A rapid assessment of natural environments in the Maldives

Charlie Dryden, Ahmed Basheer, Gabriel Grimsditch, Azim Mushtaq, Steven Newman, Ahmed Shan, Mariyam Shidha, Hussain Zahir

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EXECUTIVE SUMMARY

The Maldives archipelago is a chain of coral reefs and islands lying in the tropics at the centre of the Indian Ocean. The coral reefs of the Maldives are amongst the most biologically important habitats on earth, spanning an area of approximately 4,500 km^2 located close to the mid-point of the east and west margins of the Indian Ocean basin. The structurally complex and ecologically diverse habitat is essential to large numbers of both resident and transient marine life. Due to its geographical location the marine biodiversity has features of both the highly diverse reefs of south east Asia and of east African reefs. In addition to their ecological value, coral reefs are also of significant value to the island communities as a source of economic and social wellbeing. Coral reef related tourism alone makes up approximately 43% of GDP. Coral reefs in the Maldives were severely impacted by the 2016 global bleaching event, with approximately 73% of corals on shallow (<13 m) reefs bleaching. A range of local scale factors including dredging, island building and pollution also threatens reefs.

Though the Maldives may be best known for its marine ecosystem, the terrestrial environment has a diversity of habitats, each with high ecological and social value. The coastal fringe habitat, made up primarily of scrub vegetation, consolidates sediment aiding island development and limiting erosion. Where islands are large enough, forests develop with soils higher in nutrients and dense vegetation growth. Many islands have shallow ponds created by rainwater accumulation or an influx of seawater through channels or porous rocks. The vegetation around these ponds can vary depending on salinity, substrate pond age and depth. On many islands mangrove assemblages have developed. The largest mangrove systems in the Maldives are found in depressions inside islands or along the borders of bay areas. Mangroves provide a range of ecosystem services such as coastal protection, nursery grounds and carbon sequestration. Mangrove habitats also support a diversity of bird species and are likely to be amongst the most important areas for resident birds and migratory birds across the country. Few studies have been done on the different types of mangroves and wetland habitats found in the Maldives, and the services provided by these ecosystems is undervalued. Terrestrial systems in general are understudied, despite threat from increasing demands for land area for urban development though airport, resort and land reclamation projects.

In the context of the range and scale of impacts threatening natural environments in the Maldives it is important that a broad assessment of the state of the country's natural resources be undertaken. This report comes shortly after a severe bleaching event which impacted reefs across the country greatly reducing live coral cover. The aim of this report was to describe the ecological status of Maldivian marine and terrestrial habitats and how this information might be used to enhance the protection of the country's natural habitats and communities.

This report presents the results of a spatially extensive ecological survey conducted at 34 reef sites and three island habitats across 13 atolls. A range of reef and terrestrial habitats were surveyed during February 2017 – March 2018. Reefs were surveyed using manta tows, rapid roaming surveys and transects. Benthic and fish communities were examined, as well as reef resilience metrics. The presence of IUCN Red Listed animals and corals were recorded. Terrestrial vegetation was surveyed using random points and 5 x 5 m plots. Vegetation species, size and percent cover was recorded. All bird species observed throughout the survey period were recorded and the island area they were in was noted. Surveys of mangrove bay fish communities were performed whilst snorkelling and wading.

The mean coral cover for the country was 19.6%. Many sites had coral cover significantly below values typical of undisturbed Maldivian reefs, likely because of the bleaching event. The highest coral cover (54%) was found in the Thoondi area of Fuvahmulah and others such as Ihuru North Malé, Manta point and Villingili in Addu, and Maamigili in South Ari had values greater than 35%. It is important to identify and protect such sites to help preserve them for the future as they may play an important role in seeding reef regrowth within these atolls. Reef fish communities were found to be highly diverse and abundant across almost all survey zones. Notably, butterflyfish and grouper biomass and richness was high across much of the Maldives. The average biomass of groupers across the country was greater than or equal to that found on many other reefs in the region. Herbivore density was high across the country with a mean of 29/100 m^2. The abundance of the functionally important herbivores parrotfish and surgeonfish, was high throughout the area and the numbers found are likely to confer a level of resilience through prevention of algal overgrowth. Reef resilience metrics including coral recruits, herbivore density, coral cover and structural complexity were generally high but exhibited significant spatial variability. There were zones that may be at greater risk of not recovering following the bleaching event. These include those with low extant coral and little recruitment combined with and low densities of either parrotfish or surgeonfish.

Reef sharks were observed in 26 of the 34 zones surveyed, indicating high numbers across the country. The presence of these top predators suggests a healthy ecosystem. Turtles were regularly observed throughout the country. Green turtles (*Chelonia mydas*) were only observed in areas close to seagrass beds, a key food source for this species. There was evidence of illegal turtle and turtle egg poaching on the beaches of uninhabited islands. There were numerous locations where manta rays were observed whilst diving or snorkelling. Endangered coral species such as *Pachyseris rugosa* and *Physogyra lichtensteini*, rare on coral reefs globally were relatively common here.

The three islands surveyed had a range of environments present. Common to all three was a coastal fringe area at the high-water line where vegetation growth began. On sheltered shores sea lettuce (*Scaevola taccada*), sea hibiscus (*Talipariti tiliaceum*) and beach gardenia (*Guettarda speciosa*) dominated. Iron wood (*Pemphis scidula*) dominated on more exposed shores. The coastal fringe of all islands had significant amounts of rubbish e.g. plastic bottles, polystyrene foam and cans, accumulated on the shores.

Two of the islands, Dhigulaabadhoo and Farukolhu, had mangrove bays. The dominant the mangrove species was yellow mangrove (*Ceriops tegal*), though red mangrove (*Rhizophora mucronata*) was also present. The width of mangrove growth was very narrow around both bays, usually only a single tree deep. The bay at Farukolhu was much larger and had smaller bays extending from it. Farukolhu mangrove bay had a higher fish species diversity and evenness compared to Dhigulaabadhoo mangrove bay. Many juvenile sharks and rays were found at both sites, which indicates these habitats are important nursery grounds for these species. Both bays had juveniles of commercially important fish species such as blue-fin jacks (*Caranx melampygus*), and snapper and emperor species. Juvenile sicklefin lemon sharks (*Negaprion acutidens*), a vulnerable (IUCN Redlist) species, were observed in the bay at Farukolhu.

Keylakunu island had a mangrove forest that has formed in a large depression in the bedrock. This was dominated by the small-leafed orange mangrove (*Brugeira cylindrica*). Mature small orange-leafed mangrove trees had a density of approximately 1/ m^2 and the ground beneath was cover in thick seedling growth with approximately 30/ m^2. There was a clearly defined area of red mangrove in the south-eastern area. This was limited to a site where water was clearly flowing into the depression through the bedrock and the water depth in the pond was greater. Spread throughout the area were large grey mangrove (*Avicennia marina*) trees. The largest of these trees was over 15 m tall with a DBH of 2.4 m. A high number of white-tailed tropical birds (*Phaeton lepturus*) were observed flying over inland vegetation habitat at Keylakunu.

There are a range of threats to the natural environment in the Maldives. On a global scale climate change threatens virtually all ecosystems through increases in temperatures, sea level, storm risk and ocean acidity. Locally, land reclamation, island urban and agricultural development, pollution, rubbish dumping, overfishing and poaching all threaten ecosystems and individual species. It is therefore important that management efforts are made to mitigate or prevent environmental degradation. This study identifies important habitats within the country and the need to prioritise protection and management of them. Areas with greater resilience to these impacts are identified and recommendations for management are discussed. Broad scale protection for these habitats is key, however input for the design of policies must come from all levels of stakeholder and should account for environmental and socio-economic needs. The proposed UNESCO Biosphere Reserves for the Maldives represents a positive step towards protecting the environment for the future in this respect. This approach should provide well-developed management plans and resources for protected areas around the country. These must also be coupled with environmental education. The response of reefs across the country following the 2016 coral bleaching event should be carefully monitored to prioritise protection for those areas that fared well and understand factors behind sites that exhibited greater resilience. This would also ensure efforts can be made to help those areas not recovering. Terrestrial habitats, including mangroves, have received little attention in terms of both research and management to date seagrass habitats have been almost completely overlooked. This must be rectified as soon as possible if any hope that a harmony can be reached between continued development and the protection of one the world's most ecologically valuable habitats.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Maldives

The Maldives archipelago is a chain of coral reefs and islands lying along the Lakshadweep – Maldives – Chagos ridge. The country lies in the tropical Indian Ocean and extends from the southernmost point of Addu atoll (0042" S) to Ihavandippolhu (7006" N) in the north. The archipelago is composed of 21 atolls and 4 oceanic reef platforms (*Kench 2011*). And is one of only four atoll island nations around the world. The atolls can be divided into open (16) and closed (5) atolls. It is comprised of over 2,000 coral reefs and 1,200 low-lying coral islands, and with an average height above sea level of approximately 1.5 m. it is considered extremely vulnerable to sea-level rise and climate change. The total land area within the country is approximately 227 km^2 with 115,000 km^2 of territorial waters (*MEE 2015*). Only 193 islands are inhabited by local communities (*Shaig 2008*). Natural island habitat varies based on age, size, urban development and geographic location. The health of the environment is of great significance for the provision of resources, preservation of land and economic incomes.

Coral reefs of the Maldives

Maldivian reefs span an area of approximately 4,500 km^2 with 2,041 distinct coral reefs (*Naseer and Hatcher 2004*). The structurally complex and ecologically diverse reef habitat is essential to large numbers of resident and transient marine life. The range of reef structures the Maldives possesses is another feature which makes the habitat special. The most extensive reef development is found in Thiladhunmathi and Miladhunmadulu atoll (a single atoll structure divided into two areas for administrative purpose), which is also the largest surface level atoll in the world (*Spalding et al. 2001*). The country's position, close to the mid-point of the east and west margins of the Indian Ocean basin, means that its marine flora and fauna has the characteristics of both the highly diverse reefs of the coral triangle and east Africa (Rajasuriya et al. 2002, M.R.C 2003). Maldives has a high diversity of coral species, with approximately 250 species of hard, reef-building corals (Pichon and Benzoni 2007).

Maldives has perhaps, the greatest coral reef diversity in the central Indian Ocean. The unique characteristic that makes the Maldives so striking as compared to other reefs of the region is the sheer abundance of the islands, contrasting reef formations and associated flora and fauna. A detailed biodiversity inventory has not been completed for the coral reefs of Maldives, which is a colossal task, itself. Historical information on some aspects of marine biodiversity is available through various expeditions largely during the early part of the last century.

Some of the earliest studies on coral reefs include the pioneering works by Gardiner expedition 1899-1900 (Gardiner 1903) and that of Agassiz in 1901-2 (Agassiz 1903). Subsequently, expeditions by naturalists and scientists followed around mid-19th century. These include the Xarifa expedition lead by Hans Hass in 1957-58 and the expedition to Addu atoll lead by Dr. D.R. Stoddart in 1964. The Xarifa expedition's reef studies included seven of the 26 atolls and reported 51 scleractinian coral genera from seven atolls (Scheer, 1971).

More than 1,200 reef associated fish species have been identified (Rajasuriya et al. 2002). There have been 36 species of sponge, 285 species of algae, 5 species of seagrass, 400 species of molluscs, 350 species of crustaceans and 80 species of echinoderms recorded in the Maldives (MEE 2015). The reefs provide essential services to many migratory animals including manta rays and several shark species. Five of the seven species of marine turtle have been reported from Maldives, with two species, hawksbill (Eretmochelys imbricate) and green (Chelonia mydas) turtles nesting on beaches, while olive ridely (Lepidochelys olivacea), loggerhead (Caretta caretta) and leatherback (Dermochelys coriacea) turtles are often sited within Maldivian waters.

In addition to their ecological value, coral reefs are also of significant value to the island communities as a source of dietary protein and for economic wellbeing (Agardy et al. 2017). Coral reef tourism alone makes up approximately 43.17% of GDP and has a value of US$ 205,505/km^2/year (Spalding et al. 2017); this equates to a total of approximately US$ 1 billion/year for the whole country. However, the use of coral reefs in the Maldives is not limited to tourism activities alone and encompasses many direct and indirect activities (*Table 1 and Table 2*).

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The status of coral reefs in the Maldives

Coral reef monitoring in the Maldives began in the 1980s (*Risk and Scott 1991*). Before this, visiting scientists provided information on coral reef biology and ecology during short visits or specific studies on coral reefs of Maldives. The most recent and extensive coral reef monitoring program started in conjunction with

Extractive activities	Non-extractive activities
Fisheries	Tourism/recreation
Mariculture	Research
Aquarium trade	Education
Pharmaceuticals	Aesthetics/cultural

Table 1. Direct human values of coral reefs in the Maldives

Biological services	Physical services
Supports sea birds, turtles and marine mammals	Wave break
Supports connected ecosystems including the open ocean, deep sea or terrestrial habitats	Erosion of reef structures produces sand to maintain beaches and form islands

Table 2. Indirect human values of coral reefs in the Maldives

the large-scale coral-bleaching event in 1998. Prior to the 1998 bleaching where only 2 - 5 % of the reefs were damaged (Rajasuriya et al. 2002) coral cover ranged between 30 to 60% in most of the sites and often 100% coral cover was found in shallow areas. The reef complexity was high and dominated by branching and tabular growth forms. Acropora and Millepora colonies were abundant in most of the sites (Bianchi et al. 2006). The bleaching event caused widespread mortality of corals in the Maldives and the wider Indian Ocean (Wilkinson et al. 1999). A pilot study to report on the post bleaching status of the coral reefs provided a concise account of the live coral cover at the study sites and coral cover at comparable sites before bleaching (Allison 1999). Bleaching and subsequent mortality of branching and massive coral on artificial and natural reefs in the central atolls were also reported by Edwards et al. (2001). A significant challenge in understanding the condition of coral reefs across the country is that the reefs are highly dispersed across the country and many sites can be challenging to survey. Therefore, much of the data available is limited spatially and only fragmented summaries are available more broadly.

Fish communities on Maldivian coral reefs are considered underexploited on a national scale (Newton et al. 2007), though up to date information on this is lacking. Tuna fishing has historically been the main source of protein and the primary economic sector (Adam 2006). The grouper fishery is predominantly for export to the live restaurant trade. It began in the Maldives in the 1980s and was believed to have peaked in 1996 (Sattar and Adam 2005). The reef fishery has since expanded and developed to serve the local tourism market and now includes species of snapper, emperor and jack. These stocks may be locally overexploited near population centers and size and species-based management measures have been developed (Sattar et al. 2014). A productive aquarium trade fishery operates in the country with around 140 species of smaller reef fish collected (Saleem and Islam 2008).

Reef fish communities are not only impacted by fisheries, habitat degradation can have severe negative consequences. The loss of live coral cover and structural complexity associated with climate change impacts the reef fish communities, resulting in the loss of diversity, abundance and function of the fish community (Pratchett et al. 2008). The impacts are often noticed first in butterflyfish communities which respond quickly to losses in live coral cover (Graham et al. 2007). Climate change therefore presents a significant threat to the Maldivian reef fish community.

Maldivian coral reefs have suffered two severe nationwide coral bleaching events, the first in 1997/1998 and the second in 2016. During the 1997/1998 event approximately 80% of corals either completely or partially bleached in shallow areas (Rajasuriya et al. 2002). Reef recovery was slow and variable across Maldives during initial years post bleaching (Zahir 2007). However, the coral reefs of the Maldives showed significant resilience and by 2012 had recovered to pre-bleaching levels (Pisapia et al. 2016, Ibrahim et al. 2017). However, compared to the Chagos archipelago and other remote Indian Ocean locations with similar environmental conditions, the rate of recovery of Maldivian coral reefs was slow in the aftermath of the 1998 bleaching event (Sheppard et al. 2008). A recent report examining the impacts of the 2016 bleaching event found that the bleaching effected approximately 73% of corals on shallow (<13 m) reefs (Ibrahim et al. 2017). Despite this high level of impact there were a number of locations where bleaching incidence was relatively low (Ibrahim et al. 2017). Resilience is the ability of a reef to respond to stressors or environmental events such as bleaching (Roche et al. 2018). It is possible to include certain resilience metrics in rapid reef assessments to help researchers and managers determine how a reef will respond to environmental changes. These include herbivore abundance, coral recruitment and habitat complexity reefs among others (McClanahan et al. 2012, Graham et al. 2015)

Island vegetation

Maldivian islands are entirely coral atoll based and are small in size, ranging from less than 0.1 to 5 square kilometers. The highest natural elevation is 2.4 m (Liu et al. 2018). Freshwater comes from rain and is stored as a freshwater lens a few metres below the ground (Werner et al. 2017). The soil tends to be coarse and shallow on top of an underlying coral limestone base layer (*MFAMR 1995*). Plant communities vary depending on island type, size and the distance from the shore. Closest to the shore is scrub vegetation consisting of shrubs and small trees. Extending from the foreshore on uninhabited islands the plant life develops in a successional nature to larger, denser vegetation, including many tree species and understory growth. Many islands have shallow ponds created by rainwater accumulation or an influx of seawater. The vegetation around these ponds can vary depending on salinity, substrate pond age and depth.

On a number of islands mangrove assemblages have developed. The geomorphology of the Maldives means mangrove development is restricted to relatively narrow bands on approximately 12% of islands (*Saleem and Nileysha 2003*). These systems are highly productive and dynamic. Mangroves provide a range of ecosystem services including: sediment consolidation which helps secure shorelines and reduce erosion (Ewel et al. 1998, Spalding 2010), provide a buffer against salt spray, monsoon winds and the catastrophic flooding caused by cyclones or tsunamis (Alongi 2008), provide nursery grounds for a variety of fish and invertebrate species (Beck et al. 2001, Laegdsgaard and Johnson 2001) which may increase the biomass of coral reef fish communities (*Mumby et al. 2004, Nagelkerken et al. 2008*), support a diversity of bird species, they may be amongst the most important areas for resident and migrating birds across the country (Saleem and Nileysha 2003) and carbon sequestration (*Bouillon et al. 2008*). Worldwide, mangroves are in decline due to climate change and a range of anthropogenic factors (Valiela et al. 2001, Polidoro et al. 2010, Ellison 2015), therefore identifying, monitoring and protecting these habitats should be part of any environmental management plan.

The largest mangrove systems in the Maldives are found in depressions inside islands or along the borders of open bay areas. These mangrove depressions, such as in Keylakunu on Haa Dhaalu Atoll, often have little or no connection to the sea, but receive saltwater via seepage through porous coral rock. Open mangrove bays, such as at Farukolhu on Shaviyani Atoll and Dhigulaabadhoo on Gaaf Dhaal Atoll, are connected to the sea via large channels. This allows different faunal species to move in and out of the systems and enables mangrove propagules to be distributed more widely. Materials and nutrients within the mangrove can be exported to nearby habitats as well. The diversity and abundance of both flora and fauna differs between the Mangrove depressions and open Mangrove bays. The mangrove at Keylakunu is of particular note due an observation from previous studies of dense mangrove forest and large grey mangrove (*Avicennia marina*) trees (Saleem and Nileysha 2003).

No extensive studies have been done on the different types of mangroves and wetland habitats in the Maldives, and the services provided by these ecosystems is undervalued (but see: MFF 2018). Larger mangrove systems such as the ones found in Indonesia are considered to contribute to the food web of adjacent marine ecosystems (Unsworth et al. 2008), but this has not yet been investigated with the mangrove systems in the Maldives.

> "No extensive studies have been done on the different types of mangroves and wetland habitats in the Maldives, and the services provided by these ecosystems is undervalued..."

Island fauna

Tropical regions tend to have high bird diversity, however due to the small island size and isolation of the Maldives, avifauna is extremely restricted. Approximately 180 different bird species have been recorded in the country, with numbers dominated by seabirds and waders (shorebirds). Most of the birds found in Maldives are migratory species and are therefore seasonal visitors; very few reside and breed in Maldives. Most seabirds are seen on sandbanks and beaches where some of them breed. On islands with mangroves and large beach areas, bird species such as plovers and herons are commonly found. In the most southern atoll of Maldives (Addu City), the Eedhigali Protected area is an area famous for its grey herons and it's identified as a "hotspot" breeding ground for many bird species.

Rapid development poses a significant threat to bird species. Degradation of the few wetlands and the modification and destruction of coastal habitats through reclamation, sand mining and man-made coastal infrastructure are some of the major threats to the avifauna in the country. Although birds are protected by law, the capture of wild birds, and import of different species of birds as pets is also a serious threat to the bird populations. Of the 180 species of birds recorded in the country, 103 are protected under the Environment Protection and Preservation Act (Law 4/93). Furthermore, given the location of Maldives, it is seen as a transit zone for migratory birds, and thus the Migratory Birds Regulation (2014/R-169) gives further protection to all migratory birds found in the Maldives. Trade and transportation between islands has resulted in populations of both rats and cats arriving on many Maldivian islands (Russell et al. 2016), this includes islands considered uninhabited. These animals have been able to establish populations on these small food rich islands and now pose a significant threat to native populations of birds and reptiles (Harper and Bunbury 2015).

In the context of the range and scale of impacts threatening marine and island habitats across the Maldives it is important that a broad assessment of the state of these habitats be undertaken. This must account for the range of habitat types within the country, the impacts of the recent bleaching event and the geographical distribution of the nation's reef network as well as the range of island habitats. The resilience of the Maldivian natural environment to the impacts of climate change must also be examined. Monitoring and assessment are integral components of good ecosystem management and are necessary to make informed decisions in the future.

Aims

The aim of this report was to perform a rapid assessment of the ecological status of natural habitats in the Maldives in 2017-2018. To achieve this the six key objectives of this report are to:

1. Describe coral reef benthic habitat
2. Describe reef associated fish communities
3. Measure reef resilience metrics
4. Identify endangered, vulnerable or threatened marine species present
5. Describe island vegetation communities on three uninhabited islands
6. Describe the avian and marine fauna associated with these vegetation communities.

METHODS

The range of habitats types and conditions present in the Maldives broad the aims of this project meant that multiple methodologies were required to allow surveys to be conducted in all locations.

Marine surveys

Manta tows were used to assess the benthic condition of the reef over a large area. Using this approach, the perimeter of the reef flat was surveyed. Timed roaming surveys were used to survey the benthic habitat and fish community on all reef types and environmental conditions; between 3 – 50 were performed depending on zone size and environmental conditions. Transect surveys were used to quantitatively assess fish and benthic communities at a high taxonomic level. The number of transect surveys ranged between 0 – 30 based on zone size, environmental condition and reef type. Transect sites were selected using a stratified, haphazard process. The results of surveys are presented as averages ± standard error throughout.

Coral reef benthos

Where possible, coarse-scale assessments of the reef flat were performed using manta tows. Tows took place around areas of shallow fringing reef. This approach allows large areas of reef to be surveyed rapidly, examining broad scale patterns in reef condition. A single observer was towed behind a boat along the perimeter of the outer reef. Tows were performed in 6 – 12 m depth at a speed of 6 – 8 km/h and lasted 2 minutes. Percentage cover of the categories live coral, dead coral, sponge, turf algae, macroalgae, rock, rubble, sand and crustose coralline algae (CCA) was estimated. Depth, visibility and the identity and number of any Red Listed species or crown-of-thorns starfish were recorded. The assistant on the boat recorded the GPS coordinates of the start and end of each Manta tow. This was repeated until the perimeter of the survey area was fully surveyed.

Roaming surveys were performed either whilst snorkelling or SCUBA diving. Roaming surveys were designed to be performed on reefs where transect surveys were not possible due to strong current, depth or reef morphology. 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 percentage cover was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and CCA. Percentage cover of coral, rock and turf algae. Underlying structure was categorised in eight growth forms: table, branching, massive, foliose, free-living, encrusting, digitate and others.

Where conditions allowed, transect surveys were conducted using SCUBA at a depth of 5 – 10 m. Six transects were performed 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, CCA.

"In the context of the range and scale of impacts threatening marine and island habitats across the Maldives it is important that a broad assessment of the state of these habitats be undertaken."

Zone	Atoll	Latitude	Longitude	Reef type	Inner Atoll	MPA	Manta Tow	Roaming Survey	Transect Survey	Island Survey
Banana Reef	North Malé	4°14'21.6"N	73°31'54.7"E	Thila	Yes	Yes	-	Yes	-	-
Bandos	North Malé	4°16'09.9"N	73°29'28.1"E	Fringing	Yes	-	Yes	Yes	Yes	-
Dhigulaabadhoo	Gaaf Dhaal	0°12'32.8"N	73°09'30.7"E	Fringing	-	-	Yes	Yes	Yes	Yes
Emboodhoo Finolhu	South Malé	4°06'03.5"N	73°31'34.2"E	Patch/Outer atoll/Lagoon	-	-	Yes	Yes	-	-
Embudhoo Kandu	South Malé	4°05'09.2"N	73°31'48.2"E	Channel	-	Yes	-	Yes	-	-
Farukolhu	Shaviyani	6°11'13.7"N	73°17'48.1"E	Fringing	-	-	Yes	Yes	Yes	Yes
Fushi Kandu	Dhaalu	2°59'48.1"N	72°55'45.4"E	Channel	-	Yes	-	Yes	-	-
Fushifaru Kandu	Lhavyani	5°29'42.9"N	73°31'23.1"E	Channel/Thila	-	Yes	-	Yes	-	-
Guraidhoo Corner	South Malé	3°53'33.4"N	73°28'03.5"E	Fringing/Channel	-	Yes	Yes	Yes	-	-
Hembadhoo	North Malé	4°28'53.4"N	73°23'33.2"E	Fringing	Yes	-	Yes	Yes	Yes	-
Hitadhoo Corner	Laamu	1°48'03.5"N	73°24'40.1"E	Channel	-	-	-	Yes	-	-
Huravalhi	Lhavyani	5°31'17.2"N	73°26'29.7"E	Fringing/Channel	-	-	Yes	Yes	Yes	-
Ihuru	North Malé	4°18'24.4"N	73°24'58.3"E	Fringing	Yes	-	Yes	Yes	Yes	-
Kandoomaa Thila	South Malé	3°54'24.9"N	73°28'49.8"E	Thila/Channel	-	-	-	Yes	-	-
Keylakunu	Haa Dhaal	6°36'07.8"N	73°00'30.4"E	Fringing	Yes	-	Yes	Yes	Yes	Yes
Koattey Addu	Addu	0°34'42.1"S	73°05'38.2"E	Fringing/Outer atoll	Yes	Yes	-	Yes	Yes	-
Kuramathi	Rasdhoo	4°15'32.7"N	72°58'58.8"E	Fringing/Outer atoll	-	-	Yes	Yes	Yes	-
Kuredu	Lhavyani	5°33'00.4"N	73°27'58.7"E	Fringing/Outer atoll	-	-	Yes	Yes	Yes	-
Kuredu Express	Lhavyani	5°33'18.5"N	73°28'37.6"E	Channel	-	Yes	-	Yes	-	-
Kurumba	North Malé	4°13'34.9"N	73°31'11.2"E	Fringing	Yes	-	Yes	Yes	Yes	-
Madivaru	Rasdhoo	4°15'51.8"N	72°59'59.1"E	Channel	-	-	-	Yes	-	-
Manta Point	Addu	0°36'46.2"S	73°09'15.8"E	Fringing/Channel	-	-	-	Yes	-	-
Medhufaru	Noonu	5°42'47.3"N	73°24'52.0"E	Fringing/Lagoon	-	-	Yes	Yes	Yes	-
Nassimo Thila	North Malé	4°17'22.6"N	73°32'14.4"E	Thila	Yes	Yes	-	Yes	-	-
Olhuveli	Laamu	1°49'00.4"N	73°24'19.5"E	Fringing/Outer atoll	-	-	Yes	Yes	Yes	-
Orimas Thila	Noonu	5°50'54.8"N	73°15'09.8"E	Thila	Yes	-	-	Yes	-	-
Rasfari Corner	North Malé	4°26'30.2"N	73°21'45.9"E	Fringing	Yes	Yes	-	Yes	-	-
SAMPA	South Ari	3°28'01.9"N	72°50'20.4"E	Fringing/Channel/Outer atoll	-	Yes	Yes	Yes	Yes	-
Thoondi Area	Fuvahmulah	0°16'32.3"S	73°25'07.6"E	Fringing	-	Yes	-	Yes	-	-
Thresher Point	Fuvahmulah	0°19'20.9"S	73°26'51.4"E	Limestone platform	-	-	-	Yes	-	-
Turtle Point	South Malé	3°50'47.4"N	73°24'48.8"E	Thila	Yes	-	Yes	Yes	-	-
Vabbinfaru	North Malé	4°18'35.7"N	73°25'26.6"E	Fringing	Yes	-	Yes	Yes	Yes	-
Velavaru	Dhaalu	2°58'47.1"N	73°00'58.5"E	Fringing/Outer atoll/Lagoon	Yes	-	Yes	Yes	Yes	-
Villingili	Seenu	0°41'04.6"S	73°11'28.4"E	Fringing	-	-	Yes	Yes	Yes	-

Table 3. Name and location of all zones surveyed. Reef type describes the reef formation within the zone. Yes values indicate whether this type of survey was performed at this zone.

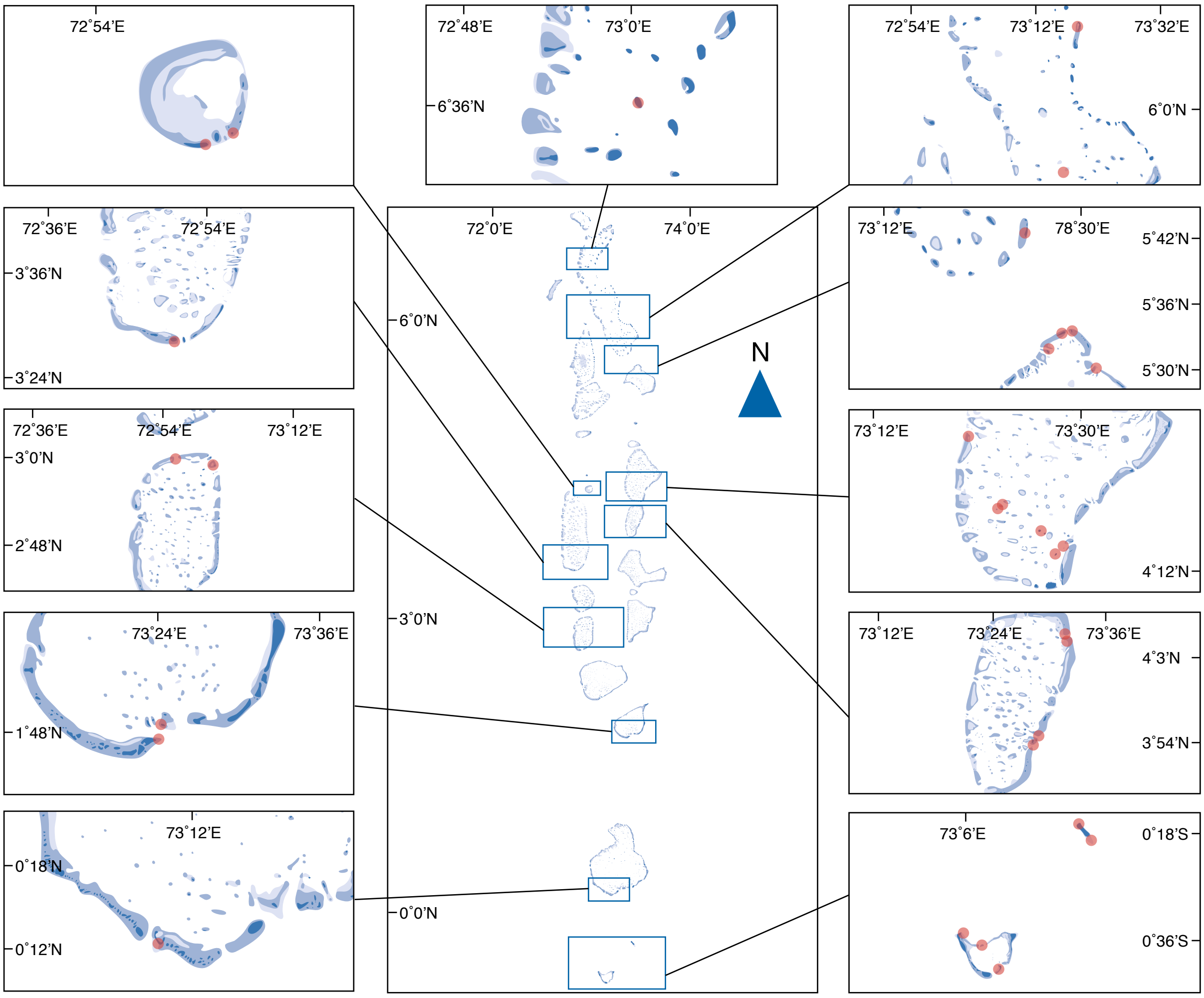

Figure 1. Distribution of survey zones throughout the Maldives archipelago. The location of each of the 34 survey zones are shown in black circles on each area inset. Green indicates reef area, blue indicates shallow lagoon area and grey indicates islands.

Fish community

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 provided a representation of how common these families were. Fish communities were also 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) sharks and rays were counted and identified to species and their total length estimated to the nearest 5 cm. Parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), Batfish (*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. The biomass of butterflyfish and groupers was calculated using the length-weight conversion: W = aLb, 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).

Reef resilience

Reef resilience metrics including coral recruitment, reef structural complexity and abundance of key herbivore species were measured. 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. 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). Abundance of key herbivorous fish species was calculated on transects following the method described above. Abundance of the corallivorous crown-of-thorns (*Acanthaster planci*) and pin-cushion (*Culcita schmideliana*) starfish species was quantified during roaming surveys.

Endangered, vulnerable or threatened species

The International Union for the Conservation of Nature (IUCN) Red List classifications, critically endangered (CR), endangered (EN), vulnerable (VU) or near threatened (NT) were used to identify marine species globally at risk that were present in the Maldives. Roaming surveys were used to quantify the presence and abundance of these species as this method covers a large area, which increases the likelihood of encounter. Five pre-selected VU coral species were selected as they were easy to identify during the rapid surveys (*Table S- 4*). All fish and turtle species (CR, EN, VU or NT (*Table S- 3*) were counted and identified to species.

Island surveys

Island habitats were classified into five vegetation habitats: coastal fringe, pond fringe, mangrove bay fringe, mangrove forest and inland forest, based on location. 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 to a handheld GPS (Garmin etrex 20x) for navigation to the point. At each 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 percentage 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 conducted. The number of survey points for each zone was dependent on zone size (*Table 4*). If identified points were inaccessible, a new point was taken as close as possible to the original and the survey was performed here.

Mangrove forest survey

The mangrove forest area of Keylakunu was surveyed using a combination of 5 x 5 m and 1 x 1 m plots. Plot locations were selected using a stratified haphazard approach and the GPS coordinates of each plot was recorded using a Garmin GPS maps 64s handheld GPS. Within each large plot, all trees > 2 m tall were counted and identified to species and the circumference at breast height of the largest tree of each species present was measured. This was converted to diameter at breast height (DBH). Where present, the numbers of taproots were counted. Within a smaller 1 x 1 m plot at the centre all trees < 2 m tall were counted, identified to species and classified as either immature (0.5 m – 2 m tall) or seedlings (< 0.5 m tall). In addition to the plot surveys, the location and DBH of all grey mangrove (*Avicennia marina*) trees within the mangrove forest area was recorded.

Island	Zone type	Number of points
Dhigulaabadhoo	Coastal fringe	63
Dhigulaabadhoo	Mangrove bay fringe	9
Dhigulaabadhoo	Pond fringe	28
Farukolhu	Coastal fringe	38
Farukolhu	Inland forest	10
Farukolhu	Mangrove bay fringe	38
Farukolhu	Pond fringe	38
Keylakunu	Coastal fringe	29
Keylakunu	Inland forest	30
Keylakunu	Mangrove forest	23

Table 4. Number of surveys points in each vegetation habitats on the three islands surveyed.

Island fauna

Bird surveys were conducted concurrent with terrestrial habitat surveys. All birds observed were counted and identified to species. Mangrove fish surveys were conducted using three approaches: (1) during high tide where the bay was sufficiently deep, surveys were conducted from a boat, (2) during low tide, surveys were conducted on foot, concurrent with mangrove bay fringe zone surveys, and (3) where possible, surveys of submerged mangrove prop root habitat were conducted while snorkelling. All fish were counted and identified to family and where possible to species.

Statistical analysis

To test for significant differences in benthic and fish communities among survey sites, a one-way analysis of variance (ANOVA) was used where data were normally distributed and a Kruskal-Wallis test if not. Distribution of the data was tested for normality using the Shapiro-Wilk test. Mangrove fish species diversity was calculated using the Shannon-Weiner diversity index. All statistical analysis was performed using R version 3.4.0 (R Core Team 2017).

RESULTS

Marine communities

Coral reef benthos

Manta tows were conducted at 18 of the zones surveyed. The number of tows required to survey the reef area ranged from 5 in turtle point, South

Malé to 141 around the outer reef of the South Ari marine protected area (SAMPA). The dominant substrate in this reef area was rock consisting of bedrock and dead coral skeleton. Mean coral cover of reef flat areas was less than 9.3% ± 3.5 (*Figure 2*).

Zones contained a range of growth forms (*Figure 3*). However, three zones: Kuramathi, Kurumba (massive) and Turtle point (branching) were dominated by a single growth form. Massive (12 zones) and branching (11 zones) growth forms formed a dominant part of the reef structure across many zones surveyed.

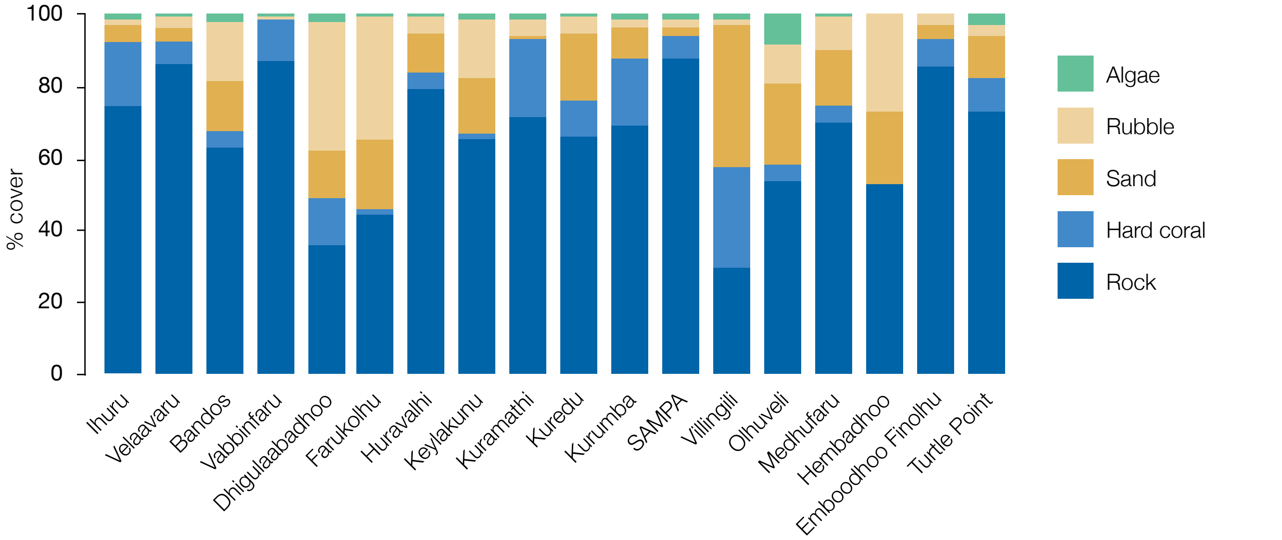

Figure 2. Percentage cover of each substrate category: rock (dark blue), hard coral (light blue), sand (yellow), rubble (red) and algae (green) from manta tows.

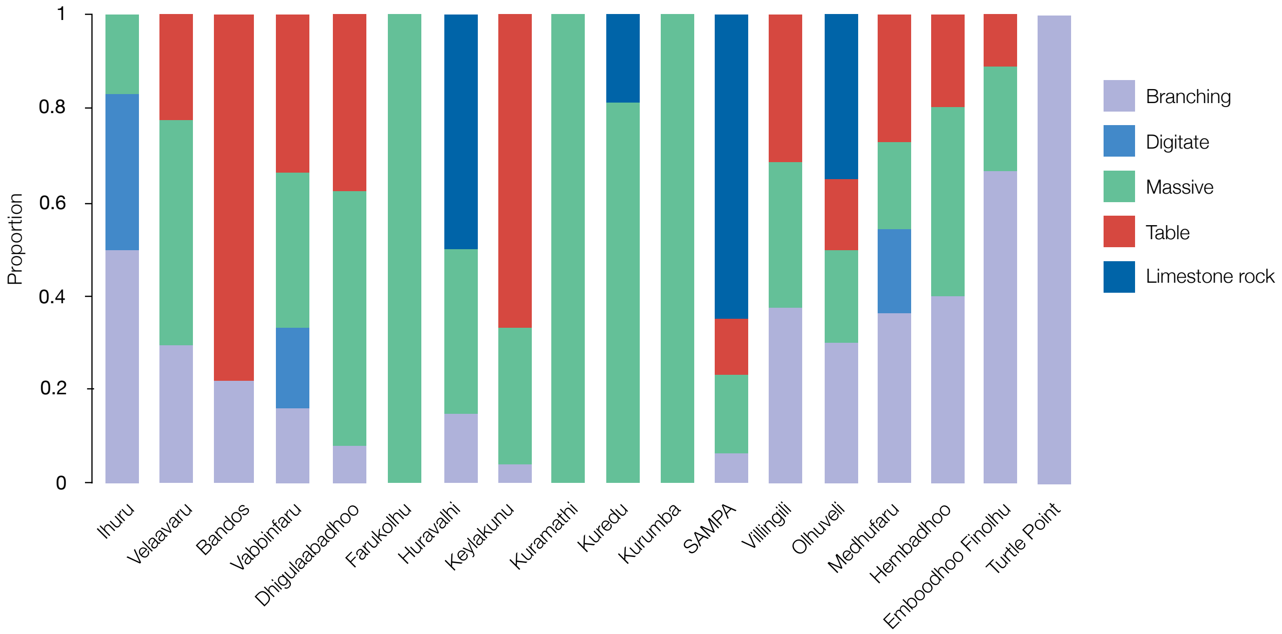

Figure 3. Proportion of hard coral, rock or turf algae covered rock on the reef in each zone in the different growth form categories: branching (violet), digitate (light blue), massive (green), table (red) and limestone rock (dark blue) from manta tows.

Mean live coral cover determined by roaming surveys was 19.2% ± 3.0 for the country (*Figure 4*). The highest coral cover was found at Thoondi area in Fuvahmulah atoll (54% ± 5.5). Villingili and Manta point Addu, both located on the most southern atoll of Maldives also had high coral covers, with a mean of 42.5% ± 5.5 and 38.6% ± 10.8. The lowest coral cover was found in Hembadhoo (3.0% ± 0.3) followed by Turtle point (5.0% ± 1.2). It should also be noted that these two reefs had the highest percentage of turf and macroalgae cover (*Figure 5*). The highest percentage of soft corals (28.3 ± 6.1) and sponge (15.7 ± 3.9) were recorded from Nassimo Thila. There was no significant difference in coral cover between protected and un-protected marine areas (ANOVA, $p > 0.05$).

Mean live coral cover determined by the transects was 19.6% ± 2.6 (Figure 6). Villingili (38.1 ± 3.1) had the highest coral cover, followed by Medhufaru (29.3% ± 2.0). The lowest coral cover was recorded in Bandos (5.3% ± 0.8) and Hembadhoo (6% ± 4.0). The remaining sites ranged between 10.5 – 28.2% live coral cover. Three categories of algae (Turf, Macro and Crustose Coralline algae (CCA)) were recorded in the transect surveys (*Figure 7*). The mean algal cover (three algae groups combined) was 16.9% ± 4.1 for the country. The highest combined algae cover was recorded at Dhigulaabadhoo (32.3% ± 15.1) and Hembadhoo (28.4% ± 3.1). The lowest algae cover was found at Medhufaru (5.9% ± 1.5) and Kuredu (6.7% ± 1.0). When separated by category, Hembadhoo had the highest percentage cover of turf algae (22.7% ± 4.5), Dhigulaabadhoo had the highest macroalgae cover (15.8% ± 4.8.) and SAMPA (8.8% ±1.6) had the highest CCA cover.

"35 genera of hard corals from 17 different families were observed during the project. Porites was the most common family, making up 39.5% of all hard coral cover observed. This was followed by Acroporidae (12.1%) and Merulinidae (11.81%) families."

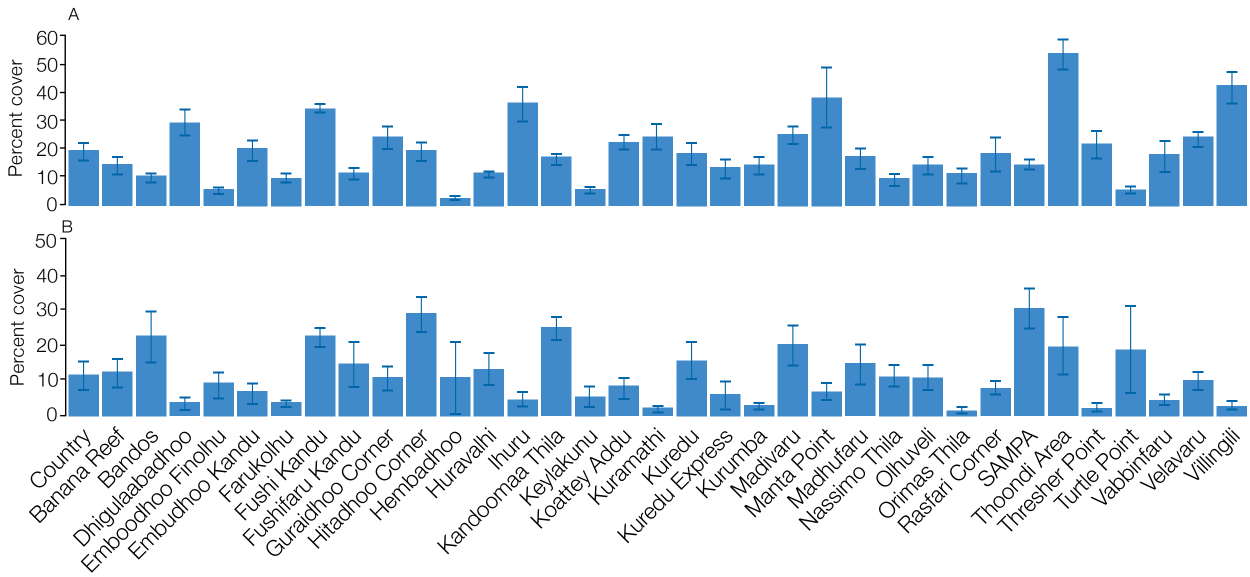

Figure 4. Percentage cover of (A) hard coral, (B) algae categories combined averaged across roaming surveys. Error bars show standard error.

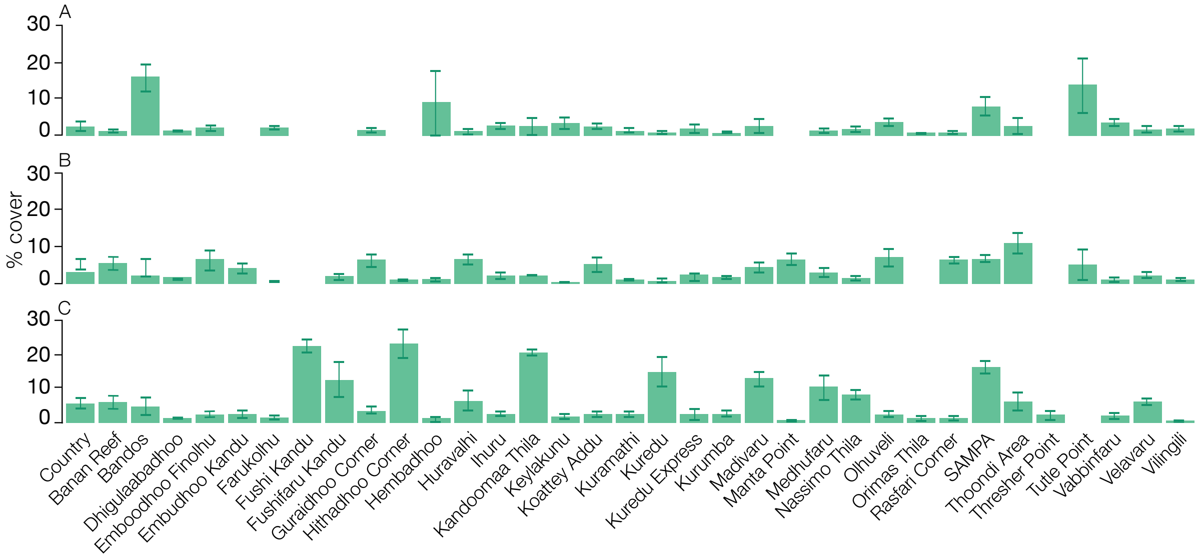

Figure 5. Percentage cover of (A) turf algae, (B) macroalgae and (C) crustose coralline algae (CCA) averaged across roaming surveys. Error bars show standard error.

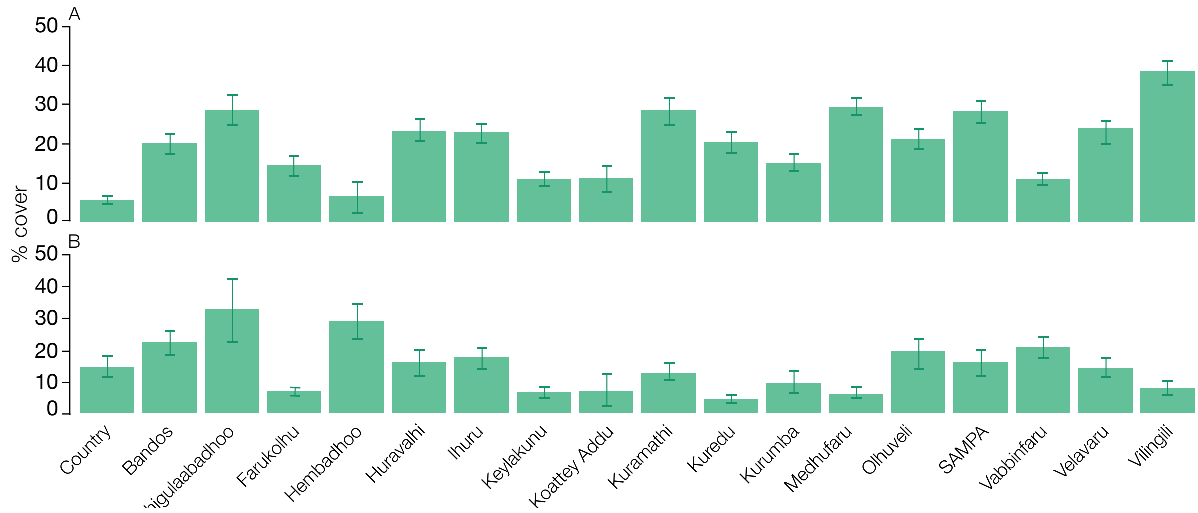

Figure 6. Percentage cover of (A) hard coral, (B) algae averaged across transect surveys. Error bars show standard error.

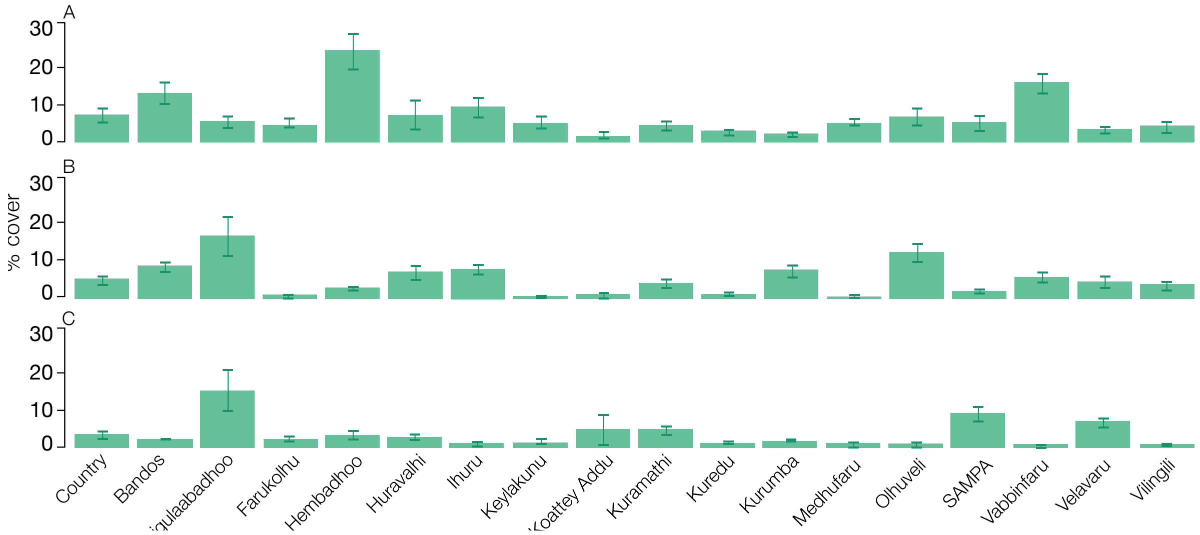

Figure 7. Percentage cover of (A) turf algae, (B) macroalgae and (c) CCA averaged across transect surveys. Error bars show standard error.

35 genera of hard corals from 17 different families were observed during the project. Porites was the most common family, making up 39.5% of all hard coral cover observed (*Figure 8*). This was followed by *Acroporidae* (12.1%) and Merulinidae (11.81%) families. The least commonly observed families were Diploastreidae and Lobophylliidae making up just 0.1% and 0.3% respectively of all coral cover. Most of the reefs had a high proportion of massive and encrusting coral growth forms. Foliose and free-living types of corals were rarely observed.

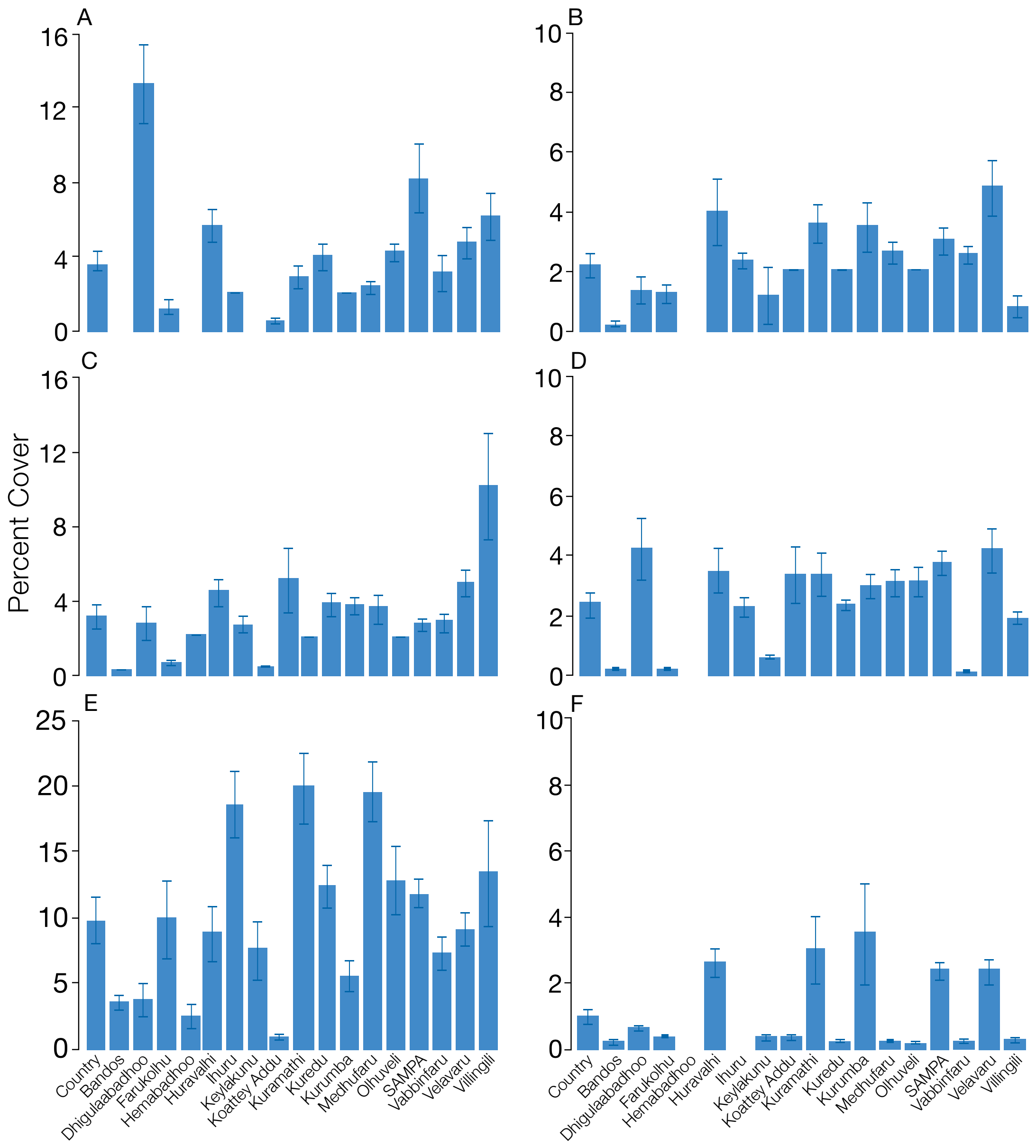

Figure 8. Percentage cover of the six most commonly observed coral families (A) Acroporidae, (B) Agariciidae, (C) Merulidae, (D) Pocilloporidae, (E) Poritidae and (F) Psammocoridae averaged across transects. Error bars indicate standard error.

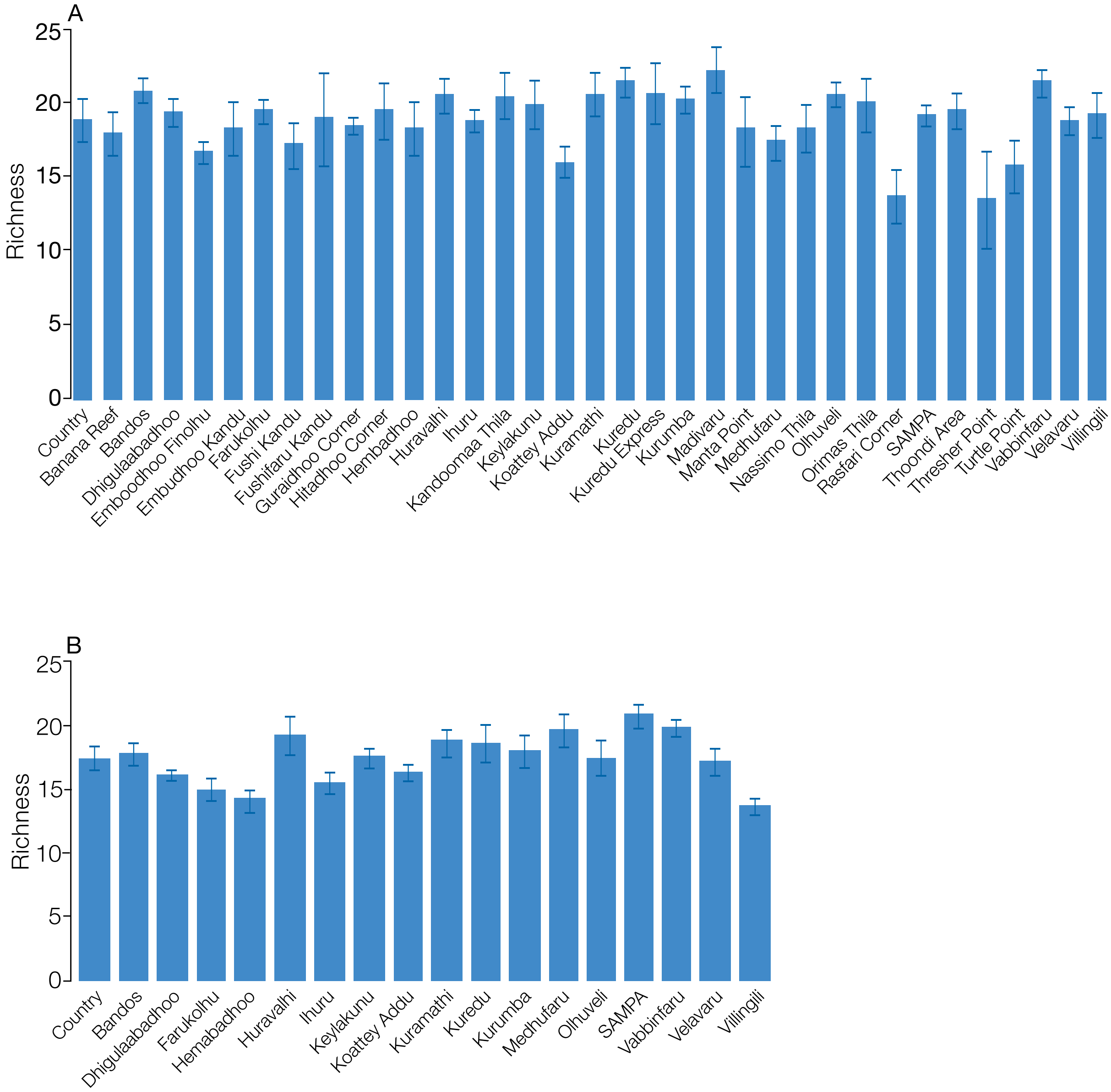

Figure 9. Number of fish families averaged across (A) roaming surveys and (B) transect surveys. Error bars show standard error.

Fish Communities

Richness of fish families was high across all zones, with a country mean of 18.8 ± 1.3 families and 17.9 ± 1.0 for roaming and transect surveys respectively (*Figure 9*). There was no spatial pattern in fish family richness, with reefs in northern, southern and central zones all exhibiting a range of richness.

In total 53 different fish families were observed during the timed roaming surveys and 48 families were observed on the transect surveys. The median observation time on roaming surveys was less than one minute for wrasse (Labridae), triggerfish (Balistidae), surgeonfish (Acanthuridae), parrotfish (Scaridae), damselfish (Pomacentridae) and butterflyfish (Chaetodontidae) (*Figure* 10). All fish families observed on a minimum of 30 surveys had a median time to first observation of less than 7 minute. Damselfish were the most commonly observed fish family on both roaming and transect surveys (Figure 11). The next most commonly observed families across both surveys were butterflyfish, groupers (Serranidae), parrotfish, surgeonfish and wrasse.

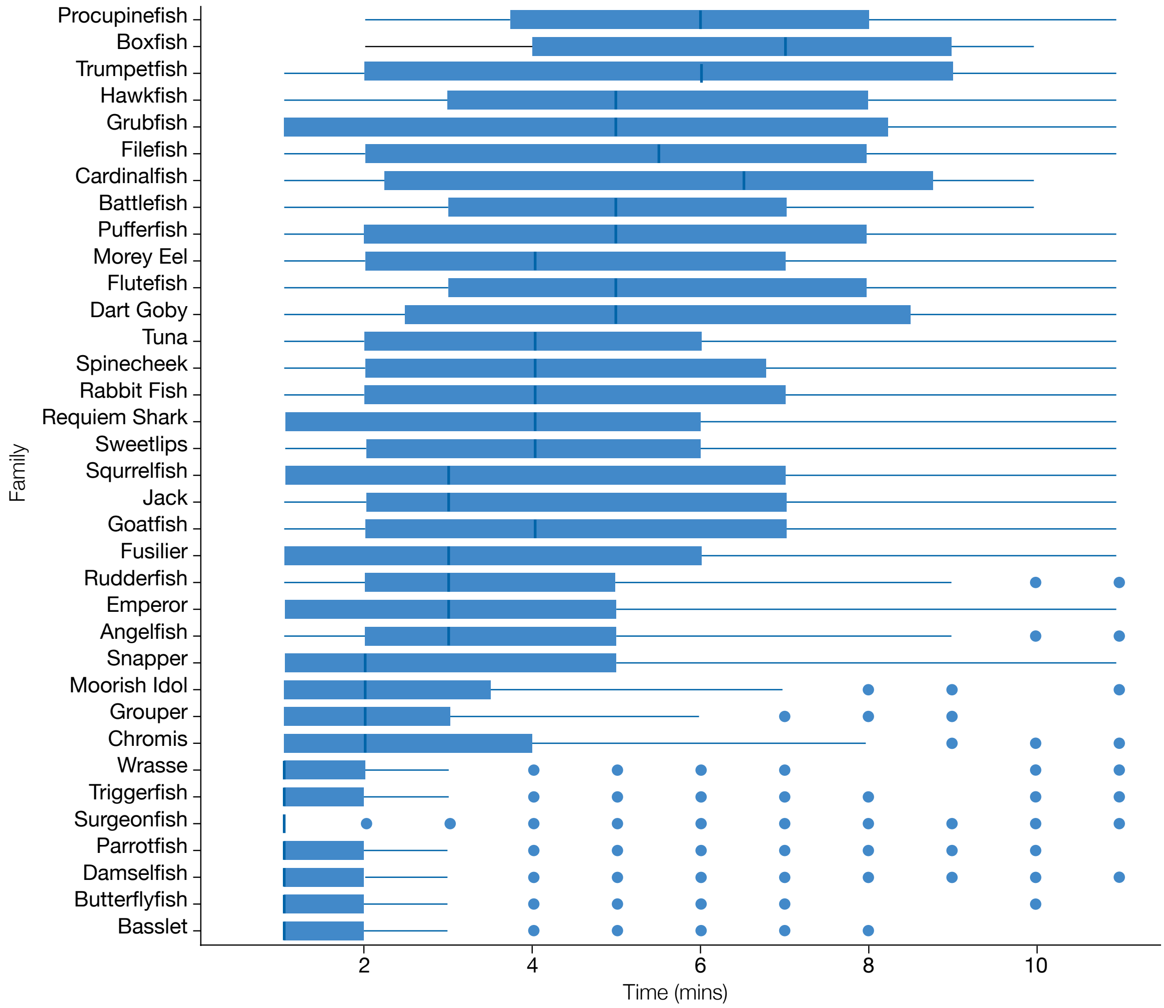

Figure 10. Boxplot showing the time to first observation of fish families on roaming surveys (n=354). Only families that were observed on a minimum of 30 surveys are included. Thick blue lines represents the median values.

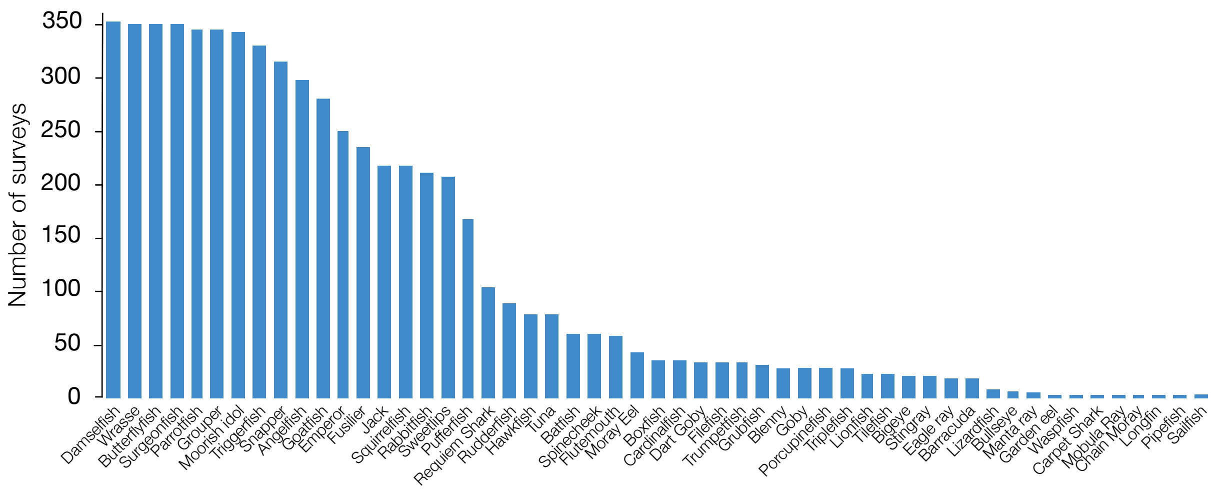

Figure 11. Frequency of occurrence of fish families on roaming surveys (n=354).

Butterflyfish and groupers were common throughout the surveys; both families were in the top five frequently most observed families on both roaming and transect surveys (*Figure 11*). These families were, on average, observed within the first 6 minutes across all survey zones. Biomass of butterflyfish (ANOVA, p< 0.01) and groupers (ANOVA, p< 0.001) varied significantly across survey zones (*Figure 12*). Kuramathi (325 g/ m^2 ± 70) had the highest biomass of butterflyfish and Bandos (1062 g/100 m^2 ±145) and Vabbinfaru (1072 g/ m^2 ± 207) had the highest grouper biomass. Hembadhoo had the lowest biomass of both families (54 g/ m^2 ± 14) and (138 g/ m^2 ± 51) respectively.

Species richness of both butterflyfish

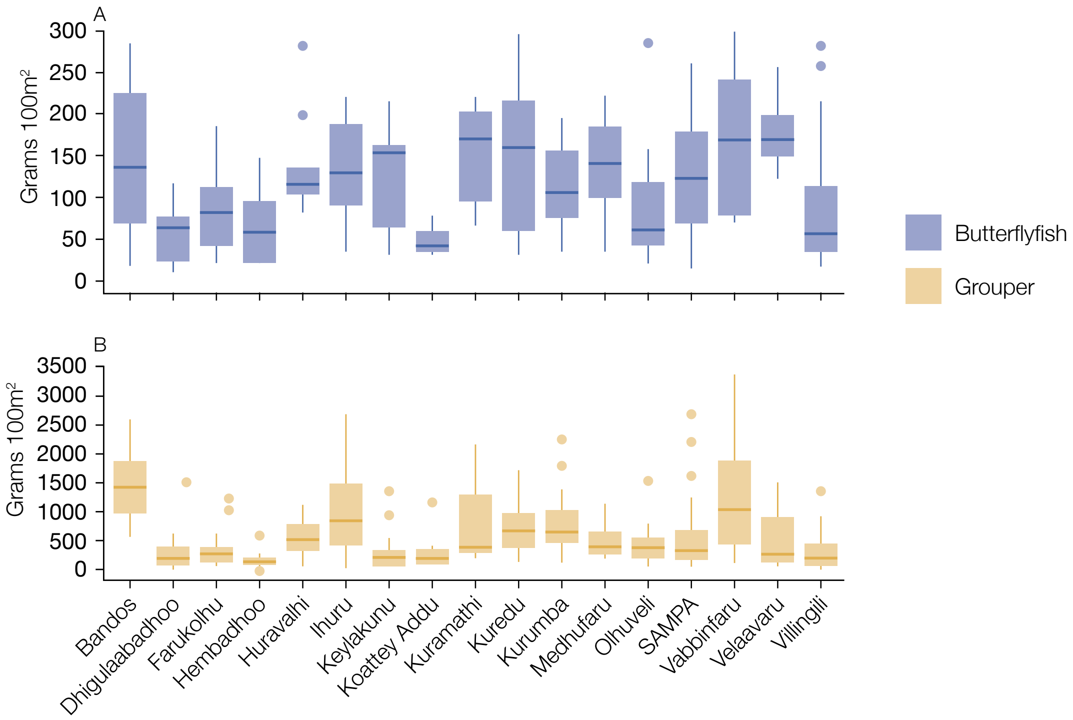

Figure 12. Butterflyfish (A) and grouper (B) biomass from transect surveys. Thick black line represents median value. Note the y axis of graphs are on different scales.

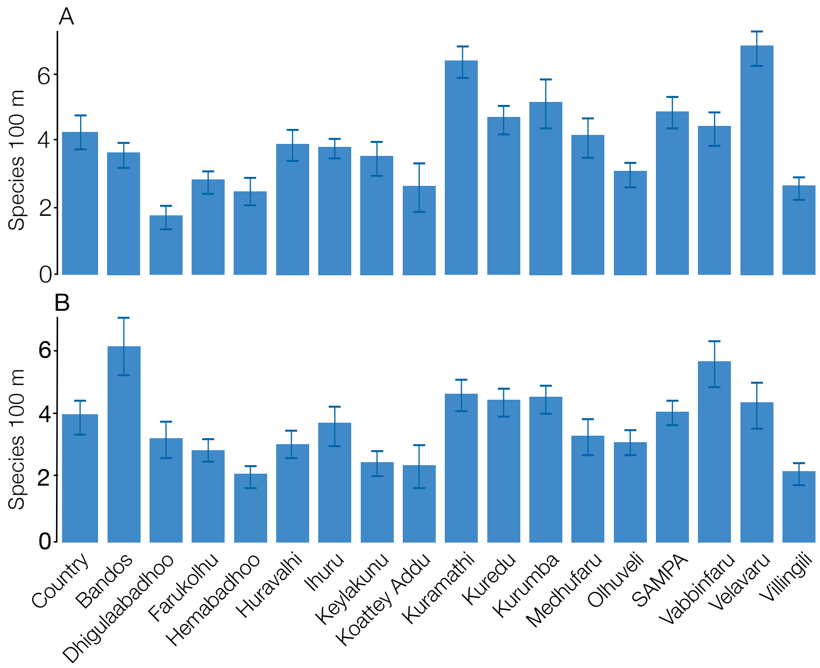

Figure 13. Species richness for (A) butterflyfish and (B) groupers averaged across transect surveys. Error bars show standard error.

(ANOVA, $p< 0.01$) and groupers (ANOVA, $p< 0.001$) varied significantly across survey zones. Velavaru (6.8/100 m^2 ± 0.5) and Kuramathi (6.3/100 m^2 ± 0.5) had the highest butterflyfish species richness (*Figure 13*). Bandos (6.1/100 m^2 ± 0.9) Vabbinfaru (5.5/100 m^2 ± 0.7) had the highest grouper species richness. Hembadhoo had the lowest richness of both butterflyfish (2.4/100 m^2 ± 0.4) and groupers (2/100 m^2 ± 0.3).

Reef resilience

Mean density of coral recruits was 7.4/ m^2 ± 0.7 (*Figure 14*). Density of recruits varied significantly between survey zones (ANOVA, $p< 0.05$). Highest density of coral recruits was observed in Kuramathi (15.7 /m^2 ± 1.5), followed by Kurumba (11.3/m^2 ±1.6). Low densities of coral recruits were found on reefs of Keylakunu (2.8/ m^2 ± 0.3) and Hembadhoo (3.1/ m^2 ± 0.6). Recruits belonging to 15 different families were recorded. Agariciidae (24.6%) and Acroporidae recruits were most abundant, while Euphylliidae (0.7%) and Milleporidae (0.2%) were rarely observed.

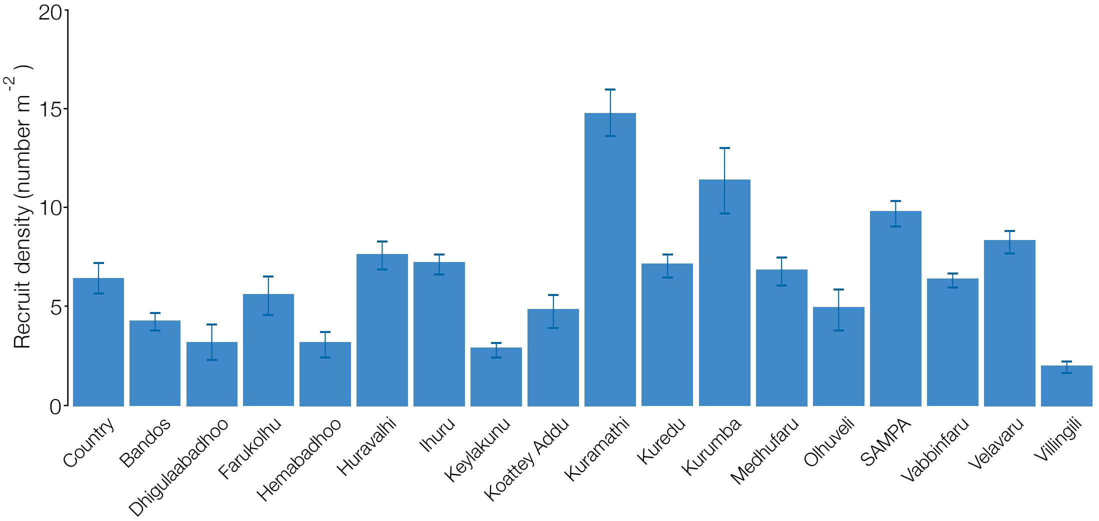

Figure 14. Density of coral recruits per m^2 averaged across transects. Error bars show standard error.

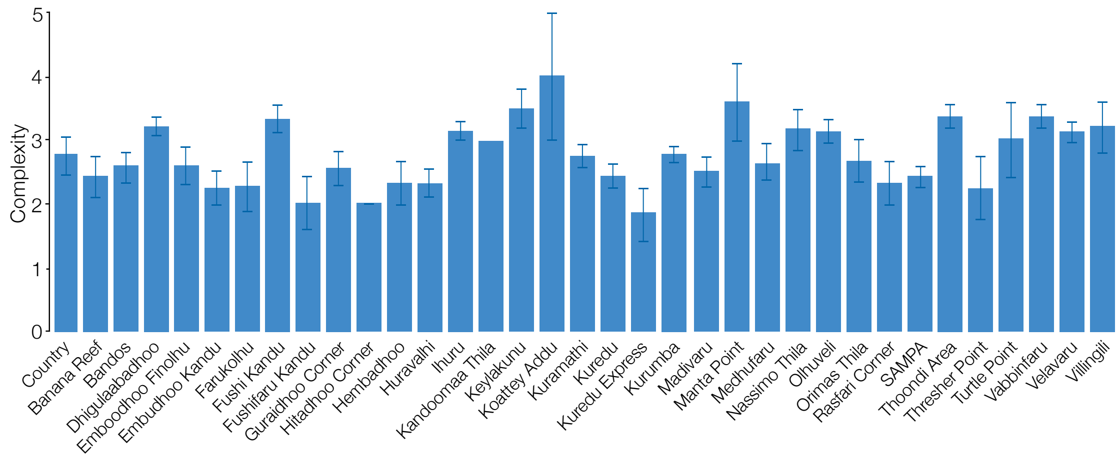

Figure 15. Structural complexity level estimates averaged across roaming surveys. Error bars show standard errors. Complexity was estimated on a scale of 0 – 5, where 0 was completely flat and 5 highly complex.

Coral reef structural complexity ranged from 1 – 5, with no sites completely flat (*Figure 15*). Mean structural complexity value for the country was 2.8 ± 0.3, and there was no significant variation in structural complexity (ANOVA, $p> 0.05$). However, Koattey in Addu atoll had the highest complexity across the zones with a mean of 4 ± 0.8, and Kuredu Express had the lowest complexity, with a mean of 1.8 ± 0.4. The zones with the lowest complexity were channel areas.

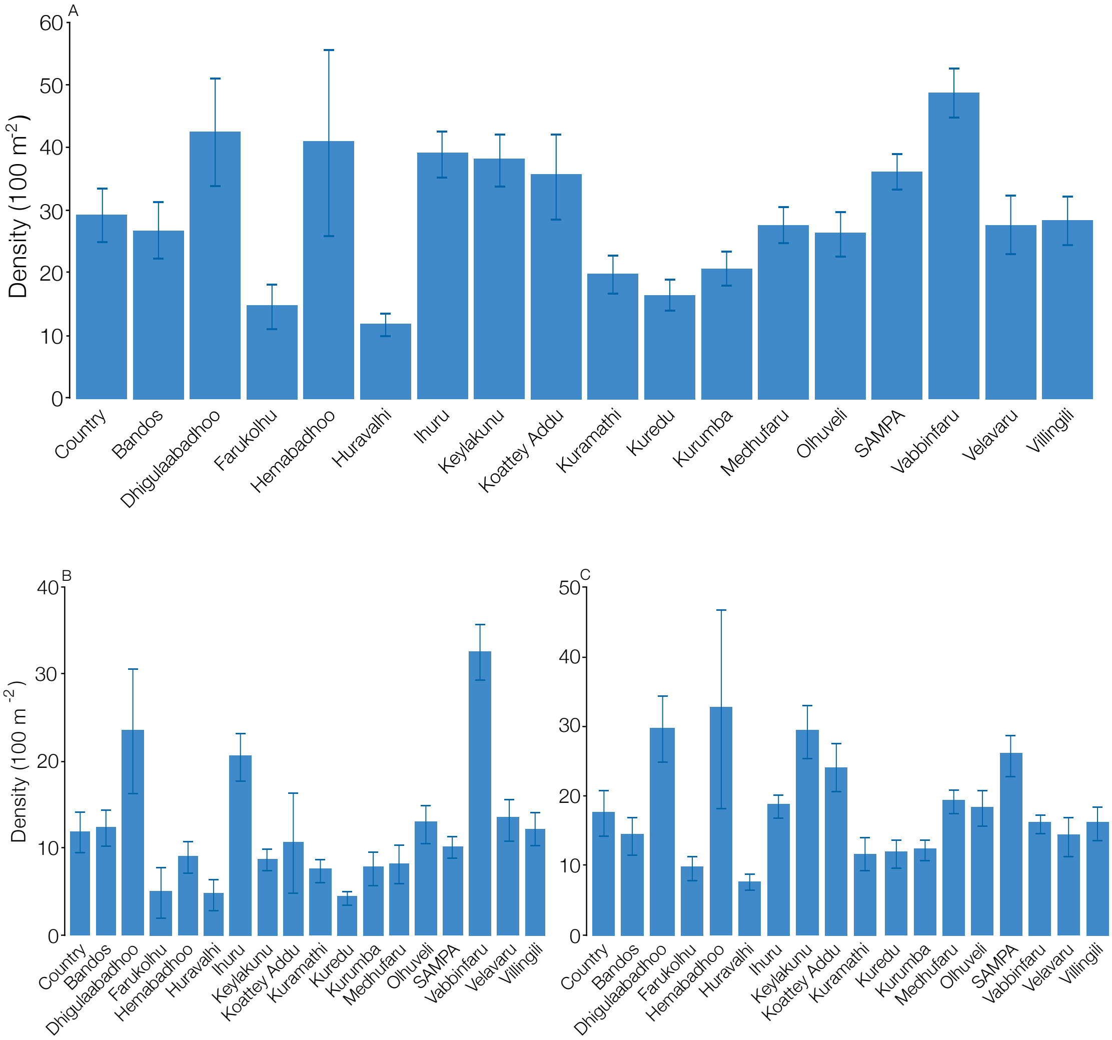

Figure 16. Density/100 m² of (A) all herbivores, (B) parrotfish and (C) surgeonfish averaged across transects surveys. Error bars show standard errors.

The abundance of surgeonfish and parrotfish, two key families of herbivorous fish, was high across all survey sites. They were among the most frequently observed families on both roaming and transect surveys (*Figure 11*). Both families had a mean time of first observation of less than five minutes at all zones except at Fushifaru Kandu. The densities of all herbivores groups varied significantly among survey zones (ANOVA, $p< 0.001$). Vabbinfaru had the highest density (48.6/100 m² ± 3.7) and Huravalhi had the lowest density (16.4/100 m² ± 2.5) (*Figure 16*). The difference in herbivore densities is primarily from a disparity in parrotfish numbers. Parrotfish (ANOVA, $p< 0.001$) densities also varied significantly among survey zones. However, parrotfish densities were over twice as high in the Vabbinfaru survey zone (32.4/100 m² ± 3.1) as those in any other zone, except Ihuru and Dhigulaabadhoo (*Figure 16*), a zone less than 500 m away. Though surgeonfish densities were generally more similar across the country, the zones did vary significantly (ANOVA, $p< 0.01$). Hembadhoo was found to have the highest densities of surgeonfish (34.3/100 m² ± 16.2), though the numbers varied greatly between survey sites within the zone.

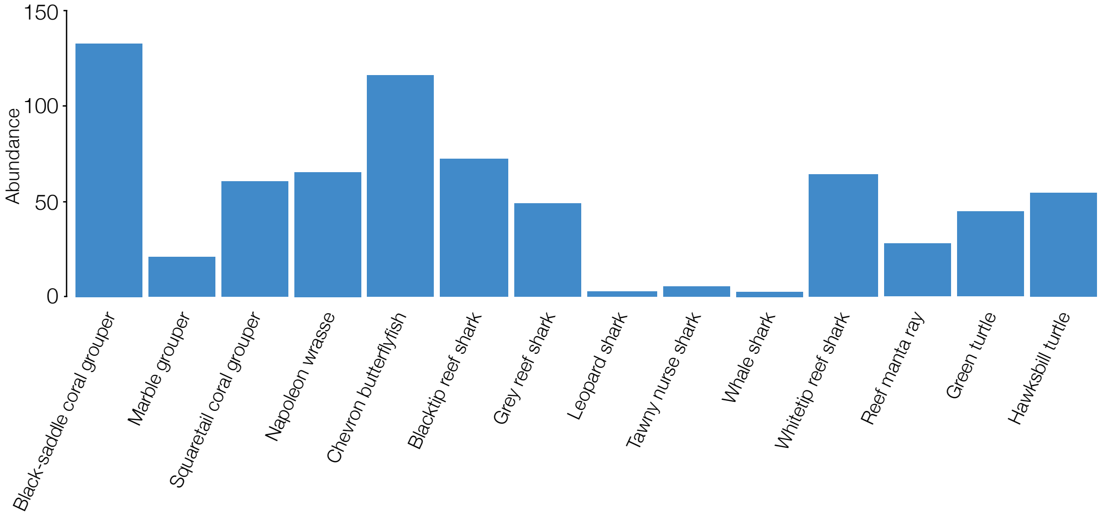

Figure 17. Total number of each IUCN Red Listed (CE, EN, VU, NT) non-coral fauna encountered during all roaming surveys (n=354).

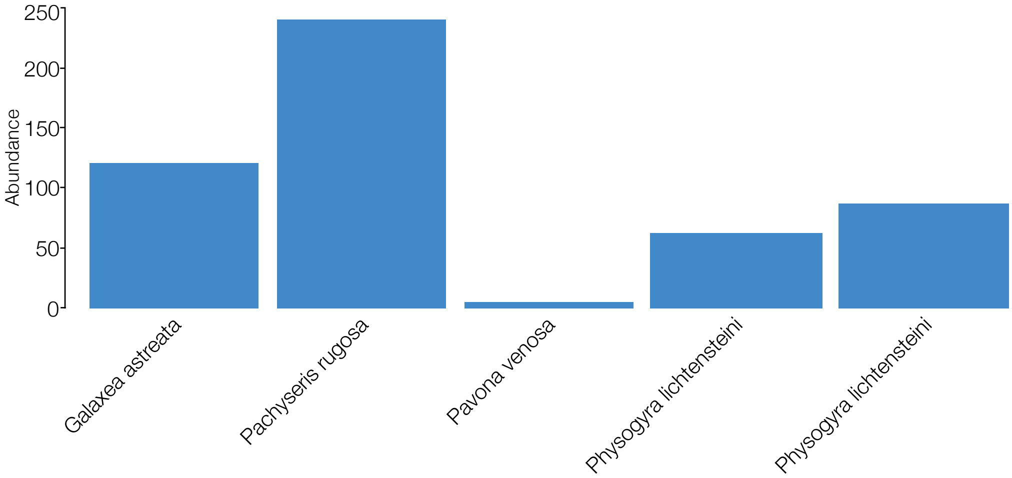

Figure 18. Total number of the five pre-selected IUCN Red Listed (EN, VU, NT) coral species found across roaming surveys (n=191) performed. Note, collection of Red Listed coral data began part way through the surveys and therefore was not collected on all roaming surveys.

Endangered species

IUCN Red Listed species (critically endangered (CR), endangered (EN), vulnerable (VU) or near threatened (NT)) of teleost fish, elasmobranchs, turtles or invertebrates were present at all zones. Giant clams (*Tridacna sp.*) were the most frequently observed with high numbers observed at Huravalhi (n=83) and Medhufaru (n=70) (*Figure 17*). High numbers of Red Listed grouper species were observed across the country. The most commonly observed Red Listed coral species was *Pachyseris rugosa*, however four of the five selected species were commonly observed throughout the roaming surveys (*Figure 18*).

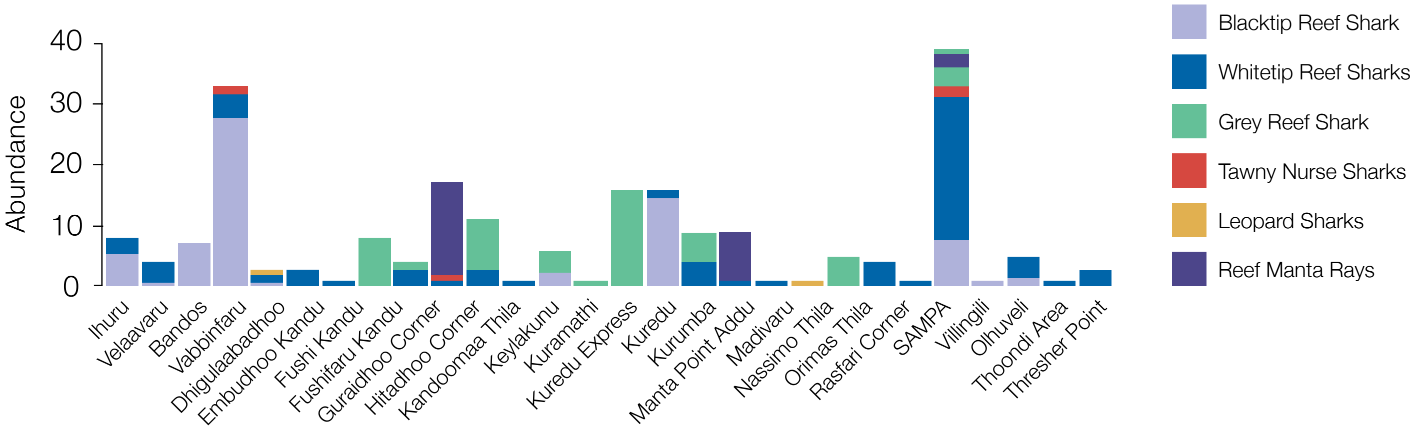

Figure 19. Total number of each IUCN Red Listed (EN, VU, NT) elasmobranch species observed: blacktip reef sharks (white), whitetip reef sharks (loose dots), grey reef shark (checkered), tawny nurse sharks (thick diagonal stripes), leopard sharks (grey), reef manta rays (narrow diagonal stripes) and whale sharks (gridded pattern).

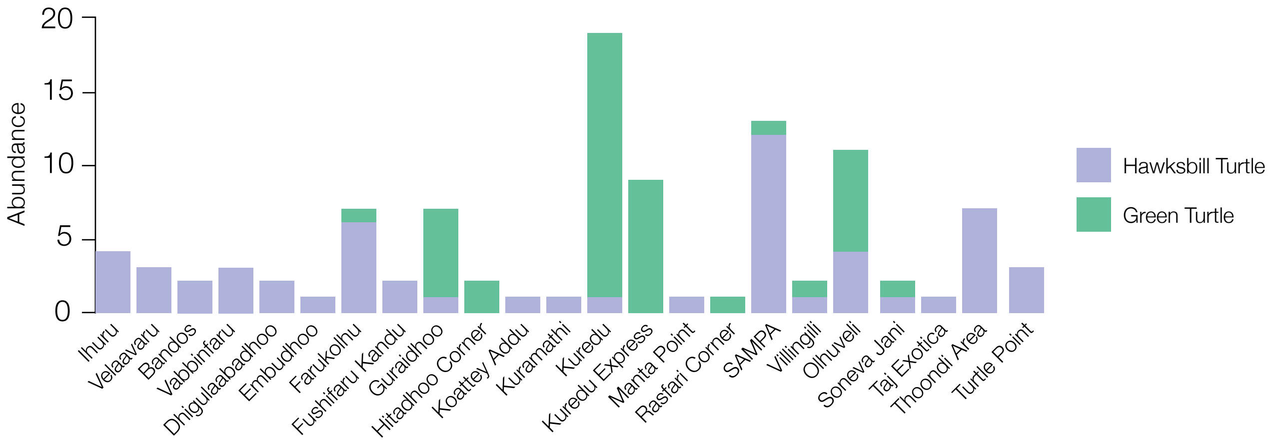

Figure 20. Total number of each IUCN Red Listed (CR, EN) turtle species observed in the 23 survey zones in which they were encountered. Hawksbill turtle (loose dots) and green turtle (thick diagonal stripes).

Elasmobranchs were observed in 26 of the 34 zones surveyed (*Figure 19*). Vabbinfaru had high numbers of reef sharks, especially the blacktip reef shark (*Carcharhinus melanopterus*). The highest numbers of grey reef sharks (*Carcharhinus amblyrhynchos*) were found in channel zones such as Fushifaru Kandu, Kandoomaa Thila, Kuredu Express and Madivaru. Hitadhoo Corner and Manta Point Addu had the highest numbers of reef manta rays (*Manta alfredi*). SAMPA had the greatest number of elasmobranch species and was the only zone where whale sharks (*Rhincodon typus*) were observed. Only one individual was recorded on roaming surveys, however, three additional individuals were observed during transit to and from surveys.

Two turtle species were observed during surveys, the hawksbill turtle (*Eretmochelys imbricata*) and the green turtle (*Chelonia mydas*). Hawksbill turtles were observed in 21 of the 34 zones surveyed (*Figure 20*). Green turtles were found in nine of the zones surveyed, all of which were near seagrass areas.

Island communities

Vegetation habitats

Plant communities differed noticeably between the three vegetation habitats (*Figure 21*). The coastal fringe area was dominated by four species, iron wood (*Pemphis scidula*), sea lettuce (*Scaevola taccada*), sea hibiscus (*Talipariti tiliaceum*) and beach gardenia (*Guettarda speciosa*). These four species formed over 60% of the coastal vegetation in Keylakunu and greater than 80% in both Dhigulaabadhoo and Farukolhu. Despite having the shortest coastline at 3.7 km, Keylakunu had the highest number of plant species (11) in its coastal habitat, followed by Dhigulaabadhoo, 6.9 km (7) and then Farukolhu, 7.4 km (5).

Pond habitats were present on both Dhigulaabadhoo and Farukolhu. The pond fringe vegetation in Dhigulaabadhoo was made up of three plant species: iron wood, sea hibiscus and sea trumpet (*Cordia subcordata*). Though the ponds at Farukolhu were also dominated by a few species, overall the plant assemblage was more diverse. The pond system at Farukolhu was much more varied with both large and small ponds, many of which were connected by narrow channels. Some of these ponds were also connected to the sea during high tide, whereas those on Dhigulaabadhoo were isolated from the sea and in many cases appeared to be drying up.

Inland areas differed between the two islands surveyed. Farukolhu was a much narrower island, and had large, brackish ponds. These factors meant there was little forest development across the island. The same species present in the coastal habitat were found inland as well. The habitat inland in Keylakunu could be considered a true forest. Surveys identified 15 different plant species in Keylakunu, many of which could be considered a true forest species. Compared to nine species inland on Farukolhu, all of which were scrub or coastal vegetation. Keylakunu had an average vegetation height of 14 m and had a maximum height of greater than 30 m. The sediment is more soil-like and is likely to be more nutrient rich than on the other islands due to microbial breakdown of the high leaf litter. There were also agricultural plots in Keylakunu. All three islands had coconut groves and there was evidence that these were regularly harvested. Rats were observed on all three islands, as well as cats on Keylakunu.

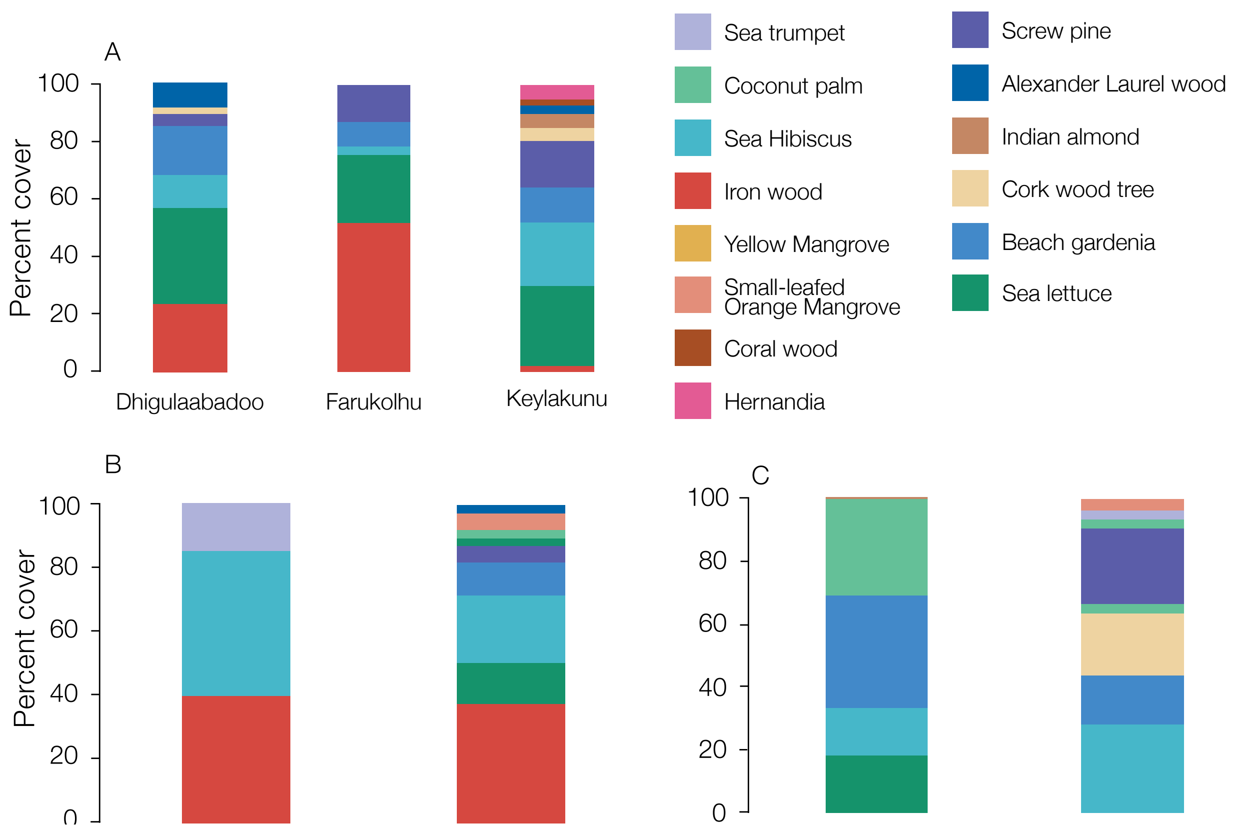

Figure 21.Percent cover of plant species in (A) coastal fringe, (B) pond fringe and (C) inland forest area averaged across surveys.

Figure 22. Three coastal zones (A) coastal fringe, (B) pond fringe and (C) inland forest

Mangrove vegetation

The mangrove habitat at both Dhigulaabadhoo and Farukolhu was a semi-enclosed bay with vegetation around the bay fringe. The habitat at Keylakunu was a large depression on the east and south-eastern area of the island which was connected to the sea only by water flowing through the porous coral bedrock. Mangrove trees grew throughout this depression in < 5 cm of water with 2 – 3 small ponds of deeper, 20 – 50 cm, water. The vegetation around the bay in Dhigulaabadhoo was dominated by the mangrove species yellow mangrove (*Ceriops tegal*) and red mangrove (*Rhizophora mucronata*) (*Figure 23*). The bay in Farukolhu was much larger than the one in Dhigulaabadhoo and had two smaller bays off the main bay. This is reflected by a greater richness of plant species. The bay itself was dominated by yellow mangrove and the mangrove associate iron wood, smaller bays had additional mangrove associates including, sea hibiscus, sea lettuce and screw pine (*Pandanus tectorius*). Mangrove species were limited to a narrow band on the water's edge and was rarely deeper than a single tree.

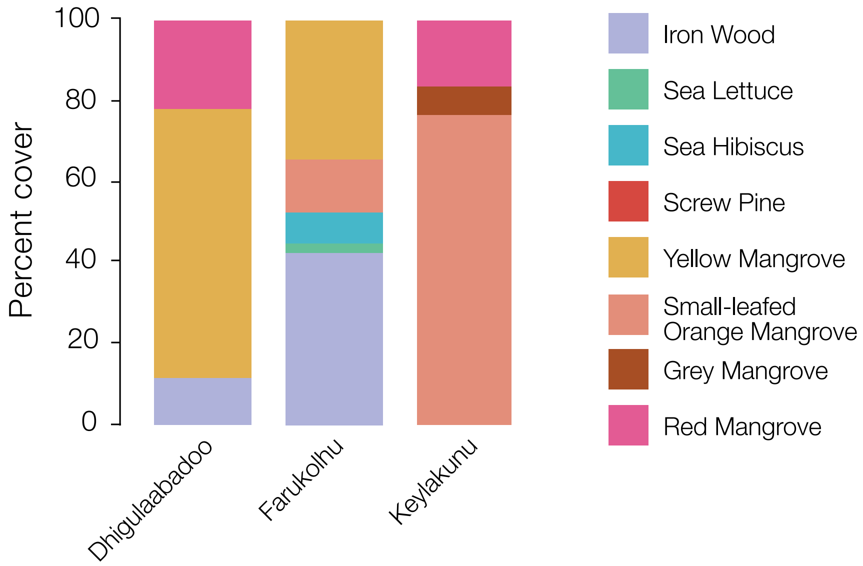

Figure 23. Percentage cover of plant species: iron wood (violet), sea lettuce (green), sea hibiscus (turquoise), screw pine (red), yellow mangrove (yellow), small-leafed orange mangrove (cream), grey mangrove (brown) and red mangrove (pink) averaged across surveys in the mangrove bays in Dhigulaabadhoo and Farukolhu and the mangrove depression in Keylakunu.

The mangrove depression in Keylakunu was dominated by small-leafed orange mangrove (*Brugeira cylindrica*) (*Figure 23*) with dense growth through most of the area. Trees less than 0.5 m tall were particularly abundant, (*Table 6*) forming a dense mat across the area. Grey mangrove trees (*Avicennia marina*) were present at a density of 1.1/20 m^2 within the mangrove depression. Red mangrove was present in high densities (1.7/ m^2 ± 0.4) in the deeper water area in the south east of the depression, with thick growths of tap roots (2.3/ m^2 ± 0.5). In total, 95 grey mangrove trees were identified and measured on Keylakunu (*Table 7*). Mean DBH was 0.95 m ± 0.05 m. The largest DBH measured was 2.36 m and a maximum height of greater than 15 m. Outside of the main mangrove area, there were numerous small depressions with mangrove growth. The majority of these consisted of 1 – 5 small-leafed orange mangrove trees with a number of seedlings. There was a single mangrove apple (*Sonneratia caseolaris*) tree growing at the northern end of the mangrove area.

Tree height (m)	Number/ m^2	Standard error
> 2 m	1.2	0.2
0.5 - 2 m	14.1	3.1
< 0.5 m	34.5	4.3

Table 6. Density of the three different size classes of small-leafed orange mangrove (*Brugeira cylindrica*) trees in the mangrove depression area of Keylakunu.

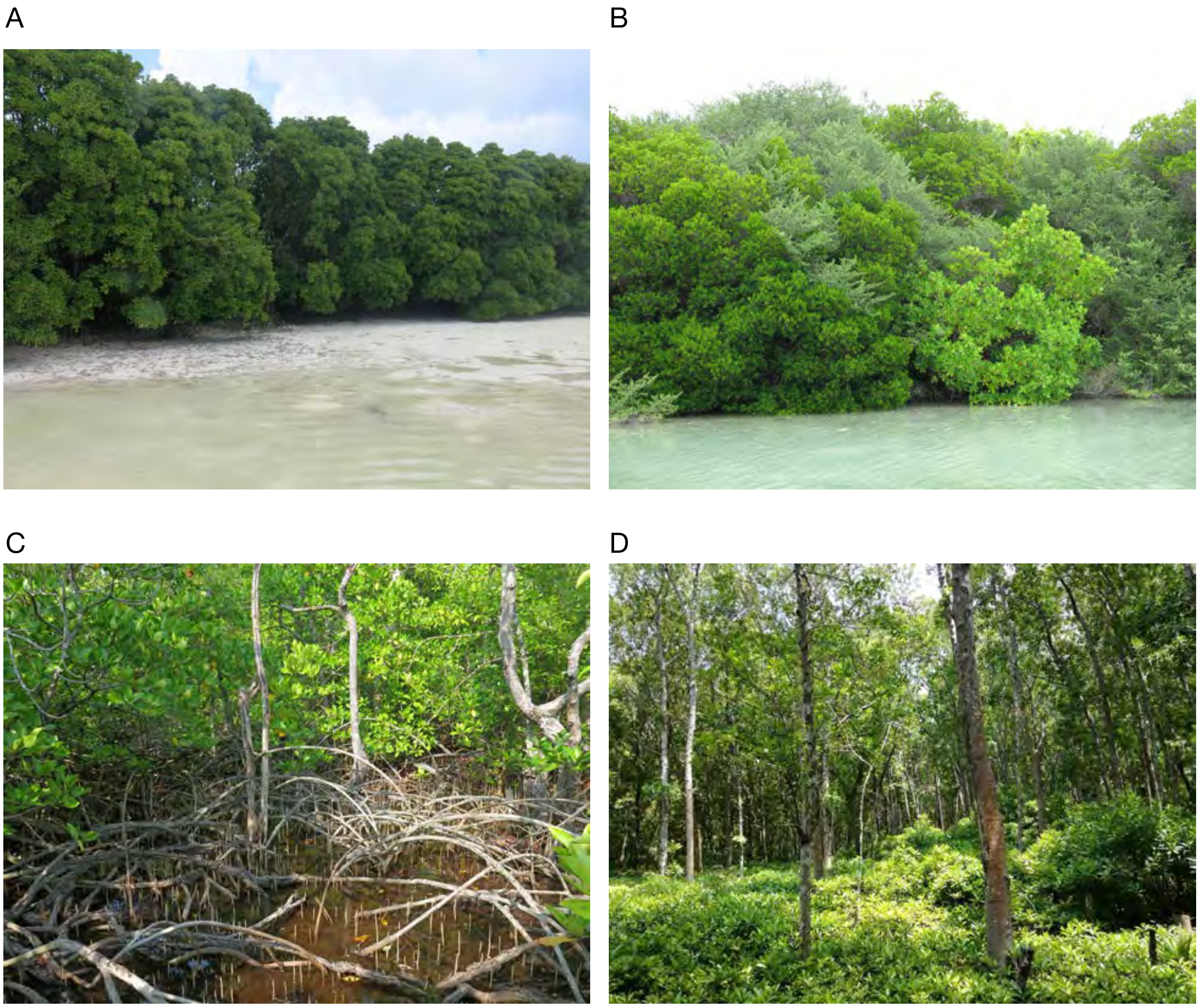

Figure 24. Mangrove habitats at (A) Dhigulaabadhoo, (B) Farukolhu and (C and D) Keylakunu.

Scientific name	Common Name	Abundance
Bruguiera cylindrica	Small-leafed orange mangrove	Abundant
Avicennia marina	Grey mangrove	Common
Rhizophora mucronata	Red mangrove	Common
Excoecaria agallocha	Blind-your-eye mangrove	Occasional
Sonneratia caseolaris	Mangrove apple	Rare (single tree)

Table 7. Relative abundance of mangrove in Keylakunu.

Avian communities

Of the 180 bird species known from the Maldives, 13 were observed during these surveys (*Figure 25*). Crows (*Corvus splendens*) and Asian koel (*Eudynamys scolopaceus*) were the most abundant species. Species were not distributed evenly throughout the island habitats (*Figure 26*). Crows and Asian koels were dominant only in the coastal fringe and inland forest habitats. Grey heron (*Ardea cinerea*) was observed across most island habitats. Keylakunu was the only island where the white-tailed tropical bird (*Phaethon lepturus*) was recorded. Many individuals were observed flying over the inland island habitat.

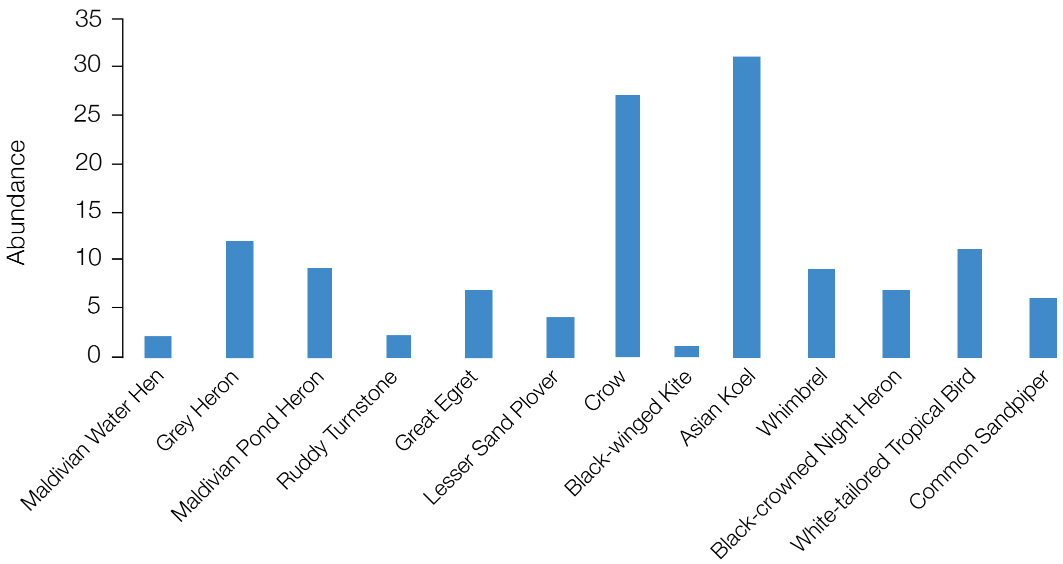

Figure 25. Total abundance of all bird species observed on surveys.

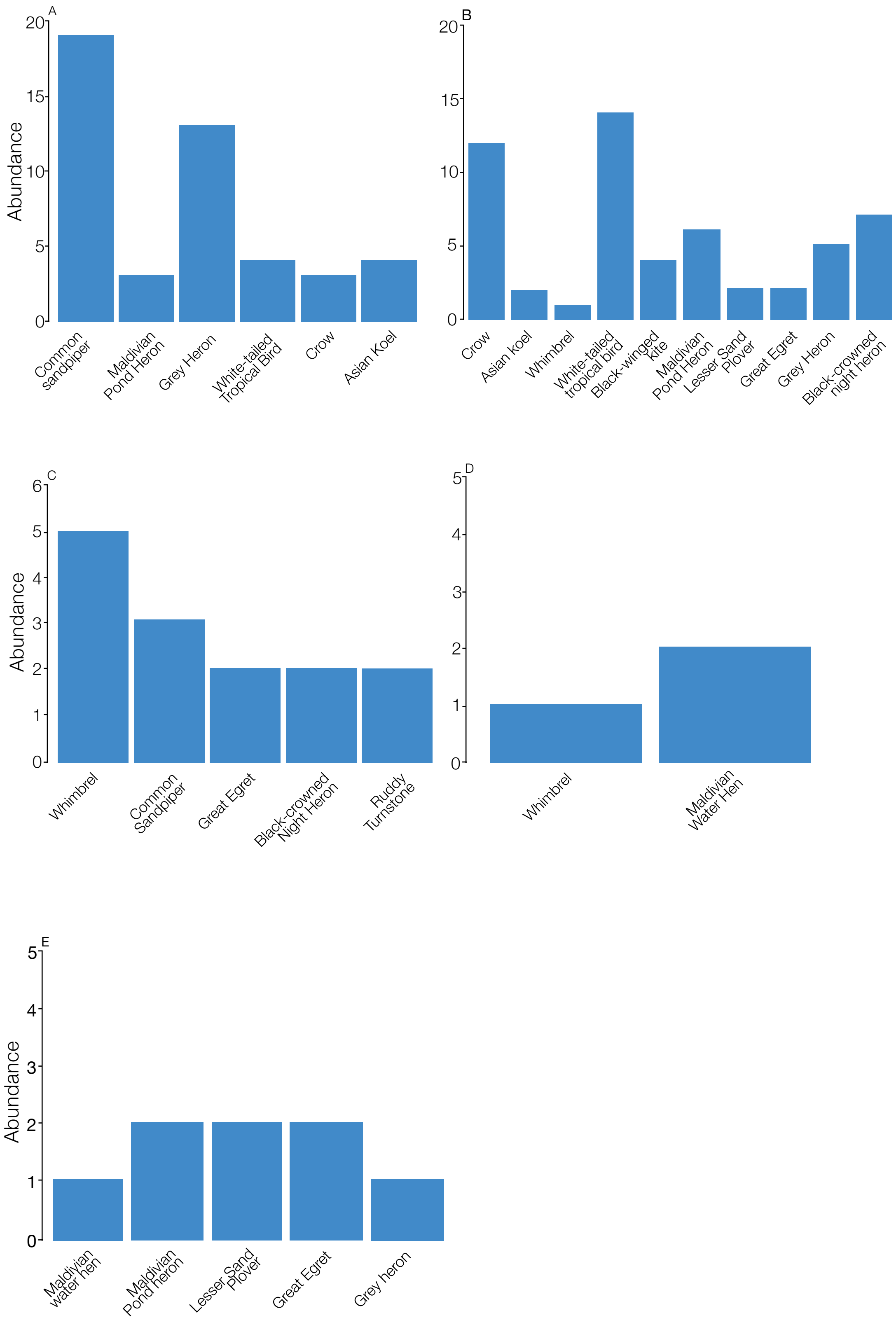

Figure 26. Total abundance of each bird species observed in the (A) coastal fringe, (B) Inland, (C) pond fringe, (D) mangrove bay and (E) mangrove forest habitats.

Mangrove bay fauna

The area of the mangrove bay of Farukolhu was more than 192,000 m^2 and the fringe had a perimeter of 3,350 m. The area of the mangrove bay of Dhigulaabadhoo was more than 15,500 m^2 and the fringe had a perimeter of 725 m. Farukolhu mangrove bay is 12 times larger in area and the perimeter of the fringe is nearly five times greater, providing more area for fauna. The number of species observed and the total abundance of all the species was greater at Farukolhu than at Dhigulaabadhoo (*Table S- 5*). The most abundant species at Farukolhu was the mangrove whipray (*Himantura granulata*) (n=69) and the most abundant species at Dhigulaabadhoo was the black-tip pursemouth (*Gerres oyena*) (n=169). Farukolhu had a higher fish species diversity and evenness than Dhigulaabadhoo. A high number of juvenile sharks and rays were found at both sites indicating these habitats are important nursery grounds for these species. Both bays had juveniles of commercially important fish species such as blue-fin jacks, snapper and emperor species. Juvenile sicklefin lemon sharks (*Negaprion acutidens*), a vulnerable (IUCN Redlist) species, were observed in the bay at Farukolhu.

Figure 27. Underwater mangrove habitat at Dhigulaabadhoo.

DISCUSSION

This report presents one of the widest ranging ecological surveys of the natural environment in the Maldives to date. A combination of the same seven surveyors travelled to 34 zones across 12 different atolls, providing a unique consistency to the dataset. Coral reef ecosystems across the country had been heavily impacted by the 2016 coral bleaching event. Many sites had a live coral cover significantly below values typical for healthy reefs in the country (Pisapia et al. 2016, Ibrahim et al. 2017). Reef fish communities were found to be highly diverse and abundant across almost all survey zones. Notably, the biomass and richness of both butterflyfish and groupers was high across much of the Maldives. Functionally important herbivorous fish were quickly observed in all zones and, where recorded, their densities were high, although they did vary significantly. The plant communities observed in coastal fringe and pond fringe habitats were broadly similar at all three islands surveyed, however the inland forest and mangrove depression areas on Keylakunu were both unique among the islands. The significant mangrove developments observed around bays and in island depressions were a positive sign for the environment; however, there were noticeable human impacts in all these areas, which may lead to future habitat degradation. Abundant bird and juvenile fish populations in the mangrove bays highlighted the value of these areas to the ecosystem.

Marine

The live coral cover of the Maldives found here ranged between 3 – 54%. Few reefs appeared to have escaped the impacts of the bleaching event. The average coral cover of 19.6% found here was similar to the values reported during or immediately following periods significant disturbances (Zahir et al. 2010, Pisapia et al. 2016). Outside of these periods national averages are 30 – 50% (Pisapia et al. 2016). There was a variation in impact and those zones with higher coral covers, such as Medhufaru in the north, Ihuru and Kuramathi in the centre and Thoondi Area and Manta Point Addu in the south may play an important role in seeding reef regrowth within these regions. However, a more detailed study examining species composition and larval transports would be required to confirm this. Quantitative observations carried out during 2016 bleaching of Maldivian coral reefs found a mean live coral cover of 27%. Sites ranged between 2 – 88% among the different atolls surveyed (Ibrahim et al. 2017). Those surveys also identified several “hope spots” which experienced relatively low bleaching and retained relatively high live coral cover. Reef geomorphology, exposure and latitude are some of the factors which influence the reefs susceptibility to reef degradation events such as coral bleaching and storm damage and may account for some of this variation. In some cases, coral reefs that were decimated in 1998 bleaching recovered from less 2% to over 50% coral cover, though took more than 10 years (Zahir et al. 2010). Therefore, there is hope for even those reefs severely impacted by the 2016 bleaching event.

The fish communities on Maldivian reefs have not received much survey attention (but see: Sluka and Miller 2001, Mcclanahan 2007) as they are relatively unexploited locally and do not undergo the same visibly striking shifts as corals following disturbances. However, specialist coral feeding fish, such as butterflyfish are particularly susceptible to the immediate impacts of coral loss (Graham et al. 2009). Reef degradation will impact fish communities through habitat degradation (Paddack et al. 2009) that over time can lead to a simplification of fish communities (Alvarez-Filip et al. 2015) and less resilient reef communities (Pratchett et al. 2014).

The increase in tourism in the country has increased the demand for reef fish and the high value of large grouper in the live restaurant trade and increase in export of fresh/chilled groupers (MEE 2015) means there is a greater risk to reef fishery target species. On healthy reefs, groupers are one of the most diverse families of fishes in the Maldives with over 40 species having been previously identified (MEE 2015). 22 species were enumerated during these surveys. The average biomass of groupers across the country is greater than or equal to that found on many other reefs in the region (Mcclanahan 2011, Karkarey et al. 2014). However, larger apex grouper species were not a large portion of the communities surveyed, which would be expected in an undisturbed system (Friedlander et al. 2010). Abundances and diversity per transect was also not as great as previously found (Sluka and Reichenbach 1995), however these grouper specific surveys may be more likely to detect cryptic species. The increasing pressure on this family means that they should be a central part of any future national monitoring plan. Many of the reefs surveyed were resort house reefs which confers a level of protection from fishing.

The most sought after grouper species including the marbled grouper (*Epinephelus fuscoguttatus*), squaretail coral grouper (*Plectropomus areolatus*), blacksaddle grouper (*Plectropomus laevis*) and roving coral grouper (*Plectropomus pessuliferus*) (MEE 2015) are listed as “Near Threatened” or “Vulnerable” on the IUCN Red List, and as such the Maldives has a responsibility to protect these species. The abundance of groupers found in this study support the idea that a sustainable grouper fishery is feasible in the Maldives, however it requires a well-developed and enforced management plan.

The average densities of herbivores found in this survey were in line with the higher ranges found in the only previous examination of this group in the country (Sluka and Miller 2001). 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 on surveys 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. Additionally, parrotfish have 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 the any change in sea level.

The majority of reefs surveyed were between medium and high complexity (2 – 5 visual grade). Such levels of complexity are associated with greater fish diversity and abundance (Wilson et al. 2007, Newman et al. 2015). Higher levels of structural complexity have also been identified as a key component of coral reef resilience (McClanahan et al. 2012, Graham et al. 2015). Structural complexity appears to provide a broad range of ecosystem services beneficial to fish and coral communities (Graham and Nash 2012). It is through these services, such as increased settlement area, shelter from predation and attenuation of wave energy that it acts to aid reef resilience. The surveys indicate a spatial variation in coral recruitments within the atolls; such variation may lead to variable rates of recovery in live coral cover. Taxonomic variability among the sites was high with 5 – 10 coral families recorded. Taxonomic patterns of recruitments observed in this study were similar to previous studies (McClanahan 2000, Zahir et al. 2002), with *Pavona* species belonging to the Agariciidae family most frequently recorded. There are zones, which may be at greater risk of not recovering following the bleaching event. These include those with low extant coral and little recruitment combined with and low densities of either parrotfish or surgeonfish. This includes zones such as Keylakunu and Hembadhoo which, despite high surgeonfish abundance had few other resilient reef characteristics suggesting these reefs will take longer to recover.

"Herbivorous fish, such as parrotfish and surgeonfish are important in preventing coral reefs from becoming overgrown by algae following disturbances..."

The study has further highlighted the importance of the Maldivian marine environment to endangered species. Sharks and turtles were particularly prominent throughout the country. These groups are highly valuable to the tourism industry. A study in 1993 estimated shark-observing dives contributed US$2.3 million to the local economy in a single year (Anderson and Ahmed 1993). This value is likely to have increased greatly over the last 25 years. There are also numerous locations to observe manta rays whilst diving or snorkelling across the country and the estimated worth of tourist visits to these sites is approximately US$ 8.1 million/year in direct revenue (Anderson et al. 2011). There are multiple projects setup across the country to monitor and study these important species and the data collected should greatly assist in the creation of national management plans which ensure sustainable and rewarding interactions with these animals.

The IUCN Red Listed coral *Pachyseris rugosa* is thought to particularly susceptible to bleaching (Hoeksema et al. 2014), and in many areas of its range colonies have been harvested for the aquarium trade (Hoeksema et al. 2014). However, this species appeared to particularly common throughout the surveys, and was observed at all but two zones. The pearl bubble coral *Physogyra lichtensteini*, was also relatively common throughout the surveys is known to create a specialist habitat for small crustaceans, creating a unique habitat and providing an important ecosystem service. Management approaches should account for these endangered species, ensuring the areas where they are found are afforded the necessary protection to prevent further loss.

Crown-of-thorns starfish (COTS) (*Acanthaster planci*) were noticeably absent from most sites surveyed during this project. Where observed, they were found in low numbers, well below outbreak levels. Many sites across the Maldives have suffered significant coral loss due to COTS outbreaks (Sluka and Miller 1999, Morri et al. 2015, Solandt et al. 2015). Additional outbreaks have been witnessed but have gone unreported in the literature, particularly on N. Malé atoll in 2014/15 (pers. comm. Steve Newman and Antonella Blue Inn Dive). The numbers witnessed during this project may be a result of the current low coral cover. Given the history of COTS outbreaks it is likely that where coral reefs do recover the starfish will return. This is of particular concern as those reefs with healthy or recovering coral populations will be important seed populations for nearby reefs.

A key target of this project was to examine multiple reef types across the country. This was achieved, with surveys performed on fringing reefs outer atoll reefs, thilas, and channels. The variability in reef types around the Maldives makes direct comparison between many of the zones surveyed impractical. Outer atoll and fringing reefs can be considered more "classic" coral reef formations. As such we would expect higher coral cover and fish numbers with both closely associated with reef health indicators. It is also possible to compare such sites in the Maldives with reefs worldwide.

Thilas and channels can be considered atypical reef areas. These areas are much less complex and structure is created by limestone features, which can include ledges, boulders and pinnacles. The substrate around these features was characterised by limestone rock and *Tubastrea* sp. corals in exposed areas, and soft corals in sheltered areas. Fish communities were dominated by small species living on the substrate surface or planktivores feeding in the water column. These zones were utilised by sharks and rays. The strong tidal currents, such as those associated with channels in the Maldives, are linked to movement and feeding patterns of sharks and rays (Jaine et al. 2012, Schlaff et al. 2014). However, it should be noted that because of these current associations there is significant temporal variation in the presence of sharks and rays in these channels. The strong currents present in these channels made detailed surveys impractical, thus quantitative transect surveys were not performed in these areas during this project.

Turtle point on South Malé atoll, was unique with its high cover of *Discosoma* sp. corallimorphs. It was estimated that over 60% of the reef was colonised by these corallimorphs, in addition to high percentage of turf and macroalgae. The main predator of these colonial carpet corallimorphs is the critically endangered hawksbill turtle (León and Bjorndal 2002). During the surveys authors observed a relatively high number of hawksbill turtles at the site, indicating it may be important for the hawksbill turtle population. Tourists from nearby resorts and local islands also frequently visit this site due to the high probability of turtle siting's. One of the most distinctive reefs surveyed was Nassimo thila, a well-known MPA in North Malé atoll. The reef was made up of caves and pinnacles. These low light intensity areas house many non-reef building species such as *Tubastrea* corals, sponges, gorgonians, black corals and high numbers of soft corals (Zahir et al. 2009).

The findings of this report present a cautiously optimistic outlook for Maldivian coral reefs following the 2016 coral bleaching event. Reefs on the outer edges of atolls appeared to have fared best. The outer atoll fringing reefs at Villingili, Thoondi area and Dhigulaabadhoo had particularly high coral covers. Reefs close to the most densely populated and heavily developed area in Malé showed no overall pattern in health and resilience traits. There were some zones which had characteristics consistent with a reef in decline. Reefs with low live coral cover, such as Keylakunu and Hembadhoo, that also had the low number of coral recruits and some of the highest percentages of algae cove are particularly at risk. However, both reefs had good numbers of herbivorous reef fish which may serve to keep algae from taking over the reef surface, preventing a coral to algae phase shift (Hughes et al. 2007). It is important to continue monitoring reefs and if necessary implement management and restoration practices to protect the reef and aid recovery.

Due to time and methodological constraints this study was unable to assess the species diversity and biomass for the whole fish community. As a result, the findings are limited to a few key indicator species. Additionally, the rapid survey protocol used in roaming can only be considered a qualitative measure of the fish and substrate communities. Though surveyors were trained beforehand estimates of cover have their limitations. When surveying the fish community there were cases where an individual from a family may have been observed in the first minute of a survey was the only one encountered. Conversely a family may have only been encountered late in a survey but in a large school. Though this roaming data may not be robust enough to make quantitative conclusions about a zone it provides useful qualitative data about the habitat, its condition and certain features, which make it important. Shortcomings such as these should not reduce the achievement of surveying such a broad range of habitats.

"...the importance of the Maldivian marine environment to endangered species. Sharks and turtles were particularly prominent throughout the country."

Islands

Coastal fringe vegetation was similar across the three islands. On sheltered shores sea lettuce, sea hibiscus and beach gardenia dominate the shoreline. Iron wood dominated on more exposed shores, with stands of the other three species behind. Islands in the Maldives experience significant sediment movement over the monsoon periods (Kench and Brander 2006) and the vegetation along the shoreline can help fix sand preventing net island erosion during this process. The coastal fringe of all islands had significant amounts of rubbish (*Figure 28*), primarily made up of plastics, polystyrene foam and glass. Much of this rubbish appears to have washed ashore, however there was also evidence of it being left over after picnics and having been dumped in large quantities from safari boats or local islands. There was also clear evidence of turtle poaching on the beaches of both Dhigulaabadhoo and Keylakunu. Two turtle skeletons were found half buried on Dhigulaabadhoo, and sharpened sticks, used for searching for eggs, and human footprints were found beside turtle nests on Keylakunu. As of April 2016, all species of sea turtles, their eggs and habitats are legally protected in the Maldives by the Environmental Protection and Preservation Act (4/93). The sale and export of turtles and turtle products is also banned under the Ministry of Fisheries Bill 24/78

The vegetation around ponds was made up of species similar to the shoreline areas rather than mangrove habitats. Some ponds may have been formed by seawater flowing through channels, which have now closed, however others appear to have been filled by rainwater or water transport through the porous underlying rocks. Only two of these closed ponds had mangrove trees present, and in both cases the trees appeared to be dying. It is important to investigate how these depressions became closed and whether it is beneficial to explore the possibility of opening up some of the more recently closed up depressions to restore the natural functions of a mangrove, such as providing a nursery habitat for marine species, as well as to remove some of the alien species such as African cichlids and mollies thriving in these water bodies. The pond network in Farukolhu covers much of the north of the island and appears to be highly dynamic; the channels between ponds and the sea and the ponds themselves are being both created and drying up with relative frequency. Mapping and monitoring of this pond network may provide insights into island development.

Mangrove depressions, such as that found on Keylakunu are limited to small low-lying islands and are rare globally and information on them is limited (but see Woodroffe 1987). This type of mangrove requires a stable sea level (Woodroffe 1987) and is therefore susceptible to climate change induced sea level change. There is a highly limited exchange of waters and/or carbon flux and the sediments or likely to be highly organic (Woodroffe 1987). Therefore, this mangrove may be a significant carbon sink, however the carbon is not locked away and removal of this habitat would quickly release it. The main mangrove depression has been split in two by a man-made path. This has likely cut off some of the water flow to the northern section and the small-leaf orange mangrove trees here appeared less healthy. Redesigning this path to allow water movement should be considered as this area may potentially dry up.

Detailed studies examining the extent of mangroves in the Maldives have not been undertaken. Few studies, mainly as non-peer reviewed reports or papers are available (e.g. Jagtap and Untawale 1999, Shazra et al. 2008). In these studies, all 12 species of mangroves observed in the Maldives were present in the northern region (atolls) whereas only 3 species were recorded from the south of Maldives (Addu) indicating relative poor diversity in the south Maldives compared to North. There are 40 islands regarded as major inhabited islands that harbour mangroves or wetlands have been reported (MEE 2015) accounting for approximately 175 hectares, which are predominantly in the northern islands of

Figure 28. Rubbish in coastal zones.

Maldives. However, there remains little information on the extent of mangrove areas on uninhabited islands and this should be an area of focus for future work.

At Farukolhu, the bay environment was observed to be more diverse and dynamic than at Dhigulaabadhoo, in addition there were many smaller bays which were connected to the main bay. Both bays had a high abundance of juvenile sharks and rays. Farukolhu Bay has an additional smaller opening, which is exposed to the outer reef of the atoll. At one of the smaller bays, higher up the tidal gradient, in a mangrove-covered muddy patch that was exposed during the low tide, African cichlids were observed. It is likely that a higher diversity and abundance of species (than found during this study) are present at both bays, particularly at Farukolhu, where the bay is larger. Due to seasonal changes and timing of the surveys, much of the initial species biomass in the bay could have been missed during surveys. Therefore, to better assess the faunal species at such locations, detailed surveys should be performed during both seasons to better understand the temporal changes in the faunal assemblage that occurs.

The importance of these mangrove bays as nursery habitats in the Maldives is underestimated. Proper evaluation of the goods and services provided by the different mangrove and wetland habitats is urgently required. This includes mangrove (1) connectivity with seagrass and coral reefs, (2) importance to fisheries productivity, (3) role in shoreline stabilisation (4) role in carbon sequestration. Key systems such as mangrove bays of Farukolhu and Dhigulaabadhoo need to be incorporated into the country's habitat management and protection programmes. Due to time constraints seagrass habitats were not surveyed during this study. This is a significant oversight and studies of this undervalued and overlooked ecosystem should be a high priority.

There is an increasing demand for land area in the Maldives, mainly for agricultural expansion, industrial growth and housing (Thupalli 2009). Population growth will continue to create demands on land area for food production and infrastructure. Furthermore, expansion of the tourist industry threatens pristine forest and mangroves on uninhabited islands, as plans for new airports and resorts are made for these areas. Littoral mangrove habitat on inhabited islands is threatened by land reclamation projects. The presence of rats and cats on islands is a concern for reptiles and birds, particularly the ground nesting white-tailed tropical bird, which is at high risk of predation.

Management

The nation has proposed to designate much of the country as a UNESCO Biosphere Reserve. This management approach will aim to provide protection to many of the key ecosystems within the country and create a setting for sustainable development towards the country's economic and social goals. Key for the development of the Biosphere Reserve management plan is the use of robust data and the engagement of stakeholders in the development of the reserve area and the management plan. The findings of this report and the data collected can be used as a baseline against which to approach and measure the ecological goals of this plan. It can also be used to create dialogue with stakeholders about the value of these systems and justify the need for management. To develop measurable and achievable goals for environmental management it is important to understand the past and current conditions of the area, but also to be able to predict future impacts or drivers of change.

Though this report has further highlighted the broad ecological value of the Maldivian ecosystem, specific areas of ecological significance have been identified. These include high coral cover areas e.g. Maamigili in SAMPA, Villingili, Thoondi area and Ihuru in North Malé; areas with indicators of high resilience e.g. Dhigulaabadhoo, Kuramathi, Koattey Addu and Vabbinfaru; areas with a high number of endangered species e.g. SAMPA, Hitadhoo corner, Kuredu and Ohluveli and valuable island habitats e.g. the bays in Dhigulaabadhoo and the mangrove depression in Keylakunu. These areas are highly valuable to the local ecosystems and should be considered high priorities for protection

In order to preserve the ecological value of the areas include in the UNESCO Biosphere Reserve plan and protect their biodiversity for future generations, a comprehensive management plan must be developed for the whole reserve network. The management plan could consider the following elements:

- The development of a long-term monitoring programme for each protected area in order to track ecological and social changes over time.
- A plan for enforcement of regulations in the area. This maybe potentially challenging due to the large and diverse range of areas that needs to be monitored. A plan for the inclusion of local communities in management and enforcement of the areas must be created.
- Updated regulations for activities in the area, especially dive tourism and interactions with vulnerable or endangered species.
- A plan for sustainable financing (e.g. potentially through user fees) of protected areas, management staff (e.g. park rangers) and infrastructure (e.g. patrol boats or drones) for the area.
- A plan for benefit-sharing for the areas, so that any revenue from them is used to empower and support the development of local communities who depend on the environment for natural resources.

CONCLUSIONS

Corals have suffered significantly following the 2016 coral bleaching event. Results from this survey indicate that the impact is not as severe as the 1998 event where many reefs were left with less than 5% live coral cover (Zahir 2000). Reef fish communities still appear to be healthy, with high family diversity and abundance and richness of indicator families and key functional groups.

Despite the significant impact the 2016 bleaching event has had on Maldivian coral reefs. The findings of this report suggest a significant level of resilience inherent in the reef ecosystem. The survivorship of coral recruits highlights the potential for regrowth and recovery and despite widespread reduction in coral cover much of the important reef structure has remained with branching and table growth forms persisting for now. High herbivore abundance and levels of structural complexity suggest that many of the areas surveyed have a good chance of recovery under the right management conditions. The authors are therefore cautiously optimistic about the prospects for recovery of many of the reefs. As highlighted however, there are some reefs, which may be a cause for concern and require additional management measures or restoration approaches to aid recovery.

Due to the limited study of island flora and fauna in the Maldives it is not possible to draw conclusions about the relative health of these systems. However, it is known from numerous studies elsewhere that mangrove habitats play a key role for numerous species and for wider ecosystem health. The bays at both Dhigulaabadhoo and Farukolhu provided habitat for numerous juvenile fish indicating the value of these areas. The mangrove forest in Keylakunu is a special habitat. The combination of large areas of dense small-leafed orange mangrove growth, red mangrove taproots and ponds and large grey mangrove trees make this a unique habitat. The stable nature of the area also means it is likely to be a significant carbon sink, though it would be quickly released if the habitat is removed. These mangrove habitats should be the subject of future research in order to shed greater light on to the value of these systems to the Maldives. It is essential that future examinations of marine vegetation should a least include seagrass habitats

The proposed nationwide network of UNESCO Biosphere Reserves for the Maldives is a positive step towards protecting the environment for the future. This approach should provide well-developed management plans and resources for protected areas around the country and must be coupled with environmental education. This should ensure a harmony can be reached between the need for continued development in the country and the protection of one the world's most ecologically valuable habitats. Future sustainability of the country's reef and island ecosystems should be at the centre of all future management plans, given their key role in island creation, development and protection; especially in the face of future climate change associated threats. Through community engagement it should be possible to change the perception of protected areas from a negative idea with burdensome restrictions to a positive one which will create a sustainable future for all involved. Those areas without management measures plan in place are likely to suffer precipitous declines in ecosystem health and increased costs from trying engineer solutions to problems such as erosion and storm damage.

Despite significant scientific interest, the Maldives' ecological communities remain understudied, especially seagrass. This is due to logistical challenges associated with surveying isolated marine and terrestrial habitats spread over a large geographic area with limited access or challenging survey conditions. However, a greater understanding of larval pathways, the value of mangrove and seagrass habitats, both as nursery habitats and in carbon sequestration, the abundance and movements of ecologically important or endangered species and the location of resilient reef areas should be prioritised. This knowledge would in turn inform management measures and allow for better protection and a greater appreciation of these valuable areas.

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APPENDIX

Table S- 1. The range of coral reef formations and structures present in the Maldives.

Reef formation	Description
Open atoll	Ring-like structure of reef have perimeter which is frequently split, creating a series of reef platforms separated by channels. This encloses a central lagoon. In the Maldives, open atolls range from 290–3,790 km^2 in area
Closed atoll	Ring-like formation of reef with a near continuous perimeter of reef with few if any channels connecting the lagoon with the ocean. In the Maldives, these range from 47–143 km^2 in area
Oceanic reef platform	Individual reefs that emerge from the inner sea and have no connection with neighbouring atolls
Faro	Ring-shaped reef structure found within open atolls. These are rare globally, but common within the Maldives
Thila	An underwater pinnacle of reef. Thilas can be found within open atolls or in channels in the atoll perimeter. They can vary greatly in size from 10 – 300 m^2
Channel (Kandu)	Connect the outside ocean to the inner atoll. These areas often have strong currents as water moves into or out of the inner atoll
Fringing reef	Reef formation the surrounds an island
Lagoon	Shallower sandy bottom habitat. Used to refer to both the area inside an atoll or the area inside an island's fringing reef
Patch reef	Small, often isolated areas of reef within a lagoon

Table S- 2. The coral and rock growth form categories used in this project.

Growth form	Description
Branching	Corals grow in criss-crossing pattern of needle, blade, club or branch-like shapes. This creates interstitial space between branches
Encrusting	Spread outward, creating a thin layer over existing hard substrates. Can take on a lumpier shape but not typically uniform like massive corals
Digitate	Exhibit vertical clusters of digitate, or finger-shaped, structures. These are generally thicker than branching corals and there is less crossing of the structures creating less interstitial space
Foliose	Have a series flattened, overlapping plates radiating out from a central point. Can often appear to spiral outward in a continuous sheet
Free Living	Individual corals that are not attached to the substrate
Limestone plateau	A relatively flat rock bottom with occasional coral growths. May be cut into a spur and groove formation by erosion
Massive	Mound or dome shape with similar length, height and width dimensions
Others	All other coral growth forms not described here
Table	Extend from a single point off the substrate creating a thin, often circular, plate-like structure with space underneath

Table S- 3. IUCN Red List category of all Red Listed non-coral fauna observed in this study.

Common name	Scientific name	Red List category
Grey reef shark	*Carcharhinus amblyrhynchos*	Near Threatened
Blacktip reef shark	*Carcharhinus melanopterus*	Near Threatened
Chevron butterflyfish	*Chaetodon trifascialis*	Near Threatened
Napoleon wrasse	*Cheilinus undulatus*	Endangered
Green turtle	*Chelonia mydas*	Endangered
Marble grouper	*Epinephelus fuscoguttatus*	Near Threatened
Hawksbill turtle	*Eretmochelys imbricata*	Critically endangered
Reef manta ray	*Manta alfredi*	Vulnerable
Tawny nurse shark	*Nebrius ferrugineus*	Vulnerable
Squaretail coral grouper	*Plectropomus areolatus*	Vulnerable
Blacksaddle coral grouper	*Plectropomus laevis*	Vulnerable
Whale shark	*Rhincodon typus*	Endangered
Whitetip reef shark	*Triaenodon obesus*	Near Threatened
Giant clam	*Tridacna* sp.	Vulnerable

Table S- 4. IUCN Red List category of the five pre-selected Red Listed corals observed in this study.

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

Table S- 5. Fish species observed at Shaviyani Farukolhu and Gaaf-Dhaal Dhigulaabadhoo with the Shannon-Weiner Diversity Index and Evenness calculated.

Species/Family	Common Name	Locations	
		Farukolhu	Dhigulaabadhoo
Abudefduf septemfasciatus	Nine-band sergeant	0	30
Caranx melampygus	Blue-fin jack	2	2
Carcharhinus melanopterus	Blacktip reef shark	23	5
Chaetodon auriga	Threadfin butterflyfish	6	0
Chaetodon lunula	Racoon butterflyfish	6	0
Chanos	Milkfish	30	0
Corythoichthys haematopterus	Reef-top pipefish	0	1
Epinephelus caeruleopunctatus	Small-spotted grouper	0	1
Gerres oyena	Black-tip pursemouth	66	189
Himantura granulata	Mangrove whipray	69	0
Lethrinidae	Emperor	3	0
Lutjanus argentimaculatus	Mangrove jack	0	1
Lutjanus fulvus	Blacktail snapper	0	3
Lutjanus monostigma	One-spot snapper	7	35
Mullidae	Goatfish	13	0
Negaprion acutidens	Sicklefin lemon shark	9	0
Ostraciidae	Pufferfish	1	0
Pastinachus sephen	Cowtail stingray	63	7
Siderea picta	Peppered moray	0	6
Sphyraena barracuda	Great Barracuda	1	1
Urogymnus asperrimus	Porcupine ray	2	0
	Shannon-Weiner Diversity Index	2.06	1.17
	Evenness	0.76	0.47

Table S- 6. All plant species identified during island surveys.

Species	Common name	Dhivehi name	Mangrove species	Mangrove associate
Pemphis scidula	Iron wood	Kuredhi	No	Yes
Scaevola taccada	Sea lettuce	Magoo	No	Yes
Pandanus tectorius	Screw pine	Boa Kashikeyo	No	No
Pandanus odorifer	Screw pine	Maa Kashikeyo	No	No
Talipariti tiliaceum	Sea hibiscus	Dhigga	No	Yes
Cocos nucifera	Coconut palm	Dhivehi ruh	No	No
Guettarda speciosa	Beach gardenia	Uni	No	Yes
Ficus benghalensis	Banyan tree	Nika	No	No
Ochrosia oppositifolia	Cork wood tree	Dhun'buri	No	No
Calophyllum inophyllum	Alexander Laurel wood	Funa	No	No
Hernandia nymphaefolia	Hernandia	Kandhu	No	No
Cordia subcordata	Sea trumpet	Kaani	No	Yes
Terminalia procera	Country almond	Midhili	No	No
Adenanthera gersenii	Coral wood	Madhoshi	No	No
Thespesia populnea	Thespesia	Hirun'dhu	No	No
Triphasia trifolia	Lime berry	Kudhi lunbo	No	No
Tournefortia argentea	Beach heliotrope	Boshi	No	No
Morinda citrifolia	Indian mulberry	Ahi	No	No
Artocarpus communis	Breadfruit	Ban'bukeyo	No	No
Premna integrifolia		Dhakan'dhaa	No	No
Cyperus sp.	Sedge grass		No	No
Ceriops tegal	Yellow mangrove	Karamana	Yes	No
Brugeira cylindrica	Small-leafed orange mangrove	Kandoo	Yes	No
Rhizophora mucronata	Red mangrove	Ran'doo	Yes	No
Acicennia marina	Grey mangrove	Baru	Yes	No
Rhizophora apiculata	Tall-stilted mangrove	Thakafathi	Yes	No
Bruguiera gymnorrhiza	Large-leafed orange mangrove	Bodavaki	Yes	No
Sonneratia caseolaris	Mangrove apple	Kulhlhava	Yes	No
Lumnitzera racemosa	Black mangrove	Burevi	Yes	No
	Vine	Velambooli	No	No
Terminalia catappa	Indian almond	Midhili	No	No

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