

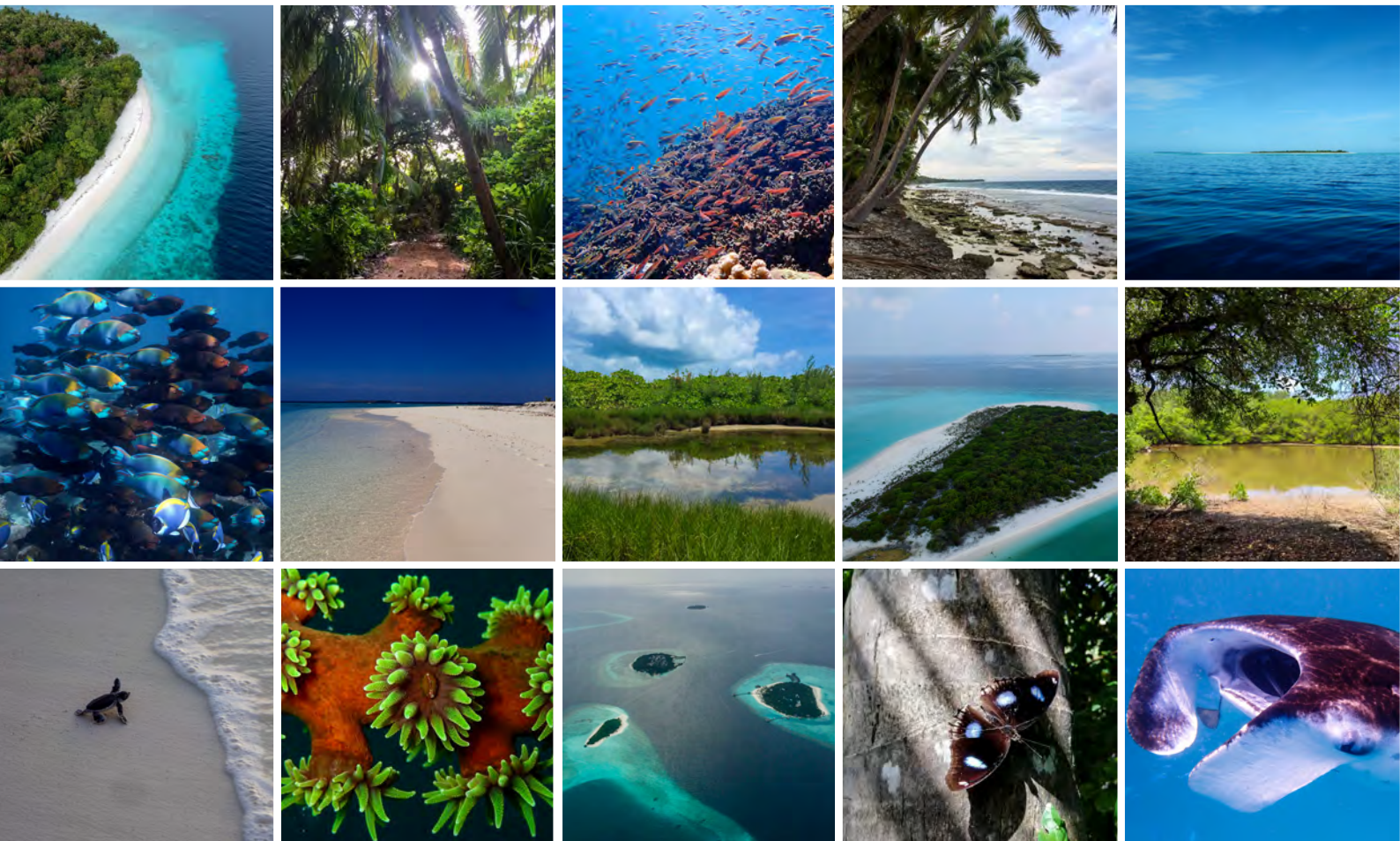


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# Applying the IUCN Global Ecosystem Typology to the Maldives

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2022



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# 1. Introduction

## 1.1 Background

This report describes the systematic application of the new International Union for the Conservation of Nature (IUCN) Global Ecosystem Typology to the Maldives (Keith et al., 2020a). The identification of units of the Global Ecosystem Typology aims to underpin any future national-scale ecosystem risk assessment under the IUCN Red List of Ecosystems and to support management and conservation efforts of diversity within Maldivian ecosystems. The report describes the details of the Maldives ecosystem typology project, which included:

- A detailed literature review of published and unpublished material regarding the natural and anthropogenic ecosystems likely to be present in the Maldives;
- The interpretation of and application of the IUCN Global Ecosystem Typology to the Maldives. Note that owing to travel restrictions, which precluded any fieldwork, the Global Ecosystem Typology was applied to Level 4 (Biogeographic Ecotype). Developing a list of ecosystem units at lower levels of the typology (such as Global Ecosystem Type, Level 5), which is an appropriate level for conducting a national scale IUCN Red List of Ecosystems assessment, requires field work and additional analyses to subdivide the Biogeographic Ecotypes listed in this report;
- Descriptions of Biogeographic Ecotypes as they pertain to the Maldives, developed from the detailed literature review and input from local experts;
- A workshop with local experts to ensure accuracy of biogeographic ecotype descriptions;
- An expert review process for the identified units and descriptions; and
- Production of this report and a 'live' spreadsheet detailing the results of this work. The report includes recommendations for further work and the 'live' spreadsheet links geographic locations to an example of each unit within the Maldives (where possible) and enables the continuous refinement of the list of ecosystems likely to be present in the Maldives.

## 1.2 The IUCN Global Ecosystem Typology

The IUCN Global Ecosystem Typology was developed to create a comprehensive and consistent framework that supports global, regional, and national efforts for assessing and managing the world's ecosystems and their services (Keith et al., 2020a). It aims to meet the need of a globally standard system that identifies Earth's ecosystems, and includes both the ecosystems' functions and its compositional features to better address ecosystem-level conservation and management targets. The typology allows for scientifically rigorous and widely applicable ecosystem assessments that can help identify critical areas of biodiversity and ecosystem services, and can enable standard comparisons across geographic regions.

The typology consists of a nested hierarchical structure with six levels of classification (Figure 1, Keith et al., 2020a). The upper levels of the typology (Realms, Functional Biomes, and Ecosystem Functional Groups) represent functional properties to enable global consistency, while the lower levels (Biogeographic Ecotypes, Global Ecosystem Type, and Local Ecosystem Type) incorporate ecosystem compositional features to ensure local accuracy. As such, units in the upper levels represent ecosystems that share functional properties, irrespective of the biota engaged in them, while the lower levels represent units with similar functionality but contrasting biotic composition (Keith et al., 2020a). With this, ecosystems around the world can be classified into specific units within levels of the typology and subsequently undergo standardised assessment, as has previously been conducted in Myanmar (Murray et al., 2020).

As more global and ecosystem-level conservation targets are established, the need for a globally consistent typology and clearly defined units for assessment become increasingly important (Convention on Biological Diversity, 2011, 2021; Nicholson et al., 2021). Effective ecosystem goals rely on monitoring ecosystem area, integrity, and risk of collapse, which require global systematic mapping to understand (Nicholson et al., 2021). The IUCN Global Ecosystem Typology enables the development of comparable regional typologies and repeatable ecosystem assessments that can address global, national, and local level conservation and management efforts. This report contributes to the growing literature of regional typologies that may be used for standardising ecosystem assessment and provide a more comprehensive understanding of ecosystems globally.

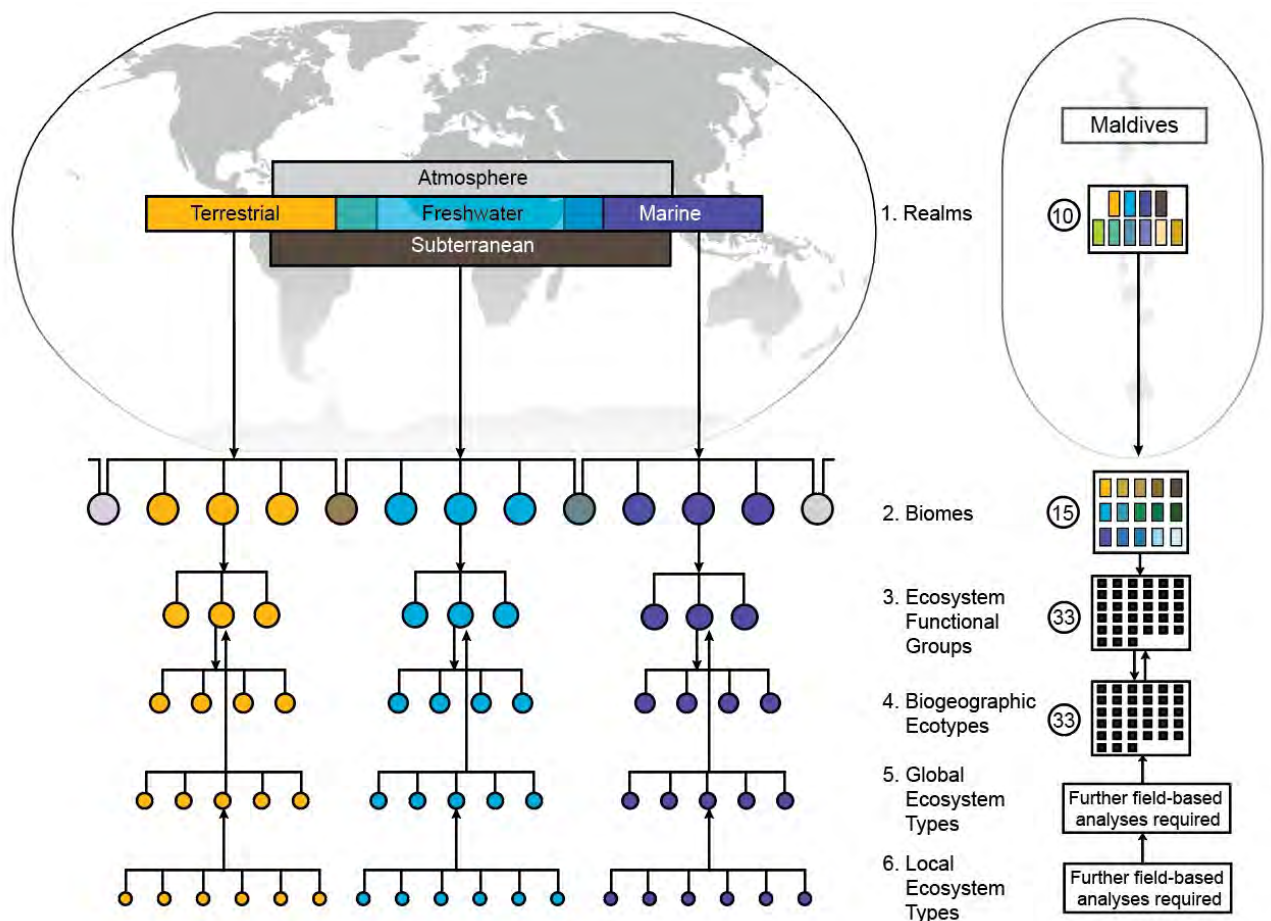


Figure 1. IUCN Global Ecosystem Typology structure (left) showing six hierarchical levels (Realms, Biomes, Ecosystem Functional Groups, Biogeographic Ecotypes, Global Ecosystem Types, and Local Ecosystem Types) and the number of units within each level (circled) that have been identified in the Maldives. Note that this review was conducted to Level 4, Biogeographic Ecotypes.

### 1.3 An overview of Maldives's environments

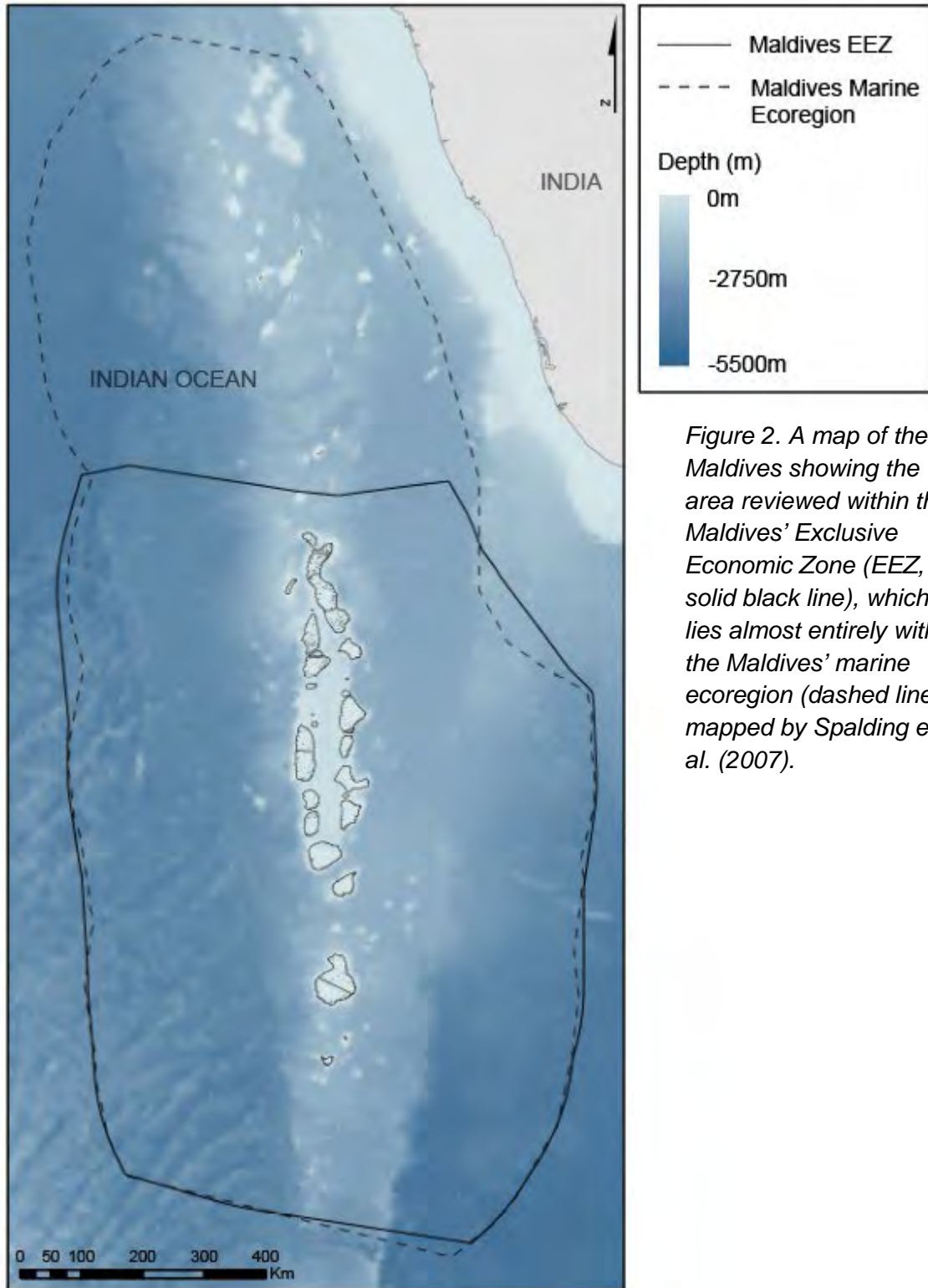
The Maldives (Figure 2) is an atoll nation that consists of approximately 1,190 islands in the Central Indian Ocean, spanning 870km from north to south (7°N - 1°S) and 128km from east to west at its widest point (Stevens and Froman, 2019). The Exclusive Economic Zone (EEZ) covers approximately 916,000km<sup>2</sup>, of which, land only occupies 230km<sup>2</sup> with a mean elevation of 1.6m above mean sea level (FAO, 2000; Naseer and Hatcher, 2004). The monsoonal climate is similar throughout the country with the majority of atolls receiving an average rainfall of approximately 1,000mm annually and only the northern atolls receiving over 2,000mm annually (ADB, 2020b). The rainy season lasts from June to November, with peak rainfall from September to November, and little rain throughout the rest of the year (ADB, 2020b).

The terrestrial ecosystems of the Maldives have been classified within one terrestrial ecoregion (Dinerstein et al., 2017), and nearly all of the EEZ has been classified as one marine ecoregion (Figure 2, Spalding et al., 2007). Due to this, the Maldives has been considered to be a single biogeographic region for the purpose of this report.

The low-lying coral islands of the Maldives consist of limestone and coral sand that support varying levels of coastal vegetation that are influenced largely by island size (and the influence of marine resources), freshwater availability and substrate (Kench, 2012a; Thupalli, 2009). The largest island is 6km<sup>2</sup> yet over 90% of vegetated islands are less than 0.5km<sup>2</sup> in area and many sand cays remain unvegetated (Kench, 2012a; MEE, 2015). Islands exist in various geomorphological atolls, including complex atolls, oceanic faros, and oceanic platform reefs (Naseer and Hatcher, 2004) that support numerous marine ecosystems such as coral reefs, seagrass meadows, and sand beds. Marine ecosystems comprise nearly half of the ecosystems present in the Maldives, including the marine shelf, pelagic waters, and the deep sea, with the sea floor extending to depths of approximately 5,500m within the Maldives EEZ (GEBCO Compilation Group, 2021).

All of the major realms identified in the Global Ecosystem Typology (Terrestrial, Marine, Freshwater, Subterranean) were identified in the Maldives, along with six transitional realms that exist at the interface of two or more major realms (Keith et al., 2020a). Fifteen biomes and 33 ecosystem functional groups were identified in the Maldives during the review process. As the Maldives is considered to be a single biogeographic ecoregion here, there are therefore 33 biogeographic ecotypes in the Maldives.

Without fieldwork to investigate the distribution of biota, abiotic components or differing ecological processes within these biogeographic ecotypes, it was not possible to work at the lower levels of the Global Ecosystem Typology. Consequently, the lowest level unit identified in this report is the biogeographic ecotype (level 4 of the typology), below which further field-based analyses are required. This level is consistent with the finest classification of marine ecosystems conducted globally to date (Western Indian Ocean Coral Reefs), and largely maps to national-scale studies conducted elsewhere (e.g. Myanmar). This report has therefore established a baseline classification for the ecosystems of the Maldives, from which lower level units may be identified through further fieldwork, expert input and continuous refinement.



*Figure 2. A map of the Maldives showing the area reviewed within the Maldives' Exclusive Economic Zone (EEZ, solid black line), which lies almost entirely within the Maldives' marine ecoregion (dashed line) mapped by Spalding et al. (2007).*



## **1.4 Methods**

### **1.4.1 Literature review**

We conducted a broad review of academic and grey literature relevant to Maldives' ecosystems. The review included targeted searches of ecosystems likely present within the Maldives and surrounding regions as well as geographically similar atoll nations around the world. The review also included searches for national scale ecosystem and land use classifications within the Maldives to ensure that all ecosystems within the country were included in the development of the Maldives' typology.

In total, 169 scientific publications, reports, books, theses or other relevant information was identified and reviewed for the task of investigating ecosystems likely to be present in the Maldives. The list is provided as a live spreadsheet in Appendix 3, together with a cross-walk to the appropriate category of the Global Ecosystem Typology. It includes notes about the relevance of each publication for classifying the ecosystems of the Maldives within the structure of the Global Ecosystem Typology. The results of the review are presented as biogeographic ecotype descriptions in Section 2 of this report, including a brief description of the global ecosystem functional group, the ecotype's occurrence in the Maldives, common compositional species (where possible), potential global ecosystem types (where possible), and recommendations for further work.

### **1.4.2 Expert consultation**

Experts on specific ecosystem functional groups or on Maldives' ecosystems were consulted when little or no literature was available to confirm the presence of ecotypes or determine if ecotypes possessed the appropriate criteria to fit the functional group descriptions. A workshop was conducted with local experts to review biogeographic ecotype descriptions and gather additional information about individual ecotypes. A peer-review process also allowed for additional input from experts familiar with the Maldives' ecosystems.

## 2.0 Applying the IUCN Global Ecosystem Typology to the Maldives

This section describes the occurrences of each hierarchical level of the IUCN Global Ecosystem Typology in the Maldives. Owing to the lack of detailed information on Maldivian ecosystems and limits to conducting field work within this project, the finest level of classification achieved was to Biogeographic Ecotype (Level 4 of the typology).

### 2.1 Terrestrial Realm (T)

The terrestrial realm includes all dry land, its vegetation cover, proximate atmosphere and substrate to the rooting depth of plants, and associated animals and microbes (Keith et al., 2020a). The terrestrial realm in the Maldives is comprised of low-lying coral islands, their associated vegetation and land-based anthropogenic development.

#### **Intensive Land Use Biome (T7)**

The intensive land use biome includes systems where human intervention is a dominating influence and the physical structure of vegetation and substrates is altered (Keith et al., 2020a). Within the Maldives, such ecosystems include industrialised cities, local villages, and agricultural land.



Figure 3. Aerial image of HA. Kelaa showing two biogeographic ecotypes, annual croplands (T7.1) and urban and industrial ecosystems (T7.4), within the intensive land use biome. Image credit: IUCN Maldives.

### **T7.1 Annual Croplands**

**Biome** Intensive land-use (T7)

**Functional group** Annual croplands ([T7.1](#))

**Description:** Annual croplands (T7.1) represent areas of intensive agricultural production supported by abundant fertiliser use, groundwater extraction and pesticide use (Keith and Harper, 2020). Although the majority of crop products are imported into the Maldives, this biogeographic ecotype, known locally as *dhandu bin*, is present as small parcels of land across a small number of islands, with 40km<sup>2</sup> of arable land reported throughout the country and approximately 6km<sup>2</sup> currently cultivated (2.8% of the total terrestrial land) (ADB, 2020c; Atapattu and Kodituwakku, 2009; FAO, 2012; MoFMA, 2019b; Van Driessche, 2018). On some islands, this ecotype represents the principal land use with up to fifty islands reportedly leased purely for commercial agricultural purposes, although few agriculture activities may occur on these islands (MoFMA, 2019b; Naseer, 2007; National Bureau of Statistics, 2020b). For example, annual croplands cover the majority of the terrestrial surface area of AA. Thoddoo and Lh. Felivaru, and more than 30% of the land in Laamu Atoll (Fallati et al., 2017).

Common crops in Maldives include taro (*Colocasia esculenta*), sweet potato (*Ipomoea batatas*), eggplant (*Solanum melongena*), pumpkin (*Cucurbita pepo*), chili (*Capsicum frutescens*), watermelon (*Citrullus lanatus*), pineapple (*Ananas comosus*), cucumber (*Cucumis sativus*), and gourds (*Cucurbitaceae* spp.) (Dryden et al., 2020a; Mohamed, 2018; Moosa et al., 2007; UNEP, 1986; Van Driessche, 2018). Sweet corn (*Zea mays*), tomato (*Lycopersicon* sp.), ginger, passionfruit (*Passiflora* sp.), and other spices (turmeric, cumin, curry leaf) are also present (Kanvinde, 1999; MEE, 2014; Mohamed, 2018). Threats to this biogeographic ecotype include saltwater inundation and pollution from chemical pesticides.

**Notes:** No efforts elsewhere have been made to formerly identify units in the lower levels of the global ecosystem typology, such as global ecosystem type, for this ecosystem functional group. Land cover maps that depict the distribution of different crop types and other nationally derived classification schemes may provide a basis for identifying units at the global ecosystem type level. However, no national cropland classification schemes exist for the Maldives and few references to Maldives agriculture were identified during the literature review.

### **T7.3 Plantations**

**Biome** Intensive land-use (T7)

**Functional group** Plantations ([T7.3](#))

**Description:** Plantations (T7.3) are ecosystems dominated by long-rotation woody vegetation that are harvested for food production or other materials, such as timber (Keith and Young, 2020). The most common plantation species in the Maldives are coconut palm (*Cocos nucifera*), known locally as *ruh faa* or *ruh dhandu*, and banana (*Musa* sp.), known locally as *keyo faa* or *keyo dhandu* (Thupalli, 2009). Other known species include breadfruit (*Artocarpus altilis*), papaya (*Carica papaya*), and mango (*Mangifera indica*) (Dryden et al., 2020a; Fosberg, 1957; Moosa et al., 2007; Thupalli, 2009; UNEP, 1986; Van Driessche, 2018).

Plantations are present across the Maldives and vary greatly in size, although they most commonly occupy small patches of land and rarely cover extensive areas of a single island. Examples include L. Baresdhoo and B. Maarikilu, where single species plantations of coconut palms occur (Kan et al., 2007). Threats to this biogeographic ecotype include pollution from chemical pesticides.

**Notes:** Coconut palms grow naturally in large areas the Maldives, however, these natural stands are considered part of MT2.1 Coastal Shrublands and Grasslands because they are not ordered in space due to a translocation of species or involve targeted management intervention. Additionally, plantations have not been addressed in any IUCN Red List of Ecosystems assessment so far, and no efforts have been made to identify units in the lower levels of the global ecosystem typology, such as global ecosystem type. Land cover maps that depict the distribution and species composition of plantations may aid in identifying any global ecosystem level units within the Maldives.

## **T7.4 Urban and industrial ecosystems**

**Biome** Intensive land-use (T7)

**Functional group** Urban and industrial ecosystems ([T7.4](#))

**Description:** Urban and industrial ecosystems (T7.4) represent cities and areas of structurally complex industrial systems comprised of various dynamic urban patches. The biotic community in this group exhibits low functional and taxonomic diversity with important ecological drivers such as water, nutrients, and energy largely influenced by humans (Keith and Corlett, 2020). In the Maldives, this biogeographic ecotype includes cities, inhabited islands, resort islands, and industrial and artificial islands that are largely characterised by buildings, paved or compressed sand surfaces, gardens or parks, grass areas, or bare ground. As such, there is a high diversity of sub-types within this ecotype, which are influenced by human population density, economic drivers, and population distribution.

Urban and industrial ecosystems are present throughout the Maldives with 187 inhabited local islands, 164 resort islands, and 128 industrial islands (National Bureau of Statistics, 2015; National Bureau of Statistics 2020a). Industrial islands within the country are largely used for waste management, manufacturing (e.g. boat/dhoni production), desalination plants, oil storage, and fish factories (Jaleel et al., 2020; MEE, 2017; Shaig, 2008). Examples of urban and industrial ecosystems in the Maldives include industrial islands of K. Thilafushi and R. Vandhoo, local islands of K. Maafushi and AA. Rasdhoo, and the urban city of Malé, which has a population of approximately 140,000 people occurring in approximately 6km<sup>2</sup>, and is therefore one of the most densely population urban systems in the world (National Bureau of Statistics, 2015). Threats to this biogeographic ecotype include pollution and improper waste management.

**Notes:** Urban and industrial ecosystems have not been addressed in any IUCN Red List of Ecosystems assessment so far, and no efforts have been made to identify units in the lower levels of the global ecosystem typology for this biogeographic ecotype. However, with further field-based analyses to distinguish development types and their ecological traits, it may be possible to differentiate lower level units.

## **2.2 Subterranean Realm (S)**

The subterranean realm includes the earth's crust and subsurface voids that receive very low intensity or no sunlight and where the substrate type influences the availability of nutrients and seepage of moisture (Keith et al., 2020a). The subterranean realm in the Maldives includes the subsurface of islands as well as the subsurface of the ocean floor throughout the Exclusive Economic Zone (EEZ).

## **Subterranean Lithic Biome (S1)**

The subterranean lithic biome includes non-aquatic lithic systems beneath the earth's surface (Keith et al., 2020a). Within the Maldives, this includes endolithic systems within terrestrial and marine substrates.

### **S1.2 Endolithic systems**

**Biome** Subterranean lithic (S1)

**Functional group** Endolithic systems ([S1.2](#))

**Description:** Endolithic systems (S1.2) occur within rocks and fissures of the Earth's crust and are inhabited by simple invertebrates and microbial lifeforms, largely supported by chemical synthesis of minerals due to a scarcity of light, nutrients, and water (Keith et al., 2020c). This group is characterised by microscopic bacteria, archaea, viruses, and small eukaryotes. Research focused on this ecosystem functional group is extremely limited, and as such, this is a poorly known functional group globally, as well as in the Maldives. According to their description, endolithic systems are expected to occur across the entirety of the Maldives' EEZ within all areas of the Earth's crust. Threats to this biogeographic ecotype are unknown due to a lack of information, though it is likely to be impacted by development and habitat modification.

**Notes:** This is a very poorly known biogeographic ecotype. Only two publications were found on endolithic organisms from the Maldives, with a focus on marine organisms within submerged dead and live coral colonies (Scoffin and Bradshaw, 2000; Zahir, 2002), however, these are included within M1.3 (Photic Coral Reefs) due to the non-aquatic requirement of endolithic systems.

## **2.3 Freshwater Realm (F)**

The freshwater realm includes all permanent and temporary freshwater bodies (Keith et al., 2020a). The freshwater realm in the Maldives includes all inland water bodies that are not directly connected to the ocean, either on the surface or subsurface.

### **Lakes Biome (F2)**

The lakes biome includes lentic ecosystems defined by still waters that vary in size, water regime, and connectivity to other aquatic systems (Keith et al., 2020a). In the Maldives, this biome is present in the form of small permanent lakes located on inland areas of some larger islands.

## **F2.2 Small permanent freshwater lakes**

**Biome** Lakes (F2)

**Functional group** Small permanent freshwater lakes ([F2.2](#))

**Description:** Small permanent freshwater lakes (F2.2) are lentic environments that support communities of aquatic and terrestrial biota including phytoplankton, zooplankton, shallow-water macrophytes, invertebrates, fish, reptiles, birds, and mammals (Kingsford et al., 2020b). Trophic structure and complexity are dependent on lake size, depth, location, and connectivity.

Small permanent freshwater lakes, known locally as *kulhi* or *koaru*, are present on a number of islands across the Maldives (ADB, 2020c), such as Dhadimagi Kilhi and Bandaara Kilhi on Gn. Fuvahmulah (MEE, 2014). They are groundwater and rainfall dependent and are therefore classified within the small permanent freshwater lakes ecosystem functional group. A freshwater fish (*Barbus* sp.) and mollusc (*Melanoides*, previously *Melania*) have been reported from Addu Atoll, however, their presence is presumed to be a result of introduction (Sewell, 1936). Additionally, a freshwater eel (*Anguilla bengalensis*) has been reported from the *kulhi* on Gn. Fuvahmulah (MEE, 2014), although marine eels (*Congridae*) have also been recorded from *kulhi* on N. Kendhikulhudhoo (IUCN, 2021 pers. comm.). Small permanent freshwater lakes in the Maldives range from intact and protected to degraded systems due to reclamation, development, and pollution (Dews et al., 2009; MEE, 2014; Zahid et al., 2017).

**Notes:** Kulhi have been recorded as both brackish (Agassiz, 1902; Dews et al., 2009; Saleem and Nileysa, 2003) and freshwater (Agassiz, 1902; Dam Roy et al., 2017; Dews et al., 2009; MEE, 2014; Saleem et al., 2007; Sewell, 1936; Stoddart, 1966; Zahid et al., 2017), and are therefore included here as freshwater lakes due to numerous references citing them as freshwater. Further research and fieldwork to determine whether, or which of, these inland water bodies are truly freshwater is recommended to confirm the presence and extent of this biogeographic ecotype.



Figure 4. Small permanent freshwater lake (F2.2) located on N. Medhufaru. Image credit: Maren Toor.

## 2.4 Terrestrial-Freshwater Realm (TF)

The terrestrial-freshwater realm is a transitional realm at the interface of both terrestrial and freshwater systems that is occupied by palustrine wetlands (Keith et al., 2020a). The terrestrial-freshwater realm in the Maldives includes small palustrine wetlands located on the inland areas of some larger islands.

### Palustrine wetlands (TF1)

The palustrine wetlands biome includes vegetated floodplains and marshes with permanent or intermittent surface water (Keith et al., 2020a). In the Maldives, this biome is present as vegetated marshes with intermittent surface water bodies and groundwater seeps.

#### **TF1.3 Permanent marshes**

**Biome** Palustrine wetlands (TF1)

**Functional group** Permanent marshes ([TF1.3](#))

**Description:** Permanent marshes (TF1.3) occur in flat areas where stable freshwater levels support reedbeds and aquatic grasses. Vegetated marsh areas



may be interspersed with patches of open water as a result of water depth, ecological feedback mechanisms or the impact of threatening processes. They are characterised by high primary productivity, bottom-up regulation, and complex trophic webs that include aquatic and terrestrial biota (Kingsford et al., 2020a).

In the Maldives, permanent marshes are present on islands across the country (Dam Roy et al., 2017; MEE, 2015), although it has been reported that they are more prevalent in southern atolls (Pernetta, 1993), such as on S. Hulhumeedhoo and Gn. Fuvahmulah (e.g. Dhadimagi Kilhi). It is likely that many of these marshes are groundwater seeps, connected to the island's freshwater lens underneath (see SF1.2). Common flora species associated with these marshes in the Maldives, known locally as *chas bin*, include *Apluda mutica*, *Cladium sp.*, *Ammannia baccifera*, *Phyla nodiflora*, *Colocasia esculenta*, *Cyclosorus interruptus*, *Ipomoea aquatica*, *Kyllinga nemoralis*, *Ludwigia hyssopifolia*, *Nephrolepis hirsutula*, and *Panicum repens* (MEE, 2014; Stoddart, 1966; Sujanapal and Sankaran, 2016). Bird species present include the eastern grey heron (*Ardea cinerea*), the endemic Maldivian pond heron (*Ardeola grayii phillipsi*), the endemic Maldivian water hen (*Amaurornis phoenicurus maldivus*), little heron (*Butorides striatus*), common myna (*Acridotheres tristis*), and the white tern (*Gygis alba*) (Dryden et al., 2020b; MEE, 2014). Seasonal species are known to include the whimbrel (*Numenius phaeopus*), garganey (*Anas querquedula*), and the little egret (*Egretta garzetta*) (Factor and Shafeega, 2010; MEE, 2014). Permanent marshes in the Maldives range from intact and well protected, to poorly managed and highly degraded due to channel construction, tourism development, water extraction, and land reclamation (Dryden et al., 2020b).

**Notes:** Permanent marshes are distinguished from seasonal floodplain marshes by the perennial presence of water, and may fluctuate in extent in response to recent rainfall. Seasonal floodplain marshes (TF1.4) were deemed to not occur in the Maldives, owing to a lack of rivers and associated large seasonal influxes of water and resources.

## 2.5 Subterranean-Freshwater Realm (SF)

The subterranean-freshwater realm is a transitional realm at the interface of both subterranean and freshwater systems (Keith et al., 2020a). The subterranean-freshwater realm in the Maldives includes subsurface systems on islands that retain freshwater and are not exposed directly to the surface.

### Subterranean Freshwaters Biome (SF1)

The subterranean-freshwater biome includes streams, lakes, and aquifers beneath the earth's surface that receive water inflow via seepage (Keith et al., 2020a). This biome in the Maldives is characterised by relatively small groundwater systems within the porous carbonate substrate of islands.

## **SF1.2 Groundwater ecosystems**

**Biome** Subterranean freshwaters (SF1)

**Functional group** Groundwater ecosystems ([SF1.2](#))

**Description:** Groundwater ecosystems (SF1.2) are low productivity, freshwater systems that occur within porous geological strata and that maintain a scarcity of nutrients, carbon, dissolved oxygen, and light (Keith et al., 2020d). Biota within this group include microbial and small invertebrates and small protozoans.

Within the Maldives, this biogeographic ecotype is present on most islands, occurring within permeable carbonate rock strata as a freshwater lens (Bailey et al., 2014; Ibrahim et al., 2002). Known locally as *meerufenuge maahaulee nizam* or *bimuge fen fashala*, these lenses are generally found approximately 1-2m below the earth's surface and their thickness is often dependent on the size of the island and its soil permeability (Ibrahim et al., 2002; Jaleel et al., 2020; Leoni et al., 2021). The majority of islands support lenses that are <12m thick, however, the island of S. Gan is known to have one of the largest groundwater systems with a freshwater lens approximately 20m thick (Ibrahim et al., 2002). Groundwater ecosystems may vary from intact to highly degraded on more densely populated islands due to pollution and saltwater intrusion from over extraction (Ibrahim et al., 2002; MEE, 2015).

**Notes:** We are not aware of any studies that have applied the global ecosystem typology to groundwater ecosystems. A sizable amount of information is available regarding the social impacts of the limited groundwater resources in the Maldives, but no information was found regarding the biotic communities of this ecosystem.

## **2.6 Freshwater-Marine Realm (FM)**

The freshwater-marine realm is a transitional realm at the interface of freshwater and marine systems, occupied by brackish aquatic systems on marine coasts (Keith et al., 2020a). The freshwater-marine realm in the Maldives includes coastal freshwater bodies that are periodically exposed to marine elements.

### **Semi-confined Transitional Waters Biome (FM1)**

The semi-confined transitional waters biome includes coastal inlets influenced by inputs of fresh and marine water from terrestrial catchments, ocean tides, waves, and currents (Keith et al., 2020a). In the Maldives, this biome is present at the interface of small lakes on island coasts that are directly and indirectly exposed to nearby marine waters.

### **FM1.3 Intermittently open and closed lakes and lagoons**

**Biome** Semi-confined transitional waters (FM1)

**Functional group** Intermittently open and closed lakes and lagoons ([FM1.3](#))

**Description:** Intermittently open and closed lakes and lagoons (FM1.3) are represented as coastal water bodies with high spatial and temporal variability due to periodic exposure to marine systems that result in variation and rapid changes in salinity, nutrients, temperature, and water level (Bishop et al., 2020e). This system is dominated by algae, microphytobenthos, micro- and macrofauna, plankton, and small-bodied fish. In the Maldives, exposure to marine systems is likely due to seasonal and long-term erosional and depositional processes of beach sediments (Aslam and Kench, 2017; Kench and Brander, 2006; Sewell, 1936) as noted in a single historical record found where an inland lake was inundated with seawater after erosion of the island ridge (Sewell, 1936). However, freshwater input is limited in the Maldives due to an absence of rivers and streams and is largely dependent on rainfall. As such, some uncertainty remains about the nature of these lakes, which may experience greater influence from the marine realm than the freshwater realm. These lakes and lagoons are present on islands across the Maldives and likely exhibit temporal variation in relation to opening and closing processes, and consequently experience varying salinity levels. They may contain fine-particled benthos and be variously fringed by mangroves, such as the lakes on N. Kendhikulhudhoo and the northern end of Sh. Farukolhu. Lagoons are locally known as *vilu*, however it is noted that this term refers to open reef lagoons. A specific term for intermittently open and closed lagoons is yet to be determined. Threats to this biogeographic ecotype are difficult to determine due to the uncertainty of its nature, however, this habitat is likely at risk from land reclamation, shoreline development, pollution, and permanent marine exposure due to erosion.

**Notes:** Although this ecosystem functional group is predominantly represented globally as open and closed lagoons occurring where rivers meet the ocean, the presence of intermittently open and closed lagoons in the Maldives is considered a special case caused by natural coastal processes. It is of note that a high level of uncertainty exists regarding the presence of this biogeographic ecotype due to the heavy marine influence and potential lack of freshwater influence. No local studies on this biogeographic ecotype were identified in the literature review and further research to investigate the dynamics of this ecotype and determine its presence within the Maldives is recommended.

## **2.7 Marine-Terrestrial Realm (MT)**

The marine-terrestrial realm is a transitional realm at the interface of marine and terrestrial systems that includes coastal ecosystems characterised by steep environmental gradients in desiccation, salinity, and wave and tidal disturbance

(Keith et al., 2020a). The marine-terrestrial realm in the Maldives is comprised of coastal shorelines and vegetated coastal systems.

### **Shorelines Biome (MT1)**

The shorelines biome includes naturally formed, intertidal abiogenic habitats situated at the interface of land and sea (Keith et al., 2020a). In the Maldives, this biome is present in the form of various shoreline substrates.

#### **MT1.1 Rocky shorelines**

**Biome** Shorelines (MT1)

**Functional group** Rocky shorelines ([MT1.1](#))

**Description:** Rocky shorelines (MT1.1) represent intertidal benthic systems regulated by waves, tides, and aerial exposure (Bishop et al., 2020c). They are often dominated by sessile and mobile species that exhibit behavioural and morphological adaptations to minimize exposure to stressors such as desiccation and temperature. Dominant trophic groups include filter feeders and grazers as well as resident and transient marine and terrestrial predators, such as echinoderms, crustaceans, fish, and bird species (Bishop et al., 2020c).

Rocky shorelines within the Maldives, known locally as *akiri gandu* or *futtaru*, are often reported as beachrock (Kench, 2012a; Stoddart, 1966), formed by coral and eroded limestone (Gardiner, 1902). This biogeographic ecotype is likely present on many islands throughout the country but is more commonly found on exposed oceanward shorelines of outer atoll islands (Gardiner, 1902). It has been reported from numerous atolls including Haa Alifu (Dryden et al., 2020a), Haa Dhaalu (Zahid et al., 2017), Raa (Gardiner, 1902), Baa (Kench, 2012a), and Seenu (Sewell, 1936; Stoddart, 1966). On some islands, rocky shorelines may form continuous deposits that can be seasonally buried by sand (Kench, 2012a), such as B. Keyodhoo and R. Kandoogandu. Threats to this biogeographic ecotype are unknown but they are likely unaffected by development and reclamation due to their exposed nature.

**Notes:** A number of references found mention the presence of rocky shorelines in the Maldives but provide little information about their extent throughout the country or any associated biota. Further research to map their extent and determine the biotic composition of this biogeographic ecotype is recommended.



Figure 5. Rocky shoreline (MT1.1) along the western side of Gn. Fuvahmulah. Image credit: Maren Toor

## **MT1.2 Muddy shorelines**

**Biome** Shorelines (MT1)

**Functional group** Muddy shorelines ([MT1.2](#))

**Description:** Muddy shorelines (MT1.2) are low energy, intertidal coastlines composed of mud and silt that support highly productive communities of burrowing organisms, deposit feeding taxa, detritivores, and bioturbating and tube dwelling taxa that oxygenate and mix sediments (Bishop et al., 2020f). These systems also support terrestrial and migratory species such as large shorebird populations. The presence of this biogeographic ecotype in Maldives is unknown and, owing to a lack of nearby rivers that act as substantial sediment sources, are considered unlikely at anything beyond sub-hectare scales. However, some small intertidal and sediment-dominated protected areas, such as the shoreline within the lagoon on the northern end of S. Hithadhoo, may represent this ecotype and are referred to locally as *chakaveli gondudhoh*. Threats to this biogeographic ecotype are unknown due to the uncertainty of its presence in the Maldives, however, it may be impacted by land reclamation and habitat modification.

**Notes:** No publications were found regarding this biogeographic ecotype in the literature search, so fieldwork guided by high-resolution imagery is recommended to confirm its presence. Inland muddy areas, known locally as *chas bin* (Saleem and

Nileysha, 2003), are present but are classified as FT1.3 (Permanent Marshes) because they are not intertidal and do not occur along the shoreline.

### **MT1.3 Sandy shorelines**

**Biome** Shorelines (MT1)

**Functional group** Sandy shorelines ([MT1.3](#))

**Description:** Sandy shorelines (MT1.3) represent moderate to high-energy intertidal coastlines composed of unstable and shifting sediments with shoreline morphology determined by exposure to waves and tides (Bishop et al., 2020d). This ecosystem functional group is characterised by low productivity, supported by detrital subsidies and phytoplankton within the surf zone, and dominated by mobile marine and terrestrial taxa (Bishop et al., 2020d).

Sandy shorelines are widespread throughout the Maldives and likely present on all natural islands where rocky shorelines are absent (Gardiner, 1902), such as those of R. Fenfushi and B. Boifushi. These systems, known locally as *dhonveli gondudhoh*, include fine-grained, coral sand beaches, spits, and sandbanks, as well as rubble or shingle beaches (Agardy et al., 2017; Agassiz, 1902; Kench, 2012a; MEE, 2015), also termed ‘coral breccia’ (Fairbridge, 2004). These shorelines are highly mobile, and experience high rates of seasonal movement around islands (Kench and Brander, 2006). Common taxa include small burrowing crustaceans, and transitory marine species such as the green sea turtle (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricata*) as well as seabirds and shorebirds including the white-tailed tropicbird (*Phaethon lepturus*), the lesser noddy (*Anous tenuirostris*), great crested tern (*Sterna bergii*), the grey heron (*Ardea cinerea*) and the whimbrel (*Numenius phaeopus*) (Dryden et al., 2020b; Factor and Shafeega, 2010; Frazier et al., 2000; Le Berre et al., 2009; MEE, 2015). Changing sediment dynamics within atolls due to dredging, island building, land reclamation and beach replenishment activities can result in the erosion of sandy shoreline ecosystems around islands (Kench, 2012b). Additional pollution, particularly from plastics, can be high in these areas with impacts on beach fauna (Dryden et al., 2020b; Patti et al., 2020).

**Notes:** Rubble beaches in the Maldives were not deemed as MT1.4 (Boulder and Cobble Beaches) due to their biogenic origin from the nearby reef and because their presence is not due to delivery by rivers or glaciers.



Figure 6. Sandy shoreline (MT1.3) located on N. Orimasvaru. Image credit: Maren Toor.

### **Supralittoral Coastal Biome (MT2)**

The supralittoral coastal biome includes the landward extent of the transition from marine to terrestrial biomes, elevated above the direct influence of waves and tides and beyond direct influence of freshwater seepage, potentially covering the extent of many small islands (Keith et al., 2020a). In the Maldives, this biome includes the coastal shrublands and dune forests present across many islands throughout the country.

#### ***MT2.1 Coastal shrublands and grasslands***

**Biome** Supralittoral coastal (MT2)

**Functional group** Coastal shrublands and grasslands ([MT2.1](#))

**Description:** Coastal shrublands and grasslands (MT2.1) represent low diversity, and generally low productivity, environments with specialised plants along coastlines that are exposed to harsh conditions such as wind and sun, salt influx, unstable substrate such as sand dunes, and a water deficit (Keith et al., 2020e). This ecosystem functional group includes low forests with strong gradients from seaward to landward, shifting from beach pioneer and littoral dune edge vegetation to inland forest vegetation (Keith et al., 2020e).

In the Maldives, coastal forests and shrublands are common on uninhabited and inhabited islands, and is the biogeographic ecotype that represents the majority of

Maldivian terrestrial vegetation. These coastal forests tend to display a seaward to landward gradient from beach pioneers and coastal fringing species to larger open forests in inland areas, which is typical of atoll island vegetation (Dryden et al., 2020b; Fosberg, 1949; Hameed, 2002; MEE, 2015; Selvam, 2007; Sujanapal and Sankaran, 2016). However, this ecosystem has been degraded on almost all inhabited islands as a result of wood extraction, weed invasion, forest clearing and other anthropogenic pressures (ADB, 2020c; Hameed, 2002; Thupalli, 2009).

Examples of coastal shrublands and grasslands in the Maldives, with the outer coastal vegetation belt known locally as *heylihifah*, include the coastal forests of HDh. Keylakunu and R. Fainu. Coastal forests cover approximately 1,000ha of land and play an important role in mitigating the effects of salt spray and storms on many of the islands (Thupalli, 2009). Common beach pioneer and littoral edge species include *Launaea sarmentosa*, *Portulaca oleracea*, *Ipomoea littoralis*, *Scaevola* species, *Pandanus tectorius*, *Pemphis acidula*, *Guettarda speciosa*, and *Suriana maritima* (Hameed, 2002; Selvam, 2007; Sujanapal and Sankaran, 2016; Thupalli, 2009). Common inland vegetation includes *Pisonia grandis*, *Cocos nucifera*, *Ficus benghalensis*, *Adenantha pavonina*, *Cordia subcordata*, *Calophyllum inophyllum*, *Terminalia catappa*, and *Hibiscus* species (Fosberg, 1957; Hameed, 2002; Newberry and Spicer, 1979; Selvam, 2007; Sujanapal and Sankaran, 2016; Thupalli, 2009).

**Notes:** *Pisonia grandis* was consistently identified as the principal forest tree species in the Maldives, and are indicative of a coastal ecosystem heavily influenced by marine processes. Owing to an absence of diverse tropical rainforest species, all terrestrial natural vegetation of the Maldives is considered to fall within this biogeographic ecotype.

### **Anthropogenic Shorelines Biome (MT3)**

The anthropogenic shorelines biome includes urbanised and industrial areas that adjoin the coast as well as some remote structures such as artificial islands (Keith et al., 2020a). Anthropogenic shorelines are present in the Maldives in the form of artificial shorelines and islands.

#### **MT3.1 Artificial shorelines**

**Biome** Anthropogenic shorelines (MT3)

**Functional group** Artificial shorelines ([MT3.1](#))

**Description:** Artificial shorelines (MT3.1) represent coastal infrastructure that create habitat for intertidal and subtidal benthic and demersal marine biota and are often dominated by opportunistic colonisers that support simple food webs (Suthers et al., 2020a). The proximity of such infrastructure to the ocean creates an increased potential for pollution due to urban runoff and outflows (Suthers et al., 2020a).

Artificial shorelines are widespread in the Maldives, present on nearly all inhabited, industrial, and resort islands to varying degrees, including structures such as harbors



and ports, reclaimed islands, sea walls or breakwaters, groynes, and jetties (ADB, 2020c; Duvat, 2020; Hameed, 2002; Kench et al., 2003; Kench, 2012b; MHE, 2011). Local names for artificial shorelines include *hihkki sarahadhu gondudhoh* and *masnooe hihkki asseyrifah*. Examples of highly altered shorelines include those of K. Malé and K. Huraa.

**Notes:** While the presence of artificial shorelines has been recorded on hundreds of islands across the country (ADB, 2020c; Duvat, 2020; MHE, 2011), the ecological communities of these structures remain largely unknown and further investigation is recommended to better describe this biogeographic ecotype and distinguish the ecosystem's components.

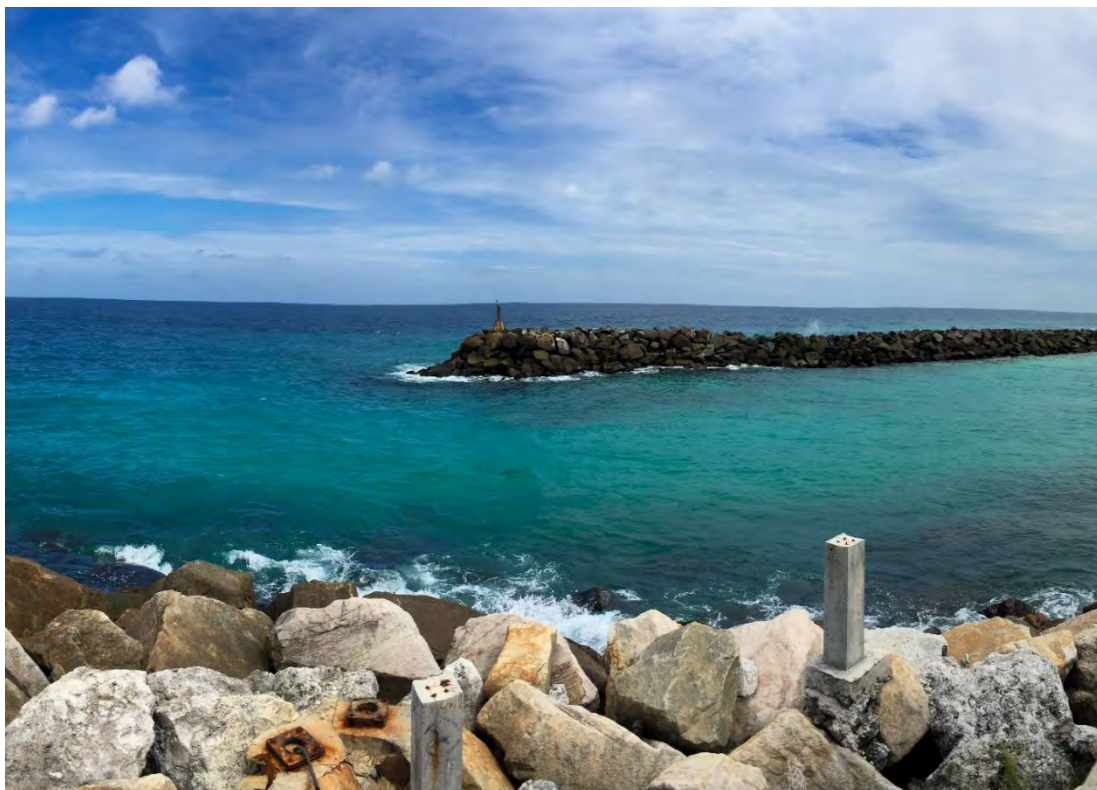


Figure 7. Artificial shorelines (MT3.1) on Gn. Fuvahmulah. Image credit: Maren Toor.

## 2.8 Marine-Freshwater-Terrestrial Realm (MFT)

The marine-freshwater-terrestrial realm is a transitional realm at the interface between marine, freshwater, and terrestrial systems where marine and terrestrial seepage can be influenced by freshwater seepage or outflow, supporting intertidal wetland systems (Keith et al., 2020a). The marine-freshwater-terrestrial realm in the Maldives includes brackish water areas around many islands throughout the country.

## **Brackish Tidal Biome (MFT1.2)**

The brackish tidal biome includes prograding depositional shorelines that are influenced by marine, terrestrial, and freshwater processes (Keith et al., 2020a). In the Maldives, this biome is represented by vegetated intertidal areas such as mangroves and coastal salt marshes.

### **MFT1.2 Intertidal forests and shrublands**

**Biome** Brackish tidal (MFT1)

**Functional group** Intertidal forests and shrublands ([MFT1.2](#))

**Description:** Intertidal forests and shrublands (MFT1.2) represent structurally complex and productive ecosystems in the intertidal zone, composed of salt tolerant aquatic and terrestrial species (Bishop et al., 2020a). Vegetation is dominated by mangrove species that act as important carbon sinks and produce large amounts of detritus that provide energy and nutrients to associated organisms, as well as complex root systems that provide shelter and canopy cover, which support a variety of invertebrate and terrestrial fauna (Bishop et al., 2020a).

In the Maldives, this biogeographic ecotype is reported throughout the country, and is confirmed to occur on approximately 150 islands (ADB, 2020a; Dryden et al., 2020b; Kathiresan and Rajendran, 2005; Le Berre et al., 2009; MEE, 2015; Saleem and Nileysha, 2003; Shazra et al., 2008). Mangrove systems are found in higher abundance on islands in the northern and southern atolls, with the largest and richest systems reported from the northernmost atolls, such as HDh. Keylakunu and HA. Baarah (MEE, 2015; Saleem and Nileysha, 2003). These systems are believed to provide important coastal structure for islands, mitigating impacts of erosion and storm surges (Saleem and Nileysha, 2003) and providing drainage areas to minimise impacts of flooding (Zahid et al., 2017). However, one publication reports no evidence of mangrove vegetation preventing erosion in the Maldives due to their predominant growth in already protected areas (MHE, 2011). Intertidal forests and grasslands in the Maldives range from intact to highly degraded due to coastal and agricultural development and waste dumping (Dryden et al., 2020a; Saleem and Nileysha, 2003).

Sixteen species of mangrove have been reported from the Maldives (Dryden et al., 2020a; Kathiresan and Rajendran, 2005; Sivakumar et al., 2018), identified as embayment and coastal mangroves (open systems) or depression mangroves (closed systems) (MEE, 2015; Saleem and Nileysha, 2003; Shazra et al., 2008). Embayment and coastal mangroves are those exposed to the open ocean with common species including *Rhizophora mucronata* (locally known as *makeha*), *Ceriops tagal* (locally known as *kharnana*), *Sonneratia caseolaris* (locally known as *kulhlhavah*) (Dryden et al., 2020a; Dryden et al., 2020b; Saleem and Nileysha, 2003). Depression mangroves exist around small brackish ponds with species including *Bruguiera cylindrica* (locally known as *kandoo*), *Bruguiera gymnorhiza* (locally known as *bodavaki*), *Lumnitzera racemose* (locally known as *burevi* or

*randoo*), *Avicennia marina* locally (known as *baru*), *Barringtonia racemosa*, *Excoecaria agallocha* (locally known as *thella*), and the critically endangered *Bruguiera hainesii* identified from a single island (Dryden et al., 2020b; MEE, 2014; Saleem and Nileysha, 2003; Sujanapal and Sankaran, 2016). Common avian fauna found within these systems include the curlew sandpiper (*Calidris ferruginea*), the eastern grey heron (*Ardea cinerea rectirostris*), the Maldivian pond heron (*Ardeola graii phillipsi*), and others (Saleem and Nileysha, 2003).

**Notes:** Mangrove systems have been classified to lower level units previously, including fringing mangrove forests and basin mangrove forests (Kathiresan and Rajendran, 2005). They have additionally been classified according to their geomorphic setting, with carbonate settings as reef flat mangroves, inland mangroves and depressions (Woodroffe, 1987), and lagoonal and open coast mangroves (Worthington et al., 2020). The mangrove systems of the Maldives have the potential for sub-classification within the global typology to global ecosystem type, such as depression mangroves, embayment mangroves, and coastal fringing mangroves. However, further fieldwork is required to investigate differences in the biotic composition and ecological function of these types.



Figure 8. Intertidal forest and shrubland (MFT1.2) located within an inland depression on HDh. Keylakunu. Image credit: IUCN Maldives.

### ***MFT1.3 Coastal saltmarshes and reedbeds***

**Biome** Brackish tidal (MFT1)

**Functional group** Coastal saltmarshes and reedbeds ([MFT1.3](#))

**Description:** Coastal saltmarshes and reedbeds (MFT1.3) represent low-energy depositional coasts that are tidally influenced and support salt-tolerant grasses and succulent shrubs (Keith et al., 2020b). They are regulated by fine scale hydrological and salinity gradients, while their proximity to marine and terrestrial ecosystems influences the complexity and function of trophic networks (Keith et al., 2020b).

Saltmarshes have been reported from the Maldives (Karthikheyana, 2010), however, their distribution is unknown, the record has not been confirmed and is considered uncertain due to a separate publication reporting no occurrence of these ecosystems within the country (Patro et al., 2017). Threats to this biogeographic ecotype are unknown due to the uncertainty about its presence in the Maldives.

**Notes:** The presence of saltmarshes within the Maldives is unconfirmed, however, due to one record of their presence (Karthikheyana, 2010), they are included here. Targeted fieldwork is recommended to determine the presence of this biogeographic ecotype within the Maldives.

## **2.9 Subterranean-Marine Realm (SM)**

The subterranean-marine realm is a transitional realm at the interface of both subterranean and marine systems (Keith et al., 2020a). The subterranean-marine realm in the Maldives is present around islands and within their porous carbonate substrate.

### **Subterranean Tidal Biome (SM1)**

The subterranean tidal biome includes coastal pools and subterranean voids with a partially or fully submerged connection to the marine environment (Keith et al., 2020a). In the Maldives, this includes subsurface systems exposed to marine environments such as sea caves or land-based water bodies that are connected to the marine environment through subsurface connections.

### ***SM1.2 Anchialine pools***

**Biome** Subterranean tidal (SM1)

**Functional group** Anchialine pools ([SM1.2](#))

**Description:** Anchialine pools (SM1.2) are brackish surface water bodies with subterranean connections between groundwater systems and the ocean through porous limestone substrates. A key feature of anchialine pools is no surface connection to the sea (Sakihara et al., 2020). With connectivity to the ocean through

substrate, they are tidally influenced and may fluctuate in water and salinity levels depending on tide height. They are exposed to air and sunlight, and support algal primary producers and complex benthic microbial communities. In the Maldives, small brackish water pools isolated from the ocean have been noted to rise and fall with the tide (Sewell, 1936) and have been locally reported on many islands (IUCN, 2021 pers. comm.), which are expected to be anchialine pools. These pools are commonly inhabited by gastropods, molluscs (e.g. *Terebralia palustris*), and crustaceans (e.g. *Leander sp.*) (IUCN, 2021 pers. comm.; Sewell, 1936). Older pools are known to support riparian and canopy vegetation (Sakihara et al., 2020), and it is possible that the expected anchialine pools in the Maldives support mangrove or other vegetation growth around the pool edges. Threats to this biogeographic ecotype are unconfirmed due to the uncertainty regarding its presence, however, they are likely to include agricultural and tourism development.

**Notes:** Due to the presence of appropriate conditions such as porous limestone substrate and groundwater systems (Bailey et al., 2014; Williams and Ting Fong, 2016), anchialine pools likely exist on many islands throughout the country, however, uncertainty still remains regarding their presence. Further field-based work to identify these pools is required, as no local studies beyond a single historical reference (Sewell, 1936) were identified during the literature review.

### **SM1.3 Sea caves**

**Biome** Subterranean tidal (SM1)

**Functional group** Sea caves ([SM1.3](#))

**Description:** Sea caves (SM1.3) are formations within rocky substrates that are normally formed by abrasive wave or current action, exposed to the external marine environment, and support a range of sessile and mobile invertebrates as well as other mobile marine biota such as fish (Gerovasileiou et al., 2020). Sea caves within the Maldives are purely subtidal and are presumed to be present on the steep walls of many reefs throughout the country (e.g. Le Berre et al., 2009).

Within the Maldives, sea caves are locally known as *faru hoholha* or *moodhu therey hohalhu* and believed to have formed due to excavation of hard reef rock during low sea-level stands (Rufin-Soler et al., 2013). A 'blue hole' cave with a depth of approximately 80m and a chemo-thermocline at approximately 50m depth has been noted in Faanu Madugau, Ari Atoll (Bianchi et al., 2009; Colantoni et al., 2003; Sandulli et al., 2014) as well as another 'blue hole' in South Malé Atoll (Betzler et al., 2015). Common species include sponges, black corals, gorgonians, crustaceans, molluscs, and cryptic fish as well as meiobenthic taxa including Nematoda, Copepoda, and Annelida (Le Berre et al., 2009; Rufin-Soler et al., 2013; Sandulli et al., 2014). Threats to this biogeographic ecotype are largely unknown but may include excess deposition of sediment from nearby land reclamation activities.

**Notes:** Few references to sea caves in Maldives were identified in the literature, so we expect further work is necessary to systematically identify and map the distribution of ecosystems within this ecosystem function group.



Figure 9. Sea cave (SM1.3) located on M. Hatharufaru. Image credit: IUCN Maldives.

## **2.10 Marine Realm (M)**

The marine realm includes all saline ocean waters characterised by waves, tides and currents (Keith et al., 2020a). The marine realm accounts for the majority of area within the Maldives' EEZ.

### **Marine Shelf Biome (M1)**

The marine shelf biome covers the area between the shoreline and the deep-sea biomes and includes both biogenic and minerogenic substrates (Keith et al., 2020a). This biome is highly diverse in the shallow, tropical waters of the Maldives.

## **M1.1 Seagrass meadows**

**Biome** Marine shelf (M1)

**Functional group** Seagrass meadows ([M1.1](#))

**Description:** Seagrass meadows (M1.1) represent shallow, subtidal or intertidal systems composed of marine angiosperms often located on soft substrates. They may be limited by wave action, tidal exposure, and depth (Bishop et al., 2020b). This ecosystem functional group is highly productive, often containing large amounts of organic matter within sediments, and provides three-dimensional structure that supports a diversity of marine biota. Seagrass meadows are present in shallow, sandy substrates throughout the Maldives, such as around Lh. Kuredu and L. Olhuveli, and are locally known as *huee gandhu*.

There are seven recorded species of seagrass from the Maldives (Milchakova et al., 2005; Roe, 2020), however, studies on Maldivian seagrass systems remain limited (Stevens and Froman, 2019). Common species include *Thalassia hemprichii* (often dominant), *Syringodium isoetifolium*, and *Thalassodendron ciliatum* (Brandano et al., 2019; Frazier et al., 2000; Miller and Sluka, 1999; Payri et al., 2012; Roe, 2020; Rotini et al., 2020). Less abundant species include *Cymodocea rotundata*, *Halodule pinifolia*, and *Halodule uninervis* (Brandano et al., 2019; Le Berre et al., 2009; Milchakova et al., 2005; Roe, 2020). Only one record of *Halophila ovalis* exists from Laamu Atoll (Roe, 2020). Seagrass meadows in the Maldives range from intact and well protected, to poorly managed and highly degraded due to land reclamation, removal for tourism development and small-scale aquaculture development (MoFMA, 2019a; Stevens and Froman, 2019)

**Notes:** Globally, seagrass meadows have been classified to lower levels, including transitory or permanent, subtidal, intertidal, or deep, and protected or exposed (Kilminster et al., 2015). Maldives seagrass meadows are likely to include a broad range of distinct types, including protected, exposed, intertidal (Ray, 2017), and, based on a study from the Chagos Archipelago (Esteban et al., 2018), deep meadows. However, due to the limited number of publications, there is insufficient information to identify global ecosystem type units. Further research into the extent and diversity of seagrass systems of the Maldives is recommended.

## **M1.3 Photic coral reefs**

**Biome** Marine shelf (M1)

**Functional group** Photic coral reefs ([M1.3](#))

**Description:** Photic coral reefs (M1.3) represent biogenic, calcium carbonate structures produced by photosynthetic Scleractinian corals that provide complex three-dimensional habitat to support highly diverse biotic communities at all taxonomic levels (Polidoro et al., 2020b). Photic coral reefs, locally known as *iruge ali libey faru*, are widespread across the Maldives in varying geomorphological forms including fringing reefs around islands, ring shaped atolls (*faros*), and shallow (*giri*)

and deep (>10m, *thila*) patch reefs (Naseer, 1997; Naseer and Hatcher, 2004; Stevens and Froman, 2019; Stoddart, 1966).

Over 2,000 distinct coral reefs (>1ha) have been reported within the archipelago, covering an area of approximately 4,000km<sup>2</sup> (Naseer and Hatcher, 2004). Common benthic biota on these reefs include hard coral species (Scleractinia), soft coral species (Alcyonacea), sponges (Porifera), and algae (Dryden et al., 2020b; Dryden et al., 2020c). Common mobile biota include tropical reef fish and pelagic fish species, invertebrates such as echinoderms and crustaceans, and megafauna including sea turtles, sharks, and cetaceans (Godfrey, 2018; Stevens and Froman, 2019). Coral reefs in the Maldives range from intact to highly degraded due to local impacts such as reclamation, resort development, and crown-of-thorns-starfish outbreaks as well as global threats such as mass coral bleaching events (Cowburn et al., 2018; Ibrahim et al., 2017)

**Notes:** We are only aware of one study that has applied the global ecosystem typology to photic coral reefs. This study, conducted in the Western Indian Ocean, suggested benthic cover was similar across reef zones and therefore photic coral reefs were not subclassified into global ecosystem types (Obura et al., In press). Based on this, alongside insufficient sampling across all photic coral reefs of the Maldives, we include all coral reefs in the country within this biogeographic ecotype.

### ***M1.5 Photo-limited marine animal forests***

**Biome** Marine shelf (M1)

**Functional group** Photo-limited marine animal forests ([M1.5](#))

**Description:** Photo-limited marine animal forests (M1.5) are represented by living, three-dimensional communities dominated by heterotrophic sessile suspension feeders in low-light environments where photosynthesis is limited to microphytobenthos and nutrient availability is dependent on influx from surface waters (Rossi et al., 2017; Stark et al., 2020). They can be composed of single species or multispecies communities with common biota including sponges, ascidians, hydrozoans, and azooxanthellate corals (Stark et al., 2020).

The only known record of benthic biota within a photo-limited zone in the Maldives is the hydrozoan *Millepora*, which was recorded from approximately 70m, however, the exact location of its collection is unknown (Agassiz, 1902). Despite only a single record, this biogeographic ecotype likely occurs across the country at depths where light penetration no longer supports photosynthesis, due to the presence of suitable conditions and sessile suspension feeder species. A change in biotic composition from zooxanthellate corals to azooxanthellate corals has been noted around 50m depth (Risk and Sluka, 2000), and additional heterotrophic communities are likely present below this depth.

**Notes:** Few publications were identified regarding the photo-limited zone of the Maldives and very little is known about the biotic community. Further research is



recommended to determine the presence and extent of this biogeographic ecotype in the Maldives and its compositional biota.

### **M1.6 Subtidal rocky reefs**

**Biome** Marine shelf (M1)

**Functional group** Subtidal rocky reefs ([M1.6](#))

**Description:** Subtidal rocky reefs (M1.6) represent ecosystems that consist of complex, subtidal habitat structures derived from irregular rocky substrates. They provide extensive topographic variation, promote habitat diversity and support complex biotic communities that are structured by depth, wave action, currents, and light availability (Polidoro et al., 2020a). These systems are inhabited by sessile primary producers and invertebrate filter feeders such as turf algae and barnacles, as well as mobile biota such as echinoderms, molluscs, and fish.

With an approximately 2,000m thick succession of limestone in the Maldives (Aubert and Droxler, 1992; Gischler, 2006; Godfrey, 2018), these rocky ecosystems are likely formed of coral fragments cemented in a limestone matrix (Stoddart, 1966). They are expected to occur across the country in areas where corals no longer occur and are locally referred to as *faru mathi*, *huraa gandu*, or *thoshi gandu*.

**Notes:** No information on this biogeographic ecotype in the Maldives was identified during the literature review, however, due to the presence of rocky limestone substrates it is presumed present throughout the country. Further research to confirm the presence and determine the extent of this ecotype and its compositional biota is recommended.

### **M1.7 Subtidal sand beds**

**Biome** Marine shelf (M1)

**Functional group** Subtidal sand beds ([M1.7](#))

**Description:** Subtidal sand beds (M1.7) represent ecosystems that consist of homogenous, medium to coarse grained, soft minerogenic, mobile sediments that are unvegetated and contain low organic matter (Polidoro et al., 2020c). They support moderate levels of biological diversity dominated by invertebrate detritivores and suspension feeders, such as polychaetes, crustaceans, echinoderms, and molluscs, but few in-situ primary producers (Polidoro et al., 2020c).

Subtidal sand beds are widespread across the Maldives, locally known as *dhon falhu*, and are present around islands in the form of shallow lagoons as well as in deeper waters within atoll lagoons (Agassiz, 1902; MEE, 2015; Sewell, 1936; Stoddart, 1966). Common species on these subtidal sand beds include echinoderms such as sea cucumbers (Holothuroidea) and sea stars (Asteroidea) (Clark and Davies, 1965; Ducarme, 2016). Meiofaunal communities within these sand beds consist largely of copepods, nematodes, Platyhelminthes, and polychaetes

(Semprucci et al., 2011). Threats to this biogeographic ecotype include removal or excess deposition of sediment from reclamation activities.

**Notes:** Few studies were identified regarding this biogeographic ecotype and further research is recommended to determine the composition of biotic communities and any functional differences that may lead to subclassification of lower level units within the global ecosystem typology.

### ***M1.8 Subtidal mud plains***

**Biome** Marine shelf (M1)

**Functional group** Subtidal mud plains ([M1.8](#))

**Description:** Subtidal mud plains (M1.8) include low energy ecosystems with weak turbulence and currents that are composed of fine-grained, muddy substrates, which typically support microalgal and bacterial primary producers, microbial decomposers, and deposit feeders with biogeochemical cycles strongly influenced by microbial communities (Polidoro et al., 2020d).

Few subtidal mud plains are known throughout the Maldives, locally known as *kisadu vilu*, and are only recorded from lagoons protected by continuous reef (Ciarapica and Passeri, 1993; Rasheed et al., 2021), such as the nearly enclosed lagoon of AA. Rasdhoo (Gischler, 2006). They are presumed present in any highly protected lagoon where fine sediment can accumulate, and are not expected in open ocean environments. Threats to this biogeographic ecotype include removal or excess deposition of sediment from reclamation activities.

**Notes:** Only three publications that discuss subtidal mud substrates in the Maldives were identified during the literature search and, to our knowledge, no attempts have been made to classify component global ecosystem types within this biogeographic ecotype. Further work to determine the extent and biotic composition within this biogeographic ecotype is recommended.

### ***Pelagic Ocean Waters Biome (M2)***

The pelagic ocean waters biome is the largest biome on earth, comprising the open-ocean water column across all latitudes (Keith et al., 2020a). This biome covers the vast majority of the Maldives EEZ that is largely open-ocean.

#### ***M2.1 Epipelagic ocean waters***

**Biome** Pelagic ocean waters (M2)

**Functional group** Epipelagic ocean waters ([M2.1](#))

**Description:** Epipelagic ocean waters (M2.1) represent the upper layer of the open-ocean (0-200m). This region of the ocean is heavily influenced by atmospheric conditions and light availability, whereby variable productivity supports diverse marine life and complex trophic networks (Watermeyer et al., 2020b).

This biogeographic ecotype is present throughout the vast majority of the Maldives, locally known as *maakanduge mathee fashala*, and may cover up to 99% of the country's EEZ (Hameed, 2002). Common species include important commercial pelagic fish species such as skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) (Adam et al., 2003; National Bureau of Statistics, 2020a), as well as resident and migratory megafauna such as humpback whales (*Megaptera novaeangliae*), whale sharks (*Rhincodon typus*), manta rays (*Manta alfredi* and *Manta birostris*), and numerous cetacean species (Anderson et al., 2012; Stevens and Froman, 2019).

**Notes:** We identified a large number of studies focused on charismatic or economically important species within this biogeographic ecotype. However, we are not aware of any studies that have identified lower level units, and therefore recommend further locally-based work to distinguish any global ecosystem types in the Maldives.



Figure 10. Pod of dolphins in the epipelagic ocean waters (M2.1) of Noonu Atoll. Image credit: Maren Toor.

## **M2.2 Mesopelagic ocean water**

**Biome** Pelagic ocean waters (M2)

**Functional group** Mesopelagic ocean water ([M2.2](#))

**Description:** Mesopelagic ocean water (M2.2) represents the low-light, twilight zone layer of the ocean (200-1000m) that is too dim for photosynthesis and relies on an influx of nutrients from upper pelagic layers, which leads to variable nutrient and energy availability (Watermeyer et al., 2020a).

No publications were identified regarding this biogeographic ecotype in the Maldives. However, bathymetric data and depth soundings suggest it is present around the Maldives island ridge and it is locally referred to as *maakanduge medhutherey fashala* (Agassiz, 1902; Betzler, 2014; Brewer et al., 2014; Harris et al., 2014).

**Notes:** This ecotype is poorly investigated in the Maldives. We are not aware of any attempts to identify lower level units of the global ecosystem typology for this functional group. Further research on the composition of this biogeographic ecotype in the Maldives is recommended.

## **M2.3 Bathypelagic ocean waters**

**Biome** Pelagic ocean waters (M2)

**Functional group** Bathypelagic ocean waters ([M2.3](#))

**Description:** Bathypelagic ocean waters (M2.3) represent deep open-ocean systems from 1000-3000m that receive no sunlight and rely on detrital fallout from upper layers of the ocean for nutrients (Linardich et al., 2020). Biota within this ecosystem functional group have specialized features to live within no-light environments.

No publications were identified regarding this biogeographic ecotype in the Maldives. However, bathymetric data and depth soundings support its presence across a large area of the EEZ and it is locally referred to as *maakanduge adee fashala* (Agassiz, 1902; Betzler, 2014; Brewer et al., 2014; Harris et al., 2014).

**Notes:** This ecotype is poorly studied in the Maldives and no attempts have been made to identify lower level units within the global ecosystem typology. Further research on the composition of this biogeographic ecotype in the Maldives is recommended.

## **M2.4 Abyssopelagic ocean waters**

**Biome** Pelagic ocean waters (M2)

**Functional group** Abyssopelagic ocean waters ([M2.4](#))

**Description:** Abyssopelagic ocean waters (M2.4) represent deep open-ocean systems from 3000-6000m that receive no light and are subject to cold temperatures and high pressures (Linardich and Keith, 2020). Living organisms within this functional group rely solely on detrital fallout from upper layers of the ocean for

nutrients, which support a low diversity and low density of life that largely consists of planktonic detritivores and gelatinous invertebrates (Linardich and Keith, 2020).

No publications were identified regarding this biogeographic ecotype in the Maldives. However, bathymetric data suggests the presence of this ecotype in all areas of the Maldives EEZ that encompass the depth range that defines the functional group and it is locally referred to as *maakanduge enme adi* (Brewer et al., 2014; Harris et al., 2014)

**Notes:** This ecosystem functional group is poorly studied and we are not aware of any attempts elsewhere to identify and describe lower level units of the global ecosystem typology. Further research on the composition of this biogeographic ecotype in the Maldives is recommended.

### **Deep Sea Floors Biome (M3)**

The deep sea floors biome covers the entire oceanic benthos below 250m, where a lack of light prevents primary productivity through photosynthesis (Keith et al., 2020a). In the Maldives, this biome is widespread across the EEZ with much of the sea floor below 250m.

#### ***M3.1 Continental and island slopes***

**Biome** Deep sea floors (M3)

**Functional group** Continental and island slopes ([M3.1](#))

**Description:** Continental and island slopes (M3.1) represent lightless sedimentary slopes of sand, mud, and rocky outcrops from depths of around 250 to 4,000m that are subject to strong depth gradients for temperature, pressure, light, and food availability (Ramirez-Llodra et al., 2020a). This functional group is dominated by microbial decomposers, detritivores, and their predators, which largely rely on nutrient fallout from upper ocean layers (Ramirez-Llodra et al., 2020a).

This biogeographic ecotype is present throughout the Maldives as the sea floor of the submerged ridge and continental shelf beneath the archipelago (Betzler et al., 2013; Brewer et al., 2014). Island slopes are locally known as *urafah*, however it is noted that this term can also refer to shallow reef slopes. Sediment samples collected from 390m in the channel between North and South Malé Atolls indicate a composition of carbonate sands, bryozoans, bivalves, gastropods, pteropods, *Halimeda*, and benthic foraminifera (Betzler, 2014). Sediment barren areas have also been reported that support echinoids, hydrozoans, and solitary corals (Reolid et al., 2017). One study was identified that reported the presence and abundance of deep demersal fish species within the Maldives, with the most abundant families including *Macrouridae*, *Congridae*, and *Lutjanidae* (Adam et al., 1998).

**Notes:** Few publications were identified regarding this ecotype during the literature review, most of which focused on bathymetric data. Further research to expand the information on the composition of this biogeographic ecotype is recommended.

### **M3.2 Submarine canyons**

**Biome** Deep sea floors (M3)

**Functional group** Submarine canyons ([M3.2](#))

**Description:** Submarine canyons (M3.2) represent productive and diverse deep sea systems where the topography modifies hydrodynamic processes, causing nutrient fluxes that promote productivity, and providing important refuge due to resource availability and habitat complexity (Fernandez de Arcaya et al., 2020).

Bathymetric data indicates that submarine canyons are likely to be present across the Maldives EEZ (Brewer et al., 2014; Harris et al., 2014). However, the literature review found no specific, locally relevant information about submarine canyons in the Maldives.

**Notes:** Few publications were found regarding this biogeographic ecotype in the Maldives, many of which focused on bathymetric data. The presence of submarine cliffs has been noted in the Maldives (Anderson, 1998; Reolid et al., 2017), however, depending on the topography of the formations, they may more closely relate to M3.1 (Continental and Island Slopes). Further research on the composition of this biogeographic ecotype from targeted canyon locations based on bathymetric data is recommended.

### **M3.3 Abyssal plains**

**Biome** Deep sea floors (M3)

**Functional group** Abyssal plains ([M3.3](#))

**Description:** Abyssal plains (M3.3) represent ecosystems that occur on the deep sea floor from about 3000 to 6000m. These plains are typically covered by a thick layer of fine sediment and support low biomass, but a high diversity of small invertebrates and microbes, larger crustaceans, demersal fish, and echinoderms. These organisms rely on the fallout of organic matter from upper ocean layers for nutrients (Ramirez-Llodra et al., 2020c).

Bathymetric data indicates the presence of this biogeographic ecotype within the Maldives EEZ (Brewer et al., 2014; Harris et al., 2014). Despite an exhaustive literature review, no other information on this biogeographic ecotype in the Maldives was found.

**Notes:** This ecosystem functional group is poorly studied, with only about 1% of the global seafloor investigated biologically. No specific studies were found relating to abyssal plains in the Maldives. Further research on the composition of this biogeographic ecotype in the Maldives is recommended.

### **M3.4 Seamounts, ridges and plateaus**

**Biome** Deep sea floors (M3)

**Functional group** Seamounts, ridges and plateaus ([M3.4](#))

**Description:** Seamounts, ridges and plateaus (M3.4) are deep, lightless ecosystems located on major geomorphic features that interact with hydrodynamics to enhance productivity in upper euphotic ocean layers, which lead to increased levels of detrital fallout below (Ramirez-Llodra et al., 2020d). This fallout, along with varied rocky habitats, supports diverse communities of sessile filter feeders, mobile benthic organisms, and aggregations of fish (Ramirez-Llodra et al., 2020d).

An analysis of bathymetric data suggests the presence of this biogeographic ecotype in the Maldives (Brewer et al., 2014; Harris et al., 2014; Kitchingman and Lai, 2004), which are generally described as rising from around 800m depth to about 100m depth (Brewer et al., 2014). This ecotype reportedly contributes to ecosystem services such as nutrient cycling and tuna fisheries and is locally known as *kandu adee thila* (Agardy et al., 2017).

**Notes:** Few publications were identified regarding this biogeographic ecotype in the Maldives, most of which focus on bathymetric data, and no information was found on biotic communities. Further research on the composition of this ecotype in the Maldives is recommended.

### **M3.5 Deepwater biogenic beds**

**Biome** Deep sea floors (M3)

**Functional group** Deepwater biogenic beds ([M3.5](#))

**Description:** Deepwater biogenic beds (M3.5) consist of complex three-dimensional structures formed by slow-growing filter feeders in lightless environments that rely on currents and fallout from upper ocean layers for energy and nutrients (Ramirez-Llodra et al., 2020b). These systems provide shelter for other organisms, including decomposers, detritivores, and their predators, and increase retention of particulate matter (Ramirez-Llodra et al., 2020b).

Little information is known about this biogeographic ecotype in the Maldives. Potential occurrences include the Kardiva Channel (457m depth) and the Malé-Vaadhoo Channel (443m depth) (Reolid et al., 2017). These occurrences are primarily present in channels and, given that deepwater channels are present across the country, we expect this biogeographic ecotype to be widespread. Biota collected from these sites include gorgonians, hydrozoans, bryozoans, and sponges as well as microbial mats, gastropods, barnacles, and ophiuroids (Reolid et al., 2017)

**Notes:** The presence of fossilised cold-water corals, including *Lophelia*, *Madrepora*, and *Enallopsammia*, were also recorded from the above channels, indicating that similar deepwater biogenic communities may exist elsewhere the country. However, environmental conditions such as oxygen levels and density may prohibit their

growth in certain areas (Reolid et al., 2017). Further research on the presence and composition of this biogeographic ecotype in the Maldives is recommended.

### **Anthropogenic Marine Biome (M4)**

The anthropogenic marine biome includes constructed, deposited, or dumped artificial structures in the oceans that manage marine organisms or attract marine biota that would not otherwise occupy such locations (Keith et al., 2020a). In the Maldives, this biome includes various forms of submerged artificial structures.

#### **M4.1 Submerged artificial structures**

**Biome** Anthropogenic marine (M4)

**Functional group** Submerged artificial structures ([M4.1](#))

**Description** Submerged artificial structures (M4.1) represent artificial hard substrates in coastal waters, often with high vertical relief and dominated by filter feeding organisms and biofouling communities (Suthers et al., 2020b). This biogeographic ecotype in the Maldives includes numerous shipwrecks, artificial reefs and reef restoration structures, low-relief structures such as rubble piles, and offshore fish aggregating devices (FADs).

Shipwrecks, artificial structures, and restoration structures are present throughout the country in shallow island and atoll lagoons, while FADs are often located offshore, anchored in 2000m of water outside of atoll rims (Adam et al., 2019; Clark and Edwards, 1999; Godfrey, 2018; Hein et al., 2020). Common species around shipwrecks and artificial structures include Scleractinian and soft corals (Clark and Edwards, 1999) while common species around FADs include skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) (Adam et al., 2019).

**Notes:** Potential lower level classifications for this ecotype include inshore and offshore structures. However, no studies have distinguished global ecosystem types within this functional group, and therefore on-ground investigations are recommended to adequately identify global ecosystem types within this biogeographic ecotype in the Maldives.





*Figure 11. Scleractinian corals growing on a submerged artificial structure (M4.1). Image credit: IUCN Maldives.*

## 3.0 Summary

### 3.1 Overview

A total of thirty-three biogeographic ecotypes were identified in the Maldives under the IUCN Global Ecosystem Typology (Table 1). Sixteen (48.5%) of these are within the Marine realm, three (9.1%) are in the Terrestrial realm, one (3%) is in the Freshwater realm, one (3%) is in the Subterranean realm, and the remaining twelve (36.4%) biogeographic ecotypes exist within transitional realms at the interface between two or more of the major realms.

**Table 1. Number of biomes, ecosystem functional groups, and biogeographic ecotypes identified in the Maldives.** Note that because nearly all of the Maldives is mapped within one marine ecoregion and one terrestrial ecoregion, the number of biogeographic ecotypes is the same as the number of ecosystem functional groups.

Realm	No. of Biomes	No. of Ecosystem Functional Groups	No. of Biogeographic Ecotypes
Terrestrial	1	3	3
Subterranean	1	1	1
Freshwater	1	1	1
Terrestrial-Freshwater	1	1	1
Subterranean-Freshwater	1	1	1
Freshwater-Marine	1	1	1
Marine-Terrestrial	3	5	5
Marine-Freshwater-Terrestrial	1	2	2
Subterranean-Marine	1	2	2
Marine	4	16	16
<b>Total</b>	<b>15</b>	<b>33</b>	<b>33</b>

This study revealed that many of the biogeographic ecotypes identified in the Maldives have been poorly investigated and thus remain poorly understood. Research has focused heavily on a small number of select functional groups (particularly coral reefs and intertidal forests), and is limited or absent for the majority of biomes that occur in the Maldives. Consequently, the presence of multiple biogeographic ecotypes, such as salt marshes and muddy shorelines, is still unconfirmed and requires field work to establish their presence and distribution. These unconfirmed types have been included here due to either (i) the presence of appropriate conditions for their existence, (ii) reference in some way in the literature, and (iii) spatial analyses suggesting they occur (particularly deep sea marine ecosystems).

Regional and local differences in biotic composition were not possible to investigate in this study due to insufficient published information or a lack of ability to conduct field work, without which it was not possible to sub-classify the biogeographic ecotypes to the lower level units of the Global Ecosystem Typology (such as global ecosystem types). In particular, many biogeographic ecotypes have not yet been distinguished in regional or national scale applications of the typology. Furthermore, although classifying to global ecosystem types is achievable for some knowledge-rich functional groups (such as intertidal forests and shrublands), this level of classification could not be universally achieved across all functional groups identified in this project. Therefore, to avoid inconsistency in the application of the typology across realms, biomes and functional groups, the report was completed at the highest level of classification (Level 4) that could be achieved across all identified units in the Maldives.

## 3.2 Recommendations and next steps

To further this work we make the following recommendations, which are primarily aimed at filling knowledge gaps and advancing the information base for Maldivian ecosystems:

1. *Knowledge gaps.* This report revealed a paucity of knowledge on the majority ecosystem types that are known to occur in the Maldives. We recommend continued monitoring of the scientific literature, increasing archive of global environmental datasets, and other applications of the IUCN Global Ecosystem Typology to fill the knowledge gaps identified in Section 2. Field-studies and spatial analysis targeted at confirming the distribution of particular functional groups, and distinguishing component ecosystems to lower level units of the typology are also needed.
2. *Spatial data.* We suggest mapping the units identified in this study via remote sensing, image interpretation, spatial analysis or field work to provide a basis of further work to develop the knowledge base on Maldivian ecosystems. Such work would initially be targeted at terrestrial ecosystems, where satellite data sources offer the means to map observable land cover types, and extended into marine ecosystems as suitable data becomes available.
3. *Risk assessment.* This work provides the basis for a national scale IUCN Red List of Ecosystems assessment. We recommend the development of an overarching red listing project aimed at filling the knowledge and data gaps outlined above, and conducting the necessary analyses to estimate the risk of ecosystem collapse for all of the ecosystems of the Maldives. This task could be reduced in scale by (i) only assessing natural ecosystems (i.e. not assessing the anthropogenic biomes, such as the intensive land use (T7),

anthropogenic shorelines (MT3), or anthropogenic marine (M4) biomes) and may be conducted sequentially, by focusing first on terrestrial ecosystems or ecosystems where the knowledge base is particularly high (e.g. intertidal forests and shrublands, or photic coral reefs).

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# Appendix 1. List of biogeographic ecotypes of the Maldives

Realm	Biome(s)	Ecosystem Functional Groups (EFGs) / Biogeographic Ecotypes	Dhivehi Name
Terrestrial	T7 Intensive land-use	T7.1 Annual croplands	Dhandu bin
		T7.3 Plantations	Ruh faa/Ruh dhandu (coconut plantation) Keyo faa/Keyo dhandu (banana plantation)
		T7.4 Urban and industrial ecosystems	Not yet determined
Subterranean	S1 Subterranean lithic	S1.2 Endolithic systems	Huraa gandu
Freshwater	F2 Lakes	F2.2 Small permanent freshwater lakes	Kulhi, Koaru
Terrestrial-Freshwater	TF1 Palustrine wetlands	TF1.3 Permanent marshes	Chas bin
Subterranean-Freshwater	SF1 Groundwater ecosystems	SF1.2 Groundwater ecosystems	Meerufenuge maahaalee nizam Bimuge fen fashala
Freshwater-Marine	FM1 Semi-confined transitional waters	FM1.3 Intermittently closed and open lakes and lagoons	Vilu (lagoon)
Marine-Terrestrial	MT1 Shorelines	MT1.1 Rocky shorelines	Akiri gandu Futtaru
		MT1.2 Muddy shorelines	Chakaveli gondudhoh
		MT1.3 Sandy shorelines	Dhonveli gondudhoh
	MT2 Supralittoral coastal	MT2.1 Coastal shrublands and grasslands	Heylhifah (outer coastal vegetation belt, coastal strands)
MT3 Anthropogenic shorelines	MT3.1 Artificial shorelines	Hihkki sarahahdhu gondudhoh Masnooe hihkki asseyrifah	
Marine-Freshwater-Terrestrial	MFT1 Brackish tidal	MFT1.2 Intertidal forests and shrublands	Kandoofaa (Some species and genera have individual Dhivehi names)
		MFT1.3 Coastal saltmarshes and reedbeds	Not yet determined
Subterranean-Marine	SM1 Subterranean tidal	SM1.2 Anchialine pools	Not yet determined
		SM1.3 Sea caves	Faru hoholha Moodhu therey hohalhu
Marine	M1 Marine shelf	M1.1 Seagrass meadows	Huee gandu
		M1.2 Photic coral reefs	Iruge ali libey faru
		M1.5 Photo-limited marine animal forests	Not yet determined
		M1.6 Subtidal rocky reefs	Faru mathi Huraa gandu Thoshi gandu
		M1.7 Subtidal sand beds	Dhon falhu
		M1.8 Subtidal mud plains	Kisadu vilu
	M2 Pelagic ocean waters	M2.1 Epipelagic ocean waters	Maakanduge mathee fashala
		M2.2 Mesopelagic ocean waters	Maakanduge medhutherey fashala
		M2.3 Bathypelagic ocean waters	Maakanduge adee fashala
		M2.4 Abyssopelagic ocean waters	Maakanduge enme adi
	M3 Deep sea floors	M3.1 Continental and island slopes	Urafah (island slope/reef slope)
		M3.2 Submarine canyons	Not yet determined
		M3.3 Abyssal plains	Not yet determined
		M3.4 Seamounts, ridges and plateaus	Kandu adee thila
		M3.5 Deepwater biogenic beds	Not yet determined
M4 Anthropogenic marine	M4.1 Submerged artificial structures	Not yet determined	

## Appendix 2. Atolls of the Maldives

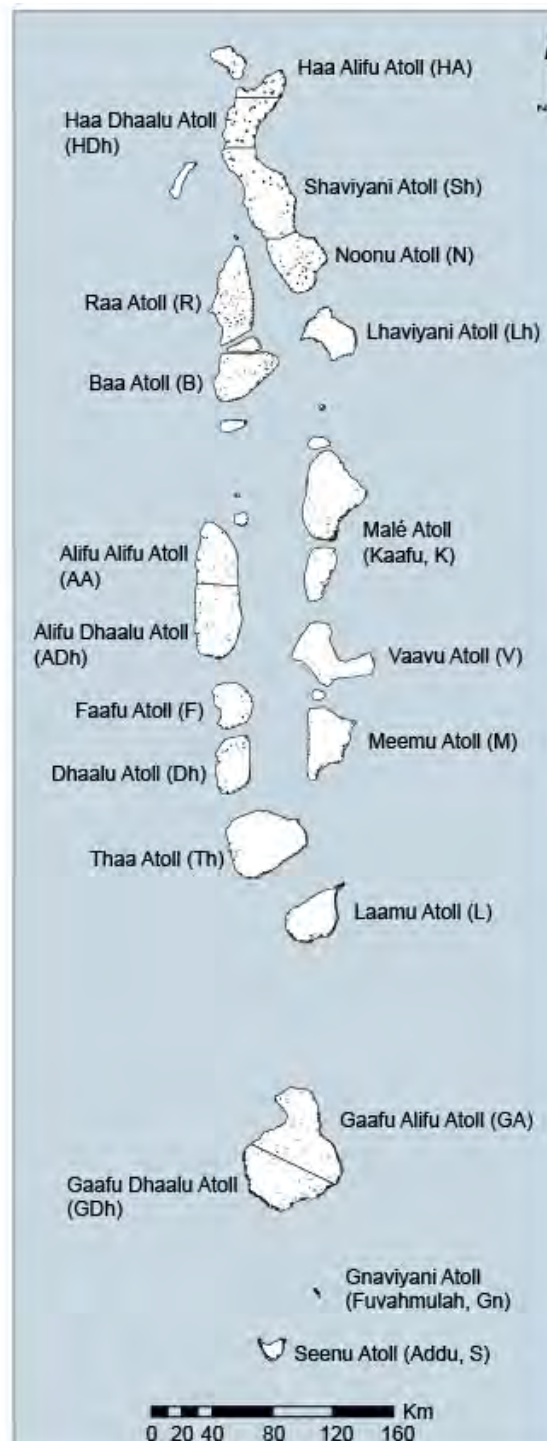


Figure A1. Map of administrative atolls of the Maldives, including atoll names and abbreviations.



## Appendix 3. List of literature reviewed

The full list of literature reviewed for the purpose of applying of the Global Ecosystem Typology to the Maldives is available in the [‘live’ spreadsheet](#).

## Appendix 4. List of workshop attendees

	Name	Organization
1	Nick Murray	James Cook University
2	Maren Toor	James Cook University
3	Charlie Dryden	IUCN
4	Ibrahim Lirar	IUCN
5	Reema Mohamed	IUCN
6	Scott Perkins	IUCN
7	Najfa Shaheem Razee	IUCN
8	Ahmed Basheer	IUCN
9	Abdul Hameed Ali	Ministry of Environment, Climate Change and Technology
10	Abdulla Naseer	Ministry of Environment, Climate Change and Technology
11	Ahmed Shan	Ministry of Environment, Climate Change and Technology
12	Hawwa Nabaahaa	Ministry of Environment, Climate Change and Technology
13	Ilham Mohamed	Ministry of Environment, Climate Change and Technology
14	Riyaz Jauhary	Maldives Marine Research Institute
15	Ahmed Najeeb	Maldives Marine Research Institute
16	Nabeela Abdulla	Maldives Marine Research Institute
17	Rifath Naeem	Environmental Protection Agency
18	Ahmed Leevan	Environmental Protection Agency
19	Roohulla Shiyam	Ministry of Arts, Culture and Heritage
20	Aishath Muneeza	Ministry of Arts, Culture and Heritage
21	Fathimath Shadiya	Maldives National University
22	Hussein Zahir	LAMER
23	Azim Musthag	LAMER
24	Fathimathi Nistharan	Waitt Institute
25	Ahmed Shaig	CDE
26	Aleef Abdulla Naseem	Water Solutions
27	Afa Hussein	

