

Baseline Assessment for Environmentally Significant Areas of Laamu

Literature Review
Ecological Baseline
Socio-Economic Baseline
Geomorphological Baseline



Ministry of Tourism
and Environment



MALDIVES
Resilient
Reefs



Prepared by Enhancing National Development through Environmentally Resilient Islands (ENDhERI) Project for the Ministry of Tourism and Environment.

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Cover photo : Marteyne van Well for Blue Marine Foundation

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Literature Review



Executive Summary

In support of the baseline environmental assessment of five environmentally significant areas (ESA) in Laamu Atoll, this literature review summarises the existing geological, economic and ecological evidence-base associated with each ESA. Laamu Atoll (Hahdhunmathi) is located in the south-central region of the Maldives and comprises 72 islands, 11 of which are inhabited. Employment and income for the atoll mostly comes from tourism, fisheries, and agriculture. Laamu Atoll has been less impacted by infrastructural changes compared to other Maldivian atolls. This enabled the coastal marine ecosystems of Laamu Atoll to be renowned as some of the most least impacted in the country, as evidenced by the declaration of the atoll a Mission Blue Hope Spot in 2021. Accordingly, Laamu Atoll boasts extensive coral reef, mangrove and seagrass habitats, which support a broad diversity of marine life.

However, like the rest of the Maldives, Laamu Atoll is threatened by both anthropogenic global and local stressors. The communities of Laamu Atoll are highly vulnerable to the impacts of global climate change, with coral bleaching due to elevated sea surface temperatures and sea-level rise of particular threat. Further to global stressors, localised impacts such as coastal development, pollution and overfishing are reducing the ability of Laamu Atoll's coastal ecosystems to resist, recover and adapt to environmental disturbances such as coral bleaching. In a measure to preserve some of Laamu Atoll's most pristine ecosystems, six Protected Areas (PAs) were established on the atoll in 2021 which cover over 2,750 ha of the atoll.

The five identified ESA differ greatly in their ecological and socio-economic characteristics and exist along varying gradients of anthropogenic exposure. Fonadhoo Diving Point (site 1) is in the southeastern side of Laamu Atoll within the jurisdictional boundary of Laamu Fonadhoo, the capital island of Laamu Atoll. The site consists of only coral reef habitat which supports healthy coral reef benthic and fish assemblages, alongside reef mantas rays which aggregate at a known 'cleaning station'.

Isdhoo Muli (site 2) is located on the northeastern tip of Laamu Atoll within the jurisdictional boundary of Laamu Isdhoo. The site spans the island's northeastern edge on the outer reef area and is predominantly coral reef habitat. There is high fishing pressure around the site, particularly for reef fishing which is the largest commercial fishery in Laamu Atoll in terms of fisher involvement and spatial footprint. Furthermore, the islands of Isdhoo and other islands in close proximity to Isdhoo Muli have undergone significant development projects over recent years, including harbour redevelopments.

Mathigulhi Sarahadhu (site 3), is located on the southwestern side of Laamu Atoll, on the western lagoon of Kunahandhoo. There are two vegetated islands and several rock banks within the ESA and scattered small seagrass habitat. Mundoo Channel (site 4) is located on the central eastern side of Laamu Atoll, north of Mundoo and south of Maabaidhoo islands. It is a channel that connects the inner atoll with the open ocean. The site consists of coral reef and seagrass habitats. The marine life around the ESA carries large ecological value, however recent ecological studies indicate a harbour extension in Maabaidhoo maybe carrying negative impacts on marine biodiversity in the ESA.

The final ESA under assessment is known as Reethi Haa and Hudhafaru (site 5), which is located on the southern inner atoll area of Laamu Atoll, north of Maamendhoo and Olhuveli islands. Multiple reef ecosystems are located within and surrounding the ESA, with healthy coral reef benthic and fish assemblages recorded throughout the ESA. With marine ecosystems on Laamu Atoll at increased threat of both localised stressors (i.e. coastal development) and global climate change, research into the socio-ecological value of the five ESAs will be critical in informing the protection of Laamu's marine resources into the future.

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Abbreviations

EEZ	Exclusive Economic Zone
ENDhERI	Enhancing National Development through Environmentally Resilient Islands
EIAs	Environmental impact assessments
ESA	Environmentally Significant Areas
GEF	Global Environment Facility
IOTC	Indian Ocean Tuna Commission
IPCC	Intergovernmental Panel on Climate Change
MCCEE	Ministry of Climate Change, Environment and Energy
MRR	Maldives Resilient Reefs
NAPA	National Adaptation Programme of Action
NC	Natural Capital
NGO	Non-Governmental Organisation
PA	Protected Areas
SIDS	Small island developing states
UNEP	United Nations Environment Programme

1. Introduction

1.1 Background

The Government of the Republic of Maldives, in collaboration with the Ministry of Climate Change, Environment and Energy (MCCEE), is implementing the Enhancing National Development through Environmentally Resilient Islands (ENDhERI) project. This initiative, funded by the Global Environment Facility (GEF) and supported by the United Nations Environment Programme (UNEP), aims to facilitate the adoption of new environmental policies and the transition toward Green Growth atoll development. This development strategy aims to sustain marine Natural Capital (NC) and enhance the resilience and recovery of reef ecosystems. The project will draw from integrated coastal zone management within a Managed Marine Area/Biosphere Reserve framework, along with innovative sustainability practices in sectors such as agriculture, fisheries, tourism, and construction. The goal is to transform the ecological impact in Laamu Atoll, leading to national-level sector transformation, spatial planning, and improved governance based on NC accounting.

The “*Consultancy Service to Develop Baseline Assessment for Environmentally Significant Areas at Laamu*” was contracted to Maldives Resilient Reefs (MRR), a Maldivian Non-Governmental Organisation (NGO) dedicated to restoring coral reefs in the Maldives as climate resilient ecosystems for the benefit of people, nature and the economies that depend on them.¹ The main objective of the consultancy is to conduct baseline assessments of five potential Environmentally Significant Areas (ESAs) of Laamu Atoll, in line with IUCN “Guidelines for coral reef and small island vegetation surveys in the Maldives”. The assignment requires a literature review and the procurement of field data (*via* field surveys and community consultation) to assess and analyze the ecological characteristics and the socio-economic setting of the five potential ESAs. The present document reports on the literature review of existing information available, including background documents and published documents related to previous projects undertaken relevant to the assignment and data from relevant Environmental Impact Assessment reports.

1.2 Scope

This report provides a summary of existing geological, economic and ecological evidence-base across Laamu Atoll and identifies atoll-level anthropogenic impacts and existing marine governance. Furthermore, ecological descriptions of each ESA are provided using the existing scientific evidence, in addition to the specific natural and anthropogenic stressors which may be influencing each area.

2. Materials and Methods

To understand the potential localised anthropogenic impacts on each ESA, associated inhabited islands were identified and characterised in terms of their socio-economic profile and existing development practices. Information has been derived from a mixture of peer-reviewed literature, technical reports, and other grey literature through ‘snowball’ literature sampling, where articles are discovered iteratively through the references of identified articles and reports.

2.1 Study site

The Maldives is an archipelagic nation located in the Indian Ocean, comprised entirely of low-lying coral islands (Figure 1). It is one of the world's smallest and most dispersed countries, consisting of around 1,200 islands and 26 distinct atolls spread over 90,000 km². The average ground level across the Maldives is only 1.5 m above sea level, making it highly vulnerable to sea level rise and coastal inundation. With its highest point at just 2.4 m, the Maldives is one of the world's lowest-lying countries, rendering it exceptionally susceptible to the impacts of climate change and extreme weather events.

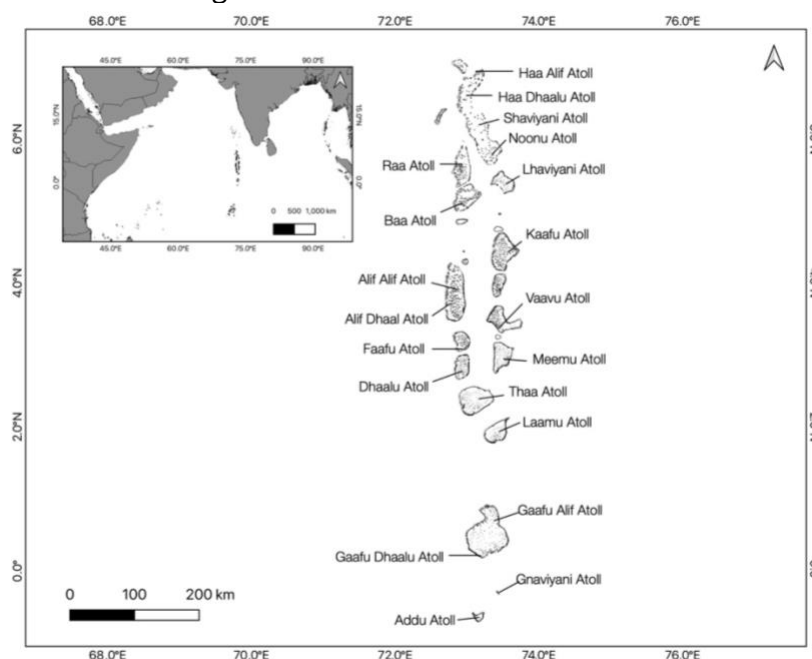


Figure 1. The administrative divisions of the Maldives archipelago in the context of the Indian Ocean Region.

Laamu Atoll (Hahdhunmathi) is one of the 20 administrative atolls of the Maldives, located in the south-central region, about 290 km south of the capital, Malé (Figure 1). The atoll consists of a ring-shaped coral reef enclosing a lagoon (Figure 2). This barrier reef has only a few channels and these join the inner atoll waters with the open ocean. It has a total land area of around 6.3 km² and is made up of 72 islands, of which 11 are inhabited most of

which are located towards the east and south of the atoll. The eastern islands are home for approximately 67% of the resident population of Laamu Atoll (McNamara, et al., 2018).

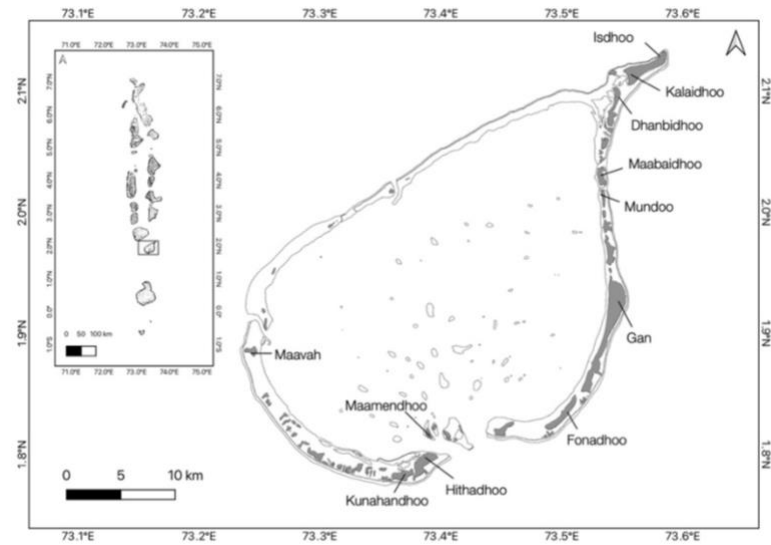


Figure 2. Map of Laamu atoll.

3. Economic overview of Laamu Atoll

The population on Laamu Atoll is around 15,000 of which the male to female ratio is approximately 50:50 and includes about 4,000 foreigners (Maldives Bureau of Statistics: Ministry of Housing, Land & Urban Development, 2020). The average household income on the atoll is around MVR 21,200 and the average monthly house expenditure is MVR 21,300 (National Bureau of Statistics: Ministry of Finance & Treasury, 2016). Generally, there is high income disparity among households in Laamu (National Bureau of Statistics: Ministry of Finance & Treasury, 2016). The total size of the workforce on the atoll is just over 7,500 people, whereas the total unemployment rate in 2022 was 4.6%, with the rate amongst women being nearly two times higher at 7.9%.

Historically, Laamu Atoll was predominately a skipjack tuna fishing community, however islands located further from the channels generated income via farming or small-scale businesses (Evans, et al., 2018). The employment and income for the atoll mostly comes from tourism, fisheries, and agriculture. On the atoll there are two resorts and three local guest houses (Ministry of Tourism: Republic of Maldives, 2024). This comprises of Six Senses Laamu (5-star resort which has 99 rooms) and Rahaa Resort (4-star resort with 81 rooms). Compared to other atolls in the Maldives, this reflects how Laamu Atoll has been less impacted by infrastructural changes over the past two decades, especially in comparison to other atolls such as Kaafu Atoll, which has over 260 accommodation facilities (Evans, et al., 2018).

The number of people employed by these tourist resorts is just less than 300, of which very few are female (Maldives Bureau of Statistics: Ministry of Planning, Housing & Infrastructure, 2020). Regarding fisheries in 2017, the atoll was catching about 8.5% of the total catch from the Maldives. In the agriculture sector, nearly half of the coconut traded in Male' markets came from Laamu Atoll, and agricultural products from the atoll represented a sixth of all agricultural products traded in Male' markets (Ministry of Fisheries and Agriculture, 2017).

4. Biodiversity overview of Laamu Atoll

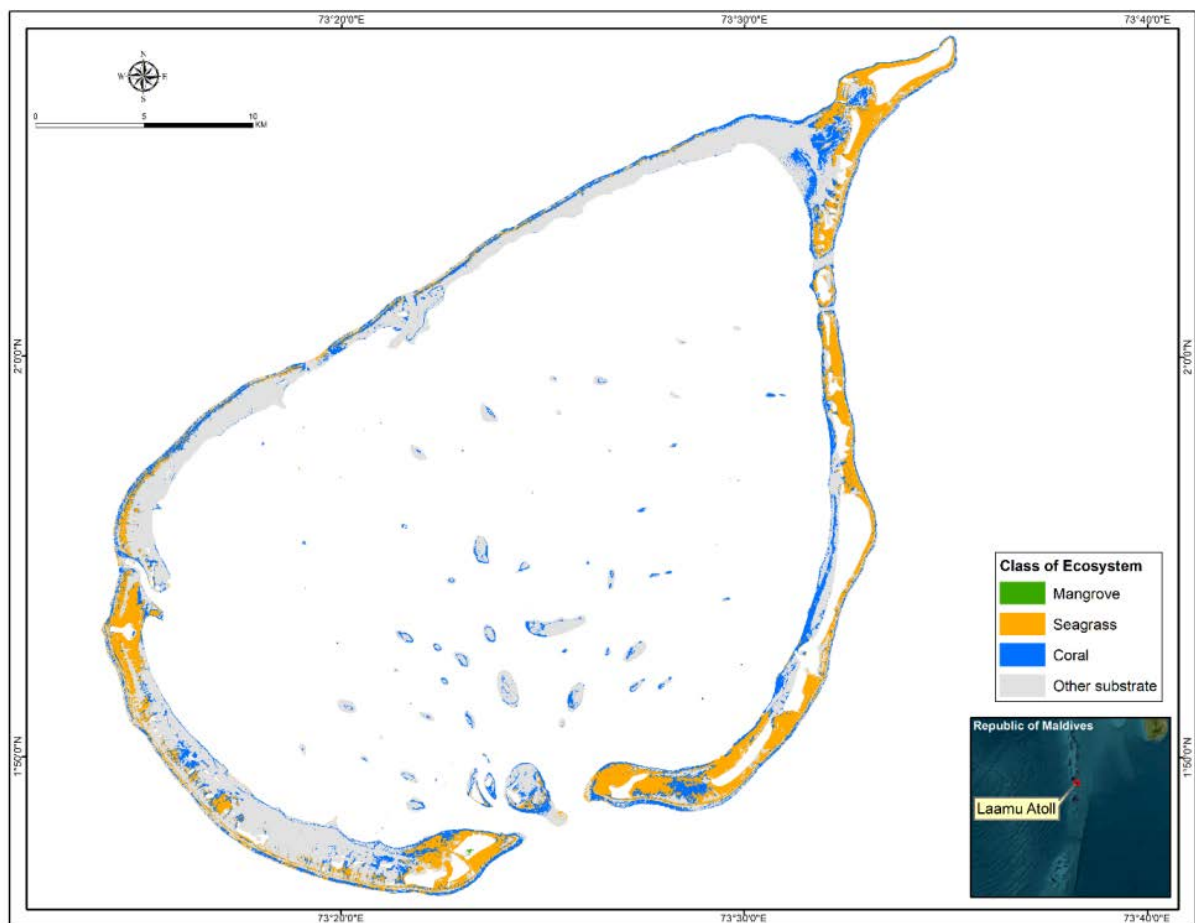


Figure 3. A map of Laamu atoll, demonstrating the presence of different marine ecosystems based on 2023 field surveys of mangrove, seagrass and coral reef extent (Rekam Nusantara Foundation, 2023).

4.1 Coral reefs: Laamu Atoll

Coral reefs in the Maldives cover around 4,500 km² and is known for harbouring potentially the highest coral reef diversity in the central Indian Ocean (Dryden, et al., 2020). Shallow coral platforms occupy 21.1% of the total area of the archipelago. Of these, 82% are rim and oceanic reefs and 17% are patch reefs within the atoll lagoons (Naseer, 2003).

Laamu Atoll is home to 56 distinct reefs that cover an area of approximately 203 km², which is around nine times than the land area (Figure 3; Naseer & Hatcher, 2004). The coastal marine ecosystems of Laamu Atoll are renowned as some of the most least impacted in the country, as evidenced by the declaration of the atoll a Mission Blue Hope Spot in 2021 (Mission Blue, 2021).

Two mass bleaching events have impacted the Maldives in 1998 and 2016, with the 1998 bleaching resulting in a major decrease of coral cover to less than 8% (Monfared, et al., 2023). In Laamu Atoll, the live coral declined by approximately 73% during the 2016 bleaching event (Ibrahim, et al., 2017). Coral reef surveys conducted at 32 reef sites at 10 m depth in the atoll in 2017 under United Nations Development Programme (UNDP)'s Low Emission Climate Resilient Development Programme (LECRd) showed that overall live

coral cover in Laamu Atoll was low at approximately 18% (UNDP, 2017, unpublished). The North of Laamu Atoll showed the highest coral cover at approaching 30% that percentage declined with latitude to the southern point of the atoll. Outer reefs had a significantly higher density of corals <5 cm (12.6/ sq m) than 8.1/ sq m on inner reefs (UNDP, 2017, unpublished). Acroporids made up almost half (48%) the composition of inner reefs, while outer reefs were composed of Acroporids (27%) Pocilloporids (20%) and Porites (20%). There was also a difference in coral assemblages in the northern and southern portions of the atoll, with *Acropora* dominating southern assemblages (~60%) and northern assemblages more mixed, with higher proportions of *Psammocora*, *Pocillopora*, and *Porites*.

MRR and Blue Marine Foundation conducted coral reef surveys in Laamu Atoll in 2019 at 19 sites, and in 2021/ 2022 at 28 sites. These surveys assessed reef recovery dynamics, changes in fish abundance and diversity. The average coral cover was found to have increased from 17.1% in 2019 to 26.9% in 2021/22. Between the two survey periods, there were notable declines in bare rock, dead coral, and soft coral and increases in hard coral, algae, and sponges. Increases in algal and sponge coverage during this period could indicate a change in ecological regime compared to pre-bleaching ecosystem dynamics. In terms of coral community composition, the surveys observed that *Acropora* coral cover accounted for approximately 18% of total live coral cover.

4.1.1 Associated reef fish diversity

Coral reefs throughout the Maldives play a critical role in safeguarding healthy populations of reef fish, many of which are relied on for local sustenance and form the cornerstone of reef fish fisheries within the region. The reefs around Laamu Atoll provide habitat for hundreds of reef fish species, many of which are targeted by commercial fisheries or are indicators of coral reef health.

The UNDP LECReD surveys of 2017 showed that there was a striking latitudinal gradient in total fish abundance, with numbers decreasing from the northern to southern reefs of the atoll. The absolute abundance of reef fish in inner reefs (192 +/- 42.5) was higher than outer reefs (131.7 +/- 35.2) although this was not statistically significant.

In 2021/22, MRR and Blue Marine assessed reef fish abundance and biodiversity at 28 sites across Laamu Atoll (Shephard, 2022). A total of 108 different species recorded across all survey sites, with a mean Simpson diversity index of 0.79 (0.43 – 0.95)¹. These surveys also aimed to compare the abundance of commercially and ecologically important fish on the Laamu Atoll between 2019 and 2021/22, with results demonstrating a recent significant increase in the abundance of ecologically important fish and a relatively similar community composition following the 2016 bleaching event (Shephard, 2022). A significant decline in abundance, however, was observed for Butterflyfish (*Chaetodontidae*). While no baseline data were available on the abundance of *Chaetodontidae* prior the 2016 bleaching event, this family is recognised as a key coral health indicator (Shephard, 2022)². Parrotfish (*Scaridae*) are widely recognised to play a crucial functional role in coral reef ecosystems,

¹ See Appendix 3 of Shephard, 2022 (pp. 43) for fish family and species surveyed.

² See Appendix 4 of Shephard, 2022 for a table of abundance biodiversity data for all 28 sites surveyed.

with observations of parrotfish in Laamu across both periods a positive reflection of ecological health of coral reefs on the atoll.

While not covered in these recent surveys, another key reef fish species in Laamu Atoll is the Napoleon or humphead wrasse (*Cheilinus undulatus*). This threatened but charismatic species was protected in the Maldives in 1995, where a ban on its capture, sale and export was put in place (Sluka, 2000). A recent study conducted in Laamu Atoll identified that 25 years on from this ban, mean densities of napoleon wrasse align with values observed in unexploited areas with similar habitats, while also highlighting the vital importance of reef channel habitat for this species (Roe, et al., 2022).

Reef channel habitat has also been identified as important for grouper species, specifically for the location of potential spawning aggregation sites. This knowledge was derived through a project implemented by Blue Marine Foundation, which indicated that grouper spawning aggregation sites are located in the seven main channels around Laamu Atoll (Evans, et al., 2018). Further timed swim and exploratory dive surveys determined that three channel sites in Laamu Atoll (Hithadhoo Corner, Maavah Kandu and Fushi Kandu) act as spawning sites for multiple grouper species. More detailed surveys officially verified Hithadhoo Corner as a multi-species spawning aggregation site for several grouper species, including brown-marble grouper (*Epinephelus fuscoguttatus*), squaretail coral grouper (*Plectropomus areolatus*) and camouflage grouper (*Epinephelus polyphekadion*) (Evans, et al., 2018).

4.2 Mangroves: Laamu Atoll

Mangrove forests are an iconic and vital ecosystem that can be found throughout the Maldives. This 'blue carbon' habitat sequesters and stores carbon, provides coastal protection services and shelter for biodiversity. Currently, mangroves (locally known as 'Kulhi') can be found on approximately 150 of all Maldivian islands, with 23 islands having at least one protected mangrove area and 14 species have been observed across just under ten per cent of all Maldivian islands (White, 2019); (Cerri, et al., 2024). One study also states that 15 of the 17 mangrove species found across Indian Ocean atolls can be found in the Maldives (White, 2019).

Mangrove forests can be found on Laamu Atoll, with several mangrove species observed across the six local islands of Maavah, Hithadhoo, Gaadhoo, Gan, Kalaidhoo and Maabaidhoo (Rekam Nusantara Foundation, 2023). The five primary genera of mangrove include red mangrove (*Rhizophora*), yellow mangrove (*Ceriops*), black mangrove (*Lumnitzera*), mangrove apple (*Sonnerati*) and small-leafed orange mangrove (*Bruguiera*). On Maabaidhoo Island, *Rhizophora mucronata* and *Ceriops tagal* can be found, with the latter two species introduced from Hithadhoo island in 2017 (White, 2019) (Cerri, et al., 2024). On Hithadhoo Island, *R. mucronata*, *C. tagal* and *Lumnitzera racemosa* can be found to form a semi-enclosed embayment mangrove (White, 2019). In Gan, *B. gymnorrhiza* has also been observed (Cerri, et al., 2024).

4.2.2 Associated fish diversity

Mangroves have been recognised for their role in supporting populations of ecologically and commercially important marine fish species, such as providing nursery habitat for early life-stage and juvenile marine fishes. Many coral reef fishes will mature in mangrove and seagrass habitats before moving onto the coral reef once they have reached adulthood. With no baseline data previously collected on the mangrove forests of Laamu Atoll, White (2019) conducted surveys on mangrove forests on Hithadhoo and Maabaidhoo islands and the respective faunal composition. This research found that both sites provided key habitat for juvenile species and demonstrated how mangroves can act as nursery grounds for fish (White, 2019). Highly abundant species included common silver-biddy (*Gerres oyena*); *Terapon jarbua* (crescent grunter) and *Siganus lineatus* (golden-lined spinefoot). *Lutjanidae* and *Gerridae* were also the most represented families across both surveyed mangrove sites.

4.3 Seagrass meadows: Laamu Atoll

Seagrass meadows, known locally as Hui or Moodhu Vina, are widespread in the Maldives, but are not well documented. Despite their prevalence, seagrass meadows in the Maldives have received little scientific attention. As of 2019, only two published studies had focused on seagrass in the country, highlighting a significant gap in research on this ecosystem. Advancements in conservation technology has enabled further insights into seagrass extent across the Maldives and enabled Laamu Atoll's seagrass ecosystems to be compared to other atolls. A recent study from 2024 used Google Earth Engine to analyse seagrass extent across the country (Floyd, 2024). According to the model's findings, seagrass habitats in the Maldives are not evenly distributed. A significant majority of the seagrass, about 76% (covering 79.8 km²), was found in the southern half of the country. The distribution across different atolls was also uneven. Just three atolls accounted for 67% of the total seagrass area in the country. Specifically, Huvadhu Atoll had 29.3 km², Laamu Atoll had 21.9 km², and Meemu Atoll had 19.4 km² of seagrass. These findings highlight the concentrated nature of seagrass distribution in the Maldives, with certain areas, such as Laamu Atoll, hosting most of this important marine habitat.

Like mangroves, seagrass meadows are another vital marine habitat that provide a plethora of ecosystem services such as carbon storage and sequestration, sediment stabilisation, water quality improvement and shelter for marine life. However, a 2017 study by the Maldives Underwater Initiative, Six Senses Laamu surveyed 49 resorts and found that half of those with seagrass actively remove it (Roe, 2020). The primary motivation for removal is aesthetic, as resorts believe seagrass may negatively impact their business.

In Laamu Atoll, six species of seagrass have been observed: *Thalassia hemprichii*, *Thalassadendron ciliatum*, *Syringodium isoetifolium*, *Cymodocea rotundata*, *Halophila ovalis* and *Halodule pinofilia* (Blatchford, 2019). A 2019 report surveyed sites at Hithadhoo, Gaadhoo and Maabaidhoo in Laamu atoll, finding that *T. ciliatum* was one of the most dominant species observed. Other recent surveys have found that seagrass meadows are the dominant habitat around the shallow waters of Laamu (Rekam Nusantara Foundation, 2023). The extent of seagrass across Laamu Atoll was recorded to be approximately 22 km² in 2021, which represents an increase of 256% in coverage since year 2000 (Floyd, et al., 2024). Surveys identified four seagrass species (*Thalassia hemprichii*, *Thalassadendron ciliatum*, *Syringodium isoetifolium* and *Cymodocea rotundata*), with *Thalassia hemprichii*

and *Cymodocea rotundata* being the most observed across most of the survey sites (Rekam Nusantara Foundation, 2023).

Seagrass surveys conducted by Maldives Underwater Initiative, Six Senses Laamu, in 2019 and 2020 in the lagoon of Olhuveli Island, showed significant growth, with seagrass coverage expanding to over 116,600 square meters in 2020 - a 20% increase from the previous year (Roe, 2020). The study observed two types of growth: new small areas sprouting from single points, and existing patches expanding and merging. This suggests favorable environmental conditions supporting both new growth and expansion of established areas.

4.3.1 Associated fish diversity

The link between seagrass meadows and the provision of critical nursery habitat for both coral reef species and species of commercial importance has been demonstrated on a global scale (Unsworth, et al., 2024). This has also been illustrated specifically for parrotfish, which is equally vital due to the species' role in produced reef island-building sediment (East, et al., 2023). The 2019 report on seagrass meadow characterisation and fish assemblages across Hithadhoo, Gaadhoo and Maabaidhoo showed that a high portion of the fish identified were juveniles, with the Hithadhoo site showing all emperor and parrotfish species as juveniles (Blatchford, 2019). This suggests that the seagrass beds offer a functional nursery role for both key fishery and coral reef families, which included species from the *Lutjanidae*, *Lethrinidae*, *Serranidae*, *Chaetodontidae* and *Scaridae* families (see Table 1 for common names and importance).

4.4 Megafauna: Laamu Atoll

Laamu Atoll is home to a range of resident and transient populations of marine megafauna, including populations of reef and oceanic elasmobranchs, cetaceans and sea turtles (iNaturalist, 2023). The most commonly observed shark species include whitetip reef sharks (*Triaeodon obesus*), blacktip reef sharks (*Carcharhinus melanopterus*) and grey reef sharks (*Carcharhinus amblyrhynchos*; iNaturalist, 2023). Sightings of other shark species such as tawny nurse sharks (*Nebrius ferrugineus*), tiger sharks (*Galeocerdo cuvier*), bull sharks (*Carcharhinus leucas*), whale sharks (*Rhincodon typus*), sicklefin lemon sharks (*Negaprion acutidens*) and silvertip sharks (*Carcharhinus albimarginatus*) have been observed, yet sightings are comparatively rare (personal observation). Moreover, various species of ray can be commonly observed across the atoll, including the charismatic reef manta ray (*Mobula alfredi*), which frequent cleaning stations around the atoll, with common re-sightings of the same individuals (Wenham, 2022). As of 2023, Manta Trust has identified 149 individual manta rays in Laamu Atoll, over half of which were encountered in 2023 (MMCP, 2023). Other rays frequently recorded around the atoll include white spotted eagle ray (*Aetobatus ocellatus*), cow tail stingray (*Pastinachus ater*), pink whipray (*Pateobatis fai*), short horned pygmy devil ray (*Mobula kuhlii*) and blotched fantail ray (*Taeniurops meyeri*; iNaturalist, 2023).

Various cetacean species are also frequently observed in the atoll, which most notably includes large populations of spinner dolphins (*Stenella longirostris*) and Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) which can be commonly observed transiting

through atoll channels during dawn and dusk daylight hours (personal observation). Less commonly observed cetacean species include false killer whales (*Pseudorca crassidens*), short-finned pilot whales (*Globicephala macrorhynchus*) and rissos dolphin's (*Grampus griseus*). Other large cetacean species such as humpback whales (*Megaptera novaeangliae*) and blue whales (*Balaenoptera musculus*) have been observed in the Maldives, yet sightings in Laamu Atoll are thought to be exceedingly rare.

The atoll is also home to two species of sea turtle: 1) green sea turtle (*Chelonia mydas*); and 2) hawksbill sea turtle (*Eretmochelys imbricata*). As of 2023, the Olive Ridley Project has identified 1,022 unique individual turtles in Laamu Atoll; 384 green turtles and 638 hawksbill turtles (ORP, 2023). This makes Laamu Atoll the atoll which hosts the third largest population of sea turtles in the Maldives, and the largest in the southern part of the country. The majority of turtles recorded in Laamu Atoll are juveniles, especially that of hawksbill turtles. There are many green sea turtle nesting beaches spread across the atoll. This includes on the island of Gaadhoo which is the one of the most significant green sea turtle nesting site in the Maldives.

5. Environmental and Anthropogenic Stressors

5.1 Environmental stressors

Small island developing states (SIDS), like the Maldives, are considered particularly vulnerable to climate change impacts due to their unique geographical, environmental and socio-economic characteristics. According to the Intergovernmental Panel on Climate Change (IPCC), SIDS will be hit first and hardest by global climate change. Not only have SIDS contributed the least to climate change, but they are also among the least equipped to respond and adapt to climate change impact (IPCC, 2023). The inherent characteristics of SIDS, such as their small size, isolated location, and remoteness, further exacerbate their vulnerability to these environmental hazards.

Coastal ecosystems of the Maldives are at risk from numerous threats with a range of impact scales from local to global level. Beyond the unpredictable consequences of climate change, the Maldives faces tropical cyclones, droughts, storm swells, temperature variations, changes in ocean chemistry, rainfall patterns, strong winds, and sea-level rise. These factors can lead to devastating consequences, including coastal erosion, flooding, and disruptions to ecosystems, food and water supplies, settlements, infrastructure, biodiversity, livelihood systems, and economic growth. The islands' low elevations make them particularly susceptible to the impacts of coastal inundation. The combination of these climatic and oceanic drivers, coupled with the unique structural features of the Maldives, narrows the islands recovery time and cumulatively damages various aspects of Maldivian societies and economies. The Maldives' National Adaptation Programme of Action (NAPA) has identified infrastructure, tourism, fisheries, human health, water resources, agriculture and food security as the most vulnerable sectors in need of urgent and immediate climate change adaptation strategies (MEE, 2015).

In addition, Maldives has been subject to an earthquake-generated tsunami reaching heights of 4.0m on land (UNEP, 2005). Historical wave data from Indian Ocean countries show that tsunamis have occurred in more than one occasion, most notable has been the 1883 tsunami resulting from the volcanic explosion of Karakatoa in Indonesia. According to the United Nations Environment Programme (UNEP), the Maldives has experienced a tsunami reaching heights of 4.0 m on land in the past. This significant wave height highlights the severe impact that a tsunami can have on the islands, many of which have an average elevation of just 1-2 m above sea level. To mitigate the risks posed by earthquakes and tsunamis, the Maldives has implemented various measures, such as early warning systems, evacuation plans, and public awareness campaigns. However, the low-lying nature of the islands and their limited resources make it challenging to fully protect against the potential devastation caused by these natural disasters (MMS, 2024). The 2004 Indian Ocean tsunami caused great damage to Laamu Atoll's inhabited islands, yet minor damage was reported on the surrounding coral reefs (Zahir, et al. 2006). The channels were found to have had the greatest damage with about 8% breakage of corals, some sand deposition and overturned rubble.

5.2 Anthropogenic stressors

The biggest threat to coastal and marine ecosystems in the Maldives comes from elevated sea waters, siltation from dredging for island harbour construction, lack of adequate infrastructures for solid waste disposal and overfishing (MEE, 2015). With the increasing population and growth in the number of visitors coming to the country, the amount of waste generated is escalating and Maldives is considerably challenged in the sustainable management of approximately 365,000 tonnes of wastes produced per year (MEE, 2016). In most islands, food and fish wastes are dumped into the sea, resulting in nutrient influxes and eutrophication (NMFS, 2009). Eutrophic water reduces growth of marine vegetation and increases harmful algal blooms, intoxicating marine organisms and humans.

In terms of the health of fisheries, studies indicate that Maldivian coral reef fisheries were not exploited until the late 1970s, with only two reef resources being exploited: live bait for tuna fisheries and cowries (MRC, 2003). However, the recent increase in resorts has amplified local demand for reef fish, expanding the export market for fish products. It is estimated that tourist resorts purchase 167 kg of fish per night to feed their guests and staff and 38% of which was estimated to be reef fish (snapper, emperor and grouper) (Knaap & Waheed, 1991). Since most of the reef fishes caught are carnivorous, their absence affects the functioning of the coral reef ecosystem. Fisheries harvests already exceeds sustainable levels on many coral reefs. Failure to prevent ecosystem overfishing will lead to a long-term reduction in habitat quality, which in turn will reduce biodiversity and the productivity of the fishery for future generations (Dhunya, et al., 2017).

5.3 EIAs and threats to ecosystem services

Environmental impact assessments (EIAs) of proposed developments across the inhabited islands of Laamu Atoll include proposals to build or redevelop harbours, build sewage systems and desalination plants and road expansions. Urban development can carry negative implications for coastal ecosystems and affect ecosystem service provision if conducted in an unethical way. Consequences of coastal development can include: 1) sedimentation and augmented turbidity; 2) chemical pollution and contamination; 3) noise and light pollution and 4) habitat fragmentation (Table 1). Potential impacts of coastal developments range from the smothering of coral reef habitats to the disruption of species life cycles movements (Table 1)

Table 1: Proposed development consequences and potential impacts on ecosystems.

Development consequences	Potential impacts on ecosystems
Sedimentation and augmented turbidity	Smother coral reefs and other benthic organisms. Can also reduce light penetration, affecting photosynthesis.
Pollution and contamination	Can lead to eutrophication and algal blooms.
Noise and light pollution	Disturb natural cycles such as breeding patterns and swimming routes of fish, turtles, sharks and other species.

6. Site-specific analysis

This section characterises the ecological and socio-economic profiles of each ESA site and surrounding local islands (Figure 4). Moreover, existing and proposed island development is discussed in the context of potential impacts upon site ecosystem service provision to local communities.

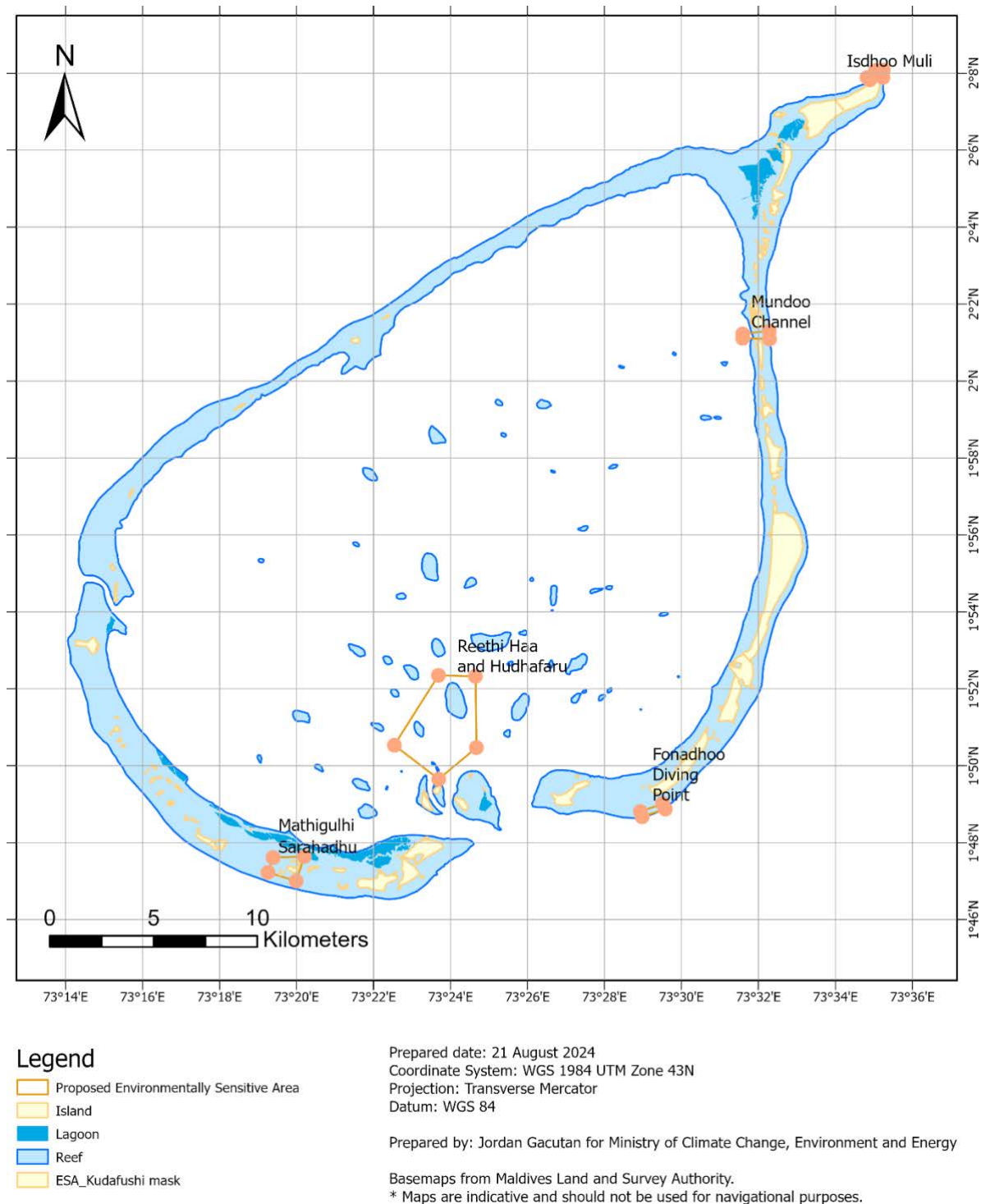


Figure 4 Five selected ESAs for the baseline assessment consultancy.

6.1 Site 1: Fonadhoo Diving Point

Fonadhoo Diving Point (FDP) is in the southeastern side of Laamu Atoll (N 1.824972, E 73.505444) within the jurisdictional boundary of Laamu Fonadhoo, the capital island of Laamu Atoll (Figure 5). It is located on the southern edge of the island on the outer reef area and consists of only coral reef habitat. The inhabited local island of Fonadhoo is most closely associated with FDP, along with Laamu's largest inhabited island of Gan which lays to the north of Fonadhoo.

Fonadhoo Diving Point

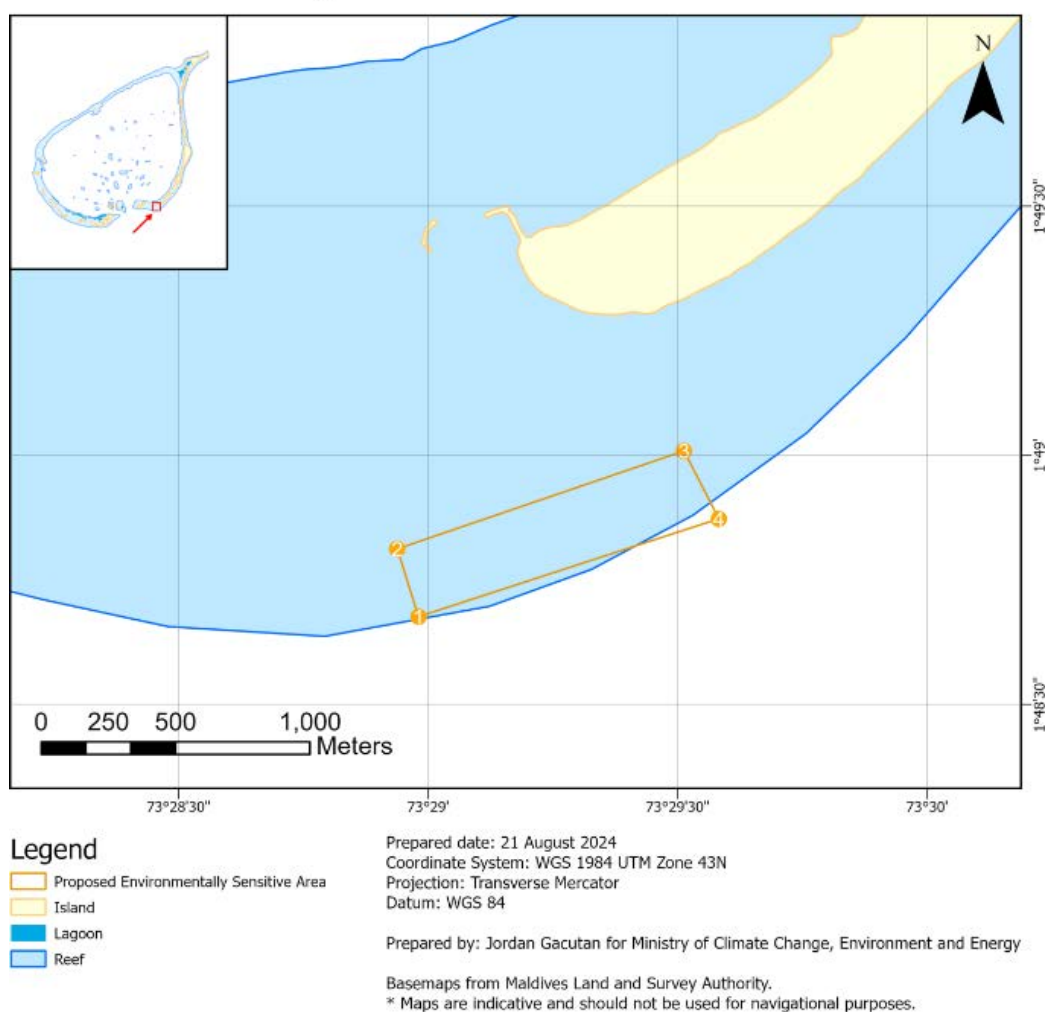


Figure 5 Map of Fonadhoo Diving Point ESA

6.1.1 Biodiversity understanding and existing research

In 2020, the Manta Trust identified a reef manta ray (*Mobula alfredi*) cleaning station at a site locally known as Fonadhoo Beyru along the outside southeastern side of Fonadhoo. The reef manta ray population in Laamu Atoll is thought to be residential, with cleaning stations an ecologically important site for reef manta ray populations (Manta Trust, 2020). It sits at

around 24m in depth, with 11 manta rays estimated to have been captured on Manta Trusts' first 'Eyes on the Reef' deployment on Fonadhoo Beyru (MUI, 2022).

MRR and partners conducted a baseline coral reef survey of a site known as Fonadhoo Outside (at 10 m and 15 m) approximately 1.75 km northeast of FDP (N 1.824972, E 73.505444) in 2019 and 2022 (Fischer, 2022). Results indicate that hard coral cover had doubled between 2019 and 2022, while sponges showed a significant increase in cover from less than 1% to 14% (Table 2). This correlated with declines in bare rock exposure and rubble cover over the same period (Table 2). Increases of hard coral could indicate ecosystem recovery from the 2016 coral bleaching event.

Table 2. Per cent (%) cover of benthic categories from 2019 surveys across Laamu Atoll. Adapted and taken from Fischer, 2022 (Appendix 4: Data summary tables, Appendix 4A and Appendix 4B (pp 41, 42)).

Survey Year	Site	Hard coral	Soft coral	Bleached coral	Diseased coral	Dead coral	Sponge	Algae	Bare rock	Sand	Rubble	Other
2019	Fonadhoo inside	32.46	10.59	0.17	0.00	4.94	0.17	0.44	17.90	23.52	18.46	1.80
2019	Fonadhoo outside	15.33	0.00	0.00	0.00	4.42	0.25	0.00	77.25	1.17	1.75	0.00
2019	Laamu Atoll average	17.09	1.72	0.34	0.00	4.95	0.51	2.57	50.55	11.63	9.77	0.87
2022	Fonadhoo inside	40.92	0.00	0.93	0.08	4.57	1.20	12.05	4.45	11.38	22.00	2.38
2022	Fonadhoo outside	34.05	0.00	0.08	0.17	3.91	14.45	0.00	12.18	0.00	0.78	32.33
2022	Laamu Atoll average (repeat sites only from 2019)	26.86	0.04	0.58	0.04	2.12	5.22	5.85	35.01	4.68	14.74	4.82

In addition to surveys covering benthic habitat and coral reef health, MRR and partners led a study to reassess spatial variability in fish abundance, richness and diversity between 2019 and 2021/22 and evaluate temporal changes in fish abundance and diversity across 19 repeat survey sites from 2019 (Shephard A., 2022; Table 3).

Table 3. Reef fish abundance and biodiversity data from 2019 and 2021/22 surveys across Fonadhoo. Adapted and taken from Femmami (2019) and Shephard (2022). The 2019 survey results do not include all metrics detailed in the 2021/22 survey results.

Survey Year	Site	No. of fish families	No. fish species	No. individuals	Species richness (species per 500m ²)	Density (individuals per 500m ²)	Simpson's biodiversity index	Most abundant family	Most abundant species
2019	Fonadhoo inside		34	261			0.92		
2019	Fonadhoo outside		35	277			0.91		
2021/22	Fonadhoo inside	8	40	256	10	64	0.89	Scaridae	C.sordidus
2021/22	Fonadhoo outside	8	36	568	9	142.24	0.79	Lutjanidae	L.kasmira

The abundance of commercially and ecologically important species increased by over 7%, with snappers (*Lutjanidae spp.*) being the most abundant fish family in both years (Table 3). However, there was a 6-10% decline in fish species richness. The 2022 surveys showed that the biomass of commercially and ecologically important fish species was 144.2 kg per 2000 m² at this site.

Resource use surveys conducted by MRR and Blue Marine in 2021 showed that there was high fishing pressure on the south and eastern edge of Fonadhoo for the lobster, octopus, reef fish (handline, pole and line, netting and spearfishing), sea cucumber and billfish fisheries (Rees, et al., 2021). The highest number of estimated fishers was for the commercial reef fish fishery (approximately 125 individuals). A kernel density analysis of spatial activities of both commercial and non-commercial fisheries revealed that reefs around Fonadhoo islands are densely fished, with a hotspot analysis further revealing a high density of fishers using areas to the east of Fonadhoo (Rees, et al., 2021).

The report also found that Fonadhoo reported the highest number of fishing vessels (53 in total), though these were all classified as smaller dinghies. The nearby island, Gan, was reportedly the location where most tuna vessels were operating from. Although the area was also identified as a tuna fishing area, this may be due to the large areas around the atoll that fishers drew on the maps. Commercial tuna species are not typically found so close to shore. Live bait fishing is not practiced in the area.

6.1.2 Socio-economic island profiles

Fonadhoo is the capital island in Laamu atoll as is approximately 163 ha, equipped with an airport. In 2022, an Environmental Impact Assessment (EIA) was conducted for the development of a regional laboratory on Fonadhoo island (Saaneez, 2022). At the time, the report found that Fonadhoo is the second most populated island of Laamu Atoll, with a population of 2,810. This high number may be associated with the higher level of development activities and commercial activities, leading to migration from other islands. Furthermore, the government relocated people of Gaadhoo to Fonadhoo in 2016, increasing the population by approximately 170 people. The report also found that there were four main economic activities, including employment in the public sector and defence; construction; retail and trade. Fishing, agriculture and tourism were not deemed as major sectors. At the time, the report lists several key infrastructure developments on the island, including a health centre; power facilities; a harbour; two telecom sites; religious sites; public administration facilities and a school, which teachers until Grade 12 and serves approximately 680 students.

In terms of active NGOs working on Fonadhoo to improve social and environmental wellbeing, there are nine classified as 'active' based a 2021 report (Rees, et al., 2021). They include Fonadhoo Innovative Youth Society; Fonadhoo Zuvaanunge Rooh; Women Enhancement (Fonadhoo); Heylhi (Fondahoo); Laamu Youth Development (Fonadhoo); Fonadhoo Youth Association; Laamu Tour; Fonadhoo Environment Sustainable Development and Fonadhoo Medha Avah Sports Club.

The nearby island Gan, when combined with adjoining island Maandhoo, is the largest geographical island in the Maldives. These areas are connected to Fonadhoo via causeways and shares the 8th largest reef system among the 20 administrative atolls (Saleem, 2017). Gan has a population of just over 4,500 people with agriculture and fisheries acting as the most dominant employment opportunities. There are over 1,000 students in Gan, which ranges from primary to higher secondary.

6.1.3 Local island development and impacts

Several EIAs have been conducted at Fonadhoo for developments such as road expansions, a desalination plant and a mariculture project. EIAs for road development were conducted in 2014 and 2021 (MRDC, 2014; MHI, 2014) (MNPFI, 2021). The sand for the backfilling and levelling work for road development were obtained from a borrow site located south of Fonadhoo, which is parallel to FDP. In 2014, it was estimated that 15,000 m³ of sand was required from this borrow site for road development in Fonadhoo. That same year, it was estimated that over 110,000 m³ of sand was required from this borrow site as well as two other borrow sites on Gan for the Gan-Fonadhoo link road development. It is unclear how much sand was required from this site for the 2021 Fonadhoo road development Phase 2. While the EIA reports deemed that the socioeconomic benefits “outweigh the negative impacts of the project on the physical environment”, they noted that mitigation measures such as controlling sedimentation and turbidity by undertaking excavation work during low tide would be essential to control sedimentation and turbidity impacts that would be caused by excavation work, and that this activity is a considerable distance from coral reefs. Furthermore, while no coral habitat was found in the borrow site for backfill material, seagrass beds were located within the site and could subsequently be impacted by reduced access to daylight for photosynthesis. The sand mining activity for backfill material resulted in the removal of seagrass and related epi/mesofauna. It is unclear how FDP was impacted by sedimentation from sand dredging activities in the southern lagoon of Fonadhoo in 2014 and possibly 2021 as coral reef baseline or monitoring information is absent.

In 2016, an EIA was undertaken to establish a 10ha sea cucumber mariculture ranching area in the northeast lagoon of Fonadhoo (Sandcays, 2016) . Overall, the project area had roughly 95% seagrass cover, primarily *Thalassia hemprichii*. Portions of seagrass was planned to be removed by the project proponent, while adding nutrient rich sand to sections of the lagoon floor where rock and debris were present. Site-specific and short-term sedimentation was expected from minor excavation work for the installation of geotubes. Further, a hatchery complex was planned to be developed on a 2ha land space. The EIA report noted that the sewer lines of the operation was planned to be connected to the recently installed sewerage system with treatment, after pre-treatment. It is unclear how this project affected the surrounding marine ecosystems as project monitoring reports are not publicly available.

6.2 Site 2: Isdhoo Muli

This site is located on the northeastern tip of Laamu Atoll within the jurisdictional boundary of Laamu Isdhoo (N 2.127097, E 73. 587400). It is on the island's northeastern edge on the outer reef area (Figure 6). The site is predominantly coral reef habitat. This section will cover content relevant to the inhabited islands of Isdhoo, Dhanbidhoo and Kalaidhoo, where available.

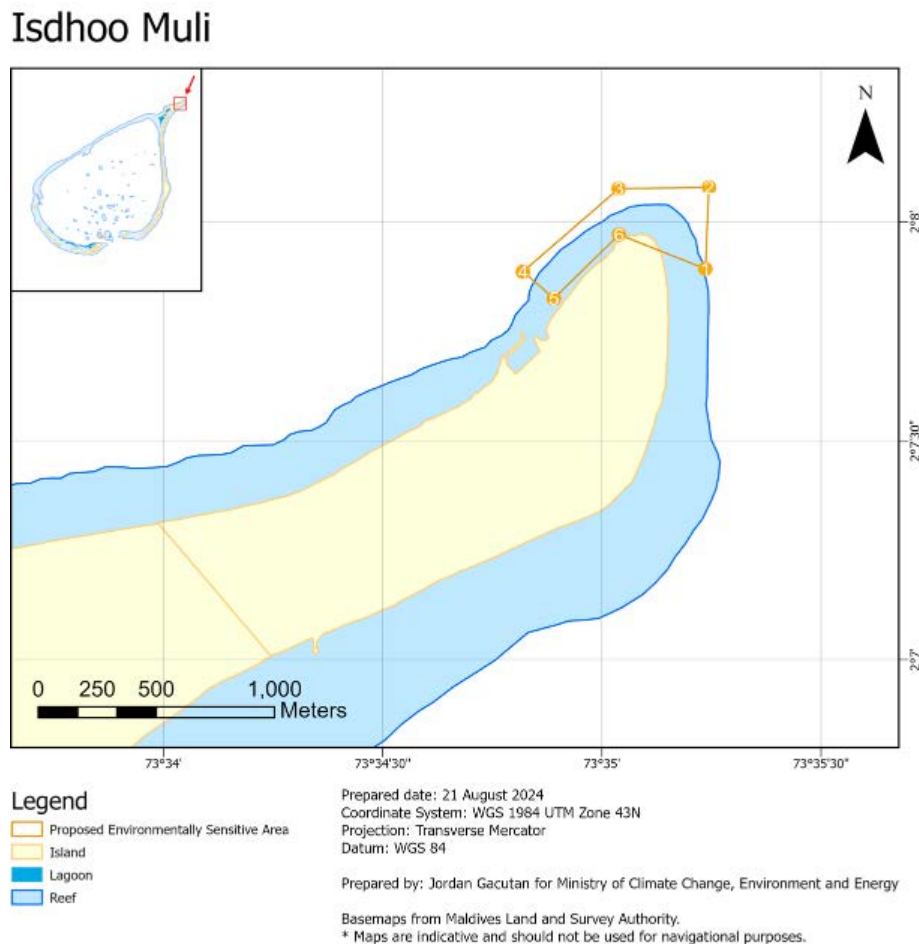


Figure 6 Map of Isdhoo Muli ESA

6.2.1 Biodiversity understanding and existing research

Coral reef surveys conducted in 2017 under UNDP's LECReD showed that the outer reef of Isdhoo had the highest amount of coral cover (40%). In 2022, MRR and partners conducted baseline coral reef surveys of a site at 5 m and 10 m approximately 0.5 km northeast of the study site in Isdhoo (Fischer, 2022). Unlike Fonadhoo, Isdhoo was a newly surveyed site in 2021/22 and no other baseline data were available prior to this date. The live coral cover at that time was 27.23%, which is just above the average recorded hard coral cover found across all surveyed sites in Laamu Atoll in 2022 (Table 4). Furthermore, Isdhoo Muli was found to contain the second highest fish abundance recorded across 28 sites surveyed in 2021/22 (Table 8; Shephard, 2022). The site also had the highest species richness, with 41

different species recorded (Table 5). Species richness was recorded at 10.25 per 500m² and fish density was recorded at 176.75 individuals per 500m² (Table 5) The most abundant fish family was Balistidae (triggerfish).

Table 4. Per cent cover of benthic categories for Isdhoo in 2021/22. Adapted and taken from Fischer (2022), Appendix 4B (pp. 41, 42).

Survey Year	Site	Hard coral	Soft coral	Bleached coral	Diseased coral	Dead coral	Sponge	Algae	Bare rock	Sand	Rubble	Other
2021/22	Isdhoo Muli	27.23	0.00	0.08	0.00	0.33	1.76	5.88	0.08	45.92	17.42	1.26
2022	Laamu Atoll average (repeat sites only from 2019)	26.8	0.04	0.58	0.04	2.12	5.22	5.85	35.0	4.68	14.74	4.82

Table 5. Reef fish abundance and biodiversity data from 2021/22 surveys across for Isdhoo Muli. Adapted and taken from Shephard, 2022 (Appendix 4, pp. 48, 49).

Survey Year	Site	No. of fish families	No. fish species	No. individuals	Species richness (species per 500m ²)	Density (individuals per 500m ²)	Simpson's biodiversity index	Most abundant family	Most abundant species
2021/22	Isdhoo Muli	8	41	707	10.25	176.75	0.90	Balistidae	<i>O. niger</i>

The Isdhoo Muli outer reef promontory was identified as a grouper spawning aggregation site by 14 local grouper fishers who were interviewed by Blue Marine Foundation in 2016-17 (Evans, et al., 2018). Almost all (95%) of the fishers who reported spawning aggregations said they had fished at the site and 75% of the fishers reported catch declines.

In Isdhoo, resource use surveys conducted by MRR and Blue Marine in 2021 showed that there was high fishing pressure for the reef fishery (handline and spearfishing), billfish fishery, tuna fishery, lobster fishery, octopus fishery, sea cucumber fishery and invertebrate collection (Rees, et al., 2021). Live bait fishing is not practiced in the area. Spatial analyses showed that the areas around Isdhoo, Kalaidhoo and Dhanbidhoo are particularly critical areas for the reef fishery, which is the largest commercial fishery in Laamu in terms of fisher involvement and spatial footprint (Rees, et al., 2021).

Isdhoo, Dhanbidhoo and Kalaidhoo, the alien species, *Holothuria scabra*, was introduced in 2016-17 as part of the 'Mariculture Enterprise Development Project' of the Ministry of Fisheries, Marine Resources and Agriculture (MoMFA) (Rees, et al., 2021).

6.2.2 Socio-economic island profiles

Isdhoo island shares a reef system with Kalaidhoo and Dhanbidhoo and is one of the largest islands in the Maldives (approximately 360 ha (Jameel & Faiz, 2020)). Currently there is no approved land use plan on the island, which has a population of approximately 1,387 individuals based on island council data from 2020 (Jameel & Faiz, 2020). The majority of the population is reported to be involved in the fishing and agriculture industries, with a

farm plot allocated to very household. The local fishing fleet is comprised of four cargo boats, nine fishing vessels, seven fishing 'small boats' and 13 dinghies. The existing harbour also hosts other vessels from other areas of Laamu atoll.

Schooling is provided on the island up to a secondary education level, with also a health centre but no water supply system (based on 2020 information). The island does have a sewage system, which was created after the 2004 tsunami. Energy is provided by three generators and an atoll ferry is the predominate mode of transport between Male', via Kahdhoo (Jameel & Faiz, 2020).

Dhanbidhoo, which is located just south of Isdhoo and Kalaidhoo, has a population of around 1,000 individuals, however some sources suggest lower estimates of around 600 (Jameel, 2012). This number is similar for Kalaidhoo, which is geographically one island as Isdhoo but represented as two different administrative islands. Dhanbidhoo has been recorded as one of the densest areas for commercial and non-commercial fisheries (Rees, et al., 2021). Local survey results also suggest there are sea cucumber processors located on Dhanbidhoo (Rees, et al., 2021). There are two active NGOs on Dhanbidhoo (Dhanbidhoo Youth Alliance and Associations for Dhanbidhoo development) and one on Kalaidhoo (Kins/Kalaidhoo).

6.2.3 Local island development and impacts

In 2017, an EIA was prepared to operationalise the waste management center located at the southeastern side of Isdhoo, roughly 1 km from the ESA (CDE Consulting, 2017). It was estimated that 0.51 tonnes of waste was generated daily, making the total annual waste generation 185 tonnes. Of the total waste generated on the island, 66% was considered compostable, 12.5% recyclable and 21.4% likely needing incineration.

In 2020, an EIA was prepared for a harbour expansion project on Isdhoo Island, which would extend and build upon the existing south side of the harbour that was deemed to small and unsustainable for its past use (Jameel & Faiz, 2020). In addition to expanding in size, it would allow additional vessels to enter the area. The report summarised that the development would have "significant negative impacts on the marine environment", primarily through permanent habitat modification and destruction. Key habitats including seagrass beds and corals would be both indirectly and directly impacted. Despite this, and as cited in several EIA reports across these sites, the report concludes that the socioeconomic benefits outweigh the negative impacts.

Marine surveys within this EIA identified *Acropora* spp. among the live corals observed, in addition to surgeon fish, trigger fish, wrasse and parrotfish. A control site was also selected on the west side of Isdhoo island, which demonstrated the highest coverage of live coral of all surveyed sites at 23.5% and marine life abundance. Across all survey sites, surgeon fishes were classed as 'abundant' (>50 individuals recorded during a 15-minute swim survey). Parrotfish were classed as 'abundant' at the control site and survey Site 1 and wrasses and damselfish were classed as 'common' (<50 individuals but observed throughout the survey) at both Site 1 and Site 2 and classed as 'abundant' and the control site.

According to 2024 press releases, President Dr. Mohamed Muizzu has outlined that a causeway between Isdhoo and Dhanbidhoo will be being built in the immediate future (One

Online, 2024; Zalif, 2023). Another source outlines the description of the project, revealed by the Maldives Transport and Contracting Company (MTCC): channel dredging operations will be required over an area of over 42,500m³; the construction of a 315m bridge; a retaining wall of over 71m and a carriageway of over 7,200m², among other activities. The project is valued at approximately MVR 144.38 million.

6.3 Site 3: Mathigulhi Sarahadhu

The site is located on the southwestern side of Laamu Atoll, on the western lagoon of Kunahandhoo (Figure 7). There are two vegetated islands and several rock banks within this area and scattered small seagrass habitat. Maafushi (2.91 ha) and Kudafushi (12.27 ha) islands are currently under the jurisdiction of Ministry of Fisheries, Marine Resources and Agriculture, with the former classified as an uninhabited island and the latter an industrial agricultural island. Two rock banks called the Bodumahigulhi (1.11 ha) and Kudamahigulhi (0.25 ha) are under the jurisdiction of Laamu Atoll Council, both classified as uninhabited islands. Anecdotal reports suggest that at least one of them was formerly vegetated. This section will cover content relevant to the inhabited Hithadhoo, Kunahandhoo and Maavah, where available.

Mathigulhi Sarahadhu

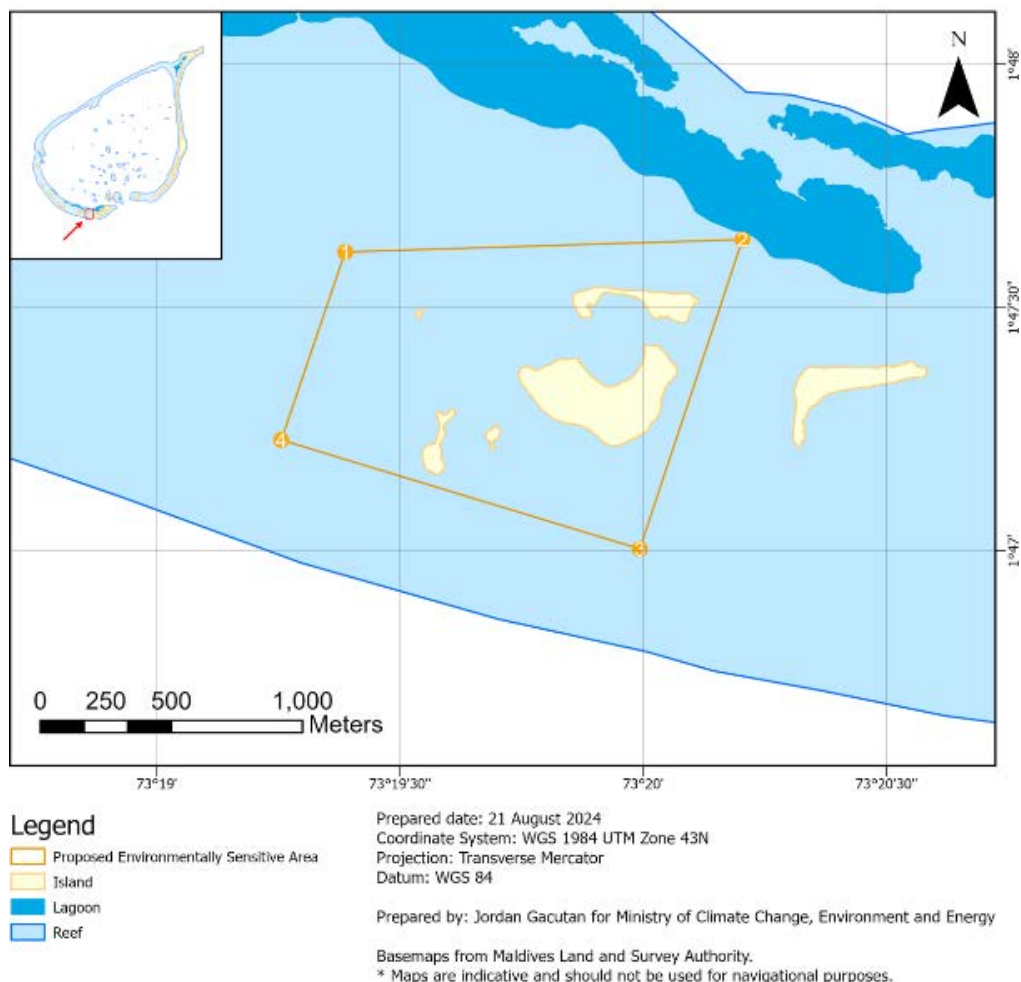


Figure 6 Map of Mathigulhi Sarahadhu ESA

6.3.1 Biodiversity understanding and existing research

This site is situated within an extensive coral reef system that covers around 4,113 ha in area. This reef system is comprised of a sloping reef, flat reef areas, and patch reefs. During low tide, these flat reef portions become exposed above the water's surface. On average, the width of the flat reef areas is approximately 700 m. The outer sloping portion of the reef that drops off has a perimeter measuring around 25,690 m and covers an area of roughly 1,798 ha. Compared to other reef systems found in the same atoll and neighbouring atolls, the geomorphology (shape and structure) of this reef system is relatively complex.

6.3.2 Socio-economic island profiles

The nearest inhabited island is Laamu Kunahandhoo, which is located on the southern rim of Laamu Atoll. It lies 264 km south of the capital city Male'. The island itself measures 1,900 m in length and 690 m in width, with a total land area spanning 46.60 ha. Around 600 people reside on the island, and the local economy relies primarily on agriculture, fishing, carpentry, and masonry work. In terms of gender ratio Kunahandhoo stands at 97 males per 100 females. Over time, some infrastructure facilities have been constructed on the island to serve the needs of its population. These include a health clinic, a school, a council office building, and a magistrate court - all considered important facilities for the community. The island's limited size and remoteness from the capital make the availability of such basic infrastructure significant.

6.3.3 Local island developments and impacts

In 2018, an EIA was prepared for agricultural development of L. Kudafushi (CDE Consulting, 2018). The report states that Kudafushi island's eastern half had been used for agriculture in the past and had numerous agricultural plots and four small buildings when surveys were undertaken. Local informants shared that the island was used for acquiring coconut palms timber in the past. The proposed project involved establishing commercial farming plots and a livestock rearing area along with a jetty, supporting infrastructure for post-harvest processing, training facilities, storage and staff accommodation. Significant adverse impact on terrestrial biodiversity was predicted from vegetation clearance and on marine water quality and marine life from sedimentation during the construction phase. It was also predicted that the use of pesticides and artificial fertilisers during the operational phase could have significant negative impacts on the environment, including soil erosion, loss of soil fertility and ground and marine water contamination. Mitigation measures were proposed including minimising and phasing vegetation clearance, revegetation after construction, carrying out marine construction during low tide and calm weather, construction of bunds where appropriate to reduce sedimentation impact. There were plans to adopt sustainable agricultural practices during the operational phase and conduct long-term monitoring, however, no monitoring reports are public available.

The summary of ecological surveys undertaken at that time is provided below:

Vegetation: The western half of the island was dominated by palms (*Cocos nucifera*) in the upper canopy while the understorey is dominated by other hardwood species such as

Dhiggaa (*Hibiscus tiliaceus*), Uni (*Guettarda speciose*), Midhili (*Terminalia catappa*), Funa (*Calophyllum inophyllum*), Magoo (*Scaevola taccada*) and Boakashikeyo (*Pandanus tectorius*). 400+ mature palm (*Cocos nucifera*) trees were counted on the island with the highest concentration on the western half of the island. The shore line of the island is dominated by species such as Magoo (*Scaevola taccada*), Boashi (*Tournefortia argentea*), Dhakandha (*Premna serratifolia*) and Kuredhi (*Pemphis acidula*). No unique trees, species or vegetation groups were observed during the field visit. It was estimated that there were about 2,000 to 8,000 trees are on the island of Kudafushi.

Fauna: The most commonly observed species on all Kudafushi were the Kaalhu (*Corvus Linnaeus*). The only resident bird observed were the Koveli (*Eudynamys scolopaceus*). Some of the sea-faring and migratory birds known to frequent Kudafushi include; Maakanaa (*Ardea cinerea*), Dhandifulhu dhooni (*Phaethon lepturus*), Findhana (*Actitis hypoleucos*) and Kirudhooni (*Sterna sumatrana*). These birds were found in very few numbers during the survey period, with the field team spotting only 2 Maakana's and 6 Findhana. Crustaceans observed on Kudafushi include the Stalk-eyed Ghost crab (*Ocypode ceratophthalmus*), the Little Ghost crab (*Ocypode cordimana*), and the Variable Land Hermit Crab (*Coenobita variabilis*) found on the beach.

Coral reef: Live coral cover was moderately good on the northern reef edge at 2 m depth. Rock was the dominant substrate covering roughly half of the reef, but live coral made up about 21% of the transect area. The dominant coral genera observed at this site was *Acropora* sp. and *Pachyseris* sp. A total of 29 fish species 12 fish families were recorded during the fish census. Highest number of fishes was recorded from families *Pomacentridae* (6 species), *Scaridae* (5 species) and *Labridae* (5 species). Another transect deployed at the reef edge showed 75% rock and 16% live coral with the dominant coral genera *Acropora* sp. and *Porites* (massive type). A total of 43 fish species 15 fish families were recorded during the fish census. Highest number of fishes was recorded from families *Scaridae* (8 species) and *Pomacentridae* (7 species). Members of *Scaridae* (Parrotfishes) are algae grazers. While members of *Pomacentridae* (Damsel-fishes) mainly feeds on benthic invertebrates, algae and zooplankton.

Seagrass: At a site located on northern section in-between the Kudafushi and Maafushi Island with the depth ranging between 0.5~1m, the dominant benthic substrate recorded was coral rubble and sand (85%) with 10% *Thalassia hemprichii*. At site located on the north eastern side of the Maafushi inner lagoon, with a depth range was 0.5~1m, the dominant benthic substrate observed was sand with seagrass patches (*Thalassia hemprichii*). Juvenile fishes were observed taking refuge in the seagrass patches.

Water quality: Marine water was slightly below the optimal pH range for seawater, nitrite level were below 5mg/L, biological oxygen demand was below 1mg/L and salinity was within the normal range for seawater. The Sulphate, Phosphate and Nitrogen Ammonia were within acceptable range in the ground water.

6.4 Site 4: Mundoo Channel

This site is located on the central eastern side of Laamu Atoll, north of Mundoo and south of Maabaidhoo islands (Figure 8). It is a channel that connects the inner atoll with the open ocean. The site consists of coral reef and seagrass habitats. MRR and partners conducted baseline coral reef surveys of a site approximately 0.15km south of the study site (N 2.016960 E 73.537928) in 2022. The surveys were conducted at 10m and 15m. This section will cover content relevant to the inhabited islands of Mundoo and Maabaidhoo, where available.

Mundoo Channel

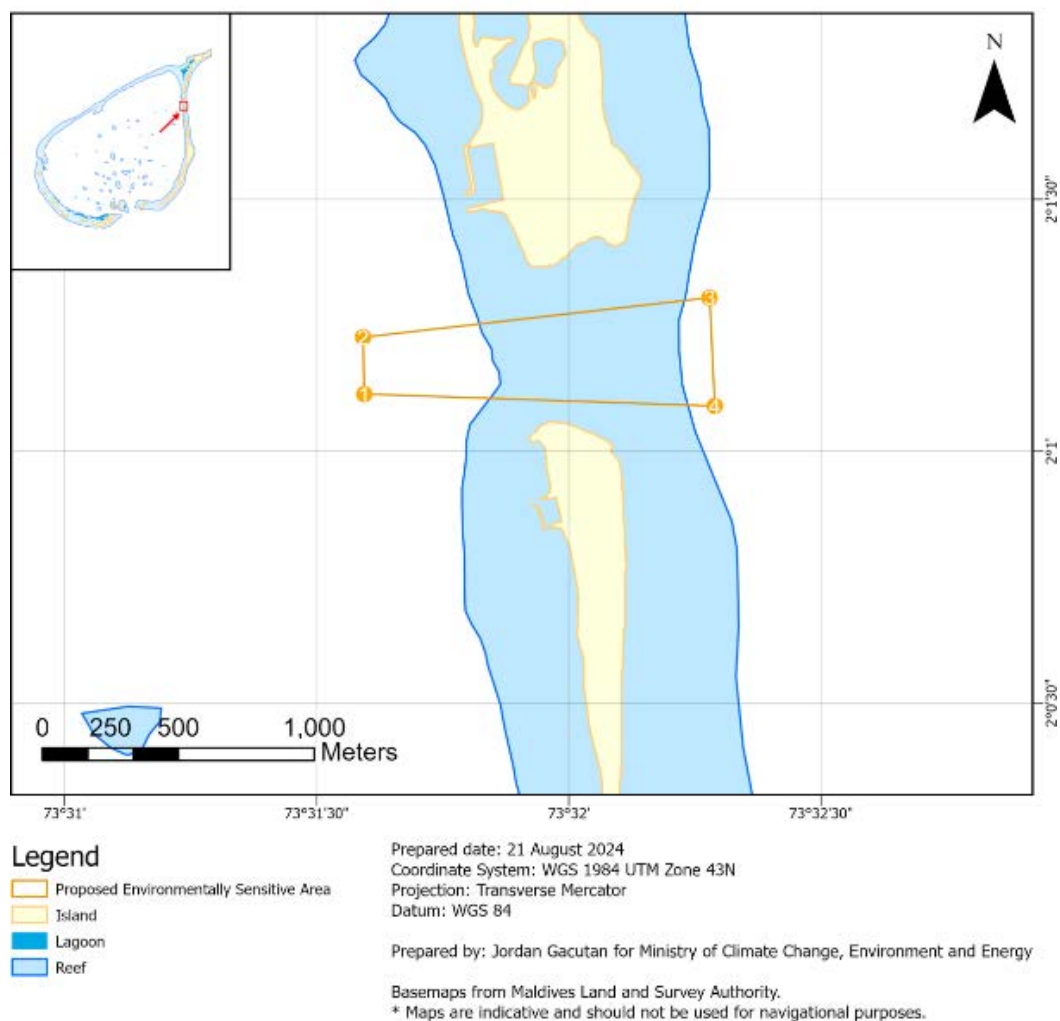


Figure 7 Map of Mundoo Channel ESA

6.4.1 Biodiversity understanding and existing research

Mundoo island's marine environment can be categorized into three main components: the coral reef, lagoon, and seagrass beds. The coral reef environment has reef-flat and reef-slope having distinctive habitat characteristics. The total reef area covers approximately 50 ha, of which 22 ha are reef flats. Marine dynamics around Mundoo have been somewhat

modified since the clearance of entrance channels on the western side of the island but impacts these coastal modifications are not known since there has been no systematic monitoring of the effects of these coastal modifications in the Maldives (Kench & Brander, 2006).

Seagrass beds are found all around Mundoo island and are known to have high ecological value as they provide food to a range of fish and invertebrates, both directly (grazing by fish and turtles) and indirectly through detrital food chains. Beyond this, seagrass beds play a vital role in absorbing carbon dioxide and provide structural habitat, shelter and nursery areas to a range of marine flora and fauna, including many species of invertebrates and fish of commercial value. While the significance of seagrass ecosystems to Maldivian biodiversity has not been studied yet, it is commonly known that seagrass beds play an important role in protecting shoreline erosion. Two species of seagrass were recorded around Mundoo (*Thalassia hemprichii* and *Thalassodendron ciliatum*). Juveniles of *Lethrinus harak*, a commercial species used as food in the Maldives, are frequently found in these coastal seagrass beds (MMS, 2024).

Reef fish and coral surveys from 2021/22 (Fischer, 2022) predicted that the decrease in coral cover in Maabaidhoo from 2019 to 2021 might be linked to a nearby harbour extension, which happened between the 2019 and 2021/22 surveys (Table 6). This example highlights the importance of reducing local physical stressors to promote coral growth and recovery. The coral cover of Mundoo Kanduu was first surveyed in 2021/22. The most abundant species across all sites were *Gnathodon speciosus* and *Melichthys indicus* (Table 7).

Table 6: Per cent cover of benthic categories for Mundoo Channel sites in 2021/22. Adapted and taken from Fischer (2022), Appendix 4B (pp. 41, 42).

Survey Year	Site	Hard coral	Soft coral	Bleached coral	Diseased coral	Dead coral	Sponge	Algae	Bare rock	Sand	Rubble	Other
2019	Maabaidhoo	34.36	0.00	0.09	0.00	0.75	0.00	0.17	40.44	12.89	9.94	1.35
2021/22	Maabaidhoo	28.5	0.08	4.44	0.25	1.44	7.34	1.10	36.33	1.25	19.11	0.08
2021/22	Mundoo Kanduu	31.8	0.00	0.00	0.00	1.43	0.25	1.17	26.0	7.47	9.72	22.01
2022	Laamu Atoll average	26.86	0.04	0.58	0.04	2.12	5.22	5.85	35.01	4.68	14.74	4.82

Table 7: Reef fish abundance and biodiversity data from 2021/22 surveys across for Mundoo and Maabaidhoo survey sites. Adapted and taken from Shephard, 2022 (Appendix 4, pp. 48, 49).

Survey Year	Site	No. of fish families	No. fish species	No. individuals	Species richness (species per 500m ²)	Density (individuals per 500m ²)	Simpson's biodiversity index	Most abundant family	Most abundant species
2021/22	Maabaidhoo inside	8	24	255	6	63.75	0.89	<i>Chaetodon tidae</i>	<i>G. speciosus</i>

2021/22	Maabaidhoo outside	8	38	436	9.5	109	0.89	<i>Balistidae</i>	<i>M. indicus</i>
2021/22	Mundoo kandu	7	36	406	9	101.5	0.92	<i>Scaridae</i>	<i>C. sordidus</i>

In surveys conducted in 1998, Mundoo channel was identified as a grouper spawning site for *Plectropomus areolatus* during the new moon period, and also possibly for *Plectropomus laevis* (Sluka, 2001). The Mundoo Kandu outer channel was identified as a grouper spawning aggregation site by 16 local grouper fishers who were interviewed by Blue Marine Foundation in 2016-17 (Evans, et al., 2018). Almost all (95%) of the fishers who reported spawning aggregations said they had fished at the site and more than half reported catch declines.

6.4.2 Socio-economic island profiles

According to a 2022 census, Mundoo island had a total population of 176, of which 104 are males and 72 are females (Anon., 2023). The main economic activities of the island are fishing, masonry and agricultural farming. There is one government owned school on the island and the highest grade taught is grade eight. Households in Mundoo do not segregate or recycle their waste and tend to dispose it in the waste disposal area designed by the Island Council. Although a waste disposal area is designated, it is not managed properly (MMS, 2024).

Maabaidhoo borders the north of the Mundoo Channel. It has a total area of 0.5281 km² and 565 inhabitants. The major income earning activities of the island people are recorded as fishing and agriculture. A number of people are working outside the island, mostly in Male' and in safari boats. Maabaidhoo is not a densely populated island. Most of the houses are built from corals and according to the island council; construction of new houses are not frequent. The island has a number of new houses built with cement blocks. The island council does not have statistics about the number of new housing plots allocated for housing, but in total there are 120 houses in the island as per the latest Council records (Jameel, 2013). The quality and availability of better services is still a concern for most of the island people. The health centre has one expatriate doctor, two nurses, two family health workers, two community health worker and administrative and support staffs. The island has a government run school which offers education up to grade 10. The island population depends on rainwater harvesting from roof tops as their main source of potable water. Households are provided with 2500 litres rainwater tanks after the Indian Ocean Tsunami of December 2004 (Jameel, 2013).

6.4.3 Local island development and impacts

In Maabaidhoo, there was a socially driven project in 2008 proposing to improve the condition of the existing harbour and to extend the harbour to cater to fishing boat demand. The main objective was to improve the condition of the harbour and ensure capacity for the many fishing dhonies. The existing harbour was developed in 1989 but was then damaged during the Indian Ocean tsunami of 2004. Since Maabaidhoo is home to a large fishing vessel fleet and the island's location has easy access to open sea, other islands use the

harbour as a base. Improvement of the harbour would increase the length of the quay wall and the size of the harbour basin, creating safer mooring conditions for large vessels (Jameel, 2013).

In 2017, there was a proposal to construct a waste management center in Mundoo. Although the island had established a waste collection center with assistance from the Canadian Red Cross after the 2004 tsunami, this facility was not operational. Estimates suggest that around 70% of the waste generated on the island could be composted. However, non-biodegradable waste, such as plastic water bottles, energy drink cans, food cans, diapers, plastic bags, noodle packets, betel nut sachets, and glass bottles, posed significant challenges. Households on the island did not segregate or recycle their waste and instead disposed of it in a designated area managed by the Island Council, which was not properly maintained. Establishing a waste management center can potentially impact the marine environment through leachate contamination, runoff and littering of waste materials, and air pollution contributing to marine debris if not properly planned and managed. Improper waste handling practices can also lead to coastal habitat degradation, odour issues, and the attraction of pests that can introduce pathogens or contaminants into the marine ecosystem. Implementing robust waste management strategies, including secure landfill systems, effective waste segregation and recycling programs, strict handling protocols for hazardous materials, and regular monitoring, is crucial to mitigate these potential impacts on the fragile marine environment (MMS, 2024).

The establishment of improved water supply and sewerage facilities has been recently proposed on the island (Rasheed, 2023). An EIA found that the project would carry negative impacts on marine biodiversity around the island due to the required brine outfall pipe. Ecosystems identified to be in proximity to the outfall pipe included coral reef and seagrass habitats. The location of the brine outfall pipe was amended in 2023 following feedback from island council. The proposed pipe footprint has now been relocated towards the south of the island, and away from the Mundoo Channel ESA. The council requested this change due to the previous pipe footprint potentially impacting vessels movements through the channel affect vessel harbouring during the southwestern monsoon. Other impacts of this development project include leakage of waste water into the groundwater lens, odour issues and deforestation. The EIA outlined a number of mitigation measures to reduce these impacts, including: 1) conducting works during calm weather periods; 2) regular maintenance of outfall pipe; 3) use of personal protective equipment; 4) regular water monitoring assessments; and 5) ensuring the secure installation of anchor blocks.

6.5 Site 5: Reethi Haa and Hudhafaru

This site is located on the southern inner atoll area of Laamu Atoll, north of Maamendhoo and Olhuveli islands (Figure 9). The southern part of the site, consisting of Laamafaru Haa and Reethi Haa dive sites and northern reef of Maamendhoo island is within the Maamendhoo island boundary. Three shallow faros (the largest being Hudhufaru, the next largest Mudiyafungiri and the smallest Reethi Haa and Laamafaru Haa) and a deep faro (Haleema Haa) is located within this area. Another deep faro, Rahdhashu Haa is located just outside the southwestern corner of the area. This section will cover content relevant to the inhabited island of Maamendhoo, where available.

Reethi Haa and Hudhafaru

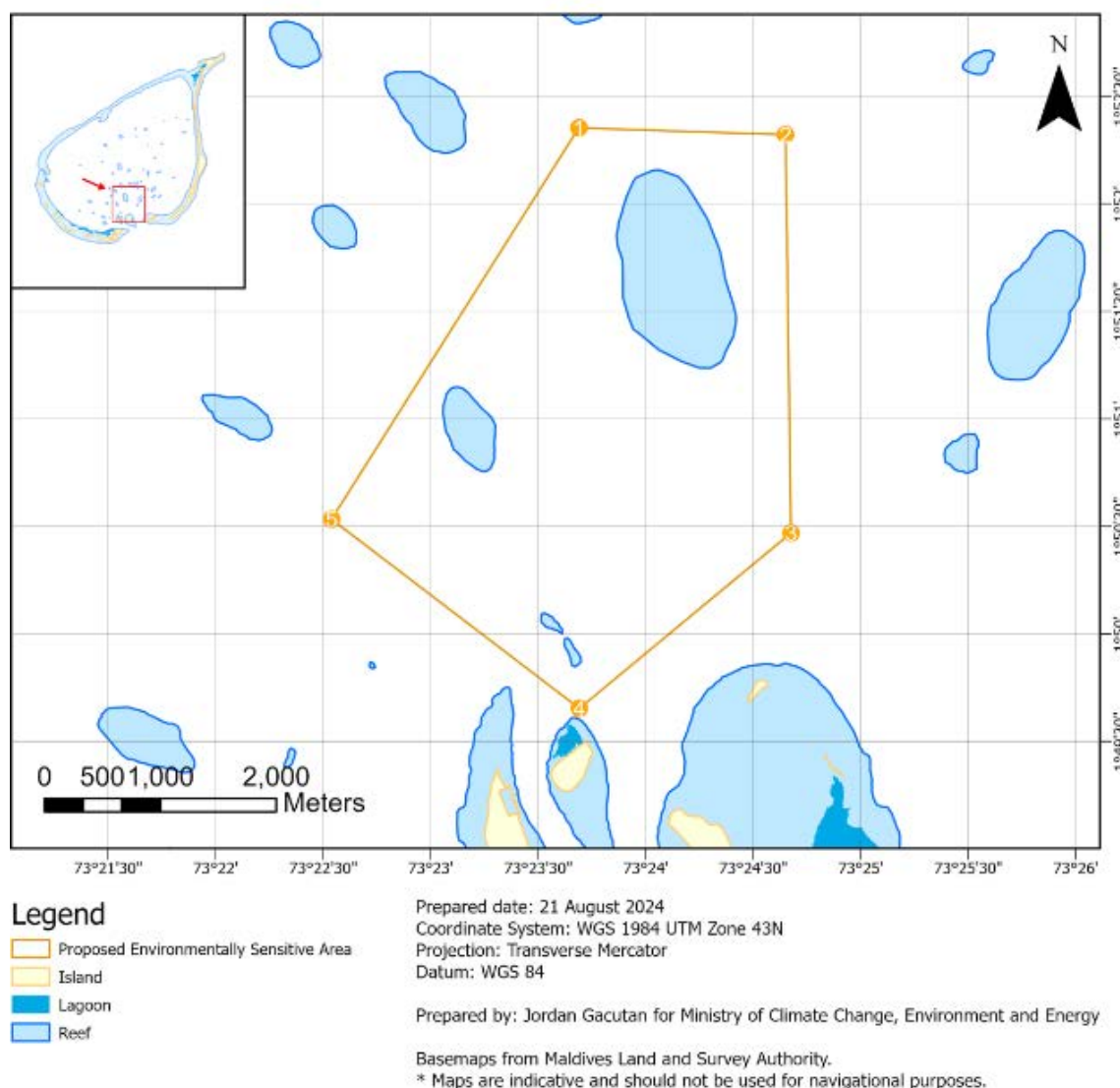


Figure 8 Map of Reethi Haa and Hudhafaru ESA

6.5.1 Biodiversity understanding and existing research

MRR and partners conducted baseline coral reef surveys of Laamafaru Haa, a site located within the study site (N 1.835056 E 73.391278) in 2019 and 2022. The surveys were conducted at 5m and 10m. Surveys found that the site is recovering well from the 2016 mass coral bleaching event, as evidenced by the live coral cover increase from 13.90% to 26.01% between the two survey years. However, the abundance of commercially and ecologically important species declined by over 19% and species richness by 36-40%. The 2022 surveys showed that the biomass of commercially and ecologically important fish species was 119.651 kg per 2000m² at this site. Resource use surveys conducted by MRR and Blue Marine in 2021 showed that there was some fishing pressure for the livebait fishery, reef fishery (handline, trolling, spearfishing and jigging), sea cucumber fishery, octopus fishery and invertebrate collection.

Hard coral in Laamafaru Haa increased from 13.09 in 2019 to 26.0 in 2022 (Table 7). Likewise, the number of fish species identified showed an increase from 35 species in 2019 to 40 in 2022 (Table 8).

Table 7: Per cent cover of benthic categories for Laamafaru Haa in 2021/22. Adapted and taken from Fischer (2022), Appendix 4B (pp. 41, 42).

Survey Year	Site	Hard coral	Soft coral	Bleached coral	Diseased coral	Dead coral	Sponge	Algae	Bare rock	Sand	Rubble	Other
2019	Laamafaru haa	13.90	0.36	1.52	0.00	22.00	0.98	0.80	31.82	6.58	20.07	1.92
2021/22	Laamafaru haa	26.0	0.26	0.25	0.00	4.44	4.71	2.83	27.26	0.63	32.40	1.19
2022	Laamu Atoll average	26.8	0.04	0.58	0.04	2.12	5.22	5.85	35.01	4.68	14.74	4.82

Table 8: Reef fish abundance and biodiversity data from 2021/22 surveys across for Laamafaru Haa and Rahdhashu Haa survey sites. Adapted and taken from Shephard, 2022 (Appendix 4, pp. 48, 49).

Survey Year	Site	No. of fish families	No. fish species	No. individuals	Species richness (species per 500m ²)	Density (individuals per 500m ²)	Simpson's biodiversity index	Most abundant family	Most abundant species
2021/22	Laamafaru Haa	7	35	393	8.75	98.25	0.79	Scaridae	<i>C. sordidus</i>
2021/22	Rahdhashu Haa	7	40	619	10	154.75	0.87	Lutjanidae	<i>L. biggattutus</i>

6.5.2 Socio-economic island profile

Maamendhoo is an island situated in the southern part of Laamu Atoll, around 14.6 km from L. Kahdhoo airport and approximately 258.48 km away from the capital city of Male'. Fishing serves as the primary economic activity on this island, which has a fleet of seven larger fishing vessels and three smaller troll dhonis (traditional sailing boats). The major population and economic hubs within Laamu Atoll are the islands of L. Fonadhoo, which serves as the administrative capital, and Gan.

Some key environmental challenges faced by Maamendhoo include coastal erosion and inadequate waste management practices. Due to a lack of available land space, nearly the entire island has now been cleared for urban development, exceeding its natural carrying capacity. In terms of commercial establishments, Maamendhoo has twelve shops, one pharmacy, three tailoring businesses, and three carpentry workshops. Apart from fishing, the island's primary economic activities revolve around carpentry work and sewing services (Zahir, 2008).

6.5.3 Local island development and impacts

No EIAs were found that could impact the proposed ESA.

7. Conclusion

The marine ecosystems of Laamu Atoll are renowned for their biodiversity and ecological productivity. This review has characterised the socio-economic and ecological characteristics of Laamu Atoll and described the marine biodiversity associated with the tropical seascape habitats extant across the region. The review has also isolated the increasing number of infrastructural developments either proposed, under construction, or completed across Laamu's inhabited islands. Being distantly located to the capital city of Male' has enabled Laamu's marine ecosystems to be less impacted by anthropogenic stressors compared to other atolls. The pristine marine ecosystems around Laamu were recognised as a Mission Blue Hope Spot in 2021, and play a vital role in support local livelihoods and the atoll's growing tourism sector. However, unsustainable urban development projects can rapidly and often irreversibly impact ecosystem functioning and ecosystem service provision.

The five sites identified differ greatly in their ecological and socio-economic characteristics and exist along varying gradients of anthropogenic exposure. This review has been able to identify existing biodiversity knowledge and published research, either within or in close proximity to each site. Furthermore, associated inhabited islands which are located near to each site were assessed, with existing and future development agendas characterised and discussed in relation to their potential impact on marine ecosystem functioning and ecosystem service provision. With marine ecosystems on Laamu at increased threat of both localised stressors (i.e. coastal development) and global climate change, research into the socio-ecological value of the five sites will be critical in informing the protection of Laamu's marine resources into the future.

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Abbreviations and Acronyms

ENDhERI	Enhancing National Development through Environmentally Resilient Islands
EPA	Environmental Protection Agency
ESA	Environmentally Significant Areas
GEF	Global Environment Facility
MAAW	Ministry of Agriculture and Animal Welfare
MBS	Maldives Bureau of Statistics
MCCEE	Ministry of Climate Change, Environment and Energy
MRR	Maldives Resilient Reefs
MPA	Marine Protected Areas
NC	Natural Capital
NGO	Non-Governmental Organisation
PMU	Project Management Unit
UNEP	United Nations Environment Programme
WDC	Women's Development Committee

Acknowledgements:

We would like to acknowledge and thank the work of the below individuals and organisations who supported this report.

Data collection for coral reef surveys: Aminath Shaha Hashim, Aishath Muflaha Ziyadh, Dua Abdullah and Mariyam Mashaahy Mueed (Maldives Resilient Reefs), Jenny Baker (Blue Marine Foundation), Jessica Hodge and Thuva Ahmed (Maldives Underwater Initiative, Six Senses Laamu), Enas Mohamed (Environmental Protection Agency), Lauren Joslyn, Ottie Buxton and Dylan Kramer (University of Exeter) and Hassan Hameez (freelance dive guide).

Data collection for seagrass surveys: Aishath Muflaha Ziyadh, Dua Abdullah, Mariyam Mashaahy Mueed, Inan Ahmed and Aminath Shaha Hashim (Maldives Resilient Reefs) and Jenny Baker (Blue Marine Foundation).

Data collection for vegetation surveys: Mohamed Tholaal and Aminath Shaha Hashim (Maldives Resilient Reefs), Dr Jordan Gacutan (Senior Research Associate, University of South Wales), Nashwan Matheen (Maldives Space Research Organisation) and Hassan Hameez (freelance dive guide).

Drone mapping: Hassan Shiraz (civil and environmental engineer), Fathimath Shifla and Mohamed Maidhu Abdul Muhsin (Maldives National University)

Data analysis and report writing: Dr Jordan Gacutan (Senior Research Associate, University of South Wales), Hassan Shiraz (civil and environmental engineer) Lauren Joslyn and Ottie Buxton (University of Exeter), Nisha Goldsworthy (Research Coordinator, Maldives Underwater Initiative, Six Senses Laamu), Jessica Arnull (University of Edinburgh) along with Aminath Shaha Hashim from Maldives Resilient Reefs.

1. Introduction

1.1 Background

The Ministry of Climate Change, Environment and Energy (MCCEE) is implementing the Enhancing National Development through Environmentally Resilient Islands (ENDhERI) project. This initiative, funded by the Global Environment Facility (GEF) and supported by the United Nations Environment Programme (UNEP), aims to facilitate the adoption of new environmental policies and the transition toward Green Growth atoll development. This development strategy aims to sustain marine Natural Capital (NC) and enhance the resilience and recovery of reef ecosystems. The project will draw from integrated coastal zone management within a Managed Marine Area/Biosphere Reserve framework, along with innovative sustainability practices in sectors such as agriculture, fisheries, tourism, and construction. The goal is to transform the ecological impact in Laamu Atoll, leading to national-level sector transformation, spatial planning, and improved governance based on NC accounting.

The “*Consultancy Service to Develop Baseline Assessment for Environmentally Significant Areas at Laamu*” was contracted to Maldives Resilient Reefs (MRR), a Maldivian Non-Governmental Organisation (NGO) dedicated to restoring coral reefs in the Maldives as climate resilient ecosystems for the benefit of people, nature and the economies that depend on them.³

The main objective of the consultancy is to conduct baseline assessments of five potential Environmentally Significant Areas (ESA) of Laamu Atoll, in line with the “Guidelines for coral reef and small island vegetation surveys in the Maldives”⁴. A literature review, accompanying this report, has been conducted and provides comprehensive existing scientific knowledge and data collected for Laamu Atoll, in addition to available data for the five study areas. The assignment requires the procurement of field data (*via* field surveys and community consultation) to assess and analyze the ecological characteristics and the socio-economic setting of the five potential ESA.

The present document reports on the individual ecological status of coral reefs, seagrass and vegetation within ESA areas using data gathered between April – August 2024. Further, results of megafauna surveys conducted by Maldives Underwater Initiative, Six Senses Laamu between 2017 –2023 are also provided.

1.2 Scope

This report provides detailed individual and combined findings on the ecological surveys and assessment including a consolidation of important findings for ecosystems presented within the designation of potential ESAs, as defined by MCCEE. The present report focuses

³ MRR’s strategic intervention areas are: 1) Increasing effective marine protection to build climate resilience; 2) Improving the sustainability of reef-based fisheries; 3) Improving environmentally responsible tourism; and 4) Strengthening local capacities for marine resource management in the Maldives. MRR is officially affiliated with the UK charity, Blue Marine Foundation. Blue Marine has a vision of a healthy ocean forever, for everyone.

⁴ Dryden and Basheer, 2021: <https://www.environment.gov.mv/v2/en/download/14746>.

on ecological characteristics, with the socio-economic and geomorphological data provided in accompanying reports.

2. Materials and Methods

2.1 Study site

Laamu Atoll is situated in the southern central region of the Maldives. The atoll is home to a diverse collection of coral reefs, mangroves, and a diverse marine ecosystem. It has a total surface area of 884.63 km² and 56 reefs with an area of 203.70 km² (Naseer & Hatcher, 2004). The atoll consists of 72 islands of which 11 islands are inhabited (www.atollsofmaldives.gov.mv) with a recorded population of around 15,000 people in 2022 (MBS, 2022). According to data from the Maldives Bureau of Statistics (MBS), fisheries constitute the primary economic activity in Laamu Atoll, closely followed by agriculture. The Five selected ESA for the purpose of the baseline assessment in Laamu Atoll are as follows (Figures 1 and 2):

- 4 **Fonadhoo Diving Point:** This site is in the southeastern side of Laamu Atoll within the jurisdictional boundary of Laamu Fonadhoo, the capital island of Laamu Atoll. It is on the island's southern edge on the outer reef area.
- 5 **Isdhoo Muli:** This site is located on the northeastern tip of Laamu Atoll within the jurisdictional boundary of Laamu Isdhoo. It is on the island's northeastern edge on the outer reef area.
- 6 **Mathigulhi Sarahadhu:** This site is located on the southwestern side of Laamu Atoll, on the western lagoon of Kunahandhoo. There are two vegetated islands and several rock banks within this area and scattered small seagrass habitat. there are two large, vegetated islands. Kudafushi (LD1025, 12.27 hectares) is classified as an industrial agricultural island under the jurisdiction of the Ministry of Agriculture and Animal Welfare and is leased to a private party for long-term since 1 November 2018. Maafushi (LD0951, 2.91 hectares) is classified as an uninhabited island and has been leased under the “varuvaa” scheme by Laamu Atoll Council. Two smaller, rubble-dominated islands, Bodumahigulhi (LD0599, 1.11 hectares) and Kudamahigulhi (LD0902, 0.25 hectares), are classified as uninhabited and fall under the jurisdiction of the Laamu Atoll Council. Additionally, a fifth, unnamed supra-tidal area, primarily composed of coral rubble and sand, is located to the northwest
- 7 **Mundoo Channel:** This site is located on the central eastern side of Laamu Atoll, north of Mundoo and south of Maabaidhoo islands. It is a channel that connects the inner atoll with the open ocean.
- 8 **Reethi Haa and Hudhafaru:** This site is located on the southern inner atoll area of Laamu Atoll, north of Maamendhoo and Olhuveli islands. The southern part of the site, consisting of Laamafaru Haa and Reethi Haa dive sites and northern reef of Maamendhoo island is within the Maamendhoo island boundary. Three shallow faros (the largest being Hudhufaru, the next largest Mudiyafungiri and the smallest Reethi Haa and Laamafaru Haa) and a deep faro (Haleema Haa) is located within this area.

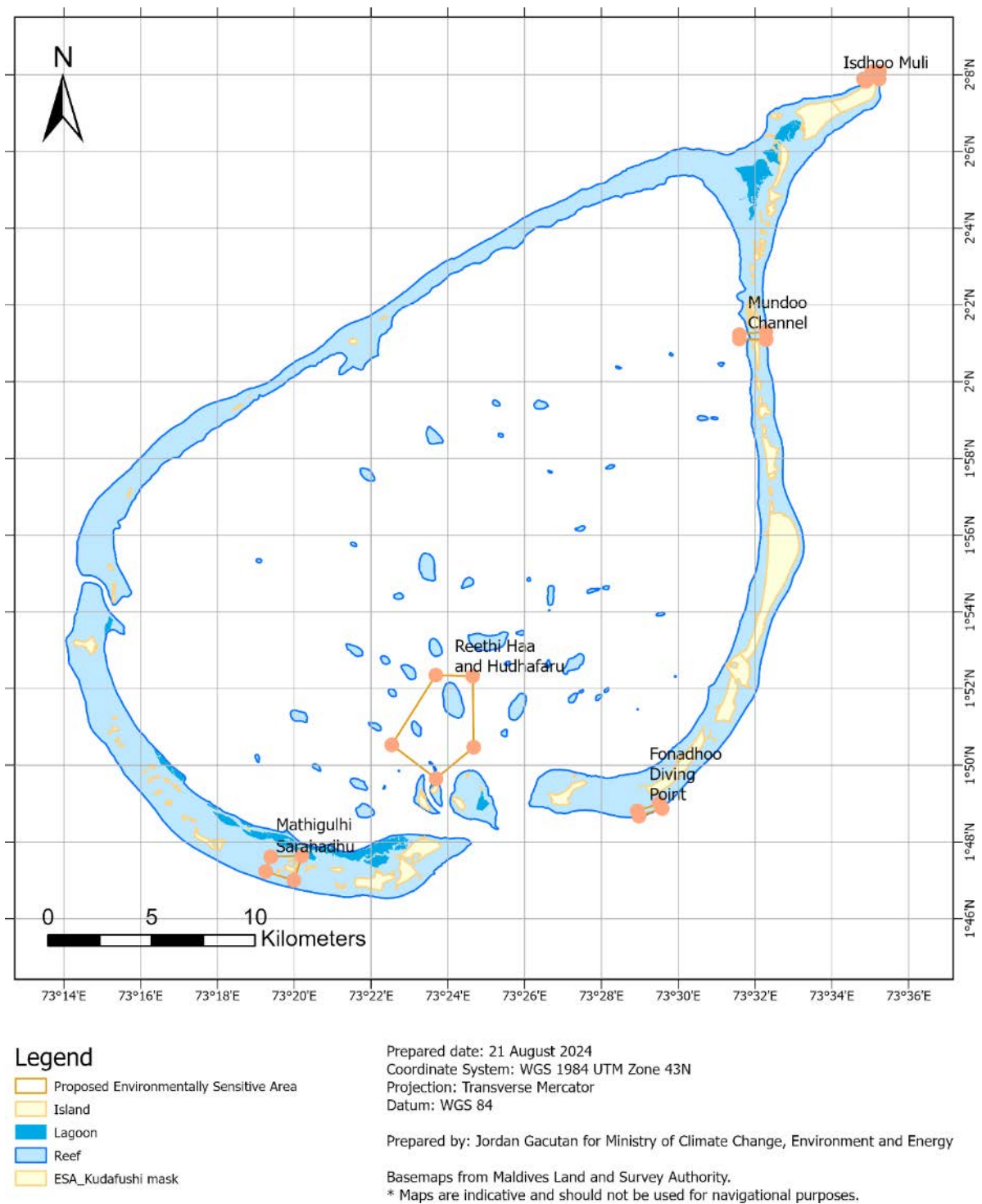


Figure 9. Five selected ESAs for the baseline assessment consultancy. Individual maps are provided in the annex.

Table 1. Site name of the environmentally sensitive area (ESA) and ecosystem present

#	Site Name	Coral reefs	Seagrass	Vegetation
1	Fonadhoo Dive Point	Yes	No	No
2	Isdhoo Muli	Yes	No	No
3	Mathigulhi Sarahadhu	No	Yes	Yes
4	Mundoo Channel	Yes	Yes	No
5	Reethi Haa and Hudhufaru	Yes	No	No

2.2 Coral Reef Surveys

Belt transect surveys were conducted at four sites containing coral reefs, namely Fonadhoo Dive Point, Isdhoo Muli, Mundoo Channel and Reethi Haa and Hudhufaru (Figure 3 and Annex 2). This is one of the most widely used methods to assess fish assemblages (Caldwell et al., 2016) and the method used in the Maldivian National Coral Reef Monitoring framework (maintained by MMRI) which allows for the data submission into the Maldives Marine Research Institute's National Coral Database. This method is widely used and respected, as it allows for the collection of high-quality data without detrimental impact to the fish or the environment (Green et al., 2010; Idris et al., 2021; Nugraha et al., 2020).

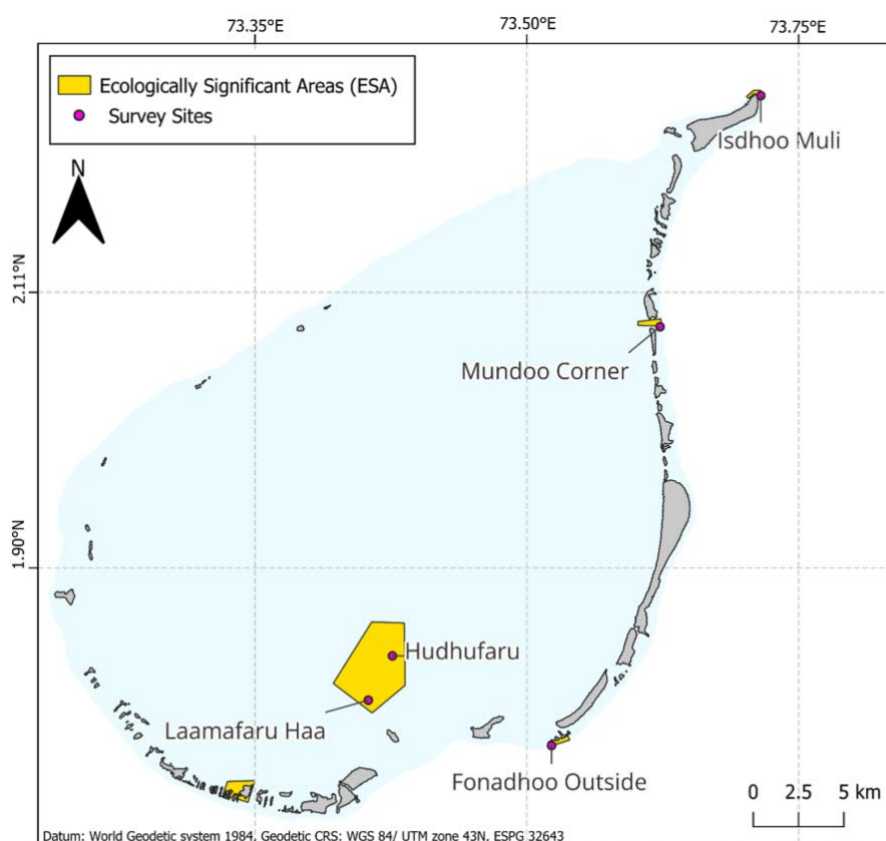


Figure 10. Map of the coral reef survey sites

Using SCUBA equipment, transect tape and other materials, coral reef surveys were conducted in April and May 2024 to obtain the following parameters:

- Benthic community composition (e.g., live coral cover);
- Coral community composition (coral genus and morphology);
- Fish abundance, richness and diversity;
- Invertebrate composition and abundance;
- Identify potential anthropogenic and non-human reef impacts; and
- Biomass of commercially and ecologically important fish species.

All fish surveyors were trained to recognise and remove bias in estimating lengths of fish underwater using the Bell et al. (1985) technique.⁵ Each survey was conducted along a 100 m transect, although data was only collected from 4 x 20 m replicates, leaving a 5 m gap between each replicate (Figure 3). Each site was surveyed with equal sampling measures, at two depths, depending on the nature of the reef (either 5m and 10m, or 10m and 15m depth). The total area surveyed was 1,600 m², although for comparability, measures were standardized 100 m².

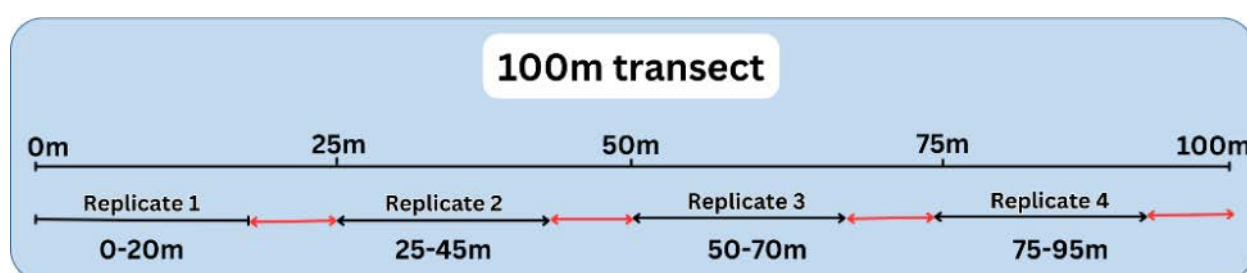


Figure 11. Survey methods diagram. Sections in red were not surveyed in line with Maldivian National Coral reef Monitoring framework.

Two buddy pairs (referred here as A1, A2, B1 and B2) descended to their allocated depths on the reef, one buddy pair per surveyed depth. A1 and B1 then deployed a Surface Marker Buoy (SMB) at the start of the transect tape and then rolled the 100 m transect tape across the reef maintaining the correct survey depth while A2 and B2 tucked tape into the reef. A2 and B2 then marked the endpoint of the transect with a second SMB. The buddy pair then swam back to the start of the transect, at least 10m away from the transect, and waited 5 minutes before starting the fish survey.

Data was only collected within the 4 x 20 m transect areas with all fish recorded 5 m wide and 5 m high, leaving a 5m gap between the transects. A1 and B1 recorded all *Acanthuridae* (surgeonfishes), *Balistidae* (triggerfishes), *Carangidae* (jacks and trevallies) *Pomacanthidae* (anglefishes), *Siganidae* (rabbitfishes), and *Scaridae* (parrotfishes) species. A2 and B2 recorded all *Chaetodontidae* (butterflyfishes) *Haemulidae* (sweetlips) and *Lethrinidae* (emperor fishes) *Lutjanidae* (snappers) and *Serranidae* (grouper) species.

⁵ The training involved 25 wooden sticks between 0-1 m attached to a 20 m rope laid out in the water. Observers then swam along parallel to the rope keeping a minimum distance of 2 m and estimating the length of each piece of wood. Results were then compared to the true lengths and this training was repeated until estimates between surveyors were no longer significantly different in a paired t-test.

Table 2. Surveyed indicator fish families, species in red were not recorded down to species level as biomass was not calculated.

Commercially Important Families	Ecologically Important Families
<i>Carangidae</i>	<i>Acanthuridae</i>
<i>Lethrinidae</i>	<i>Balistidae</i>
<i>Lutjanidae</i>	<i>Chaetodontidae</i>
<i>Serranidae</i>	<i>Haemulidae</i>
<i>Siganidae</i>	<i>Pomacanthidae</i>
	<i>Scaridae</i>

The next two buddy pairs (referred here as C1, C2, D1 and D2) followed the fish surveys to conduct invertebrate and impact surveys. Data was only collected within the 4 x 20 m transect areas with all invertebrates and impacts being recorded 5 m wide, leaving a 5 m gap between the transects. In the 2.5 m area on their side of the transect tape, each surveyor recorded the presence of coral feeders *Acanthaster planci* (crown of thorns starfish) and *Culcita novaeguineae* (pin cushion starfish), and commercially and ecologically important invertebrate species including *Nephropidae* (Lobsters), *Octopoda* (Octopus), *Holothuroidea* (sea cucumber), *Tridacna* (giant clam), *Echinoidea* (sea urchin), and *Lambis* (Spider conch). Lobster, sea cucumber and giant clam were recorded to species level and sizes were estimated for giant clams. Smaller sea urchins less than 5 cm were not recorded. They also recorded the presence/ absence of **impacts** including coral damage due to crown of thorns starfish or cushion starfish, marine debris, fishing line, anchor scars, Drupella damage, disease and others.

Once they finished the invertebrate and impact survey, C1 and D1 removed the SMB at the end of the transect and C2 and D2 took images of the transect at every 1 meter, alternating between the sides of the transect. Thus, 20 images per transect (80 images per depth) were taken. Photos were properly sorted and labeled and analysed using Reef Cloud, which is an open-access platform designed to quickly and efficiently collate and analyse data using artificial intelligence and human collaboration.⁶

Statistical analysis of fish assemblages

Fish biodiversity was assessed using biomass, family richness, fish abundance, and the Simpson's diversity index. For statistical analysis, QGIS (v3.32.0, 'Lima') and R (v4.3.1) were used (QGIS Development Team, 2024; R Core Team, 2024). QGIS was used for map creation whereas RStudio was used for data visualisations and analyses. The R package dplyr was used to manipulate and clean the data to prepare it for data analyses (Wickham et al., 2023). To visualise the data for model prediction the *ggplot2* package was used (Wickham et al., 2024). To fit statistical models and to assess the model fit, the packages used were *lme4*

⁶ ReefCloud by Australian Institute of Marine Science: <https://reefcloud.ai/>

and *DHARMA* (Bates et al., 2024; Hartig and Lohse, 2022). Fish abundance was assessed using a Generalised Linear Model with a Gamma distribution (GLM) due to the positively skewed, continuous data. To calculate the biomass of the relevant species using the equation: $\text{biomass} = a * (\text{length}^b)$, parameters a and b were obtained from FishBase (FishBase, 2024). Fish biomass was analysed with a GLM with Gamma distribution to assess variations in biomass between sites and across different levels of commercial or ecological importance.

2.3 Seagrass Surveys

Seagrass surveys were conducted at two of the survey sites containing seagrass meadows, namely Mathigulhi Sarahadhu ESA and Mundoo Channel ESA (Figure 5 and Annex 3). The surveys were conducted using the Maldives Seagrass Monitoring Network – Monitoring Methods (v1.3, 2020). Mathigulhi Sarahadhu ESA was surveyed following the Level 2 of the protocols which is ‘small scale assessment of 50m x 50m areas’. Due to the strong current conditions, Mundoo Channel ESA was surveyed by placing the quadrats randomly along the seagrass meadow area but recording the same parameters.

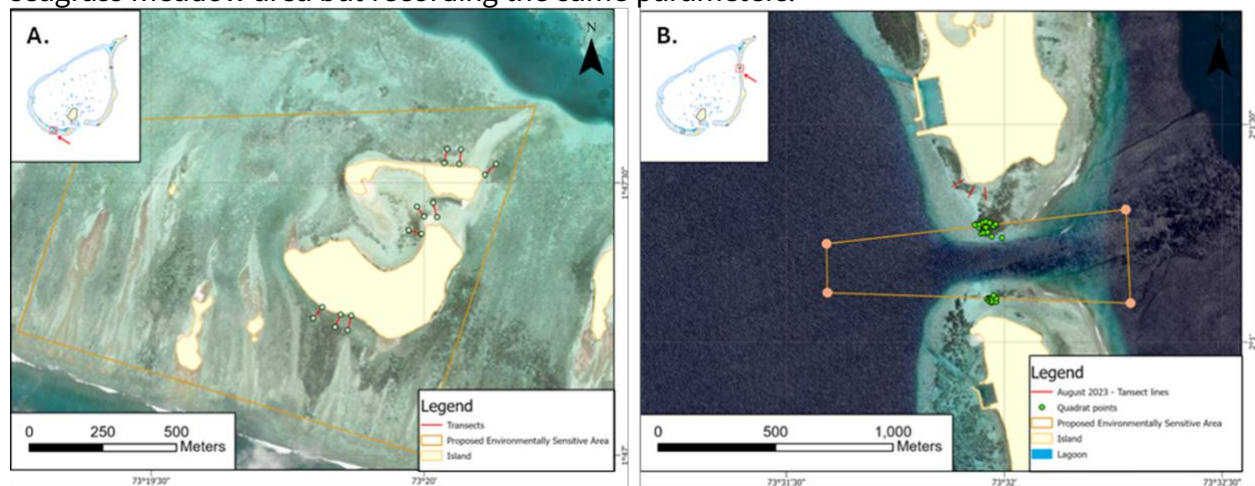


Figure 12. Locations of seagrass survey sites for (A) Mathigulhi Sarahadhu and (B) Mundoo Channel. Coordinates provided in the Annex 3. Note transects were used in Mathigulhi Sarahadhu, but random quadrats were used in Mundoo channel due to weather consistency. For consistency, previously data available through the ENDhERI project was also analyzed.

At Mathigulhi Sarahadhu ESA, three 50m x 50m relatively homogenous areas (low variability, even topography) were selected for surveys at the eastern and western lagoons of the islands and in the bay area. Within these areas, three transects of 50m were laid parallel to each other, at least 25m apart and perpendicular to the beach. The surveys consisted of recording seagrass variables within 0.5m x 0.5m quadrats. Quadrats were placed every 5m per transect line (total 11 per transect line) until all 33 quadrats were completed. Photos were taken from each quadrat, along with GPS coordinates and depth. The following parameters were assessed:

- % cover of seagrass, macroalgae, coral and others;
- % seagrass species composition;
- Canopy height;
- Epiphyte cover; and
- Sediment type (sand, mud, coarse gravel).

Megafauna and other interesting fish or invertebrate species observed in the meadow were recorded along with important site information, such as resource use and impacts.

2.4 Small Island Vegetation Surveys

Following the 'Guidelines for Coral Reef and Small Island Vegetation Surveys in the Maldives' (Dryden and Basheer, 2020) guidance for terrestrial surveys, a vegetation survey was conducted at Mathigulhi Sarahadhu ESA that consists of two islands (Maafushi and Kudafushi).

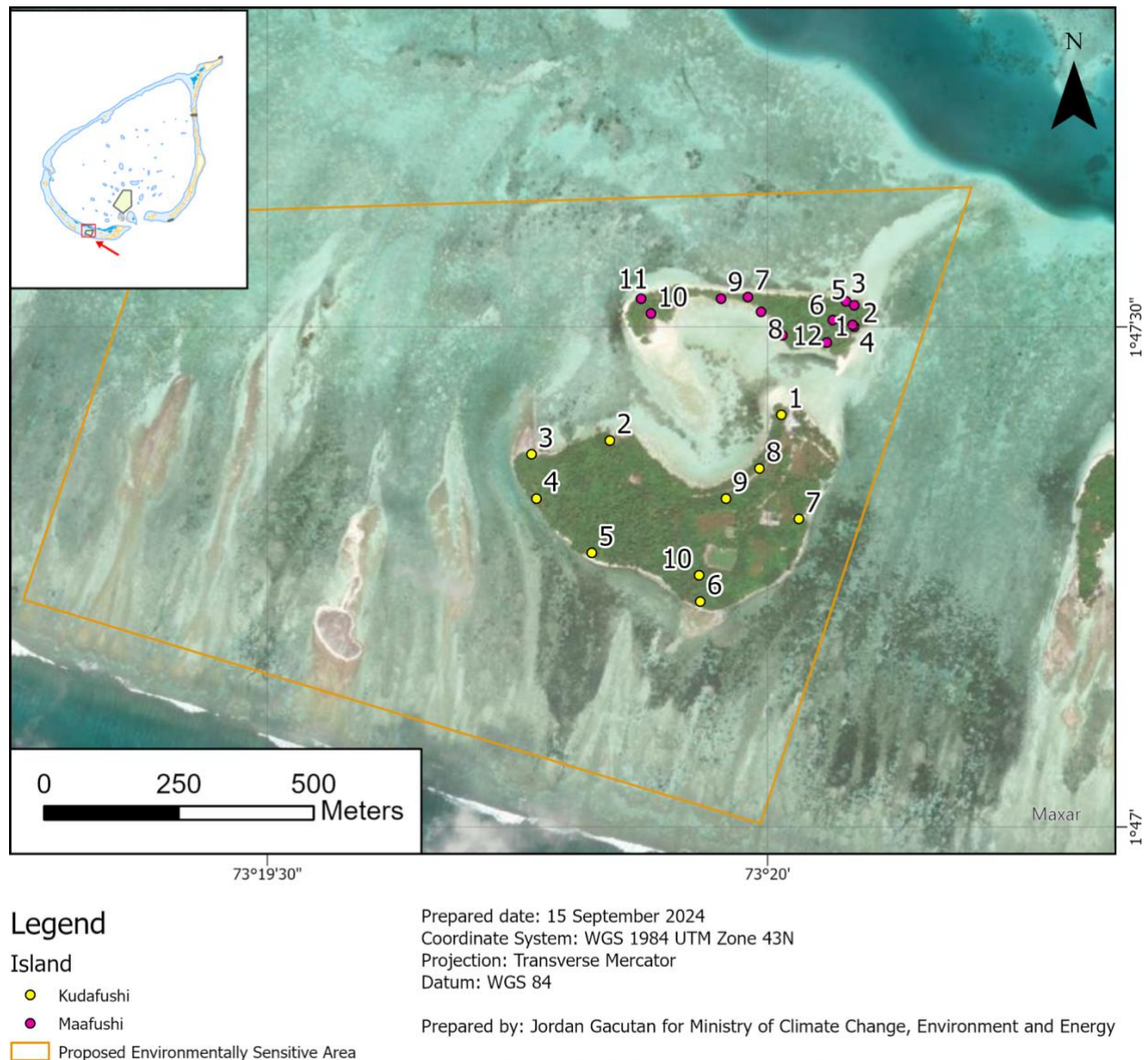


Figure 13. Map of vegetation survey sites. Coordinates provided in the Annex 4.

The vegetation survey focused on the flora and faunal community present and assessing water quality and the presence of rubbish. The **point survey method** (see Section 3.5 of Dryden and Basheer, 2020) was used with pre-determined survey points for each of the

habitat categories. The method was chosen as there is limited known data from the islands and a large area that needs to be covered. The following parameters were assessed:

- Habitat type
- Species diversity
- Condition (of the habitat)

The survey team underwent training in flora and fauna species identification and area cover estimation. The survey sites were pre-determined using aerial images of the survey area. At each survey point, a 2.5m radius circle was surveyed, noting the:

- Dominant, secondary and tertiary plant species with the percentage of the survey area covered by each species;
- Additional plant species;
- The height of the tallest plant estimated to the nearest 0.5m;
- Canopy cover;
- Soil type;
- If rubbish is present, the type and count of rubbish;
- No. of crab burrows;
- Photo of the site with the GPS tag; and
- Species of fauna including birds, fish and insects.

In the following Section 3.2.6 of the guidance, aerial surveying was also conducted via drone imagery.

2.5 Water quality surveys

Marine water quality samples were collected from all five ESA sites and groundwater samples were only collected from Mathigulhi Sarahadhu (coordinates provided in Annex 5). Important variables related to water quality were measured, including pH, dissolved oxygen, temperature, salinity, turbidity, electrical conductivity, using an Aquameter probe (at 1 m depth). Marine water samples were taken from the start and end points of surveys (two samples per survey) using prelabeled syringes which were washed three times with seawater before taking samples. The water was filtered using syringe filters, 20ml of sample were rinsed through membrane filter into pre-labelled 50 ml centrifuge tubes. Samples were stored in a cool box and then in a deep freezer until it was sent Scottish Association of Marine Sciences (SAMS) Laboratory in Edinburgh, UK, which has the capacity to test oligotrophic sea water. All samples were tested for Ammonia, Nitrate, Nitrite and Phosphate.

2.6 Megafauna Species Diversity and Abundance

Maldives Underwater Initiative, Six Senses Laamu, has been collecting megafauna sightings data on all their dive and snorkel trips since 2017. Their datasets were used to understand megafauna species diversity and abundance at the dive sites located within and adjacent to the survey sites.

Megafauna sightings were recorded during SCUBA dives and snorkeling sessions by the Six Senses Laamu diving and research team from January 2017 to December 2023 across several sites in Laamu Atoll. Fonadhoo Diving Point, Isdhoo Muli, Mundoo Channel, and Reethi Haa and Hudhufaru were selected as sites for analysis. The total number of each megafauna species observed per dive or snorkel was documented including when none were sighted, along with the dive or snorkel duration.

For each species recorded, the global extinction risk status was determined from the IUCN Red List of Threatened Species (IUCN, 2024). The proportion of dives and snorkels where megafauna was sighted was calculated. The top five most commonly sighted megafauna species from each site were selected for analysis of sighting occurrence, and a series of generalized linear models (glms) and generalized linear mixed effect models (glmm) were constructed using the glmmTMB function in R (Brooks et al., 2017; R Core Team, 2021). Models used either Poisson or Negative Binomial probability distributions to assess the mean number of megafauna sighted per hour of diving/snorkeling overall, and the mean counts for each site. For the latter, the number of dives and snorkels at each site was also assessed as a random effect. The best-fitting models were selected using the Akaike Information Criterion (AIC) (Sakamoto et al., 1986), with models differing by more than 2 AIC units were considered superior. Model validation was assessed assessing residual distributions.

3. Overall baseline ecological condition of the ESA sites

3.1 Coral Reefs, Fish Assemblages and Megafauna

3.1.1. Benthic composition (cover and condition)

The benthic cover composition across the surveyed areas reveals both biotic (coral, sponge, and algae) and abiotic (sand, rubble) elements. Hard coral emerges as the dominant biotic cover type, with a mean coverage of 19.44%, closely followed by algae at 17.06%. However, the high standard deviation for both hard coral (12.18%) and algae (14.24%) indicates considerable variability across the surveyed sites, reflecting localized differences in environmental conditions or disturbance histories.

Among the abiotic cover types, bare rock shows the highest mean coverage at 19.22%, closely matching that of hard coral. This is followed by rubble (15.54%) and sand (8.38%). The presence of substantial rubble could indicate past disturbances or ongoing reef dynamics. Notably, soft corals and sponges contribute minimally to the overall cover, with means of 0.40% and 0.70% respectively. The relatively high standard deviations, particularly for sand (16.50%) and bare rock (15.81%), suggest a heterogeneous substrate composition across the surveyed area.

Bleaching emerges as a significant issue, affecting an average of 11.54% of the coral cover. This substantial level of bleaching suggests that the reef was recently exposed to environmental stressors, likely related to elevated water temperatures or other climate-related factors. The high standard deviation of 8.59% indicates considerable variability in bleaching across different ESA sites, potentially reflecting localized differences in resilience or exposure to stressors. The presence of dead coral is relatively low at 1.55% on average. No diseased coral was recorded during the survey.

3.1.2 Trends by depth

The benthic cover composition shows notable trends across the surveyed depths: 5m, 10m, and 15m (Figure 7, A). Algal cover increases with depth (10.34% at 5m to 26.77% at 15m), suggesting more favorable conditions in deeper waters. Hard coral coverage remains relatively stable between 5m (19.70%) and 10m (20.12%) but shows a slight decrease at 15m (17.83%). Intuitively, rubble cover displays an inverse trend to algae, decreasing from 22.33% at 5m to 11.31% at 15m. Sand cover peaks at 10m (11.18%) compared to 5m and 15m.

Bleaching shows a clear depth-related pattern, with the highest mean occurrence at 5m (13.02% \pm 9.77), decreasing to 11.53% at 10m, and further reducing to 10.07% at 15m (Figure 7, B and Table 3). This trend suggests that shallower corals are more susceptible to bleaching, possibly due to increased exposure to temperature fluctuations and light intensity. Dead coral percentages show less pronounced depth-related variation, with means ranging from 1.46% to 1.68% across all depths, and slightly lower variability at 15 meters (SD: 0.72) compared to shallower depths.

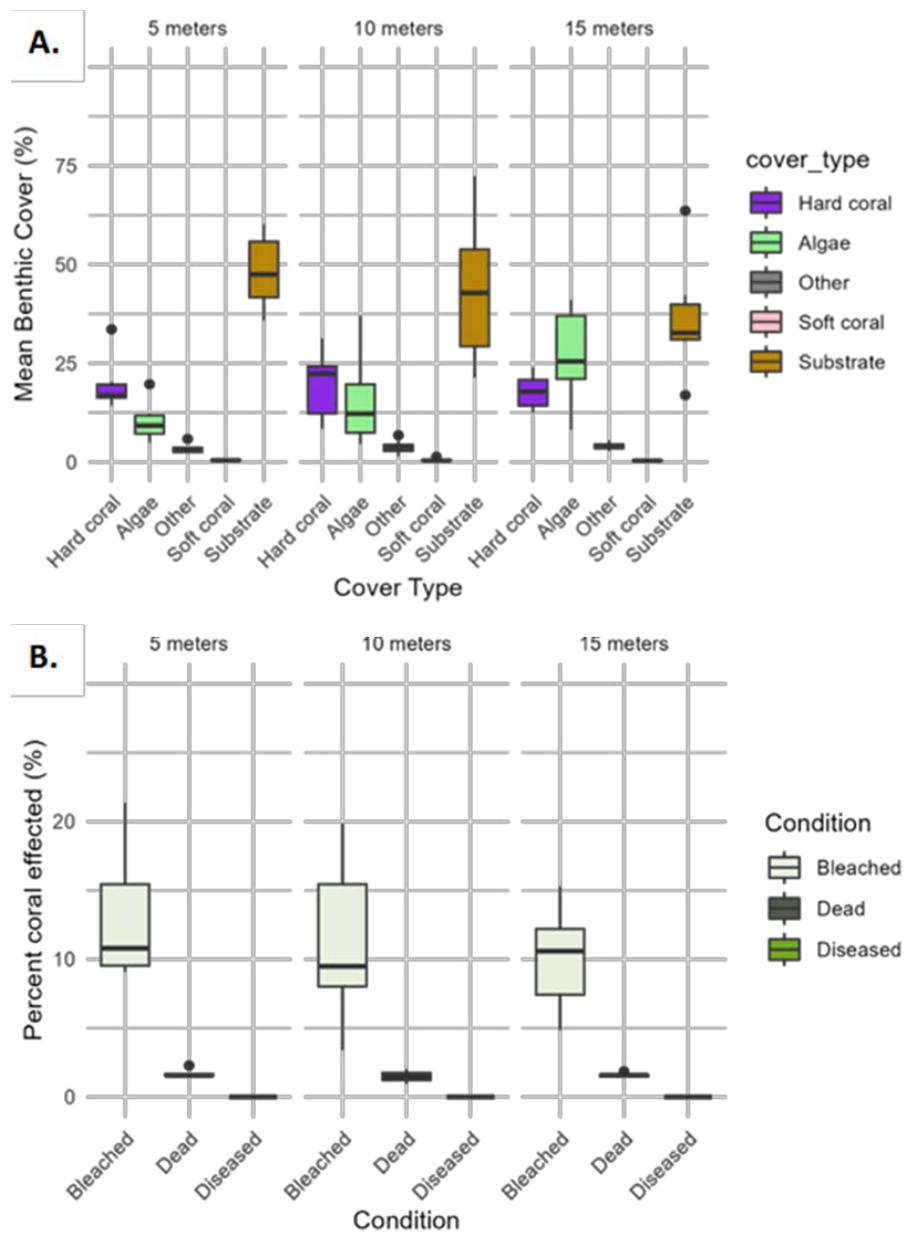


Figure 14. Mean benthic cover by class (%) for 5, 10 and 15m (A) and condition of coral (by % effected) for 5, 10 and 15m (B), aggregated across sites.

3.1.3 Fish assemblages

The fish diversity assessment across five ESAs in Laamu Atoll revealed significant variations in abundance and biomass of both commercially and ecologically important fish families. For commercially important fish families, the ESA site average abundance was 4.59 individuals per 100m², with Isdhoo Muli showing the highest abundance at 11.8/100m² and Fonadhoo Outside the lowest at 1.13/100m². Ecologically important fish families demonstrated a higher average abundance of 19.3 individuals per 100m², peaking at Hudhufaru with 26.3/100m² and again reaching its lowest point at Fonadhoo Outside with 1.13/100m².

Biomass measurements further highlighted the disparities between sites. Commercially important fish families had a site average biomass of 0.54 kg/100m², with Isdhoo Muli leading at 2.29 kg/100m² and Fonadhoo Outside trailing at 0.045 kg/100m². For ecologically important fish families, the average biomass was 0.43 kg/100m², once again with Isdhoo Muli showing the highest value at 1.064 kg/100m² and Fonadhoo Outside the lowest at 0.131 kg/100m². These findings underscore the ecological significance of Isdhoo Muli and the potential concerns at Fonadhoo Outside.

Biodiversity metrics provided additional insights into the health of these marine ecosystems. The average family richness across ESA sites was 8.8, with Isdhoo Muli containing the highest richness of 10 families and Fonadhoo Outside the lowest with 7 families. The Simpson's Diversity Index averaged 0.767 across all sites, peaking at Isdhoo Muli with 0.818, while Hudhufaru showed the lowest diversity at 0.69. Collectively, these results indicate that Isdhoo Muli consistently demonstrates the highest overall reef fish assemblage health among the surveyed ESA sites, while Fonadhoo Outside may require targeted conservation efforts to improve its ecological status.

Based on all parameters assessed, Isdhoo Muli demonstrated the highest overall reef fish assemblage health among the surveyed ESAs. In contrast, Fonadhoo Outside consistently showed the lowest values across multiple metrics, indicating potential ecological concerns in this area. There was, however:

- Significant variation between the **biomass** of commercially and ecologically important fish families across the ESA sites (GLM: $X^2(4) = 75.7$, $p < 0.001$; GLM: $X^2(4) = 111.7$, $p < 0.001$, respectively), and
- no significant variation in the **abundance** of either commercially important or ecologically important fish across all ESA sites (GLM: $X^2(4) = 3.55$, $p = 0.471$).

Table 3. Summary of coral health across ESA sites, by percentage. No diseased coral was identified during the survey period.

**Sites located within Reethi Haa and Hudhufaru.*

Metric	Unit	Fonadhoo Diving Point		Isdhoo Muli		Mundoo channel		*Laamafaru Haa		*Hudhufaru	
		10m	15m	10m	15m	10m	15m	5m	10m	5m	10m
Bleached	% (± SD)	7.09 (3.57)	9.74 (4.46)	18.03 (9.44)	15.29 (7.09)	19.10 (9.42)	11.44 (5.75)	21.36 (14.21)	7.42 (8.10)	16.96 (9.15)	9.23 (4.21)
Dead	% (± SD)	1.41 (0.47)	1.59 (0.82)	1.69 (0.80)	1.85 (1.02)	2.04 (1.60)	1.44 (0.38)	1.43 (0.67)	1.00 (0.80)	1.56 (0.64)	1.72 (0.98)

Table 4. Summary of fish statistics across ESA sites.

** Sites located within Reethi Haa and Hudhufaru.*

Group	Metric	Unit	Fonadhoo Diving Point	Isdhoo Muli	Mundoo channel	*Laamafaru Haa	*Hudhufaru
Commercially important fish families	Abundance	(count / 100m ²)	13.8	11.8	1.38	3.81	4.81
	Biomass	(kg / 100 m ²)	0.045	2.29	0.144	0.076	0.127
Ecologically important fish families	Abundance	(count / 100m ²)	1.13	24	16.1	26.3	16.4
	Biomass	(kg / 100m ²)	0.131	1.064	0.14	0.641	0.175
Health Indices	Family Richness	-	7	10	9	9	9
	Simpson's Diversity Index	-	0.737	0.818	0.812	0.69	0.779

3.1.4 Megafauna

Twenty-five megafauna categories were sighted from a total of 23,024 dives and snorkels from January 2017 to December 2023. According to the IUCN Red List of Threatened Species, 4% were Near Threatened, 32% were Vulnerable, 40% were Endangered, and 20% were Critically Endangered. No species were of Least Concern. All species had decreasing population trends (Annex 6).

At Fonadhoo Dive Point, whitetip reef sharks were the most frequently observed species, with an average sighting rate of 3.6 per hour (95% CI: 2.5, 5.3), followed by pink whiprays at 2.1 per hour (1.5, 3.2). Green and hawksbill turtles were sighted at a rate of 1.7 per hour, while other species had sighting rates of less than 1 per hour. At Reethi Haa and Hudhufaru, hawksbill turtles were the most commonly sighted species, with a rate of 1.8 per hour (1.7, 2.0), with other species sighted less than once per hour. Isdhoo Muli, a less frequented site, showed the highest variability in sighting rates; whitetip reef sharks were observed at 3.1 per hour (95% CI: 0.8, 11.8). Mundoo Channel stands out as the most productive sites for megafauna sightings. At this site, grey reef sharks, whitetip reef sharks, and spotted eagle rays were the most observed species, with sighting rates of 10.1, 7.1, and 6.0 per hour, respectively. These species were observed at rates three to five times higher than the next most common species, the hawksbill turtle, which had a sighting rate of 1.8 per hour (Figure 8). Additional information about the megafauna analysis is provided in Annex 7.

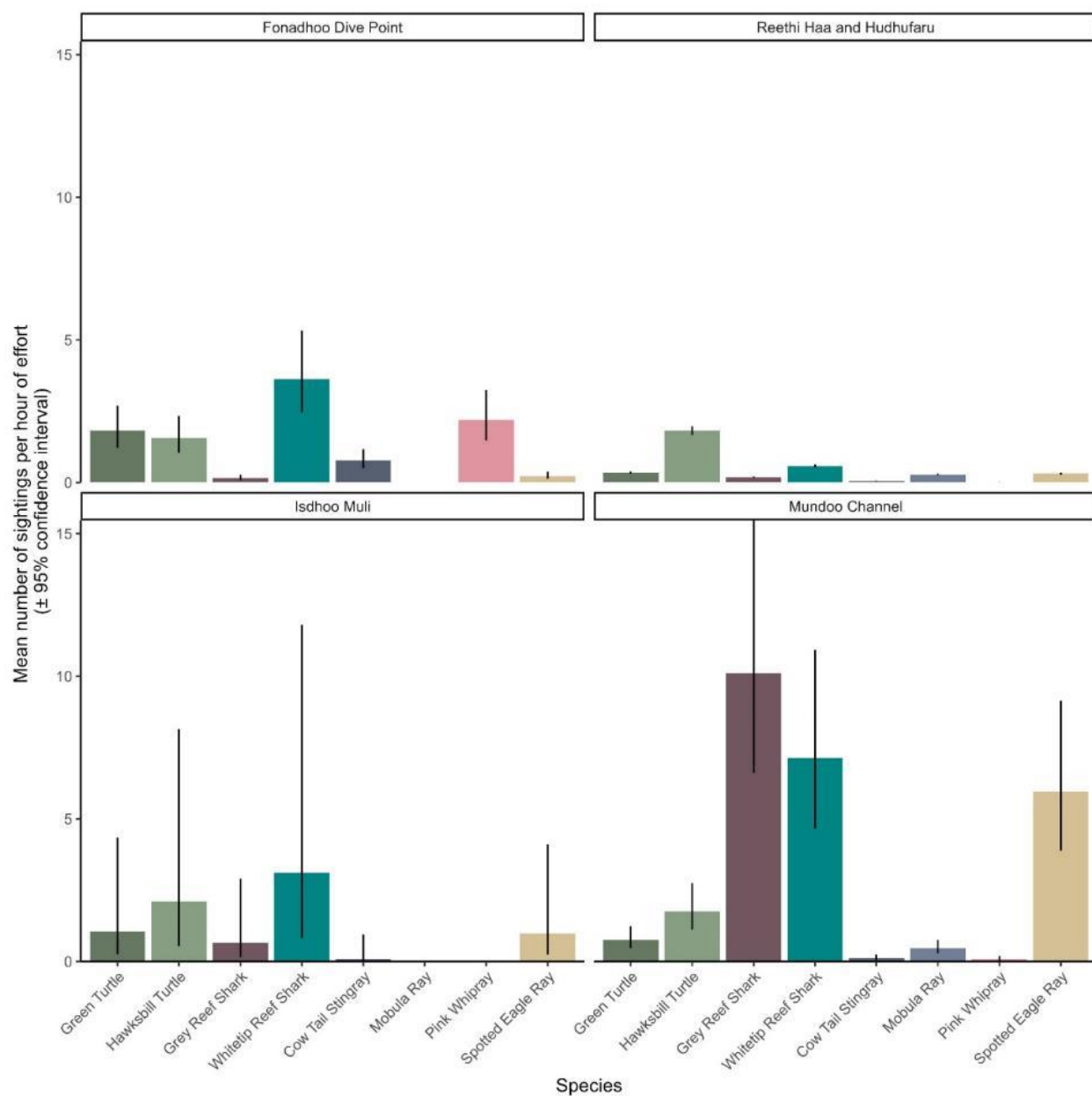


Figure 15. Mean number of sightings per hour of diving or snorkelling effort (\pm 95% confidence intervals derived from a Negative Binomial distribution) for the most commonly sighted megafauna species for Fonadhoo Dive Point ($n = 1064$), Isdhoo Muli ($n = 88$), Mundoo Channel ($n = 832$), Reethi Haa and Hudhufaru ($n = 21040$), where n = number of dives/snorkels.

3.2 Seagrass

Two ESAs contained significant seagrass cover, namely Mundoo channel and Mathigulhi Sarahadhu (Table 5). There is a notable variation in seagrass cover across different sites and distances from shore. The cover ranges from as low as 17% at Maafushi outside to as high as 92% at Maabaidhoo South (>160m from shore). Sites closer to shore (<50m) generally show lower seagrass cover percentages, with Maafushi outside, Kudafushi lagoon, and Kudafushi outside having 17%, 20%, and 27% cover respectively. In contrast, sites further from shore tend to exhibit higher seagrass cover, as seen in Maabaidhoo South (92% at >160m) and Mundoo North (79% at >50m).

The data indicates a trend in canopy height related to seagrass cover. Sites with higher seagrass cover percentages tend to have taller canopy heights. For instance, Maabaidhoo South, which has the highest seagrass cover (92%), also has the tallest canopy height at 21cm. Conversely, sites with lower seagrass cover, such as Maafushi outside and Kudafushi lagoon, have shorter canopy heights of 9cm and 10cm respectively. This suggests a possible relationship between seagrass density and its vertical growth in these ESA sites. Epibenthic cover was overall low across all sites, suggesting good health.

Table 5. Seagrass statistics for Mundoo channel and Mathigulhi Sarahadhu. *Data collected in August 2023 was conducted using the transect method, which also captures data closer to shore.

ESA	Site	Date	Distance from shore	Cover		Health indicators	
				Seagrass cover	Macroalgae cover	Epibenthic cover	Canopy height
				%	%	L/M/H	cm
Mundoo Channel	Maabaidhoo South	Aug-23*	<50m	54.70	1.52	L	15.10
		Aug-24	> 160m	92.07	0.87	L	20.76
	Mundoo North	Aug-24	> 50m	78.64	1.36	L	18.36
Mathigulhi Sarahadhu	Kudafushi outside	Apr-24	<50m	27.42	6.76	L	18.33
	Kudafushi lagoon	Apr-24	<50m	19.70	2.73	L	9.67
	Maafushi outside	Jun-24	<50m	17.09	8.48	L	9.27

For species composition, three species were observed directly within ESA sites, namely *Cymodocea rotundata* (Cr), *Thalassodendron ciliatum* (Tc), and *Thalassia hemprichii* (Th) (Table 6). In the Mundoo Channel area, both Maabaidhoo South and Mundoo North show a complete dominance of Th species inside the ESA, with 100% cover and no variation (SD = 0). This suggests a monospecific seagrass meadow in these locations due to dynamic currents in the channel. It should be noted that transects closer to shore captured other seagrass species.

In contrast, the Mathigulhi Sarahadhu area displays more diverse species composition. Kudafushi outside and Kudafushi lagoon both show a presence of Th (54% and 54% respectively) and Tc (43% and 7% respectively), but no Cr. Interestingly, Maafushi outside presents a different pattern, with Cr dominating at 54% cover, some Th presence at 19%, and no Tc observed. These variations in species composition across sites indicate that local environmental factors may be influencing the distribution and abundance of different seagrass species in these ESA sample sites.

Table 6. Benthic cover in seagrass meadows, by percentage, for the three species observed across ESA sample sites.

ESA	Site	Cr		Tc		Th	
		Mean	SD	Mean	SD	Max	SD
Mundoo Channel	Maabaidhoo South	-	-	-	-	100	0
	Mundoo North	-	-	-	-	100	0
Mathigulhi Sarahadhu	Kudafushi outside	-	-	43.03	46.06	53.94	46.43
	Kudafushi lagoon	-	-	6.97	20.69	53.64	48.21
	Maafushi outside	54.09	50.18	-	-	18.64	39.00

3.3 Water Quality

3.3.1 Nutrients

Phosphate concentrations were below the limit of detection at all marine sites (Table 7). Higher nitrate and phosphate levels were detected in groundwater in Kudafushi, compared to below detection limit levels in all marine sites. The sites generally show low levels of ammonium and phosphate, with many measurements below the limit of detection, especially in surface-level samples. This suggests oligotrophic conditions (low nutrient levels). This is expected as ammonium is quickly taken up by organisms, more quickly than nitrate.

The highest ammonium concentrations were found at Maafushi at the end of the seagrass transect T1. This could indicate localized sources or conditions favoring ammonium retention. Most sites generally showed lower ammonium concentrations, potentially indicating lower nutrient inputs or faster uptake by biological processes. Overall, Ammonium concentrations were not uniformly distributed across the sites and depths, with certain locations showing higher concentrations (e.g., Mundoo Channel coral reef 15m) that could be related to site-specific factors like water depth, local nutrient inputs, and biological activity.

NOx concentrations observed in the samples range from 0.07 to 4.99, reflecting varying nutrient levels across different sites and depths. Concentrations are generally low, typically ranging between 0.07 and 0.85 across most sites, with only a few locations, such as Kudafushi groundwater Well 1, 2, and 3, showing higher levels (2.06–4.99). This variability suggests that nutrient concentrations are influenced by local environmental conditions, including site-specific factors and depth.

Table 7. Nutrients results table for all marine (coral reef and seagrass) and groundwater sites with the ESAs.

Site	Ammonium (uM)	Phosphate (uM)	NO _x (uM)
Isdhoo Muli coral reef 10m	<MDL	<MDL	0.67
Isdhoo Muli coral reef 15m	<MDL	<MDL	0.29
Mundoo Channel coral reef 10m	<MDL	<MDL	0.80
Mundoo Channel coral reef 15m	0.69	<MDL	0.68
Hudhufaru coral reef 5m	<MDL	<MDL	0.66
Hudhufaru coral reef 10m	<MDL	<MDL	0.85
Fonadhoo Diving Point coral reef 10m	<MDL	<MDL	0.56
Fonadhoo Diving Point coral reef 15m	<MDL	<MDL	0.59
Method Detection Limit (MDL)	0.15	0.13	0.09
Maafushi seagrass T1 start	<MDL	<MDL	0.07
Maafushi seagrass T1 end	1.26	<MDL	0.12
Maafushi seagrass T2 start	<MDL	<MDL	<MDL
Maafushi seagrass T2 end	0.31	<MDL	0.07
Maafushi seagrass T3 start	<MDL	<MDL	<MDL
Maafushi seagrass T3 end	<MDL	<MDL	<MDL
Kudafushi seagrass T1 start	0.67	<MDL	0.29
Kudafushi seagrass T2 start	0.29	<MDL	0.18
Kudafushi seagrass T1 end	0.41	<MDL	0.22
Method Detection Limit (MDL)	0.28	0.53	0.06
Kudafushi groundwater Well 1	<MDL	1.32	2.06
Kudafushi groundwater Well 2	<MDL	3.08	4.99
Kudafushi groundwater Well 3	<MDL	1.17	2.07
Method Detection Limit (MDL)	0.16	0.35	0.13

3.3.2 Water quality parameters

At each location, water quality was assessed using a water quality probe, recording parameters temperature, pH, salinity, dissolved oxygen, electric conductivity, and turbidity (Table 8).

The temperature across all sites ranged from 29°C at Kudafushi Well 2 (agricultural groundwater) to 34.4°C at Hudhufaru (thila), with the marine sites generally displaying warmer temperatures compared to the groundwater locations.

pH values vary between 6.4 at Kudafushi Well 3 and 8.13 at Isdhoo Muli, with marine sites typically neutral to alkaline, which is expected for seawater.

The salinity shows significant variation, ranging from as low as 0.14 ppt at Kudafushi Well 3, representing freshwater or highly diluted conditions, to 38.63 ppt at Isdhoo Muli, indicative of oceanic saline water.

Dissolved oxygen (DO) percentages vary widely, with the groundwater sites showing extremes—Kudafushi Well 3 has an unusually high DO percentage of 138.7%, while Kudafushi Well 2 has a much lower value of 47.2%. Marine sites have DO levels between 80.5% and 95.2%, consistent with healthy oxygenation levels. Dissolved oxygen in mg/L similarly follows this pattern, from 3.67mg/L at Kudafushi Well 2 to 10.34mg/L at Well 3, with marine sites showing moderate values between 4.93mg/L and 7.92mg/L. Electrical conductivity (EC) is highest at the marine sites (44.04–58.38mS/cm), reflecting their saline nature, while groundwater sites have much lower EC values (0.43–2.208mS/cm), consistent with their lower salinity.

Across all sites, turbidity remained at 0NTU, indicating clear waters with no significant particulate matter, which is favourable for coral reef health. Except for Kudafushi Well 3, which shows some turbidity (14NTU), likely due to particulate matter in the groundwater.

Table 8. Water quality results for all ESA sites

Site	Temp (°C)	pH	Salinity	DO (%)	DO (mg/L)	EC (mS/cm)	Turbidity (NTU)
Isdhoo Muli	31.3	8.13	38.63	89	5.5	58.38	0
Mundoo Corner	31.15	7.33	33.54	95.2	5.92	50.9	0
Hudhufaru	34.4	7.05	29.03	80.5	4.93	44.04	0
Fonadhoo Diving Point	31	7.01	35	78.3	4.8	53.05	0
Well 1	31.3	7.7	0.8	60.8	4.4	1.645	0
Well 2	29	7.58	1.12	47.2	3.67	2.208	0
Well 3	31.7	6.4	0.14	138.7	10.34	0.43	14
Kudafushi outside 5m from shore	32.4	7.91	27.9	124	7.92	43.35	0
Kudafushi outside 20m from shore	31.9	7.93	27.86	123.6	7.92	43.3	0

4. Individual baseline ecological condition of the ESA sites

4.1 Fonadhoo Diving Point

The site only contains a coral reef ecosystem, which was sampled at “Fonadhoo Outside”. Thus, only benthic composition, fish assemblage and megafauna were assessed.

4.1.1 Benthic composition

At 10m depth, the benthic cover is dominated by abiotic components, with bare rock being the most prevalent cover type at 34.79% (± 12.63). This is followed closely by algae, which covers 27.79% (± 12.46). Hard coral accounts for 12.32% (± 7.68) of the cover. The site shows relatively low coverage of rubble (4.25% ± 2.72) and sand (1.51% ± 0.55) at this depth. At 15m depth, we observe shifts in the benthic composition. Bare rock remains the dominant cover type (28.72% ± 11.37). Algal cover decreases to 20.64% (± 10.33), while hard coral coverage increases to 17.26% (± 7.39). Notably, rubble cover increases substantially to 11.00% (± 6.59) at this depth.

These data, presented in the Figure below (Figure 9), suggest that Fonadhoo Outside is characterized by a high proportion of bare substrate, particularly at shallower depths. The site shows moderate algal cover, which decreases with depth, possibly due to reduced light availability. The increase in hard coral cover at 15m, coupled with the increase in rubble, might indicate a transition zone. The high standard deviations, particularly for dominant cover types, indicate considerable variability.

At Fonadhoo Diving Point, there's a slight increase in both bleaching and mortality with depth. Bleaching increases from 7.09% (± 3.57) at 10m to 9.74% (± 4.46) at 15m. Similarly, coral mortality shows a minor increase from 1.41% (± 0.47) at 10m to 1.59% (± 0.82) at 15m. The relatively low standard deviations suggest consistent conditions across the surveyed area.

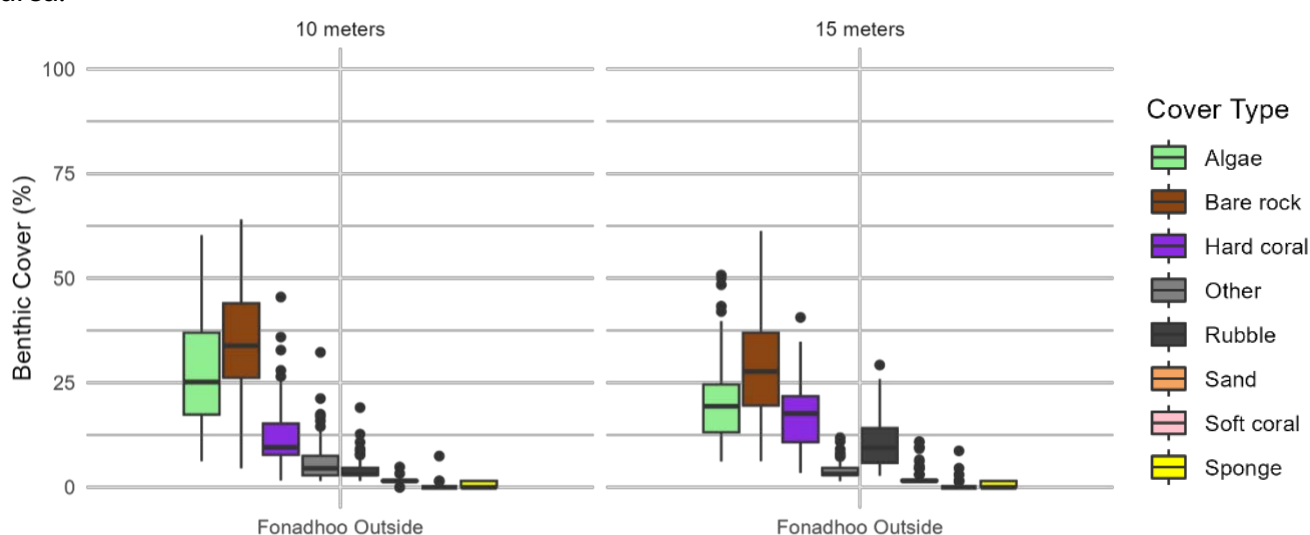


Figure 16. Benthic cover by transect depth for site Fonadhoo outside

4.1.2 Fish Assemblages

Fonadhoo Outside had the highest abundance of commercially important fish families (13.8/100m²), but the lowest abundance of ecologically important fish families (1.13/100m²). It also had the lowest biomass for either group across the five potential ESA sites (0.045kg/100m² for commercially important fish families and 0.131kg/100m² for ecologically important fish family). The site also had the lowest family richness (7) and the second lowest Simpson's Diversity Index (0.737). Considering all the parameters Fonadhoo Outside had the lowest reef fish assemblage health.

Table 9. Fish assemblage health at Fonadhoo Diving Point ESA

Parameter	Result
Commercially Important Fish Family Abundance	13.8/100m ²
Ecologically Important Fish Family Abundance	1.13/100m ²
Commercially Important Fish Family Biomass	0.045kg/100m ²
Ecologically Important Fish Family Biomass	0.131kg/100m ²
Family Richness	7
Simpson's Diversity Index	0.737

4.1.3 Megafauna

At Fonadhoo Diving Point, whitetip reef sharks were the most frequently observed species, with an average sighting rate of 3.6 per hour (95% CI: 2.5, 5.3), followed by pink whiprays at 2.1 per hour (CI: 1.5, 3.2). Green and hawksbill turtles were sighted at a rate of 1.7 per hour, while other species had sighting rates of less than 1 per hour.

A reef manta ray (*Mobula alfredi*) cleaning station was observed about 200m south of the survey site at 20-25m depth at the end of the survey. Three reef manta rays were using the cleaning station during the 10 minutes of observation time.

4.1.4 Water Quality

Ammonium and phosphates were below detection limit at both depths, with lower NOx concentration at the shallower depth (see Tables 7 and 8)

4.2 Isdhoo Muli

The site only contains a coral reef ecosystem. Thus, only benthic composition, fish assemblage and megafauna were assessed.

4.2.1 Benthic composition

At 10m, hard corals dominate the biotic cover with a mean coverage of 22.50% (± 8.41), followed by algae at 12.73% (± 6.28). Among the abiotic components, bare rock is the most prevalent, covering 23.69% (± 11.93) of the substrate, followed by rubble at 9.36% (± 7.25) and a small proportion of sand at 1.95% (± 1.20).

At 15m depth, several shifts in the benthic composition become apparent. Algal cover shows a substantial rise to 22.34% (± 9.82). Bare rock coverage decreases slightly to 21.85% (± 9.11), as does rubble, which drops to 6.71% (± 4.79). Sand coverage remains stable.

The data from Isdhoo Muli (Figure 10) reveal a dynamic benthic ecosystem with notable depth-related variations. The increase in total biotic cover from approximately 36% at 10m to nearly 48% at 15m suggests more favorable conditions for biological growth at the deeper depth. This is particularly evident in the substantial increase in algal cover. Conversely, the abiotic cover decreases with depth, primarily due to reductions in bare rock and rubble cover. The relatively high standard deviations across most cover types indicate considerable spatial variability within the surveyed area, suggesting a heterogeneous benthic landscape. This variability could be attributed to factors such as localized differences in environmental conditions, disturbance history, or ongoing ecological processes.

Isdhoo Muli exhibits a decrease in bleaching with depth, from 18.03% (± 9.44) at 10m to 15.29% (± 7.09) at 15m. However, mortality slightly increases from 1.69% (± 0.80) at 10m to 1.85% (± 1.02) at 15m.

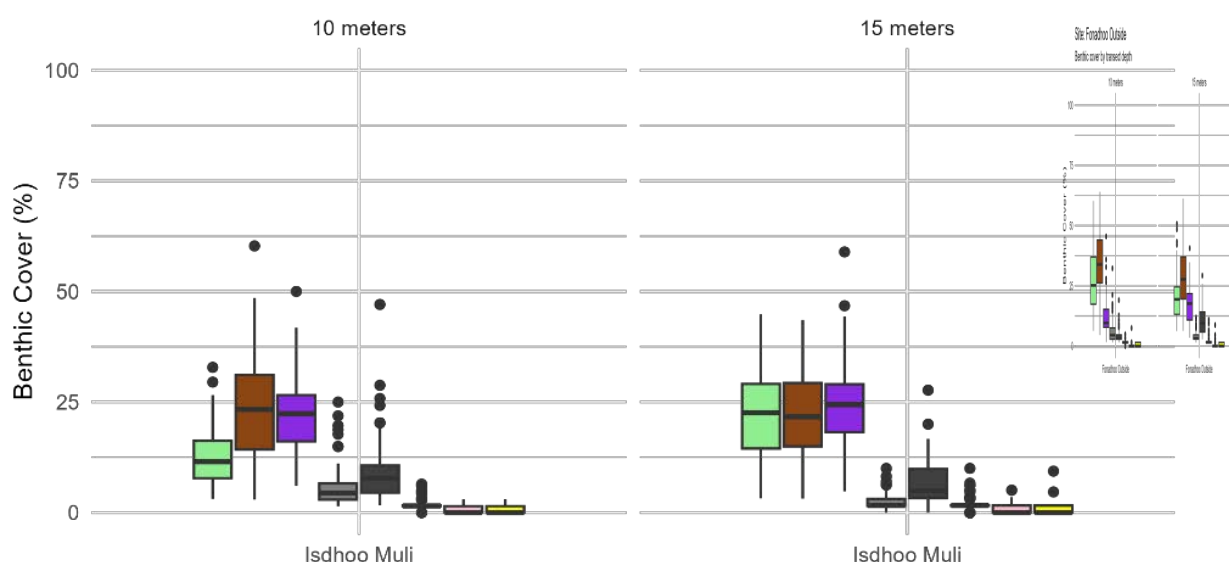


Figure 17. Benthic cover by transect depth for site Isdhoo Muli

4.2.2 Fish Assemblages

Isdhoo Muli had the highest abundance of commercially important fish families (11.8/100m²) and the second highest abundance of ecologically important fish families (24/100m²) among the surveyed ESA sites. The site also recorded the highest biomass for both commercially (2.29kg/100m²) and ecologically (1.064kg/100m²) important fish families. Additionally, Isdhoo Muli had the highest Simpson's Diversity Index (0.818) and family richness (10). Overall, Isdhoo Muli exhibited the highest reef fish assemblage health.

Table 10. Fish assemblage health at Isdhoo Muli ESA

Parameter	Result
Commercially Important Fish Family Abundance	11.8/100m ²
Ecologically Important Fish Family Abundance	24/100m ²
Commercially Important Fish Family Biomass	2.29kg/100m ²
Ecologically Important Fish Family Biomass	1.064kg/100m ²
Family Richness	10
Simpson's Diversity Index	0.818

4.2.3 Megafauna

Isdhoo Muli, a less frequented site, showed the highest variability in sighting rates; whitetip reef sharks were observed at 3.1 per hour (95% CI: 0.8, 11.8).

4.2.4 Water Quality

Ammonium and phosphates were below detection limit at both depths, with lower NOx concentration at the deeper depth (see Tables 7 and 8).

4.3 Mathigulhi Sarahadhu

The site contains both seagrass and terrestrial vegetation habitats.

4.3.1 Seagrass

Seagrass cover varies across Mathigulhi Sarahadhu sample sites, with Kudafushi outside (oceanward) having the highest mean cover at 27%, followed by Kudafushi lagoon (protected) at 20%, and Maafushi outside (lagoon) at 17%. However, there is considerable variability from shore to 50 m. Algae cover is highest at Maafushi outside (lagoon) with 8%, followed closely by Kudafushi outside (oceanward) at 7%. Kudafushi lagoon (protected) has the lowest algae cover at 3%.

Regarding seagrass canopy height, Kudafushi outside (oceanward) shows the tallest maximum height at 18 cm, while Kudafushi lagoon (protected) and Maafushi outside (lagoon) have lower maximum heights of 10 cm and 9 cm respectively. The standard deviations for canopy height are relatively smaller compared to the cover measurements, indicating less variability in height across samples within each site.

These data suggest that the oceanward site (Kudafushi outside) generally has higher seagrass cover and taller canopy height compared to the protected and lagoon sites. However, the high variability in most measurements indicates that there may be significant patchiness or other factors influencing seagrass and algae distribution within each site.

In terms of species (Table 11), distinct patterns of seagrass species distribution across the three different site types. Kudafushi outside (oceanward) and Kudafushi lagoon (protected) show similar patterns, both dominated by *Thalassia hemprichii* (Th) at 54% cover, but differ in their *Thalassodendron ciliatum* (Tc) composition (43% and 7% respectively). Neither of these sites had *Cymodocea rotundata* (Cr) in the transects. In contrast, Maafushi outside (lagoon) was dominated by Cr at 54% cover, with some Th presence at 19%, and no Tc. This stark difference in species composition, particularly the presence of Cr only in the lagoon site, suggests that local environmental factors specific to each site type are likely influencing the distribution and abundance of these seagrass species.

Table 11. Species cover per site within seagrass at Mathigulhi Sarahadhu

* Cr = *Cymodocea rotundata*, Tc = *Thalassodendron ciliatum*, Th = *Thalassia hemprichii*

Site	Type	Cr		Tc		Th	
		Max	SD	Max	SD	Max	SD
Kudafushi outside	Oceanward	0	0	43.03	46.06	53.94	46.43
Kudafushi lagoon	Protected	0	0	6.97	20.69	53.64	48.21
Maafushi outside	Lagoon	54.09	50.18	0	0	18.64	39.00

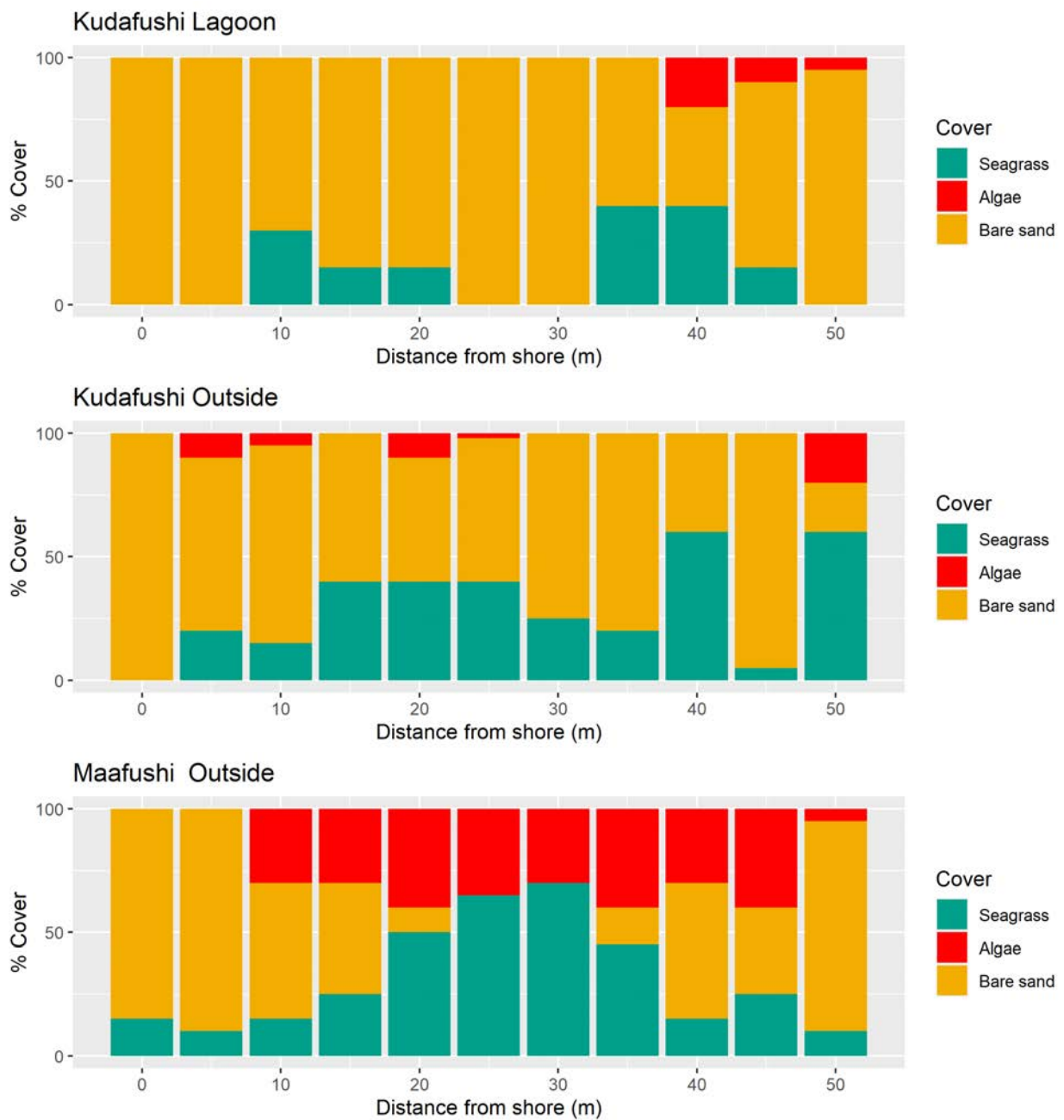


Figure 18. Benthic cover across the three sampled seagrass meadows at Mathigulhi Sarahadhu ESA, by percentage from shoreline (0m) and 50m into the meadow.

Table 12. Transect locations for Mathigulhi Sarahadhu ESA

Transect			Start		End	
Island	Location	Replicate	Lat	Lon	Lat	Lon
Kudafushi	Outside	1	1.787861	73.33022	1.787528	73.32994
	Outside	2	1.787639	73.33078	1.78725	73.33061
	Outside	3	1.787611	73.33111	1.787167	73.331
	Lagoon	1	1.791056	73.33361	1.79062	73.33372
	Lagoon	2	1.790639	73.33333	1.790944	73.33311
	Lagoon	3	1.790111	73.33325	1.790222	73.33286
Maafushi	Outside	1	1.791919	73.33518	1.792247	73.33553
	Outside	2	1.792242	73.33441	1.792697	73.33445
	Outside	3	1.792269	73.33394	1.792706	73.33403

4.3.2 Small island vegetation surveys

The small island survey was conducted on two islands: Kudafushi (10 sites) and Maafushi (12 sites), with site details presented in Annex 4.

Kudafushi

The primary species were *Pemphis acidula* (Kuredhi), *Guettarda speciosa* (Uni), *Talipariti tiliaceum* (Dhigga) and *Cocos nucifera* (Dhivehi ruh). *P. acidula* is known as a pioneer species in coastal areas, it helps stabilize shorelines. Similarly, *T. tiliaceum* performs soil stabilization. Secondary species for the sites included *Scaevola taccada* (Magoo), *Artocarpus communis* (Banbukeyo), *Pandanus orifer* (Maa kashikeyo) and *Crinum asiaticum* (Kandholhu). Canopy cover across sites was 84% (SD: 0.22).

Maafushi

Similar primary species were found on Maafushi, which included *Pemphis acidula* (Kuredhi), *Cocos nucifera* (Dhivehi ruh), *Morinda citrifolia* (Ahi) and *Scaevola taccada* (Magoo). *Pandanus orifer* (Maa kashikeyo) and *Ceriop tagal* (Yellow mangrove), aside from existing vegetation identified were secondary species across sites. Canopy cover across sites was 60% (SD: 0.23).

Within the surveyed areas, a total of 155 items of marine debris / litter were found on Kudafushi and Maafushi islands, composed predominantly of plastics (138 items), followed by metals (n = 10) and glass (n = 6). Plastic bottles were the most common item, with 109 counted. Most of the litter was found on Maafushi island (123 counts).

Table 13. Primary tree species across Kudafushi and Maafushi sites within the Mathigulhi Sarahadhu ESA

	No. of trees across sites	Height		DBH	
		Avg (cm)	SD	Avg (cm)	SD
Kudafushi (n = 10)	17	583.67	-	43.06	-
<i>Artocarpus communis</i>	1	762.00	-	92.00	-
<i>Calophyllum Inophyllum</i>	1	952.57	-	66.00	-
<i>Cocos nucifera</i>	1	366.00	397.16	51.00	18.89
<i>Guettarda speciosa</i>	5	615.96	-	35.30	-
<i>Hernandia nymphaefolia</i>	1	914.00	-	95.00	-

<i>Pandanus orifer</i>	1	588.67	317.15	48.00	34.03
<i>Pemphis acidula</i>	3	546.22	0.00	44.33	1.70
<i>Talipariti tiliaceum</i>	4	405.16	247.10	17.63	28.12
Maafushi (n = 12)	24	351.04	364.18	34.91	12.06
<i>Cocos nucifera</i>	8	594.13	107.48	72.33	5.66
<i>Guettarda speciosa</i>	2	320.00	58.40	19.00	5.45
<i>Morinda citrifolia</i>	4	228.75	-	12.50	-
<i>Pandanus orifer</i>	1	335.00	35.22	56.00	1.73
<i>Pemphis acidula</i>	3	264.33	35.81	13.00	1.15
<i>Scaevola taccada</i>	3	141.67	0.00	7.67	17.68
<i>Talipariti tiliaceum</i>	2	290.00	-	36.50	-
<i>Thespesia populnea</i>	1	470.00	285.37	55.00	27.91

Other observations

Additional *Ceriops tagal* (Yellow mangrove) trees and saplings were observed in both Maafushi and Kudafushi, which were outside of the survey plots. On Kudafushi, the trees were located at the northwest coast fringe and on Maafushi they were located on the southcentral coastal fringe.

Several megafauna species were observed in the central lagoon of the islands on both survey days. These include juvenile *Carcharhinus diphreutes* (Blacktip reef shark) x 25 individuals, *Negaprion acutidens* (sicklefin lemon shark) x 1 individual, *Pastinachus sephen* (Cowtail stingray) x 3 individuals and *Aetobatus narinari* (Spotted eagle ray) x 1 individual. The prevalence of such a high number of juvenile Blacktip reef shark may indicate that the lagoon is acting as a nursery habitat for juvenile sharks. The lagoon also appears to be an important habitat for rays.

Two species of birds were observed which may indicate that this area is an important habitat for bird species. The species observed were *Nycticorax nycticorax* (Black-crowned night-heron) x 6 individuals and *Ardea cinerea* (Grey heron) x 2 individuals. Dead crab, possibly *Scylla serrata* (Giant mud crab) was observed in Kudafushi island.

4.3.4 Water Quality

There was a high ammonium concentration at Maafushi seagrass T1 end, this could indicate mixing or relating to currents at time of sampling. Phosphate was below detection level in all marine samples, but elevated nitrate and phosphate levels detected in groundwater wells at Kudafushi (see Tables 7 and 8).

4.4 Mundoo Channel

The site contains seagrass and coral reef ecosystems, at a site named “Mundoo corner”. Benthic composition, fish assemblage and megafauna were assessed.

4.4.1 Benthic composition

The benthic composition at Mundoo Corner shows significant variations between the 10m and 15m depths. At 10m depth, the substrate is characterized by a balanced mix of biotic and abiotic components. Hard corals dominate the biotic cover with a mean coverage of 24.67% (± 8.70), followed by algae at 15.99% (± 7.50). Bare rock and rubble cover 27.20%, with a small proportion of sand at 2.32% (± 2.46).

As we descend to 15m depth, we observe dramatic shifts in the benthic composition. The most striking change is the substantial increase in algal cover, which more than doubled to 39.85% (± 13.86). This increase is accompanied by a slight decrease in hard coral coverage to 21.58% (± 10.36). Bare rock and rubble coverage reduces to 14.51%.

These data reveal notable depth-related variations (Figure 12). The substantial increase in algal cover suggests a shift towards algal dominance at greater depths. The high standard deviations, particularly for algae and rubble at 15m, indicate considerable spatial variability within the surveyed area. This heterogeneity could be attributed to factors such as localized differences in substrate stability, water movement, or ecological interactions.

At Mundoo Channel, there's a high amount of bleaching (19%), that decreases with depth at 10m to 11.44% (± 5.75) at 15m. Mortality decreases from 2.04% (± 1.60) at 10m to 1.44% (± 0.38) at 15m.

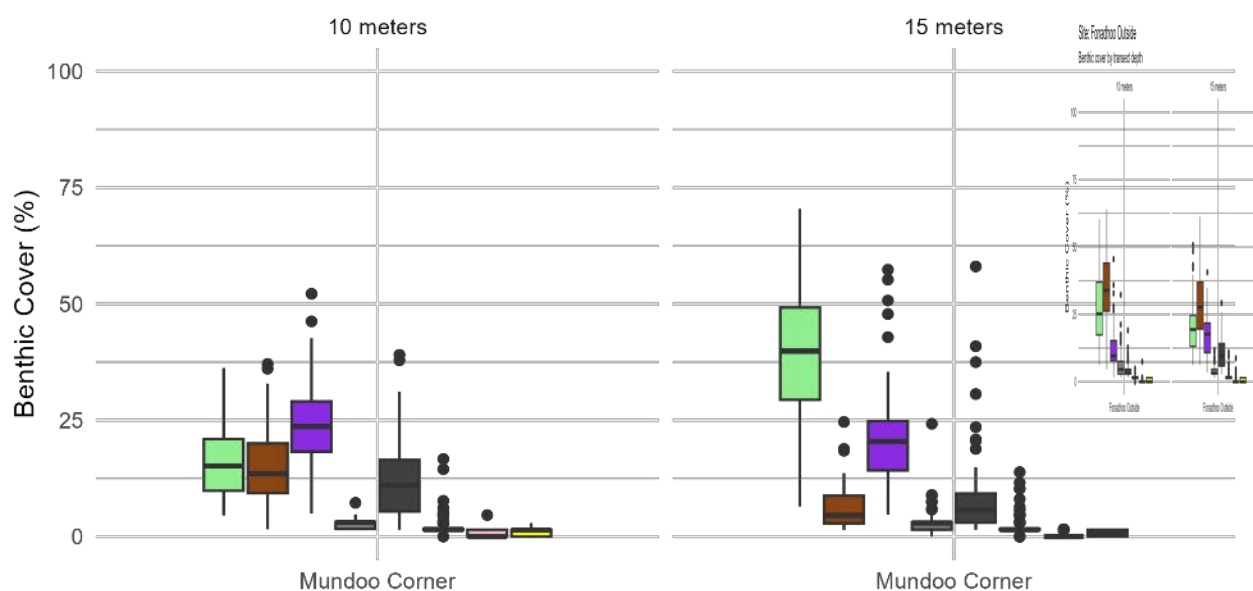


Figure 19. Benthic cover by transect depth for site Mundoo corner.

4.4.2 Fish Assemblages

Mundoo Channel had the second lowest abundance of both commercially (1.38/100m²) and ecologically (16.1/100m²) important fish families among the surveyed ESA sites. This may infer a high fishing pressure at the site. While the biomass of commercially important fish families was the second highest at this site (0.144kg/100m²), the biomass of ecologically important fish families was the second lowest (0.14kg/100m²). The site recorded the second highest Simpson's Diversity Index (0.812) and family richness (9). However, when considering all parameters, Mundoo Kandu had the second lowest reef fish assemblage health.

Table 14. Fish assemblage health at Mundoo Channel ESA

Parameter	Result
Commercially Important Fish Family Abundance	1.38/100m ²
Ecologically Important Fish Family Abundance	16.1/100m ²
Commercially Important Fish Family Biomass	0.144kg/100m ²
Ecologically Important Fish Family Biomass	0.14kg/100m ²
Family Richness	9
Simpson's Diversity Index	0.812

4.4.3 Megafauna

Mundoo Channel stands out as the most productive sites for megafauna sightings among the ESAs. At this site, grey reef sharks, whitetip reef sharks, and spotted eagle rays were the most commonly observed species, with sighting rates of 10.1, 7.1, and 6.0 per hour, respectively. These species were observed at rates three to five times higher than the next most common species, the hawksbill turtle, which had a sighting rate of 1.8 per hour.

4.4.4 Seagrass

Due to strong currents, transects could not be used safely across the two sites (Maabaidhoo South and Mundoo North). Instead, a random quadrat method was employed to provide a representative assessment of seagrasses within Mundoo ESA. The random quadrats were taken between 0.3m and 1.5m water depth (mean = 0.61m, SD = 0.21). Data for Maabaidhoo South were compared to statistics from a previous survey survey by the University of New South Wales in April 2023, presented in Table 5.

All quadrats were composed entirely of the seagrass species *Thalassodendron ciliatum* (Tc) in August 2024. However, *Cymodocea rotundata* (Cr), *Halodule pinifolia* (Hp), *Syringodium isotifolium* (Si), and *Thalassia hemprichii* (Th) were earlier observed in August 2023. These transects, however, were taken much closer to shore and less exposed than the sampled quadrats.

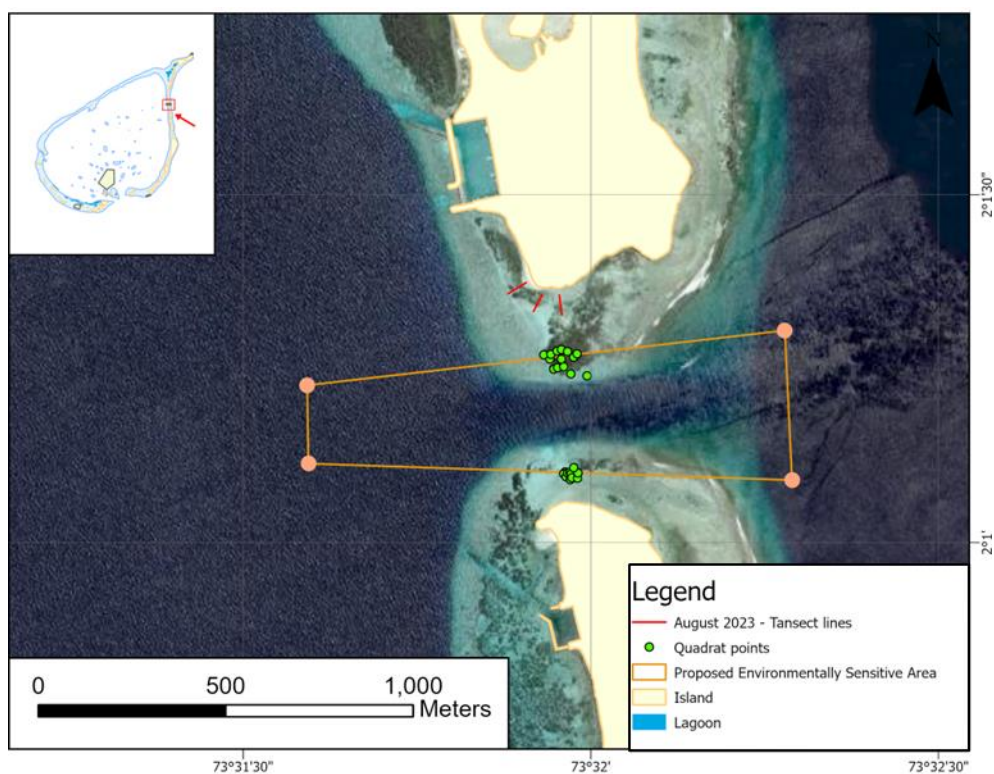


Figure 20 Location of presented data for Mundoo channel ESA.

Table 21 Location of quadrats for Mundoo channel ESA.

Site	Quadrat no	Lat	Lon
Maabaidhoo South	1	2.020838	73.53245
	2	2.020827	73.53245
	3	2.020855	73.53254
	4	2.020884	73.53268
	5	2.02071	73.53286
	6	2.020659	73.53324
	7	2.021103	73.53293
	8	2.02106	73.53263
	9	2.021065	73.53235
	10	2.021166	73.5322
	11	2.021178	73.53238
	12	2.021257	73.53252
	13	2.021287	73.53263
	14	2.021244	73.53278
	15	2.021186	73.533
Mundoo North	1	2.018364	73.53272
	2	2.01831	73.53268
	3	2.01824	73.53274
	4	2.01833	73.53278
	5	2.01835	73.53283
	6	2.0183	73.53285

	7	2.01818	73.53284
	8	2.01822	73.53288
	9	2.01821	73.53301
	10	2.01834	73.53303
	11	2.01846	73.53292

Water Quality

Water quality at Mundoo Channel ESA exhibited moderate ammonium level at 15m, suggesting some nutrient presence. Relatively higher NO_x concentrations were also observed compared to other sampled sites (see Tables 7 and 8).

4.5 Reethi Haa and Hudhufaru

The site only contains a coral reef ecosystem, at two sites: “Laamafaru Haa” and “Hudhufaru”. Thus, only benthic composition, fish assemblage and megafauna were assessed.

4.5.1 Benthic composition

Hudhufaru

The benthic composition at Hudhufaru shows significant variations between 5m and 10m depths. Bare rock dominates with 22.20% (± 10.98) coverage, followed closely by algae at 19.67% (± 12.49) and hard corals at 16.27% (± 6.83). At 10m depth, there's a dramatic shift in composition. Algal cover increases substantially to 31.28% (± 11.78), becoming the dominant cover type. Hard coral coverage also increases to 22.19% (± 9.65). Conversely, bare rock coverage decreases significantly to 6.49% (± 4.41).

Laamafaru Haa

At 5m, rubble dominates the substrate at 22.21% (± 17.13), followed by hard corals at 16.45% (± 11.38) and bare rock at 14.08% (± 9.12). Algal cover is relatively low at 6.77% (± 3.79), while sand covers 10.96% (± 21.93) of the area. At 10m depth, there's a dramatic increase in sand coverage to 48.47% (± 32.69), becoming the dominant substrate type. Hard coral coverage decreases to 11.49% (± 9.22), while algal cover further reduces to 4.54% (± 3.87). The extremely high standard deviation for sand coverage indicates significant spatial heterogeneity at this depth.

Comparison of Hudhufaru and Laamafaru Haa:

Hudhufaru and Laamafaru Haa exhibit distinct benthic compositions and depth-related trends (Figure 15), reflecting different ecological conditions. Hudhufaru shows a shift towards algal dominance with increasing depth, coupled with an increase in hard coral cover and rubble. In contrast, Laamafaru Haa is characterized by a transition to sand-dominated substrate at greater depth, with decreases in most other cover types.

Both sites show high spatial variability, as indicated by large standard deviations, particularly for dominant cover types. Hudhufaru appears to have higher overall biotic cover, especially algae and hard corals, while Laamafaru Haa is characterized by higher abiotic cover, particularly sand and rubble.

4.5.2 Benthic condition

Laamafaru Haa shows a high amount of bleaching at 5m at 21.36% (± 14.21), dropping to 7.42% (± 8.10) at 10m. Mortality is low, and also decreases from 1.43% (± 0.67) at 5m to 1.00% (± 0.80) at 10m. At Hudhufaru, bleaching also decreases notably from 16.96% (± 9.15) at 5m to 9.23% (± 4.21) at 10m. However, mortality slightly increases from 1.56% (± 0.64) at 5m to 1.72% (± 0.98) at 10m. The decrease in standard deviation for bleaching suggests more uniform conditions at 10m compared to 5m.

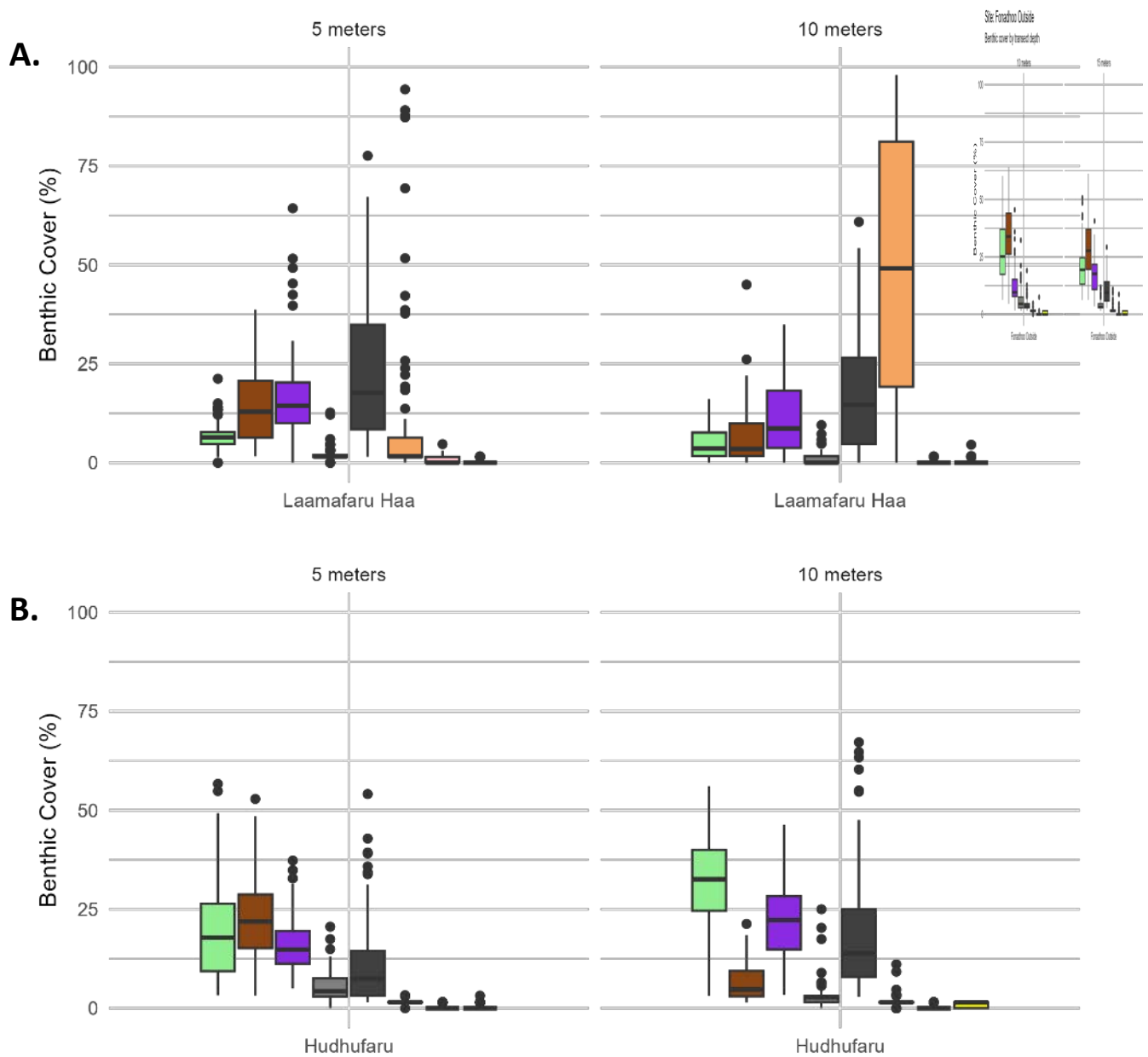


Figure 22. Benthic cover by transect depth for Laamafaru Haa (A) and Hudhufaru (B) within Reethi Haa and Hudhufaru ESA at 5 and 10m depth.

4.5.3 Fish Assemblages

Laamafaru Haa had the second highest abundance of commercially important fish families (4.81/100m²) and the third highest abundance of ecologically important fish families (16.4/100m²) among the surveyed ESA sites. The biomass of both commercially (0.127kg/100m²) and ecologically (0.175kg/100m²) important fish families was also third highest at this site. Additionally, Laamafaru Haa recorded the third highest Simpson's Diversity Index (0.779) and the second highest family richness (9), tied with Hudhufaru and Mundoo Kanduu. Overall, when considering all parameters, Laamafaru Haa had the third highest reef fish assemblage health.

Table 15. Fish assemblage health at Laamafaru Haa within Reethi Haa and Hudhufaru ESA

Parameter	Result
Commercially Important Fish Family Abundance	4.81/100m ²
Ecologically Important Fish Family Abundance	16.4/100m ²
Commercially Important Fish Family Biomass	0.127kg/100m ²
Ecologically Important Fish Family Biomass	0.175kg/100m ²
Family Richness	9
Simpson's Diversity Index	0.779

Hudhufaru had the third highest abundance of commercially important fish families (3.81/100m²) and the highest abundance of ecologically important fish families (26.3/100m²). Despite having the second lowest biomass of commercially important fish families (0.076kg/100m²), it recorded the second highest biomass of ecologically important fish families (0.641kg/100m²). The site also had the lowest Simpson's Diversity Index (0.812) but tied for the second highest family richness (9). When considering all parameters, Hudhufaru ranked second in overall reef fish assemblage health.

Table 16. Fish assemblage health at Hudhufaru within Reethi Haa and Hudhufaru ESA

Parameter	Result
Commercially Important Fish Family Abundance	3.81/100m ²
Ecologically Important Fish Family Abundance	26.3/100m ²
Commercially Important Fish Family Biomass	0.076kg/100m ²
Ecologically Important Fish Family Biomass	0.641kg/100m ²
Family Richness	9
Simpson's Diversity Index	0.812

4.5.4 Megafauna

At Reethi Haa and Hudhufaru, hawksbill turtles were the most sighted species, with a rate of 1.8 per hour (1.7, 2.0), with other species sighted less than once per hour.

4.5.5 Water Quality

At Laamafahu Haa and Hudhufaru, ammonium and phosphate levels were below the detection limit. Both sites had consistent and relatively higher NO_x levels (see Tables 7 and 8).

5. Key Outcomes

The data from the surveys regarding ecological condition of the five Environmentally Significant Areas (ESA) in Laamu Atoll has provided important baseline information about the marine and terrestrial habitats of these areas from which appropriate management interventions can be formulated to protect and preserve these areas and the associated biodiversity into the future.

The coral reef benthic cover composition across the surveyed areas revealed that hard coral is the dominant biotic cover type, with a mean coverage of 19.44%, closely followed by algae at 17.06%. The ESA sites with the highest hard coral cover were Isdhoo Muli (22.5 - 24%) and Mundoo Channel (21.6 - 24.7%). Fonadhoo Outside had a hard coral cover of 12.3 - 17.2% while the Reethi Haa and Hudhufaru survey sites, Laamafaru Haa had 11.5 - 16.5% and Hudhufaru 16.8 - 22.2% hard coral cover. The 2024 mass coral bleaching event had affected an average of 11.54% of the coral cover, however, there was considerable variability in bleaching across different ESA sites, potentially reflecting localized differences in resilience or exposure to stressors. Our results were consistent with previous research from across Maldives which found that corals at greater depths were less susceptible to bleaching and hence showed lower mortality after bleaching events (Muir et al., 2017; Cowburn et al., 2019; Montefalcone, M. et al., 2020). Deeper reef areas may therefore provide a thermal refuge for corals and aid the replenishment of shallower areas after severe bleaching (Muir et al., 2017).

There were significant variations in abundance and biomass of both commercially and ecologically important fish families, with Isdhoo Muli demonstrating the highest overall reef fish assemblage health among the surveyed ESAs. In contrast, Fonadhoo Outside consistently showed the lowest values across multiple metrics, indicating potential ecological concerns in this area.

Over 25 megafauna species were recorded at the ESA sites between 2017 and 2023. Most of these species are classified as Vulnerable, Endangered, or Critically Endangered on the IUCN Red List and are all experiencing declining population trends. The species composition varied between sites, with some locations like Mundoo Channel exhibiting exceptionally high abundances, with up to 15 individuals observed per hour. During the coral reef surveys, a reef manta ray cleaning station was observed with multiple manta rays using the area within the Fonadhoo Diving Point ESA, signifying the ecological importance and potential for eco-tourism activities.

Seagrass and vegetation surveys were conducted at the Mathigulhi Sarahadhu ESA which showed a diverse vegetation at the coastal fringe. Of particular interest is the observations of Yellow mangrove trees and saplings at both Kudafushi and Maafushi islands and the high number of juvenile black-tip reef sharks and rays at the central lagoon. These observations indicate that this area may be functioning as a nursery habitat for sharks and may be an important aggregation site for rays.

5.1 Key findings and recommendations.

Protecting marine ecosystems from climate change is challenging as protected or conserved areas may not mitigate global threats such as ocean warming and acidification (Graham et al., 2020). However, increasing the robustness of biodiversity, such as reef fish assemblages on coral reefs, by enhancing their biodiversity through protective measures can improve their resilience to these global changes.

A debate when informing Marine Protected Area (MPA) designation is whether to protect pristine habitats or restore degraded sites (Roberts and Hawkins, 2000). If the latter is done, the next debate is where is the point of no return. Establishing MPAs in areas with perfect conditions helps preserve existing biodiversity and ecosystem functions (Grorud-Colvert et al., 2021). Protecting these sites can serve as benchmarks for healthy ecosystems and ensure the survival of species and habitats in their optimal state (Roberts and Hawkins, 2000). These areas can also act as sources for the recovery of nearby degraded areas through spillover effects (Kough et al., 2019).

Focusing conservation efforts on a site already struggling can aid in the recovery of the degraded ecosystem and prevent further biodiversity loss (Salgueiro et al., 2020). For early or pilot MPAs, it is suggested to not choose degraded sites, as although they may be easier to implement, they are likely to take longer to show the benefits and their success is uncertain (Roberts and Hawkins, 2000; Grorud-Colvert et al., 2021). However, for areas that already have multiple MPAs such as Laamu Atoll, including more degraded sites is encouraged, as they can make a powerful case for the benefits that protection can bring (Roberts and Hawkins, 2000; Gann et al., 2019; Grorud-Colvert et al., 2021). This is if there are still source populations present and the habitats have not been degraded beyond recovery (Gann et al., 2019; Grorud-Colvert et al., 2021). Identifying the point of no return, where protection efforts may no longer be viable or effective, is crucial, and if a site has passed this threshold, resources may be better allocated (Roberts and Hawkins, 2000; Gann et al., 2019).

Following this advice and reviewing scientific literature, a set of criteria for MPA suitability for the ESA sites (Roberts and Hawkins, 2000; Grorud-Colvert et al., 2021; Giannonne, 2024) can be split into ecological and practical. The ecological criteria focus on whether the potential MPA has ecological significance, supports declining species and/or habitats and has high natural biodiversity. The practical criteria focus on if there was potential for recovery, management success, economic value, or anthropogenic damage.

Within the ESA sites, Isdhoo Muli had the highest hard coral cover and the healthiest reef fish assemblage. This provides evidence that there is ecological significance and a high natural biodiversity and therefore potential for management success and economic value. Therefore, Isdhoo Muli is recommended for MPA designation to help conserve the existing high biodiversity.

In contrast, Fonadhoo Diving Point and Reethi Haa and Hudhufaru were among the sites that had lower hard coral cover and reef fish assemblage health. However, as the sites had a high Simpson's Diversity Index, there is potential ecological significance and opportunity for recovery and management success. It can be beneficial to protect a degraded site if that site is not beyond repair. Temporal data would further aid the MPA designation of these

sites and future monitoring would be able to indicate whether the management efforts are effective. Further, protecting the manta ray cleaning station at Fonadhoo Diving Point would benefit biodiversity and eco-tourism development in the atoll.

Mundoo Corner also exhibited high hard coral cover and notable fish biodiversity levels. Though these were not as high as Isdhoo Muli, there is potential for conservation and restoration efforts. Mundoo Corner is particularly important for IUCN Red Listed megafauna species such as grey reef sharks, whitetip reef sharks, spotted eagle rays and other megafauna, so should be prioritized for biodiversity conservation.

Conservation of megafauna species is critical due to their unique life history characteristics. Many are long-lived, slow-growing, and have low reproductive output, making them particularly susceptible to population decline (Calder, 1984; Peters, 1983). The global decline of megafauna is a pressing concern because of the vital ecosystem services that such species provide to humans and the environment. For example, sharks play a crucial role in regulating prey populations by exerting top-down control (Baum & Worm, 2009), while green sea turtles maintain seagrass beds through their grazing activities, which is essential for the health of these ecosystems (Smulders et al., 2023). Beyond their ecological importance, megafauna are charismatic species that significantly benefit the tourism industry, which is a foundation of the Maldivian economy (Zimmerhackel et al., 2018). Although megafauna species are protected under Maldivian law, enhanced conservation measures are necessary for the preservation of their populations (Gilmour et al., 2022). Reducing the human impact in the ESA locations will help safeguard the future of the megafauna species that play a vital role in maintaining the health and resilience of the Maldivian marine ecosystem and economy.

The below management recommendations aim to meet the following Maldivian NBSAP 2016-2025 targets (MEE, 2015):

1. Strengthen governance, policies, and strategies for biodiversity.
2. Enhance communication and outreach through awareness programs and capacity building.
3. Work together globally for biodiversity conservation.
4. Address threats to conserve biodiversity.

5.1.1 Recommendation 1: Zoning

Within an MPA, zoning can be a beneficial spatial planning tool (Day et al., 2019). This approach involves creating zones with varying levels of protection to regulate activities and safeguard ecologically important or recovering areas. By assigning different uses, zoning can help balance conservation efforts with anthropogenic activities.

5.1.2 Recommendation 2: Responsible Tourism Policy

Despite Laamu Atoll's currently underdeveloped tourism industry, tourism can have adverse effects on reef fish biodiversity, therefore proactively implementing a responsible tourism policy throughout the MPAs would be highly advantageous (Delevaux et al., 2019). As tourism begins to develop within the atoll, such a policy would provide guidelines to ensure that tourism benefits both the economy and the environment.

5.1.3 Recommendation 3: Community Involvement

Involving local communities in MPA management is crucial. When communities feel engaged in MPA management, they are more likely to support conservation efforts (Roberts and Hawkins, 2000; Katikiro et al., 2021). Exclusively government-led enforcement can alienate locals, in turn fostering resentment (Baker-Médard et al., 2021; Katikiro et al., 2021). Moreover, government resources often limit the necessary patrol levels for effective protection, highlighting the need for community involvement in monitoring and enforcement to ensure sustainable conservation outcomes (Roberts and Hawkins, 2000; Baker-Médard et al., 2021).

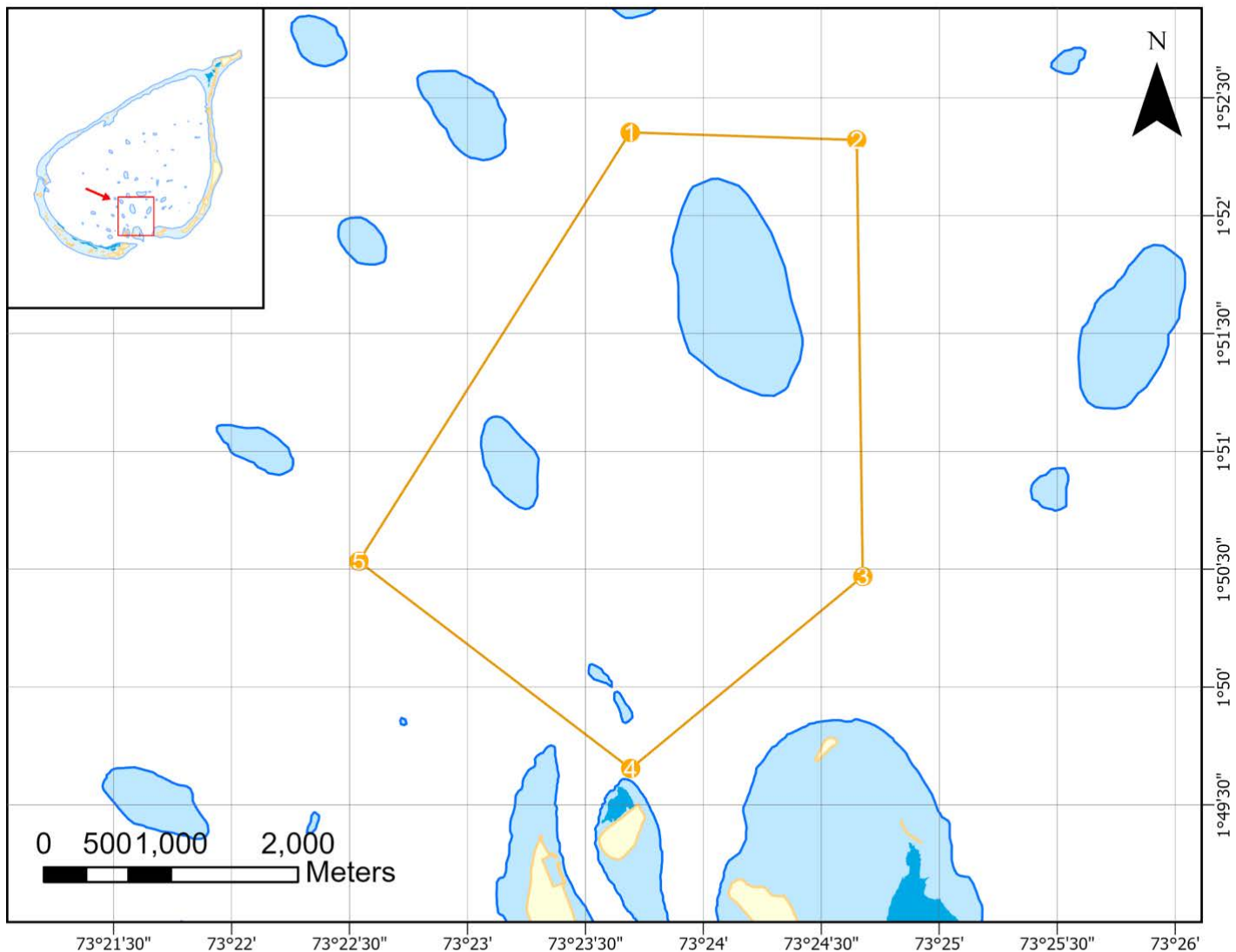
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Annex 1: Map coordinates of ESA

Reethi Haa and Hudhafaru



Legend

- Proposed Environmentally Sensitive Area
- Island
- Lagoon
- Reef

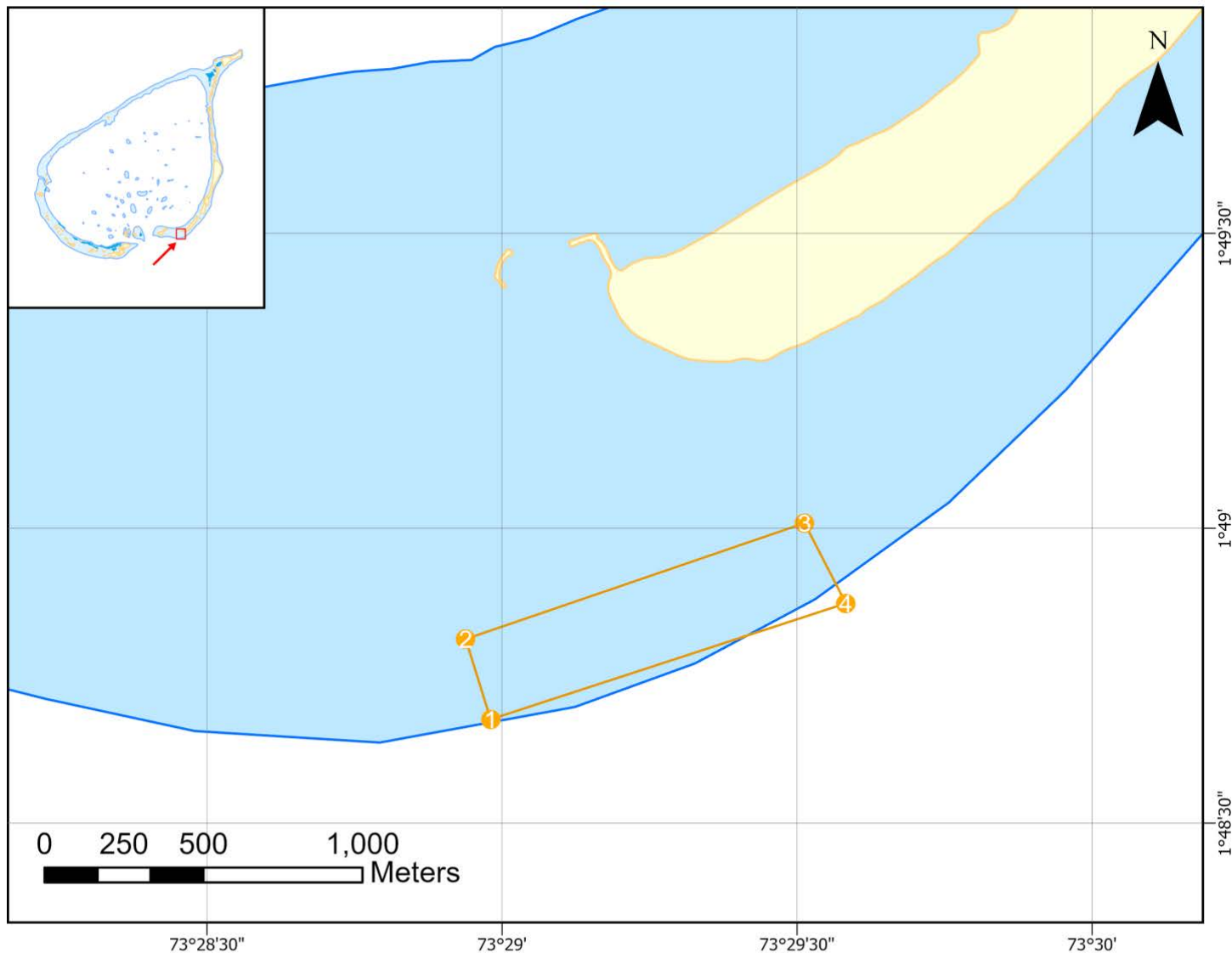
Prepared date: 21 August 2024
Coordinate System: WGS 1984 UTM Zone 43N
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Datum: WGS 84

Prepared by: Jordan Gacutan for Ministry of Climate Change, Environment and Energy

Basemaps from Maldives Land and Survey Authority.

* Maps are indicative and should not be used for navigational purposes.

Fonadhoo Diving Point



Legend

- Proposed Environmentally Sensitive Area
- Island
- Lagoon
- Reef

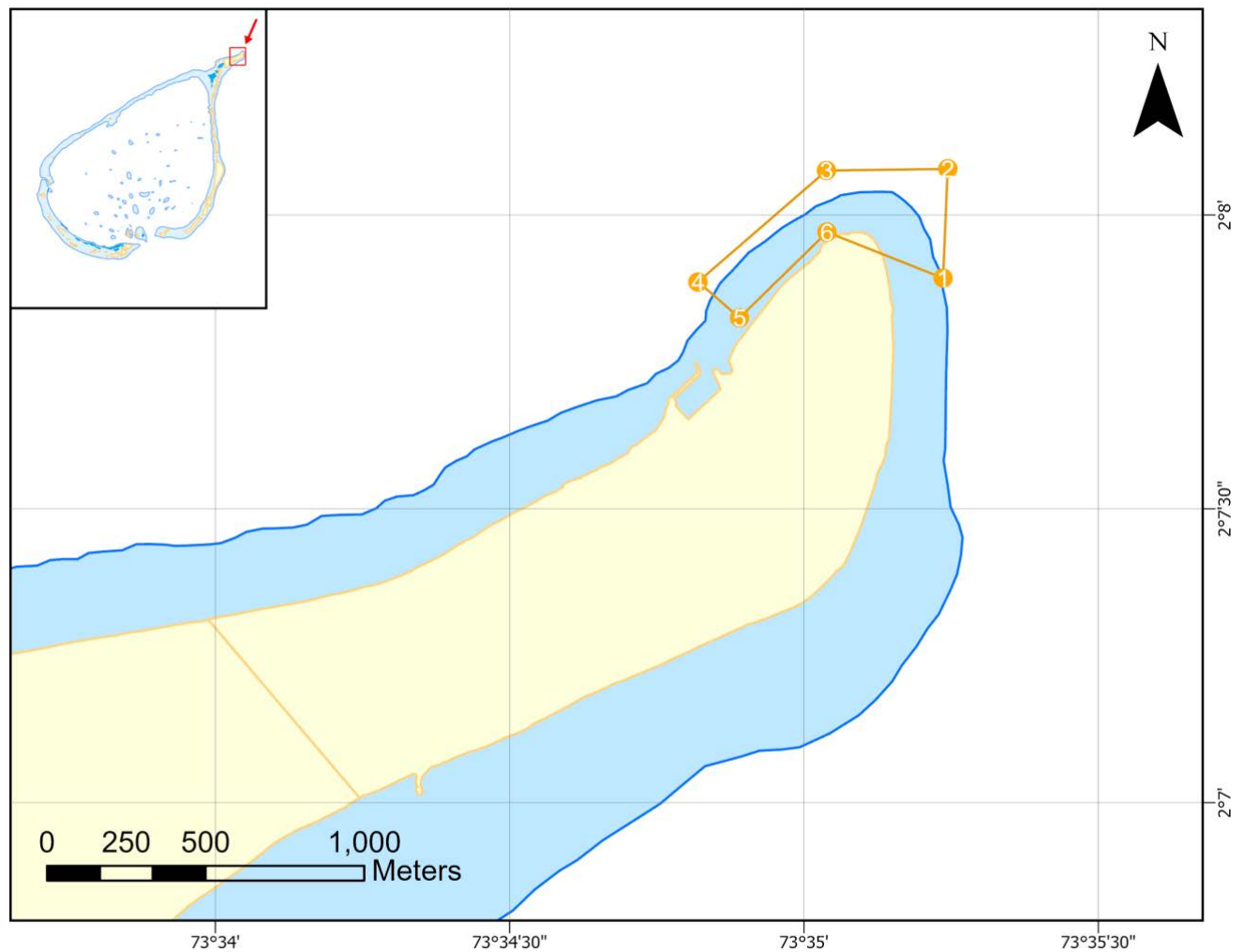
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Isdhoo Muli



Legend

- Proposed Environmentally Sensitive Area
- Island
- Lagoon
- Reef

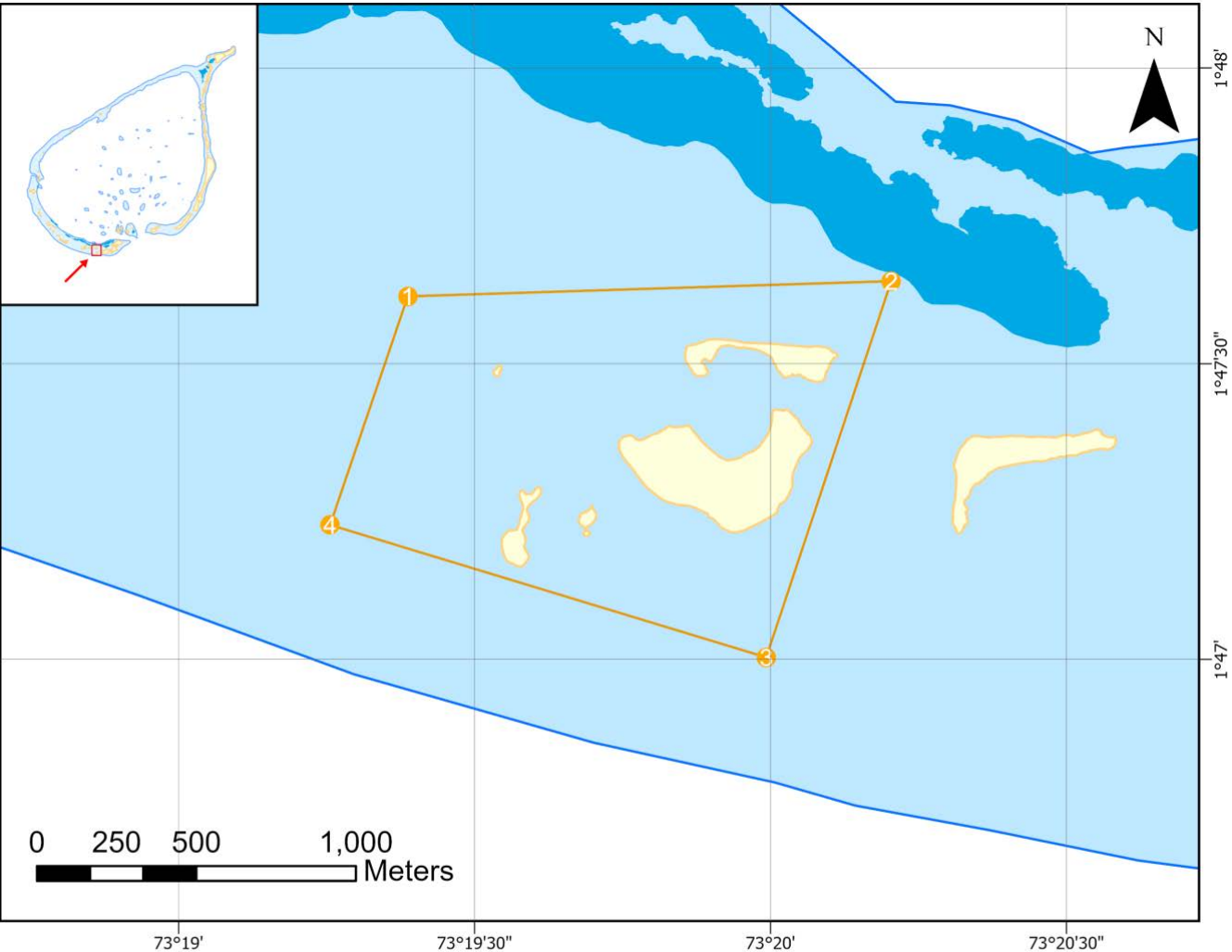
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Basemaps from Maldives Land and Survey Authority.

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Mathigulhi Sarahadhu



Legend

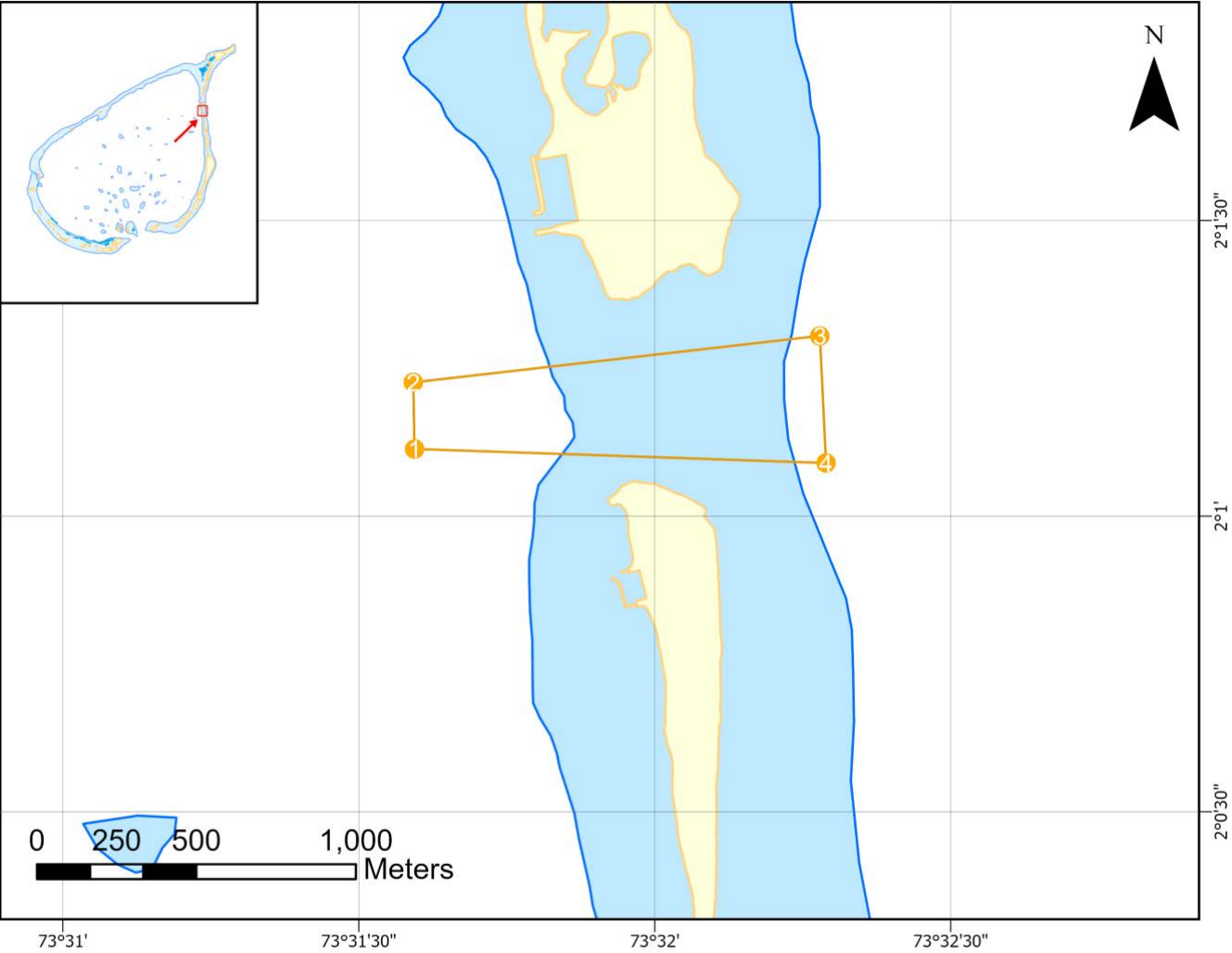
- Proposed Environmentally Sensitive Area
- Island
- Lagoon
- Reef

Prepared date: 21 August 2024
Coordinate System: WGS 1984 UTM Zone 43N
Projection: Transverse Mercator
Datum: WGS 84

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Basemaps from Maldives Land and Survey Authority.
* Maps are indicative and should not be used for navigational purposes.

Mundoo Channel



Legend

- Proposed Environmentally Sensitive Area
- Island
- Lagoon
- Reef

Prepared date: 21 August 2024
Coordinate System: WGS 1984 UTM Zone 43N
Projection: Transverse Mercator
Datum: WGS 84

Prepared by: Jordan Gacutan for Ministry of Climate Change, Environment and Energy

Basemaps from Maldives Land and Survey Authority.
* Maps are indicative and should not be used for navigational purposes.

Name	Vertices	Easting	Northing
Fonadhoo Diving Point	1	331261.061	200270.498
	2	331182.901	200521.426
	3	332248.257	200882.931
	4	332377.75	200631.973
Isdhoo Muli	1	342890.9	235672.56
	2	342905.611	236015.145
	3	342524.208	236010.311
	4	342119.328	235661.797
	5	342249.446	235548.777
	6	342525.625	235817.149
Mathigulhi Sarahadhu	1	313469.326	198328.803
	2	314983.993	198374.875
	3	314591.391	197202.445
	4	313225.348	197616.56
Mundoo Channel	1	336126.636	223186.773
	2	336123.321	223394.223
	3	337397.03	223538.135
	4	337415.765	223141.693
Reethi Haa and Hudhufaru	1	321454.762	207055.546
	2	323237.423	206994.791
	3	323281.035	203582.875
	4	319319.124	203703.711
	5	321455.218	202080.401

Annex 2. Coral reef survey sites metadata

Survey Date	Site Code	Site Name	Management	Depth	Latitude	Longitude	Transect Direction
1-May-24	LH	Laamafaru Haa	Reethi Haa and Hudhafaru ESA	5-10m	1.834	73.3930333	South to North
2-May-24	H	Hudhufaru	Reethi Haa and Hudhafaru ESA	5-10m	1.855291	73.402249	West to East
2-May-24	IM	Isdhoo Muli	Isdhoo Muli ESA	10-15m	2.13188333	73.5874833	South to North
4-May-24	FO	Fonadhoo Outside	Fonadhoo Diving Point ESA	10-15m	1.81175	73.4839833	West to East
4-May-24	MC	Mundoo Corner	Mundoo Channel ESA	10-15m	2.01801667	73.5376167	South to North


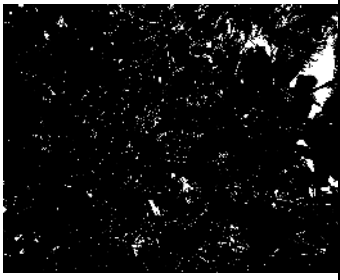

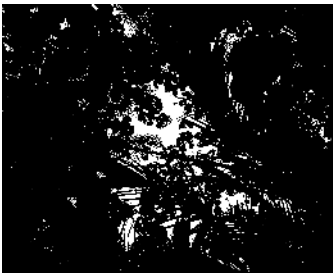





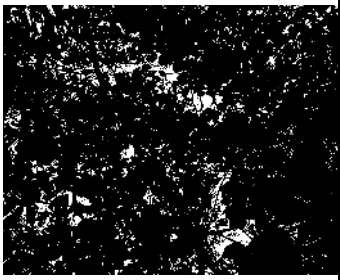



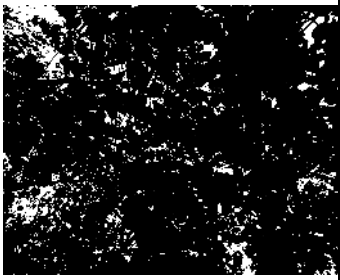

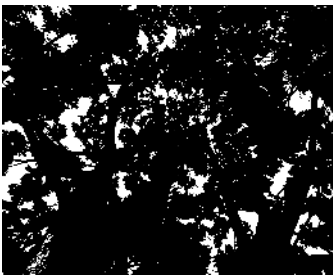

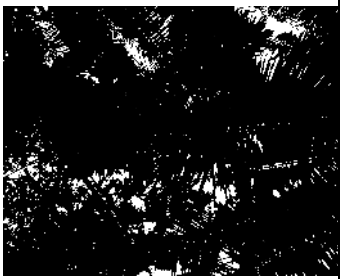

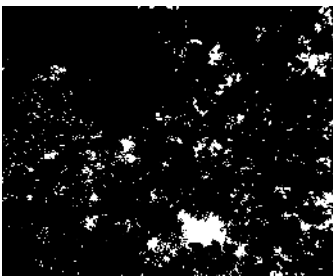
Annex 3. Seagrass survey sites metadata

Survey Date	Site Code	Site Name	Transect No.	Latitude	Longitude	Depth
17-Apr-24	KO	Kudafushi Outside	T1	1.787861	73.330222	> 1m
			T2	1.787639	73.330778	> 1m
			T3	1.787611	73.331111	> 1m
17-Apr-24	KL	Kudafushi Lagoon	T1	1.791056	73.333611	> 1m
			T2	1.790639	73.33333	> 1m
			T3	1.790111	73.33325	> 1m
7-Jun-24	MO	Maafushi Outside	T1	1.791919	73.335183	> 1m
			T2	1.792242	73.334406	> 1m
			T3	1.792269	73.333944	> 1m
31-Aug-24	MS	Maabaidhoo South	Q1	2.0208383	73.5324477	> 1m
			Q2	2.0208266	73.5324467	> 1m
			Q3	2.0208547	73.5325389	> 1m
			Q4	2.0208842	73.5326834	> 1m
			Q5	2.0207103	73.532859	> 1m
			Q6	2.0206587	73.5332403	> 1m
			Q7	2.0211033	73.5329288	> 1m
			Q8	2.0210598	73.532628	> 1m
			Q9	2.0210651	73.5323538	> 1m
			Q10	2.0211663	73.5322006	> 1m
			Q11	2.021178	73.5323756	> 1m
			Q12	2.0212574	73.5325238	> 1m
			Q13	2.0212873	73.5326307	> 1m
			Q14	2.021244	73.5327759	> 1m
			Q15	2.0211864	73.5330009	> 1m
31-Aug-24	MN	Mundoo North	Q1	2.018364	73.532717	> 1m
			Q2	2.01831	73.53268	> 1m
			Q3	2.01824	73.53274	> 1m
			Q4	2.01833	73.53278	> 1m
			Q5	2.01835	73.53283	> 1m
			Q6	2.0183	73.53285	> 1m
			Q7	2.01818	73.53284	> 1m
			Q8	2.01822	73.53288	> 1m
			Q9	2.01821	73.53301	> 1m
			Q10	2.01834	73.53303	> 1m
			Q11	2.01846	73.53292	> 1m


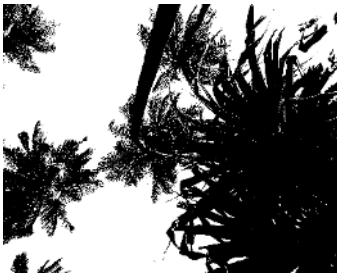















Annex 4. Small island vegetation survey and canopy cover

#	Island	Code	Survey point	LAT	LON	Habitat
1	Kudafushi	K1	Kudafushi #1	1.790201	73.333559	Coastal fringe
2	Kudafushi	K2	Kudafushi #2	1.789776	73.330704	Coastal fringe
3	Kudafushi	K3	Kudafushi #3	1.789543	73.329402	Coastal fringe
4	Kudafushi	K4	Kudafushi #4	1.788808	73.329485	Coastal fringe
5	Kudafushi	K5	Kudafushi #5	1.787898	73.330405	Coastal fringe
6	Kudafushi	K6	Kudafushi #6	1.787089	73.332213	Coastal fringe
7	Kudafushi	K7	Kudafushi #7	1.788464	73.333855	Coastal fringe
8	Kudafushi	K8	Kudafushi #8	1.789305556	73.33319444	Island interior
9	Kudafushi	K9	Kudafushi #9	1.788805556	73.33263889	Island interior
10	Kudafushi	K10	Kudafushi #10	1.787527778	73.33219444	Island interior
11	Maafushi	M1	Maafushi #1	1.791404	73.334324	Coastal fringe
12	Maafushi	M2	Maafushi #2	1.79167	73.334773	Coastal fringe
13	Maafushi	M3	Maafushi #3	1.792094	73.334636	Coastal fringe
14	Maafushi	M4	Maafushi #4	1.791694444	73.33475	Coastal fringe
15	Maafushi	M5	Maafushi #5	1.792027778	73.33477778	Coastal fringe
16	Maafushi	M6	Maafushi #6	1.791777778	73.33441667	Island interior
17	Maafushi	M7	Maafushi #7	1.792166	73.333002	Coastal fringe
18	Maafushi	M8	Maafushi #8	1.791916667	73.33322222	Coastal fringe
19	Maafushi	M9	Maafushi #9	1.792138889	73.33255556	Coastal fringe
20	Maafushi	M10	Maafushi #10	1.791888889	73.33138889	Coastal fringe
21	Maafushi	M11	Maafushi #11	1.792138889	73.33122222	Coastal fringe
22	Maafushi	M12	Maafushi #12	1.791527778	73.33358333	Coastal fringe

Kudafushi Canopy Cover

			
K1 – 94%		K2 – 93%	
			
K3 – 23%		K4 – 88%	
			
K5 – 92%		K6 – 85%	
			
K7 – 91%		K8 – 89%	
			
K9 – 93%		K10 – 93%	

Maafushi Canopy Cover

			
M4 – 55%		M5 – 67%	
			
M6 – 79%		M7 – 21%	
			
M8 – 90%		M9 – 55%	
			
M10 – 89%		M11 – 43%	
			
M12 – 41%			

Annex 5 – Map coordinates for water quality sampling locations

Site	Latitude	Longitude
Isdhoo Muli coral reef	2.13188333	73.5874833
Mundoo Channel coral reef	2.01801667	73.5376167
Hudhufaru coral reef	1.855291	73.402249
Fonadhoo Diving Point coral reef	1.81175	73.4839833
Maafushi seagrass T1 start	1.791919	73.335183
Maafushi seagrass T1 end	1.792247	73.335528
Maafushi seagrass T2 start	1.792242	73.334406
Maafushi seagrass T2 end	1.792697	73.334453
Maafushi seagrass T3 start	1.792269	73.333944
Maafushi seagrass T3 end	1.792706	73.334033
Kudafushi seagrass T1 start	1.787861	73.330222
Kudafushi seagrass T2 start	1.787639	73.330778
Kudafushi seagrass T1 end	1.787528	73.329944
Kudafushi groundwater Well 1	1.789750	73.333861
Kudafushi groundwater Well 2	1.789250	73.333500
Kudafushi groundwater Well 3	1.787972	73.332528

Annex 6 Megafauna species sighted at ESA sites, their IUCN Red List of Threatened Species status, and IUCN population trend.

Common Name	Scientific Name	IUCN Status	Population Trend
Black Blotched Fantail Ray	<i>Taeniura meyeni</i>	Vulnerable	Decreasing
Blacktip Reef Shark	<i>Carcharhinus melanopterus</i>	Vulnerable	
Bowmouth Guitarfish	<i>Rhina ancylostoma</i>	Critically Endangered	
Cow Tail Stingray	<i>Pastinachus sephen</i>	Near Threatened	
Giant Guitarfish	<i>Rhynchobatus djiddensis</i>	Critically Endangered	
Green Turtle	<i>Chelonia mydas</i>	Endangered	
Grey Reef Shark	<i>Carcharhinus amblyrhynchos</i>	Endangered	
Gulf Torpedo	<i>Torpedo sinuspersici</i>	Data Deficient	
Hawksbill Turtle	<i>Eretmochelys imbricata</i>	Critically Endangered	
Jenkins Ray	<i>Himantura jenkinsii</i>	Endangered	
Mangrove Ray	<i>Himantura granulata</i>	Endangered	
Marbled Electric Ray	<i>Torpedo marmorata</i>	Vulnerable	
Mobula Ray (Excluding Manta Rays)	<i>Mobula species</i>	Endangered	
Oceanic Manta Ray	<i>Mobula birostris</i>	Endangered	
Ornate Eagle Ray	<i>Aetomylaeus vespertilio</i>	Critically Endangered	
Pink Whipray	<i>Himantura fai</i>	Vulnerable	
Porcupine Ray	<i>Urogymnus asperrimus</i>	Endangered	
Reef Manta Ray	<i>Mobula alfredi</i>	Vulnerable	
Scalloped Hammerhead Shark	<i>Sphyrna lewini</i>	Critically Endangered	
Silvertip Shark	<i>Carcharhinus albimarginatus</i>	Vulnerable	
Spotted Eagle Ray	<i>Aetobatus narinari</i>	Endangered	
Tawny Nurse Shark	<i>Nebrius ferrugineus</i>	Vulnerable	
Whale Shark	<i>Rhincodon typus</i>	Endangered	
Whitetip Reef Shark	<i>Triaenodon obesus</i>	Vulnerable	
Zebra Shark	<i>Stegostoma tigrinum</i>	Endangered	

Annex 7 Additional information on the megafauna analysis

Megafauna were sighted on 58% of dives/snorkels and were not sighted on 42% of dives/snorkels (Figure Annex 3.1a). The optimum model to determine the mean number of megafauna sightings per hour had a Negative Binomial family. Hawksbill Turtle sightings were the most frequent, with an average of 1.8 (95% CI: 1.6, 2.0) sightings per hour. Whitetip Reef Sharks were also commonly sighted, with mean values of 1 (95% CI: 0.9, 1.1) per hour. The Spotted Eagle Ray, Whitetip Reef Shark, Green Turtle, had lower mean sightings per hour of ~ 0.5 per hour. Mobula Rays, Pink Whiprays, and Cowtail Stingrays were the least frequently observed with an average of 0.1 – 0.3 sightings per hour (Figure Annex 3.1b).

The optimal model to determine the mean number of megafauna sightings per hour of diving or snorkeling effort at each site had a Negative Binomial distribution. Addition of the random effect of the number of dives and snorkels at each site did not result in model improvement. There was significant interaction between the variables site and species, indicating that the rate of sightings of each species was dependent on the site ($F(21, 22848) = 80.2, p < 0.01$).

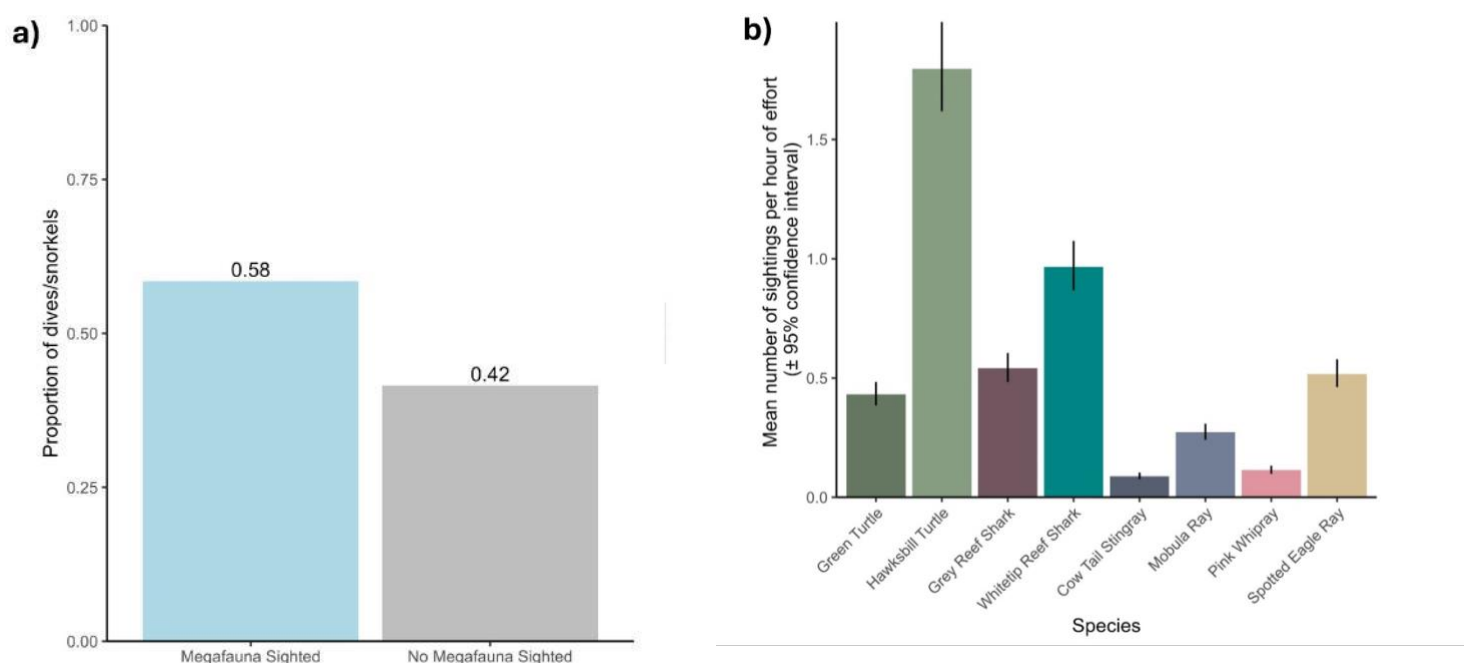


Figure Annex 3.1: a) Proportion of dives and snorkels where megafauna was sighted, vs not. B) Mean number of sightings per hour of diving or snorkelling effort (\pm 95% confidence intervals derived from a Negative Binomial distribution) for the top 5 most sighted megafauna species at each site.

Socio-Economic Baseline



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Abbreviations and Acronyms

ENDhERI	Enhancing National Development through Environmentally Resilient Islands
EPA	Environmental Protection Agency
ESA	Environmentally Significant Areas
GEF	Global Environment Facility
MBS	Maldives Bureau of Statistics
MCCEE	Ministry of Climate Change, Environment and Energy
MRR	Maldives Resilient Reefs
NC	Natural Capital
NGO	Non-Governmental Organisation
PMU	Project Management Unit
UNEP	United Nations Environment Programme
WDC	Women's Development Committee

Acknowledgements

Maldives Resilient Reefs would like to acknowledge and thank the below individuals and organisations who supported this report.

Data collection: Local surveyors from Laamu Atoll who conducted the individual semi-structured interviews in their respective islands: Mohamed Jazwan (L. Fonadhoo), Aishath Sumeetha (L. Isdhoo), Hussain Hoodh Abdulla Waheed (L. Maamendhoo), Ali Shafeeu (L. Mundoo), Mariyam Suzana (L. Kalaidhoo), Ali Hafeez (L. Dhanbidhoo), Ali Faisal (L. Maabaidhoo) and Ahmed Rameez (L. Kunahandhoo) along with Maldives Resilient Reefs team members Mohamed Tholaal (L. Hithadhoo) and Aishath Mufliha Ziyadh (L. Gan).

Questionnaire development, data analysis and report writing: Jake Edmiston (Projects Researcher, Blue Marine Foundation), Kaija Barisa (Senior Economist, Blue Marine Foundation) and Dr Jordan Gacutan (Senior Research Associate, University of South Wales) along with Aminath Shaha Hashim and Aishath Mufliha Ziyadh of Maldives Resilient Reefs.

1. Introduction

1.1 Background

The Government of the Republic of Maldives, in collaboration with the Ministry of Climate Change, Environment and Energy (MCCEE), is implementing the Enhancing National Development through Environmentally Resilient Islands (ENDhERI) project. This initiative, funded by the Global Environment Facility (GEF) and supported by the United Nations Environment Programme (UNEP), aims to facilitate the adoption of new environmental policies and the transition toward Green Growth atoll development. This development strategy aims to sustain marine Natural Capital (NC) and enhance the resilience and recovery of reef ecosystems. The project will draw from integrated coastal zone management within a Managed Marine Area/Biosphere Reserve framework, along with innovative sustainability practices in sectors such as agriculture, fisheries, tourism, and construction.

The goal is to transform the ecological impact in Laamu Atoll, leading to national-level sector transformation, spatial planning, and improved governance based on NC accounting. The marine environment and coastal communities are intrinsically linked, with the ocean providing a myriad of provisioning, regulating, and cultural ecosystem system services to coastal communities. When characterizing the significance of marine areas, an understanding of both ecological and socio-economic contexts, and the dependencies between them can support evidence-based decision making for coastal and marine sites.

The “Consultancy Service to Develop Baseline Assessment for Environmentally Significant Areas at Laamu” was contracted to Maldives Resilient Reefs (MRR), a Maldivian Non-Governmental Organisation (NGO) dedicated to restoring coral reefs in the Maldives as climate resilient ecosystems for the benefit of people, nature and the economies that depend on them.⁷ The main objective of the consultancy is to conduct baseline assessments of five potential Environmentally Significant Areas (ESA) of Laamu Atoll, in line with “Guidelines for coral reef and small island vegetation surveys in the Maldives”⁸. A literature review, accompanying this report, has been conducted and provides comprehensive existing scientific knowledge and data collected for Laamu Atoll, in addition to available data for the five study areas. The assignment requires the procurement of field data (via field surveys and community consultation), in addition to remote sensing, to assess and analyze the ecological characteristics of the five potential ESA.

1.2 Scope of report

This report provides a socio-economic baseline assessment of the five ESA identified in Laamu Atoll. Understanding the socio-economic context of each ESA will be vital in ensuring coherent marine resource management. This report focuses on four key aspects:

⁷ MRR’s strategic intervention areas are: 1) Increasing effective marine protection to build climate resilience; 2) Improving the sustainability of reef-based fisheries; 3) Improving environmentally responsible tourism; and 4) Strengthening local capacities for marine resource management in the Maldives. MRR is officially affiliated with the UK charity, Blue Marine Foundation. Blue Marine has a vision of a healthy ocean forever, for everyone.

⁸ Dryden and Basheer, 2021: <https://www.environment.gov.mv/v2/en/download/14746>.

1. The socio-economic settings of selected sites, including current resource use;
2. Existing nature and human indicators of stress and threats to the ESA; and
3. Extent of ecosystem service provisioning to communities.

2. Materials and methods

The socio-economic setting is derived from individual semi-structured surveys conducted between 13 July and 5 August 2024. It further contains a preliminary assessment of shoreline and land use change between 2013 and 2023.

2.1 Study sites

Laamu Atoll is situated in the southern central region of the Maldives. The atoll consists of 99 islands (77 vegetated and 22 unvegetated) of which 11 islands are inhabited with a recorded population of 18,281 individuals. The atoll has an estimated surface area of 884.63 km², with approximately 56 reefs (203.70 km²). Fisheries constitute the primary economic activity in Laamu Atoll, closely followed by agriculture.⁹

The inhabited islands of Laamu Atoll are administered by their own island council led by elected councillors. Each island also has an elected Women's Development Committee (WDC). The capital island of the atoll is Fonadhoo, which is the base for the Atoll Council. The Laamu Atoll Council (also Haddhunmathi Atoll Council) is comprised of an elected president and the presidents of all island councils. There are 13 public schools on the atoll, 12 of which provide up to secondary level education.

The five selected ESA for the purpose of the baseline assessment in Laamu Atoll are as follows (presented in Figure 1):

- 1. Fonadhoo Diving Point:** Located in the south-eastern side of Laamu Atoll, on the outer reef area. The site falls within the jurisdictional boundary of Laamu Fonadhoo, the capital island of Laamu Atoll. The outer reef area consists of only coral reef habitat which extends from approximately 10 m to over 30 m in depth.
- 2. Isdhoo Muli:** Located on the northeastern tip of Laamu Atoll, on the outer reef area. It lies within the jurisdictional boundary of Laamu Isdhoo.
- 3. Mathigulhi Sarahadhu:** Located on the southwestern side of Laamu Atoll, on the western lagoon of Kunahandhoo. There are two vegetated islands and several rock banks within this area. Kudafushi (LD1025, 12.27 hectares) is classified as an industrial agricultural island under the jurisdiction of the Ministry of Agriculture and Animal Welfare and is leased to a private party for long-term since 1 November 2018. Maafushi (LD0951, 2.91 hectares) is classified as an uninhabited island and has been leased under the "varuvaa" scheme to by Laamu Atoll Council. Two smaller, rubble-dominated islands, Bodumahigulhi (LD0599, 1.11 hectares) and Kudamahigulhi (LD0902, 0.25 hectares), are classified as uninhabited and fall under the jurisdiction of the Laamu Atoll Council. Additionally, a fifth, unnamed supra-tidal area, primarily composed of coral rubble and sand, is located to the northwest.
- 4. Mundoo Channel:** The channel is located between Mundoo and Maabaidhoo islands. It is a channel that connects the inner atoll with the open ocean.
- 5. Reethi Haa and Hudhafaru:** Located on the southern inner atoll area of Laamu Atoll, north of Maamendhoo and Olhuveli islands. The southern part of the site, consisting of Laamafaru Haa and Reethi Haa dive sites and northern reef of

⁹ Maldives Bureau of Statistics (MBS): <https://statisticsmaldives.gov.mv/laamu-atoll/>

Maamendhoo island is within the Maamendhoo island boundary. Three shallow faros (the largest being Hudhufaru, the next largest Mudiyafungiri and the smallest Reethi Haa and Laamafaru Haa) and a deep faro (Haleema Haa) is located within this area.

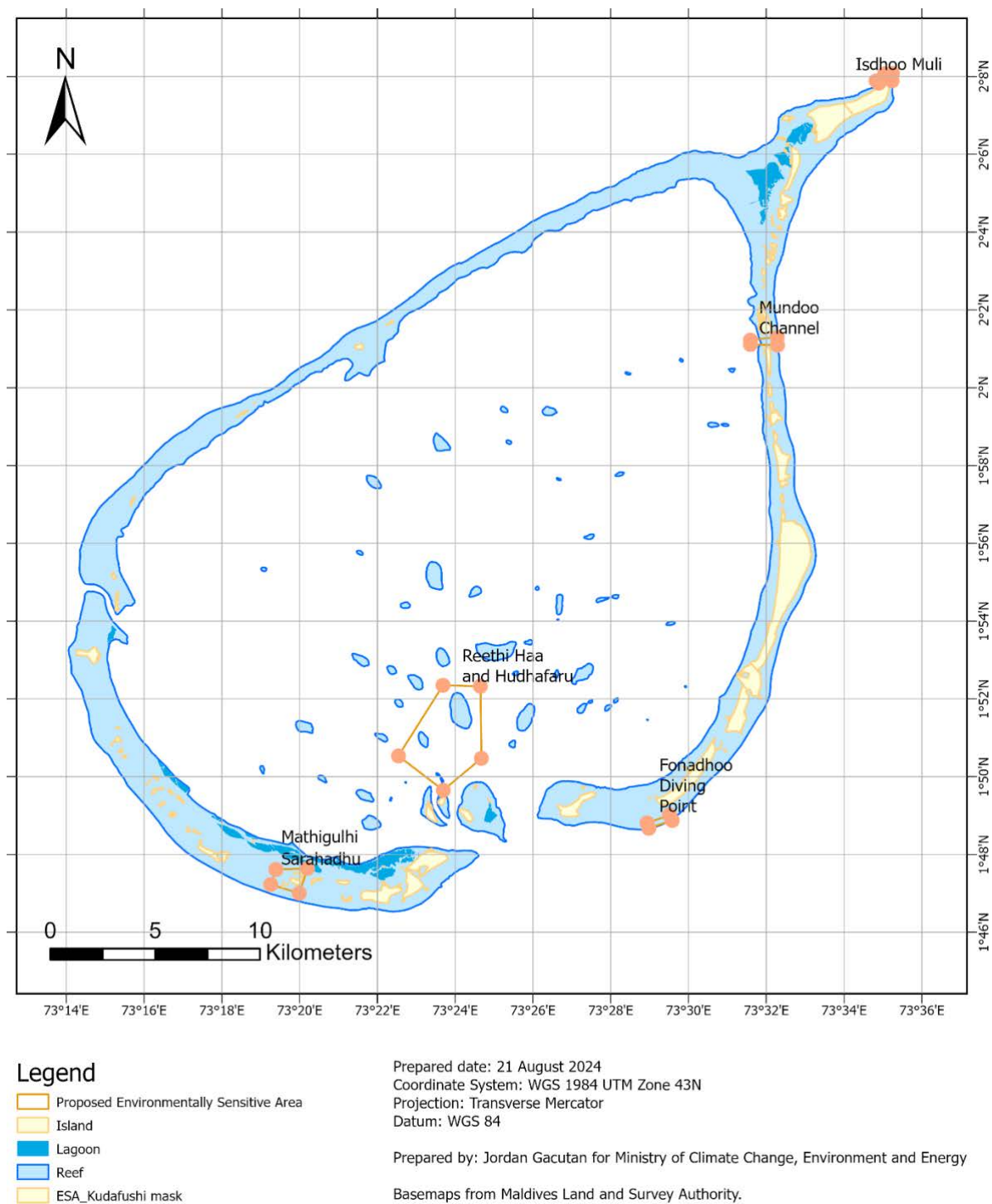


Figure 23. Five selected ESA for the baseline assessment consultancy. Individual site maps are provided in Annex 1.

2.2 Socio-economic surveys

2.2.1 Survey design

The socio-economic settings of the five ESA were identified using a survey (developed using Microsoft Forms). The semi-structured survey was designed to cover all assignment objectives (Section 1.2) and was built with branching questions, enabling respondents to outline further qualitative details about ESA, beyond single input / multiple choice questions. Most questions were non-mandatory, allowing respondents to skip if they were unsure or did not want to answer. The survey was divided into three sections concerning the use of each ESA:

1. General site information and recreational use,
2. Commercial and recreational fishing use, and
3. Tourism use.

2.2.2 Data collection

The surveys were conducted across ten inhabited islands around Laamu and were divided into primary and secondary islands. The primary islands were the inhabited islands in close proximity to the ESA boundaries, namely, Fonadhoo, Isdhoo, Mundoo, Maabaidhoo and Maamendhoo. The secondary islands were Gan, Kalaidhoo, Dhanbidhoo, Hithadhoo and Kunahandhoo. No surveys were conducted in Maavah, which is located further away from the ESA on the western side of the atoll. The survey team aimed to collect 20 island community responses from primary islands and 10 community responses from secondary islands (Table 1). Five stakeholder groups were also identified, as follows: 1) Island councils; 2) Women's Development Committees (WDCs); 3) Fishing communities (tuna, reef fish & invertebrates); 4) Civil society (NGOs); and 5) tourism operators. The surveys were conducted across 23 days between 13 July 2024 to 5 August 2024.

A local community member from each island was contracted by MRR as a surveyor for their local island. This enabled a "snowball" approach¹⁰, to increase participation and elicit genuine responses to the potential ESA, cultivate a sense of local ownership and stewardship over the ESA sites and survey responses within communities. The surveyors were provided training and supported to identify potential candidates for the survey per stakeholder group. The representation per stakeholder group differed relative to each island's specific context, although efforts were made to provide representation to each group.

Surveyors used their personal smart devices to complete the survey with each respondent using the Microsoft Form. Group communications were conducted via a group on the mobile application, "Viber", to provide support to surveyors from the MRR team. Surveyors were paid for each survey they completed, with a maximum number of surveys stipulated during the training day. Data were collected in both English and Dhivehi. All local island surveys were conducted in Dhivehi, with English speaking tourism and resort operators preferring to be interviewed in English.

¹⁰ Snowball sampling is a nonprobability sampling technique where existing study subjects recruit future subjects from among their acquaintances.

2.2.3 Data Processing and Analysis

All data were translated into English prior to data processing and analysis. Data were aggregated by site for socio-economic analysis, with respondent demographics calculated across the entire survey population. Qualitative survey questions were analysed through question coding, with answers aggregated into common themes.

3. Results and discussion

3.1 Respondent demographic analysis

Overall, 171 respondents were surveyed, from ten local islands and two resorts on Laamu Atoll (Figure 2).

The respondents could be disaggregated by the following demographics:

- 88% identified as male, with 12% as female.¹¹
- 96% were Maldivian, with 4% of responses from foreign nationals,¹²
- The majority were between '31 – 40 years' (35%) and '41 – 50 years' (27%), with only 12% of respondents for both '20 – 30 years' (12%) and 'above 61 years' (12%) categories.

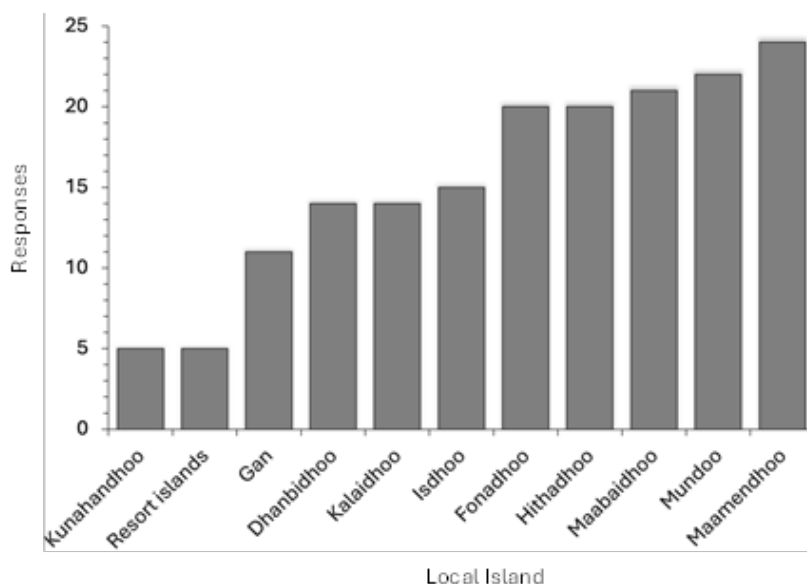


Figure 24. Number of respondents per local island.

¹¹ Surveyors ensured the inclusion of female voices within the survey. The large number of male responses is likely due to targeted resource use sectors (i.e. fishing) being male dominated.

¹² Other countries represented included Australia, Austria, France, India and South Africa (mostly tourism industry and based on resort islands) and Bangladesh (pole-and-line tuna fishery).

Over half of respondents were involved with fisheries (n=137), of which 21% fished tuna, 17% fished reef fish and 18% fished for invertebrates. A significant portion of respondents were also involved with island councils (10%) and WDCs (9%). Respondents were also involved in 'Other sectors', such as Maldives National Defence Force (MNDF), healthcare, and the private sector (Figure 3).

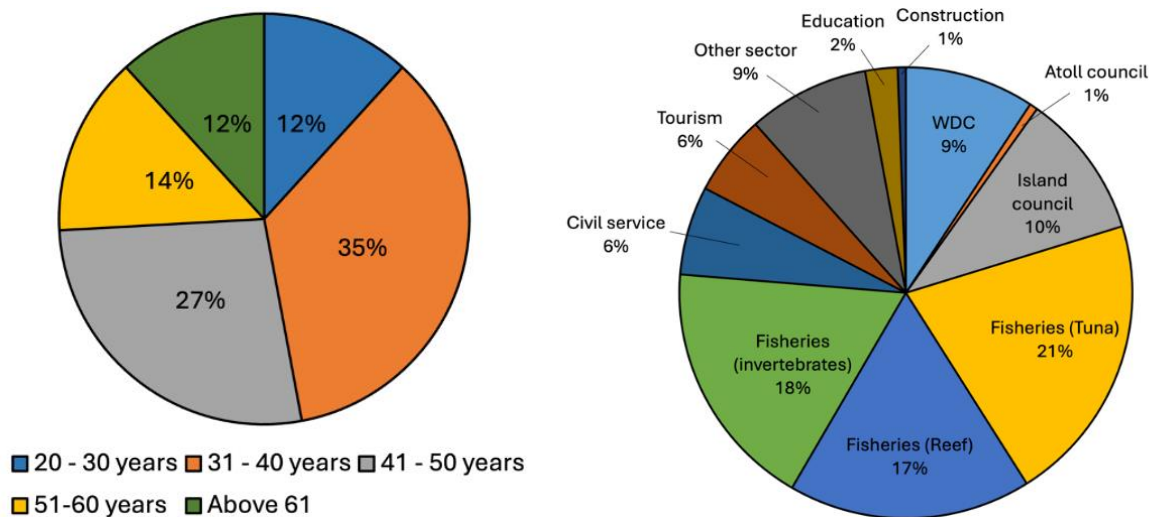


Figure 25. Age of respondents (left) and Occupations of respondents (right)

3.2 Fonadhoo Diving Point (FDP)

There were 23 respondents claiming knowledge of the site, of which:

- Most derived from the islands of Hithadhoo (n=7) and Maamendhoo (n=6), with other respondents from the islands of Maabaidhoo (n=2), Kalaidhoo (n=2), Fonadhoo (n=2), Six Senses Laamu (n=2), Gan (n=1) and Dhanbidhoo (n=1).
- 87% of respondents were men (n=20).
- Most respondents were within the '31-40 year' age category (n=11), followed by '41-50 years' (n=5) and '51-60 years' (n=3).
- Fishing was the most common profession of respondents (n=11) followed by tourism services (n=4).

Of respondents:

- Over half (n=14) had recently observed the site (< 1 year), while another 12 people had not interacted with the site for over 4 years. Thus, most observations were based on the site over multiple years.
- Three people had never been but had a positive opinion of the site as a dive spot, with high number of turtles and fishing derived from friends and local community.
- 65% of respondent claimed the site was "important" or "very important", while 30% provided a negative response ("not important")¹³.

Respondents generally indicated that the site was ecologically "good" (67%) and "very good" (6%). Most respondents (60 %) indicated that there were threats impacting the site, which included local island development (12%), sharks (12%) and warming ocean temperatures (12%).

In assessing responses based on perceptions over multiple years, less than half of respondents (44%) indicated a perceived ecosystem change (Figure 4). Of those identifying a change:

- 60% indicated a negative change, perceived to be driven by low fisheries yields, increases in sharks and ecosystem decline (including coral bleaching; Figure 4).
- 20% indicated a positive change, perceived to be driven by coral recovery and more sharks (Figure 4).

Interestingly, coral bleaching and recovery were linked in responses, while the increase in sharks was viewed both positively and negatively by the community (Figure 4). Poor fishing, however, was solely perceived as negative (Figure 4).

¹³ Site importance to local island residents was scored by respondents on a five-grade scale from 'very unimportant' to 'very important' (see Annex 2 for survey questions).

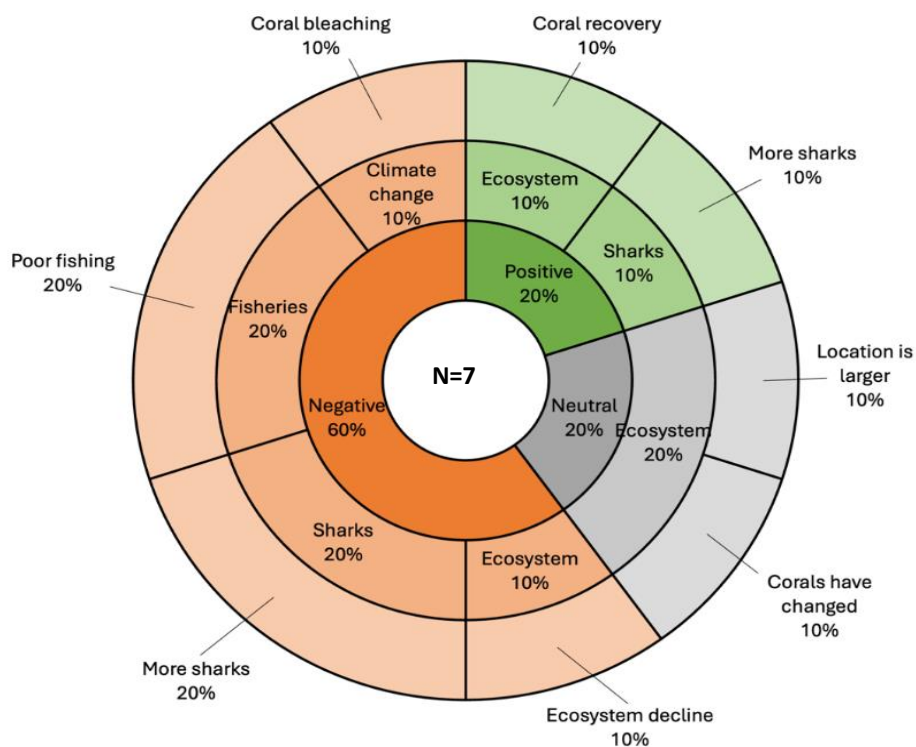


Figure 26. Perceived ecosystem changes at Fonadhoo Diving Point. Central value indicates the number of respondents who thought there had been ecosystem change over time.

3.2.1 Recreational and tourism use

There were 25% of respondents that claimed to use the site recreationally (n=4). SCUBA diving was the dominant activity (75%), followed by recreational fishing – which was only conducted “once every few weeks”. Respondents claimed to dive on a “less than monthly” basis, which could be linked to the presence of other sites in the area.

Three tourism operators indicated that they conducted commercial activities at the site, on a ‘less than monthly’ basis. All operators claimed to followed sustainability guidelines when visiting the site (e.g., informing guests to not touch or take anything from the site). One of the recreational fishing operators practiced catch-and-release and the other releases small fish and giant trevallies and mainly catches red snappers. All operators take mainly international tourists to the site, with one operator occasionally taking local tourists.

3.2.2 Fisheries use

A total of 20 fishers conducted their fishing activities at FDP, with fishers mainly deriving from the local islands of Hithadhoo (39%) and Gan (38%). Overall, fishing was conducted commercially (65%), with the reef fishery dominating fishing activity (45%) followed by lobster (20%) and livebait fishing (15%). Other fisheries conducted at FDP included billfish (5%), octopus (5%), tuna (5%) and sea cucumber (5%).

Reef fishing was conducted by nine fishers on a predominantly commercial basis (67%), with catches mainly sold to local island communities (43%) and local middlemen (43%) in addition to directly to resorts (14%; Figure 5). Handlines was the most used fishing method (n=8) followed by trolling (n=4) and jigging (n=4). Fishers indicated the northeast (45%) and southwest monsoon (33%) as the most productive reef fishing periods at FDP. Fishers were split in their opinions of ecosystem change, with five of nine fishers indicating that they had observed fisheries decline over time.

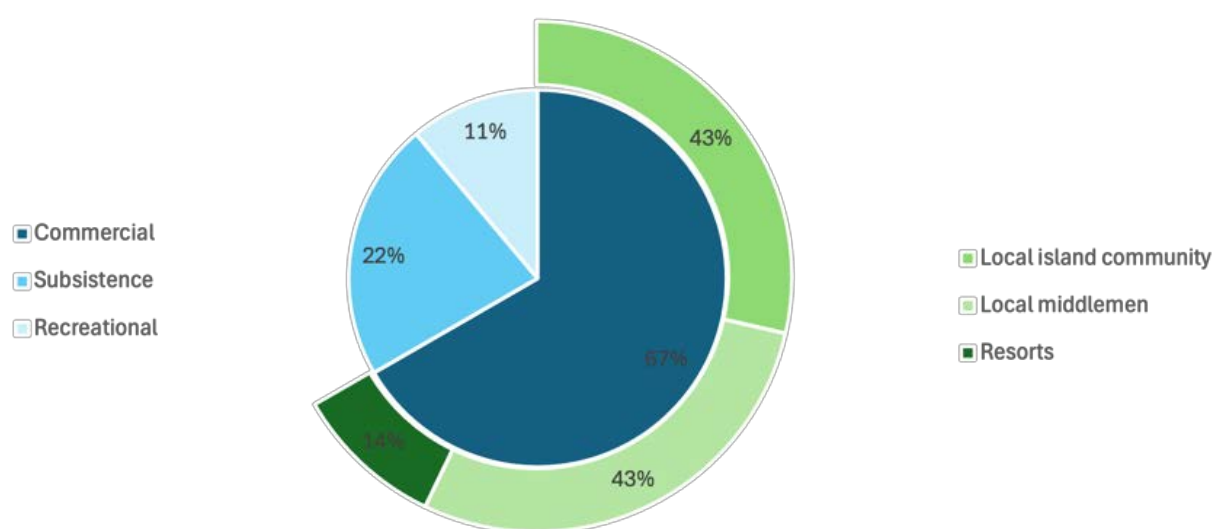


Figure 27. Reef fishing at Fonadhoo Diving Point. Inner chart = type of fishery conducted. Outside chart = commercial reef fish markets.

Other fisheries

- *Lobster fishery*, four fishers operate at both commercial (n=2) and subsistence (n=2) scales at the site. All fishers use torch/ lights to catch lobster on a 'less than monthly' basis. All fishers indicated that they have not seen any change in the fishery over time, with two of four fishers having fished at the site for over 20 years.
- *Livebait fishery*, two fishers operate on subsistence scales and one fisher operates at a commercial level at the site. The commercial fisher catches 500kg weekly from the site, with fishing especially productive around new moon. All three fishers indicate that they have observed negative fisheries decline at the site.
- *Billfish fishery*, one fisher operates commercially at FDP using a combination of buoy lines, handlines and 'Thaikuraa vadhu' fishing methods. Catches are sold to local islands around the atoll.
- *Sea cucumber fishery*, one fisher operates commercial at FDP and collects 50 sea cucumbers per trip which is sold to local middlemen. The fisher uses torches/ lights and indicates that fishing is most productive at full moon.
- *Octopus fishery*, one fisher operates commercially using a paint roller stick to catch 8kg of octopus once every few weeks. The fisher indicates that fishing has declined at the site over time due to climate change.

Isdhoo Muli (IM)

A total of 84 respondents indicated knowledge of the site, with seven respondents having never visited. The second-hand perceptions from those that have not visited indicate that IM is good for fishing and diving (tuna, billfish, trevally and wahoo), although some respondents mentioned there were strong currents and a history of diving fatalities. More than half reported extensive interaction with the area, with 46 respondents first interacting with IM over 11 years ago, while 58 respondents identified interaction with IM in the last year.

Of respondents:

- The majority derived from the local islands of Isdhoo (n=15), Kalaidhoo (n=14) and Dhanbidhoo (n=14). A significant portion of fishers also derived from Gan (n=10), Maamendhoo (n=9) and Maabaidhoo (n=9), with a smaller number of fishers deriving from the islands of Mundoo (n=4), Fonadhoo (n=4), Hithadhoo (n=3), Kunahandhoo (n=1) and Six Senses Laamu (n=1).
- Most respondents were within the '31-40 year' (n=25) category, followed by '41-50 years' (n=19) and 'above 61 years' (n=14).
- 80% of respondents were men and 20% were women.
- Most respondent's primary occupations were fishing (n=49) followed by island council (n=8) and WDC (n=7).

Respondents with first-hand experience of IM indicated that:

- IM is highly important to their community, with 85% of respondents indicating the area was "important" to "very important", and
- IM was perceived in good health (70%), and 49% perceived a change over time.

Those reporting a change perceived it to be negative (84%), driven by:

- Lower fisheries yield (invertebrates and fish; Figure 6),
- Degraded coral reefs and climate change impacts (Figure 6).

Changes were perceived to be caused by local island development (12%), sharks (13%), and warming ocean temperatures (14%), overfishing (10%), and pollution (7%).

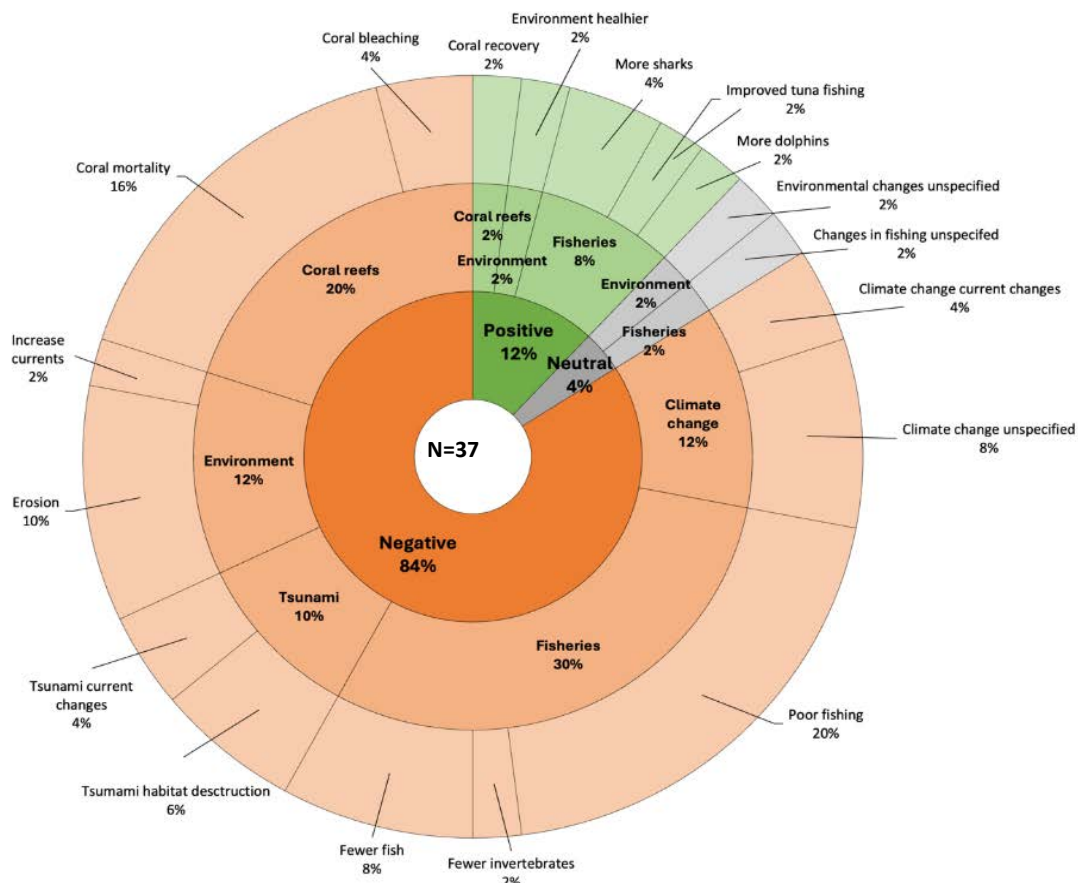


Figure 28. Perceived ecosystem change at Isdhoo Muli. Central value indicates the number of respondents who perceived an ecosystem change over time.

3.3.1 Recreational use

A relatively small number of respondents (n=12) indicated conducting recreational activities at IM. The majority (42%) conducted freediving and snorkelling at the site, 'once a week' or 'less than monthly' basis. A few respondents indicated that they surf at IM on a regular basis, dive or conduct recreational fishing at the site.

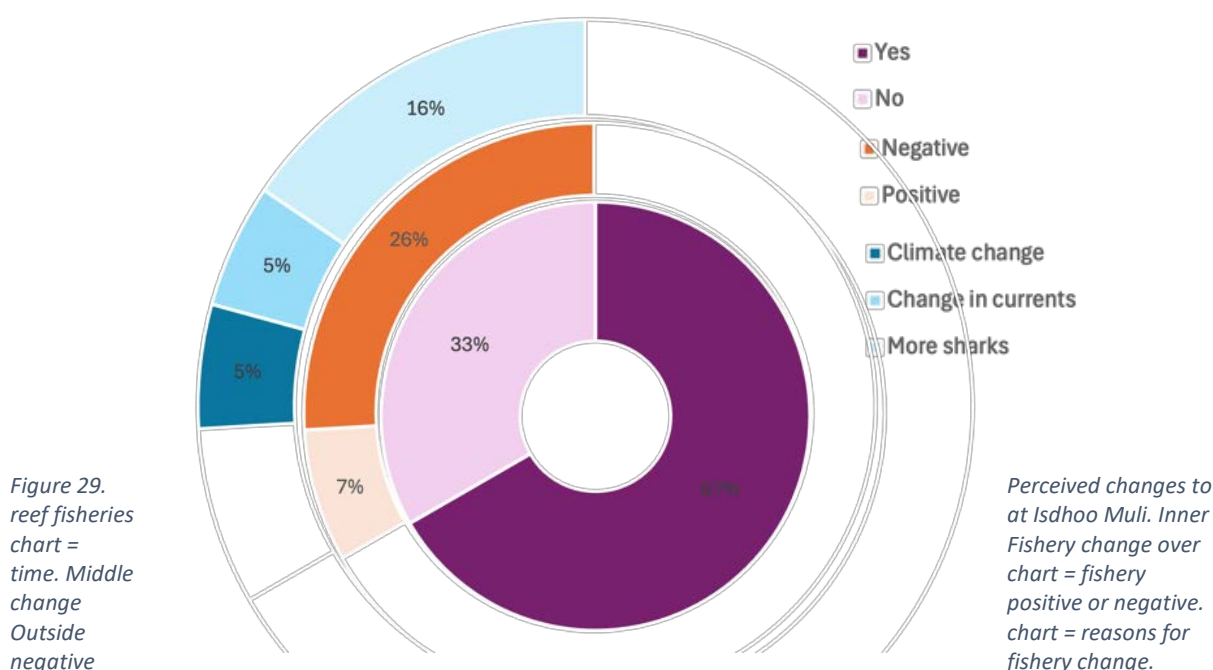
3.3.2 Tourism use

Only two tourism operators indicated that they conducted commercial activities at IM, which included SCUBA diving and recreational fishing which were both conducted on a 'less than monthly' basis. Both operators claimed to follow sustainability guidelines when visiting each site. The SCUBA diving operators indicated that they do "general things to protect the area like asking safaris to remove anchors". The fishing operator indicated that they only target red snappers and release small fish and giant trevallies. The fishing operator indicated that they have seen an increase in tourism at the ESA over time, but no timeline was mentioned for this change.

3.3.3 Fisheries use

A total of 65 fishers conducted their fishing activities at IM, with fishers deriving from 8 local islands, majorly comprising Dhanbidhoo (25%), Maabaidhoo (22%), Kalaidhoo (18%) and Isdhoo (18%). In terms of target species, reef fishing was dominant (43%), followed by tuna (25%). Octopus, sea cucumber, livebait, billfish and lobster fishing activity were also identified. Generally, fishing was for commercial purposes (60%), with a smaller portion of fisheries activities for subsistence (11%) or recreational (29%) purposes.

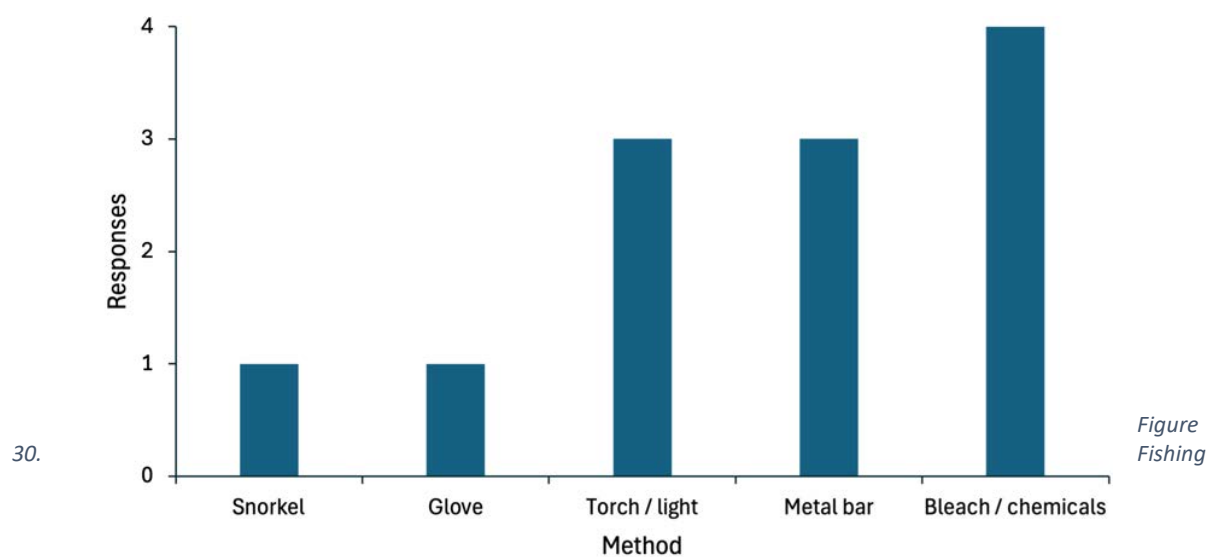
Nevertheless, the majority (48%) of reef fishing at IM is conducted for subsistence purposes, with a smaller portion of catch for recreational (22%) or commercial (30%) purposes. Fishers indicated that they use handlines/ droplines (n=23) most commonly, with a large number also using trolling (n=13) and jigging techniques (n=9). Fishers were split in the health of the reef fishery at IM, with 46% indicating fishing was healthy.



One third (33%) of fishers at IM indicate that the fishery has changed over time, with 26% of all fishers perceiving a negative change (Figure 7). Negative changes were mainly attributed to increased shark populations, in addition to changes in currents and climate change (Figure 7). Fishers indicated that the best time to fish at IM was southwest monsoon (35%) followed by full moon (26%) and northeast monsoon (23%).

A total of 16 fishers indicated that they fish for tuna on a commercial basis at IM using solely pole-and-line fishing methods. Fishers sell their catch to the local tuna processing facility (36%) and their local island community (29%). Fishers indicate that the best tuna fishing is during northeast monsoon (57%). The majority of fishers indicate that the fishery has declined over time (81%) with some fishers indicating sharks and overfishing are to blame.

Seven fishers indicated that they fish for octopus at IM for mainly subsistence purposes (57%). Fishers most commonly use bleach and chemicals to catch octopus (n=4) followed by metal bars and lights (n=3; Figure 8). A little over 57% of fisher indicated that octopus fishing had declined at IM, with fishers attributing these changes to use of lights, damaged coral habitats and the 2004 tsunami.



methods used to catch octopus at IM.

Other fisheries

- *Livebait fishery*, five fishers operate commercially using nets and lights. The fishery is most productive during southwest monsoon, yet four of five fishers indicate the fishery has declined over time due to climate change and overfishing.
- *Sea cucumber fishery*, three fishers operate commercially using torches and lights. All fishers indicate the fishery has declined over time.
- *Lobster fishery*, one fisher operates commercially using lights and catches 21kg per trip every few weeks. Most productive lobster fishing is around full moon, but the fisher has observed decline over past 5 years due to climate change and habitat destruction.

3.4 Mathigulhi Sarahadhu (MS)

A total of 29 respondents indicated that they had information about Mathigulhi Sarahadhu (MS), all of which were firsthand observations. Respondents derived from six local islands, with the majority from Maamendhoo (n=10) and Hithadhoo (n=8). A smaller number of fishers were from Maabaidhoo (n=5), Kunahandhoo (n=4), Gan (n=1) and Dhanbidhoo (n=1). Respondents majorly fell within with '41-50 years' (n=11) and '31-40 years' (n=9) age categories. 86% of respondents were men and 4 respondents were women. Tuna fishing was the most common occupation identified by respondents (n=8) followed by tourism (n=3) and reef fishing (n=3).

Most respondents observed MS over 11 years ago (n=18), and recently observed the site 'Less than 1' year (n=20). Consequently, many respondents who completed the survey were basing their observations of MS over a multi-year period.

Respondents indicated that MS is:

- Important to their community (90%),
- Either in "good" state (49%) or poor state (31%), and
- A large proportion have identified a negative change in ecosystem health over time (Figure 9).

Of the 19 of respondents indicating a change, 94% perceived a negative change over time, caused by erosion (46%) and coastal development (12%; Figure 9). Interestingly, almost half of respondents did not mention any threat (46%), although pollution was most mentioned (16%), followed by deforestation (7%) and warming water temperatures (6%).

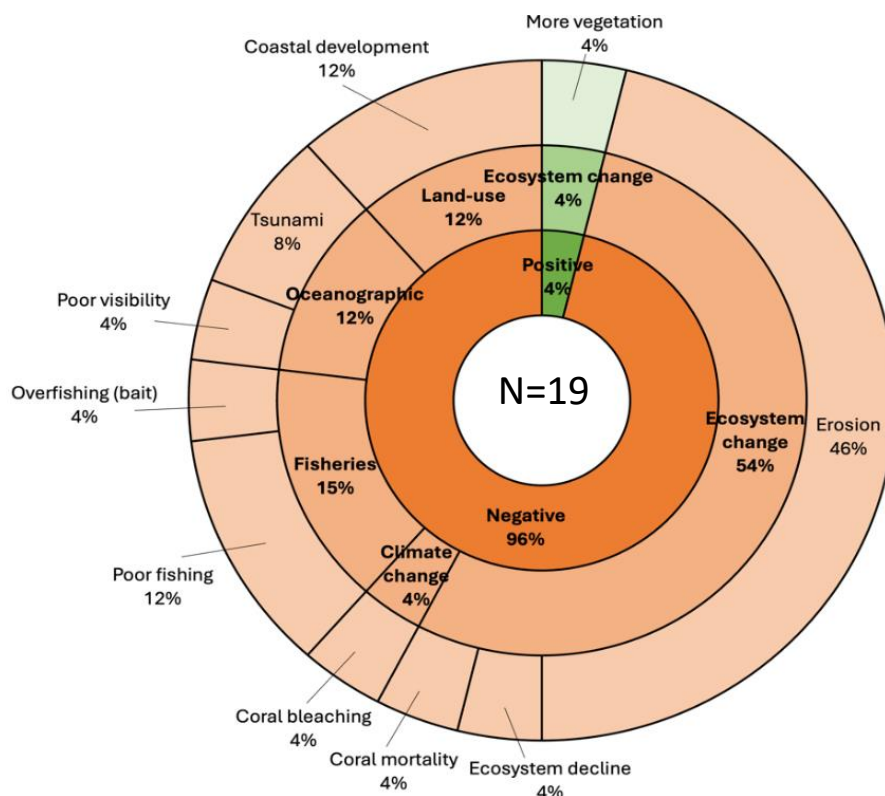


Figure 31. Perceived ecosystem changes at Mathigulhi Sarahadhu. Central value indicates the number of respondents who thought there had been ecosystem change over time.

3.4.1 Recreational use

Less than one-third (N=9) of respondents indicated that they conduct recreational activities at MS. The major recreational activity conducted at the site were picnics (mostly on a 'less than monthly' basis) and snorkelling (mostly on a 'less than monthly basis').

3.4.2 Fisheries use

A total of 12 fishers conducted their fishing activities at MS, with 50% of fishers from Maabaidhoo, with others from Hithadhoo (17%) and Kunahandhoo (33%). In terms of target species, reef fishing was dominant (54%), followed by live bait (23%). Octopus, sea cucumber and lobster fishing activity were also identified. Fishing was for commercial purposes (69%), as opposed to subsistence fishing.

The majority (57%) of reef fishing at MS is conducted for commercial purposes (Figure 10). Of commercial activity, local communities (23%) are the major market for catch, followed by local middlemen and atoll middlemen (23%; Figure 10). Only 11% of catch are sold directly to resorts (Figure 10). Fishers indicate that reef fish are most caught at MS during the northeast monsoon (37%) followed by full moon (25%; Figure 11).

Most fishers (86%) indicated that they had seen a change in reef fishing at MS over time, with 72% respondents perceiving a negative change. For responders:

- Those indicating no change have been fishing at the site for less than 5 years, while
- All fishers who had been fishing at MS for more than 5 years indicated that they had seen a change in fishery health.

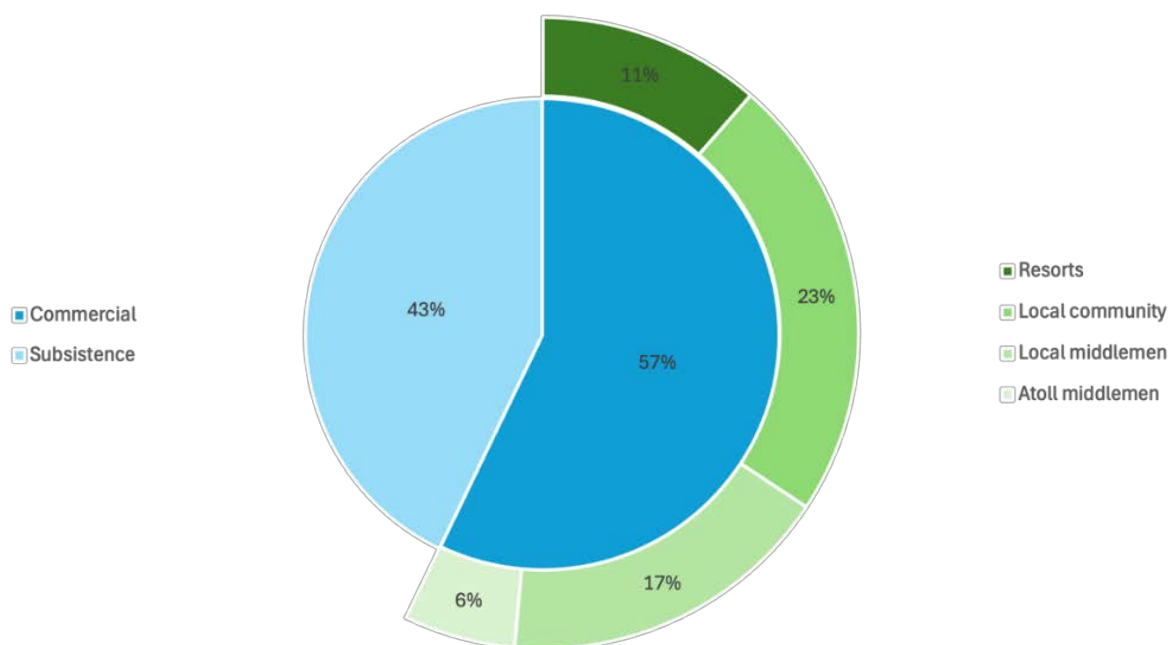


Figure 32. Central chart = purpose of the reef fish fishery at Mathigulhu Sarahadhu. Outside donut chart = markets for reef fish caught at Mathigulhu Sarahadhu.

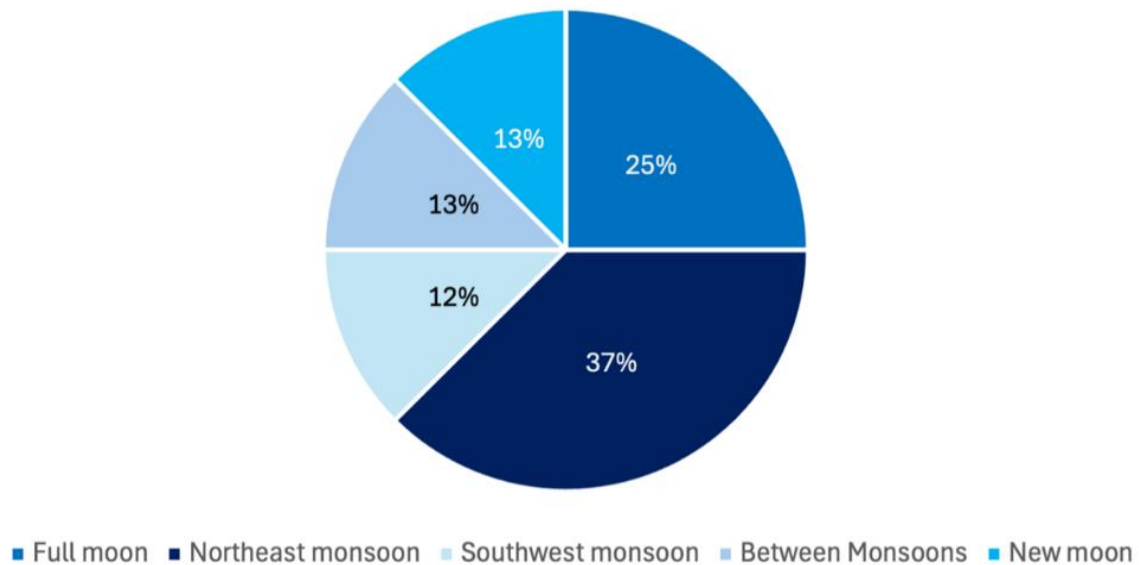


Figure 33. Seasons where most reef fish are caught from Mathigulhu Sarahadhu.

Other fisheries

- One fisher reported to have been harvesting sea cucumbers from MS commercially over 26 years. This fisher normally catches ~70kg per trip and sells to middlemen and the local community. The fisher mentioned a decline of sea cucumbers at the site over time.
- One fisher harvests octopus from MS on subsistence scales using bleach/chemicals and metal rods. This fisher has been harvesting octopus for 16 to 25 years and has not seen any change at the site over that time – rating the fishery as very healthy.
- One fisher respondent harvest lobster at MS on commercial scale using torch and lights. The fisher has been fishing for 6 – 10 years and usually catches 5 kilos per trip which is sold to the local island community. The fisher indicates that there has been no change in fishery health at the site and rates the fishery as healthy.

Three fishers indicated that they catch livebait at MS. Fishers most commonly catch livebait during the southwest monsoon (67%). Live bait is also caught during the northeast monsoon at MS. Livebait fishing at MS is conducted for the commercial tuna fishery, with between 120kg to 200kg caught per trip. All respondents indicated that the livebait fishery has declined at MS over time.

3.4.3 Tourism use

No tourism operators indicated commercial activities at MS.

3.5 Mundoo Channel (MC)

A total of 94 respondents indicated that they knew information about Mundoo Channel (MC), of which seven respondents had never visited the site in person.¹⁴ Respondents mainly derived from the local islands of Mundoo (n=22) and Maabaidhoo (n=20), with a large number of respondents also from the islands of Kalaidhoo (n=13), Fonadhoo (n=10) and Dhanbidhoo (n=8). Most respondents fell within the '31-40 years' age category (n=32) followed by '41-50 years' (n=21) and 'above 61 years' and '51-60 years' (n=16). 84% of respondents were men with the remaining 16% women. Over 50% of respondents indicated that their primary occupation was fishing (n=52) followed by island council (n=8) and civil society (n=5).

Most respondents first observed MC over 11 years ago (n=47) and most recently observed MC 'Less than 1' year (n=61) prior to the survey taking place. Respondents indicated that MC is highly important to their community, with 85% of respondents indicating the area was either 'very important' (59%) or 'important' (26%). There were 66% of respondents that identified MC as at least "good" ecosystem state. A smaller number of respondents also indicated that MC was in poor health (9%), with zero respondents indicated that MC was in 'very poor' health (Figure x).

Almost two thirds of respondents (65%) indicated that they had observed ecosystem change at MC over time (Figure 12). Overall, most of respondents indicating changes (97%) perceived MS to have negatively changed over time (Figure 12). The most highlighted issues included fisheries decline (36%) and more sharks (11%; Figure 12).

Most respondents (66%) indicated that there are threats impacting the MC. Of threats mentioned, sharks were most mentioned by 14% of respondents, followed by pollution (13%) and warming water temperatures (11%).

¹⁴ Perceptions of non-visitors included the site was good for fishing and diving. Diving is good due to the presence of sea turtles and large groupers.

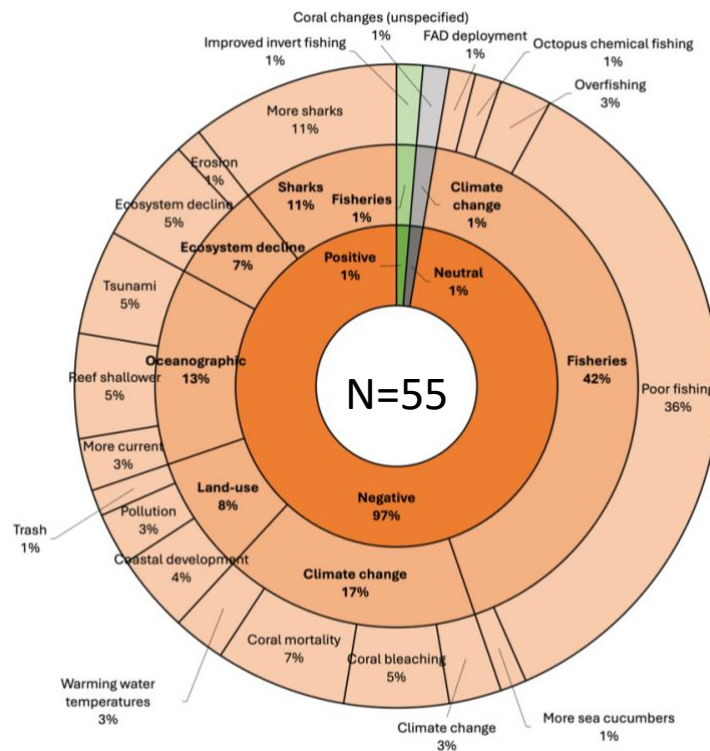


Figure 34. Perceived ecosystem changes at Mundoo Channel. Central value indicates the number of respondents who thought there had been ecosystem change over time.

3.5.1 Recreational use

Only 13% of respondents indicated that they conduct recreational activities at MC (Figure 13). The major recreational activity was fishing, on a 'less than monthly' and 'once every few weeks' basis (Figure 13). All respondents indicated that MC is 'one of at least five areas' where they go for recreational fishing (Figure 13). Additionally, a few respondents indicated SCUBA diving at MC on a 'less than monthly' basis (Figure 13). Other recreational activities include surfing and freediving / snorkelling (Figure 13).

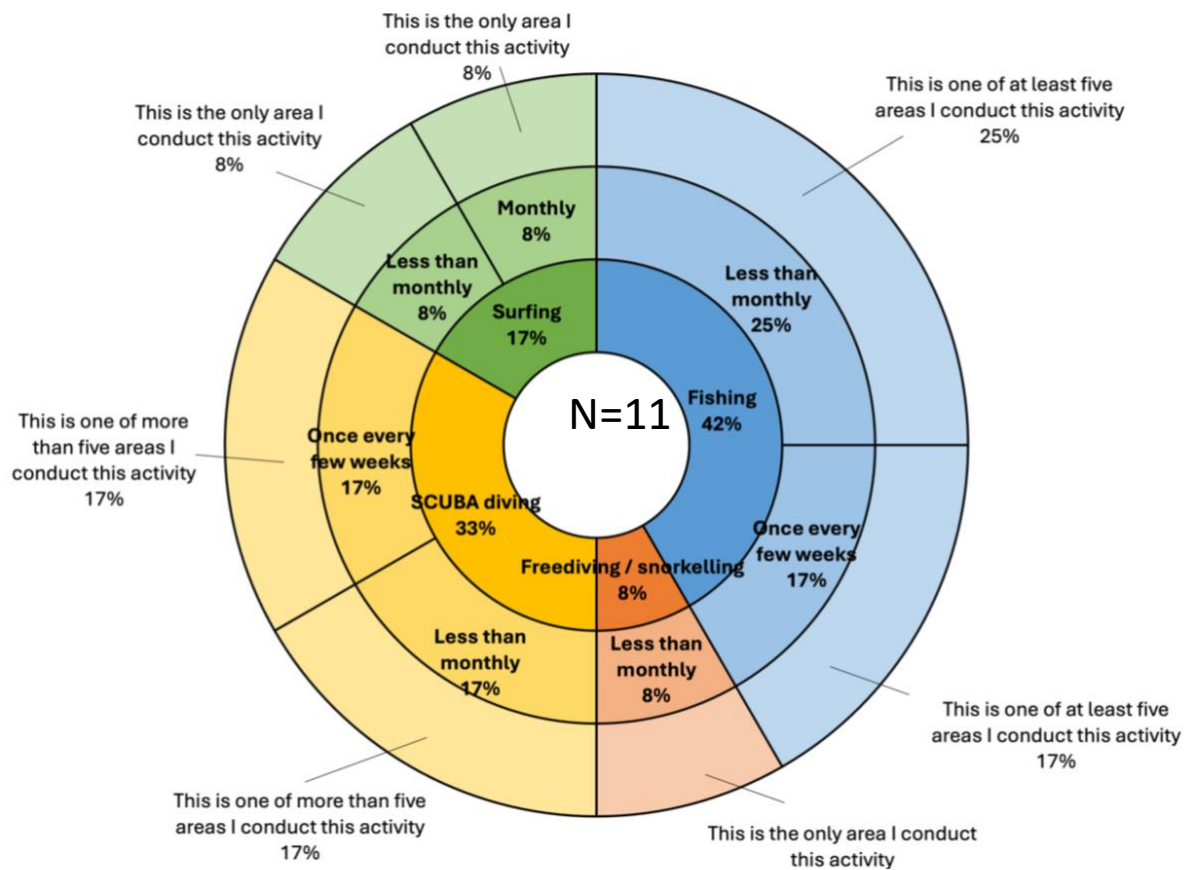


Figure 35. Recreational activities conducted at Mundoo Channel. Central value indicates the number of respondents conducting recreational activities at the site.

3.5.2 Fisheries use

A total of 83 fishers conducted their fishing activities at MC, with fishers mainly deriving from Maabaidhoo (38%) and Mundoo (33%), in addition to Fonadhoo (10%), Kalaidhoo (10%), Gan (6%) and Dhanbidhoo (3%). Reef fishing was the most dominant fisheries sector at MC, comprising 57% of respondent being fishers. Other fisheries identified include octopus (15%), livebait (8%), sea cucumber (7%), lobster (7%), tuna (5%) and billfish (2%).

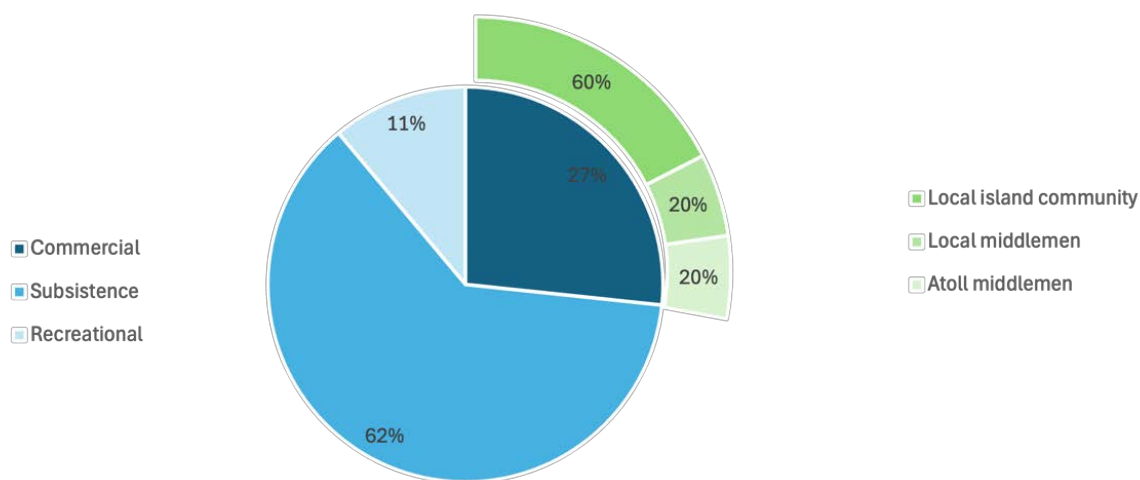


Figure 36. Reef fishing at Mundoo Channel. Inner chart = type of fishing conducted. Outer chart = commercial markets for reef fish.

The reef fishery at MC is dominated by subsistence fishers (n=28; Figure 14). A smaller portion (27%) of fishers operate commercially, with the majority (60%) of commercial catch being sold to local communities (Figure 14). Reef fishers majorly used handlines (n=42), with a significant portion also using trolling methods (n=22). Overall, 67% of reef fishers indicated that they had observed a negative change in fisheries productivity at the site. An increase in the number of sharks at the site was the most mentioned reason behind this change (n=11) ahead of climate change, overfishing and tsunami impacts (n=1).

A total of 12 fishers indicated that they collect octopus from MC, with most collection for subsistence purposes (58%). Fishers indicated that they mainly use metal rods to catch octopus (n=2) with only two fishers indicating that they use bleach or chemicals (Figure 15). Nine of twelve fishers indicated that octopus fishing productivity had changed, with 89% of fishers indicating that these changes are negative. Fishers mainly attributed declining octopus production to the degrading reef environment.

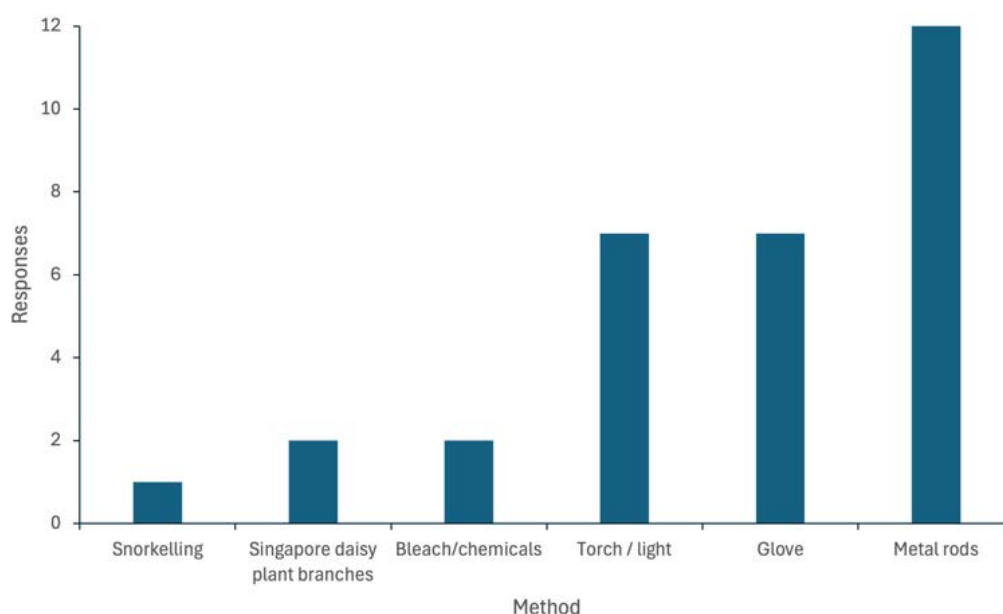


Figure 37. Methods used to collect octopus at Mundoo Channel

Other fisheries

- *Livebait fishery*: six fishers commercially harvest livebait using nets and one fisher operates on a subsistence scale. Fishers indicated that livebait fishing is most productive during the southwest (46%) and northeast (36%) monsoon. All seven fishers indicated that the fishery has declined with reasons mentioned including: 1) too many sharks (n=2); 2) use of lights (n=2); and 3) low visibility (n=1).
- *Sea cucumber fishery*: six fishers commercially harvest sea cucumbers, with the majority (80%) of catch sold to Male'-based middlemen. All fishers use torch/lights methods and catch most sea cucumbers during full moon (56%). Moreover, 67% of fishers indicated that the fishery had declined over time, with changes in the reef given as the primary reason by fishers.
- *Lobster fishery*: three fishers commercially harvest lobster and two fishers harvest lobster on subsistence scales using lights and metal rods. The majority (75%) of commercial catch is sold to the local island community. All fishers perceived that the fishery has declined over time, with all fishers indicating that the MC has average ecological health.
- *Tuna fishery*: four fishers catch tuna from MC, of which two operate on a commercial scale and catch over 200kg of tuna per trip using pole-and-line methods. Subsistence fishers catch no more than 25kg per trip using primarily trolling and jigging methods. Three of four fishers indicate that the fishery has negatively changed.
- *Billfish fishery*: two fishers catch billfish for commercial purposes using buoy lines on weekly and 'few times per week' basis. Fishers sell their catch to local communities and middlemen, and both indicate that the fishery has decline at MC over time.

3.5.3 Tourism use

Six tourism operators conduct commercial activities at MC. A large portion of operators conduct SCUBA diving (43%) and fishing (43%), with SCUBA diving conducted on at least 'once every few weeks'. Similarly, most recreational fishing operators conduct activities on a 'less than monthly' basis. Five operators indicated that they follow sustainability guidelines:

- Fishing operators mentioned practicing catch and release and releasing small fish.
- SCUBA diving operators indicated that they ask guests to take action to avoid damaging the reef and ask safaris to remove their anchors.
- Three operators indicated that there had been changes in tourism over time, with one operator indicated that there are now more tourists than in the past. The other operators commented that there is now more giant trevally, and the diving is attractive for their guests. Tourists visiting MC are majorly international, with only one recreational fishing operator indicating that they take more local than international tourists.

3.6 Reethi Haa and Hudhafaru (RHH)

A total of 54 respondents indicated that they had information about Reethi Haa and Hudhafaru (RHH), of which 3 respondents had never visited the site in person¹⁵.

Of respondents:

- Most respondents derived from the local island of Maamendhoo (n=19), followed by Hithadhoo (n=11) and Maabaidhoo (n=6).
- Respondents most frequently comprised the '31-40 years' age category (n=20), followed by '41-50 years' (n=16).
- Men comprised 89% of respondents.
- 29 respondents indicated their primary occupation was fishing, of which 19 were involved with tuna fishing. Other common occupations of respondents included tourism (n=4), island council (n=4) and civil society (n=3).

Most respondents first observed RHH over 11 years ago (n=20) and most respondents recently observed RHH 'Less than 1' year (n=34) prior to the survey taking place. Consequently, many respondents who completed the survey were basing their observations of RHH over a multi-year period.

Respondents indicated that:

- RHH was important to their community (90%), and
- The ecological health of the area was "good", reported by two thirds of respondents (62%)

Over half of respondents (n=26) indicated that they had observed ecosystem change, with 88% perceived RHH to have negatively changed over time, perceived to be driven by 'poor fishing' (48%), and 'coral mortality' (11%, Figure 16). Most respondents (62%) perceived overfishing to be a significant threat (18%), followed by pollution (11%), and increase in sharks (10%).

¹⁵ Perceived views of non-visitors indicated the site was good for bait fishing, surfing and contained a beautiful reef.

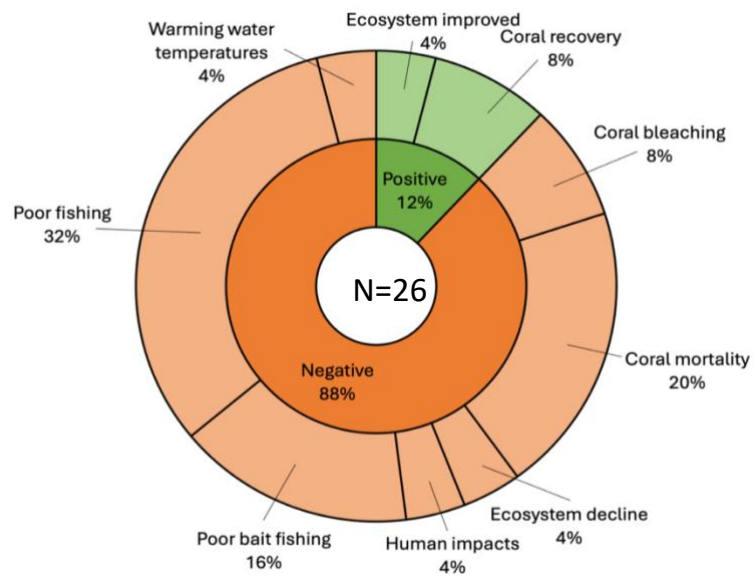


Figure 38. Perceived ecosystem changes at Reethi Haa and Hudhafaru. Central value indicates the number of respondents who thought there had been ecosystem change over time.

3.6.1 Recreational use

Nearly one-third of respondents (n=16) indicated that they conduct recreational activities at RHH (Figure 17). The major recreational activity conducted at the site was freediving and snorkelling, conducted by 84% of respondents mainly on a 'less than monthly' but also conducted on a 'monthly', 'few times a week' and 'weekly' basis (Figure 17). All respondents indicated that RHH is both 'one of more than five areas' and 'one of at least five areas' where they go freediving/ snorkelling (Figure 17). Additionally, 16% of respondents indicated that they conduct SCUBA diving at RHH on both a 'less than monthly' and 'few times a week' basis (Figure 17). All respondents indicated that MC is 'one of more than five areas' where they go SCUBA diving (Figure 17).

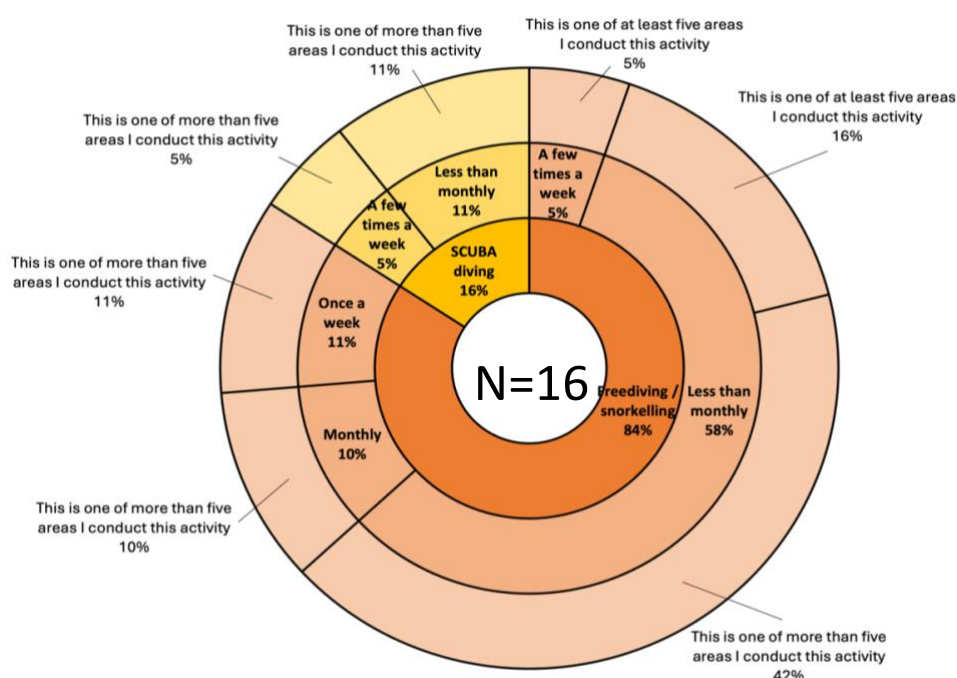


Figure 39. Recreational activities conducted at Reethi Haa and Hudhafaru. Central value indicates the number of respondents conducting recreational activities at the site.

3.6.2 Tourism use

Four tourism operators conducted commercial tourism activities at RHH. Three operators indicated that they conduct snorkelling excursions to the site across a 'few times a week', 'less than monthly, and 'once a week' basis. One operator also conducts SCUBA diving to the site 'a few times a week'. All operators follow sustainability standards when visiting the site. Snorkelling and SCUBA diving sustainability actions included: 1) not touching marine life and corals; 2) collecting trash if they see it; and 3) follow green fins and Olive Ridley Projects turtle code of conduct. All operators indicated that they have not seen a change in tourism at the site and that they all solely take international tourists to the site.

3.6.3 Fisheries use

A total of 43 fishers conducts their activities at RHH, with fishers mainly deriving from the island of Maamendhoo (46%), in addition to Maabaidhoo (16%), Hithadhoo (19%), Gan (13%), Kunahandhoo (3%) and Dhanbidhoo (3%). Fisheries at RHH are dominated by the livebait fishery (54%) and reef fishing (44%), with a small portion of fishers (2%) involved with the sea cucumber collection.

The tuna caught using commercially caught livebait from RHH is primarily sold to the atoll processing facility (62%) in addition to local island communities (38%). Fishers indicate that the livebait fishery is most productive during the monsoons, northeast (31%) and southwest (28%), in addition to the new moon (24%). The majority (68%) of respondents indicated that they had observed negative decline in the livebait fishery at RHH over time. Fishers put this down to the overuse of lights and increased shark populations.

Most of the reef fishing (55%) at RHH was conducted on a commercial scale, with the major markets for reef fish being resorts (43%) and local island communities (35%; Figure 18). A smaller portion of reef fish is conducted for subsistence (17%) and recreational (28%) purposes (Figure 18). Handlines were the most mentioned fishing method used at RHH (n=17) followed by jigging (n=6) and trolling (n=5). Most fishers (78%) indicated that they observed negative declines in the reef fishery at RHH over time, with fishers mentioning the increase in sharks as the reason for this decline.

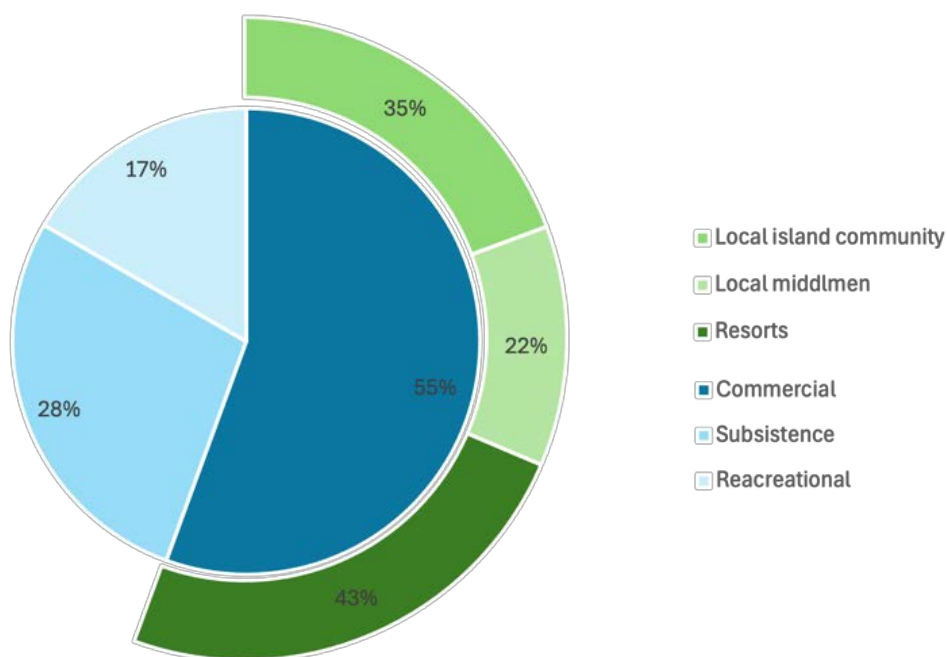


Figure 40. Reef fishing at RHH. Inner chart = type of reef fishing. Outer chart = market for commercially caught reef fish.

One fisher indicated that they fish for sea cucumbers at RHH for commercial purposes using lights. The fisher catches over 100 sea cucumbers each week from the site and sells their catch to local middlemen. The fisher indicated that the fishery is very healthy and has seen no change in fisheries productivity over the past 10 years.

4. Key outcomes

The data from the survey regarding perceptions of the five Environmentally Sensitive Areas (ESA) in Laamu Atoll reveal complex relationships between ecological health, community perceptions, and human activities. Across all sites, there is a strong consensus on the importance of these areas to local communities, with 65-90% of respondents rating them as important or very important. However, there's a notable contrast between the generally positive perceptions of current ecosystem health and the widespread observation of negative changes over time. While 62-73% of respondents across most sites perceive the current ecological state as "good" or better, a significant proportion (44-66%) have observed changes in these areas, with the vast majority (60-97%) viewing these changes negatively.

The perceived threats to these ESAs provide insight into the potential drivers of the observed negative changes. Common threats identified across multiple sites include warming ocean temperatures, coral health decline, pollution, and human activities such as overfishing and coastal development. Interestingly, sharks are mentioned both as a threat and, in some contexts, as an indicator of ecosystem health. This duality highlights the complex relationships within these marine ecosystems and the potentially conflicting perceptions of the local communities towards specific ecosystem components. The identification of both local (e.g., pollution, overfishing, coastal development) and global (e.g., warming temperatures, declining coral reef health) threats suggests an awareness of the challenges of climate change facing these specific areas.

Human activities in these ESAs are primarily centred around recreational use, fishing, and tourism. Recreational activities vary across sites but generally include SCUBA diving, snorkelling, and fishing, with 13-32% of respondents engaging in such activities. Fishing activities are reported in some areas, with a mix of recreational, subsistence and commercial practices. Tourism is present in most of the ESAs, primarily focused on SCUBA diving and fishing. Notably, tour operators across the sites report following various sustainability practices, such as catch-and-release fishing, avoiding anchor damage, and adhering to codes of conduct for wildlife interaction. This suggests a degree of awareness and effort towards sustainable use of these marine resources. However, the persistence of perceived threats and negative changes indicates that current practices may not be sufficient to fully protect these valuable ecosystems.

4.1 Key findings and recommendations

Based on the general themes observed across the five ESA in Laamu Atoll, a comprehensive and adaptive management approach is needed to address the challenges facing these valuable marine ecosystems. The strong community recognition of the importance of these areas provides a solid foundation for engaging local stakeholders in conservation efforts. However, the widespread perception of negative changes over time, despite generally positive views of current ecosystem health, suggests a need for more proactive and preventative measures. Management strategies should focus on addressing both local and global threats, with particular attention to issues such as warming ocean temperatures, declining coral reef health, pollution, overfishing, and coastal development. Given the complex nature of these ecosystems and the conflicting perceptions of their components

(e.g., sharks as both threats and indicators of health), it is crucial to incorporate scientific monitoring alongside community knowledge in decision-making processes.

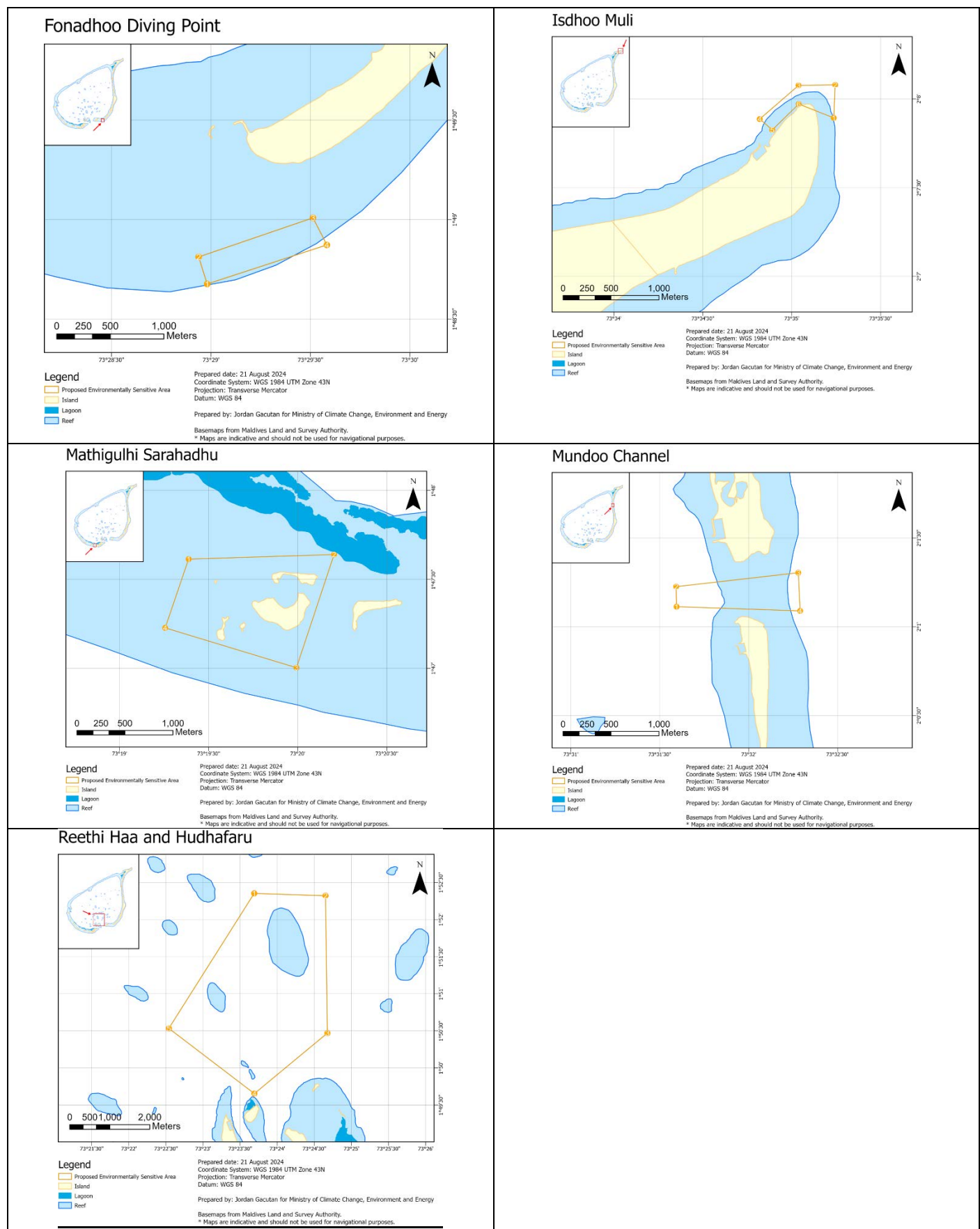
To effectively manage these ESAs and promote their long-term sustainability, the following practical next steps are recommended:

1. Establish a comprehensive monitoring programme that combines scientific data collection with community-based observations to track changes in ecosystem health over time.
2. Develop and implement site-specific management plans that address the unique threats and use patterns of each ESA, while maintaining a cohesive atoll-wide strategy. This should include strengthening regulations and enforcement mechanisms to address local threats such as overfishing/ destructive fishing practices and pollution. Fisheries management measures should focus on protecting importance fish spawning grounds and restricting destructive fishing gear such as:
 - a. The use of chemicals/ bleach for octopus fishing: the use of bleach to catch octopus has understudied ecological consequences yet is likely to negatively impact reef environments and affect re-habitation rates of octopus burrows.
 - b. The emerging jigging method: this method is used to catch deeper-sea species which could be more vulnerable to fisheries overexploitation
3. Enhance education and awareness programmes for both local communities and tourists, focusing on the importance of these areas and sustainable use practices. Collaborate with tourism operators to develop and implement a standardized set of best practices for sustainable tourism across all ESA.
4. Initiate a coastal management programme to address erosion and mitigate the impacts of coastal development on these sensitive marine environments.
5. Explore opportunities for community-led conservation initiatives, leveraging the strong local connection to these areas to foster stewardship and sustainable use. This should include developing partnerships with regional and international organizations to address broader issues like climate change and its impacts on these marine ecosystems.

Table 17. Summary table of survey findings across the 5 potential ESA sites.

Aspect	Fonadhoo Diving Point	Isdhoo Muli	Mathigulhi Sarahadhu	Mundoo Channel	Reethi Haa and Hudhafaru
Number of respondents	23 respondents	83 respondents	29 respondents	93 respondents	53 respondents
Overall importance	65% "important" or "very important"	85% "important" to "very important"	90% important	85% "important" or "very important"	90% important
Perceived ecosystem health	73% "good" or "very good"	70% good health	Mixed: 49% "good", 31% poor	66% at least "good"	62% "good"
Observed changes	7 respondents perceived change: 60% negative	37 respondents perceived change: 84% negative	19 respondents perceived change: 94% negative	55 respondents perceived change: 97% negative	26 respondents perceived change: 88% negative
Common threats	Local island development, sharks, warming ocean temperatures	Local island development, sharks, warming ocean temperatures, overfishing, pollution	Erosion, coastal development, pollution, deforestation, warming water temperatures	Sharks, pollution, warming water temperatures	Overfishing, pollution, increase in sharks
Recreational use	25% use site; mainly diving	14% use site; mainly freediving and snorkelling	31% use site; mainly picnics and snorkelling	13% use site; mainly fishing, some diving	32% use site; mainly freediving/snorkelling, some SCUBA diving
Fishing activities	Limited recreational fishing	Reef and tuna fishing.	Reef fishing (54%), live bait (23%), some invertebrate fishing	Recreational fishing	Livebait fishing, sold to atoll processing plant.
Tourism activities	3 operators; diving and fishing	2 operators; diving and fishing	No tourism operators reported	6 operators; mainly diving and fishing	4 operators; mainly snorkelling, some SCUBA diving
Sustainability practices	Operators follow guidelines; catch-and-release fishing	Operators follow guidelines; anchor removal, selective fishing	Not applicable	Catch-and-release, anchor removal	Not touching marine life, collecting trash, following codes of conduct

Annex 1: Individual maps of ESA



Annex 2: Survey questions

Survey 1 (General information and recreational use)

1. Island name
2. Survey date and time
3. What is your full name?
4. How old are you?
5. What is your nationality?
6. What is your gender?
7. What is your primary occupation?
8. What is the name of the NGO?
9. How long have you been in this occupation?
10. Do you permanently live on a local island or elsewhere?
11. Do you have any knowledge of any of the below marine areas?
12. Have you ever made a personal observation in the area?
13. Please explain your knowledge of the area and how you gained this knowledge.
14. When did you last make an observation in the area?
15. How would you rate the environmental health of this area, when you made your last observation?
16. Can you explain your answer?
17. When did you first make an observation in the area?
18. Has this area changed between the first and last years' of observation?
19. Please describe these changes
20. How important would you describe this area for residents of your local island?
21. Explain your answer
22. Do you perceive any current threats to the area?
23. Do you participate in any recreational activities in the area?
24. What type of recreational activity do you conduct in this area?
25. Over the past 12 months, how often did you conduct this activity?
26. Please select the statement that best applies.
27. Over the past 12 months, did you conduct any other recreational activities in this area?

Survey 2 (Fisheries use)

4. Island name
5. Survey date
6. Full name of participant
7. Do you engage in any type of fishing activity at any of the marine areas?
8. Which fishery are you involved with in this area?
9. What type of fishing gear do you use for the fishery in this area?
10. Do you operate on a commercial, subsistence or recreational basis in this area?
11. What is the size of the fishing vessel you use?
12. How long have you been fishing in this area?
13. Over the past 12 months, how often have you fished there?
14. Over the past 12 months, what has been your average catch per trip in this area?
15. Over the past 12 months, where have you been selling your catch from this area?

16. Is your fishing seasonal in this area?
17. In which season do you obtain most of your catch from this area?
18. Have you noticed any changes in fishing in this area since you first visited?
19. Please describe these changes
20. How would you describe the health of fishing in this area today?
21. Are you involved in another fishery in this area?
22. Do you engage in any type of fishing activity at any of the marine areas?

Survey 3 (Tourism use)

1. Island name
2. Survey date
3. Full name of participant
1. Do you engage in any type of tourism activity at any of the marine areas?
2. Which activities do you conduct in this area?
3. Over the past 12 months, how often have you conducted this activity in this area?
4. Do you follow sustainability guidelines when conducting this activity in this area?
5. Please describe the sustainability guidelines you follow.
6. Do you conduct any other tourism activities in this area?
7. Have you noticed a change in the number of tourists visiting the area in recent years? Single choice.
8. Please explain these changes.
9. Do you typically take local or international tourists on trips to the area?
10. Do you engage in tourism activity in another marine area?

Geomorphology & Land use



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Keywords

Geomorphology, Land use change, shoreline change

Acknowledgement

We would like to acknowledge and thank the work of the below individuals and organisations who supported this report.

GIS and Drone mapping: Hassan Shiraz (civil and environmental engineer), Fathimath Shifla and Mohamed Maidhu Abdul Muhsin (Maldives National University), Dr Jordan Gacutan (University of New South Wales)

Data analysis and report writing: Dr Jordan Gacutan and Sophia German (University of New South Wales)

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Abbreviations and Acronyms

ENDhERI	Enhancing National Development through Environmentally Resilient Islands
ESA	Environmentally Significant Areas
GEF	Global Environment Facility
IUCN	The International Union for Conservation of Nature
MAAW	Ministry of Agriculture and Animal Welfare
MBS	Maldives Bureau of Statistics
MCCEE	Ministry of Climate Change, Environment and Energy
MRR	Maldives Resilient Reefs
NC	Natural Capital
NGO	Non-Governmental Organisation
PMU	Project Management Unit
UNEP	United Nations Environment Programme
WDC	Women's Development Committee

1. Introduction

1.1 Background

The Ministry of Climate Change, Environment and Energy (MCCEE) is implementing the Enhancing National Development through Environmentally Resilient Islands (ENDhERI) project. This initiative, funded by the Global Environment Facility (GEF) and supported by the United Nations Environment Programme (UNEP), aims to facilitate the adoption of new environmental policies and the transition toward Green Growth atoll development. This development strategy aims to sustain marine Natural Capital (NC) and enhance the resilience and recovery of reef ecosystems. The project will draw from integrated coastal zone management within a Managed Marine Area/Biosphere Reserve framework, along with innovative sustainability practices in sectors such as agriculture, fisheries, tourism, and construction. The goal is to transform the ecological impact in Laamu Atoll, leading to national-level sector transformation, spatial planning, and improved governance based on NC accounting.

The *“Consultancy Service to Develop Baseline Assessment for Environmentally Significant Areas at Laamu”* was contracted to Maldives Resilient Reefs (MRR), a Maldivian Non-Governmental Organisation (NGO) dedicated to restoring coral reefs in the Maldives as climate resilient ecosystems for the benefit of people, nature and the economies that depend on them.¹⁶

The main objective of the consultancy is to conduct baseline assessments of five potential Environmentally Significant Areas (ESA) of Laamu Atoll, in line with the *“Guidelines for coral reef and small island vegetation surveys in the Maldives”*¹⁷. A literature review, accompanying this report, has been conducted and provides comprehensive existing scientific knowledge and data collected for Laamu Atoll, in addition to available data for the five study areas. The assignment requires the procurement of field data (*via* field surveys and community consultation) to assess and analyze the ecological characteristics and the socio-economic setting of the five potential ESA.

1.2 Land use and shoreline change

Studying shoreline and land-use changes in island environments is crucial for understanding the resilience and adaptability of these vulnerable ecosystems in the face of climate change. Contrary to the long-held belief that low-lying coral reef islands would become uninhabitable due to sea level rise, recent research has shown that these landforms are highly dynamic and capable of adjusting to changing environmental conditions. This adaptability represents a valuable geomorphic ecosystem service, potentially ensuring the

¹⁶ MRR’s strategic intervention areas are: 1) Increasing effective marine protection to build climate resilience; 2) Improving the sustainability of reef-based fisheries; 3) Improving environmentally responsible tourism; and 4) Strengthening local capacities for marine resource management in the Maldives. MRR is officially affiliated with the UK charity, Blue Marine Foundation. Blue Marine has a vision of a healthy ocean forever, for everyone.

¹⁷ Dryden and Basheer, 2021: <https://www.environment.gov.mv/v2/en/download/14746>.

continued habitability of atoll nations like the Maldives. Furthermore, understanding these changes is essential for assessing impacts on freshwater resources, as island morphology directly affects the size and quality of freshwater lenses - a critical source of potable water for island communities.

1.3 Scope

The consultancy requires the team to “Assess and analyze historical changes to the area including geomorphology, development, and vegetation using Google Earth satellite information/images, aerial images.”

Of the five proposed ESA, only Mathigulhi Sarahadhu contains significant areas above sea level. This report focuses on the geomorphology and land use change of the five islands that are consistently above sea level within the area. The largest island, Kudafushi, is designated as an industrial island for agriculture. By examining these islands over a 10-year timeframe (2014 to 2023), we aim to quantify morphological changes, present shoreline dynamics, and the increasing use of Kudafushi for cropland.

2. Materials and Methods

2.1 Study site

Laamu Atoll is situated in the southern central region of the Maldives. It has a total surface area of 884.63 km² and 56 reefs with an area of 203.70 km². The atoll consists of 99 islands (77 vegetated and 22 unvegetated) of which 11 islands are inhabited with a recorded population of 18,281 individuals. According to data from the Maldives Bureau of Statistics (MBS), fisheries constitute the primary economic activity in Laamu Atoll, closely followed by agriculture.

The inhabited islands of Laamu Atoll are administered by their own island council led by the elected councillors. Each island also has an elected Women’s Development Committee (WDC). The capital island of the atoll is Fonadhoo, which is the base for the Atoll Council. The Atoll Council is comprised of an elected president and the presidents of all island councils. There are 13 public schools on the atoll, with all schools except one providing secondary level education.

The Five selected ESA for the purpose of the baseline assessment in Laamu Atoll (Figure 1A) are as follows:

- 6. Fonadhoo Diving Point:** This site is in the southeastern side of Laamu Atoll within the jurisdictional boundary of Laamu Fonadhoo, the capital island of Laamu Atoll. It is on the island's southern edge on the outer reef area.
- 7. Isdhoo Muli:** This site is located on the northeastern tip of Laamu Atoll within the jurisdictional boundary of Laamu Isdhoo. It is on the island's northeastern edge on the outer reef area.

- 8. Mathigulhi Sarahadhu:** This site is located on the southwestern side of Laamu Atoll, on the western lagoon of Kunahandhoo. There are two vegetated islands and several rock banks within this area and scattered small seagrass habitat.
- 9. Mundoo Channel:** This site is located on the central eastern side of Laamu Atoll, north of Mundoo and south of Maabaidhoo islands. It is a channel that connects the inner atoll with the open ocean.
- 10. Reethi Haa and Hudhafaru:** This site is located on the southern inner atoll area of Laamu Atoll, north of Maamendhoo and Olhuveli islands. The southern part of the site, consisting of Laamafaru Haa and Reethi Haa dive sites and northern reef of Maamendhoo island is within the Maamendhoo island boundary.

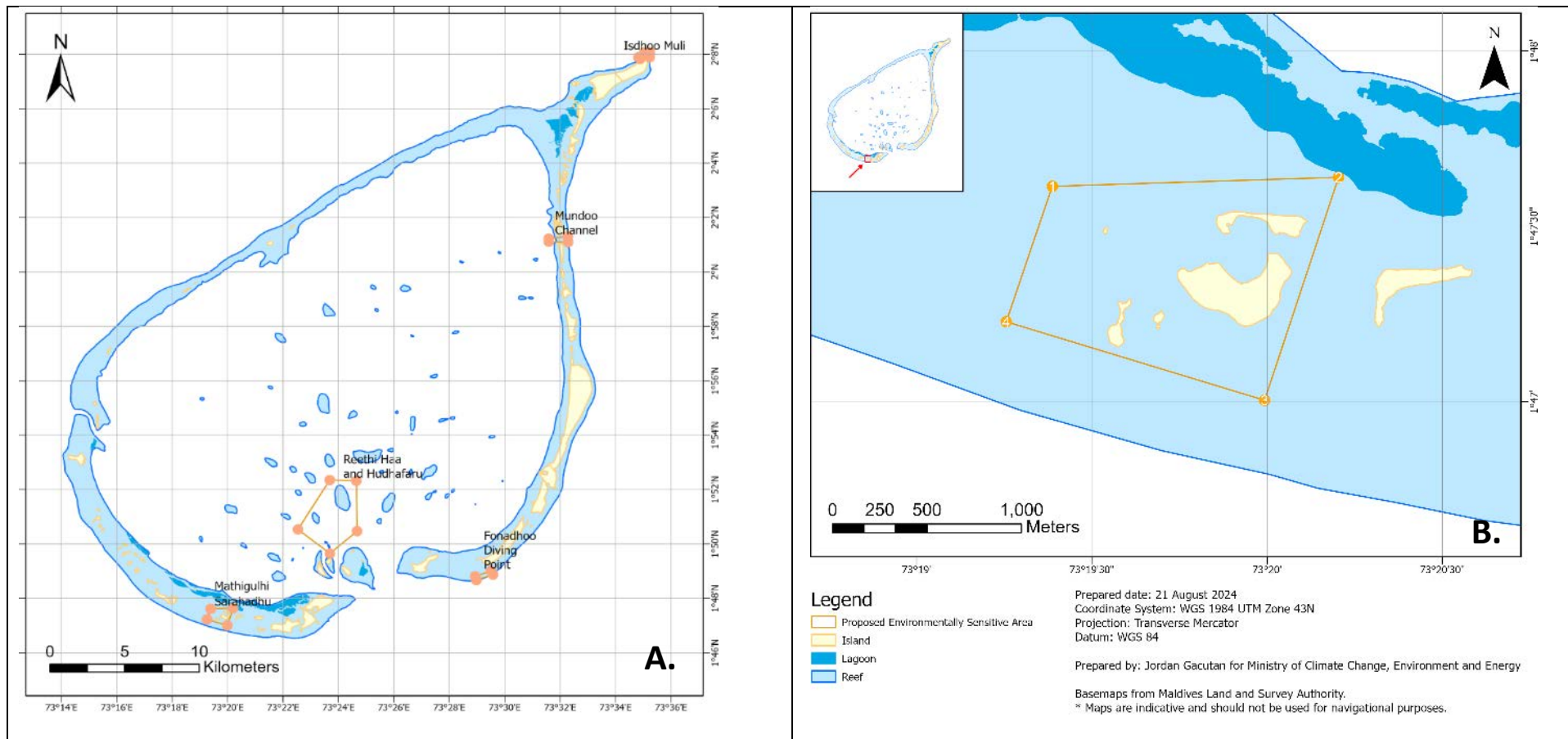


Figure 41. Overview of five selected ESAs for the baseline assessment (A) and view of Mathigulhi Sarahadhu.

Table 18. Vertex coordinates for Mathigulhi Sarahadhu ESA.

Name	Vertices	Easting	Northing
Mathigulhi Sarahadhu	1	313469.3	198328.8
	2	314984	198374.9
	3	314591.4	197202.4
	4	313225.3	197616.6

As Mathigulhi Sarahadhu is the only ESA with significant land area, it is the focus of the report (Figure 2). Within this area, there are two large, vegetated islands. Kudafushi (LD1025, 12.27 hectares) is classified as an industrial agricultural island under the jurisdiction of the Ministry of Agriculture and Animal Welfare and is leased to a private party called Eco Edge Pvt. Ltd., K. Male' for long-term since 1 November 2018. Maafushi (LD0951, 2.91 hectares) is classified as an uninhabited island and has been leased under the “varuvaa” scheme to Aminath Abdullah Haalam, Green Design, H.Dh. Kulhuffushi by Laamu Atoll Council. Two smaller, rubble-dominated islands, Bodumahigulhi (LD0599, 1.11 hectares) and Kudamahigulhi (LD0902, 0.25 hectares), are classified as uninhabited and fall under the jurisdiction of the Laamu Atoll Council. Additionally, a fifth, unnamed supra-tidal area, primarily composed of coral rubble and sand, is located to the northwest (Table 2).

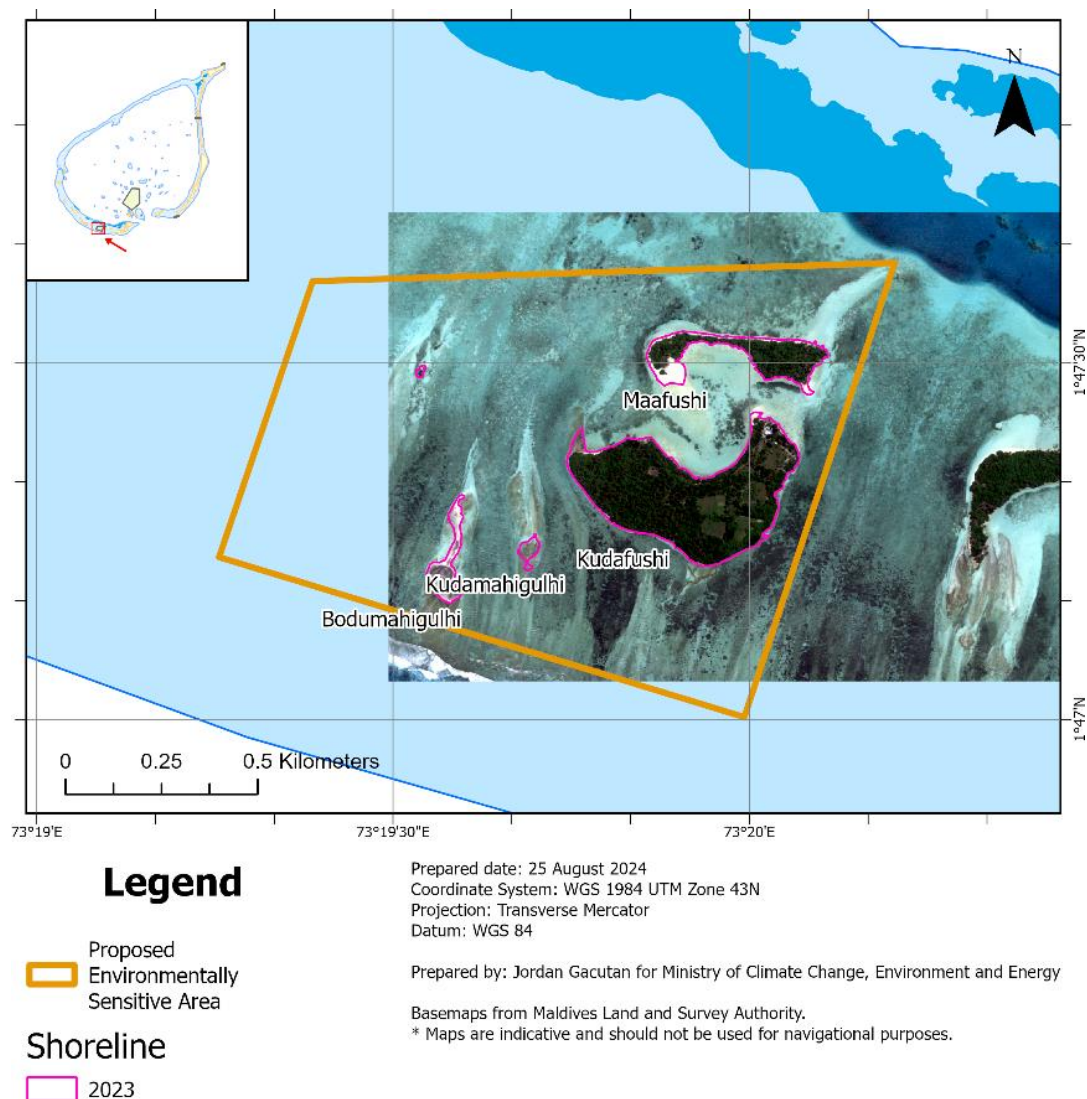


Figure 42. Overview of land areas of Mathigulhi Sarahadhu, marking the shoreline in 2023.

Table 19. Island names within Mathigulhi Sarahadhu proposed ESA. *MAAW = Ministry of Agriculture and Animal Welfare

Island name (English)	FCODE	Area in 2023 (ha)	Longitude	Latitude	Category	Primary Agency*
Bodumahigulhi	LD0599	1.00	73° 19' 34.636" E	1° 47' 13.089" N	Uninhabited Island	Laamu Atoll Council
Unnamed	LD0368	0.05	73° 19' 32.344" E	1° 47' 29.235" N	Uninhabited Island	-
Maafushi	LD0951	3.30	73° 19' 59.419" E	1° 47' 30.460" N	Uninhabited Island	MAAW
Kudafushi	LD1025	12.59	73° 19' 54.691" E	1° 47' 19.074" N	Industrial Island / Agriculture	Unclear
Kudamahigulhi	LD0902	0.25	73° 19' 41.445" E	1° 47' 14.114" N	Uninhabited Island	Laamu Atoll Council

2.2 Shoreline and land classification

Land classification involves mapping and categorizing the different types of habitats. For this purpose, high-resolution satellite imagery from Airbus were utilized due to its superior spatial resolution.

The Pléiades satellites, also operated by Airbus Defence and Space, provide very high-resolution imagery with a spatial resolution of 0.5 meters. This level of detail allows for exceptionally precise mapping of benthic environments, capturing fine-scale features of coral reefs, seagrass beds, and other underwater habitats. Pléiades satellites offer both panchromatic and multispectral imagery, which includes blue, green, red, and near-infrared bands, essential for accurate benthic classification. Pléiades Neo offers even higher resolution imagery at 0.3 meters. This ultra-high resolution enhances the ability to detect and classify detailed habitats with even higher accuracy.

To assess shoreline changes on the two selected islands in Laamu Atoll, we employed high-resolution satellite imagery analysis. These ultra-high-resolution images allowed for precise mapping and tracing of shorelines using ArcGIS Pro (v3.1). The multispectral capabilities of these satellites, including blue, green, red, and near-infrared bands, further enhanced our ability to accurately delineate the land-water interface.

Land-use changes were evaluated through a combination of remote sensing and field validation techniques. We conducted visual interpretation of the high-resolution satellite imagery to identify and map different land cover types and uses. This process was significantly aided by the satellite imager which allowed for the detection of fine-scale features and detailed habitat classification. To ensure the accuracy of our remote sensing-based land use classifications, we carried out field validation surveys in 2023. These surveys followed the methodology for Small Island Vegetation Assessments¹⁸, providing ground-truth data to refine and verify our satellite-based land use maps.

¹⁸ Dryden and Basheer, 2021: <https://www.environment.gov.mv/v2/en/download/14746>.

3. Geomorphological change at Mathigulhi Sarahadhu

Results from the shoreline land classification analysis revealed a series of geomorphological changes at Mathigulhi Sarahadhu (Figure 3). From 2014 to 2023, changes in size are noted for Bodumahigulhi, Kudafushi, and Maafushi (Table 3), whereas Kudamahigulhi and the unnamed island remained stable.

Bodumahigulhi and Kudafushi both increased in size from 2018 to 2019, however from 2019 to 2023 they both declined in size (Table 3). The fluctuation in size over time is largely due to erosion and movement of sand spits. The change in shoreline of both islands can be observed in Figure 3.

Maafushi increased in size from 2016 through to 2023 (Table 3). This island experienced the most erosion from 2014 to 2016 on the west side of the island, however much of it is likely due to changes in shoreline via sand spit movements (Figure 3).

Dynamics in sand spit movement were observed for Kudamahigulhi and the unnamed island (Figure 3), however this did not influence the overall area of those islands.

Table 20. Areal change between 2014 and 2023

	Area (ha)				
Island name (EN)	2014	2016	2017	2019	2023
Unnamed	0.05	0.05	0.05	0.05	0.05
Bodumahigulhi	1.11	1.11	1.11	1.19	1.00
Kudafushi	12.27	12.27	12.27	12.66	12.60
Kudamahigulhi	0.25	0.25	0.25	0.25	0.25
Maafushi	2.91	2.91	2.91	3.25	3.30

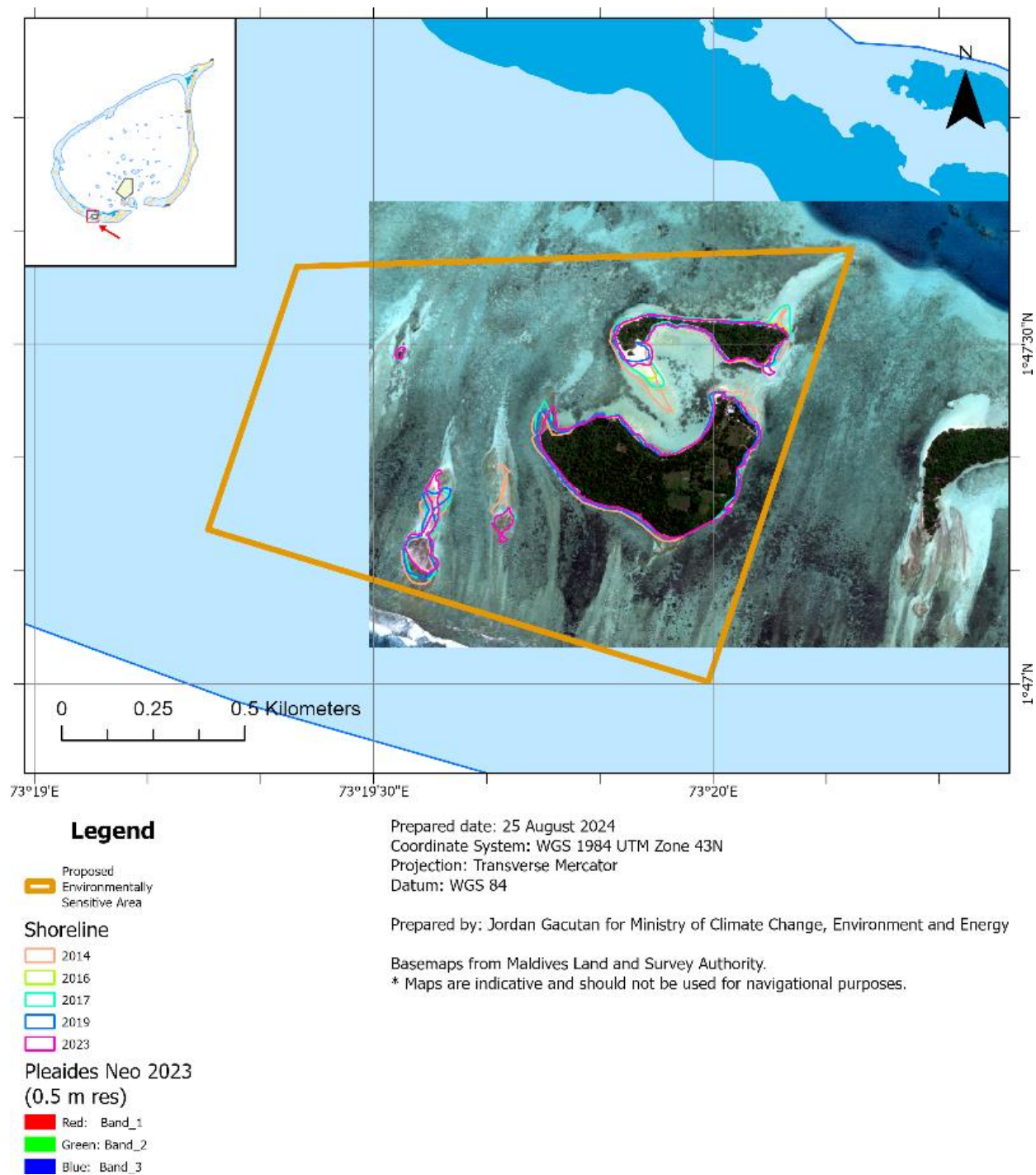


Figure 43. Shoreline change for islands of Mathigulhi Sarahadhu between 2014 and 2023.

4. Land cover change at Kudafushi

As an industrial agricultural island, land use change was only identified on Kudafushi. Variability in cleared land is observed between 2014 and 2023, with the clearing for fields and paths. Differences in the shape and size of cleared land may be due to the time of year and increasing resolution from at 0.5 m (2013 – 2019) to 0.3 m in 2023.

Before 2016, the island was completely vegetated, with lower canopy cover of the vegetation to the North-East of the island. The satellite image in 2016 first detected clearing for agricultural land and paths, with four agricultural fields and a path from east to west across the island's northern coast (Figure 5). There also appears to be a structure built in the north-east of the island. A north to south path may have already been developed by 2016, but there is a degree of uncertainty since the satellite image was obscured by clouds (see Annex, Table A1). At this time, cleared land amounted to approximately 19% of the total island area.

The total area taken up by cleared land increased to 21% in 2017, and then to 25% in 2019 with the addition of a field to the southeast of the island (Figure 5). Further, areas to the north-east were utilised for other purposes beyond agriculture, as indicated by additional built infrastructure.

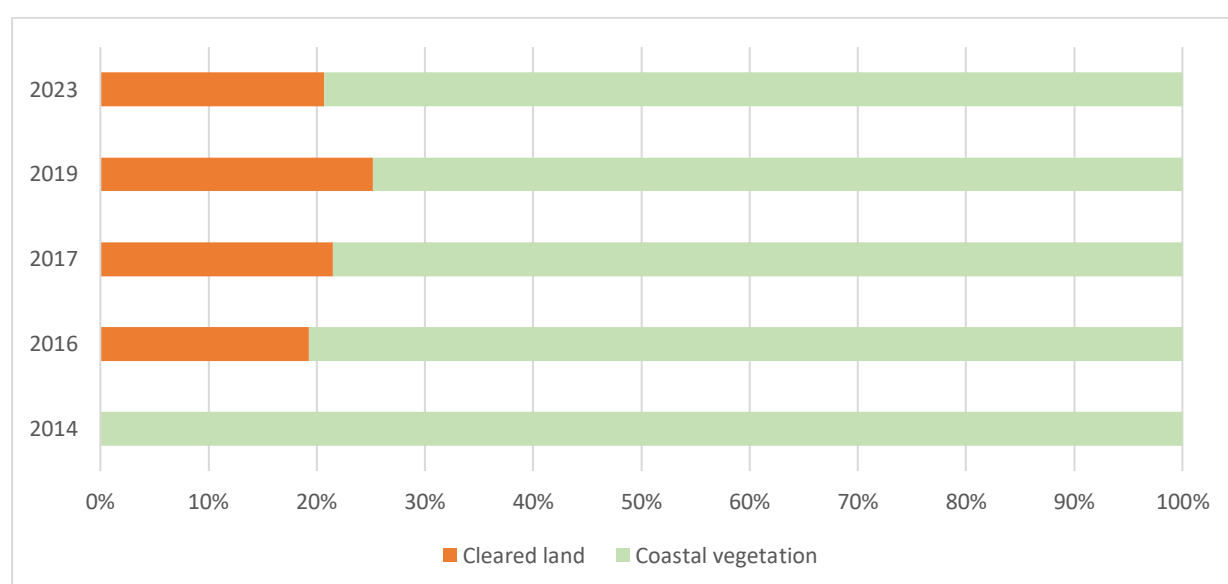


Figure 44. Land clearing as a percentage of total area on Kudafushi island between 2014 and 2023.

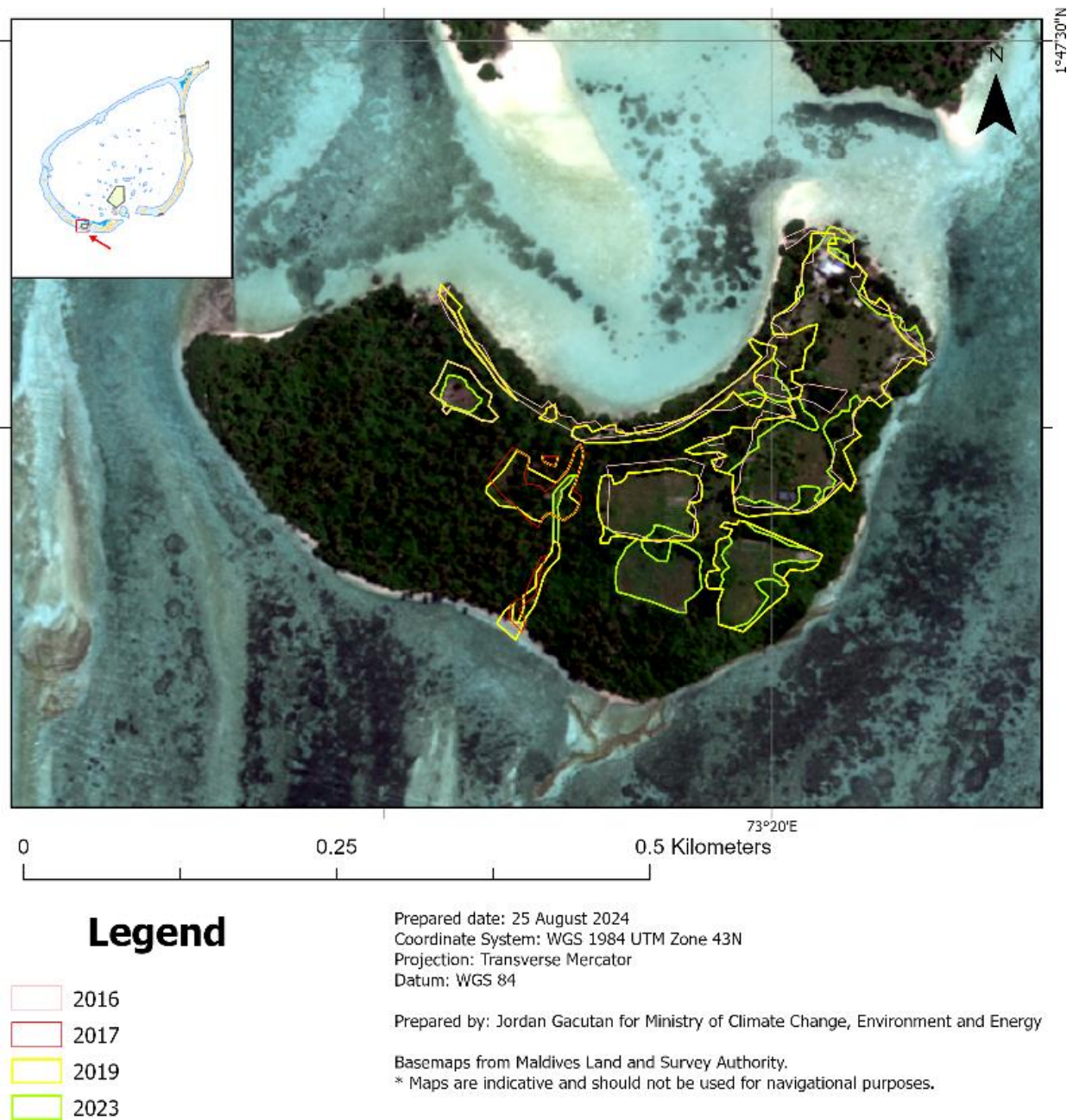









Figure 45. Overview of land cover change from coastal vegetation to cropland on Kudafushi island between 2014 (no clearing) and 2023.

Annex 1: Satellite images

Table. A1. Airbus satellite images procured for Mathigulhi Sarahadhu between 2013 and 2023, recording date and time of capture, satellite platform, resolution, capture angle and cloud cover.

	
16 Dec 2013 05:34 UTC / Pléiades / 0.5m / 16° / 0%	25 Jan 2014 05:26 UTC / Pléiades / 0.5m / 28° / 1%
	
17 Dec 2016 05:45 UTC / Pléiades / 0.5m / 16° / 2%	05 Jan 2017 05:48 UTC / Pléiades / 0.5m / 25° / 0%
	
10 Sep 2019 05:27 UTC / Pléiades / 0.5m / 27° / 0%	14 Mar 2022 05:29 UTC / Pléiades / 0.5m / 20° / 9%
	
28 Jun 2023 05:49 UTC / Pléiades Neo / 0.3m / 30° / 3%	