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CONTENTS

Introduction 8

Natural environment of the Maldives 8

- Study Site 9
- Aims 11

Methods 11

- Vegetation survey 11
- Aerial surveys 14
- Entomological surveys 14
- Water quality 15
- Marine survey 15

Results 16

Discussion 24

Management 30

Conclusion 32

References 33

Appendix 34

LIST OF FIGURES

Figure 1. HA. Kelaa island and wetland area 10

Figure 2. Boundary of the Kelaa Management Area 11

Figure 3. Location of the survey sites 12

Figure 4. Design of the transect surveys used to survey fringe and wetland habitats on Kelaa..... 13

Figure 5. Images from terrestrial surveys conducted on HA. Kelaa 13

Figure 6. Top: UV insect trap. Bottom: left, filtered sample with mosquito larvae; right, water in the wetland with larvae clearly visible 14

Figure 7. The proportion of cover of the 16 different vegetation species observed during random point sample surveys. 16

Figure 8. The proportional abundance of trees recorded on transect plots in the four survey zones. Numbers in brackets represents the number of transects conducted in each survey zone. 16

Figure 9. The total abundance of trees recorded on transect plots in the four survey zones. Numbers in brackets represents the number of transects conducted in each survey zone. 17

Figure 10. Mean density of A) mangrove seedlings, B) mangrove saplings and C) mature mangrove trees on transects in the four survey areas. Only transect plots four and five were used from the coastal and western fringe surveys as only these were in the mangroves 17

Figure 11. Digital elevation model (DEM) of the wetland habitat and the 100 m buffer zone. 18

Figure 12. Proportion of all mangrove trees in five health categories. 19

Figure 13. Mean density of mosquito larvae from water samples taken on transects in the four survey zones 20

Figure 14.Non-metric multidimensional scaling (NMDS) plot of lab tested water quality data. Site close together are most similar in terms of total water quality. 20

Figure 15. Mean values from in situ water quality survey recorded on transects in each survey area. Due to a probe error there are no pH values for the coastal fringe survey area. 21

Figure 16. Mean percent cover of coral reef substrate categories 22

Figure 17. Mean time to first observation of fish families. Families with a * beside their name were observed on fewer than three surveys and therefore are not mean values. Families are arranged in order of mean time first observation. 22

Figure 18. Images from marine surveys on HA. Kelaa 23

Figure 19. Images of Bruguiera hainesii on HA. Kelaa. Black outlines on top row indicate the location of *B. hainesii* trees 25

Figure 20. Semi-enclosed bay at the southern tip of Kelaa with a small stand of Rhizophora sp. Red box in the top image indicates the location of the mangrove..... 26

Figure 21. Areas of unhealthy or dying mangrove trees in the Kelaa wetland. 28

Figure 22. Trails used to move through the wetland areaWaste management on the island is limited

to landfill and burning. The two sites where this was observed were some distance from the wetland and are unlikely to be causing any damage to this habitat. No significant amounts of rubbish had been dumped around the wetland habitat, and the limited rubbish observed was likely limited to small items dropped whilst moving through the area. 29

Figure 23. Kelaa wetland area (green polygon) with 100 m boundary (black shaded area). 30

LIST OF TABLES

Table 1. Description of the four types of mangrove ecosystems found in the Maldives. From Saleem and Nileysha (2003). 8

Table 2. Description of the four survey areas 12

Table 3. Insects recorded during night surveys with UV light 19

Table A 1. All mangrove species recorded during Kelaa surveys 34

Table A 2. All non-mangrove plant species recorded during Kelaa surveys 34

Table A 3. Water quality data from the eight samples collected and sent for detailed analysis 35

Table A 4. Fish families recorded during roaming surveys 36

Table A 5. Habitat type and GPS location of all vegetation point surveys 37

Table A 6. Habitat type and GPS location of all transect surveys 38

Table A 7. Habitat type and GPS location of insect surveys 39

Table A 8. GPS start and end points of marine roaming surveys 39

INTRODUCTION

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

NATURAL ENVIRONMENT OF THE MALDIVES

The Maldives is an archipelago of coralline islands located in the middle of Indian Ocean. Around 1192 islands are distributed across 25 natural atolls which are divided into 16 complex atolls, 5 oceanic faros, 4 oceanic platform reefs covering a total surface area of 21,372 km^2 (Naseer and Hatcher 2004). Maldivian islands are known as low lying islands with 80% of the country being less than a meter above the sea level and the majority of islands being less than 5 km^2 in size (Ministry of Environment and Energy 2015). Studies to understand the atoll and island formation have suggested that the island reefs in the Maldives have been around since 4000 yr. B.P (Kench et al. 2005, Perry et al. 2013). Fresh groundwater exists in a lens below the island where it sits on top of denser saltwater. The size of the groundwater store depends on island width, recharge rate and ease of freshwater transmission through aquifers (White et al. 2007). Water is lost through island vegetation, household use and agricultural practices and must be carefully managed on inhabited islands.

The terrestrial fauna and flora have a rich biodiversity. The range of natural island habitats includes beaches, marshes, brackish ponds, mangroves and woodlands. There are 583 species of terrestrial flora found, of which 323 are cultivated and 260 are natural. Mangrove ecosystems can be classified based on the system's exposure to the sea as either open or closed mangrove systems. These can then be further subdivided into four categories (Saleem and Nileysha 2003) (*Table 1*). In all but marsh-based (basin) mangroves, tree growth is limited to a narrow band around the water's edge. Around 14 species of mangroves are found across approximately 150 islands (Ministry of Environment and Energy 2015). Maldivian avifauna is made up of seasonal migrants, breeding residents and introduced birds. Over 167 species of birds have been recorded in the Maldives. Around 70 species of shorebirds are found, some of which are breeding residents while others are recorded as migrants. Migratory birds visit during certain seasons to breed or use the islands to transit to their breeding grounds (Ministry of Environment and Energy 2015).

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

"There are 583 species of terrestrial flora found, of which 323 are cultivated and 260 are natural"

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

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

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

Terrestrial habitats are threatened by many local scale factors including infrastructure development, human waste and land reclamation projects. Similar to the marine environment, habitats such as mangrove areas are known for their ecological significance and diversity, providing habitats and services to animal and human communities (Kuenzer et al. 2011). Due to historical and continued undervaluation, most of these areas are not given the level of respect and protection they require. Many mangroves across the country have been reclaimed to pave the way for land and infrastructure development.

Refuse dumping has had a major impact on the terrestrial and marine environment. Around 1.7kg of waste is generated per capita in Male' alone (Ministry of Environment and Energy 2015). Open burning is still widely practiced in most islands and there are no mechanisms in place to address hazardous, liquid, and electronic waste. This highlights the need for proper waste management in the Maldives. The strategic action plan (SAP) (Government of the Maldvies 2019) lays out a plan for dealing with waste through integrating international waste management strategies, putting more responsibility on the producers and polluters, increased recycling and a ban on single use plastics by 2023. The plan also calls for the wider establishment of regional waste management treatment facilities and aims to make reducing damage to the environment a key priority. Many populated islands are far away from regional waste management centres making dumping waste on land or in the sea the most convenient disposal option for island populations.

Agriculture in the Maldives is limited to the small-scale production of crops, coconuts, firewood and fruits. Though it's contribution to GDP has declined, total agricultural production has increased significantly (National Bureau of Statistics 2019) and the sector remains an important source of income and food security in rural communities. There is estimated to be only around 30 square km of land area in the country available for cultivation (Shabau 2006). Tree crops are often grown in gardens include breadfruit, mango, papaya, custard apple, bilimbi, arecanut and banana. Crops grown on agricultural land include taro, sweet potato, eggplant, pumpkin, chilli, watermelon, papaya and leaf cabbage. The limited space and low fertility of island soils means fertilisers and pesticides are commonly used. The use of fertilisers can lead to increased nutrient levels in nearby water bodies, changing the water chemistry that can result in eutrophication. Using pesticides can be effective in removing crop pests however it can have widespread impacts on non-target insects as well as nearby by aquatic and soil communities (Gill and Garg 2014).

There is limited information about insect communities in the Maldives, exceptions being agricultural pests (Watson et al. 1995), dragonflies (Anderson 2009) and mosquitoes. Mosquitoes are a significant pest throughout the country. On many of the islands there are no natural sources of standing water meaning proper management of wells and waste-water areas limits larvae habitat and can control mosquito populations. However, on islands with wetland habitats predators of both larvae and adult mosquitoes are necessary to control populations and, in some cases, active management measures may be necessary.

The terrestrial and marine biota serve as a source of income, food, and socio-economic benefits to the community. Tourism and fishing industries depend directly on the natural resources, and the country's economy is primarily dependent on the profits around these industries. This highlights the significance of the natural environment to the Maldives as well as the need to protect and conserve valuable and threatened habitats across the country. Therefore, there is an immediate need for biodiversity assessments and management plans to ensure the sustainable use and management of these natural resources within communities. Such approaches will play a key role in standardizing the efforts to manage and monitor the resources in a co-managed concept.

Study Site

Kelaa island is part of the Haa Alif Atoll (*Thiladhunmathi Uthuruburi*) the northernmost administrative district of the Maldives (*Figure 1*). Geographically, the island is located on the north east point of Thiladhummathi Atoll. Kelaa is approximately 3 km long and 1.4 km at its widest point, with a total land area of 202.5 ha. The resident population is 1,074 (National Bureau of Statistics 2014). The community area is concentrated in the north west of the island. The main occupations are agriculture, fishing and tourism. Solid waste management on the island is limited to the collection and burning of waste at a waste yard away from the town.

A significant amount of agriculture takes place on the island with large areas extending south and east from the town used for farming. Crops grown in these areas include taro, sweet potato, watermelon, papaya, banana,

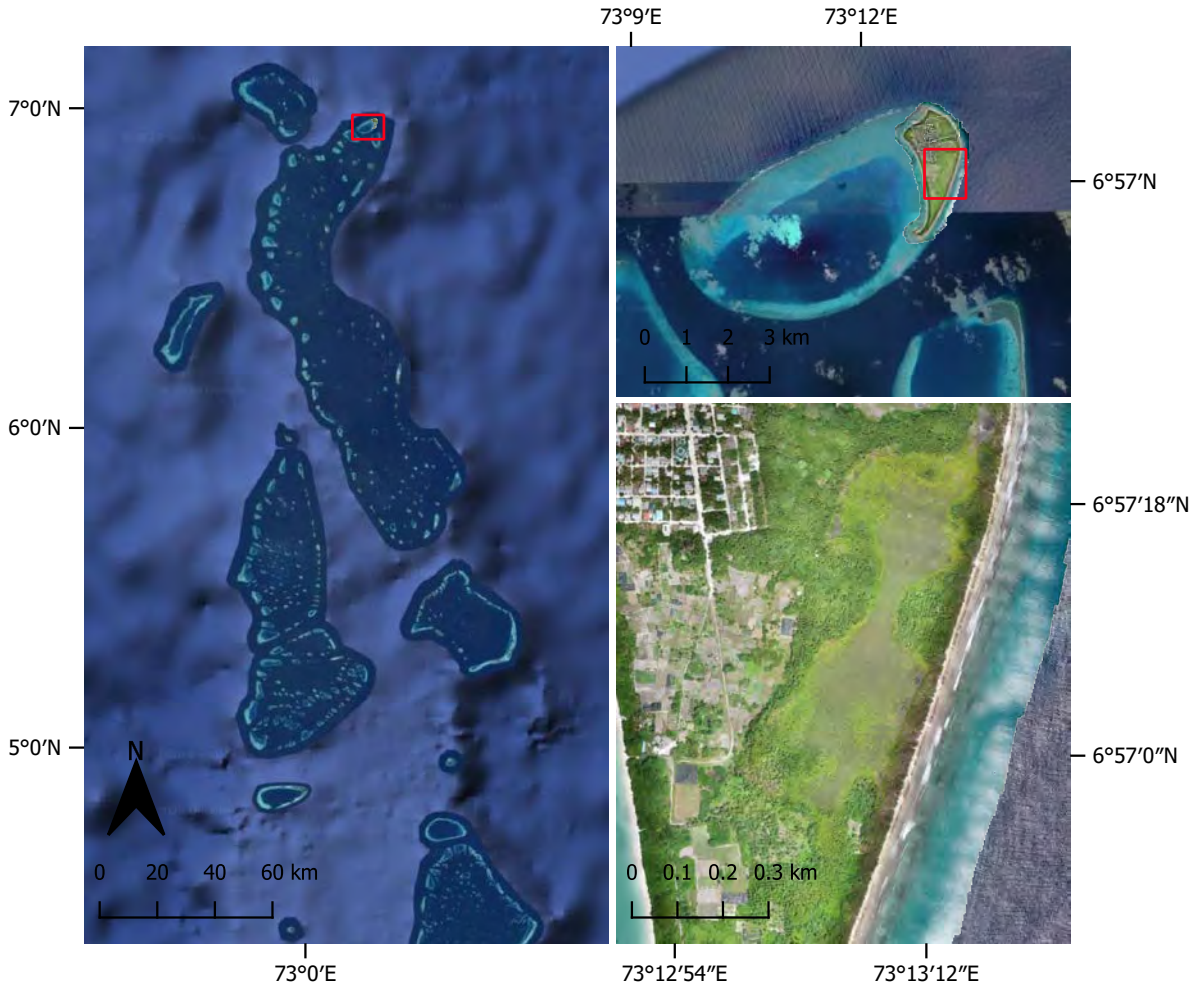

Figure 1. HA. Kelaa island and wetland area.

brinjal and pumpkin. The north east of the island is dominated by coconut trees, with additional coconut tree plantation extending across much of the island. There is a large wetland area of approximately 22 ha on the eastern side of the island. The area is dominated by the mangrove species Bruguiera cylindrica, though other species including B. gymnorrhiza, Lumnitzera racemosa, and Sonneratia caseolaris are also reported from the area (IDEAS 2019).

The Kelaa Management Area (KMA) (*Figure 2*) was designated as a protected area under the Environment Protection and Preservation Act of Maldives (4/93) on the 17th June 2019. The KMA includes the 22 ha of wetland, a 100 m boundary area around the wetland to the north, south and east and extends out past the reef edge to the west. The total area is 112 ha and falls under the category of "protected areas with sustainable use". The area is of ecological significance due the abundance and diversity of the mangrove species that exist here and the habitat they provide for a range of birds and invertebrates. The wetland is also of historical significance, providing a source of timber for firewood and local construction. The *B. cylindrica* propagules were a vital food source during the nationwide famine of World War 2. It was this event that led to a great appreciation of the mangrove area, and though locals are no longer reliant on the area for food. The mangrove continues to contribute to the local livelihood by providing forest resources such as timber, firewood and thatching materials and is still of significant cultural value.

"Refuse dumping has had a major impact on the terrestrial and marine environment. Around 1.7kg of waste is generated per capita in Male' alone"

The island is on the outer edge of the atoll on a ring of reef or 'faro'. The west side of the island has an exposed rocky shore and a fringing reef that extends approximately 200 m from the island. The eastern side of the island has a long sheltered sandy beach that gently slopes into a sandy-bottomed lagoon. At the southern tip of the island is a small bay area.

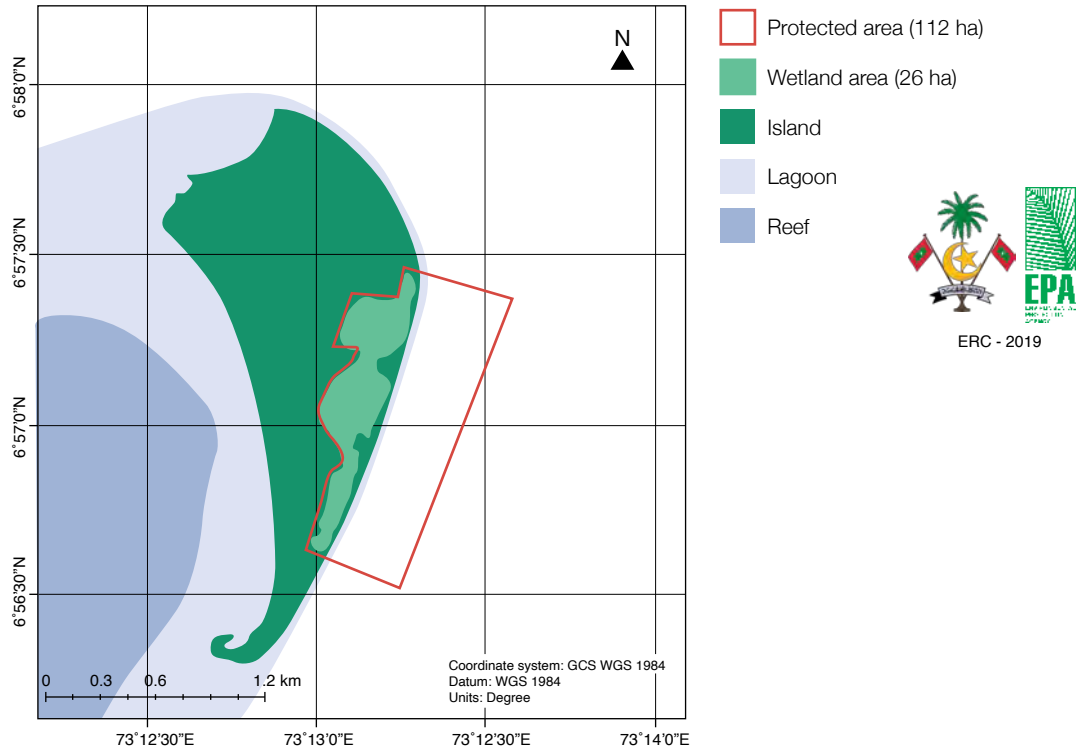

Figure 2. Boundary of the Kelaa Management Area.

Aims

The aims of this report were to:
1) assess the species biodiversity and distribution of the area and;
2) attempt to identify whether human activities have had a noticeable impact on the wetland area. These aims were met by focusing on the following specific goals to:

1. Describe the plant community present across the KMA
   a. How this varies between the mangrove basin, the coastal fringe and non-mangrove woodland?
   b. How plant community composition changes across the boundary fringe on the eastern and western sides of the wetland?
   c. What is the plant species composition and health of the wetland area?
2. Assess the water quality in the wetland habitat and determine whether the agricultural developments have had any noticeable impact on water quality
3. Make observations about the insect community as bio-indicators of ecosystem condition for further investigation
4. Describe the condition of the reef within the proposed management area
5. Make recommendations for wetland management, sustainable development opportunities and further study of the wetland and surrounding management area
   a. Verify the integrity of the management boundary
   b. Identify any man-made changes within the protected area

METHODS

Vegetation survey

Vegetation within the KMA was surveyed using two different methods. The first approach used a stratified random sampling approach to identify 57 survey points across the wetland and KMA boundary habitats (*Table 2* and *Figure 3*). Survey points were selected within four defined zones: the western boundary fringe, the coastal fringe, the north wetland area and the south wetland area. Due to the low number of points in the south wetland area, all wetlands points were combined and analysed as wetland.

GPS points were entered into the android phone application SW Maps (©Softwell (P) Ltd. 2020) which was used for navigation to the point. At a survey point, a 2.5 m radius circle was estimated and the dominant, secondary, and tertiary flora within the area were identified to species and their respective percent covers were estimated. The height of the dominant species was estimated to the nearest 0.5 m. Substrate type was recorded and counts of crab burrows and rubbish were conducted. Where identified points were inaccessible, a new point was taken as close as possible to the original point and the survey was performed there.

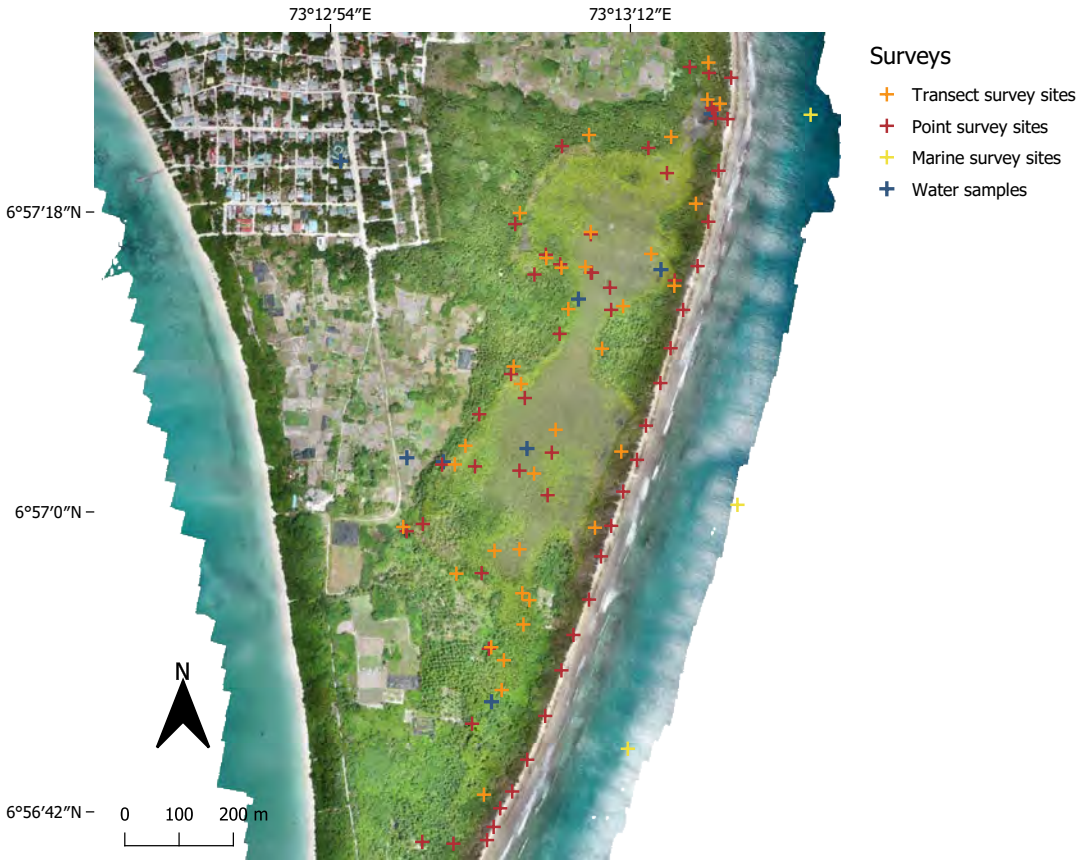

Figure 3. Location of the survey sites

Vegetation changes across the wetland fringe and density and community composition within the wetland were surveyed using transects (*Figure 4*). Transects were conducted at 35 locations in the KMA across the four defined zones (*Table 2*). Transects were 20 m long. At 5 m intervals (0, 5, 10, 15 and 20 m) a 2.5 x 2.5 m plot was surveyed. For each plot the habitat was classified as dwarf woodland, coastal scrub, pond fringe, pond or farmland; the number of crab burrows and pieces of rubbish were counted, soil type was described and soil depth was measured; evidence of natural, timber and disease disturbance were recorded and canopy cover was estimated as the proportion of a 50 x 50 cm quadrat covered by the canopy. All mature trees within the plot were counted and identified to species and their diameter at breast height (DBH) was measured. The health of each mature mangrove tree was classified as good, fair, average, poor or dead based on the condition of the tree. The number of seedlings (<0.5 m) and saplings (0.5 – 2 m) were counted and identified to species on a smaller 1 x 1 m plot nested within the 2.5 x 2.5 m plot. Transects in the fringe habitat were started approximately 10 m outside the wetland and were laid perpendicular to the wetland edge. Transects inside the wetland were laid north – south.

Zone name	Description	Number of point surveys	Number of transect surveys
Western fringe	Western area of surveys. The surveyed area encompassed the edge of the proposed management area boundary and the western fringe of the wetland habitat.	16	10
Coastal fringe	Eastern area of surveys. The surveyed area encompassed the coastal fringe habitat and the eastern fringe of the wetland habitat	24	10
North wetland	The survey area encompassed the wetland habitat in the northern half of the area above the narrower "neck" in the middle.	12	6
South wetland	The survey area encompassed the wetland habitat in the southern half of the area below the narrower "neck" in the middle.	5	9

Table 2. Description of the four survey areas.

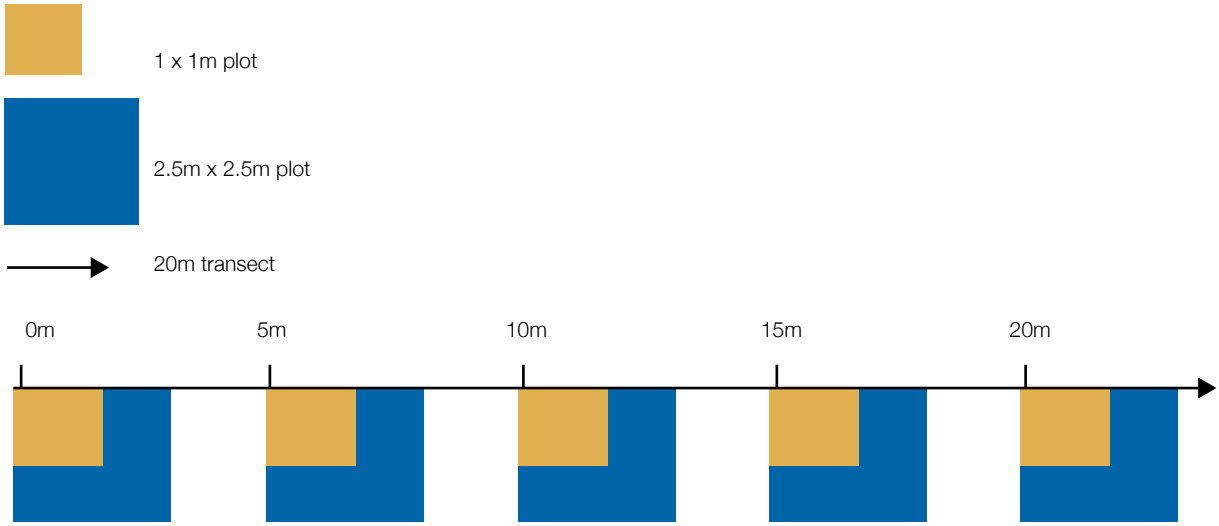

Figure 4. Design of the transect surveys used to survey fringe and wetland habitats on Kelaa

Figure 5. Images from terrestrial surveys conducted on HA. Kelaa.

Aerial surveys

Aerial surveys were conducted to create an accurate, high resolution map of Kelaa and the KMA. Aerial imagery was collected using the DJI Phantom 4 Pro UAV with 1-inch 20 Mega Pixel CMOS sensor. The flight plans were created using DroneDeploy Free Mobile App, with a height of 120 meters from ground level. At this height, with a small format camera it is possible to get a pixel size of less than 5 cm. The overlay of the pictures were 75% on front-lap and 75% on side-lap. Ground control points (GCPs) were used to ensure the map was as accurate as possible. To increase geo-location accuracy during post-processing, five GCPs were randomly distributed across the island and marked in open areas using natural markers painted Red. Horizontal GPS locations of these markers were taken with Topcon GR-5 GPS and Base Station at a ± 10.0 mm or ± 1 cm accuracy using the RTK mode. The GCP's were taken before the mapping of the island. A total of 2209 geo-referenced images were processed using the Agisoft Metashape Software this generated a high-resolution geo-referenced Orthomosaic and detailed digital elevation models.

Entomological surveys

A UV light trap was used to conduct an exploratory survey of the island insect community. The trap was an an open-ended box (1 m x 0.3 m x 0.3 m), with a UV light placed inside (*Figure 6*). The walls of the box were made using white fabric to allow the light to pass through, while providing a surface for the insects to land on. The trap was left in place for an hour from 20:00 – 21:00. After an hour, all insects on or inside the trap were counted and identified to highest level of classification possible. Pictures were taken for identification purposes and insect samples were also collected. Three island habitats were selected for surveys: an urban environment within the main community area, an agricultural field and the fringe of the wetland habitat. To examine the abundance of mosquito larvae in the wetland habitat, water samples were collected from three points along each transect. 100 ml from each sample was filtered through a fine mesh to separate out the larvae. These were then counted to give number of larvae per 100 ml.

Figure 6. Top: UV insect trap. Bottom: left, filtered sample with mosquito larvae; right, water in the wetland with larvae clearly visible.

Water quality

Water quality on each transect was tested in situ using a Hach™ HQD portable meter. This sampled dissolved oxygen, conductivity, total dissolved solids, pH and water temperature. Water samples were also collected from six sites in the wetland, one agricultural well and the community water supply. These samples were then sent to Maldives Water and Sewerage Company (MWSC) for laboratory analysis.

Marine survey

Marine surveys were performed using a roaming survey approach where two surveyors swam in a single direction along the reef flat/crest for 15 minutes. Three surveys were conducted along the eastern, outer atoll reef. Start and finish times, survey location (GPS of start/finish or entry/exit), estimated average depth and visibility recorded. All surveys were conducted whilst snorkelling. The percent cover was visually estimated for eight different substrate categories: live coral, sponge, turf algae, macroalgae, rock, rubble, sand, and crustose coralline algae (CCA). Reef structural complexity was estimated on a scale of 0 – 5, where 0 was considered completely flat and 5 highly complex with many holes and refuges, complex coral growth forms and tall coral or rock structures. Fish surveys were conducted simultaneously over the same area as the roaming benthos surveys. During surveys, the presence and time of first observation for each fish family was recorded. This provides a representation of how common these families were.

RESULTS

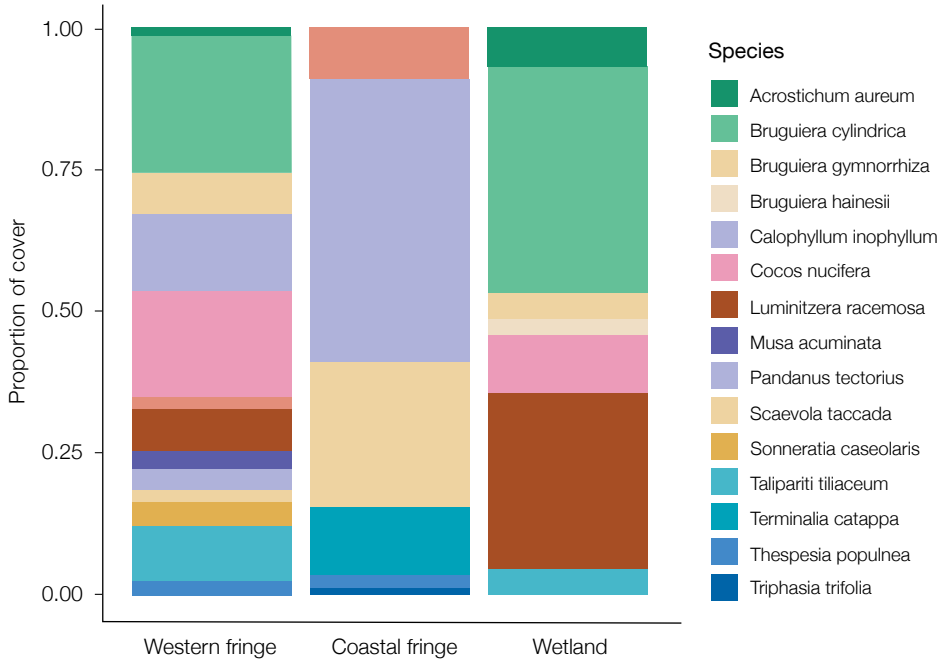

Figure 7. The proportion of cover of the 16 different vegetation species observed during random point sample surveys.

A total of nineteen species of flora were identified during the random point surveys (*Table A 1* and *Table A 2*), including five species of mangrove trees. The most diverse area was the western fringe of the wetland in the boundary area between the KMA and farmland (*Figure 7*). This area had a mix of farm crops, including banana (*Musa acuminate*) and papaya (*Carica papaya*) trees, common island vegetation such as coconut palms (*Cocos nucifera*), Alexander Laurel wood (*Calophyllum inophyllum*) and the Portia tree (*Thespesia populnea*), and mangrove trees on the edge of the wetland. The coastal fringe habitat was less diverse and was dominated by coastal scrub vegetation including screw pines (*Pandanus tectorius*) and sea lettuce (*Scaevola taccada*). The most common mangrove species in the wetland habitat were *Bruguiera cylindrica* and *Lumnitzera racemosa*.

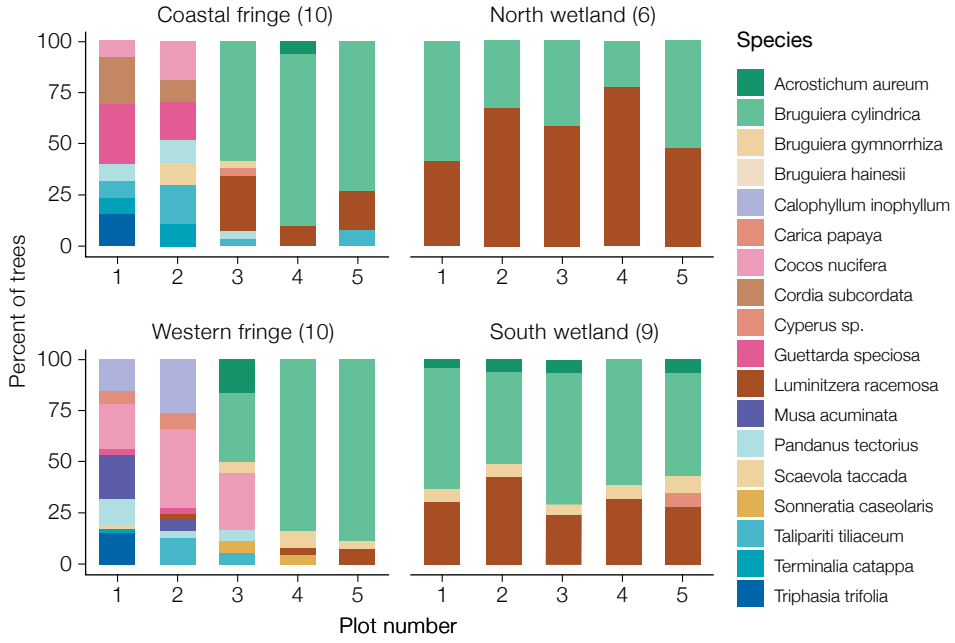

Figure 8. The proportional abundance of trees recorded on transect plots in the four survey zones. Numbers in brackets represents the number of transects conducted in each survey zone.

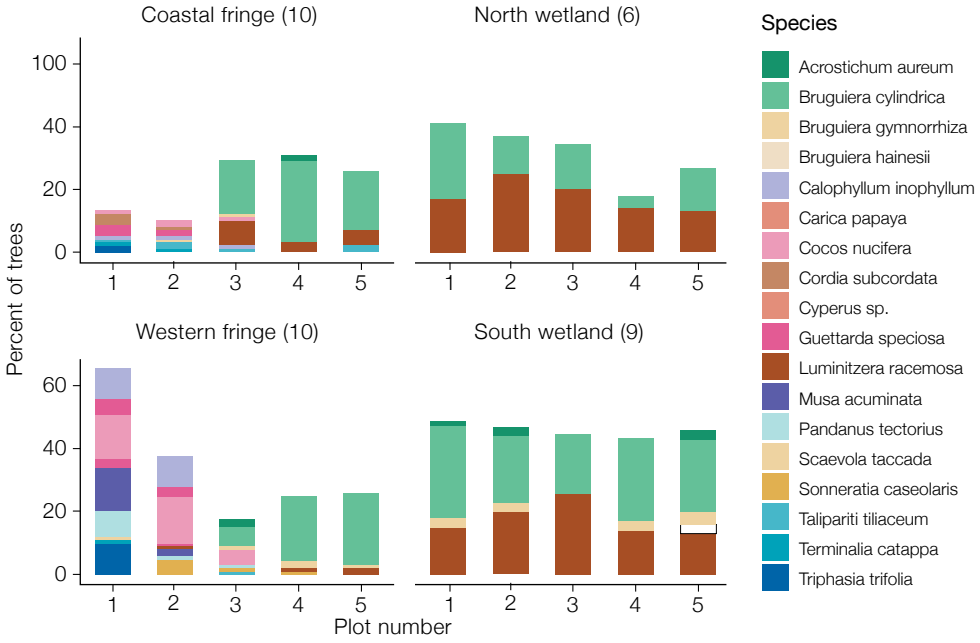

Figure 9. The total abundance of trees recorded on transect plots in the four survey zones. Numbers in brackets represents the number of transects conducted in each survey zone.

The community composition changed across the wetland fringe areas (*Figure 9* and *Figure 8*). Fringe transect plots one and two, which were just outside the wetland, had the highest number of species and were comprised of island dwarf forest vegetation. As these transects moved into the wetland the species transitioned to mangrove and mangrove associate species. Species richness decreased in the transition across this boundary from outside the wetland to inside the wetland. The abundance of trees was greater in the western fringe area than the coastal fringe which, despite having a relatively high species richness had the lowest species abundance. The transects in the northern section of the wetland had only two species, *B. cylindrica* and *L. racemosa*, whereas the southern section also had *B. gymnorrhiza* and mangrove associate species.

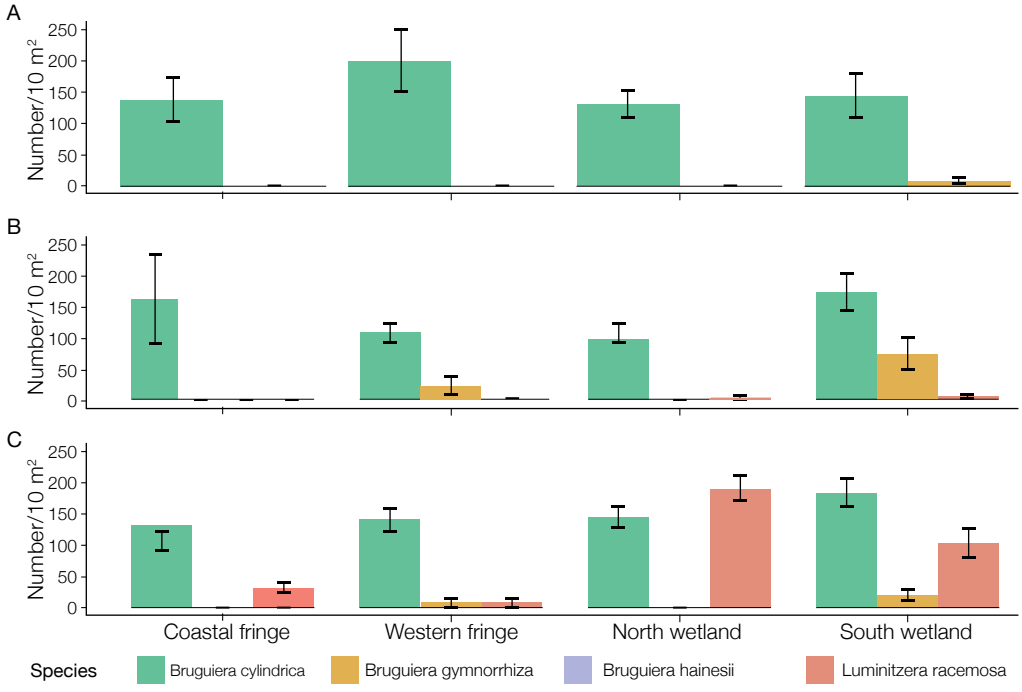

Figure 10. Mean density of A) mangrove seedlings, B) mangrove saplings and C) mature mangrove trees on transects in the four survey areas. Only transect plots four and five were used from the coastal and western fringe surveys as only these were in the mangroves.

There was high number of mangrove seedlings and saplings throughout the wetland habitat, in some areas densities were greater than 200 and 70 individuals per 10 m^2 respectively (*Figure 10*). *B cylindrica* dominated both the seedling and sapling communities, with a small number of *B. gymnorrhiza* seedlings present in the southern wetland area. The mature tree community around the fringes of the wetland was primarily *B. cylindrica*, however within the wetland *L. racemosa* formed a greater part of the community, notably in the north wetland, where it was the most abundant mature tree species.

The digital elevation model (DEM) shows the vegetation within the wetland rarely exceeded 15 m, despite the maximum height for the species observed being significantly greater than this. The tallest, densest areas of vegetation are in at the southern tip of the wetland area and the north western buffer zone. These are likely to be dense stands of *Bruguiera* spp. in the south and coconut palms in the buffer zone. The vegetation it noticeably shorter and less dense towards the centre and eastern side of the wetland, these areas were dominated by *L. racemosa*. Two areas of standing water are evident, one in the north and one on the eastern edge. Areas with a height of less than 5 m in the buffer zone are likely to be farmland, where the natural vegetation has been removed.

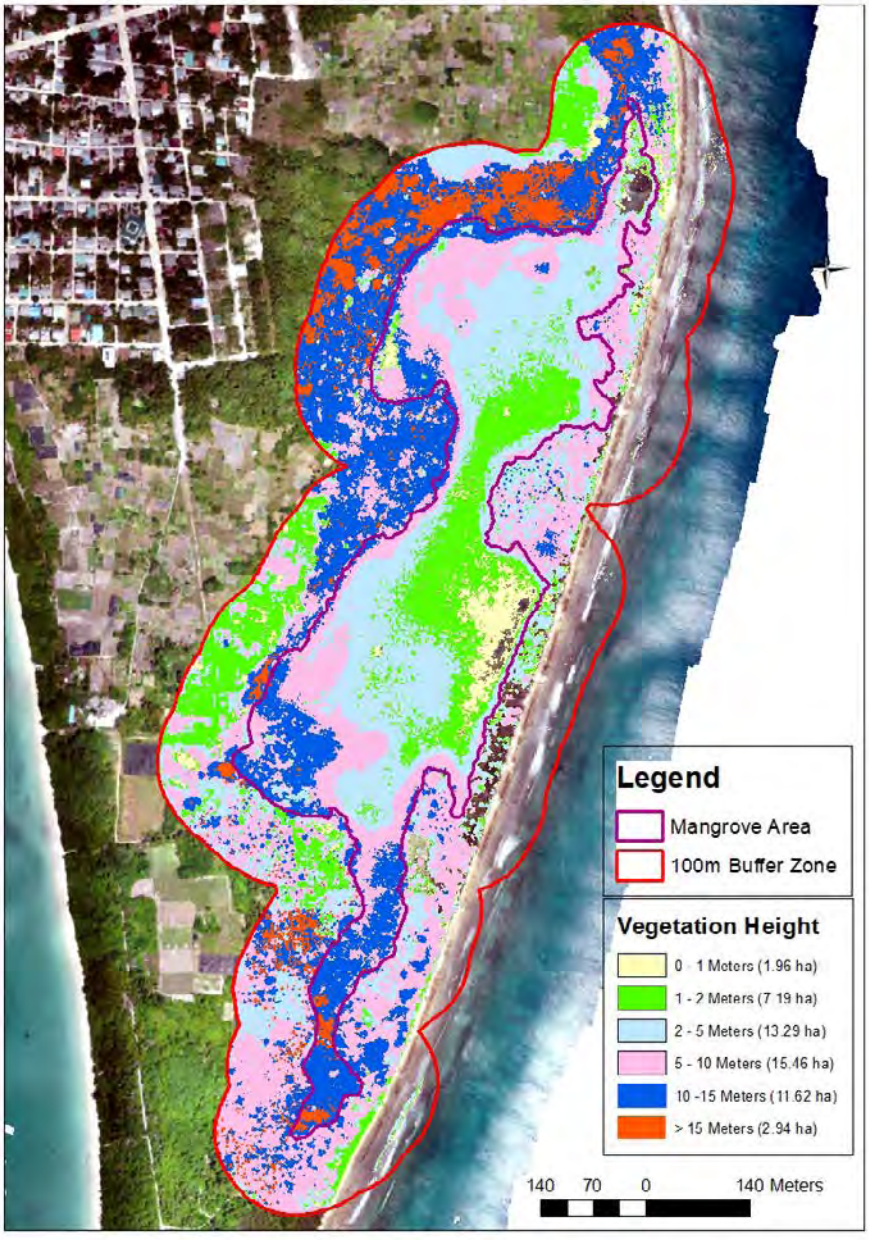

Figure 11. Digital elevation model (DEM) of the wetland habitat and the 100 m buffer zone.

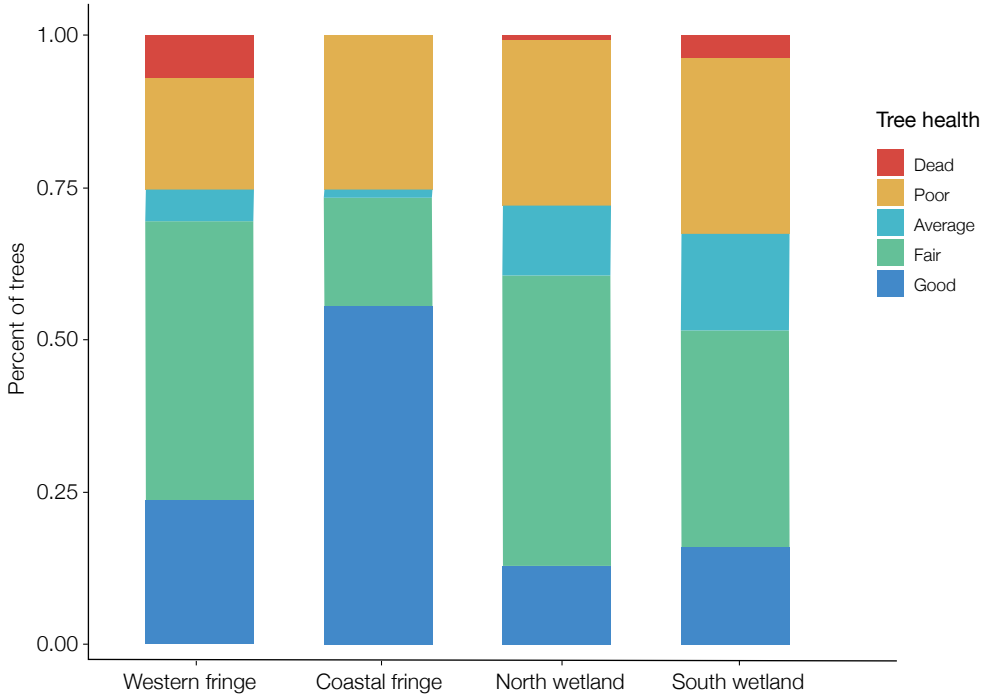

Figure 12. Proportion of all mangrove trees in five health categories.

The coastal fringe area had the highest number of trees in good health (>60% of trees) and no dead trees were present on transects (*Figure 12*). Trees in the south wetland area had the lowest overall level of health, almost 50% of trees were of average or below average health.

The entomological survey recorded a total of 371 individual insects representing seven insect orders during night UV light surveys (*Table 3*). The highest numbers were found in the urban survey area, followed by the mangrove areas. The agricultural area had a relatively small number of insects compared to the other sites. The number of mosquito larvae was significantly higher in water samples taken from the coastal and western fringe habitat (*Figure 13*).

Order	Highest level of identification possible	Urban: Disturbed weedy beach vegetation, sea almond trees infested with Euproctis fraterna nearby	Agricultural: Near a well, within the agricultural farms	Mangrove: Entrance to mangrove lake, rocky area with rubbish, close to farmland
Coleoptera	Paederus	5	1	
	Hydaticus	13	3	
	Cryptarchinae	53	1	95
	Monommatini			7
Hymenoptera	Formicidae	3	5	2
Orthoptera	Tettigoniidae	8		
Odonata	Epiprocta	1	1	1
Hemiptera	Cicadellidae	113	6	8
	Pentatomidae	1	1	1
Lepidoptera		15	6	10
Diptera	Culicidae	5	2	2
	Tipulidae			2
Total		217	26	128

Table 3. Insects recorded during night surveys with UV light.

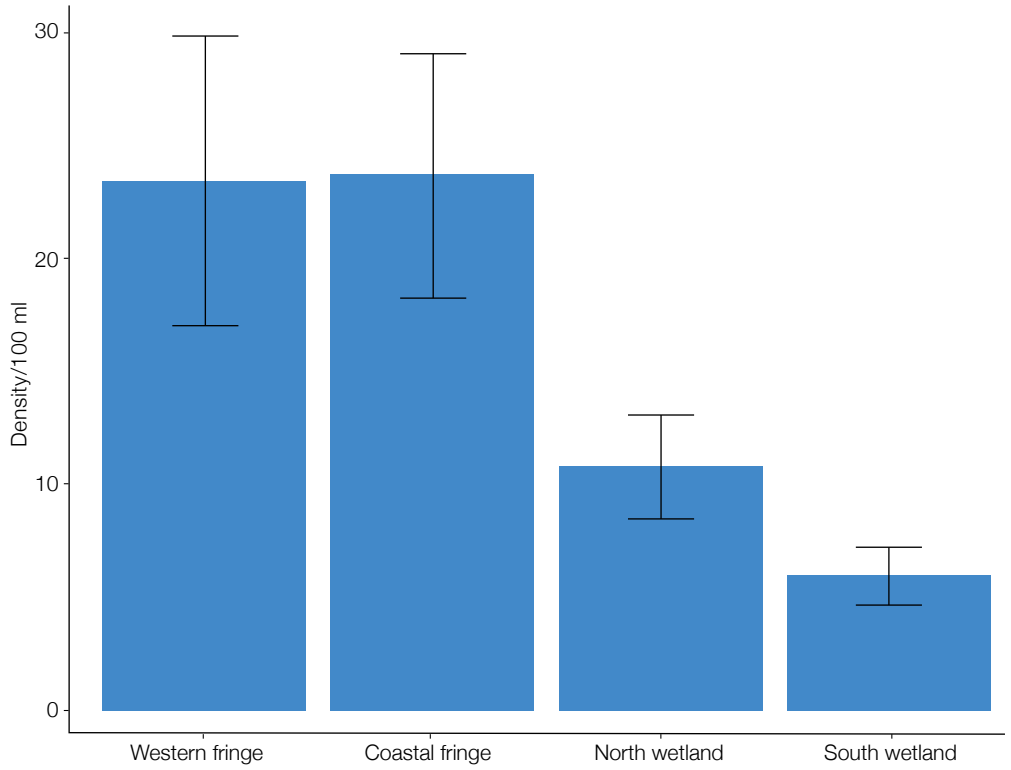

Figure 13. Mean density of mosquito larvae from water samples taken on transects in the four survey zones.

Salinity was the only in situ water quality measure that varied noticeably between survey areas (*Figure 15*). It was higher in the northern and coastal areas of the wetland. However, there was greater variation in the samples collected from the western fringe and southern wetland areas. The non-metric multidimensional scaling analysis (NMDS) was used to determine the similarity in water quality across the sampling sites; sample sites within close proximity of each other showed the highest level of similarity in water quality measurements. The NMDS of the lab analysed samples indicates that the northern point, the eastern edge of the wetland and the centre of the southern wetland were most similar to each other in their water quality properties (*Figure 14*), these were also the areas observed to have the deepest water and were connected by a contiguous body of water. The samples of the western sites, the southern tip and the farm well were separated from the other wetland samples along a gradient towards higher levels of nitrate, nitrite, and ammonia. These areas were not connected to the wider wetland area by above ground water flow, but instead has small, shallow patches of water.

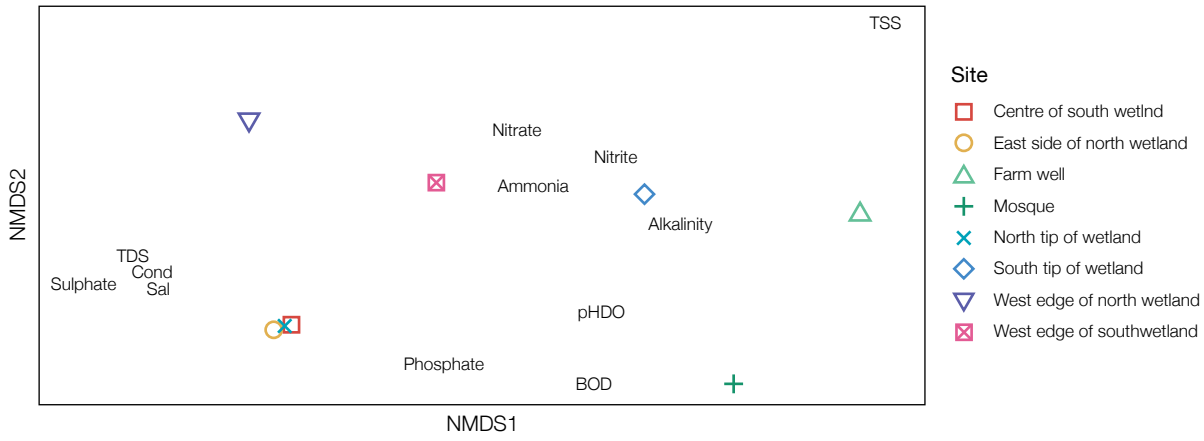

Figure 14.Non-metric multidimensional scaling (NMDS) plot of lab tested water quality data. Site close together are most similar in terms of total water quality.

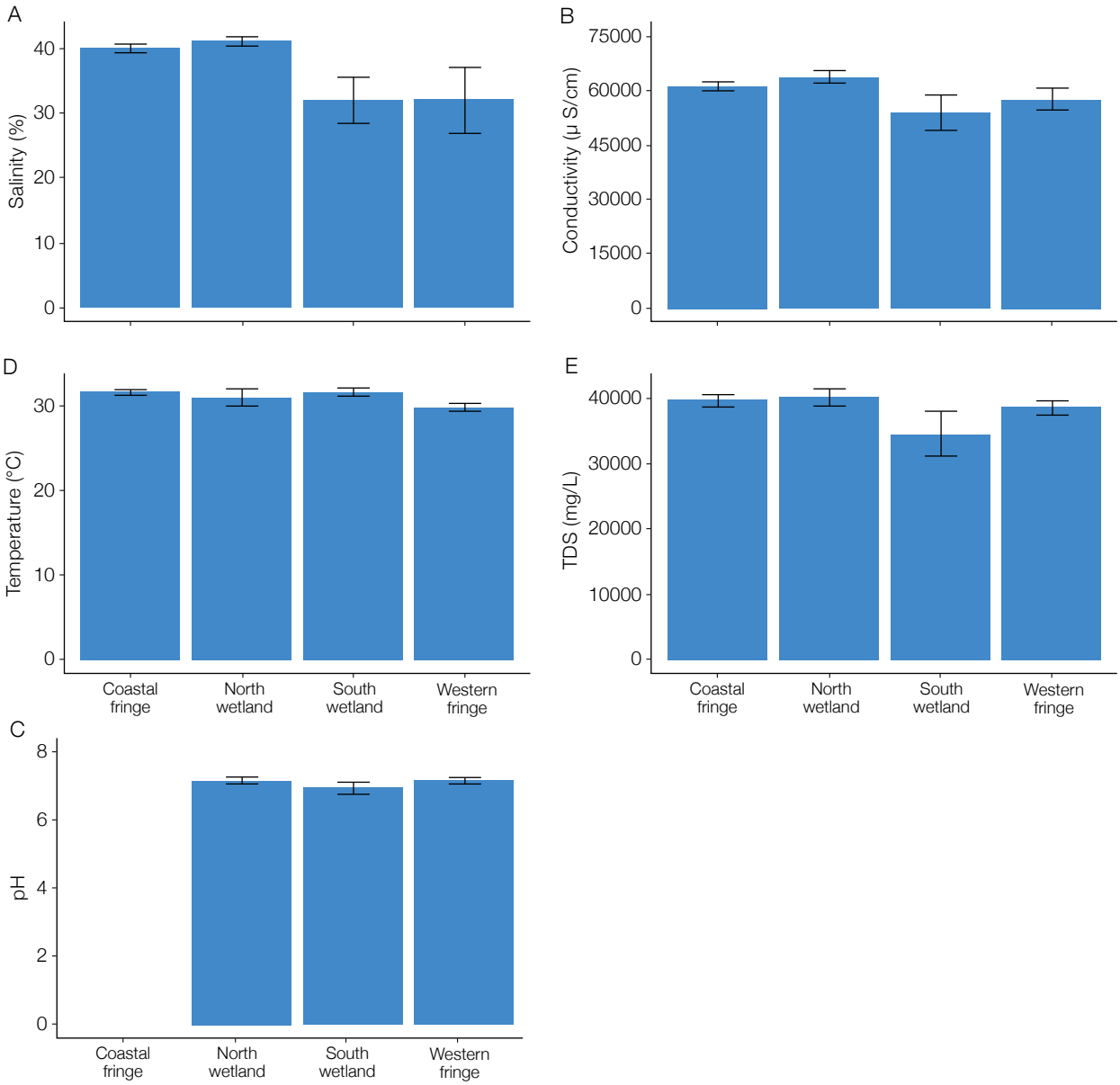

Figure 15. Mean values from in situ water quality survey recorded on transects in each survey area. Due to a probe error there are no pH values for the coastal fringe survey area.

The reef area on the eastern outer atoll edge survey area was a relatively flat rocky platform at about 10 – 15 m deep that extended between 150 – 200 m offshore before dropping off steeply. The habitat was dominated by coral rock, which made up over 70% of the benthic habitat (*Figure 16*). Hard coral cover was 14% and algae made up approximately 2% of the substrate cover. The mean structural complexity of the reef area was 1.7 (± 0.3 s.e.). A total of 22 fish families were observed during surveys (*Table A 4*). The important fishery species groupers (*Serranidae*) and snappers (*Lutjanidae*) were observed on all surveys. A large mixed school of snappers was observed on survey three (approximately 6.9524oN 73.2226oE), that included three species, red snapper (*Lutjanus bohar*), black snapper (*Macolor niger*) and midnight snapper (*M. macularis*) as well as bigeye jacks (*Caranx sexfasciatus*). The herbivore species, surgeonfish (*Acanthuridae*) and parrotfish (*Scaridae*), were common across the ref area.

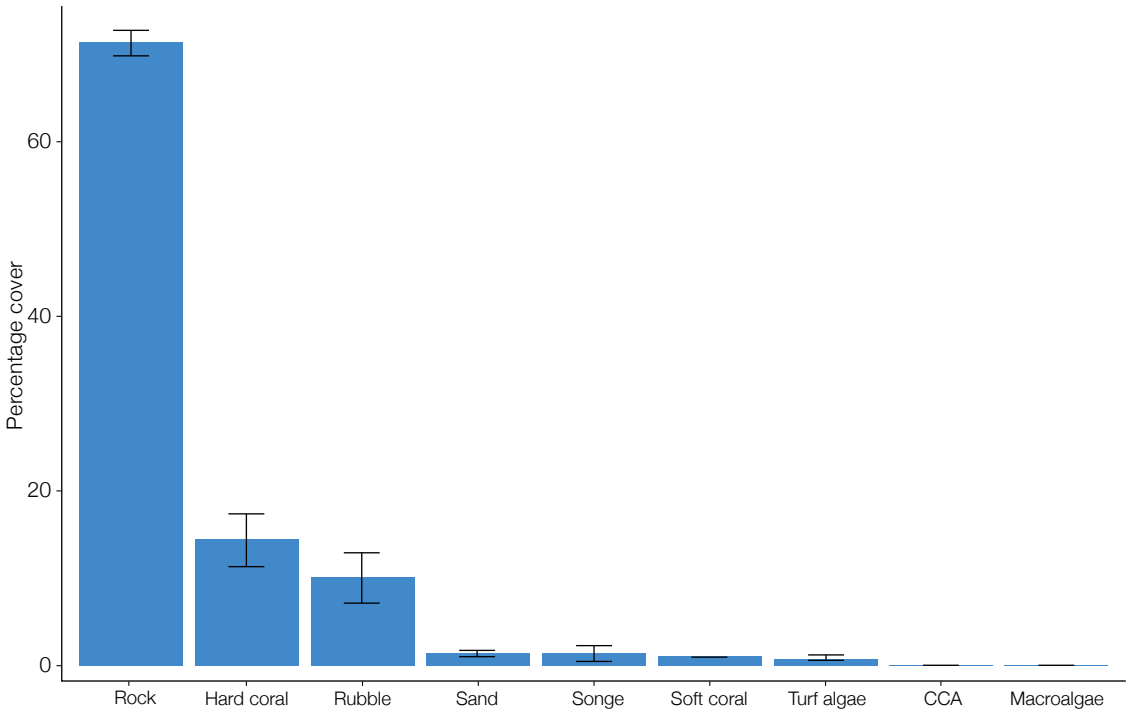

Figure 16. Mean percent cover of coral reef substrate categories.

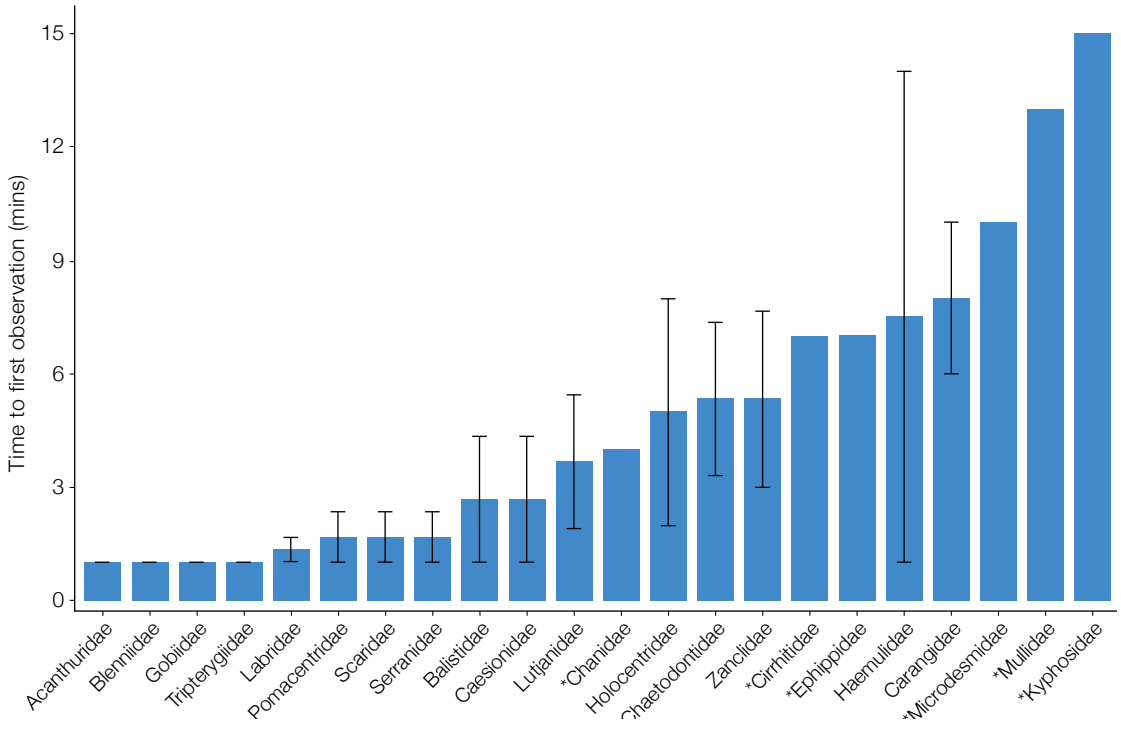

Figure 17. Mean time to first observation of fish families. Families with a * beside their name were observed on fewer than three surveys and therefore are not mean values. Families are arranged in order of mean time first observation.

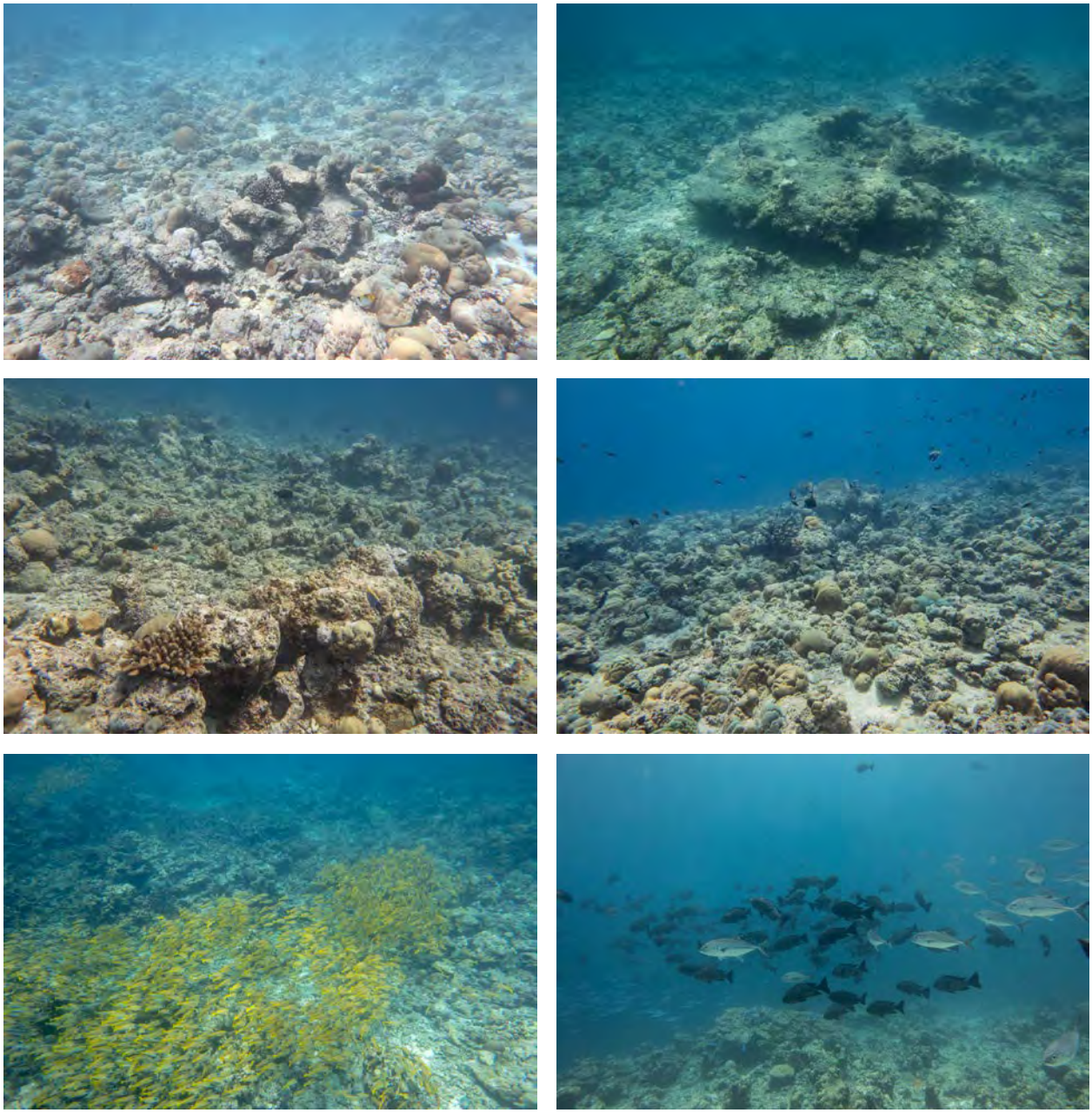

Figure 18. Images from marine surveys on HA. Kelaa.

DISCUSSION

The Kelaa wetland habitat is an exceptionally rare habitat. Basin mangroves are rare globally and are even more unusual on small islands. The wetland is a complex and system with a relatively high plant diversity when compared to other mangrove systems in the Maldives. There were five species of mangrove recorded on surveys (*Table A 1*). Of note was the first recorded observation of the critically endangered mangrove species B. hainesii in the Maldives. At least four individual trees were identified on the eastern fringe of the pond at the north of the wetland area Figure 19). The wetland habitat is in close proximity to farmland, particularly the western fringe area where crops are grown within metres of the mangrove trees. The wetland showed signs of disturbance, there were a number of patches of dead or dying trees throughout. The value of the habitat, and the proximity to farmland makes the development of a sustainable management plan a high priority.

The wetland habitat was a well-defined mangrove basin (Lugo and Snedaker 1974, Ewel et al. 1998) running along much of the eastern side of the island. The basin is closed off from the sea by a berm made of rubble from the reef. Coastal scrub vegetation has grown over the berm consolidating the rubble and sand isolating it from the sea. The berm is 20 – 80 m wide, meaning water entering through overwash will be limited to storm events. Therefore, most water moves between the sea and the wetland by groundwater seepage. The water quality measures showed the north (32.9‰) and eastern (38.0‰) areas of the wetland to have salinities most similar to sea water. It therefore appears this is the area where most of the seepage occurs. This water then flows deeper into the wetland where channels allow it. Due to the enclosed nature of the habitat, evaporation and precipitation cycles create a variable environment. The result is large fluctuations in water and soil salinity, temperature and depth. The fluctuations will be most significant in the less connected western and southern areas of the habitat where areas will flood and dry based on rainfall.

The wetland during these surveys was a mix of wet mud with small shallow patches of turbid water around the fringes and areas of deeper, clearer water in the north and centre. *B. cylindrica* dominated in the muddy fringe and *L. racemosa* was the most common species in the centre. There are many other enclosed salt pond systems throughout the Maldives. Some of these, such as found in Haa Alifu Keylakunu island have developed mangrove basin habitats, whereas others are small ponds with no mangrove growth and no apparent connection to the sea. This habitat has been understudied across the country and the ecological role it plays is poorly understood. Given the rarity of the habitat it is also poorly understood globally. Therefore, further study of the Kelaa habitat could provide important contributions globally. Salt ponds and mangrove basins elsewhere in the world are known to play important roles for birds, insects and invertebrates (Jarecki 1999, Gangemi 2003). Due to their low connectivity, mangrove basins are nutrient and carbon sinks (Ewel et al. 1998). The height of the trees in the wetland was below the maximum height for all species observed. Mangroves growing in basin forests are often stunted due to limited water and nutrient flows.

An important finding of this study was the identification of B. hainesii. Consultation with an expert on the species (Dr. Jean W. H. Yong) confirmed the identification. It is one of two species of mangrove classified as “Critically Endangered” on the IUCN Red List of Threatened Species (Duke et al. 2010). This record represents a range expansion for the species, whose distribution is currently known to extend from North Australia through Papua New Guinea, Indonesia, Singapore and the Malay peninsula, Thailand and Myanmar (Cooper et al. 2016, Ono et al. 2016). Fewer than 300 individual trees have been recorded and protecting habitats where they are known to occur should be a high management priority (Polidoro et al. 2010).

"The Kelaa wetland habitat is an exceptionally rare habitat. Basin mangroves are rare globally and are even more unusual on small islandse"

Figure 19. Images of *Bruguiera hainesii* on HA. Kelaa. Black outlines on top row indicate the location of *B. hainesii* trees.

The semi-enclosed bay at the southern tip of the island had two saplings of a Rhizophora species (*Figure 20*). Both were less than 1.5 m tall. The small size of the trees and the lack of flowers or fruit made identification difficult, but it was almost certainly either *R. apiculata* or *R. mucronata*. The mangrove is growing in the only part of the bay fringe that remains permanently submerged due to a deep, narrow channel that runs through the bay. In the bay's current form, it is unlikely the mangrove will expand due to the tidal range and exposure regime. However, it may be possible through careful planning, management and mangrove planting to create a mangrove bay area.

Figure 20. Semi-enclosed bay at the southern tip of Kelaa with a small stand of Rhizophora sp. Red box in the top image indicates the location of the mangrove.

Significant numbers of mosquito larvae were found in samples from the wetland, in some cases numbers were greater than 100 larvae/100 ml of water. They were particularly prominent in small patches of turbid water at the fringe of the wetland. They were present in lower numbers in the clearer waters deeper in the wetland. The wetland area is apparently an important breeding ground for mosquitoes on the island and given their potential as a vector for disease it may be desirable to explore options for managing them, provided it can be done without harming the wider environment. The island community is concerned about the mosquito abundance and without some form of management it could result in a negative community opinion of the wetland habitat.

The night insect surveys revealed apparent differences in insect abundance between the three habitats surveyed. The low numbers in the agricultural area were particularly apparent. It is likely that the use of pesticides in this area are causing the low numbers. Given the value of insects to the wider ecosystem, managing the use of pesticides to prevent additional impacts is necessary. The use of pesticides may have reduced the number of insects that either during their adult or larval phase help control mosquito populations e.g. dragonfly and damselfly form the class Odonata (Quiroz-Martínez and Rodríguez-Castro 2007), however only a single individual from this class was recorded during the insect surveys.

This report found that greater than 75% of trees surveyed were of above average health. This suggest that the overall condition of the system is good, however there were areas where there was a high number of dead or dying trees (*Figure 21*). The health of the seedlings and saplings was not recorded during the survey, and though their density remained high, in some areas they were clearly unhealthy. Particularly troubling was the condition of the pond at the north of the wetland where the *B. hainesii* were found (bottom left image in *Figure 21*). Despite the apparent health of the Bruguiera spp. trees there is clearly something disturbing the area. Many of the *L. racemosa* trees are dead and there are large patches of algal growth covering the pond surface. This may indicate stagnation of the water, high nutrient levels or other unfavourable conditions. The area has been physically altered in the past through attempts to farm fish (IDEAS 2019), this will have changed the hydrology of the pond, negatively impacting the trees. Changes to the hydrology and the addition of fish to the pond would also alter the water chemistry, resulting in further impacts to the vegetation. The results of the water quality surveys here are not enough to determine the optimum conditions for this habitat as there is no baseline to compare the data to. Continued monitoring of environmental parameters of this habitat and new studies of similar habitats across the country are needed for comparison to design management targets for the habitat. Very few crabs were observed around the Kelaa wetland habitat. This is unusual for these environments, where they play a role in forest structure, zonation, litter dynamics, productivity, and nutrient cycling (Ewel et al. 1998). The presence of fiddler crabs (Uca spp.) have been associated with significant increases in the health of mangrove trees (Smith et al. 2009).

"The night insect surveys revealed apparent differences in insect abundance between the three habitats surveyed."

Figure 21. Areas of unhealthy or dying mangrove trees in the Kelaa wetland.

There is an increasing demand for land area in the Maldives, mainly for agricultural expansion, industrial growth and for housing (Thupalli 2009). On Kelaa the growth of tourism will also mean the development of guesthouses and tourism related activities. The biggest threat to the wetland habitat likely comes from the encroachment of agricultural activities and human development of the land. In some areas crops such as bananas and papaya were less than 10 m from the wetland, with other more intensively farmed plots also within the 100 m boundary area of the KMA. The water quality surveys indicate that areas near farmland have higher nutrient content, suggesting fertilisers used by local farmers are entering the wetland. The mangrove basin on Kelaa has limited flushing of the system allowing nutrients accumulate (Ewel et al. 1998). The nutrients promote growth at the expense of resilience against mortality during drought, with mortality increasing with greater soil and water salinities (Lovelock et al. 2009). In addition to this direct impact, high nutrient levels can lead to algae and bacterial blooms which can result alter the oxygen levels of the water and soil, which have consequences for other organisms. Replacement of mangroves by competing plants is unlikely due to tidal inundation and soil conditions (Reef et al. 2010)

Due to equipment availability it was not possible to examine the soil conditions during these surveys, however soil salinity is a key measure of mangrove ecosystem condition and combined with other metrics such as soil pH, sulphide levels and redox potential can be used to more closely understand and monitor the health of the system (Twilley and Rivera-Monroy 2005). It is important that this data is collected as part of a future monitoring programme, without it, it is not possible to fully understand the health of the system and extent of external pressures.

"High nutrient levels can lead to algae and bacterial blooms which can result alter the oxygen levels of the water and soil, which have consequences for other organisms."

Though the surveys did not specifically focus on avian communities, birds were noticeably absent from the wetland area. During vegetation surveys the team observed very few birds, though a nest was recorded, and birds were seen along the shoreline. Fish or molluscs, both potential food for birds, were absent from the wetland. The abundance of insects, particularly mosquitoes, may provide food for some bird species. The area may be important for nesting or roosting.

Surveys were conducted between 10:00 – 16:00 meaning this behaviour would not have been observed. Lhos trees (*Pisonia grandis*) were present on the eastern shoreline near the wetland, these trees are known to be important roosting areas for frigate birds, though none were recorded using the trees. A bird trap was found at the southern point of the wetland. It is unknown whether there were more traps, or what would be done with captured birds.

Harvesting of mangrove trees was apparent within the wetland area. *L. racemosa* was the most harvested species. The trees were used to build fences around the farm plots. In some areas, trails ran through the wetland to allow access (*Figure 22*). Provided these are not filled in with rubble or soil, inhibiting water movement, these paths are unlikely to damage the ecosystem and instead provide a way of moving through the area whilst causing minimal damage to the surrounding trees or seedlings.

Figure 22. Trails used to move through the wetland area.

Waste management on the island is limited to landfill and burning. The two sites where this was observed were some distance from the wetland and are unlikely to be causing any damage to this habitat. No significant amounts of rubbish had been dumped around the wetland habitat, and the limited rubbish observed was likely limited to small items dropped whilst moving through the area.

The marine habitat on ocean ward side of the island had a low coral cover. Elsewhere in the country these outer atoll reefs are typically in better condition, particularly following the 2016 coral bleaching event (IUCN, 2019). Despite the large amount of settlement surface available, as indicated by the dominance of rock substrate, there appeared to be limited coral growth. The coral community present was dominated by massive or encrusting corals such as those from the genera Porites or Pavona. The dominance of these growth forms and the low complexity of the reef indicate that wave exposure is a strong determinant of the reef habitat, which is common among exposed reef areas (Done 1982). Recruitment or community composition of the coral was not examined during this survey. Therefore, it is not possible to say whether the reef may be recovering following a disturbance (e.g. bleaching) or whether this is likely to be the stable-state of this reef area. The fish community appeared to be healthy, with high numbers of functionally important herbivores and fishery species such as groupers (Serranidae) and snappers (Lutjanidae) present. One area at approximately 6.9524°N, 73.2226°E, was particularly notable for a large mixed school of snappers, this was later confirmed to be a popular fishing spot and therefore may need to be part of a management plan to ensure sustainable use.

MANAGEMENT

The ecological management goal for Kelaa is to provide a means to promote and ensure the long-term conservation and protection of the island's ecosystem and habitats. The KMA was designated in 2019 with the aim of achieving this goal. Its primary aim is to protect the wetland and marine habitats, both of which are ecologically and socially significant. The KMA includes the 22 ha of wetland, a 100 m boundary area around the wetland to the north, south and east and extends out past the reef edge to the west. The total area is 112 ha and falls under the category of "protected areas with sustainable use". It is clear from the findings of this report that protection and sustainable use management is necessary for this area. The current KMA design should provide protection from activities occurring directly inside the habitat however, it is apparent from aerial surveys and the findings of this report and others (IDEAS 2019) that the boundary is not intact and much of the 100 m boundary area has been encroached upon and is already being used for farming activities (*Figure 23*). This means that the impacts of these activities are unlikely to buffered by the boundary area.

The findings of this report and the data collected can be used to further inform decision making for the KMA and as a baseline against which to measure the effectiveness of the area. The main goal of management can be broken down into two sub-goals:

1. to maintain the resilience of biological communities to stressors associated with anthropological change and;
2. to maintain populations of natural communities for social development, fishery enhancement and island health. Future efforts should aim to monitor and manage the habitat to maintain overall system health and function (Flower et al. 2017, Lam et al. 2017).

Figure 23. Kelaa wetland area (green polygon) with 100 m boundary (black shaded area).

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

1. The identification of the critically endangered mangrove species B. hainesii
2. The presence of potentially harmful farming activities within the proposed 100 m boundary of the KMA
3. Higher nutrient levels in the wetland close to the farming areas
4. Areas of dead or unhealthy mangrove within in the wetland including:
    a. The pond at north of the wetland
    b. The north east wetland fringe
    c. The south west boundary fringe
5. Low numbers of insects in the farmland and the high numbers of mosquito larvae in the wetland water bodies
6. High numbers of fishery target species in a popular fishing location on the reef (approximately 6.9524°N 73.2226°E). This area is on the edge of the eastern boundary, just within the KMA.

Management recommendations based on the findings

1. The development of a monitoring programme for the wetland habitat is strongly recommended to track ecological changes over time. Aerial surveys should also be used where possible to examine vegetation density and health across the area and to identify dead patches. Permanent monitoring sites should be setup around the habitat. These should include the pond at the north of the wetland, sites at the northern and southern areas of the both the east and west boundary fringes and sites within the northern and southern wetland areas. Ideally three transects would be set at each site. These sites should be surveyed at least once per monsoon period each year and at a minimum the following should be recorded at each site:
    i. Tree species monitoring, including: age category, abundance, DBH and health
    ii. iWater and soil depth, salinity, pH and temperature during both high and low tides
    iii. Invertebrate, reptile and bird observations
2. Soil and water quality measures should be gathered from multiple areas of the wetland. These should include sites at the:
    i. eastern coastal fringe
    ii. the northern pond
    iii. sections along the western fringe where the buffer zone is still intact
    iv. areas where farmland is encroaching on the wetland habitat
    v. north and south inside the wetland

This data should then be used to establish baseline values and safe levels of nutrients for the habitat, and to identify areas where these values are being exceeded. Fertiliser, pesticide and herbicide use on farms should then be managed and monitored, to ensure safe levels are not exceeded.

3. The proposed 100 m boundary for the KMA appears to be unrealistic given the existing encroachment and current land use in some parts of the area. A more realistic boundary should be negotiated for areas currently in use for agriculture that would still allow farmers to use some of the area but to stop activities on the land closest to the wetland. Where the 100 m boundary does still exist, effective enforcement should be in place to prevent agricultural encroachment to these areas.
4. It is essential that the hydrology of the area is fully understood before any active management occurs in the area. There are many examples where disruptions to the natural hydrology has killed mangrove ecosystems (Lewis III 2005). This includes any dredging or dumping of sediment for access to the area. Attempts have been made in the past to dig out pond areas to harvest fish (IDEAS 2019). The changes to the hydrology caused, as well as the impacts to water chemistry through the introduction of fish, may have been the cause of some of the tree die offs in the area. It is recommended that any restoration planning should first look at the potential existence of stresses such as blocked tidal inundation or changes to internal water flow that might have caused the damage, and plan on removing that stress before attempting more intensive restoration.
    i. To understand the hydrology of the area detailed topographic maps should be created through elevation models, soil regulators (salinity, redox and pH) measured and hydroperiod (water levels) should be measured throughout the wetland (Twilley and Rivera-Monroy 2005). Water and soil measures should be surveyed over tidal, lunar and seasonal cycles to fully understand how the conditions fluctuate.
5. Given the fragile nature of the habitat it is not recommended that any active management approaches be undertaken to control the mosquito population in the habitat. Elsewhere in the country Poecilia spp. fish have been added to water bodies to feed on mosquito larvae. Their effectiveness in controlling larvae numbers and the wider ecosystems impacts are generally poorly understood (Kumar and Hwang 2006). Aside from the potential impacts of introducing non-native species they are also unlikely to be effective here. The highest concentration of larvae were found in unconnected shallow patches of water in the wetland fringe which would be inaccessible and uninhabitable for the fish and any attempts to change this could alter the hydrology of the system.
6. A coral reef monitoring programme should be developed for the outer reef area. This could focus on the fishing spot identified and be used to monitor both the health of the reef and the populations of fishery target species. This would provide a greater understanding of the Kelaa reef ecosystem and could be used to develop a plan for the sustainable use of this resource.
7. The presence of a healthy and visually appealing habitat, as well as the presence of a critically endangered species in the KMA creates up opportunities for tourism in the area. The area at north of the wetland where the B. hainesii was identified is easy to access and walking tours of this area could be done with little impact to the area. Walks along the eastern or western fringe are likely to be appealing to tourists, especially if they are coupled with local knowledge of the history and value of habitat. If the necessary facilities and personnel were available, the coral reef of the KMA surrounding areas and could make Kelaa a popular dive location.

CONCLUSION

The Kelaa wetland is an ecologically and socially valuable resource that needs protection and management. The species present, particularly the critically endangered B. hainesii, make it a key habitat for mangrove associated species and a site of great significance for the country more generally. There is a high density of generally healthy vegetation across the habitat, suggesting the system does not require active management efforts. However, there are some areas of significant disturbance that has led to localised mortality. The results described here and in another recent report (IDEAS 2019) are not enough to determine the cause of this damage. These findings instead provide a comparative baseline dataset for the KMA against which changes in the habitat can be measured and used to determine if they are positive or negative. Without more information it is not possible to determine whether these findings represent healthy or unhealthy sites, whether they are part of natural fluctuations or part of a degraded system in decline. This is also true for similar sites across the country. A nationwide effort is needed to identify and understand the locations and dynamics of these systems, their value to the environment and how best to protect and manage them for the future. This would play an important part in furthering the global understanding of island ecosystems of this nature.

There is evidence of human impacts throughout the environment from farming, harvesting timber and pond management activities. It is important that the management plan protects the habitat from these impacts, keeping them at a sustainable level. This report makes several recommendations regarding management of the area which should include: a monitoring programme for both the wetland and marine habitats, limits to certain farming activities close to the KMA, re-evaluation and greater enforcement of the 100 m boundary area and a hydrological study to understand the dynamics of the system. The management plan should ensure benefit-sharing for the area, so that the environment can have a positive impact on the wider community and can be used to empower and support the development of those who depend on the area.

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APPENDIX

Table A 1. All mangrove species recorded during Kelaa surveys.

Species	Common name	Local name
Bruguiera cylindrica	Small-leafed orange mangrove	Kandoo
Bruguiera gymnorrhiza	Large-leafed orange mangrove	Bodavaki
Bruguiera hainesii	Haines' Orange Mangrove	
Lumnitzera racemosa	Black mangrove	Burevi
Sonneratia caseolaris	Mangrove apple	Kulhlhava

Table A 2. All non-mangrove plant species recorded during Kelaa surveys.

Species	Common name	Local name	Mangrove species	Mangrove associate
Acrostichum aureum	Mangrove fern	*Maakeha*	No	Yes
Calophyllum inophyllum	Alexander Laurel wood	*Funa*	No	No
Carica papaya	Papaya tree		No	No
Cocos nucifera	Coconut palm	*Dhivehi ruh*	No	No
Cordia subcordata	Sea trumpet	*Kaani*	No	Yes
Cyperus sp.	Sedge grass		No	No
Guettarda speciosa	Beach gardenia	*Uni*	Yes	Yes
Musa acuminata	Banana tree		No	No
Pandanus tectorius	Screw pine	*Boa Kashikeyo*	No	No
Scaevola taccada	Sea lettuce	*Magoo*	No	Yes
Talipariti tiliaceum	Sea hibiscus	*Dhigga*	No	Yes
Terminalia catappa	Indian almond	*Midhili*	No	No
Thespesia populnea	Portia tree	*Hirun'dhu*	No	No
Triphasia trifolia	Lime berry	*Kudhi lunbo*	No	No

Table A 3. Water quality data from the eight samples collected and sent for detailed analysis.

Sample ID	Site description	Latitude	Longitude	Physical appearance	Conductivity (µS/cm)	pH	Salinity (0/00)	Temperature (oC)
1	Pond at the north end of the wetland close to eastern shoreline	73.2213480	6.956638	Clear with particles	50400	7.16	32.95	20.7
2	Eastern fringe of the north wetland area	73.2205100	6.954041	Clear with particles	50500	7.07	32.97	19.6
3	Well inside the mosque premises	73.2151710	6.955850	Clear with particles	874	7.51	0.43	19.2
4	Western fringe of the north wetland area	73.2191340	6.953550	Brown and opaque with particles	64800	7.19	43.62	19.2
5	Centre of south wetland area, inside the wetland	73.2182756	6.951058	Brown and opaque with mosquito larvae	58200	6.93	38.67	19.1
6	Well in farm area	73.2162739	6.950904	Opaque and light brown with particles	848	7.59	0.42	19.2
7	Western fringe of the south wetland area	73.2168812	6.950836	Brown with particles	20900	7.12	12.46	19.1
8	Southern point of the wetland area	73.2176841	6.946836	Brown with particles	8240	7.54	4.57	19

Sample ID	Total dissolved solids (mg/L)	Total suspended solids (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	Sulphate (mg/L)	Sulphide (µg/L)	Alkalinity (mg/L)	Phosphate (mg/L)	Dissolved oxygen (mg/L)	Biological oxygen demand (mg/L)
1	25000	11	3	0.015	0.46	2450	<5 (LoQ 5 µg/L)	137	0.18	4.77	9
2	25200	9	2.5	0.018	0.28	2700	5	110	0.21	4.28	10
3	437	12	2	0.016	0.75	12	<5 (LoQ 5 µg/L)	302	0.13	6.21	9
4	32400	194	8.5	0.045	1.04	3150	25	241	<0.05 (LoQ 0.05 mg/L)	5.21	3
5	29100	115	3.1	0.029	0.5	2950	<5 (LoQ 5 µg/L)	142	0.1	6.03	6
6	424	930	2.4	0.049	0.12	17	<5 (LoQ 5 µg/L)	262	<0.05 (LoQ 0.05 mg/L)	5.95	7
7	10440	38	12.2	0.064	3.15	780	4020	402	1.02	5.43	9
8	4120	20	7.9	0.043	1.54	220	5	636	0.07	6.11	6

Table A 4. Fish families recorded during roaming surveys.

Family	Common name	Predominant diet	Notes
Acanthuridae	Surgeonfish	Herbivore	
Balistidae	Triggerfish	Zoobenthivore	
Blenniidae	Blenny	Zoobenthivore	
Caesionidae	Fusilier	Zooplanktivore	
Carangidae	Jack	Piscivore	Large school Caranx sexfasciatus. Also mixed with snappers survey 3
Chaetodontidae	Butterflyfish	Corallivore	
Chanidae	Milkfish	Planktivore	
Cirrhitidae	Hawkfish	Zoobenthivore	
Ephippidae	Batfish	Herbivore	
Gobiidae	Goby	Zoobenthivore	
Haemulidae	Sweetlips	Zoobenthivore	
Holocentridae	Squirrelfish	Zoobenthivore	
Kyphosidae	Rudderfish	Planktivore	
Labridae	Wrasse	Zoobenthivore	
Lutjanidae	Snapper	Piscivore	School of L. kasmira on survey 1. School of M. niger and L. bohar observed on survey 3
Microdesmidae	Dart Goby	Planktivore	
Mullidae	Goatfish	Zoobenthivore	
Pomacentridae	Damselfish	Herbivore	
Scaridae	Parrotfish	Herbivore	
Serranidae	Grouper	Piscivore	
Tripterygiidae	Triplefin	Zoobenthivore	
Zanclidae	Moorish idol	Spongivore	

Table A 5. Habitat type and GPS location of all vegetation point surveys.

Habitat	Latitude	Longitude
Mangrove Fringe	6.944500	73.216530
Mangrove Fringe	6.946470	73.217360
Mangrove Fringe	6.947720	73.217640
Mangrove Fringe	6.948980	73.217520
Mangrove Fringe	6.949680	73.216270
Mangrove Fringe	6.949800	73.216540
Mangrove Fringe	6.950790	73.216860
Mangrove Fringe	6.951630	73.217480
Mangrove Fringe	6.952300	73.218010
Mangrove Fringe	6.952970	73.218820
Mangrove Fringe	6.953960	73.218400
Mangrove Fringe	6.954800	73.218080
Mangrove Fringe	6.956100	73.218860
Mangrove Fringe	6.956070	73.220300
Mangrove Fringe	6.957420	73.220990
Mangrove Fringe	6.957320	73.221310
Wetland	6.955652	73.220614
Wetland	6.954631	73.219342
Mangrove Fringe	6.954131	73.218829
Wetland	6.954294	73.218587
Wetland	6.953985	73.219365
Wetland	6.953989	73.219337
Wetland	6.953742	73.219663
Wetland	6.953375	73.219679
Wetland	6.953864	73.220739
Wetland	6.950757	73.217409
Wetland	6.950689	73.218150
Wetland	6.950276	73.218617
Wetland	6.950987	73.218687
Wetland	6.951898	73.218241

Habitat	Latitude	Longitude
Wetland	6.965143	73.215262
Wetland	6.965058	73.215690
Wetland	6.964837	73.216284
Wetland	6.956739	73.221362
Wetland	6.956704	73.221389
Wetland	6.956558	73.221419
Coastal fringe	6.944465	73.217047
Coastal fringe	6.944184	73.217474
Coastal fringe	6.944526	73.217605
Coastal fringe	6.944748	73.217724
Coastal fringe	6.945058	73.217834
Coastal fringe	6.945343	73.218034
Coastal fringe	6.945875	73.218276
Coastal fringe	6.946600	73.218584
Coastal fringe	6.947364	73.218846
Coastal fringe	6.947949	73.219047
Coastal fringe	6.948537	73.219313
Coastal fringe	6.949259	73.219511
Coastal fringe	6.949774	73.219684
Coastal fringe	6.950341	73.219884
Coastal fringe	6.950866	73.220107
Coastal fringe	6.951436	73.220258
Coastal fringe	6.952150	73.220499
Coastal fringe	6.952735	73.220674
Coastal fringe	6.953370	73.220882
Coastal fringe	6.954099	73.221122
Coastal fringe	6.954837	73.221295
Coastal fringe	6.955691	73.221467
Coastal fringe	6.956545	73.221615
Coastal fringe	6.957237	73.221676

Table A 6. Habitat type and GPS location of all transect surveys.

Transect ID	Habitat	Latitude	Longitude
1	Western fringe	6.9452878	73.2175578
2	Mangrove pond	6.9475290	73.2178909
3	Western fringe	6.9477448	73.2176802
4	Western fringe	6.9489716	73.2170987
5	Western fringe	6.9497513	73.2162131
6	Western fringe	6.9511050	73.2172498
7	Western fringe	6.9562540	73.2206794
8	Western fringe	6.9562858	73.2193108
9	Western fringe	6.9549848	73.2181571
10	Western fringe	6.9533835	73.2189654
11	Western fringe	6.9524256	73.2180539
12	Mangrove pond	6.9546683	73.2193394
13	Mangrove pond	6.9540719	73.2188511
14	Mangrove pond	6.9542333	73.2185982
15	Mangrove pond	6.9540854	73.2192504
16	Mangrove pond	6.9534324	73.2198780
17	Mangrove pond	6.9543028	73.2203471
18	Mangrove pond	6.9507929	73.2170733
19	Mangrove pond	6.9506410	73.2183937
20	Mangrove pond	6.9513713	73.2187534
21	Mangrove pond	6.9521346	73.2181770
22	Coastal fringe	6.9574929	73.2213014
23	Coastal fringe	6.9568073	73.2214915
24	Coastal fringe	6.9470318	73.2178544
25	Coastal fringe	6.9485304	73.2183165
26	Coastal fringe	6.9497380	73.2194089
27	Coastal fringe	6.9510073	73.2198481
28	Coastal fringe	6.9527227	73.2195281
29	Coastal fringe	6.9537711	73.2207327
30	Coastal fringe	6.9551402	73.2210927
31	Coastal fringe	6.9568761	73.2212845
32	Mangrove pond	6.9493545	73.2177346
33	Mangrove pond	6.9493781	73.2181512
34	Mangrove pond	6.9486456	73.2181974
35	Mangrove pond	6.9481254	73.2182166

Table A 7. Habitat type and GPS location of insect surveys.

Habitat	Latitude	Longitude
Community	6.955386	73.212814
Farmland	6.957890	73.217661
Wetland fringe	6.957159	73.221107

Table A 8. GPS start and end points of marine roaming surveys.

Survey Number	Latitude start	Longitude start	Latitude end	Longitude end
1	6.946053	73.219957	6.947521	73.22091
2	6.956623	73.223005	6.955235	73.222807
3	6.95012	73.221785	6.953757	73.222342

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