



Ministry of Climate Change,  
Environment and Energy



# Report of findings on habitat pattern of the ICZM

using remotely sensed data and through  
field validation



**Project: Consultancy Service for Development of Natural Capital Accounting with initiating pilot testing of the SEEA Ecosystem Accounting (SEEA EA) in Laamu Atoll**

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*Consultants:*

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## 1. Executive summary

This report provides a baseline analysis of the habitat patterns within Laamu Atoll, with specific attention to habitat and vegetation within mangrove and seagrass ecosystems, in support of pilot testing of the System of Environmental-Economic Accounting Ecosystem Accounting (SEEA EA) in Laamu Atoll. The report contains:

- Time series of mangrove and seagrass ecosystem extent within each protected area,
- Analysis of potential drivers of seagrass species distribution across Laamu Atoll, and
- Analyses of factors contributing to species diversity and community composition.

Data was gathered from multiple sources, including field visits, remote sensing and literature review.

### Key Findings:

1. Four protected areas contained mangroves (Hithadoo Wetland and Surrounding Marine Area, Maabaidhoo Koaru Area, Gaadhoo Turtle Nesting Area, Mangrove and Seagrass Area and Gan Boda Fengan'du Area). The Hithadoo Wetland on Laamu Atoll contains the only pure stand areas (>80% mangrove coverage). Limited changes have been observed since 2017.
2. Seagrass meadows in Laamu Atoll are extensive and support six out of seven (according to Stevens and Froman, 2019) seagrass species found in the Maldives (although potentially 8 have been identified). This indicates a diverse and abundant seagrass ecosystem in the protected areas of Laamu Atoll.
3. There has been both a marginal decrease and a marginal increase in seagrass extent in some of the protected areas between 2017 and 2022. The change in extent may be influenced by a range of factors related to remote sensing, such as reflectance, capture angle, and cloud cover. Changes due to anthropogenic and natural causes could not be decoupled specifically through remote sensing.
4. The dominant seagrass species in most of Laamu Atoll and its protected areas is *Thalassia hemprichii*, followed by *Cymodocea rotundata*. However, there are variations in species composition in different areas, indicating that environmental factors may influence the presence and distribution of seagrass species.

## 2. Introduction

### Background

The Government of the Republic of the Maldives is developing natural capital accounts through pilot testing the [SEEA Ecosystem Accounting \(SEEA EA\)](#) framework in Laamu Atoll, an ecologically sensitive and economically important area in southern Maldives. The framework serves as a tool to promote sustainable developments and help ensure that the value of natural resources and the ecosystem in the Maldives, especially in Laamu Atoll, are fully accounted for in the decision-making process.

### *Supporting Ecosystem Accounting*

The SEEA Ecosystem Accounting (SEEA EA) is an integrated and comprehensive statistical framework developed to organize data about habitats and landscapes, measure ecosystem services, track changes in ecosystem assets, and link this information to economic and other human activities in a spatially explicit manner (Figure 1). That is achieved by measuring:

- ecosystem extent (i.e., area), commonly through field survey and remote sensing,
- ecosystem condition - specific to ecosystem type, and
- services in physical and monetary terms.

The SEEA Ecosystem Accounting is particularly important for the management of blue carbon ecosystems because it enables the valuation and recognition of their contributions to climate change mitigation, adaptation and societal well-being, provides the basis for incorporating the value of blue carbon ecosystems into decision-making and sustainable development planning (see Edens et al. 2022).

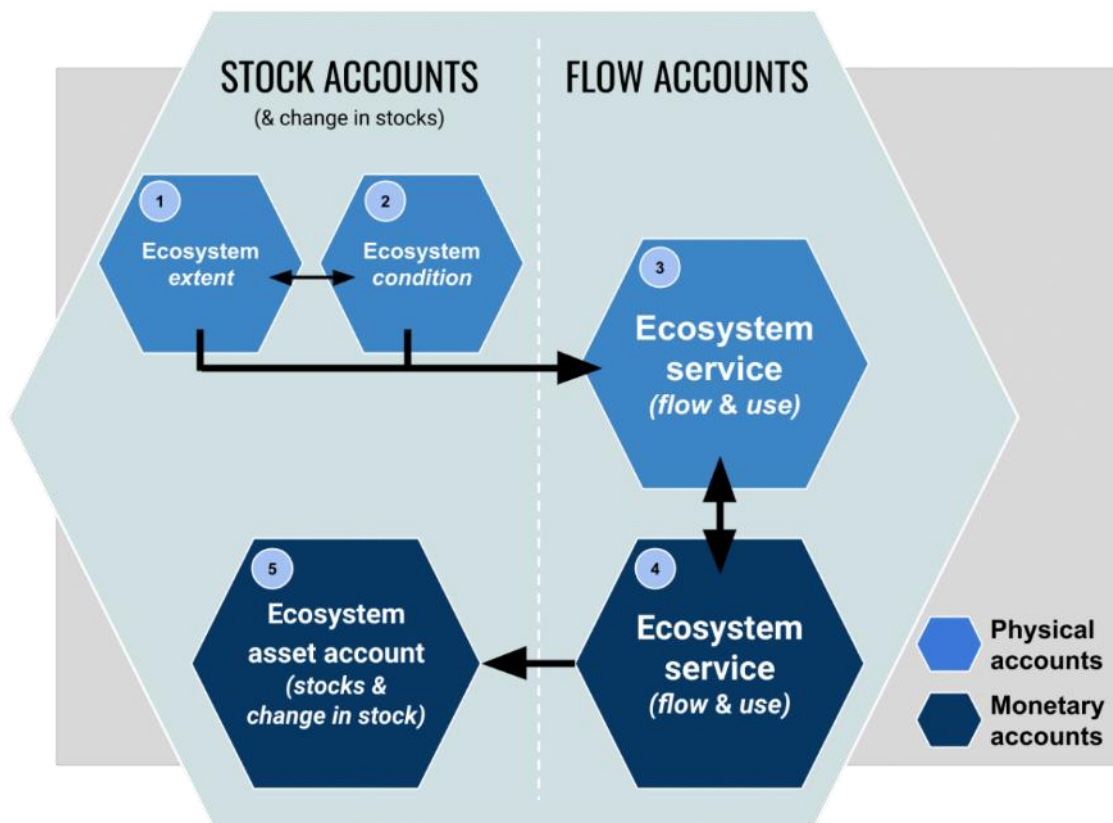


Figure 1. Ecosystem Accounting structure. Source: <https://seea.un.org/ecosystem-accounting>

### Seagrass

The measurement of extent and condition for seagrass ecosystems in the context of SEEA Ecosystem Accounting (SEEA EA) is based on the following principles:

- **Extent:** Seagrass extent is measured as the total area of seagrass meadows within a defined ecosystem accounting area (EAA). This can be done using a variety of methods, including remote sensing (e.g., satellite imagery and aerial surveys) and ground surveys.
- **Condition:** Seagrass condition is measured using a set of variables that reflect the health and functioning of seagrass ecosystems. These variables can include parameters such as seagrass density and coverage, shoot length, biomass, and species diversity.

### Mangroves

The measurement of extent and condition for mangrove ecosystems in the context of SEEA Ecosystem Accounting (SEEA EA) is based on the same principles as for seagrass ecosystems:

- **Extent:** Mangrove extent is measured as the total area of mangrove forests within a defined ecosystem accounting area (EAA). This can be done using the same methods as for seagrass ecosystems, such as remote sensing, aerial surveys, and ground surveys.



- **Condition:** Mangrove condition is measured using a set of variables that reflect the health and functioning of mangrove ecosystems. These variables can include parameters such as mangrove density, tree height, canopy cover, and species diversity.

The specific methods used to measure seagrass and mangrove extent and condition will vary depending on the availability of data and resources. However, it is important to use consistent methods over time to ensure that changes can be accurately tracked.

### *Relevance to Protected Areas*

SEEA EA provides a comprehensive framework for accounting for the full range of ecosystem assets and their services, in physical and monetary terms. SEEA Ecosystem Accounting, as performed for Laamu Atoll, can support the management of protected areas in a number of ways, including:

1. **Identifying and tracking the extent and condition of ecosystems within protected areas.** This information can be used to track changes in the extent and condition of ecosystems over time, as well as to identify areas that may be under stress.

For example, SEEA EA could be used to track changes around seagrass meadows, the number of mangrove trees, or the biomass of fish stocks within a protected area. This information could be used to identify trends in ecosystem health and to identify areas where management interventions may be needed.

2. **Underpinning adaptive management.** SEEA EA allows for the continuous monitoring and assessment of ecosystem assets and services, enabling adaptive management strategies that can respond to changing ecological conditions and conservation needs.

For example, through the SEEA EA framework, it is possible to regularly assess the extent, health and biodiversity of the marine ecosystems, tracking changes over time. Such changes can be linked to management approaches and provide insights related to their outcomes. Successful outcomes can show the efficacy of specific measures while unsuccessful measures can be changed and monitored.

This adaptive management approach, informed by the comprehensive and up-to-date insights from SEEA EA, ensures that the the objectives of protected areas management are met effectively.

3. **Assessing the value of protected areas to society.** SEEA EA can be used to assess the economic and social benefits that protected areas provide, such as recreation, tourism, water purification, and climate regulation. This information can be used to justify the investment of resources in protected area management and to demonstrate the value of protected areas to decision-makers and stakeholders.

For example, SEEA EA could be used to estimate the economic value of the tourism revenue generated by a protected area or the value of the water purification services provided by wetlands within a protected area. This information could be used to make the case for increased funding for protected area management or to

secure payments for ecosystem services from businesses that benefit from the services provided by protected areas.

4. **Supporting integrated decision-making.** SEEA EA can be used to integrate information about ecosystems and their services into broader decision-making processes, such as land use planning, economic development planning, and climate change adaptation planning. This can help to ensure that the benefits of protected areas are considered alongside other factors when making decisions that affect them.

For example, SEEA EA could be used to inform decisions about where to locate new roads or development projects to minimize the impact on protected areas. SEEA EA could also be used to inform decisions about how to allocate resources to different sectors of the economy, such as agriculture, tourism, and energy, to maximize the benefits from protected areas while also minimizing the trade-offs.

As SEEA EA becomes more widely adopted, it could play an increasingly vital role in supporting the management of protected areas within the Maldives.

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## Scope and aims

This report accompanies two complementary deliverables provided to the Ministry of Environment, Climate Change and Technology (MECCT), in support of Natural Capital Accounting within the Maldives. The contents of the reports are listed below, in addition to the scope of the present report.

1. Report on historical analysis of the dynamic of the ecosystem and their services under current intervention management inside the ICZM
  - Change in ecosystem extent for mangrove, seagrass and coral reefs within protected areas < 10 m in depth,
  - Potential change in ecosystem services (provisioning, regulating and cultural) per protected area, and
  - Description of potential methods to expand analyses to examine specific ecosystems and their services.
2. Flora, fauna, and soil assessment report, inside and in the vicinity of the ICZM by using remotely sensed data and field verification.
  - An assessment of soil (sub-tidal and land) across Laamu Atoll, with specific attention to protected areas,
  - An assessment of biodiversity (both flora and fauna) with Laamu Atoll, **describing species** for mangroves and seagrass by direct survey and citizen science databases for other species,
  - General analysis of changes in species diversity and community composition across the islands, from windward (ocean-facing) to leeward (lagoon-facing) areas.

The present report focuses on ecological aspects of mangroves and seagrass within the protected areas of Laamu Atoll, using extensive statistical analyses. Specifically, we:



- Assess the extent of mangroves across Laamu Atoll over time in support of NCA,
- Assess the condition of mangroves using field surveys (conducted in May and August 2023),
- Assess the extent and condition of seagrass in support of NCA using field surveys (conducted in May and August 2023), and
- Assess potential factors influencing species composition of seagrass, within protected areas.

### Objectives

This report furthers the objectives of the Terms of Reference (TOR, 438-ENV/438/2022/27) by:

- Testing methods of data collection within Laamu Atoll, with the view to extend this exercise to the whole Maldives, and
- Establishing analyses that support the compilation of NCA.

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### Protected Areas of Laamu Atoll

Protected areas play a crucial role in preserving biodiversity and maintaining the health and resilience of ecosystems. They attempt to reduce human pressures on endangered species, promote ecosystem services, and contribute to scientific research and environmental education. Six sites of environmental significance at Laamu Atoll were declared protected in 2021 (Figure 2), under the Environment Protection and Preservation Act [(IUL)438-ENV/438/2021/371]. The sites include wetlands, reefs, lagoons, mangroves, seagrass meadows, and beaches and include:

- Bodu Finolhu and Vadinolhu Kandu Olhi Area,
- Fushi Kan'du Area & Maabaidhoo Koaru Area,
- Gan Boda Fengan'du Area,
- Gaadhoo Turtle Nesting Area, Mangrove and Seagrass Area,
- Gaadhoo – Hithadhoo Gan'du Area, and
- Hithadhoo Wetland and Surrounding Marine Area.

The protected areas are either marine or terrestrial and may be defined under six categories: Internationally recognized areas, Strict nature reserve, Wilderness Areas, National Park, Natural Monument, Habitat/Species Managed area, or Protected areas with sustainable use.

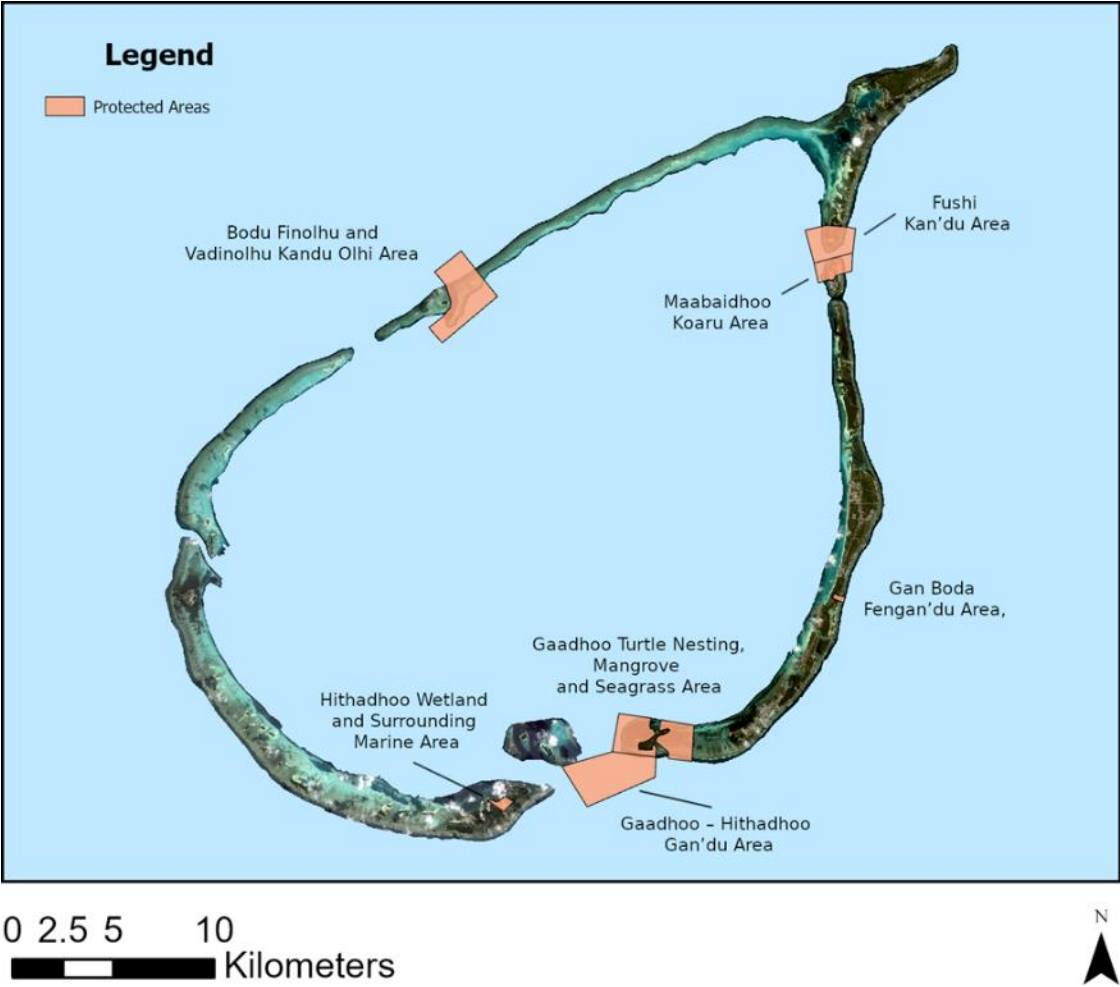


Figure 2. Protected areas within Laamu Atoll, since 2021.

### 3. Methodology

#### Overview of the process

Data was collected to align with SEEA Ecosystem Accounting, to provide information on ecosystem extent and condition, to provide insights into the habitat pattern of the ICZM.

The following process was conducted for analysis:

1. **Define scope of analysis**, including the classifications and methods for sampling extent and condition.
2. **Classification and Mapping**. Classification was conducted using the supervised classification algorithms within ENVI (Harris Geospatial). The algorithm was trained using ground-truthing points. Mapping was conducted on ArcGIS.
3. **Habitat pattern analysis**. Data was analyzed using R (v4.1) to determine trends in community composition and species diversity for seagrass.

#### Analysis scope

The present study analyses the extent and condition of mangroves and seagrass, in support of SEEA Ecosystem Accounting. Further, we perform an analysis of factors influencing seagrass distribution and abundance to determine the important biophysical factors related to community composition. The report used the following methods:

- Remote sensing (satellite data for benthic classification) to classify ecosystems and measure their **extent**,
- Field surveys (ground truthing and species surveys) to assess **condition**, and
- Further spatial and statistical analyses to detect factors influencing species diversity and abundance.

Seagrass and mangroves were defined in line with the IUCN's Global Ecosystem Typology (GET) to provide a standardized and consistent classification of ecosystems.<sup>1</sup> The GET provides a hierarchical system for categorizing terrestrial, marine, and freshwater ecosystems based on their ecological characteristics and functions. The typology employs a robust set of criteria, considering biophysical attributes, species composition, and ecosystem dynamics, to classify ecosystems into distinct units and group them into broader categories.

#### Classification and Mapping

##### *Remote sensing*

Remote sensing is a cost-effective technique in detecting the coverage of an ecosystem and changes over time. Satellite imagery was used to support the mapping of substrate across Laamu Atoll. SPOT-6 and SPOT-7 satellites were used (operated by Airbus Defence and Space), which are twin optical imaging satellites that form a constellation that provides

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<sup>1</sup> Please also see "Applying the IUCN Global Ecosystem Typology to the Maldives" (IUCN, 2022): <https://www.environment.gov.mv/v2/en/download/14710>

high-resolution, wide-swath imagery of the Earth. SPOT-6 and SPOT-7 have a resolution of 1.5 meters in the panchromatic band and 5.5 meters in the four multi-spectral bands (blue, green, red, and near-infrared).

The following process was conducted for mapping:

- Multi-spectral satellite data were acquired for the target areas,
- Supervised classification was used to define the extent of seagrass and other classes across the atoll, based on visual interpretation, ground truthing points and spectral analysis, and
- Maps were produced and processed using ENVI (Harris Geospatial) and ArcGIS.

**Note:**

- Habitats with a total patch area > 5 m in area were detected accurately.
- 'Cloud' refers to areas masked by cloud cover.

*Ground truthing*

Before analyses took place, a site visit was conducted in March 2023 to discuss the potential coverage of ecosystems with local stakeholders, identify appropriate sampling and classification method and ensure the accuracy and reliability of data acquired through remote sensing techniques. Ground truthing was employed adjacent to habitat surveys, to align and validate the remote sensing data. A critical component of this involved considering variations in color tone and object characteristics observed in satellite imagery compared to the subsequent characteristics on land and at sea during ground truthing for mangrove, seagrass, and coral reef features.

Ground truthing surveys were conducted to enable remote sensing of soil and substrate variability across Laamu Atoll. Two field surveys were conducted, in March and August 2023, resulting in 357 ground truth points and over 300 images / video transects (Figure 3).

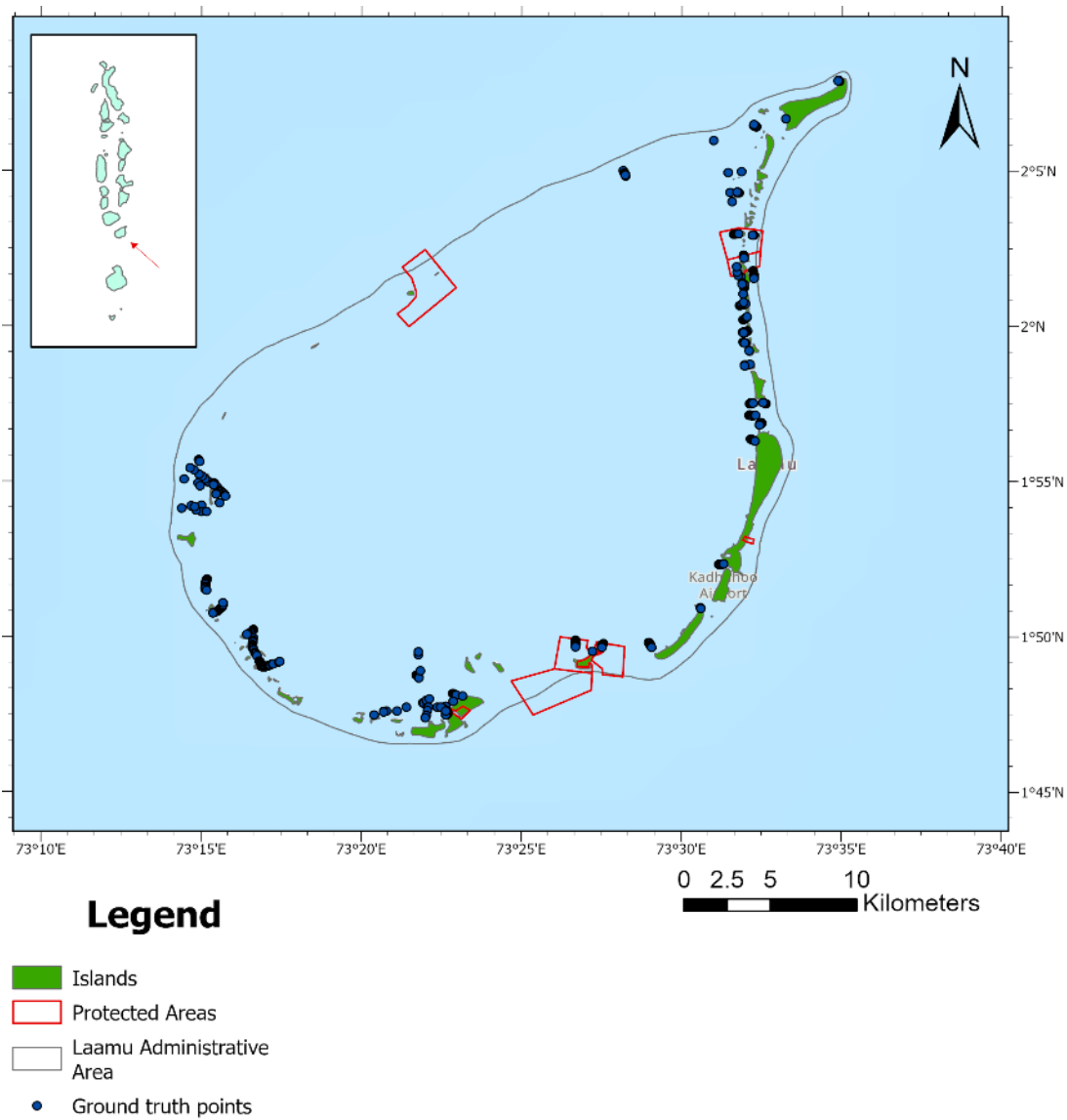


Figure 3. Map of ground truth points collected in March and August 2023 across Laamu Atoll. Protected Areas highlighted in red.

## Habitat pattern analysis

### Field surveys

Field surveys are an essential part of collecting biodiversity and community composition data on mangroves and seagrass that cannot currently be gained through remote sensing. Field surveys collect data on a variety of factors, including species composition, abundance, distribution, and indicators of health. The data collected during the field surveys of mangroves and seagrass included:

- **Species Identification:** Comparison of observed individuals with visual guides.
- **Density / Abundance:** The abundance of a species is the number of individuals of that species that are present in a mangrove or seagrass community.

- **Distribution:** 31 sites were sampled for seagrass, while 3 sites identified true mangroves in Laamu Atoll. By comparing sites spatially, the important factors influencing distribution could be identified.

Observation sites were determined before the field visit, based on data from satellite imagery. The initial mapping of the seagrass ecosystem in Laamu Atoll considered the differences in color tone and object characteristics on the satellite imagery. After that, survey locations were selected by considering several aspects, including the cardinal directions and wind direction (windward and leeward). Some other considerations in determining the survey locations included weather conditions and accessibility to the locations.

### Seagrass

Seagrass observations employed the line transect method, modified from Seagrass Watch guidelines (McKenzie, 2003) and aligned with the national standard. The transect line was drawn perpendicular from the shoreline to the reef crest for a maximum distance of 50 m. This method ensured the representation of the condition and species of seagrass found in the location and detect any potential pressures. Furthermore, observations were made using a 1 x 1 m squared transect placed systematically along the transect line with 5 m between transects. The quadratic transect was divided into 100 squares (10x10 cm) to facilitate observation and estimation of seagrass cover (Figure 4). The parameters observed included:

- Substrate/sediment type,
- Percentage cover of seagrass and by seagrass species,
- Percentage of cover from other organisms (coral, macroalgae), and
- Seagrass canopy height and diameter, and epibenthic cover (Figure 5).

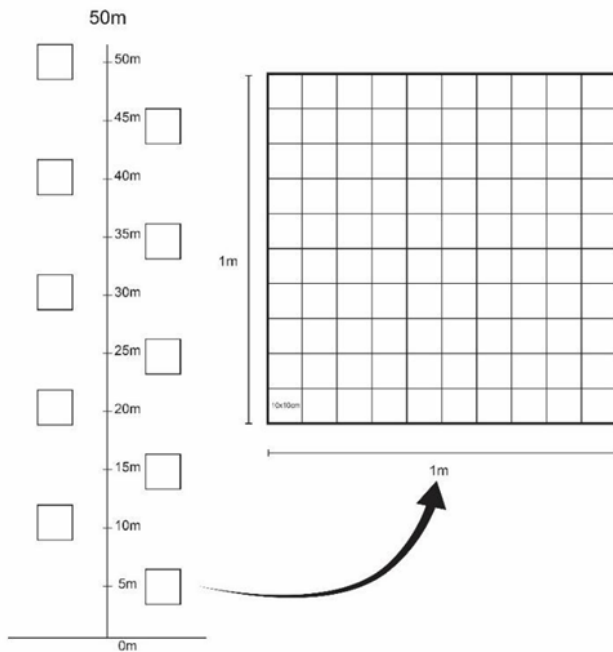


Figure 4. Illustration of seagrass data collection transects.



Sediment type was determined by digging the top layer of the substrate on each quadratic transect and identifying the texture. Sediments can be categorized based on the size of the particles collected (e.g., rubble, sand, mud). Seagrass cover percentage was taken in each squared transect using a visual estimation method based on Seagrass-Watch guidelines for standard seagrass cover percentage.

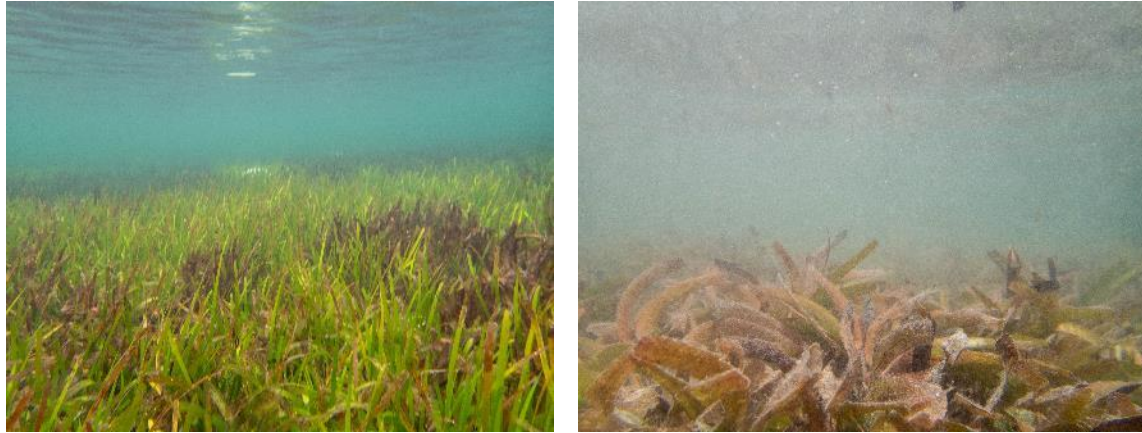


Figure 5. Healthy seagrass (left) and seagrass with high macroalgae and epiphyte cover (right) from Laamu Atoll, taken in March 2023 by consultants.

## Mangrove

Mangroves were identified in only three protected areas, namely:

- L. Maabaidhoo Koaru Area,
- L. Gan Boda Fengan'du Area, and
- L. Hithadhoo Wetland and Surrounding Marine Area.

Vegetation structure was measured using the Quarter plot sampling method to obtain baseline data for mangroves, including an analysis of the current condition of the mangrove community. Sampling was carried out with the transect quadrat plot of 10 x 10 meters for mangrove trees, plot 5 x 5 meters for saplings, and plot 1 x 1 m for seedlings (Figure 6).

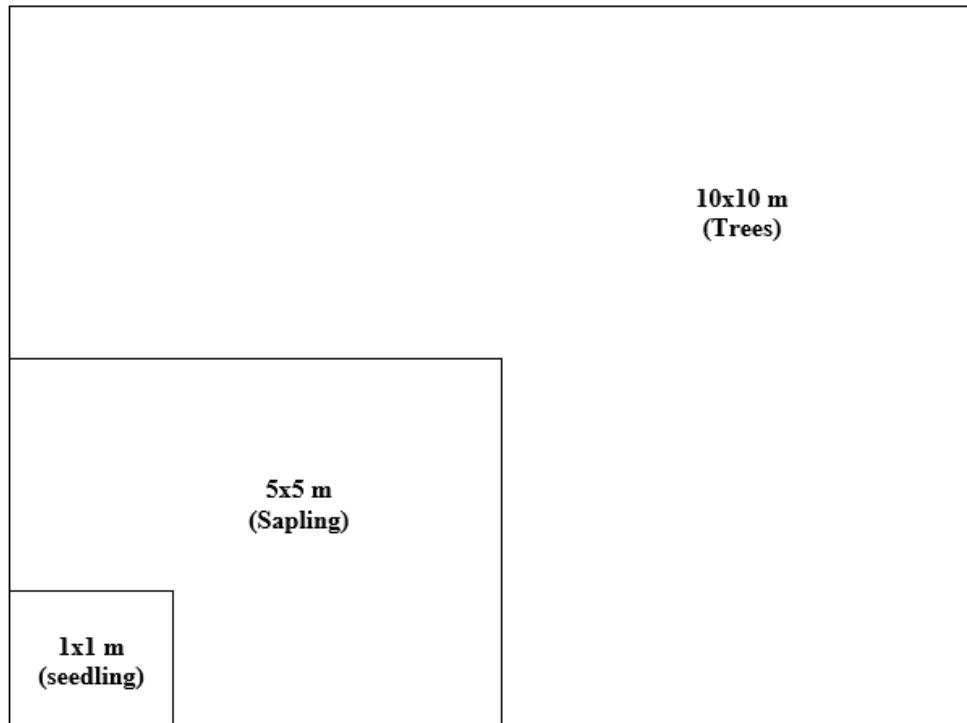


Figure 6. Sampling plot of mangrove ecosystem to measure vegetation structure.

The method for collecting mangrove data in the research referred to the Manual for Mangrove Community Structure Monitoring in Indonesia-LIPI (Dharmawan et al., 2020). The purpose of vegetation structure measurement is to describe the current condition of the mangrove structure. Species name, number of trees, diameter of tree, and height of tree were recorded per plot.

Canopy cover of mangrove in Laamu Atoll was calculated by measuring the percentage of the forest floor that is covered by tree canopy (trunk and foliage). A ground-based method was used to estimate the cover of mangrove. A hemispherical camera was used to capture the image of the sky and vegetation from the fixed position. The images were then assessed using ImageJ to analyse the canopy percentage.

## Habitat pattern analysis for extent and condition

Due to data limitations, more complex habitat patterns could **only be assessed for seagrass ecosystems**. Seagrass community composition changes in response to a variety of natural and human-induced disturbances: such as storms, hurricanes, and human activities (agriculture, dredging, sand mining).

We analysed the following:

- **Changes to seagrass cover** - as an indicator of coastal development, which lead to increased sedimentation and runoff from land.
- **Changes to species** - some species are more resistant to pollution than others.

### *Percentage Cover*

While there was limited evidence for major changes to seagrass extent within the examined years, field surveys examining the percentage cover within a seagrass meadow could reveal changes to health. Seagrass meadows with high percentage cover are healthy, while meadows with low percentage cover (relative to the site context or baseline) may be considered unhealthy. Tracking percentage cover is an indicator of seagrass ecosystem health as:

- **Abundance is related to ecosystem functioning:** Seagrass plants are the primary producers in seagrass ecosystems, and they provide food and habitat for a variety of other organisms. Therefore, a high percentage cover of seagrass indicates that the ecosystem is productive and can support a diverse range of life.
- **Cover is related to structural complexity:** More complex habitat provides important refuge for fish and other marine life from predators and currents. Such cover may also be related to water filtration and reducing erosion.
- **Cover may be linked to resilience:** Seagrass meadows with high percentage cover may be able to better withstand disturbances, such as storms and pollution, than meadows with low percentage cover.

### *Species composition as an indicator*

Seagrass species respond differently to various environmental and human pressures. For instance, some seagrass species may be more sensitive to nutrient pollution than others, while some may be more resilient to changes in salinity or temperature. The diversity of seagrass species in each ecosystem can provide indicators for the stressors that ecosystem is facing. Species could change over time due to factors such as nutrients, exposure to wave energy, salinity and temperature.

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## Seagrass extent and condition in protected areas

Seagrass were identified in all protected areas **except** the Bodu Finolhu and Vadinolhu Kandu Olhi Protected Area and Gaadhoo – Hithadhoo Kan'du Area. Laamu Atoll contains extensive seagrass meadows, which support six of the seven known seagrass species within the Maldives. The extent and condition of seagrass were assessed using a combination of remote sensing and field surveys.

## Extent

Seagrass field surveys were conducted over two periods, in March and August 2023, with the goal of validating the available satellite imagery. Satellite images were compiled for 2017, 2020 and 2022. Analyses of habitats across Laamu Atoll in 2020 estimated seagrass as the dominant ecosystem (in coastal areas < 10 m depth), with an area of 4,128.77 Ha, relative to coral reefs (at 3,121.21 Ha) and mangroves (at 3.30 ha).

Between 2017 and 2022 (see Table 1):

- A marginal decrease in seagrass could be observed in three of the protected areas.
- A marginal increase could also be observed in three protected areas.

In explaining the change in extent per protected area, major additions or losses of seagrass could be explained from factors within the satellite imagery, such as reflectance, capture angle, cloud cover or other related factors.

Please note:

- Detailed maps of extent **per protected area** can be found in, “Report on historical analysis of the dynamic of the ecosystem and their services under current intervention management inside the ICZM,” and
- Description of seagrass species per protected area is explored in, “Flora and fauna soil assessment report, inside and in the vicinity of the ICZM.”

Table 1. Seagrass coverage for the years 2017, 2020 and 2022 per protected area.

Protected Area	2017	2020	2022*
Maabaidhoo Koaru Area	0.1970	0.1783	0.1811
L. Fushi Kan’du Area	0.4745	0.5278	0.4637
Gan Boda Fengan’du Area	0.0946	0.1117	0.0989
Gaadhoo Turtle Nesting Area, Mangrove and Seagrass Area	2.4911	2.5076	2.4362
Hithadhoo Wetland and Surrounding Marine Area	0.0321	0.0324	0.0401

Note: The 2022 satellite data had significant amounts of surface reflectance which may alter the accuracy of the remote sensing.

## Condition

### *Data available to link with protected areas*

For assessing trends in condition, 11 of the 31 sites were relevant to protected areas due to proximity. Across the sites, 32 transects were taken and the data was averaged across transects to assess condition. Relevant sites are listed in the **appendix**.

### *Percentage cover*

The following trends were identified:

- Seagrass cover ranged from 14% to 86% across sampled transects (Figure 7). Most areas adjacent to the shoreline within or near protected areas are dominated by seagrass meadows. Higher cover was found on exposed sites, compared to sites facing the lagoon in most islands.
- The Gaadhoo Protected Area showed stable or increase amounts of seagrass with increasing distance from shore. East Gaadhoo had higher amounts of macroalgae with increasing distance from shore.
- Gan Boda Fengan'du Area contained rubble substrate, which explained the reduced cover of seagrass.
- Hithadoo had higher amounts of macroalgal cover across sampled areas relative to other islands. It was also the only island where seagrass was absent up to 10 m from the shore. South Hitnadoo also had high amounts of macroalgae 30 - 50 m offshore.

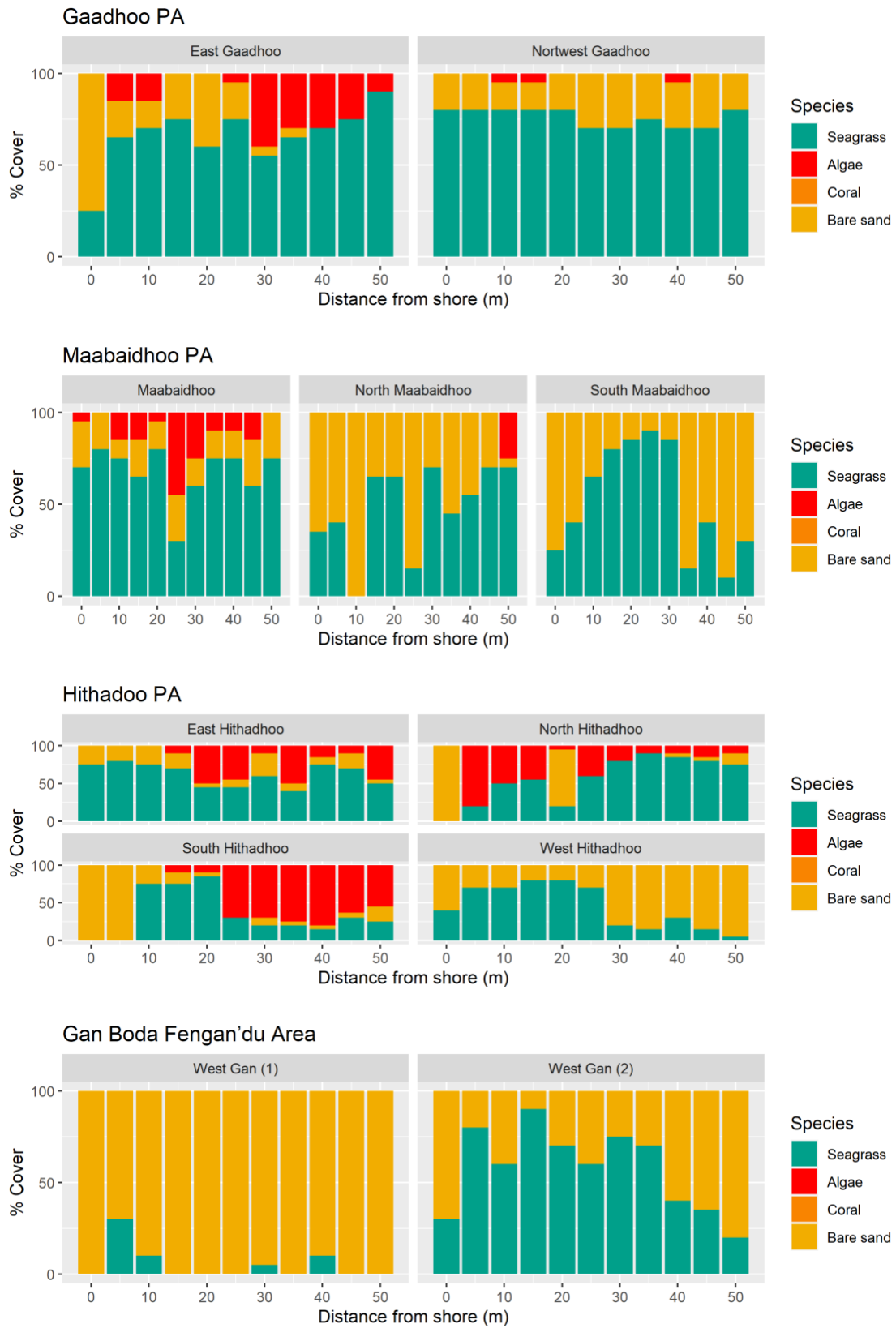


Figure 7. Trends in percentage cover for sites adjacent or within protected areas, from surveys taken in March and August 2023.



## Biodiversity

The following six species were observed across Laamu Atoll:

- *Thalassia hemprichii* (Th),
- *Thalassidendron ciliatum* (Tc),
- *Syringodium isoetifolium* (Si),
- *Cymodocea rotundata* (Cr),
- *Halodule pinofilia* (Hp), and
- *Halodule uninervis* (Hu).

Diagrams of each species are provided in the report, “Flora and fauna soil assessment report, inside and in the vicinity of the ICZM.”

### *Species composition as an indicator of condition*

This report explored the differences in the species composition of seagrass ecosystems, scientists can better understand the pressures that these ecosystems are facing and develop more effective management strategies to protect them.

The following trends were identified for the protected areas:

- *Thalassia hemprichii* (**Th**) was the dominant seagrass across most of Laamu Atoll, followed by *Cymodocea rotundata* (**Cr**). The same trend was reflected across most areas adjacent to or within protected areas (Figure 8).
- Almost all nearshore areas sampled were dominated by **Th**, although notable exceptions include East Gaadhoo, Maabaidhoo and South Maabaidhoo sites, which were dominated by **Cr**.
- *Halodule pinofilia* (**Hp**), which was found in sites with low percentage cover, was found in both sites in Gan and South Maabaidhoo.

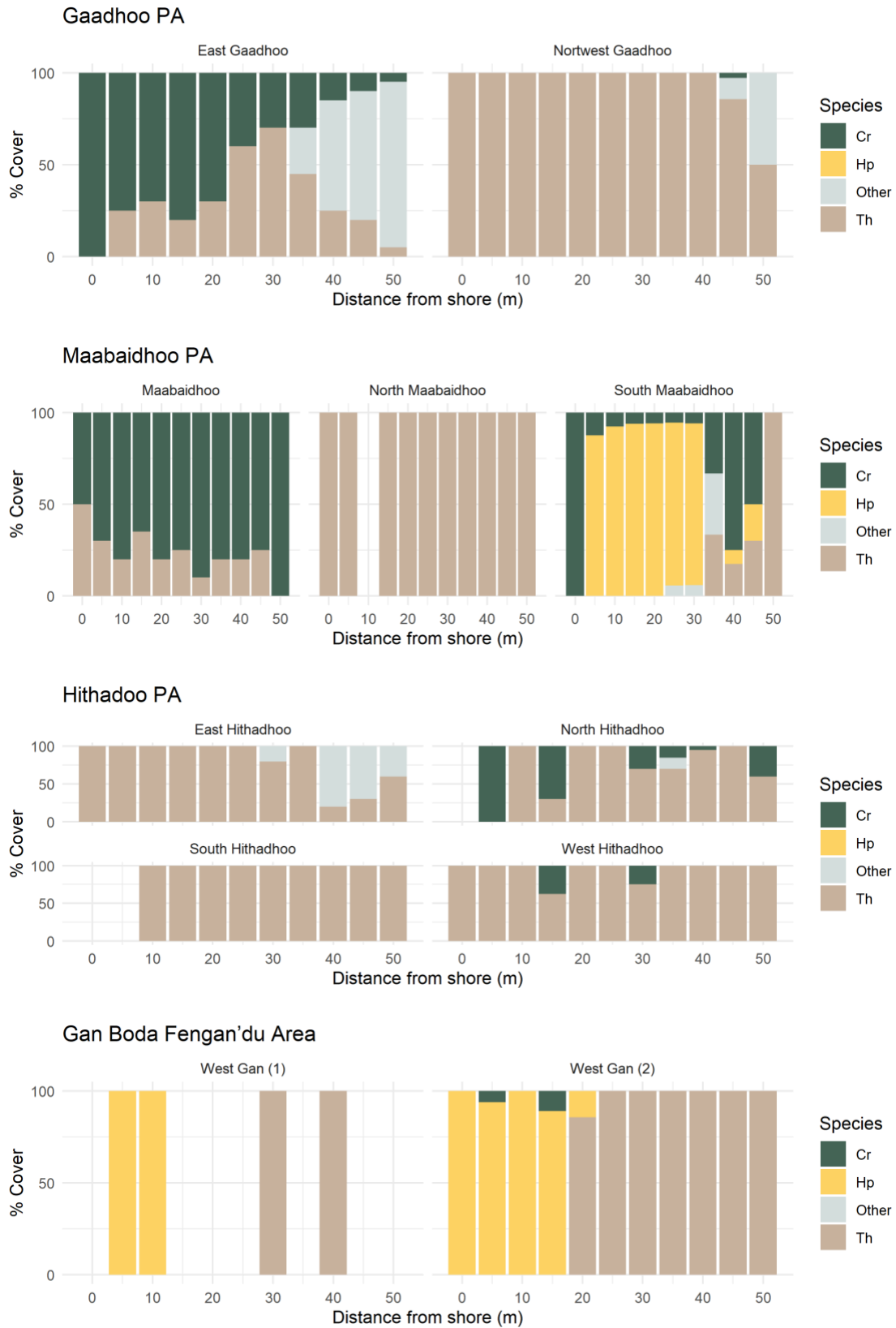


Figure 8. Percentage composition of seagrass species for the observed seagrass cover for sites adjacent or within protected areas, from surveys taken in March and August 2023. Note that **Tc**, **Si** and **Hu** were combined due to low percentage cover in most areas.

## Mangrove extent and condition in protected areas

An assessment of mangroves across Laamu Atoll identified their presence in the following protected areas:

- L. Maabaidhoo Koaru Area,
- L. Gan Boda Fengan'du Area,
- L. Gaadhoo Turtle Nesting Area, Mangrove and Seagrass Area, and
- L. Hithadhoo Wetland and Surrounding Marine Area.

### Extent

The Hithadoo Wetland contains the only pure stand areas on Laamu Atoll, where mangrove coverage is > 80% of trees within the area. In Hithadhoo, there were sections of high and low density (as identified in Figure 8, 9 below), and contained mixed species of *Rhizophora mucronata*, *Ceriops tagal*, *Lumnitzera racemosa*, *Derris trifoliata*, and *Sonneratia caseolaris*. There is limited evidence of change in the wetland since 2017.

The Maabaidhoo Koaru Area consists of an inhabited island located in the northeastern part of the atoll and hosts a large semi-enclosed brackish water area. Local consultation suggests that mangroves were introduced/planted in 2017, from propagules taken from Hithadhoo island. The species *Pemphis acidula* is dominant, although 24 saplings and 54 seedling of *R. mucronata* are seen. Five older trees (*Ceriops tagal*) with a height 0.5 - 1.5 m were identified.

Mangrove vegetation on Gan Island was concentrated at Gan Boda Fengan'du Protected Area. *Brugueira gymnorriszha* was dominant, surrounding a small brackish water lake. The tree height was greater than 20 m and mangroves seedlings and saplings were observed under the larger trees. The extent for the three protected areas is presented in Table 2.

Due to vegetation density, mangroves in the **Gaadhoo Turtle Nesting Area, Mangrove and Seagrass Area** could not be directly sampled and require the use of a drone. It may also require clearing a path to access the limited area of mangroves.

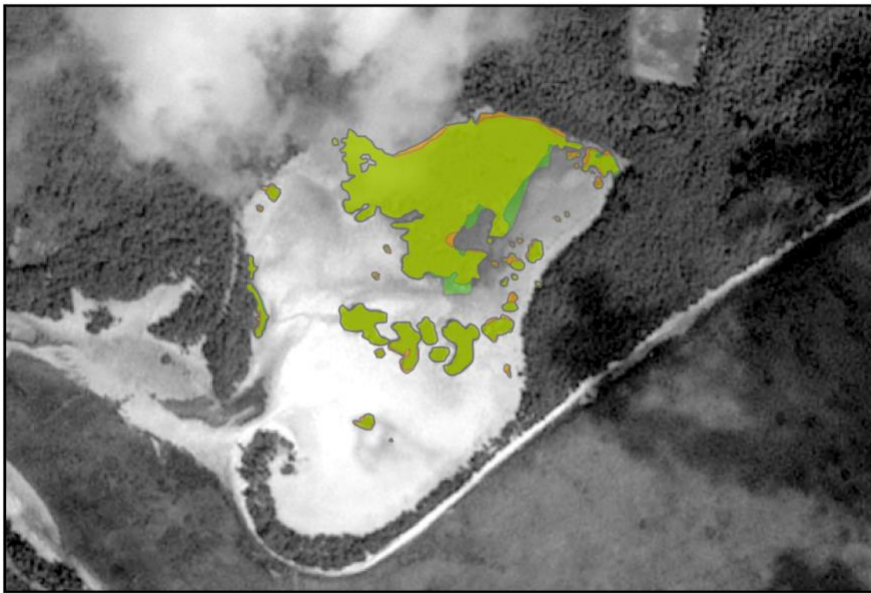
Table 2. Mangrove coverage for the years 2017, 2020, and 2023, via remote sensing.

Site Name	2017	2020	2021	2022*	2023
Maabaidhoo Koaru Area	ND	ND	ND	ND	32 individuals (5 were trees, 27 were saplings < 1 m in height)
Gan Boda Fengan'du Area	ND	ND	ND	ND	7 - 12 trees
Hithadhoo Wetland	0.0317 km2	0.0324 km2	0.0318 km2	0.0309 km2	Not yet available

### Note:

Due to the small size of the mangrove forest, changes may be inaccurate. ND = Not detectable by satellite. The year 2022 contained higher resolution imagery (0.3 m resolution, Pleiades Neo) compared to 2017 - 2021 (1.5 m resolution, SPOT6/7).

Hithadoo mangrove change (2017 - 2020)



Basemap: Spot 6/7 (2020)



Figure 8: Aerial view of the mangrove change in extent between 2017 and 2020 using SPOT 6/7 imagery.

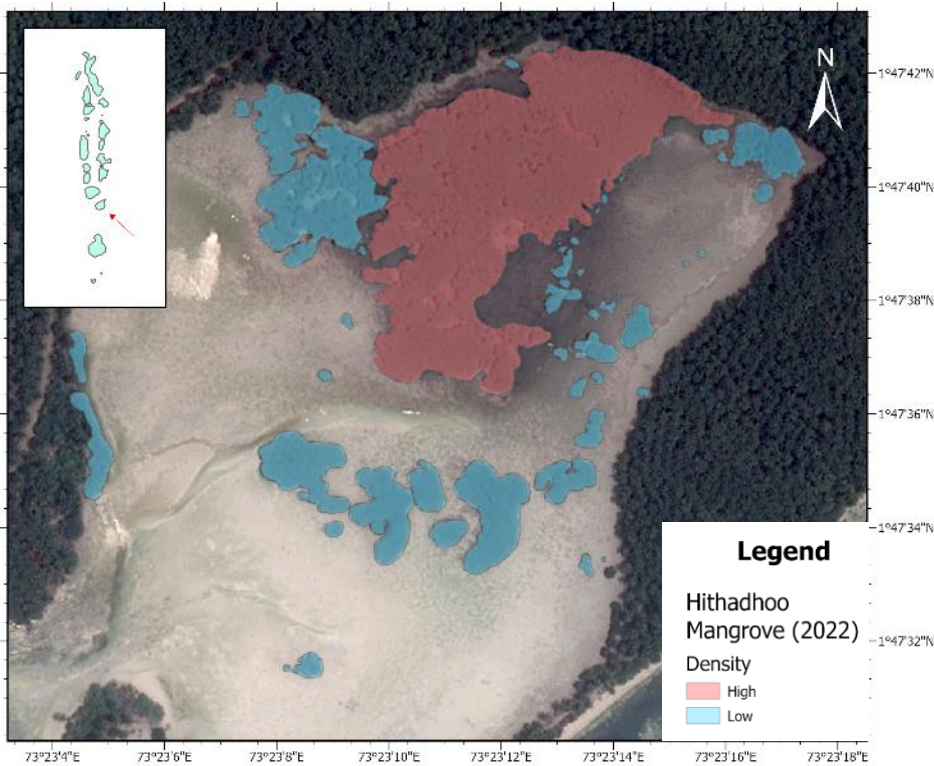


Figure 9. Aerial view of the mangrove extent in 2022 using Pleiades Neo imagery (0.3 m resolution). High (red) and low (blue) density areas highlighted.



## Condition

A more extensive analysis of mangrove **species** is presented in the “Flora, fauna, and soil assessment report.” Six genera of mangrove were identified across protected area sites: *Rhizophora*, *Ceriops*, *Lumnitzera*, *Sonnerati*, *Bruguiera*, and *Pemphis*.

Hithadoo mangrove was the only area with true mangrove stands (>80% coverage) and was thus the only area assessed for condition measures (canopy cover, tree density, sapling and seedling density), using the Quadrat plot method.

### Canopy cover

Within Hithadoo, two stratified zones could be identified - namely high (Zone A) and low density (Zone B) areas. Canopy cover averaged 72% in the high-density area and 14% in low density areas (Table 3).

Table 3. Canopy cover for two areas of Hithadoo

No	Site Name	Stratification	Average of canopy (%)
1	Hithadhoo Zone A	High density	72.12
2	Hithadhoo Zone B	Low density	14.16



Figure 10. Canopy cover for Zone A (high density) within Hithadoo mangrove



Figure 11. Canopy cover for Zone B (low density) within Hithadoo mangrove

### Tree, sapling and seedling density

Mangrove trees, saplings, and seedlings are all different life stages of the mangrove plant. Mangrove trees are the mature form of the plant, and they can grow to be quite tall and have a wide canopy (> 1.5 m). Saplings are younger mangrove plants that are not yet fully grown (0.3 - 1.5 m). Seedlings are the youngest form of the mangrove plant, and they are typically less than 0.3 m tall. Another key difference between mangrove trees, saplings, and seedlings is their reproductive ability. Mangrove trees are the only life stage of the plant that can reproduce sexually. Saplings and seedlings are not yet sexually mature, and they reproduce by cloning.

Across the wetland, tree density was 225 per km<sup>2</sup>, with an average height of 3.7 m and basal area of 10.51 m (Table 4). Within **high density areas** of Hithadoo, *R. mucronata* was the dominant species, with an estimated density of 2200 individuals / hectare, relative to *C. tagal* (200 individuals / hectare). Tree height varied between 3 and 6 m. In contrast, **low density areas** saw higher densities of *C. tagal*, although tree height was limited to approximately 3.3 m.

Table 4. Condition measures for mangroves in the Hithadoo wetland, separated into low- and high-density zones.

Plot	Species	No. Seedling	No. Sapling	No. Trees	Average tree height (m)	Basal Area (cm <sup>2</sup> )	Species density (Ind/Ha)
Hithadhoo A	<i>R. mucronata</i>	2	8	22	6	800	2200
Hithadhoo A	<i>C. tagal</i>	-	-	2	3	49	200
Hithadhoo B	<i>R. mucronata</i>	-	-	5	3.3	208	500
Hithadhoo B	<i>C. tagal</i>	2	2	16	2.5	1045	1600



## Conclusion

In summary, this report presents an evaluation of habitat patterns within the ICZM sites across Laamu Atoll, focusing on mangroves, seagrass, and habitat patterns related to cover and diversity. Satellite data enabled an assessment of the key habitats (mangrove and seagrass), with ground truthing providing an understanding of local conditions and changes.

The analysis provides a means to:

- Assess the presence of habitats across Laamu Atoll,
  - Provide a baseline to for potential future changes to ecosystems, and
  - Provides considerations for the alteration or extension of managed areas.
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## Appendix

Table A1. Seagrass and ground truthing sampling sites relevant to protected areas.

Sampling Site	Protected Area	Latitude	Longitude
South Hithadhoo	Hithadhoo Wetland and Surrounding Marine Area	1.793045	73.38882
North Hithadhoo	Hithadhoo Wetland and Surrounding Marine Area	1.800387	73.38625
East Hithadhoo	Hithadhoo Wetland and Surrounding Marine Area	1.796174	73.3942
West Hithadhoo	Hithadhoo Wetland and Surrounding Marine Area	1.794467	73.37945
Maabaidhoo	Maabaidhoo Koaru Area	2.029419	73.52985
North Maabaidhoo	Maabaidhoo Koaru Area	2.033001	73.53258
South Maabaidhoo	Maabaidhoo Koaru Area	2.022981	73.53189
West Gan (1)	Gan Boda Fengan'du Area	1.923392	73.55114
West Gan (2)	Gan Boda Fengan'du Area	1.910497	73.54502
East Gaadhoo	Gaadhoo Turtle Nesting Area, Mangrove and Seagrass Area	1.820744	73.45349
Nortwest Gaadhoo	Gaadhoo Turtle Nesting Area, Mangrove and Seagrass Area	1.824533	73.45286