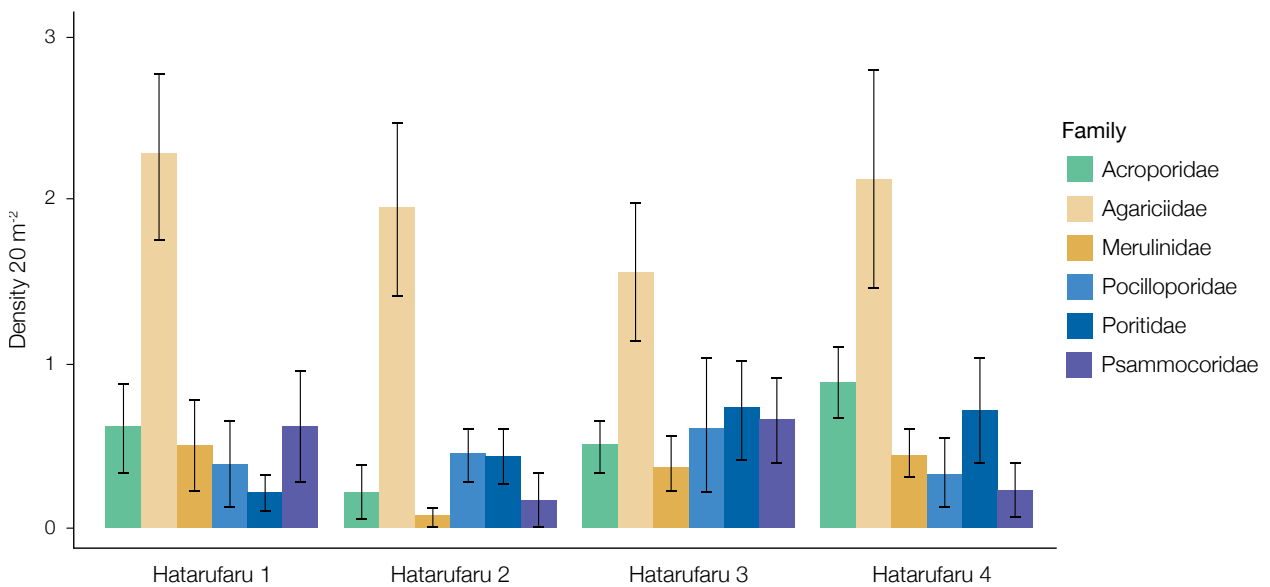


Figure 5: Density of the six most common coral recruits per m² by family at the four outside reef survey sites

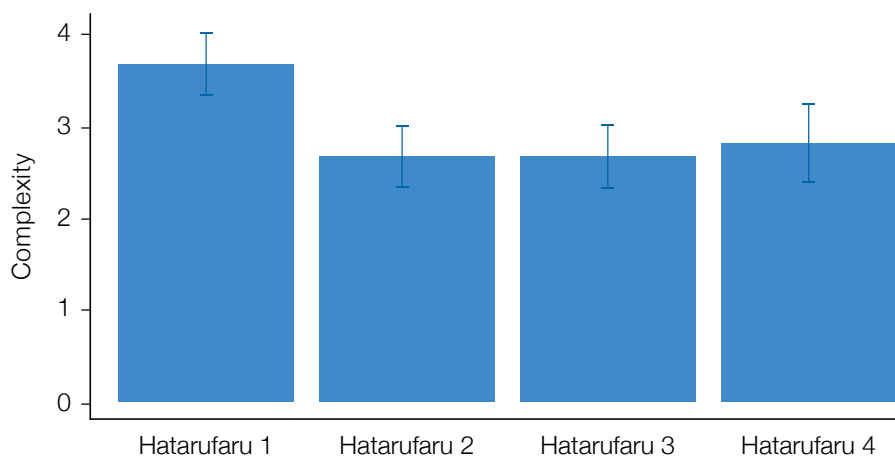


Figure 6: Mean visual complexity at the four outside reef survey sites

Mean reef complexity across all sites was 2.9 (± 0.3 s.e.). Complexity was significantly higher at Hatarufaru 1 (ANOVA, $p < 0.05$) (Figure 6). Lutjanidae was the dominant predatory fish family across all four outside reef survey sites (Figure 7a), however their biomass was highly variable, and wasn't always significantly greater than the biomass of other carnivorous families. Biomass of these families did not vary significantly between the survey sites (ANOVA, $p > 0.05$). Herbivore biomass was relatively high across all sites. *Scaridae* was the dominant herbivore family at all sites, though its biomass varied within sites (Figure 7b). The biomass of *Chaetodontidae* did not vary between survey sites.

Discussion

The coral reef habitat at Hatarufaru appears to be relatively healthy. Coral cover across the area is high, particularly on the outside reefs and two of the inside reef sites. The four faro reefs in a row creates a diverse habitat ranging between exposed outer reef slope, sheltered inner reefs and high current channel areas. These habitats all have different characteristics allowing a range of species to thrive in the area. There is however, evidence that the reefs have been impacted by the 2016 coral bleaching and the coral cover is below the historical average for the country (Pisapia et al. 2016).

The resilience of the reefs here is likely to be quite high, which is reflected

by the relatively high coral cover. The mean coral cover for the outside reefs was over 10 % higher than found during a wide-ranging survey in 2017 – 2018 (IUCN, in press). This may reflect either the areas were less impacted by the bleaching or have recovered faster than many reefs around the country. Other indicators of resilience such as juvenile coral recruitment and structural complexity were similar to the national averages. This may indicate that the reefs suffered less from the bleaching, however recovery can be strongly dependent on local factors which can act to inhibit or promote recovery. This reef area is some distance from any large human population and therefore less likely to suffer from the negative impacts of pollution, coastal development or overfishing.

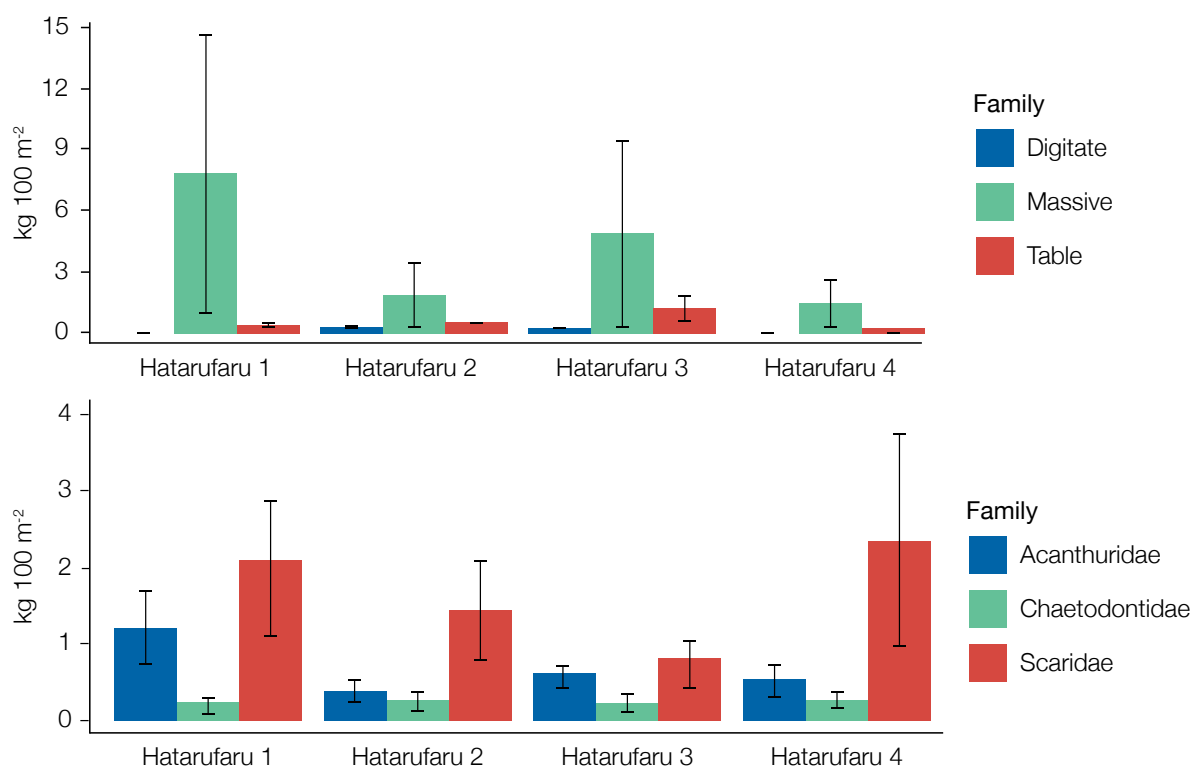


Figure 7: Biomass of (a) predatory reef fish families and (b) herbivorous and corallivorous fish families at the four outside reef survey sites



Figure 8: Coral covered area on the inside of Hatharufaru 4 inside

There is variation between the reef types as well. The southern two inside reefs had very high coral cover, Hatharufaru 4 inside in particular had a higher coral cover than observed anywhere during the 2017 – 2018 surveys (IUCN, in press). However, the northern two inside reefs had some of the lowest coral covers observed anywhere. The reef at these two sites was dead coral skeleton with very little live coral growth. There also appeared to be a difference between the channel habitats. Channels on the north side of the reefs had clearer water with steeper rocky slopes. The corner area where the channel met the outer reef had large schools of Lutjanidae and Carangidae. The southern channel areas were more turbid with gentler slopes reaching a sandy bottom about 25 m. The corner habitat was different the northern corners and had no large schools of fish.

Herbivore populations at all sites were greater than the average numbers found during a 2017 – 2018 nationwide survey (IUCN, in press). The parrotfish community had a high number of large bodied species which explains some of the variability in biomass within sites as these species contribute disproportionately to the biomass when present. Herbivorous fish, such as parrotfish and surgeonfish are important in preventing coral reefs from becoming overgrown by algae following disturbances (Hughes et al. 2007, Mumby et al. 2007). The numbers found at surveys across the country, and here are likely to confer a level of resilience to Maldivian reefs. Herbivores can experience short- to medium-term benefits following reductions in coral cover (Wilson et al. 2006, 2009). There is no fishery targeting these species meaning there is no reason their numbers should decline in the near-future, however there is

evidence that localised parrotfish is occurring in some areas. It is therefore key management efforts include education on their importance to reef health. Parrotfish have also been found to play an important role in sediment creation and island development and maintenance (Morgan and Kench 2016). With future sea level change threatening to impact the low-lying islands of the Maldives healthy parrotfish populations will be important in maintaining island growth at the rates of any change in sea level.

The main reef fishery target families, Lutjanidae and *Serranidae* were present at all survey sites. Large schools of Lutjanids were encountered in certain areas along the reefs. This resulted in their biomass being highly variable on the surveys. This family exhibits schooling behaviour around large structures on reefs during the day before moving across the reef to forage

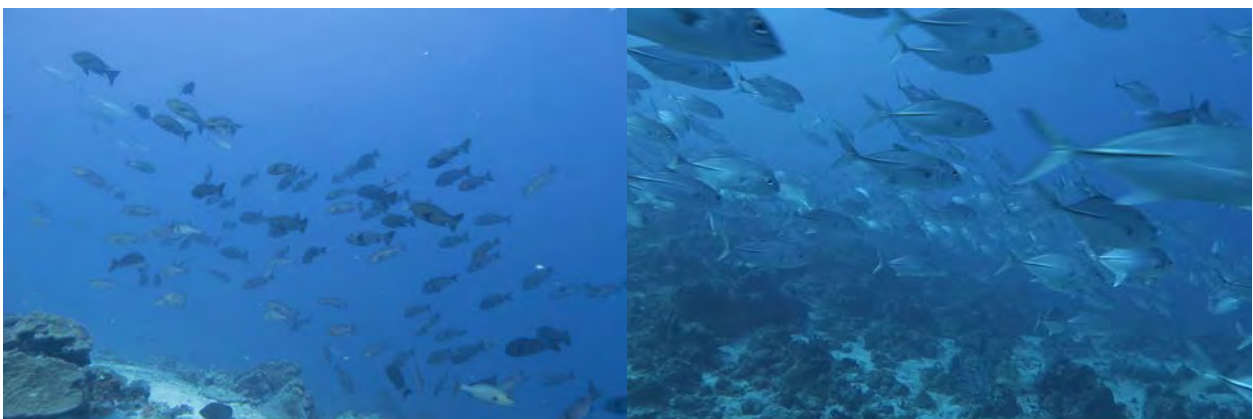


Figure 9. Schools of fish at the north corners of the channels

at night (Kulbicki et al. 2005). The presence of high numbers of these high trophic level predators indicates a healthy reef with many prey species. It also suggests a low level of fishing pressure on the reef area.

Human activities over the past 150 years have caused approximately 0.85°C of climate warming (IPCC 2014) and it is likely that it will continue to warm by at least 1.5°C between 2030 and 2052 (IPCC 2018). The impacts of climate change will pose a significant threat to the natural environment of Hatharufaru. Increases in ocean temperatures will lead to more frequent and severe coral bleaching events (Hoegh-Guldberg 2011), similar to 2016 which had led to widespread coral mortality (Ibrahim et al. 2017). 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 on reefs and both are important for a healthy reef habitat, however, increases in nutrients from pollution or declines in certain herbivorous fish species allows algae to proliferate and outcompete corals, especially following coral die-offs (Bellwood et al. 2004). However, when the opposite is true, and corals have less competition for space on reefs colonies are able to expand and coral larvae are able to settle and grow more successfully (Johns et al. 2018). This increases a coral reef's chances of recovery following disturbances.

Faro reefs such as the four that make up the Hatharufaru reef area are relatively common across the Maldives, however they are rare across the rest of the world (Kench 2011). Therefore, further study and increased protection for such areas is of great importance. The presence of these four matching reefs alongside one another creates a special habitat, with multiple connected systems. However, there are significant differences both between and within reef areas and therefore likely to be

different processes acting on each. Coral cover was amongst the highest observed across the country since the 2016 bleaching area. Key fish families, including fishery targets and important herbivores were abundant. These characteristics should make a further detailed research project and the development of a management plan for Hatharufaru reef area a high priority.

Management

The ecological management goal for Kendhikuhudhoo is to provide a means to promote and ensure the long-term conservation and protection of the island's ecosystem. Existing local management efforts should be coordinated and developed further 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 reports on biodiversity (Ministry of Environment and Energy 2015) 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 this goal. The main goal is broken down into two sub-goals: 1) to maintain the resilience of biological communities to stressors associated with climate change and 2) to maintain populations of unharvested species for reef health and social development. Future efforts should aim to monitor and manage for resilience (Flower et al. 2017, Lam et al. 2017).

In order to preserve the ecological resilience of the reef area and to protect its biodiversity for future generations, it is recommended that a management plan is developed. The management plan could consider the following elements:

- The development of a long-term monitoring programme for in order to track ecological changes over time
- A plan for development and enforcement of regulations in the area which will include a plan for inclusion of the local community in management and enforcement.
- Detailed regulations for activities across the reef areas.

- Key areas of management or future protection should include:
 - + North corner areas of the four reefs
 - + Inside reefs of Hatharufaru 3 and 4 to protect current high coral cover
 - + Inside reef areas of Hatharufaru 1 and 2 to promote recovery
- A plan for benefit-sharing for the area, so that benefits from the management have a positive impact on the wider community and can be used to empower and support the development of those who depend on the area for natural resources.
- Detailed mapping and zonation of the four reefs

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Appendix

Species	Common name	Family
<i>Acanthurus leucosternon</i>	Powder-blue surgeonfish	<i>Acanthuridae</i>
<i>Acanthurus nigricauda</i>	Eye-line surgeonfish	<i>Acanthuridae</i>
<i>Acanthurus nigrofuscus</i>	Dusky surgeonfish	<i>Acanthuridae</i>
<i>Acanthurus thompsoni</i>	Night surgeonfish	<i>Acanthuridae</i>
<i>Ctenochaetus binotatus</i>	Two-spot bristletooth	<i>Acanthuridae</i>
<i>Ctenochaetus striatus</i>	Fine-lined bristletooth	<i>Acanthuridae</i>
<i>Ctenochaetus truncatus</i>	Gold-ring bristletooth	<i>Acanthuridae</i>
<i>Naso elegans</i>	Orange-spine unicornfish	<i>Acanthuridae</i>
<i>Naso vlamingii</i>	Big-nose unicornfish	<i>Acanthuridae</i>
<i>Zebrasoma desjardini</i>	Sailfin surgeonfish	<i>Acanthuridae</i>
<i>Zebrasoma scopas</i>	Brown Tang	<i>Acanthuridae</i>
<i>Carangoides ferdau</i>	Banded trevally	<i>Carangidae</i>
<i>Caranx melampygus</i>	Blue-fin jack	<i>Carangidae</i>
<i>Elegatis bipinnulata</i>	Rainbow runner	<i>Carangidae</i>
<i>Triaenodon obesus</i>	Whitetip reef shark	<i>Carcharhinidae</i>
<i>Chaetodon auriga</i>	Threadfin butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon falcula</i>	Double-saddle butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon guttatissimus</i>	Spotted butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon kleinii</i>	Brown butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon madagaskariensis</i>	Madagascar butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon meyeri</i>	Meyers butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon triangulum</i>	Triangular butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon trifasciatus</i>	Pinstriped butterflyfish	<i>Chaetodontidae</i>
<i>Chaetodon xanthocephalus</i>	Yellow-head butterflyfish	<i>Chaetodontidae</i>
<i>Forcipiger flavissimus</i>	Long-nose butterflyfish	<i>Chaetodontidae</i>
<i>Forcipiger longirostris</i>	Very long-nose butterflyfish	<i>Chaetodontidae</i>
<i>Hemitaenichthys zoster</i>	Black pyramid butterflyfish	<i>Chaetodontidae</i>
<i>Heniochus pleurotaenia</i>	Phantom bannerfish	<i>Chaetodontidae</i>
<i>Plectorhinchus vittatus</i>	Oriental sweetlips	<i>Haemulidae</i>
<i>Myripristis bembdi</i>	Blotcheye soldierfish	<i>Holocentridae</i>
<i>Myripristis pralinia</i>	Big-eye soldierfish	<i>Holocentridae</i>
<i>Sargocentron caudimaculatum</i>	White-tail squirrelfish	<i>Holocentridae</i>
<i>Lethrinus obsoletus</i>	Orange-stripe emperor	<i>Lethrinidae</i>
<i>Lutjanus bohar</i>	Red bass	<i>Lutjanidae</i>
<i>Lutjanus gibbus</i>	Humpback snapper	<i>Lutjanidae</i>
<i>Lutjanus kasmira</i>	Blue-striped snapper	<i>Lutjanidae</i>

Species	Common name	Family
<i>Lutjanus monostigma</i>	One-spot snapper	Lutjanidae
<i>Macolor macularis</i>	Midnight snapper	Lutjanidae
<i>Macolor niger</i>	Black snapper	Lutjanidae
<i>Calotomus carolinus</i>	Starry-eye parrotfish	Scaridae
<i>Cetoscarus bicolor</i>	Two-colour parrotfish	Scaridae
<i>Chlorurus sordidus</i>	Shabby parrotfish	Scaridae
<i>Chlorurus strongylocephalus</i>	Sheephead parrotfish	Scaridae
<i>Hipposcarus harid</i>	Longnose parrotfish	Scaridae
<i>Scarus frenatus</i>	Bridled parrotfish	Scaridae
<i>Scarus niger</i>	Dusky parrotfish	Scaridae
<i>Scarus quoyi</i>	Green-blotched parrotfish	Scaridae
<i>Scarus rubroviolaceus</i>	Ember parrotfish	Scaridae
<i>Scarus scaber</i>	Five-saddle parrotfish	Scaridae
<i>Scarus tricolor</i>	Three-colour parrotfish	Scaridae
<i>Aethaloperca rogaa</i>	Red-flushed grouper	Serranidae
<i>Anyperodon leucogrammicus</i>	White-lined 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>Epinephelus spilotoceps</i>	Foursaddle grouper	Serranidae
<i>Gracila albomarginata</i>	White-square grouper	Serranidae
<i>Plectropomus laevis</i>	Black-saddle coral grouper	Serranidae
<i>Variola louti</i>	Lunar-tailed grouper	Serranidae

Table A 1: All species of *Acanthuridae*, *Chaetodontidae*, *Holocentridae*, *Lethrinidae*, *Lutjanidae*, *Scaridae* and *Serranidae* observed on transects in Hatharufaru

Family	Common family	Family	Common family	Family	Common family
<i>Acanthuridae</i>	Surgeonfish	Haemulidae	Sweetlips	Pomacanthidae	Angelfish
<i>Apogonidae</i>	Cardinalfish	Holocentridae	Squirrelfish	Pomacentridae	Damselfish
<i>Aulostomidae</i>	Trumpetfish	Kyphosidae	Rudderfish	<i>Scaridae</i>	Parrotfish
Balistidae	Triggerfish	Labridae	Wrasse	Scombridae	Tuna
Blenniidae	Blenny	Lethrinidae	Emperor	Scorpaenidae	Lionfish
Caesionidae	Fusilier	Lutjanidae	Snapper	Scorpaenidae	Scorpionfish
Carangidae	Jack	Malacanthidae	Tilefish	<i>Serranidae</i>	Basslet
Carcharhinidae	Requiem Shark	Microdesmidae	Dart Goby	<i>Serranidae</i>	Grouper
<i>Chaetodontidae</i>	Butterflyfish	Monacanthidae	Filefish	Siganidae	Rabbitfish
Cirrihitidae	Hawkfish	Mullidae	Goatfish	Sphyrnaeidae	Barracuda
Congridae	Garden eel	Muraenidae	Moray Eel	Synodontidae	Lizardfish
Diodontidae	Porcupinefish	Myliobatidae	Eagle ray	Tetraodontidae	Pufferfish
Ephippidae	Batfish	Nemipteridae	Spinecheek	Zanclidae	Moorish idol
Fistulariidae	Flutemouth	Ostraciidae	Boxfish		
Gobiidae	Goby	Pinguipedidae	Grubfish		

Table A 2: All fish families observed on roaming surveys

Genus	Family	Genus	Family
Acropora	Acroporidae	Leptoseris	Agariciidae
Astreopora	Acroporidae	Lobophytum	Alcyoniidae
Diploastrea	Diploastreidae	Merulina	Merulinidae
Echinopora	Merulinidae	Montastrea	Paramonastrea
Favia	Mussidae	Montipora	Acroporidae
Favites	Merulinidae	Mycedium	Merulinidae
Fungia	Fungiidae	Pavona	Agariciidae
Galaxea	Euphylliidae	Physogyra	Insertae sedis
Goniastrea	Merulinidae	Platygyra	Merulinidae
Goniopora	Poritidae	Pocillopora	Pocilloporidae
Halimeda	Halimedaceae	Porites	Poritidae
Heliopora	Helioporidae	Psammocora	Psammocoridae
Hydnophora	Merulinidae	Sacrophyton	Alcyoniidae
Isopora	Acroporidae	Turbinaria	Dendrophyllidae
Leptoria	Merulinidae	Tydemanina	Udoteaceae

Table A 3: All coral genera observed on transects

Genus	Family
Acropora	Acroporidae
Diploastrea	Diploastreidae
Echinopora	Merulinidae
Favia	Mussidae
Favites	Merulinidae
Fungia	Fungiidae
Gardineroseris	Agariciidae
Goniastrea	Merulinidae
Leptastrea	Insertae sedis
Leptoria	Merulinidae
Leptoseris	Agariciidae
Montastrea	Paramonastrea
Montipora	Acroporidae
Pavona	Agariciidae
Pocillopora	Pocilloporidae
Porites	Poritidae
Psammocora	Psammocoridae
Unidentified	Unkown

Table A 4: All coral recruit genera observed on transects

Species	Common name	Family
<i>Carcharhinus amblyrhynchos</i>	Grey reef shark	Carcharhinidae
<i>Cheilinus undulatus</i>	Napoleon wrasse	Labridae
<i>Epinephelus fuscoguttatus</i>	Marble grouper	Serranidae
<i>Eretmochelys imbricata</i>	Hawksbill turtle	Cheloniidae
<i>Nebrius ferrugineus</i>	Tawny nurse shark	Ginglymostomatidae
<i>Plectropomus areolatus</i>	Squaretail coral grouper	Serranidae
<i>Plectropomus laevis</i>	Black-saddle coral grouper	Serranidae
<i>Triacodon obesus</i>	Whitetip reef shark	Carcharhinidae

Table A 5: All IUCN RedList species observed

HITADHOO CORNER ZONE

Area type: Rocky Plateau

Location: Laamu Atoll

Zone description

Hitadhoo corner is a flat rocky plateau at the southern edge of Laamu atoll. The area has a number of large (5 – 10 m diameter and up to 5 m tall) coral patches. These are structurally complex with many large holes and ledges for fish to shelter in. These patches have created habitat for many small wrasses

and invertebrates. This has attracted manta rays to the area which use these patches as cleaning stations. Reef manta rays (*Manta alfredi*) are frequently observed in the area. This has made the area a popular dive site. The area is also close to Hitadhoo, a large local island that both fishes and dumps trash in the area.

Start		End	
Latitude	Longitude	Latitude	Longitude
1.801083	73.41094	1.814528	73.41192

Table 1. Start and end GPS points of the survey dive

"Hitadhoo Corner is a very important reef manta ray habitat. Reef manta rays (*Manta alfredi*) are frequently observed in the area."

Coral reef benthos:

The average coral cover for the area was 18.8%. The coral cover was concentrated in the large coral patches, where cover was almost 100%, the rest of the area was bare rock area. Soft

coral was recorded growing within the coral patches. Much of the coral on the patches bleached in 2016, however they had fully recovered by the time these surveys were conducted.

Survey No.	1	2	3	4	5	6
Depth	18	22	20	20	19	15
Complexity	2	2	2	2	2	2
Coralline algae	18	15	22	40	34	40
Hard Coral	18	25	18	7	25	20
Macro algae	0	0	2	0	0	0
Rock	29	33	42	45	30	30
Rubble	8	5	3	2	3	3
Sand	2	2	2	2	1	1
Soft Coral	15	12	2	1	2	1
Sponge	10	8	8	1	2	2
Turf algae	0	0	0	0	0	0
Others	0	0	0	2	3	3

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish diversity:

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 33 of which were found on Hitadhoo

Corner. Groupers and butterflyfish are indicators of unfished and healthy reef areas and were observed within the first two minutes of all surveys. The key herbivores, surgeonfish and parrotfish were also observed within the first two minutes of all surveys. Herbivores are a functionally important group on coral

reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Site	Total number of families	Mean number of families
Hitadhoo corner combined	31	22

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Hitadhoo Corner is a very

important reef manta ray habitat. Multiple individuals were observed on all surveys. Large grouper species were also abundant. These species shelter

in the in complex reef habitats and form aggregations in channel areas to spawn (Robinson et al. 2008).

Survey number	<i>Cheilinus undulatus</i>	<i>Chelonia mydas</i>	<i>Manta alfredi</i>	<i>Nebrius ferrugineus</i>	<i>Plectropomus areolatus</i>	<i>Plectropomus laevis</i>	<i>Triaenodon obesus</i>
1		1	2	1	3	1	
2			2		3	1	1
3	2		3			1	
4		1	2		2	2	
5			3			1	
6	2		3		4		

Table 4. Survey number and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed during rapid surveys.

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight different substrate categories: live

coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5

(highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	Pomacanthidae	Grouper	<i>Serranidae</i>	Squirrelfish	Holocentridae
Basslet	<i>Serranidae</i>	Hawkfish	Cirrhitidae	Stingray	Dasyatidae
Batfish	Ephippidae	Jack	Carangidae	Surgeonfish	<i>Acanthuridae</i>
Bullseye	Pempheeridae	Manta ray	Myliobatidae	Sweetlips	Haemulidae
Butterflyfish	<i>Chaetodontidae</i>	Moorish idol	Zanclidae	Tilefish	Malacanthidae
Cleaner Wrasse	Labridae	Parrotfish	<i>Scaridae</i>	Triggerfish	Balistidae
Damselfish	Pomacentridae	Pufferfish	Tetraodontidae	Tuna	Scombridae
Dart Goby	Microdesmidae	Rabbitfish	Siganidae	Waspfish	Tetrarogidae
Emperor	Lethrinidae	Requiem Shark	Carcharhinidae	Wrasse	Labridae
Flutemouth	Fistulariidae	Snapper	Lutjanidae		
Goatfish	Mullidae	Spinecheek	Nemipteridae		

Table A1. All fish families recorded at Hitadhoo Corner

KANDOOMAA THILA ZONE

Area type: Channel

Location: South Malé Atoll

Zone description

Kandoomaa Thila is a large rocky pinnacle, locally called a thila, which lies in a channel on the eastern edge of South Malé atoll. It is exposed to the strong currents common to channel habitats in the Maldives. It is a well-known shark aggregation area. Grey reef (*Carcharhinus amblyrhynchos*) sharks are commonly observed at the

head of the thila. The top is relatively flat, but the sides have a number of ledges which are sheltered from the currents and have significant soft coral development. The area is frequently dived by local resorts and safari boats, however changeable conditions make it a challenging dive site.

Start		End	
Latitude	Longitude	Latitude	Longitude
3.906917	73.4805	3.902061	73.47717

Table 1. Start and end GPS points of the survey dive

"Grey reef (*Carcharhinus amblyrhynchos*) sharks are commonly observed at the head of the thila. High numbers of grey reef shark were recorded during the survey, predominantly at the head of the thila in the channel area."

Coral reef benthos:

Mean coral cover in Kandoomaa Thila was 17%. There was a high cover of CCA on the exposed rock area. The sheltered ledge areas which ran along the sides of the thila, was dominated

by soft corals, though there was also sponge cover. These ledges created a complex habitat along the sides while the top of the thila was relatively flat, with little shelter.

Survey number	1	2
Depth	25	25
Complexity	3	3
Coralline algae	21	20
Hard Coral	18	16
Macro algae	2	2
Rock	10	20
Rubble	0	0
Sand	10	5
Soft Coral	23	25
Sponge	9	10
Turf algae	5	0
Others	2	2

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish community:

Values for the fish community were below the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 21 of which were recorded on Kandoomaa Thila. Lower numbers are

may be due to the different environment this site presents when compared to typical reef areas. Though it was not possible to survey to the high level of detail required to state definitively, it is likely that the high currents and soft corals provide habitat for a different range of species compared to most sites surveyed.

Site	Total number of families	Mean number of families
Kandoomaa Thila combined	21	20.5

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. High numbers of grey reef shark were recorded during the survey,

predominantly at the head of the thila in the channel area. Smaller white-tip reef sharks (*Triaenodon obesus*) were observed resting on the thila and large grouper and humphead wrasse

(*Cheilinus undulatus*) were recorded in and around the ledges on the thila sides.

Site	<i>Carcharhinus amblyrhynchos</i>	<i>Cheilinus undulatus</i>	<i>Plectropomus laevis</i>	<i>Triaenodon obesus</i>
Kandoomaa Thila	8	3	4	3

Table 4. Number of IUCN Redlisted (endangered, vulnerable and least concern) fish species observed

METHODS

Divers entered the water at the eastern end of the thila and drifted back over the thila switching from side to top at regular intervals. The strong currents and challenging dive conditions resulted in only two surveys being conducted. Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming

surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching,

massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Common name	Famiy name	Common name	Famiy name	Common name	Famiy name
Angelfish	Pomacanthidae	Fusilier	Caesionidae	Spinecheek	Nemipteridae
Basslet	<i>Serranidae</i>	Grouper	<i>Serranidae</i>	Squirrelfish	Holocentridae
Boxfish	Ostraciidae	Jack	Carangidae	Surgeonfish	<i>Acanthuridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Moorish idol	Zanclidae	Sweetlips	Haemulidae
Damselfish	Pomacentridae	Parrotfish	<i>Scaridae</i>	Triggerfish	Balistidae
Emperor	Lethrinidae	Requiem Shark	Carcharhinidae	Tuna	Scombridae
Flutemouth	Fistulariidae	Snapper	Lutjanidae	Wrasse	Labridae

Table A1. All fish families recorded at Kandoomaa Thila

KUREDU EXPRESS ZONE

Area type: Channel

Location: Lhaviyani Atoll

Zone description

Kuredu Express is a channel that connects the Indian ocean with the inner atoll waters of Lhaviyani atoll. It is subject to strong currents as the water runs into or flushes out of the atoll depending on the tides. During times of strong currents, it is a well-known

shark aggregation area where grey reef (*Carcharhinus amblyrhynchos*) sharks are commonly observed. There is also a structurally complex area on the outside of the channel corner with some coral growth and cryptic fish species.

"Large grouper species were also abundant. These species shelter in the in complex reef habitats and form aggregations in channel areas to spawn."

Start		End	
Latitude	Longitude	Latitude	Longitude
5.555528	73.47844	5.558417	73.47981

Table 1. Start and end GPS points of the survey dive

Coral reef benthos:

The channel area was relatively flat with little coral growth. Mean coral cover was 13.3%. The substrate was predominantly rock with a fine layer of sandy sediment on top. There were

small ledges in the channel corner which provided limited structure. There was an area on the outside of the corner where an area of rock as caved in and a sheltered, complex habitat has been created with hard coral growth.

Survey No.	1	2	3	4	5	6
Depth	15	20	12	16	20	16
Complexity	1	1	3	1	2	3
Coralline algae	0	0	0	2	0	10
Hard Coral	8	12	15	10	10	25
Macro algae	4	4	3	0	0	0
Rock	8	20	54	20	60	30
Rubble	1	5	6	20	10	10
Sand	72	55	5	30	10	15
Soft Coral	0	0	5	0	0	0
Sponge	3	4	10	3	0	0
Turf algae	0	0	2	8	0	0
Others	3	0	0	7	10	10

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach use

Fish community:

Values for the fish community were above the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the

country, 35 of which were found at Kuredu Express. Groupers and butterflyfish are indicators of unfished and healthy reef areas and were observed within the first five minutes of all surveys. Large schools of jacks were observed at the channel corner.

Site	Total number of families	Mean number of families
Turtle Point combined	35	20.3

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. High numbers of grey reef shark were recorded during the survey, predominantly on the outer atoll edge

and channel corner. Large grouper species were also abundant. These species shelter in the in complex reef habitats and form aggregations in channel areas to spawn (Robinson et al. 2008). Green turtles were abundant

in this area, the seagrass beds nearby provide foraging grounds and the ledges present at Kuredu Express provide shelter.

Survey No.	<i>Carcharhinus amblyrhynchos</i>	<i>Chelonia mydas</i>	<i>Epinephelus fuscoguttatus</i>	<i>Plectropomus areolatus</i>	<i>Plectropomus laevis</i>
1	5	2	1	3	
2	3	2			2
3	1			3	
4	5	2	1	1	2
5	3	2			2
6				4	

Table 4. Survey number and number of IUCN Rdlisted (endangered, vulnerable and least concern) species observed

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated

on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were.

ANNEX

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	Pomacanthidae	Grouper	<i>Serranidae</i>	Snapper	Lutjanidae
Basslet	<i>Serranidae</i>	Grubfish	Pinguipedidae	Squirrelfish	Holocentridae
Batfish	Ephippidae	Hawkfish	Cirrhitidae	Stingray	Dasyatidae
Boxfish	Ostraciidae	Jack	Carangidae	Surgeonfish	<i>Acanthuridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Snapper	Lutjanidae	Sweetlips	Haemulidae
Damselfish	Pomacentridae	Moorish idol	Zanclidae	Tilefish	Malacanthidae
Dart Goby	Microdesmidae	Moray Eel	Muraenidae	Triggerfish	Balistidae
Eagle ray	Myliobatidae	Parrotfish	<i>Scaridae</i>	Tuna	Scombridae
Emperor	Lethrinidae	Pufferfish	Tetraodontidae	Waspfish	Tetrarogidae
Flutemouth	Fistulariidae	Rabbitfish	Siganidae	Wrasse	Labridae
Fusilier	Caesionidae	Requiem Shark	Carcharhinidae		
Goatfish	Mullidae	Rudderfish	Kyphosidae		

Table A1. All fish families recorded at Kuredu Express

MADIVARU ZONE

Area type: Channel

Location: Rasdhoo Atoll

Zone description

Madivaru is a channel that connects the Indian ocean with the inner atoll waters of Rasdhoo atoll. There is an extension of outer atoll fringing reef that extends into the channel which is quite rare. This has created a reef habitat for reef fish within the channel and a sheltered sand covered area behind the reef. At the reef's extent in the

channel, grey reef sharks (*Carcharhinus amblyrhynchos*) are common. There used to be a scalloped hammerhead (*Sphyrna lewini*) aggregation that formed just outside the channel area, however high fishing pressure significantly reduced their numbers and these sharks are now rarely observed.

51 reef associated fish families were observed across the country, 34 of which were found in Madivaru.

Start		End	
Latitude	Longitude	Latitude	Longitude
4.265139	73.00169	4.262806	72.99839

Table 1. Start and end GPS points of the survey dive

Coral reef benthos:

The mean coral cover of 25% was high for a channel zone. This is due the ridge of reef which extends out across the channel area. Coral growth here was healthy and was frequently

the dominant substrate category in surveys. High water-flow may confer some resilience to temperature increases (Nakamura and Van Woesik 2001) which may explain the high

coral cover here. Structural complexity along the reef area was created by the significant coral development.

Survey No.	1	2	3	4	5	6
Depth	20	15	15	15	19	16
Complexity	2	2	2	3	3	3
Coralline algae	6	13	18	7	20	12
Hard Coral	35	30	20	20	30	15
Macro algae	4	7	8	0	1	6
Rock	15	20	10	25	25	40
Rubble	5	5	2	15	0	0
Sand	5	0	2	25	0	0
Soft Coral	0	10	8	0	3	2
Sponge	30	15	20	3	5	3
Turf algae	0	0	0	0	4	12
Others	0	0	13	5	12	10

Table 1. Start and end GPS points of the survey dive

Fish community:

Values for the fish community was above the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 34 of which were found in Madivaru. The combination of the reef and channel habitats likely increased

species diversity, though it was not possible to survey to the high level of detail required to state this definitively. Groupers and butterflyfish are indicators of unfished and healthy reef areas and were observed within the first two minutes of all surveys. The key herbivores, surgeonfish and parrotfish were also observed within the first two minutes of all surveys.

Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Site	Total number of families	Mean number of families
Madivaru combined	34	22.3

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Grey reef sharks were recorded during

the survey, predominantly on the edge of the reef extension. Large grouper species were also abundant. These species shelter in the in complex reef

habitats and form aggregations in channel areas to spawn (Robinson et al. 2008).

Survey number	<i>Carcharhinus amblyrhynchos</i>	<i>Cheilinus undulatus</i>	<i>Plectropomus laevis</i>	<i>Triaenodon obesus</i>
1	3		1	1
2			1	1
3	2	1	2	
4			2	2
5			2	
6		2		

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated

on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	Pomacanthidae	Goatfish	Mullidae	Rabbitfish	Siganidae
Barracuda	Sphyraenidae	Grouper	<i>Serranidae</i>	Requiem Shark	Carcharhinidae
Basslet	<i>Serranidae</i>	Hawkfish	Cirrhitidae	Snapper	Lutjanidae
Boxfish	Ostraciidae	Jack	Carangidae	Spinecheek	Nemipteridae
Butterflyfish	<i>Chaetodontidae</i>	Snapper	Lutjanidae	Squirrelfish	Holocentridae
Damselfish	Pomacentridae	Lionfish	Scorpaenidae	Surgeonfish	<i>Acanthuridae</i>
Dart Goby	Microdesmidae	Lizardfish	Synodontidae	Sweetlips	Haemulidae
Eagle ray	Myliobatidae	Moorish idol	Zanclidae	Triggerfish	Balistidae
Emperor	Lethrinidae	Moray Eel	Muraenidae	Tuna	Scombridae
Flutemouth	Fistulariidae	Parrotfish	<i>Scaridae</i>	Waspfish	Tetrarogidae
Fusilier	Caesionidae	Pufferfish	Tetraodontidae	Wrasse	Labridae
Garden eel	Congridae				

Table A1. All fish families recorded at Madivaru

MANTA POINT ADDU ZONE

Area type: Channel

Location: Addu Atoll

Zone description

Manta Point Addu is a channel that connects the Indian ocean with the inner atoll waters of Addu atoll. It is subject to strong currents as the water runs into or flushes out of the atoll depending on the tides. There are two sections to the area, one just outside the channel has an exceptionally high coral cover with significant *Acropora*

growth. The area appeared to be unaffected by the bleaching event. The second section was a manta cleaning station around a large porites coral within the channel area. During certain times multiple reef manta rays (*Manta alfredi*) can be observed hovering around the coral area.

"High numbers of the IUCN Red Listed Chevroned butterflyfish (*Chaetodon trifascialis*) are likely due to the high cover of tabular *Acropora* corals."

Start		End	
Latitude	Longitude	Latitude	Longitude
0.579028	73.08325		73.08878
0.611472	73.15461	0.609306	73.1485

Table 1. Start and end GPS point Latitude and longitude of the dive surveys

Coral reef benthos:

Coral cover across the zone averaged 38.6%, however it was significantly higher than this in large area where tabular *Acropora* corals dominated. High water-flow may confer some

resilience to temperature increases (Nakamura and Van Woesik 2001). Macro algae cover was relatively high in this area, growing around dead coral skeleton. Structural complexity was high, with multiple reef layers created

by overlapping table coral growth interspersed with digitate *Porites* coral colonies. The area within the channel was flat by comparison and the substrate was dominated by rock.

Survey No.	1	2	3	4	5
Depth	15	12	9	17	10
Complexity	2	5	5	3	3
Coralline algae	0	0	1	0	0
Hard Coral	15	60	50	10	58
Macro algae	4	9	8	1	10
Rock	70	17	37	87	20
Rubble	0	3	1	0	0
Sand	0	5	0	0	10
Soft Coral	0	0	0	0	0
Sponge	10	5	2	2	0
Turf algae	0	0	0	0	0
Others	0	0	0	0	2

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish community:

Values for the fish community were slightly below the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 27 of which were found Manta Point Addu. Groupers and butterflyfish

are indicators of unfished and healthy reef areas and were observed within the first two minutes of surveys in the highly complex reef area. The key herbivores, surgeonfish and parrotfish were also observed within the first two minutes in this area. Herbivores are a functionally important group on coral reefs. They play a key role in keeping

algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country. In the channel area fewer families were observed as this was a less structurally complex coral habitat for fish.

Site	Total number of families	Mean number of families
Turtle Point combined	27	19

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. High numbers of the IUCN

Red Listed Chevroned butterflyfish (*Chaetodon trifascialis*) are likely due to the high cover of tabular *Acropora* corals. The zone was also an important

reef manta ray habitat, high numbers of this species were recorded and are frequently observed by local dive operators.

Survey number	<i>Chaetodon trifascialis</i>	<i>Cheilinus undulatus</i>	<i>Eretmochelys imbricata</i>	<i>Manta alfredi</i>	<i>Plectropomus laevis</i>	<i>Triaenodon obesus</i>
1	2	1		8	4	
2	7	1			1	1
3	3	2				
4	4	2	1			
5		1		4	2	

Table 4. Number of fish families observed on each survey and the total and mean number observed across all surveys

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5

(highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were.

ANNEX

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	Pomacanthidae	Grouper	<i>Serranidae</i>	Requiem Shark	Carcharhinidae
Batfish	Ephippidae	Hawkfish	Cirrhitidae	Rudderfish	Kyphosidae
Bigeye	Priacanthidae	Jack	Carangidae	Snapper	Lutjanidae
Bullseye	Pempheridae	Lizardfish	Synodontidae	Spinecheek	Nemipteridae
Butterflyfish	<i>Chaetodontidae</i>	Manta ray	Myliobatidae	Squirrelfish	Holocentridae
Damselfish	Pomacentridae	Moorish idol	Zanclidae	Surgeonfish	<i>Acanthuridae</i>
Emperor	Lethrinidae	Parrotfish	<i>Scaridae</i>	Sweetlips	Haemulidae
Fusilier	Caesionidae	Pufferfish	Tetraodontidae	Triggerfish	Balistidae
Goatfish	Mullidae	Rabbitfish	Siganidae	Wrasse	Labridae

Table A1. All fish families recorded at Manta point

NASSIMO THILA ZONE

Area type: Rocky Pinnacle

Location: North Malé Atoll

Zone description

Nassimo Thila is a large rocky pinnacle, locally called a thila, in the south-eastern corner of North Malé Atoll. A large section of the thila has broken off leaving a complex sheltered area. A number of long overhangs and

crevices run along the edges of the thila and large boulders. These areas were dominated by soft corals. Large schools of fish also shelter within this area

"This area was dominated by soft corals. Structural complexity in this area was high due to the ledges and large boulders."

Start		End	
Latitude	Longitude	Latitude	Longitude
4.286472	73.53675	4.286472	73.53675

Table 1. Start and end GPS point Latitude and longitude of the dive survey

Coral reef benthos:

Mean coral cover was 10%. The main area of survey was the section where sections of the thila had broken off. This area was dominated by soft corals. Structural complexity in this

area was high due to the ledges and large boulders. Outside of this area the thila was relatively flat with little coral development and the dominant substrate cover is rock

Survey No.	1	2	3	4
Depth	20	17	25	18
Complexity	3	3	4	4
Coralline algae	10	12	8	4
Hard Coral	15	12	8	5
Macro algae	4	3	0	0
Rock	10	20	10	20
Rubble	0	2	0	0
Sand	0	0	0	0
Soft Coral	40	30	40	40
Sponge	20	21	10	8
Turf algae	0	0	4	3
Others	0	0	20	20

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish community:

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 30 of which were recorded on Nassimo Thila. Groupers and butterflyfish are indicators of unfished and healthy reef areas and were observed within the first two minutes of all surveys. The key herbivores, surgeonfish and parrotfish were also observed within the first two minutes of all surveys. Herbivores are

a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country. Though it was not possible to survey to the high level of detail required to state definitively, it is likely that the soft corals provide habitat for a different range of species compared to most sites surveyed.

Site	Total number of families	Mean number of families
Nassimo Thila combined	30	16.5

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Smaller white-tip reef sharks

(*Triacnodon obesus*) were observed resting on the thila and large groupers were recorded in and around the ledges on the thila sides.

<i>Chaetodon trifascialis</i>	<i>Plectropomus laevis</i>	<i>Triacnodon obesus</i>
2	1	1

Table 4. Survey number and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5

(highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were.

ANNEX

Common Family	Scientific Family	Common Family	Scientific Family	Common Family	Scientific Family
Angelfish	Pomacanthidae	Goatfish	Mullidae	Requiem Shark	Carcharhinidae
Basslet	<i>Serranidae</i>	Grouper	<i>Serranidae</i>	Rudderfish	Kyphosidae
Boxfish	Ostraciidae	Hawkfish	Cirrhidae	Snapper	Lutjanidae
Butterflyfish	<i>Chaetodontidae</i>	Jack	Carangidae	Spinecheek	Nemipteridae
Cardinalfish	Apogonidae	Lionfish	Scorpaenidae	Squirrelfish	Holocentridae
Damselfish	Pomacentridae	Moorish idol	Zanclidae	Surgeonfish	<i>Acanthuridae</i>
Dart Goby	Microdesmidae	Parrotfish	<i>Scaridae</i>	Sweetlips	Haemulidae
Emperor	Lethrinidae	Porcupinefish	Diodontidae	Triggerfish	Balistidae
Flutemouth	Fistulariidae	Pufferfish	Tetraodontidae	Trumpetfish	Aulostomidae
Fusilier	Caesionidae	Rabbitfish	Siganidae	Wrasse	Labridae

Table A1. All fish families recorded at Nassimo Thila

ORIMAS THILA ZONE

Area type: Rocky Pinnacle

Location: Noonu Atoll

Zone description

Orimas Thila is a rocky pinnacle, locally called a thila, in the centre of Noonu atoll. The pinnacle has sloping sides and a flat top. The thila was not as large as those surveyed on other atolls. Grey reef (*Carcharhinus amblyrhynchos*)

sharks are commonly observed around the thila. The top was relatively flat, but the sides had many ledges which were sheltered from the currents and have coral development.

This was one of only two sites where a leopard shark (*Stegostoma fasciatum*) was recorded.

Start		End	
Latitude	Longitude	Latitude	Longitude
5.84856	73.25272	5.84794	73.25228

Table 1. Start and end GPS point Latitude and longitude of the dive survey

Coral reef benthos:

Mean coral cover across the thila was 11.3%. The area was dominated by rock, with few large patches of sand. Soft corals and sponges grew in the

sheltered ledges found along the thila's sides. These ledges created complex structures in many areas across the thila.

Survey No.	1	2	3	4
Depth	15	17		
Complexity	2	2		
Coralline algae	0	0	2	2
Hard Coral	15	18	7	5
Macro algae	0	0	0	0
Rock	65	40	70	25
Rubble	5	10	1	5
Sand	4	15	6	55
Soft Coral	2	5	10	3
Sponge	8	10	2	4
Turf algae	0	0	1	1
Others	0	0	1	0

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used. Note depth and complexity were not recorded on two surveys.

Fish community:

Values for the fish community were slightly below the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 27 of which were found on Orimas Thila. The lower numbers are

likely due to the different environment this site presents when compared to typical reef areas. Reef fishery target species were found to be abundant in this area. Large schools of snappers were observed, and the site is known locally as spot to fish for giant trevally (*Caranx ignobilis*).

Site	Total number of families	Mean number of families
Orimas Thila combined	27	19.8

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. High numbers of grey reef shark were recorded during the survey, predominantly at the tip of the thila.

This was one of only two sites where a leopard shark (*Stegostoma fasciatum*) was recorded. White-tip reef sharks (*Triaenodon obesus*) were observed resting on the flat substrate at the foot of the thila.

Site No.	<i>Carcharhinus amblyrhynchos</i>	<i>Plectropomus laevis</i>	<i>Stegostoma fasciatum</i>	<i>Triaenodon obesus</i>
1	2	2		2
2	2			
3	1		1	2

Table 4. Survey number and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed.

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated

on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were.

ANNEX

Common Family	Scientific Family	Common Family	Scientific Family	Common Family	Scientific Family
Angelfish	Pomacanthidae	Fusilier	Caesionidae	Requiem Shark	Carcharhinidae
Barracuda	Sphyraenidae	Goatfish	Mullidae	Snapper	Lutjanidae
Batfish	Ephippidae	Grouper	<i>Serranidae</i>	Spinecheek	Nemipteridae
Butterflyfish	<i>Chaetodontidae</i>	Jack	Carangidae	Squirrelfish	Holocentridae
Cardinalfish	Apogonidae	Lionfish	Scorpaenidae	Surgeonfish	<i>Acanthuridae</i>
Damselfish	Pomacentridae	Moorish idol	Zanclidae	Sweetlips	Haemulidae
Dart Goby	Microdesmidae	Moray Eel	Muraenidae	Triggerfish	Balistidae
Emperor	Lethrinidae	Parrotfish	<i>Scaridae</i>	Tuna	Scombridae
Flutemouth	Fistulariidae	Pufferfish	Tetraodontidae	Wrasse	Labridae

Table A1. All fish families recorded at Orimas Thila

RASFARI CORNER ZONE

Area type: Shallow Reef

Location: North Malé Atoll

Zone description

Rasfari corner is large shallow reef platform which extends to the north of Rasfari island. On the western edge of North Malé Atoll. The reef area is exposed to rough seas which has created a spur and groove formation across the platform. During the season

reef manta rays (*Manta alfredi*) are commonly observed. This has made it a popular day trip for tourists staying at resorts on North Malé. This may impact the manta ray's natural behaviour and a clear management plan with interaction guidelines is required.

Survey No.	Start		End	
	Latitude	Longitude	Latitude	Longitude
1	4.436472	73.35886	4.435472	73.35967
2	4.435722	73.35978	4.438667	73.36086
3	4.439028	73.36094	4.441722	73.35811

Table 1. Start and end GPS point Latitude and longitude of the roaming surveys. Note GPS points were not recorded for survey four

"Mean coral cover was 22.5% The area was predominantly rock cut into a spur and groove formation by wave action on the reef."

Coral reef benthos:

Mean coral cover was 22.5% The area was predominantly rock cut into a spur and groove formation by wave action on the reef. On the spurs (small ridges) hard coral development created structurally complex patches, however

much of the area was flat. Grooves between the ridges often contained sand. Macro algae cover was relatively high compared other sites across the country.

Survey No.	1	2	3	4
Depth	3	5	5	5
Complexity	2	2	3	1
Coralline algae	0	0	0	1
Hard Coral	15	45	20	10
Macro algae	10	8	5	5
Rock	70	32	59	70
Rubble	0	10	5	2
Sand	5	5	10	5
Soft Coral	0	0	1	2
Sponge	0	0	0	5
Turf algae	0	0	0	0
Others	0	0	0	0

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish community:

Values for the fish community were below the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 24 of which were recorded at Rasfari Corner. Low structural complexity means less favourable fish habitat in the area which may account for the lower fish family richness. Butterflyfish were observed within the first two minutes of all surveys. Groupers took greater than 10 minutes to observe on some surveys

suggesting a low abundance. The key herbivores, surgeonfish and parrotfish were also observed within the first two minutes of all surveys. Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Site	Total number of families	Mean number of families
Rasfari Corner combined	24	16.25

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. This area was one of only three where manta rays were observed. Though only one individual was observed on

surveys the area is well-known for high numbers during the right time of year. Development and enforcement of a management plan for this area is important given its proximity to many tourist resorts. Chevron butterflyfish

(*Chaetodon trifascialis*) is highly susceptible to the loss of coral, particularly Acroporids, and identifying areas where this species persists is important following the 2016 bleaching event.

Survey number	<i>Chaetodon trifascialis</i>	<i>Eretmochelys imbricata</i>	<i>Manta alfredi</i>
1			
2		1	1
3			
4	4		

Table 4. Number of IUCN Redlisted (endangered, vulnerable and least concern) species observed

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed either whilst snorkelling. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5

(highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Common Family	Scientific Family	Common Family	Scientific Family	Common Family	Scientific Family
Angelfish	Pomacanthidae	Grubfish	Pinguipedidae	Spinecheek	Nemipteridae
Boxfish	Ostraciidae	Hawkfish	Cirrhidae	Squirrelfish	Holocentridae
Butterflyfish	<i>Chaetodontidae</i>	Jack	Carangidae	Surgeonfish	<i>Acanthuridae</i>
Chain Moray	Ophichthidae	Manta ray	Myliobatidae	Sweetlips	Haemulidae
Damselfish	Pomacentridae	Moorish idol	Zanclidae	Tilefish	Malacanthidae
Emperor	Lethrinidae	Parrotfish	<i>Scaridae</i>	Triggerfish	Balistidae
Fusilier	Caesionidae	Pufferfish	Tetraodontidae	Wrasse	Labridae
Goatfish	Mullidae	Rabbitfish	Siganidae		
Grouper	<i>Serranidae</i>	Snapper	Lutjanidae		

Table A1. All fish families recorded at Rasfari Corner

THOONDI AREA ZONE

Area type: Fringing Reef

Location: Gnaviyani Atoll

Zone description

Thoondi Area is an area of fringing reef that extends from the northern point of the Fuvahmulah. The reef and the pebble beach are included in the Thoondi protected area. The reef has a shallow flat area extending from shore with steep slope. It is dominated by robust massive coral growth forms which are resilient to the waves in this exposed area. Fuvahmulah is

oceanic reef platform, a solitary island surrounded by fringing reef which is very different to the typical atoll formations found across the country.

This oceanic position means that migrating animals, including whale sharks, ocean sunfish (*Mola mola*) and oceanic manta rays (*Manta birostris*) are often observed.

Start		End	
Latitude	Longitude	Latitude	Longitude
-0.27705	73.42064	-0.27961	73.41244

Table 1. Start and end GPS point Latitude and longitude of the survey dive

"Mean coral cover was 53.3%. This was amongst the highest found anywhere in the Maldives during these surveys. The area was relatively unaffected by the 2016 bleaching event."

Coral reef benthos:

Mean coral cover was 53.3%. This was amongst the highest found anywhere in the Maldives during these surveys. The reef was predominantly massive corals with branching corals interspersed. This has created a structurally complex area with varying growth forms and a range of shelter types. The area

was relatively unaffected by the 2016 bleaching event. The area had one of the highest covers of macro algae. This may outcompete coral for free space on the reef should a disturbance or future degradation cause a decline in coral cover.

Survey No.	1	2	3	4	5	6
Depth	10	10	15	15	10	10
Complexity	3	4	3	4	3	3
Coralline algae	3	12	16	0	0	0
Hard Coral	30	50	55	65	65	55
Macro algae	6	18	19	4	0	20
Rock	40	15	9	20	10	3
Rubble	12	4	0	3	0	0
Sand	3	1	1	4	0	0
Soft Coral	0	0	0	1	0	0
Sponge	5	0	0	2	2	2
Turf algae	1	0	0	0	20	0
Others	0	0	0	1	3	0

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish community:

Values for the fish community matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 33 of which were found at Thoondi Area. Groupers and butterflyfish are indicators of unfished and healthy reef areas and were observed within the first two minutes of all surveys. The key

herbivores, surgeonfish and parrotfish were also observed within the first two minutes of all surveys. Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not typically targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Total number of families	Mean number of families
31	23.5

Table 3. Number of fish families observed on each survey and the total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. A very high number of the

critically endangered hawksbill turtle (*Eretmochelys imbricata*) were recorded at the site.

Survey number	<i>Cheilinus undulatus</i>	<i>Eretmochelys imbricata</i>	<i>Triaenodon obesus</i>
1		1	1
2		1	
3		2	
4		1	
5	1		
6		1	
7		1	

Table 4. Location and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed during rapid surveys.

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated

on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Common Family	Scientific Family	Common Family	Scientific Family	Common Family	Scientific Family
Angelfish	Pomacanthidae	Groupers	<i>Serranidae</i>	Rudderfish	Kyphosidae
Barracuda	Sphyraenidae	Grubfish	Pinguipedidae	Snapper	Lutjanidae
Boxfish	Ostraciidae	Hawkfish	Cirrhitidae	Squirrelfish	Holocentridae
Bullseye	Pempheridae	Jack	Carangidae	Surgeonfish	<i>Acanthuridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Moorish idol	Zanclidae	Sweetlips	Haemulidae
Damselfish	Pomacentridae	Moray Eel	Muraenidae	Triggerfish	Balistidae
Emperor	Lethrinidae	Parrotfish	<i>Scaridae</i>	Trumpetfish	Aulostomidae
Filefish	Monacanthidae	Porcupinefish	Diodontidae	Tuna	Scombridae
Flutemouth	Fistulariidae	Pufferfish	Tetraodontidae	Wrasse	Labridae
Fusilier	Caesionidae	Rabbitfish	Siganidae		
Goatfish	Mullidae	Requiem Shark	Carcharhinidae		

Table A1. All fish families recorded at Thoondi Area

THRESHER POINT ZONE

Area type: Thila

Location: Gnaviyani Atoll

Zone description

Thresher Point is a section on a rocky limestone plateau that extends from the south of Fuvahmulah. The top of the plateau is relatively flat with large boulders creating some structure. The sides of the plateau are steep, have several large ledges running along and descend very quickly to deep water. Two species of thresher sharks, bigeye (*Alopias superciliosus*) and common (*Alopias vulpinus*) thresher sharks, are frequently observed in

the area and there is believed to be a cleaning station nearby. Fuvahmulah is oceanic reef platform, a solitary island surrounded by fringing reef which is very different to the typical atoll formations found across the country. This oceanic position means that migrating animals, including whale sharks, ocean sunfish (*Mola mola*) and oceanic manta rays (*Manta birostris*) are often observed.

Start		End	
Latitude	Longitude	Latitude	Longitude
-0.322472	73.44764	-0.32942	73.44705

Table 1. Start and end GPS point Latitude and longitude of the survey dive

"Two species of thresher sharks, bigeye (*Alopias superciliosus*) and common (*Alopias vulpinus*) thresher sharks, are frequently observed in the area."

Coral reef benthos:

Mean coral cover was 16.25%. The area was dominated by bare rock substrate. The exposed nature of the area means there is likely to be high wave action preventing significant coral

development. The ledges running along the walls of the rocky platform created some structural complexity, however much of the top and wall areas were flat.

Survey No.	1	2	3	4
Depth	30	13	25	20
Complexity	1	2	2	2
Coralline algae	2	5	0	0
Hard Coral	20	15	15	15
Macro algae	0	0	0	0
Rock	65	70	75	70
Rubble	0	0	0	0
Sand	5	5	0	10
Soft Coral	0	0	0	0
Sponge	5	5	5	5
Turf algae	0	0	0	0
Others	3	0	5	0

Table 2. Depth, complexity and percent cover of substrate categories estimated during roaming surveys. See methods section for description of approach used

Fish community:

Values for the fish community were below the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 22 of which were found at Thresher Point. Lower numbers are

may be due to the different environment this site presents when compared to typical reef areas. Though it was not possible to survey to the high level of detail required to state definitively, it is likely that the high currents and exposed, oceanic environment created a habitat for a different range of species compared to most sites survey.

Total number of families	Mean number of families
22	14.5

Table 3. Total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Endangered species of sharks and

rays including whale sharks (*Rhincodon typus*), big eye and common thresher sharks, tiger sharks (*Galeocerdo cuvier*) and oceanic manta rays (*Manta*

birostris) have been observed here, however these surveys recorded only three white-tip reef sharks (*Triaenodon obesus*).

Survey No.	<i>Triaenodon obesus</i>
1	2
2	1

Table 4. Location and number of IUCN Redlisted (endangered, vulnerable and least concern) species observed during rapid surveys.

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst SCUBA diving. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated

on a scale from 0 (completely flat) to 5 (highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Common Family	Scientific Family	Common Family	Scientific Family	Common Family	Scientific Family
Angelfish	<i>Pomacanthidae</i>	Parrotfish	<i>Scaridae</i>	Wrasse	<i>Labridae</i>
Boxfish	<i>Ostraciidae</i>	Porcupinefish	<i>Diodontidae</i>		
Butterflyfish	<i>Chaetodontidae</i>	Pufferfish	<i>Tetraodontidae</i>		
Damselfish	<i>Pomacentridae</i>	Requiem Shark	<i>Carcharhinidae</i>		
Emperor	<i>Lethrinidae</i>	Snapper	<i>Lutjanidae</i>		
Filefish	<i>Monacanthidae</i>	Squirrelfish	<i>Holocentridae</i>		
Fusilier	<i>Caesionidae</i>	Surgeonfish	<i>Acanthuridae</i>		
Goatfish	<i>Mullidae</i>	Sweetlips	<i>Haemulidae</i>		
Grouper	<i>Serranidae</i>	Tilefish	<i>Malacanthidae</i>		
Jack	<i>Carangidae</i>	Triggerfish	<i>Balistidae</i>		
Moorish idol	<i>Zanclidae</i>	Tuna	<i>Scombridae</i>		

Table A1 All fish families recorded at Thresher Point

TURTLE POINT ZONE

Area type: Channel

Location: South Malé Atoll

Zone description

Turtle Point is a submerged reef area inside the southern section of South Malé atoll. The reef is a complex structure approximately 5 – 20 m deep. Though it has been created by coral growth it is now dominated by algae

and zoanths (*Palthoa spp.*). The area is known locally for an abundance of hawksbill turtles (*Eretmochelys imbricata*) which feed on the zoanths (León and Bjorndal 2002). This has made it a popular day trip for tourists.

Survey No.	Start		End	
	Latitude	Longitude	Latitude	Longitude
1	3.849972	73.41858	3.846667	73.41364
2	3.846667	73.41364	3.846611	73.41247

Table 1. Start and end GPS point Latitude and longitude of the survey dive

A very high number of the critically endangered hawksbill turtle were recorded at the site.

Coral reef benthos:

Mean hard coral cover was 5% which was amongst the lowest of all sites surveyed. The reef area was predominantly covered in zoanths (genus: Palythoa) which were categorised as other in surveys. At no other reef area did zoanths form greater than 5% of the substrate cover, however here mean cover was

32.75%. The complex reef structure remained intact underneath the zoanths cover which meant structural complexity was high. Areas of the reef also had high turf and macro algae cover. The dominance of these substrates means it is unlikely the reef will return to a coral dominated habitat in the short-term.

Survey No.	1	2	3	4
Depth	3	3	6	8
Complexity	2	2	4	4
Coralline algae	0	0	0	0
Hard Coral	5	2	8	5
Macro algae	0	0	18	2
Rock	30	30	20	17
Rubble	23	25	10	8
Sand	0	1	2	5
Soft Coral	0	0	0	5
Sponge	0	0	0	0
Turf algae	2	1	18	33
Others	40	41	25	25

Table 1. Start and end GPS point Latitude and longitude of the survey dive

Fish community:

Values for the fish community were below the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). 51 reef associated fish families were observed across the country, 22 of which were recorded at Turtle Point. Lower numbers are may

be due to the different environment this site presents when compared to typical reef areas. Though it was not possible to survey to the high level of detail required to state definitively, it is likely that the cover of zoanths and algae present at this site will have created a different species composition at the site compared to other areas surveyed.

Site	Total number of families	Mean number of families
Turtle Point combined	22	15

Table 3. Total and mean number observed across all surveys

Endangered species

These species are under threat and identifying and protecting habitat where they are found is key to their survival. A very high number of the critically endangered hawksbill turtle were

recorded at the site. It is likely that the site is an important feeding ground for this turtle species due to the high cover of zoanthids (León and Bjørndal 2002).

Survey No.	<i>Eretmochelys imbricata</i>	<i>Plectropomus laevis</i>
1	3	1
2	4	
3	2	1
4	2	

Table 4. IUCN Red Listed species observed on each survey

METHODS

Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions. Roaming surveys were performed whilst snorkelling. Each survey lasted 15 minutes with survey location (GPS of start/finish or dive entry/exit), and average depth recorded. The percent cover was visually estimated for eight

different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percent cover of coral, rock and turf algae (the underlying structure) was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, finger and others. The structural complexity of the reef was estimated on a scale from 0 (completely flat) to 5

(highly complex). Roaming fish surveys were conducted at the same time and over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were

ANNEX

Common Family	Scientific Family	Common Family	Scientific Family	Common Family	Scientific Family
Surgeonfish	<i>Acanthuridae</i>	Rudderfish	<i>Kyphosidae</i>	Damselfish	<i>Pomacentridae</i>
Trumpetfish	<i>Aulostomidae</i>	Wrasse	<i>Labridae</i>	Parrotfish	<i>Scaridae</i>
Triggerfish	<i>Balistidae</i>	Emperor	<i>Lethrinidae</i>	Grouper	<i>Serranidae</i>
Fusilier	<i>Caesionidae</i>	Snapper	<i>Lutjanidae</i>	Rabbitfish	<i>Siganidae</i>
Jack	<i>Carangidae</i>	Filefish	<i>Monacanthidae</i>	Pufferfish	<i>Tetraodontidae</i>
Butterflyfish	<i>Chaetodontidae</i>	Goatfish	<i>Mullidae</i>	Moorish idol	<i>Zanclidae</i>
Batfish	<i>Ephippidae</i>	Moray Eel	<i>Muraenidae</i>		
Squirrelfish	<i>Holocentridae</i>	Angelfish	<i>Pomacanthidae</i>		

Table A1. All fish families recorded at Turtle Point

RESORT REEFS

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Aerial image of the zone to be provided by Basheer

ANGSANA IHURU

Area type: Fringing reef

Location: North Malé Atoll

Coral cover: 34%

This value is in line with historic levels of coral cover nationwide (Pisapia et al. 2016). This was noticeably higher than the national average of 19%, which was impacted by the severe 2016 coral bleaching event caused by high ocean temperatures. Corals around Angsana Ihuru have survived better than other reefs around the country. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009). Examples of this, such as crown-of-thorns starfish removal and coral replanting are undertaken around Angsana Ihuru.

Fish diversity:

Fish family 15, Grouper species: 4, Butterflyfish species 4

These values matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 34 of which were found on Ihuru. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Invertebrates (7), Groupers (2), Sharks (8), Turtles (2)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives, however their populations are at risk from a decline in available nesting sites and the declining health of coral reefs.

Grouper Biomass: 865 g/100 m²

This is above the country average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of

protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover: 4%

This value is significantly lower than the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa spp.* which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits: 7/m²

This is in-line with the national average of 7/m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 3.2

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact."

Herbivore Density: 46/100 m²

This is significantly higher than the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 245 g/100 m²

This the same as the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Angsana Ihuru

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Goatfish	<i>Mullidae</i>	Requiem Shark	<i>Carcharhinidae</i>
Barracuda	<i>Sphyraenidae</i>	Hawkfish	<i>Cirrhitidae</i>	Rudderfish	<i>Kyphosidae</i>
Batfish	<i>Ephippidae</i>	Grouper	<i>Serranidae</i>	Snapper	<i>Lutjanidae</i>
Bigeye	<i>Priacanthidae</i>	Grubfish	<i>Pinguipedidae</i>	Squirrelfish	<i>Holocentridae</i>
Boxfish	<i>Ostraciidae</i>	Jack	<i>Carangidae</i>	Surgeonfish	<i>Acanthuridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Lizardfish	<i>Synodontidae</i>	Sweetlips	<i>Haemulidae</i>
Cardinalfish	<i>Apogonidae</i>	Moorish idol	<i>Zanclidae</i>	Triggerfish	<i>Balistidae</i>
Damselfish	<i>Pomacentridae</i>	Moray Eel	<i>Muraenidae</i>	Trumpetfish	<i>Aulostomidae</i>
Eagle ray	<i>Myliobatidae</i>	Parrotfish	<i>Scaridae</i>	Tuna	<i>Scombridae</i>
Emperor	<i>Lethrinidae</i>	Porcupinefish	<i>Diodontidae</i>	Wrasse	<i>Labridae</i>
Flutemouth	<i>Fistulariidae</i>	Pufferfish	<i>Tetraodontidae</i>		
Fusilier	<i>Caesionidae</i>	Rabbitfish	<i>Siganidae</i>		

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Angsana Ihuru

Common name	Scientific name	Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>	Red-flushed grouper	<i>Aethaloperca rogaa</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>	Snout-spots grouper	<i>Epinephelus polyphkadion</i>
Honeycomb grouper	<i>Epinephelus merra</i>	Squaretail coral grouper	<i>Plectropomus areolatus</i>
Lunar-tailed grouper	<i>Variola louti</i>	Vermilion rock cod	<i>Cephalopholis miniata</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>	White-lined grouper	<i>Anyperodon leucogrammicus</i>
Peacock rock cod	<i>Cephalopholis argus</i>		

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Angsana Ihuru

Common name	Scientific name	Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>	Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>	Threadfin butterflyfish	<i>Chaetodon auriga</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>	Triangular butterflyfish	<i>Chaetodon triangulum</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>	Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Phantom bannerfish	<i>Heniochus pleurotaenia</i>	Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>		

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Angsana Ihuru

Endangered Species observed at Angsana Ihuru

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Blacktip reef shark	<i>Carcharhinus melanopterus</i>
Giant clam	<i>Tridacna sp.</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Squartail coral grouper	<i>Plectropomus areolatus</i>
Whitetip reef shark	<i>Triaenodon obesus</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 7) around Angsana Ihuru

GPS coordinates of transect survey sites

Transect survey site	Latitude	Longitude
1	4.30544	73.41619
2	4.30739	73.41692
3	4.30725	73.4135

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Complexity	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	3.0	17.9	7.4	10.7	28.6	14.4	9.4	4.0	2.3	3.8
2	3.0	28.2	5.7	12.2	34.4	9.2	1.6	2.7	2.3	2.0
3	3.7	15.6	4.6	7.7	39.0	16.4	9.1	3.0	0.0	3.6

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	6.4	3.0
2	3.1	3.0
3	3.9	3.7

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	23	14.2
2	22	13.5
3	27	18.7

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Grouper and butterflyfish species at transect survey sites

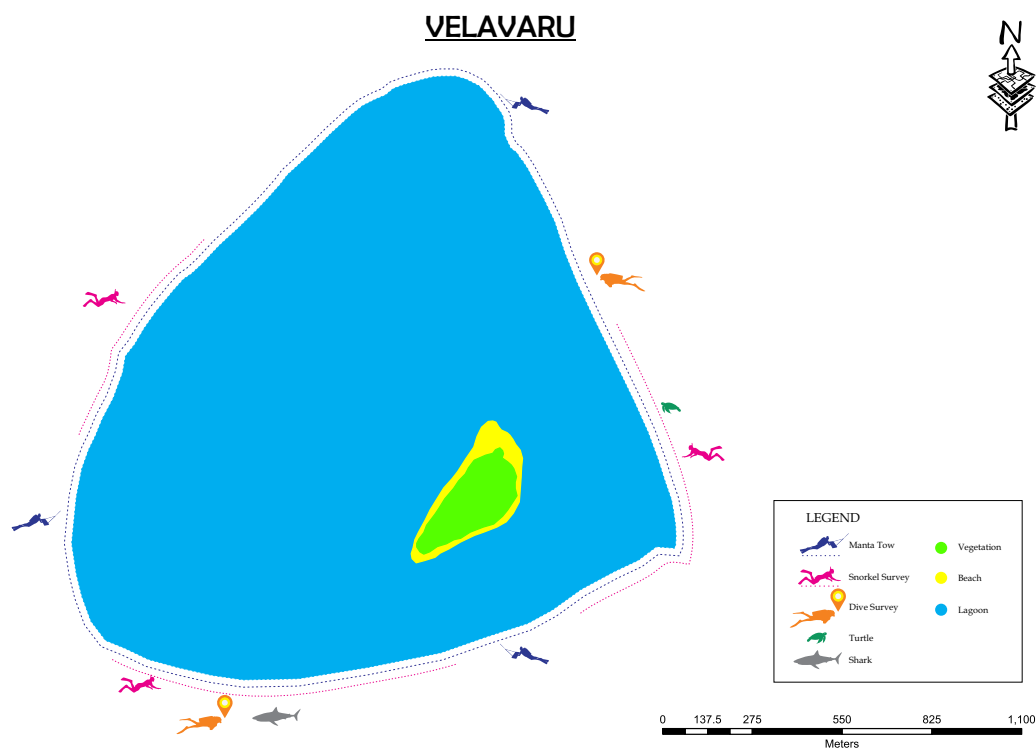
Transect survey site	Total grouper species observed	Mean grouper species observed	Mean grouper density/100m ²	Total butterflyfish species observed	Mean butterflyfish species observed	Mean butterflyfish density/100m ²
1	8	3.3	4.2	9	3.7	6.3
2	7	3.8	3.3	6	3.0	5.3
3	7	3.7	3.6	7	3.7	6.4

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100m ²	Mean surgeonfish density/100m ²
1	21.0	25.3
2	15.7	16.5
3	24.4	13.2

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



ANGSANA VELAVARU

Area type: Resort island

Location: Dhaalu Atoll

Introduction

Angsana Velavaru is on the edge of Dhaalu atoll and therefore the reef encompasses outer and inner atoll areas, as well as two channels connecting the atoll lagoon to the open ocean. This variety of reef environment increases the diversity of marine species which may utilise the area. Oceanic silky sharks are often seen in the northern channel. Inside the reef is a large sandy lagoon area. This acts as a nursery area for juvenile blacktip reef sharks and a foraging habitat for many ray species. There is an existing monitoring and management programme for the reef that includes regular surveys, the removal of corallivorous starfish and a coral nursery.

Coral cover: 24%

This value was higher than the national average of 19% observed on these surveys. However, both values are below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Corals around Angsana Velavaru have survived better than other reefs around the country. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009). Examples of this, such as crown-of-thorns starfish removal and coral replanting are undertaken around Angsana Velavaru.

Fish diversity:

Fish family: 17, Grouper species: 4, Butterflyfish species: 7

These values were above the national averages for fish diversity. A diverse fish

community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 38 of which were found on Velavaru. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (30), Groupers (3), Sharks (4), Turtles (1)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Giant clams were the most common endangered invertebrate.

Grouper Biomass: 430 g/100 m²

This is below the country average of 740 g/100 m². Groupers are a key target of coral reef fisheries and a higher biomass value indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover:

This value is lower than the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions

Coral Recruits: 8/ m²

This is slightly above the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al.

2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 3.1

This value indicates an intermediate level of reef complexity and is the average for the country. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 33/100 m²

This is in-line with the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 149 g/100 m²

This slightly below the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will

likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Angsana Velavaru

surveys (n = 24) around Angsana Velavaru

Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Dart Goby	<i>Microdesmidae</i>
Barracuda	<i>Sphyaenidae</i>	Eagle ray	<i>Myliobatidae</i>
Batfish	<i>Ehippiidae</i>	Emperor	<i>Lethrinidae</i>
Bigeye	<i>Priacanthidae</i>	Filefish	<i>Monacanthidae</i>
Boxfish	<i>Ostraciidae</i>	Flutemouth	<i>Fistulariidae</i>
Butterflyfish	<i>Chaetodontidae</i>	Fusilier	<i>Caesionidae</i>
Cardinalfish	<i>Apogonidae</i>	Goatfish	<i>Mullidae</i>
Damselfish	<i>Pomacentridae</i>		

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Angsana Velavaru

Common name	Scientific name
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>
Peacock rock cod	<i>Cephalopholis argus</i>
Red-flushed grouper	<i>Aethaloperca rogaa</i>
Vermilion rock cod	<i>Cephalopholis miniata</i>
White-lined grouper	<i>Anyperodon leucogrammicus</i>

Table A2. All grouper species recorded across detailed underwater visual census (n = 12) around Angsana Velavaru

Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>
Phantom bannerfish	<i>Heniochus pleurotaenia</i>
Pig-face butterflyfish	<i>Chaetodon oxycephalus</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Triangular butterflyfish	<i>Chaetodon triangulum</i>
Very long-nose butterflyfish	<i>Forcipiger longirostris</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 12) around Angsana Velavaru

Endangered Species observed at Angsana Velavaru

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Blacktip reef shark	<i>Carcharhinus melanopterus</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Giant clam	<i>Tridacna sp.</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Napoleon wrasse	<i>Cheilinus undulatus</i>
Squaretail coral grouper	<i>Plectropomus areolatus</i>
Whitetip reef shark	<i>Triaenodon obesus</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 24) around Angsana Velavaru

GPS coordinates of transect survey sites

Transect survey site	Latitude	Longitude
1	2.9858	73.0187
2	2.9748	73.0086

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	15.1	0.6	0.6	40.3	25.1	2.8	9.0	3.4	2.0
2	32.8	4.8	3.2	37.3	5.8	6.0	4.2	2.3	2.0

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	9.7	3.0
2	6.8	3.0

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	30	17.0
2	30	17.3

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Groupers and butterflyfish species at transect survey sites

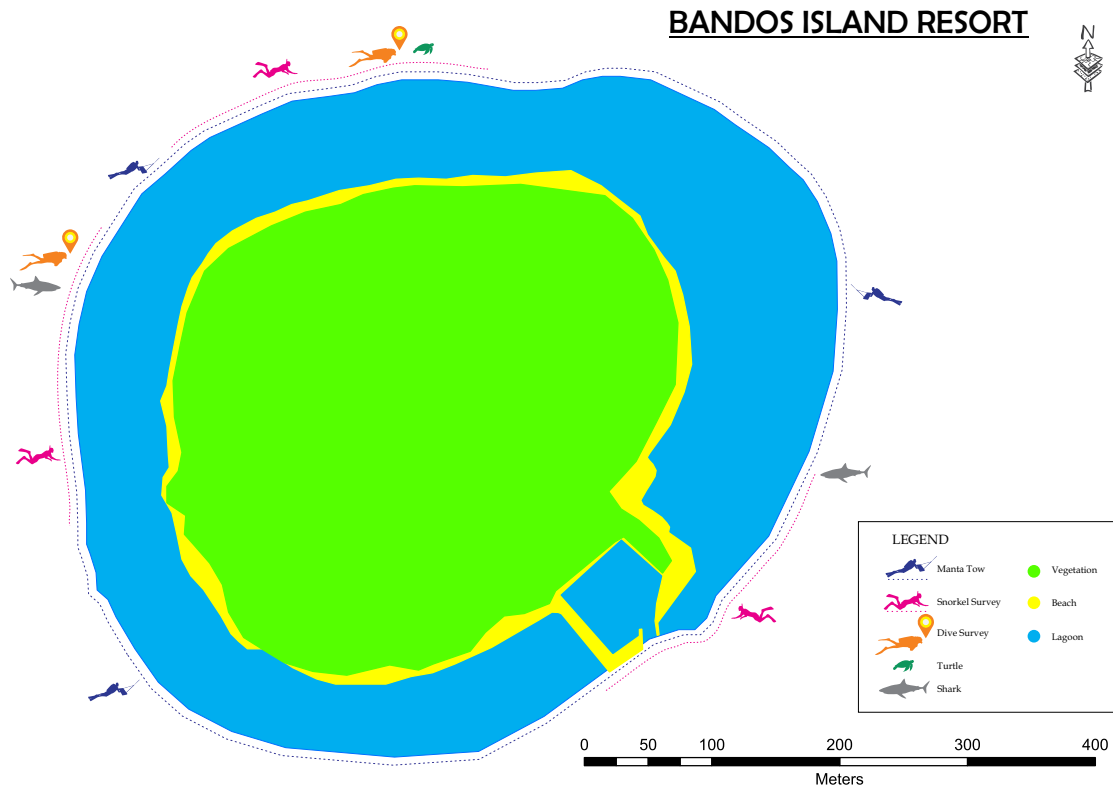
Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	5	3.3	5.3	9	5.5	17.2
2	6	5.2	7.8	11	7.2	15.7

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	17.4	19.9
2	10.3	9.3

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



BANDOS ISLAND RESORT AND SPA

Area type: Resort Island

Location: North Malé Atoll

Introduction

Bandos has a diverse reef environment with slope, wall and pinnacle habitats. Bandos rock is a popular SCUBA dive location and management would benefit this key area. The lagoon has a high number of juvenile blacktip reef sharks, and pregnant females are often observed on the outer reef. Bandos has been part of the government's permanent monitoring network since 1998. Its reefs are used to understand factors affecting reef health across the region. A separate study has identified the presence of vulnerable hard coral species.

Coral cover: 10%

This value is below the national average of 19% found across surveys. However, both values are below historic levels of coral cover

nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family 17, Grouper species: 6, Butterflyfish species 4

These values were above the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 33 of which were found on Bandos. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing

for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (8), Groupers (1), Sharks (7), Turtles (2)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives, however their populations are at risk from a decline in available nesting sites and the declining health of coral reefs.

Grouper Biomass: 1055 g/100 m²

This is above the country average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates

low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover: 22%

This value is higher than the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions

Coral Recruits: 6/ m²

This is close to the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity 2.8

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 32/100 m²

This is in-line with the national average of 35/100 m². Herbivores are a functionally important group on coral reefs They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 215 g/100 m²

This the same as the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape

every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat were counted and identified to genus where possible. Structural complexity

was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Bandos

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Fusilier	<i>Caesionidae</i>	Requiem Shark	<i>Carcharhinidae</i>
Batfish	<i>Ephippidae</i>	Goatfish	<i>Mullidae</i>	Rudderfish	<i>Kyphosidae</i>
Bigeye	<i>Priacanthidae</i>	Grouper	<i>Serranidae</i>	Scorpionfish	<i>Scorpaenidae</i>
Boxfish	<i>Ostraciidae</i>	Jack	<i>Carangidae</i>	Snapper	<i>Lutjanidae</i>
Butterflyfish	<i>Chaetodontidae</i>	Lionfish	<i>Scorpaenidae</i>	Squirrelfish	<i>Holocentridae</i>
Cardinalfish	<i>Apogonidae</i>	Moorish idol	<i>Zanclidae</i>	Surgeonfish	<i>Acanthuridae</i>
Damselfish	<i>Pomacentridae</i>	Moray Eel	<i>Muraenidae</i>	Sweetlips	<i>Haemulidae</i>
Dart Goby	<i>Microdesmidae</i>	Parrotfish	<i>Scaridae</i>	Triggerfish	<i>Balistidae</i>
Emperor	<i>Lethrinidae</i>	Porcupinefish	<i>Diodontidae</i>	Trumpetfish	<i>Aulostomidae</i>
Filefish	<i>Monacanthidae</i>	Pufferfish	<i>Tetraodontidae</i>	Tuna	<i>Scombridae</i>
Flutemouth	<i>Fistulariidae</i>	Rabbitfish	<i>Siganidae</i>	Wrasse	<i>Labridae</i>

Table A1. All fish families recorded across rapid surveys (n = 14) around Bandos

Grouper and butterflyfish species observed at Bandos

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>
Lunar-tailed grouper	<i>Variola louti</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Peacock rock cod	<i>Cephalopholis argus</i>
Red-flushed grouper	<i>Aethaloperca rogaa</i>
Squairetail coral grouper	<i>Plectropomus areolatus</i>
Vermillion rock cod	<i>Cephalopholis miniata</i>
White-lined grouper	<i>Anyperodon leucogrammicus</i>

Table A2. All grouper species recorded across detailed underwater visual census (n = 16) around Bandos

Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>
Phantom bannerfish	<i>Heniochus pleurotaenia</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Triangular butterflyfish	<i>Chaetodon triangulum</i>
Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 16) around Bandos

Endangered Species observed at Bandos

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Blacktip reef shark	<i>Carcharhinus melanopterus</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 14) around Bandos

GPS coordinates of transect survey sites

Transect survey site	Latitude	Longitude
1	4.27256	73.49006
2	4.27081	73.48867

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	4.5	9.0	12.8	37.8	22.0	8.8	2.0	0.0	2.7
2	5.4	6.9	11.1	31.4	25.3	12.8	2.0	2.1	3.0

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	4.6	2.8
2	4.1	2.3

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	26	18.8
2	30	17.2

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Grouper and butterflyfish species at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	7	6.0	7.1	8	4.0	4.6
2	9	6.2	6.4	8	2.8	4.9

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	12.3	15.2
2	12.2	13.3

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



Aerial image of the zone to be provided by Basheer

BANYAN TREE VABBINFARU

Zone information:

Area type: Resort Island

Location: North Malé Atoll

Introduction

Despite significant coral loss during previous bleaching events the reef around Banyan Tree has repeatedly bounced back. This resilience makes the reef very important to the local marine communities. The reef is one of the best understood in the area thanks to a monitoring programme and several scientific studies. Monitoring and management of the reef includes regular surveys, the removal of corallivorous starfish and a coral nursery. The island has a large sandy lagoon that is an important foraging ground for stingrays. The reef area to north has a high number of reef sharks; over 20 blacktip and whitetip reef sharks were observed on a single 15-minute swim.

Coral cover: 16%

This value is slightly below the national average of 19% found across surveys. Both values are below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009). Examples of this, such as crown-of-thorns starfish removal and coral replanting are undertaken around Banyan Tree Vabbinfaru

Fish diversity:

**Average number of families: 20,
Grouper species: 6, Butterflyfish
species: 4**

These values were above the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation

(Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 30 of which were found on Banyan Tree. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

**Values: Invertebrates (3), Groupers
(3), Sharks (33), Turtles (3)**

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives, however their populations are at risk from a decline in available nesting sites and the declining health of coral reefs.

Grouper Biomass: 770 g/100 m²

This is above the country average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover: 4%

This value is significantly lower than the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits: 8/ m²

This is slightly above the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation

of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 3.4

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 58/100 m²

This is significantly higher than the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 255 g/100 m²

This slightly above the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Banyan Tree

surveys (n = 8) around Banyan Tree

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Fusilier	<i>Caesionidae</i>	Rudderfish	<i>Kyphosidae</i>
Barracuda	<i>Sphyrnidae</i>	Goatfish	<i>Mullidae</i>	Scorpionfish	<i>Scorpaenidae</i>
Batfish	<i>Ephippidae</i>	Grouper	<i>Serranidae</i>	Snapper	<i>Lutjanidae</i>
Bigeye	<i>Priacanthidae</i>	Jack	<i>Carangidae</i>	Squirrelfish	<i>Holocentridae</i>
Boxfish	<i>Ostraciidae</i>	Moorish idol	<i>Zanclidae</i>	Surgeonfish	<i>Acanthuridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Parrotfish	<i>Scaridae</i>	Sweetlips	<i>Haemulidae</i>
Damselfish	<i>Pomacentridae</i>	Porcupinefish	<i>Diodontidae</i>	Triggerfish	<i>Balistidae</i>
Emperor	<i>Lethrinidae</i>	Pufferfish	<i>Tetraodontidae</i>	Trumpetfish	<i>Aulostomidae</i>
Filefish	<i>Monacanthidae</i>	Rabbitfish	<i>Siganidae</i>	Tuna	<i>Scombridae</i>
Flutemouth	<i>Fistulariidae</i>	Requiem Shark	<i>Carcharhinidae</i>	Wrasse	<i>Labridae</i>

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Banyan Tree

Common name	Scientific name	Common name	Scientific name
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>	Marble grouper	<i>Epinephelus fuscoguttatus</i>
Black-saddle coral grouper	<i>Plectropomus laevis</i>	Peacock rock cod	<i>Cephalopholis argus</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>	Red-flushed grouper	<i>Aethaloperca rogaa</i>
Honeycomb grouper	<i>Epinephelus merra</i>	Squaretail coral grouper	<i>Plectropomus areolatus</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>	Vermilion rock cod	<i>Cephalopholis miniata</i>
Lunar-tailed grouper	<i>Variola louti</i>	White-lined grouper	<i>Anyperodon leucogrammicus</i>

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Banyan Tree

Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>
Lined butterflyfish	<i>Chaetodon lineolatus</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>
Phantom bannerfish	<i>Heniochus pleurotaenia</i>
Pig-face butterflyfish	<i>Chaetodon oxycephalus</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Triangular butterflyfish	<i>Chaetodon triangulum</i>
Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Banyan Tree

Endangered Species observed at Banyan Tree

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Blacktip reef shark	<i>Carcharhinus melanopterus</i>
Squaretail coral grouper	<i>Plectropomus areolatus</i>
Tawny nurse shark	<i>Nebrius ferrugineus</i>
Whitetip reef shark	<i>Triaenodon obesus</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 8) around Banyan Tree

GPS coordinates of transect survey sites

Transect survey site	Latitude	Longitude
1	4.31214	73.42411
2	4.30886	73.42600
3	4.30786	73.42206

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	4.7	5.8	9.3	54.3	15.7	5.0	2.0	0.0	2.3
2	11.1	2.2	15.3	40.8	13.3	8.9	2.5	3.4	2.3
3	14.0	6.8	13.5	29.0	20.8	10.5	2.0	0.0	3.3

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	3.4	3.0
2	4.7	3.0
3	3.5	3.0

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	33	21.2
2	29	19.7
3	32	18.5

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Groupers and butterflyfish species at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	8	5.3	6.0	9	3.5	9.0
2	9	6.0	7.2	9	3.7	9.6
3	8	5.3	6.9	9	5.0	10.3

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	23.2	12.2
2	41.8	16.7
3	32.2	18.8

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



Aerial image of the zone to be provided by Basheer

HURAWALHI ISLAND RESORT

Area type: Resort House Reef

Location: Lhaviyani Atoll

Introduction

Hurawalhi is a narrow island positioned in the middle of two channels, which is rare for resort islands in the country. This location means protection would cover the special characteristics relating to atoll channels. At the tip of the island large schools of fish are ever-present and silvertip sharks are often observed, while the sheltered inner atoll edge has significant reef development. Manta rays are seasonal visitors, regularly appearing in January. Very high numbers of vulnerable giant clams were observed on the reefs.

Coral cover: 11%

This value is below the national average of 19% found across surveys. C Both values are below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral

bleaching event which was caused by high ocean temperatures. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family 19, Grouper species: 3, Butterflyfish species 4

These values matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 33 of which were found on Hurawalhi. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (83), Groupers (7), Turtles (1)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives, however their populations are at risk from a decline in available nesting sites and the declining health of coral reefs. The reef around Hurawalhi had exceptionally high numbers of giant clams.

Grouper Biomass: 576 g/100 m²

This is slightly below the country average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007)

as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover: 13%

This value is in-line with the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits: 8/ m²

This is slightly above the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 2.3

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 20/100 m²

This is below the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 200 g/100 m²

This is slightly below the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Hurawalhi

surveys (n = 15) around Hurawalhi

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Goatfish	<i>Mullidae</i>	Rudderfish	<i>Kyphosidae</i>
Barracuda	<i>Sphyaenidae</i>	Grouper	<i>Serranidae</i>	Snapper	<i>Lutjanidae</i>
Bigeye	<i>Priacanthidae</i>	Grubfish	<i>Pinguipedidae</i>	Spinecheek	<i>Nemipteridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Hawkfish	<i>Cirrhidae</i>	Squirrelfish	<i>Holocentridae</i>
Cardinalfish	<i>Apogonidae</i>	Jack	<i>Carangidae</i>	Surgeonfish	<i>Acanthuridae</i>
Damselfish	<i>Pomacentridae</i>	Lionfish	<i>Scorpaenidae</i>	Sweetlips	<i>Haemulidae</i>
Dart Goby	<i>Microdesmidae</i>	Mobula Ray	<i>Mobulidae</i>	Tilefish	<i>Malacanthidae</i>
Emperor	<i>Lethrinidae</i>	Moorish idol	<i>Zanclidae</i>	Triggerfish	<i>Balistidae</i>
Filefish	<i>Monacanthidae</i>	Parrotfish	<i>Scaridae</i>	Trumpetfish	<i>Aulostomidae</i>
Flutemouth	<i>Fistulariidae</i>	Pufferfish	<i>Tetraodontidae</i>	Tuna	<i>Scombridae</i>
Fusilier	<i>Caesionidae</i>	Rabbitfish	<i>Siganidae</i>	Wrasse	<i>Labridae</i>

Table A1. All families recorded across rapid

Grouper and butterflyfish species observed at Hurawalhi

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>
Peacock rock cod	<i>Cephalopholis argus</i>
Red-flushed grouper	<i>Aethaloperca rogae</i>
Snubnose grouper	<i>Epinephelus macrospilos</i>
Tomato rock cod	<i>Cephalopholis sonnerati</i>
Vermilion rock cod	<i>Cephalopholis miniata</i>

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Hurawalhi

Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>
Head-band butterflyfish	<i>Chaetodon collare</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>
Madagascar butterflyfish	<i>Chaetodon madagaskariensis</i>
Phantom bannerfish	<i>Heniochus pleurotaenia</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Threadfin butterflyfish	<i>Chaetodon auriga</i>
Triangular butterflyfish	<i>Chaetodon triangulum</i>
Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Hurawalhi

Endangered Species observed at Hurawalhi

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Napoleon wrasse	<i>Cheilinus undulatus</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 15) around Hurawalhi

GPS coordinates of transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	17.7	2.7	6.7	38.0	12.9	17.5	2.0	0.0	1.8
2	27.5	7.7	2.8	35.8	1.8	12.5	3.2	2.8	6.4

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Latitude	Longitude
1	5.51922	73.44511
2	5.51753	73.43994

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	7.8	2.8
2	7.3	2.2

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	33	20.2
2	27	18.3

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Grouper and butterflyfish species at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	5	2.3	3.2	8	3.3	5.1
2	5	3.7	5.1	10	4.2	7.9

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	6.5	9.0
2	2.3	6.0

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



Aerial image of the zone to be provided by Basheer

KURAMATHI ISLAND RESORT

Area type: Resort House Reef

Location: Rasdhoo Atoll

Introduction

Kuramathi island has a long outer atoll reef edge. Manta rays are occasionally observed passing the reef in the mornings. There was high number of large and vulnerable groupers recorded across the reef. Reef sharks are observed in high numbers along the reef edge and juveniles are found in the lagoon area, and by the sandbank to the west. False killer whales pass near to the island annually. There is management and education programme at the resort, which helps protect the reef and teaches visitors about the importance of the reef environment.

Coral cover: 25%

This value was higher than the national average of 19% observed on these surveys. However, both values are

below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Corals around Kuramathi have survived better than other reefs around the country. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family 18, Grouper species: 5, Butterflyfish species 6

These values were above the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 29 of which were found on Kuramathi. The relationship between the fish community and the

coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (4), Groupers (14), Sharks (5), Turtles (1)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. These groupers were present high numbers around Kuramathi.

Grouper Biomass: 812 g/100 m²

This is significantly above the country average of 615 g/100 m². G Groupers are a key target of coral reef fisheries

and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover: 2%

This value is significantly below the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa spp.* which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits 15/ m²

This is much higher than the national average of 7/ m². This value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is

susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 2.8

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 27/100 m²

This is below the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 520 g/100 m²

This significantly higher than the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Kuramathi

surveys (n = 8) around Kuramathi

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Jack	<i>Carangidae</i>	Spinecheek	<i>Nemipteridae</i>
Batfish	<i>Ephippidae</i>	Lionfish	<i>Scorpaenidae</i>	Squirrelfish	<i>Holocentridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Moorish idol	<i>Zanclidae</i>	Surgeonfish	<i>Acanthuridae</i>
Damselfish	<i>Pomacentridae</i>	Moray Eel	<i>Muraenidae</i>	Sweetlips	<i>Haemulidae</i>
Emperor	<i>Lethrinidae</i>	Parrotfish	<i>Scaridae</i>	Tilefish	<i>Malacanthidae</i>
Flutemouth	<i>Fistulariidae</i>	Pufferfish	<i>Tetraodontidae</i>	Triggerfish	<i>Balistidae</i>
Fusilier	<i>Caesionidae</i>	Rabbitfish	<i>Siganidae</i>	Trumpetfish	<i>Aulostomidae</i>
Goatfish	<i>Mullidae</i>	Requiem Shark	<i>Carcharhinidae</i>	Tuna	<i>Scombridae</i>
Grouper	<i>Serranidae</i>	Rudderfish	<i>Kyphosidae</i>	Wrasse	<i>Labridae</i>
Hawkfish	<i>Cirrhidae</i>	Snapper	<i>Lutjanidae</i>		

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Kuramathi

Common name	Scientific name	Common name	Scientific name
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>	Peacock rock cod	<i>Cephalopholis argus</i>
Black-saddle coral grouper	<i>Plectropomus laevis</i>	Red-flushed grouper	<i>Aethaloperca rogae</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>	Squaretail coral grouper	<i>Plectropomus areolatus</i>
Honeycomb grouper	<i>Epinephelus merra</i>	Vermillion rock cod	<i>Cephalopholis miniata</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>	White-square grouper	<i>Gracila albomarginata</i>
Lunar-tailed grouper	<i>Variola louti</i>		

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Kuramathi

Common name	Scientific name
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>
Honeycomb grouper	<i>Epinephelus merra</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>
Lunar-tailed grouper	<i>Variola louti</i>
Peacock rock cod	<i>Cephalopholis argus</i>
Red-flushed grouper	<i>Aethaloperca rogae</i>
Squairetail coral grouper	<i>Plectropomus areolatus</i>
Vermilion rock cod	<i>Cephalopholis miniata</i>
White-square grouper	<i>Gracila albomarginata</i>
Triangular butterflyfish	<i>Chaetodon triangulum</i>
Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Yellow butterflyfish	<i>Chaetodon andamanensis</i>
Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Kuramathi

Endangered Species observed at Kuramathi

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Blacktip reef shark	<i>Carcharhinus melanopterus</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Napoleon wrasse	<i>Cheilinus undulatus</i>
Squairetail coral grouper	<i>Plectropomus areolatus</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 8) around Kuramathi

GPS coordinates of transect survey sites

Transect survey site	Latitude	Longitude
1	4.26081	72.96489
2	4.25681	72.97814

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	31.5	3.6	2.0	29.6	15.1	6.8	5.7	2.5	2.7
2	23.1	1.8	4.4	38.4	18.9	6.6	3.4	0.0	2.5

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	13.9	2.8
2	15.6	3.0

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	31	20.0
2	31	17.5

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Groupers and butterflyfish species at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/10 0m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	9	4.8	6.4	11	5.3	16.3
2	6	4.3	5.1	11	6.0	15.0

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	6.7	7.8
2	8.1	15.3

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



KUREDU ISLAND RESORT & SPA

Area type: Resort House Reef

Location: Lhaviyani Atoll

Introduction

Kuredu island has a long outer atoll reef edge and a large lagoon area with expansive seagrass growth. A high number of endangered green turtles were observed around the island, and the seagrass beds are clearly an important food source. Such beds are rare in the Maldives making this area vital to the turtle population. The outer reef edge has a number of caves which have high soft coral cover and shelter sleeping turtles. Reef sharks are often present in the channel to the east of the island. Manta rays are observed in the channel to the west during certain times of the year.

Coral cover: 19%

This value was in-line with the national average observed on these surveys. Both values are below historic levels

of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family 19, Grouper species: 4, Butterflyfish species 5

These values matched the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 36 of which were found on Kuredu. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected

by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals

Number of Endangered Animals:

Values: Invertebrates (8), Groupers (2), Sharks (3), Turtles (19)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. High numbers of green turtles were observed around Kuredu due to the expansive seagrass beds, the most important food source for this endangered species.

Grouper Biomass: 655 g/100 m²

This is slightly above the national average of 615 g/100 m². Groupers

are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover: 15%

This value is slightly above the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits: 7/ m²

This is in-line with the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and

Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity 2.5

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 19/100 m²

This is below the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 194 g/100 m²

This slightly below the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Kuredu

surveys (n = 14) around Kuredu

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Goatfish	<i>Mullidae</i>	Rudderfish	<i>Kyphosidae</i>
Battfish	<i>Ephippidae</i>	Grouper	<i>Serranidae</i>	Snapper	<i>Lutjanidae</i>
Bigeye	<i>Priacanthidae</i>	Grubfish	<i>Pinguipedidae</i>	Spinecheek	<i>Nemipteridae</i>
Bullseye	<i>Pempheridae</i>	Hawkfish	<i>Cirrhitidae</i>	Squirrelfish	<i>Holocentridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Jack	<i>Carangidae</i>	Surgeonfish	<i>Acanthuridae</i>
Cardinalfish	<i>Apogonidae</i>	Lionfish	<i>Scorpaenidae</i>	Sweetlips	<i>Haemulidae</i>
Damselfish	<i>Pomacentridae</i>	Moorish idol	<i>Zanclidae</i>	Tilefish	<i>Malacanthidae</i>
Dart Goby	<i>Microdesmidae</i>	Moray Eel	<i>Muraenidae</i>	Triggerfish	<i>Balistidae</i>
Eagle ray	<i>Myliobatidae</i>	Parrotfish	<i>Scaridae</i>	Trumpetfish	<i>Aulostomidae</i>
Emperor	<i>Lethrinidae</i>	Porcupinefish	<i>Diodontidae</i>	Tuna	<i>Scombridae</i>
Flutemouth	<i>Fistulariidae</i>	Pufferfish	<i>Tetraodontidae</i>	Wrasse	<i>Labridae</i>
Fusilier	<i>Caesionidae</i>	Rabbitfish	<i>Siganidae</i>		

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Kuredu

Common name	Scientific name	Common name	Scientific name
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>	Small-spotted grouper	<i>Epinephelus coeruleopunctatus</i>
Blacktip grouper	<i>Epinephelus fasciatus</i>	Tomato rock cod	<i>Cephalopholis sonnerati</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>	Vermilion rock cod	<i>Cephalopholis miniata</i>
Peacock rock cod	<i>Cephalopholis argus</i>	White-lined grouper	<i>Anyperodon leucogrammicus</i>
Red-flushed grouper	<i>Aethaloperca rogae</i>		

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Kuredu

Common name	Scientific name	Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>	Phantom bannerfish	<i>Heniochus pleurotaenia</i>
Black-back butterflyfish	<i>Chaetodon melannotus</i>	Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>	Raccoon butterflyfish	<i>Chaetodon lunula</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>	Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>	Threadfin butterflyfish	<i>Chaetodon auriga</i>
Head-band butterflyfish	<i>Chaetodon collare</i>	Triangular butterflyfish	<i>Chaetodon triangulum</i>
Lined butterflyfish	<i>Chaetodon lineolatus</i>	Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>	Yellow teardrop butterflyfish	<i>Chaetodon interruptus</i>
Madagascar butterflyfish	<i>Chaetodon madagaskariensis</i>	Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>		

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Kuredu

Endangered Species observed at Kuredu

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Grey reef shark	<i>Carcharhinus amblyrhynchos</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Napoleon wrasse	<i>Cheilinus undulatus</i>
Green turtle	<i>Chelonia mydas</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 14) around Kuredu

GPS coordinates of transect survey sites

Transect survey site	Latitude	Longitude
1	5.55186	73.46222
2	5.54644	73.46775
3	5.53706	73.43636

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	14.1	0.0	2.1	73.7	1.4	3.8	3.0	2.4	
2	13.3	2.5	5.6	35.8	13.5	23.8	2.7	0.0	2.0
3	30.3	0.9	1.6	49.9	0.6	6.9	2.0	3.7	3.3

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	7.6	2.0
2	6.2	2.2
3	7.4	2.0

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	33	17.2
2	39	23.3
3	29	15.3

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Grouper and butterflyfish species at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	5	3.8	5.1	14	6.2	14.4
2	7	4.8	6.8	11	3.2	4.2
3	6	4.3	5.1	10	4.2	16.9

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	4.2	11.0
2	4.6	19.4
3	3.7	4.4

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



KURUMBA MALDIVES

Area type: Resort House Reef

Location: North Malé atoll

Introduction

Kurumba is the oldest resort in the Maldives and as such the island is a valuable model of how tourism can help protect Maldivian coral reefs. A high number of reef sharks were observed on the reefs. An above average density of coral recruits means the reefs have a high potential for recovery following the bleaching event. Reclamation and development of nearby Hulhumalé island has led to concern about the future health of the reef, and has highlighted the need for enforceable management measures.

Coral cover: 14%

The national average during the surveys was 19%. Both values are below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high

ocean temperatures. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family: 18, Grouper species: 4, Butterflyfish species: 5

These values were in-line with the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 33 of which were found on Kurumba. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish

communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (3), Groupers (1), Sharks (16)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. The high number of sharks observed suggests this is an important area for these fish.

Grouper Biomass: 680 g/100 m²

This is slightly above the national average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on

a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Question 1: What effects will climate change have on Maldivian coral reefs?

The impacts of climate change pose significant threats to coral reefs both within the Maldives and globally. Increased temperatures may periodically reduce coral cover as a result of coral bleaching. Changes in ocean pH risk altering the ability of reef building corals to grow. Changes in sea levels will require continued vertical coral growth to remain in optimal water depths. These threats may seem imposing, however, the reefs in the Maldives have shown significant resilience to such impacts in the past. The right combination of local education and reef management practices can reduce local pressures and ensure reefs have a good chance of continuing to thrive.

Question 2: How will a UNESCO Biosphere Reserve help protect the reef?

Designation as a biosphere reserve core zone affords the reef area a high level of protection from local impacts, including fishing, pollution and over-development. Monitoring of the reef area will enable a better understanding of reef health and allow for the addition of extra management measures when required e.g. removal of the coral eating crown-of-thorns starfish. The Biosphere Reserve project also includes an awareness and education campaign which will

aim to raise the levels of appreciation for this incredible environment and encourage behavioural changes which will help protect the coral reef habitat. This proposed core zone will not be a standalone biosphere reserve, but part of a network of core, buffer and transition zones that will make up the nationwide biosphere reserve. Through this approach the Maldives will pledge to protect, educate and develop the country with the environment at its core.

Algae Cover: 2%

This value is significantly below the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa spp.* which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruit:s 11/ m²

This is above the national average of 7/ m². This value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 2.8

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 25/100 m²

This is below the national average of 35/100 m². Herbivores are a functionally important group on coral reefs They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 205 g/100 m²

This slightly below the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Kurumba

surveys (n = 14) around Kurumba

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Goatfish	<i>Mullidae</i>	Scorpionfish	<i>Scorpaenidae</i>
Batfish	<i>Ephippidae</i>	Grouper	<i>Serranidae</i>	Snapper	<i>Lutjanidae</i>
Bigeye	<i>Priacanthidae</i>	Jack	<i>Carangidae</i>	Spinecheek	<i>Nemipteridae</i>
Boxfish	<i>Ostraciidae</i>	Moorish idol	<i>Zanclidae</i>	Squirrelfish	<i>Holocentridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Moray Eel	<i>Muraenidae</i>	Stingray	<i>Dasyatidae</i>
Cardinalfish	<i>Apogonidae</i>	Parrotfish	<i>Scaridae</i>	Surgeonfish	<i>Acanthuridae</i>
Damselfish	<i>Pomacentridae</i>	Porcupinefish	<i>Diodontidae</i>	Sweetlips	<i>Haemulidae</i>
Emperor	<i>Lethrinidae</i>	Pufferfish	<i>Tetraodontidae</i>	Triggerfish	<i>Balistidae</i>
Filefish	<i>Monacanthidae</i>	Rabbitfish	<i>Siganidae</i>	Trumpetfish	<i>Aulostomidae</i>
Flutemouth	<i>Fistulariidae</i>	Requiem Shark	<i>Carcharhinidae</i>	Tuna	<i>Scombridae</i>
Fusilier	<i>Caesionidae</i>	Rudderfish	<i>Kyphosidae</i>	Wrasse	<i>Labridae</i>

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Kurumba

Common name	Scientific name	Common name	Scientific name
Indian coral grouper	<i>Plectropomus pessuliferus</i>	Six-spot rock cod	<i>Cephalopholis sexmaculata</i>
Lunar-tailed grouper	<i>Variola louti</i>	Small-spotted grouper	<i>Epinephelus coeruleopunctatus</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>	Snubnose grouper	<i>Epinephelus macrospilos</i>
Peacock rock cod	<i>Cephalopholis argus</i>	Vermillion rock cod	<i>Cephalopholis miniata</i>
Red-flushed grouper	<i>Aethaloperca rogae</i>	White-lined grouper	<i>Anyperodon leucogrammicus</i>

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Kurumba

Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>
Head-band butterflyfish	<i>Chaetodon collare</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>
Phantom bannerfish	<i>Heniochus pleurotaenia</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Triangular butterflyfish	<i>Chaetodon triangulum</i>
Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Kurumba

Endangered Species observed at Kurumba

Common name	Scientific name
Blacktip reef shark	<i>Carcharhinus melanopterus</i>
Whitetip reef shark	<i>Triaenodon obesus</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 14) around Kurumba

GPS coordinates of transect survey sites

Transect survey site	Longitude	Latitude
1	4.22844	73.51861
2	4.22639	73.51625

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	12.9	4.1	3.0	53.9	14.4	7.5	0.0	0.0	3.8
2	16.0	9.8	3.1	44.8	14.3	5.3	0.0	2.7	4.2

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	11.1	2.8
2	11.6	2.7

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	33	19.3
2	29	16.7

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Groupers and butterflyfish species at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	6	3.8	5.6	9	4.666666667	8.055555556
2	9	5.0	5.3	10	4.333333333	7.083333333

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	10.8	10.3
2	4.3	13.8

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



SHANGRI-LA

Area type: Resort House Reef

Location: Seenu Atoll

Introduction

Shangri-La was the only resort surveyed on Seenu Atoll, the most southern atoll in the Maldives. This location means the reefs are exposed to environmental conditions which can differ from the more northerly atolls. Villingili is a large island with an important terrestrial environment consisting of inland forest and brackish water and mangrove ponds. The long, exposed outer reef has clear water and is subject to a high energy environment. The sheltered inner reef is more turbid and nutrient rich. These two different environments mean the reefs around Shangri-La support a high diversity of coral and fish species. Particularly notable was the high coral cover observed during these surveys. This could indicate a strong coral survivorship during the 2016 mass coral bleaching event, or alternatively a rapid recovery in the two years since the event.

Coral cover: 42.5%

This value is in line with historic levels of coral cover nationwide (Pisapia et al. 2016). This was noticeably higher than the national average of 19%, which was impacted by the severe 2016 coral bleaching event caused by high ocean temperatures. This high value means that either corals around Shangri-La survived better than other reefs around the country or there has been significant regrowth of corals in the 12 months between this survey and the majority of other surveys. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family 18, Grouper species: 2, Butterflyfish species 3

These values matched the national averages for fish families, however were below the grouper and butterflyfish averages. A diverse fish community

indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 33 of which were found on Shangri-La. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (11), Groupers (6), Sharks (1), Turtles (4)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives, however their populations are at risk

from a decline in available nesting sites and the declining health of coral reefs.

Grouper Biomass: 395 g/100 m²

This is below the country average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Question 1: What effects will climate change have on Maldivian coral reefs?

The impacts of climate change pose significant threats to coral reefs both within the Maldives and globally. Increased temperatures may periodically reduce coral cover as a result of coral bleaching. Changes in ocean pH risk altering the ability of reef building corals to grow. Changes in sea levels will require continued vertical coral growth to remain in optimal water depths. These threats may seem imposing, however, the reefs in the Maldives have shown significant resilience to such impacts in the past. The right combination of local education and reef management practices can reduce local pressures and ensure reefs have a good chance of continuing to thrive.

Question 2: How will a UNESCO Biosphere Reserve help protect the reef?

Designation as a biosphere reserve core zone affords the reef area a high level of protection from local impacts, including fishing, pollution and over-development. Monitoring of the reef area will enable a better understanding of reef health and allow for the addition of extra management measures when required e.g. removal of the coral eating crown-of-thorns starfish. The Biosphere Reserve project also includes an awareness and education campaign which will aim to raise the levels of appreciation for this incredible environment and encourage behavioural changes which will help protect the coral reef habitat. This proposed core zone will not be a standalone biosphere reserve, but part of a network of core, buffer and transition zones that will make up the nationwide biosphere reserve. Through this approach the Maldives will pledge to protect, educate and develop the country with the environment at its core.

Algae Cover: 2.4%

This value is significantly lower than the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits: 3/ m²

This is below the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016

bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 3.2

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 28/100 m²

This is below than the national average of 35/100 m². Herbivores are a functionally important group on coral reefs They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 150 g/100 m²

This slightly below the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value

may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

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Fish families observed at Shangri-La

surveys (n = 5) around Shangri-La

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Fusilier	<i>Caesionidae</i>	Rabbitfish	<i>Siganidae</i>
Batfish	<i>Ephippidae</i>	Goatfish	<i>Mullidae</i>	Rudderfish	<i>Kyphosidae</i>
Blenny	<i>Blenniidae</i>	Goby	<i>Gobiidae</i>	Snapper	<i>Lutjanidae</i>
Boxfish	<i>Ostraciidae</i>	Grouper	<i>Serranidae</i>	Spinecheek	<i>Nemipteridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Hawkfish	<i>Cirrhidae</i>	Squirrelfish	<i>Holocentridae</i>
Cardinalfish	<i>Apogonidae</i>	Jack	<i>Carangidae</i>	Surgeonfish	<i>Acanthuridae</i>
Damselfish	<i>Pomacentridae</i>	Moorish idol	<i>Zanclidae</i>	Sweetlips	<i>Haemulidae</i>
Dart Goby	<i>Microdesmidae</i>	Moray eel	<i>Muraenidae</i>	Triggerfish	<i>Balistidae</i>
Eagle ray	<i>Myliobatidae</i>	Parrotfish	<i>Scaridae</i>	Triplefin	<i>Tripterygiidae</i>
Emperor	<i>Lethrinidae</i>	Porcupinefish	<i>Diodontidae</i>	Trumpetfish	<i>Aulostomidae</i>
Filefish	<i>Monacanthidae</i>	Pufferfish	<i>Tetraodontidae</i>	Wrasse	<i>Labridae</i>

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Shangri-La

Common name	Scientific name
Red-flushed grouper	<i>Aethaloperca rogaa</i>
White-lined grouper	<i>Anyperodon leucogrammicus</i>
Peacock rock cod	<i>Cephalopholis argus</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>
Black-saddle coral grouper	<i>Plectropomus laevis</i>

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Shangri-La

Common name	Scientific name
Citron butterflyfish	<i>Chaetodon citrinellus</i>
Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>
Raccoon butterflyfish	<i>Chaetodon lunula</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>
Triangular butterflyfish	<i>Chaetodon triangulum</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Shangri-La

Benthic cover at transect survey sites

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Blacktip reef shark	<i>Carcharhinus melanopterus</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Giant clam	<i>Tridacna sp.</i>
Green turtle	<i>Chelonia mydas</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Napoleon wrasse	<i>Cheilinus undulatus</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 5) around Shangri-La

Endangered Species observed at Shangri-La

Transect survey site	Latitude	Longitude
1	-0.68304	73.18389
2	-0.66278	73.19380
3	-0.67333	73.18899

Table A5. Latitude and longitude of transect surveys

GPS coordinates of transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	34.5	10.0	8.2	31.7	10.4	0.0	2.0	0.0	2.3
2	26.5	3.2	0.5	49.5	12.7	4.0	2.0	0.0	
3	48.0	2.8	5.5	32.0	2.0	0.0	2.0	2.3	3.0

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	2.2	3.7
2	2.2	2.0
3	1.1	4.0

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	21	15.8
2	18	13.3
3	19	11.7

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Grouper and butterflyfish species at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	4	2.5	2.1	7	2.7	4.3
2	3	1.8	2.0	9	3.0	6.1
3	3	2.0	1.7	5	2.0	3.2

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	16.0	18.3
2	10.8	16.7
3	9.4	12.8

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



SIX SENSES LAAMU

Area type: Resort House Reef

Location: Laamu atoll

Introduction

The island has an extensive reef area, with an exposed outer atoll reef and a sheltered back reef, which has several patch reefs extending from it. Prior to the 2016 coral bleaching event the reef had an abundant and diverse coral community. The reef had a very high number of vulnerable grouper species. Inside the reef is a large lagoon area with a combination of seagrass, sand and rubble areas. The seagrass beds provide food for green turtles, which are abundant around the island. Guitarfish and other rays are often observed foraging in the sandy and rubble areas. Monitoring and management of the reef includes regular surveys, tourist education, a coral nursery and a local outreach programme.

Coral cover: 17%

The national average during the surveys was 19%. Both values are below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009). Examples of this, such as silt curtains around sand pumping sites and coral replanting are undertaken around Six Senses

Fish diversity:

Values: Fish family 17, Grouper species: 3, Butterflyfish species 3

A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 32 of which were found at Six Senses. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (28), Groupers (26), Sharks (5), Turtles (9)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. High numbers of green turtles were observed around Six Senses due to the expansive seagrass beds, the most important food source for this endangered species.

Grouper Biomass: 450 g/100 m²

This is below the national average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover: 14%

This value is in-line with the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa*

spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits: 5/ m²

This is slightly below the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 3

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 31/100 m²

This is in-line with the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the

Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 181 g/100 m²

This slightly below the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Six Senses

surveys (n = 14) around Six Senses

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Grouper	<i>Serranidae</i>	Scorpionfish	<i>Scorpaenidae</i>
Batfish	<i>Ephippidae</i>	Hawkfish	<i>Cirrhidae</i>	Snapper	<i>Lutjanidae</i>
Bigeye	<i>Priacanthidae</i>	Jack	<i>Carangidae</i>	Spinecheek	<i>Nemipteridae</i>
Butterflyfish	<i>Chaetodontidae</i>	Lizardfish	<i>Synodontidae</i>	Squirrelfish	<i>Holocentridae</i>
Cardinalfish	<i>Apogonidae</i>	Moorish idol	<i>Zanclidae</i>	Surgeonfish	<i>Acanthuridae</i>
Damselfish	<i>Pomacentridae</i>	Moray Eel	<i>Muraenidae</i>	Sweetlips	<i>Haemulidae</i>
Eagle ray	<i>Myliobatidae</i>	Parrotfish	<i>Scaridae</i>	Triggerfish	<i>Balistidae</i>
Emperor	<i>Lethrinidae</i>	Pufferfish	<i>Tetraodontidae</i>	Trumpetfish	<i>Aulostomidae</i>
Filefish	<i>Monacanthidae</i>	Rabbitfish	<i>Siganidae</i>	Tuna	<i>Scombridae</i>
Fusilier	<i>Caesionidae</i>	Requiem Shark	<i>Carcharhinidae</i>	Wrasse	<i>Labridae</i>
Goatfish	<i>Mullidae</i>	Rudderfish	<i>Kyphosidae</i>		

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Six Senses

Common name	Scientific name	Common name	Scientific name
Foursaddle grouper	<i>Epinephelus spilotoceps</i>	Small-spotted grouper	<i>Epinephelus coeruleopunctatus</i>
Honeycomb grouper	<i>Epinephelus merra</i>	Squaretail coral grouper	<i>Plectropomus areolatus</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>	Vermilion rock cod	<i>Cephalopholis miniata</i>
Peacock rock cod	<i>Cephalopholis argus</i>	White-lined grouper	<i>Anyperodon leucogrammicus</i>
Red-flushed grouper	<i>Aethaloperca rogaa</i>		

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Six Senses

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Blacktip reef shark	<i>Carcharhinus melanopterus</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Napoleon wrasse	<i>Cheilinus undulatus</i>
Squairetail coral grouper	<i>Plectropomus areolatus</i>
Whitetip reef shark	<i>Triaenodon obesus</i>
Green turtle	<i>Chelonia mydas</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Giant clam	<i>Tridacna sp.</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Six Senses

Endangered Species observed at Six Senses

Common name	Scientific name	Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>	Raccoon butterflyfish	<i>Chaetodon lunula</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>	Spotted butterflyfish	<i>Chaetodon guttatissimus</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>	Threadfin butterflyfish	<i>Chaetodon auriga</i>
Head-band butterflyfish	<i>Chaetodon collare</i>	Triangular butterflyfish	<i>Chaetodon triangulum</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>	Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>	Yellow butterflyfish	<i>Chaetodon andamanensis</i>
Phantom bannerfish	<i>Heniochus pleurotaenia</i>	Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>
Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>		

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 14) around Six Senses

GPS coordinates of transect survey sites

Transect survey site	Latitude	Longitude
1	1.81189	73.40525
2	1.82178	73.40278
3	1.83089	73.41117

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	31.9	2.3	0.0	52.1	2.6	1.2	2.6	4.3	2.0
2	14.5	18.2	8.8	30.8	5.3	13.0	2.0	2.7	4.0
3	10.5	8.8	11.3	41.0	10.7	7.2	4.0	2.5	2.0

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	8.3	3.3
2	2.8	3.5
3	3.4	3.7

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	30	17.8
2	33	16.5
3	30	17.8

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Grouper and butterflyfish species at transect survey sites

Transect survey site	Mean parrotfish density/100m ²	Mean surgeonfish density/100m ²
1	9.4	26.9
2	12.5	9.4
3	16.1	18.2

Table A9 Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	6	3.3	3.3	12	4.3	8.8
2	5	1.7	1.5	7	2.4	3.5
3	7	4.2	5.0	7	2.3	3.8

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



SONEVA JANI

Area type: Resort House Reef

Location: Noonu atoll

Introduction

The island was one of only two surveyed which face the eastern Indian Ocean and is therefore exposed to currents and organisms arriving from the Indo-Pacific area. The reef has a range of boulder, wall and slope habitats. The island has a long outer atoll reef edge and a large lagoon with patches of seagrass growth and mangrove development on island edge. Juvenile reef sharks are regularly observed in the lagoon, as well as foraging eagle rays and stingrays. There is frequent hawksbill and green turtle nesting on the island's beaches. This is rarely observed on resort islands. The limited development of the actual island area and the protection afforded by the resort could make this an important protected nesting area. There are three areas of closed mangrove at the south of the island which are home to many nesting birds and rare insect species.

Coral cover: 8%

The national average during the surveys was 19%. Both values are below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Local stress such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family 19, Grouper species: 3, Butterflyfish species 4

These values were in-line with the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country,

30 of which were found at Soneva Jani. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (70), Groupers (13), Turtles (2)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives, however their populations are at risk from a decline in available nesting sites and the declining health of coral reefs. Nesting turtles have been observed on Soneva Jani, making this an area of considerable importance.

Grouper Biomass: 450 g/100 m²

This is below the national average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Question 1: What effects will climate change have on Maldivian coral reefs?

The impacts of climate change pose significant threats to coral reefs both within the Maldives and globally. Increased temperatures may periodically reduce coral cover as a result of coral bleaching. Changes in ocean pH risk altering the ability of reef building corals to grow. Changes in sea levels will require continued vertical coral growth to remain in optimal water depths. These threats may seem imposing, however, the reefs in the Maldives have shown significant resilience to such impacts in the past. The right combination of local education and reef management practices can reduce local pressures and ensure reefs have a good chance of continuing to thrive.

Algae Cover: 10%

This value is in-line with the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can

become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits: 7/ m²

This is in-line with the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 3.3

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 33/100 m²

This is in-line with the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 196 g/100 m²

This is slightly below the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Soneva Jani

surveys (n = 14) around Soneva Jani

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Grouper	<i>Serranidae</i>	Rabbitfish	<i>Siganidae</i>
Barracuda	<i>Sphyraenidae</i>	Grubfish	<i>Pinguipedidae</i>	Rudderfish	<i>Kyphosidae</i>
Butterflyfish	<i>Chaetodontidae</i>	Hawkfish	<i>Cirrhitidae</i>	Snapper	<i>Lutjanidae</i>
Cardinalfish	<i>Apogonidae</i>	Jack	<i>Carangidae</i>	Spinecheek	<i>Nemipteridae</i>
Damselfish	<i>Pomacentridae</i>	Lionfish	<i>Scorpaenidae</i>	Squirrelfish	<i>Holocentridae</i>
Dart Goby	<i>Microdesmidae</i>	Moorish idol	<i>Zanclidae</i>	Surgeonfish	<i>Acanthuridae</i>
Emperor	<i>Lethrinidae</i>	Moray Eel	<i>Muraenidae</i>	Sweetlips	<i>Haemulidae</i>
Filefish	<i>Monacanthidae</i>	Parrotfish	<i>Scaridae</i>	Triggerfish	<i>Balistidae</i>
Fusilier	<i>Caesionidae</i>	Porcupinefish	<i>Diodontidae</i>	Wrasse	<i>Labridae</i>
Goatfish	<i>Mullidae</i>	Pufferfish	<i>Tetraodontidae</i>		

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Soneva Jani

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Leopard rock cod	<i>Cephalopholis leopardus</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Peacock rock cod	<i>Cephalopholis argus</i>
Red-flushed grouper	<i>Aethaloperca rogaa</i>
Small-spotted grouper	<i>Epinephelus coeruleopunctatus</i>
Vermilion rock cod	<i>Cephalopholis miniata</i>
White-lined grouper	<i>Anypserdon leucogrammicus</i>

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Soneva Jani

Common name	Scientific name	Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaurichthys zoster</i>	Phantom bannerfish	<i>Heniochus pleurotaenia</i>
Black-back butterflyfish	<i>Chaetodon melannotus</i>	Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>	Threadfin butterflyfish	<i>Chaetodon auriga</i>
Head-band butterflyfish	<i>Chaetodon collare</i>	Triangular butterflyfish	<i>Chaetodon triangulum</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>	Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Meyers butterflyfish	<i>Chaetodon meyeri</i>	Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Soneva Jani

Endangered Species observed at Soneva Jani

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Chevron butterflyfish	<i>Chaetodon trifascialis</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Green turtle	<i>Chelonia mydas</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 14) around Soneva Jani

GPS coordinates of transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	23.4	0.9	4.0	43.2	14.4	6.5	2.0	2.6	2.0
2	32.1	0.6	2.8	49.4	2.4	5.4	3.0	2.4	1.0

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Latitude	Longitude
1	5.71836	73.40325
2	5.73558	73.41086

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	7.6	3.0
2	5.9	3.5

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	29	18.7
2	33	20.7

Table A8. Total number of fish families observed, and average number of fish families observed across six transects at each site

Grouper and butterflyfish species at transect survey sites

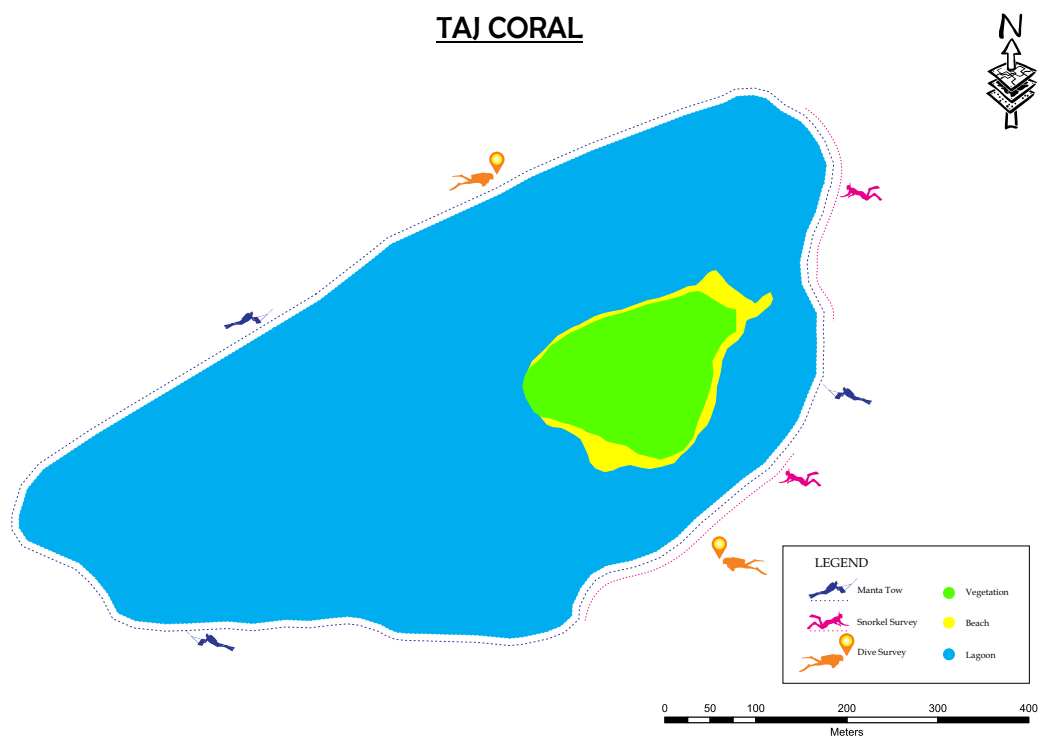
Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	7	4.2	3.9	11	4.2	9.2
2	4	2.3	2.4	8	3.5	7.9

Table A9. Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	7.4	15.7
2	8.9	22.5

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



VIVANTA BY TAJ CORAL REEF MALDIVES

Area type: Resort House Reef

Location: North Malé atoll atoll

Introduction

The island is positioned at the back of a large channel, meaning there is a high chance of megafauna passing by the reef area. The reef has been badly damaged by a crown-of-thorns starfish outbreak and the recent bleaching event. Ensuring protection and management will be important to help rehabilitation and future resilience. There is a small shipwreck at the base of the reef, a feature rare in the Maldives, which is a haven for groupers and small invertebrates.

Coral cover: 6%

The national average during the surveys was 19%. Both values are below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Local stress

such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family: 14, Grouper species: 2, Butterflyfish species: 2

These values were slightly below the national averages for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 21 of which were found on Vivanta by Taj. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (1), Groupers (1), Turtles (1)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives, however their populations are at risk from a decline in available nesting sites and the declining health of coral reefs

Grouper Biomass: 295 g/100 m²

This is below the national average of 615 g/100 m². Groupers are a key target of coral reef fisheries and a high biomass value such as this indicates low fishing pressure on the reef. The coral reef fishery in the Maldives is underdeveloped on a national scale (Newton et al. 2007) as tuna has historically been the main source of protein and primary economic sector (Adam 2006). However, the reef

fishery has expanded recently due to tourist demand. Reefs around resort islands are generally protected from fishing due to the resort's control over reef management. Maintaining this protection whilst working to limit the impact of reef fish consumption on nearby reefs should be components of a resort's reef management strategy.

Algae Cover: 8%

This value is below the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals (Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions

Coral Recruits: 3/ m²

This is below the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef..

Coral Reef Complexity: 2.6

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore Density: 48/100 m²

This is significantly higher than the national average of 35/100 m². Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish Biomass: 115 g/100 m²

This below the national average. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Methods

Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. Transect sites were selected using a stratified, haphazard process. Transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were conducted at each site and a gap of at least 5 m was left between each transect to ensure independence of samples. The cover of different substrate categories was collected using a point intercept

approach along the 30 m transect tape. Starting at 0.5 m the substrate type directly under the transect tape every 50 cm along the transect was identified as one of the categories: live coral, dead coral, sponge, algae, rock, rubble, sand and CCA. Coral reef structural complexity was visually assessed during roaming surveys, for the duration of the timed swim, and for the length of the transects. Juvenile coral recruitment was measured using a 25 x 25 cm quadrat. This was placed above and below the transect at 5 m intervals, starting at 5 m. The number of coral recruits (colonies < 5 cm diameter) within each quadrat

were counted and identified to genus where possible. Structural complexity was estimated on a scale from 0 (completely flat) to 5 (highly complex) (following Wilson et al. 2007). Fish communities were surveyed on six 4 x 30 m transects using the same transects as the benthos surveys. The presence of all fish families was recorded on each transect. All butterflyfish (*Chaetodontidae*), groupers (*Serranidae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm.

Fish families observed at Vivanta by Taj

surveys (n = 3) around Vivanta by Taj

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Grouper	<i>Serranidae</i>	Rudderfish	<i>Kyphosidae</i>
Butterflyfish	<i>Chaetodontidae</i>	Grubfish	<i>Pinguipedidae</i>	Snapper	<i>Lutjanidae</i>
Damselfish	<i>Pomacentridae</i>	Jack	<i>Carangidae</i>	Squirrelfish	<i>Holocentridae</i>
Eagle ray	<i>Myliobatidae</i>	Moorish idol	<i>Zanclidae</i>	Surgeonfish	<i>Acanthuridae</i>
Emperor	<i>Lethrinidae</i>	Parrotfish	<i>Scaridae</i>	Sweetlips	<i>Haemulidae</i>
Fusilier	<i>Caesionidae</i>	Pufferfish	<i>Tetraodontidae</i>	Triggerfish	<i>Balistidae</i>
Goatfish	<i>Mullidae</i>	Rabbitfish	<i>Siganidae</i>	Wrasse	<i>Labridae</i>

Table A1. All fish families recorded across rapid

Grouper and butterflyfish species observed at Vivanta by Taj

Common name	Scientific name
Blackfin rock cod	<i>Cephalopholis nigripinnis</i>
Foursaddle grouper	<i>Epinephelus spilotoceps</i>
Honeycomb grouper	<i>Epinephelus merra</i>
Indian coral grouper	<i>Plectropomus pessuliferus</i>
Marble grouper	<i>Epinephelus fuscoguttatus</i>
Red-flushed grouper	<i>Aethaloperca rogaa</i>
White-lined grouper	<i>Anyperodon leucogrammicus</i>

Table A2. All grouper species recorded across detailed underwater visual census (n = 18) around Vivanta by Taj

Common name	Scientific name	Common name	Scientific name
Black pyramid butterflyfish	<i>Hemitaenichthys zoster</i>	Pinstriped butterflyfish	<i>Chaetodon trifasciatus</i>
Brown butterflyfish	<i>Chaetodon kleinii</i>	Very long-nose butterflyfish	<i>Forcipiger longirostris</i>
Double-saddle butterflyfish	<i>Chaetodon falcula</i>	Yellow butterflyfish	<i>Chaetodon andamanensis</i>
Long-nose butterflyfish	<i>Forcipiger flavissimus</i>	Yellow-head butterflyfish	<i>Chaetodon xanthocephalus</i>
Pig-face butterflyfish	<i>Chaetodon oxycephalus</i>	Blackfin rock cod	<i>Cephalopholis nigripinnis</i>

Table A3. All butterflyfish species recorded across detailed underwater visual census (n = 18) around Vivanta by Taj

Endangered Species observed at Vivanta by Taj

Common name	Scientific name
Black-saddle coral grouper	<i>Plectropomus laevis</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 3) around Vivanta by Taj

GPS coordinates of transect survey sites

Transect survey site	Latitude	Longitude
1	4.48339	73.39147
2	4.48003	73.39372

Table A5. Latitude and longitude of transect surveys

Benthic cover at transect survey sites

Transect survey site	Hard Coral	Macro algae	Turf algae	Rock	Rubble	Sand	CCA	Soft coral	Sponge
1	0.6	1.1	17.9	50.8	14.9	3.6	2.0	2.8	5.8
2	9.2	0.2	11.6	17.4	17.0	32.8	5.0	0.0	4.0

Table A6. Benthic cover of substrate categories averaged across six transects at each site

Recruitment and complexity at transect survey sites

Transect survey site	Mean recruit density/m ²	Complexity
1	2.4	3.0
2	3.7	3.0

Table A7. Juvenile coral recruit density and structural complexity averaged across six transects at each site

Fish families at transect survey sites

Transect survey site	Total number of families observed	Mean number of families observed
1	26	13.4
2	24	14.8

Table A8 Total number of fish families observed, and average number of fish families observed across six transects at each site

Groupers and butterflyfish species at transect survey sites

Transect survey site	Total number of grouper species observed	Mean number of grouper species observed	Mean grouper density/100 m ²	Total number of butterflyfish species observed	Mean number of butterflyfish species observed	Mean butterflyfish density/100 m ²
1	3	1.5	1.7	6	2.0	2.5
2	6	2.5	2.3	8	2.7	29.0

Table A9 Total number of grouper and butterflyfish species observed, average number of grouper butterflyfish species observed and average density of grouper and butterflyfish species across six transects at each site

Parrotfish and surgeonfish abundance at transect survey sites

Transect survey site	Mean parrotfish density/100 m ²	Mean surgeonfish density/100 m ²
1	6.5	60.0
2	11.4	12.9

Table A10. Abundance of parrotfish and surgeonfish averaged across six transects at each site



TAJ EXOTICA RESORT AND SPA

Area type: Resort House Reef

Location: South Malé atoll

Introduction

The island was one of only two surveyed which face the eastern Indian Ocean and is therefore exposed currents and organisms arriving from the Indo-pacific area. The channel to south of the island is renowned for reef shark aggregations. Inside the reef is very large sandy lagoon where juvenile blacktip reef sharks are regularly observed. There is also a twin chain of coral patch reefs extending out from the resort which act as a reef fish nursery.

Coral cover: 8%

The national average during the surveys was 19%. Both values are below historic levels of coral cover nationwide (Pisapia et al. 2016) due to the severe 2016 coral bleaching event which was caused by high ocean temperatures. Local stress

such as predation, sedimentation and competition with algae can increase a coral's susceptibility to bleaching (Ateweberhan et al. 2013). Reducing this local stress on corals through reef management efforts can improve coral reef resilience (Carilli et al. 2009).

Fish diversity:

Values: Fish family: 17

This value was slightly below the national average for fish diversity. A diverse fish community indicates a healthy reef and a resilience against future degradation (Bellwood et al. 2004). Groupers and butterflyfish are indicators of unfished and healthy reef areas. 51 reef associated fish families were observed across the country, 25 of which were found on Taj Exotica. The relationship between the fish community and the coral habitat exhibits a feedback loop, where changes in one is reflected by the other. This means managing for a healthy coral habitat will help ensure fish diversity and protecting fish communities will help maintain healthy corals.

Number of Endangered Animals:

Values: Invertebrates (12), Groupers (2), Turtles (1)

These species are under threat and identifying and protecting habitat where they are found is key to their survival. Complex reef flats and slopes are foraging grounds for reef sharks and provide shelter spaces for large groupers. Endangered hawksbill turtles are relatively common in the Maldives, however their populations are at risk from a decline in available nesting sites and the declining health of coral reefs.

Algae Cover: 8%

This value is below the national average of 12%. A low cover of algae such as this is important as it means there is less competition with corals for settlement and growth. Algae can become prevalent when coral cover and herbivorous fish numbers decline or in areas of nutrient input such as sewage outflows. Some reefs have experienced outbreaks of *Caulerpa* spp. which can outcompete corals

(Montano et al. 2012). Monitoring of algae on reefs should be used to help inform future management decisions.

Coral Recruits: 3/ m²

This is below the national average of 7/ m². This country-wide value indicates that there has been strong survivorship of juvenile corals despite the 2016 bleaching event, suggesting that under the right conditions reefs have a good chance of recovery. Larval settlement success and recruit survivorship are inhibited by high temperatures, poor water quality and high macroalgae abundance (Ritson-Williams et al. 2009). Transplantation of juvenile corals to reefs has been proposed as a method to augment recovery following disturbances. However this process has thus far had mixed results (Edwards and Gomez 2007) and is susceptible to the same disturbances which previously damaged the reef.

Coral Reef Complexity: 2.6

This value indicates an intermediate level of reef complexity. This level of complexity has been shown to support diverse fish communities and provide resilience from climate change impacts. One of the biggest risks to coral structure on reefs is direct impact from individuals standing on or kicking corals. This can destroy years of reef growth in seconds. Ensuring people are educated on snorkelling and diving rules and techniques, and that reefs are accessible through channels can significantly reduce this impact.

Herbivore observations: less than 1 min

That herbivores were always observed within the first minute of surveys indicates a high number on the reefs. Herbivores are a functionally important group on coral reefs. They play a key role in keeping algae levels low enough for corals to thrive (Mumby et al. 2006). Herbivorous fish are not targeted

by fisheries in the Maldives and are generally present in high numbers on reef throughout the country.

Butterflyfish observations: less than 2 minutes

That butterflyfish were always observed within the first two minutes indicates a high number on the reefs. Butterflyfish are a key indicator of coral reef health as they rely on an abundant coral community for food. This value may be lower than historic levels due to the decline in coral cover however, it represents a healthy remnant butterflyfish population. Butterflyfish reflect coral communities, therefore increasing coral cover and diversity will likely result in a more abundant and diverse butterflyfish community.

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Annex

Fish families observed at Taj Exotica

surveys (n = 12) around Taj Exotica

Common name	Scientific name	Common name	Scientific name
Angelfish	<i>Pomacanthidae</i>	Parrotfish	<i>Scaridae</i>
Boxfish	<i>Ostraciidae</i>	Pufferfish	<i>Tetraodontidae</i>
Butterflyfish	<i>Chaetodontidae</i>	Rabbitfish	<i>Siganidae</i>
Damselfish	<i>Pomacentridae</i>	Rudderfish	<i>Kyphosidae</i>
Eagle ray	<i>Myliobatidae</i>	Snapper	<i>Lutjanidae</i>
Emperor	<i>Lethrinidae</i>	Spinecheek	<i>Nemipteridae</i>
Flutemouth	<i>Fistulariidae</i>	Squirrelfish	<i>Holocentridae</i>
Fusilier	<i>Caesionidae</i>	Surgeonfish	<i>Acanthuridae</i>
Goatfish	<i>Mullidae</i>	Sweetlips	<i>Haemulidae</i>
Grouper	<i>Serranidae</i>	Triggerfish	<i>Balistidae</i>
Hawkfish	<i>Cirrhidae</i>	Trumpetfish	<i>Aulostomidae</i>
Jack	<i>Carangidae</i>	Wrasse	<i>Labridae</i>
Moorish idol	<i>Zanclidae</i>		

Table A1. All fish families recorded across rapid

Endangered Species observed at Taj Exotica

Common name	Scientific name
Napoleon wrasse	<i>Cheilinus undulatus</i>
Squaretail coral grouper	<i>Plectropomus areolatus</i>
Hawksbill turtle	<i>Eretmochelys imbricata</i>
Giant clam	<i>Tridacna sp.</i>

Table A4. All IUCN Redlisted species recorded across rapid surveys (n = 12) around Taj Exotica



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