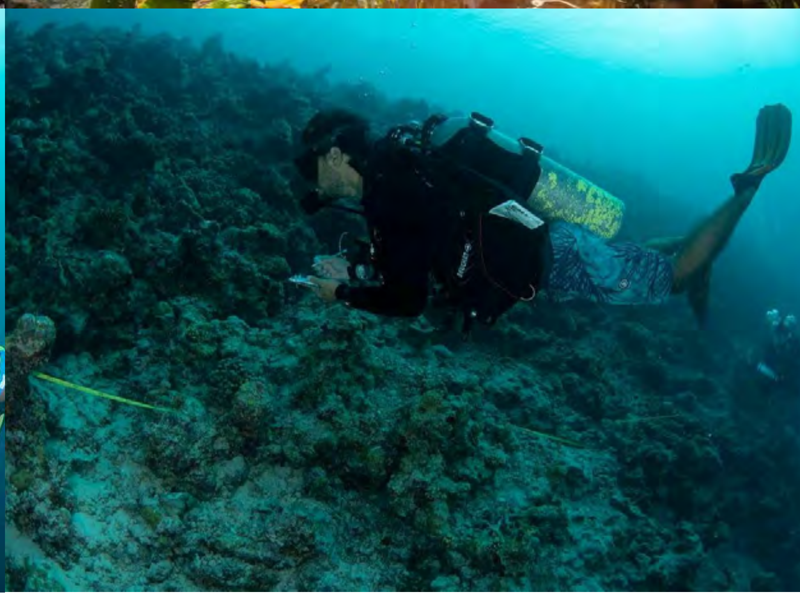
Guidelines for coral reef and small island vegetation surveys in the Maldives

Charlie Dryden and Ahmed Basheer



This publication has been made possible in part by generous funding from USAID.

This publication has been made possible with the collaboration and expertise of Ministry of Environment, Environmental Protection Agency (EPA)

The authors are grateful to Najfa Shaheem Razee, Fathimath Shihany Habeeb and Rifath Naeem for reviewing the report and providing feedback.

Published by: IUCN and the Government of Maldives in collaboration with USAID

Authors: Charlie Dryden[1] and Ahmed Basheer[1]

[1] IUCN (International Union for Conservation of Nature) Maldives, Malé, Maldives

Citation: Dryden C, and Basheer A. (2020). *Guidelines for coral reef and small island vegetation surveys in the Maldives.*
Malé, Maldives: IUCN and Government of Maldives. xx pp.

Cover photo: © Ahmed Basheer, IUCN Maldives

Layout by:

Produced by: IUCN Maldives, Malé, Maldives

Table of contents

List of tables

List of figures

1 Introduction

1.1 Overview

The Maldives are a double chain of atolls in the central Indian Ocean. The country has approximately 1,190 islands with a total land area around 21,372km^2 (Naseer & Hatcher, 2004). Islands ranges from small sand banks with no vegetation to large islands of over 5 km^2 with well-developed woodland habitats. Islands are typically low lying, with 80% of the country being less than a meter above the sea level (Ministry of Environment and Energy, 2015). Terrestrial habitats include beaches, marshes, brackish ponds, mangroves and woodlands. These areas can be rich in biodiversity and natural resources for local communities.

Maldivian coral reefs are the seventh largest reef system in the world, representing as much as 3.14% of the worlds' reef area. There are approximately 2,040 individual reefs covering an 4,493.85km^2 (Naseer & Hatcher, 2004). Coral reefs across the country come in a range of formations and sizes including fringing reefs, faros, thilas and channels, all of which exist at both inner and atoll edge locations. They are found at depths of less than 1 m to greater than 40 m. Reefs can be exposed to different environmental conditions such as currents, nutrient flows, temperatures, sedimentation and wave exposure. The variety in reef type, location and environment poses a significant challenge to survey design, as no one approach can be used for all habitats, and remote locations can take significant time and funding to access. Some reef formations are rare elsewhere in the world and are not discussed in other survey manuals.

Habitats in the Maldives show great variation in space and time where populations and environment vary in response to changing conditions. Temporal changes are caused by seasons, tides, disturbance events (e.g. temperatures or ship groundings) and coastal development. Spatial variations exist over environmental gradients e.g. a fringing reef around an island experiences ocean-ward, channel an inner atoll area conditions; or variations in island vegetation changing with distance from the shore as groundwater salinity and sediment nutrient levels change.

Island use in the Maldives can be divided into three categories community inhabited islands, resort islands and uninhabited islands. Each category will have its own stakeholder values and impacts on the terrestrial and marine habitats and understanding these are key to sustainable resource development and management across the country. Alongside local dangers to the environment there are climate change associated threats that are also likely to affect the Maldives.

Many islands have undergone significant construction projects for island expansion, infrastructure development or the joining of island chains. In some cases, new islands have been built on top of reefs through the deposition of sand and aggregates. Much of the material used in these reclamation and island building projects is dredged up from inner atoll areas.

The only way to determine the likely impacts of local and global scale changes to the natural environment is to conduct surveys and setup monitoring programmes. Through an improved understanding of these environments necessary steps can be taken to mitigate negative impacts and to develop effective management strategies. Without the correct information efforts may be misdirected and inappropriate. Continued monitoring of areas will be necessary to determine whether a management approach has been effective. Therefore, surveying and monitoring Maldivian natural environments is key to protecting the ecosystem.

1.2 Scope of these guidelines

The challenges associated with surveying the Maldives' natural environments has been a barrier to developing a more complete understanding of the habitats. Though many research and survey projects have taken place in the Maldives, a range of issues has resulted in a less complete understanding of the environment than should be the case. Survey results from the range of reef habitats are not easily extrapolated from one reef habitat to another. Observations on a reef flat are not necessarily the same for a reef slope, and an atoll-ward reef slope/flat area likely differs from oceanward reefs. These also differ around community, uninhabited and resort islands and between faro reefs and island reefs. Furthermore, typical reef flats and slopes are a very different environment from the reefs around thilas and even more so than channel habitats. All these ecologically valuable habitats will require its own survey and potentially its own survey methodology. A variety of survey methods have been developed for marine and terrestrial areas and are described in sections 2 and 3 respectively.

Ideally there would always be adequate time and resources to conduct well-designed surveys, in reality most projects have severe limitations on one or both. In a worst-case-scenario, data collection can be poorly designed and executed leading to virtually worthless data, that impacts on data analysis and interpretation and can result in incorrect conclusions. Sampling procedures should follow strict sampling design and field protocol to ensure consistent data collection of the best possible quality. The aim of this manual is to provide surveyors with a toolbox of techniques that can be used to survey many of the habitats present in the Maldives. It is by no means comprehensive, however where time and resources are limited it can be used to design and undertake marine and terrestrial surveys to provide consistent and accurate data.

Surveys are conducted with the aim of producing a specific project that ends in a final report or publication. Monitoring programmes are the repeated survey of an area over time to identify change. Such data is valuable and are needed to examine trends and changes in the environment. The entry and archiving of data is therefore particularly important.

This manual focuses on conducting surveys that will establish baseline information about an area. Such surveys assess the conditions at a moment in time and the data provides only a snapshot of the habitat and the associated communities. The methods described here are conducted over a short period of time using limited equipment and requiring relatively basic training.

To assess changes over time monitoring programmes should follow on from initial surveys. Monitoring is particularly important where changes have been made to an area, such as the implementation of habitat management or coastal development projects. Monitoring will detect progress towards management targets or assess the environmental impacts had by development. The outcome of monitoring projects can be used to inform future conservation actions or provide more detailed information about how coastal development may impact the natural environment.

This manual does not discuss ecological theory and additional information you might need to know about the habitat or community being studied. Understanding this information is key to designing the aims of the project and should come from background research. Once you have clear aims this manual can then be used to identify the most appropriate methods to collect the data which will help you meet them.

1.3 Survey objectives and design

Different objectives require different survey approaches and no one design is suitable to address all questions about the status of a habitat. It is therefore essential that the most appropriate survey design is used. This requires an understanding of the aims of the study, the field conditions and the procedures to be used in processing and analysis. It is also important undergo training in the field survey methods that will be used. Where possible pilot studies should be conducted, these contribute to surveyor training and allow the team to understand the survey environment and ensure the most suitable methods are used. If clear project objectives have not been defined and a sensible survey plan designed, the results can be inaccurate, irrelevant or at worst misleading. Therefore, the first step of any survey project should be to carefully identify the project objectives, the sampling design and the analysis protocols before undertaking field activities.

1.3.1 Survey objectives

1. **Baseline assessment** – the presence and location of environmental resources
2. **Habitat mapping** – the extent and boundaries of habitats.
3. **Impact of a disturbance** – how has a disturbance event e.g. coral bleaching or tsunami affected the environment.

4. **Impact of human activities** – how have the activities of human communities affected the environment and associated resources. Including fishing, tourism, coastal development and land use practices.
5. **Education and awareness** – providing support for environmental management through raising awareness and education of local communities and stakeholders.
6. **Improving environmental management** – using data from surveys to better design protected areas or develop management plans.
7. **Scientific study –** data collected will be used to write scientific reports or papers

1.3.2 What surveying approach to use?

Once the objectives of your survey is established you will need to decide what methods to use. This will depend on multiple factors including:

1. The type of habitat that you need to survey
2. Scale of the area you need to survey
3. The resources you have available
4. Level of local and scientific expertise available

This survey manual focuses on two habitats in the Maldives, coral reefs and island vegetation (including mangroves). The decisions to be made regarding surveys in these habitats are covered in sections 3 and 4, respectively.

Surveys can be loosely grouped into qualitative and quantitative surveys. Qualitative surveys can be performed faster, can cover a larger area and generally require some level of estimation. As a result, they are less precise and are sensitive to inter-observer differences. Quantitative surveys have greater precision, provide more reliable data and are better suited to statistical analysis. However, they take longer to perform and tend to cover a smaller sample of the area or community. All surveys should be repeated in nearby areas to for multiple replicates of a site or area. This provides a more accurate representation, gives more confidence in the data and allows statistical analyses to be performed.

1.3.3 **Indicator selection**

To determine the status or biodiversity of an ecosystem we need to identify measurements – or indicators – that will tell us about the health and integrity of the system. These indicators are then used to help assess pressures or threats, the state of species or ecosystems, management or conservation response and benefits to people provided by the environment. Broad scale indicators that aggregate information can be used to report on the national environment and the benefits of environmental policy, Fine scale indicators can be used to understand local conditions and inform local decisions, such as local management efforts.

Deciding which indicators to use for your survey will depend on the objectives and goals of the project. Baseline assessments impacts of disturbance or humans, environmental management and scientific study objectives will require precise indicators that provide detail on the status of the habitat and can be monitored over time to detect change. Examples of these include coral cover and fish species diversity for a coral reef or tree density and health for an area of mangrove. Where the objectives require less precision, indicators may be more simplistic. Habitat mapping projects are likely to use broad categories to identify where environments change between terrestrial zones such as mangrove to coastal fringe or coral reef to seagrass. This manual provides methods which allow you to collect data on a range of Maldivian ecosystem indicators.

2 Marine Surveys

2.1 Site selection

Site selection is critical first step in design of a marine survey. The chosen site must be one where the survey can meet the aims of the project and suitable and accurate data can be collected. The site chosen should be representative of the area of interest. In the Maldives, the habitat can differ significantly based on physical or social parameters. If the aim is to examine the reefs around an atoll edge island it is important that surveys account for the differences between atollward and oceanward reefs. Rapid survey methods that cover large areas can be used to identify areas which can be surveyed by more detailed methods. Site selection should consider the following:

- Are sites are representative of the habitat you want to survey?
- The range of physical and social influences on the sites
- Safety of the survey team. Is it safe to survey given the wave, current or other conditions?

Sample design (Box 1) will be an important factor in survey site selection, particularly surveys that sample smaller areas of the habitat and where time is limited. Depending on the goals of the survey and approach to data analysis, different sample designs will be more appropriate.

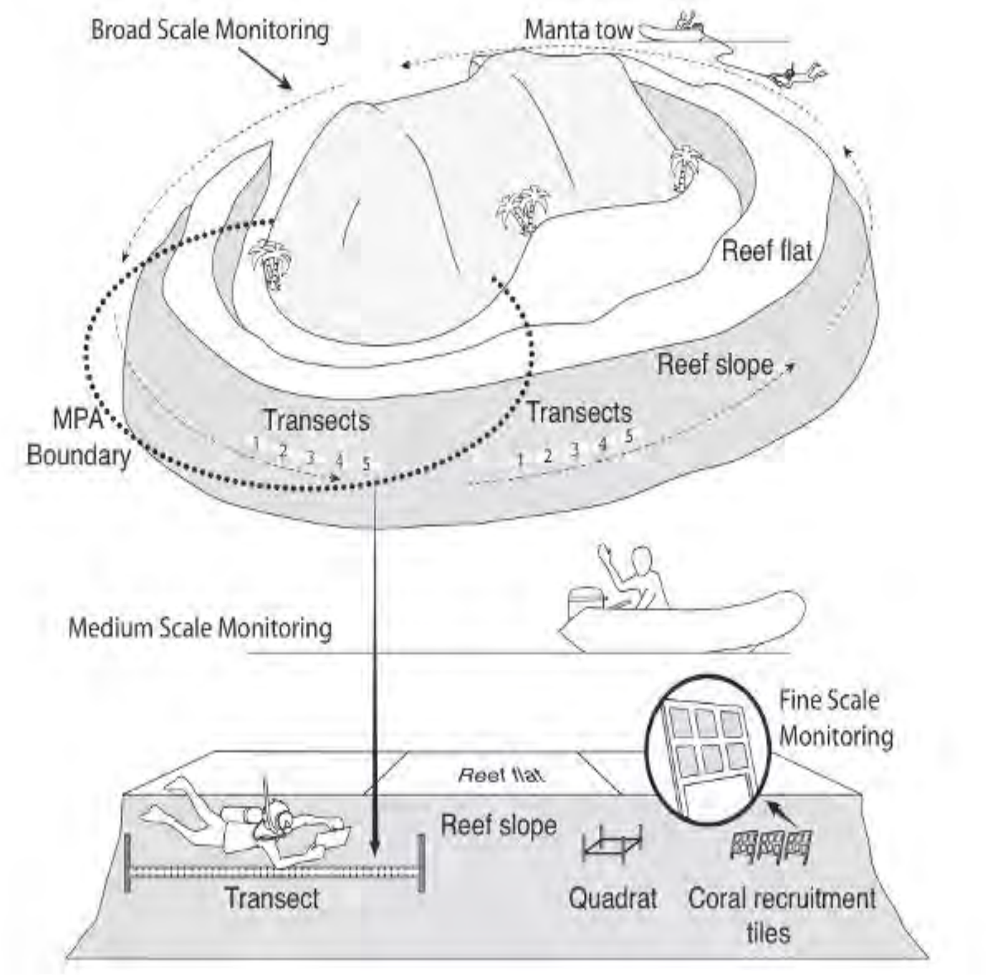


Figure 1. Where to use different survey methods. - we will need to create our own version of this diagram with roaming surveys and without settlement tiles and quadrats. Also, with different Maldivian reef structures - reef, channel, thila etc.

Box 1: Sample design

It is rarely, if ever possible to perform a complete survey of a habitat or population, therefore we must select a sample (small area or group) to survey. There are different approaches to selecting a sample and the approach chosen can significantly impact your site selection and survey outcomes. The most common approaches used for environmental surveys are:

- **Random sampling**: An entirely random method of selecting the sample. Using this approach random points are generated across the entire survey area.
    - **Advantages**: Unbiased, no need for prior knowledge about the area, simple approach
    - **Limitations**: Can miss key areas, survey sites may be clustered together, may require a high survey intensity to collect data representative of the whole area, may lead to selection of inaccessible areas
    - **Should be used when:** the survey area is clearly defined, where a high number of samples can be surveyed, and little is known about the area prior to surveying
- **Stratified random sampling**: The survey area is divided into sub-groups based on shared attributes or characteristics and random points are surveyed within each sub-group
    - **Advantages**: Can provide more accurate results with smaller sample size than random sampling, makes sure all target habitats are surveyed.
    - **Limitations**: Requires prior knowledge of the survey area, requires training, can be subject to bias
    - **Should be used when:** information is known about the area prior to surveys, the survey aims require a representative sample from sub-groups within the survey area and less time is available for surveying
- **Systematic sampling**: The surveyor chooses survey sites by selecting a random starting point and selects sample sites at a fixed 'sampling interval.' e.g. every 50 m
    - **Advantages**: Simple to create and conduct surveys, unbiased
    - **Limitations**: Can miss key areas, may lead to selection of inaccessible areas
    - **Should be used when**: little is known about the area prior to surveying, it is important for survey sites to be spread throughout the survey area

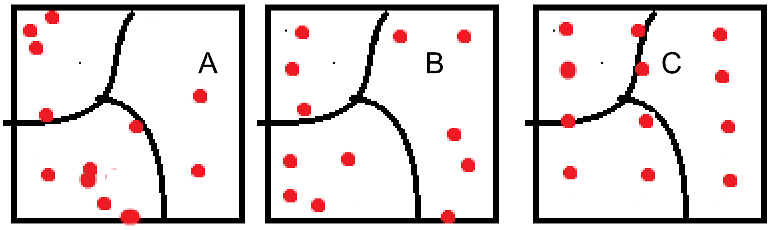


Figure 2. How survey sites may be distributed across a survey area with three different habitats using A) random sampling, B) stratified random sampling and C) systematic sampling

Box 2: Metadata

Metadata is an essential component of all environmental surveys. It provides necessary contextual information about datasets making them easier to understand and use. Metadata should answer the following questions:

Who:
- o collected the data?
- o processed the data?
- o should be contacted for questions about the data?

What:
- o are the data about?
- o project the data was collected for?
- o is the quality of the data?
- o are the appropriate uses of the data?
- o parameters measured?

Why:
- o was the data collected?

Where:
- o was the data collected?
- o is the original data located?

When
- o was the data collected?

How:
- o was the data collected?
- o how was the data processed?

The "**where"** question about the data is particularly important for ecological surveys. The answer is not limited to the name of an island or site, it should also include additional information related to the survey and the environment. For example, the population of an island where multiple sites are surveyed or general comments or observations about the survey area, such as exposed shoreline or strong currents.

Datasheets used for data collection should have sections or space for noting metadata information such as surveyor(s), date, time, and general comments.

During data entry a metadata table should be created with all the necessary information about the survey and survey sites. This table should clearly link to the relevant parts of the data and should always be sent with the raw data.

2.2 Benthic community

The benthic community describes the composition of the living and non-living substrate. There are many different components of the benthos, some of which require targeted approaches to survey appropriately. Data describing the benthic community can be collected at different levels of precision from rapid surveys covering large areas to more rigorous surveys examining smaller areas of reef in high detail.

2.2.1 **Benthic cover**

This is commonly collected as the percent of the substrate covered by different categories. Simple categories can be used e.g. hard coral, algae, etc. These can be further divided (Table 1) into growth form e.g. for hard corals – branching, tabular, encrusting etc.; or into taxonomic groups e.g. macroalgae and turf algae or to genus or species. The level of precision for the indicator used will depend on the survey objectives, time and the expertise available. This is data is easy to collect and understand, it can be used to capture changes in the reef over time or following a disturbance and can be collected using a range of survey methods.

Table 1. Additional levels of detailed that can be used to add precision to surveys of the benthic community

Level 1	Level 2 progression	Level 3 progression
Hard coral	To growth form	To family, genus or species
Soft coral	-	To family, genus
Algae	Macroalgae, turf algae and CCA	Macroalgae to genus
Rock	To growth form	To growth form
Rubble	-	-
Sand		-
Other	Include values for sponge cover	Include values for additional categories e.g. anemones, zoanthids etc.

2.2.2 **Coral community**

To assess coral community dynamics in greater detail, colony size can be collected alongside taxonomic data. This is done by measuring each coral colony within the sample area using either callipers or a small tape measure and identifying them to the required taxonomic level. Colonies are typically group into 5 cm size classes for analysis, with colonies less than 5 cm classed as new recruits. Surveys may target coral recruits as this can provide valuable information of about reef resilience. Size class data can provide information about the population structure of a coral community and about the potential resilience of the reef. Size class data is collected on belt transects, where all corals within the belt area are counted, measured and identified. This can be time consuming and will only cover a small area. Recruit specific surveys can be performed using quadrats along transects and can easily be added to other benthic surveys. Targeting only recruits will reduce survey time.

2.2.3 **Coral health**

Including indicators of coral health in surveys is important to identify and understand the causes of coral stress and mortality. Broad scale surveys can be used to identify the occurrence of bleaching or disease at a site and to estimate the proportion of colonies affected. Using more detailed survey methods it is possible to collect information about the number and taxonomic groups impacted, whether it has resulted in colony mortality and in the case of disease what type it is. To track and assess the impacts and recovery on corals following bleaching or disease, specific colonies can be tagged and monitoring of the site can be used to follow survivorship vs. mortality.

2.2.4 **Structural complexity**

Coral reefs are structurally complex habitats with an intricate three-dimensional matrix that provides a range of ecosystem services for many reef dwelling species. Monitoring reef complexity provides information about how this structure changes and the impact this may have on the reef community. The most common method for measuring reef complexity is using a fine-linked chain that is laid over the reef, closely following the reef contours, alongside a transect tape to calculate the rugosity index (Risk, 1972). The actual length of the chain is divided by the length of the chain over the reef contours, giving a rugosity index (Equation 1).

$$RI = \frac{actual\ chain\ length}{chain\ length\ over\ reef}$$

Equation 1. Calculating rugosity index (RI) using a fine-linked chain

Another method of assessing reef complexity is to estimate it on a graded scale of 1 to 5 (Wilson et al., 2007), where 1 represents a flat reef and 5 represents an extraordinarily complex reef. However, this approach requires training and experience of a range of reef types and complexities, it can vary between observers and can be subject to observer bias.

Box 3: Data codes

Writing out the full name of species is time consuming and can often be illegible when having to write small on datasheets where space is limited, especially when underwater. Using abbreviations or codes can make recording data easier. Codes should be used for benthic and fish surveys. Where multiple individuals will be recording the data, codes should be agreed before beginning data collection.

Examples of codes include:

1. HC – hard coral
2. ALG – algae
3. ACR – Acropora
4. POR – Porites
5. LBOH – *Lutjanus bohar*
6. CARG – *Cephalopholis argus*

2.3 Fish community

Depending on the goals of the survey, experience of the surveyors, time available and survey area, the method and detail used for surveying the fish community can vary greatly. A detailed assessment of the fish community that examines size and abundance of individual species will require experienced surveyors and will usually only be able to cover a small proportion of the reef area. However, simpler surveys at higher taxonomic levels, or targeting only a portion of the fish community can be used collect useful information specific to the goals of the survey. Where detailed surveys are required, training must be undertaken to ensure correct species identification and accurate estimates of size. Collecting size and species level data on transects allows the calculation of fish biomass, which is a useful measure of the condition of the fish community.

Fish community surveys can be conducted using timed roaming surveys or transect surveys. Roaming surveys cover a wider area and can be used to provide information on presence/absence or diversity, whereas transect surveys combined with abundance and size estimation can provide accurate measures of fish per unit area which can be compared between reefs or management regimes.

The fish community is highly variable, as large schools of fish or highly mobile individuals move around the reef area, survey design and interpretation of the data should reflect this. Accuracy of the data can also be affected by the surveyor, who should aim to move at a slow and steady speed across the reef to cause as little disturbance as possible and reduce variability in the data. Surveyors should also be capable divers, able to swim close to the substrate to search the reef matrix (holes, caves etc.) without damaging the reef.

2.3.1 **Taxonomic diversity**

Surveying species diversity requires a high level of expertise; however, it can also be useful to evaluate the fish community at genus, sub-family or family level. The diversity of the fish community and the presence or absence of certain taxonomic groups can reveal a lot about reef health and can be used as a measure of change if surveyed over time. Diversity assessments can be simple presence/absence surveys or can be combined with counts of abundance per taxonomic group and individual size estimates.

2.3.2 **Fish groups**

This fish community can be divided into groups that perform different functions on reefs. At the simplest level this can be diet or trophic groups e.g. carnivores, herbivores etc. (Table 2). Targeting these groups will reduce the number of fish the surveyor needs to be able to identify and count, making the job easier. This can provide useful information about the health and resilience of the reef.

Table 2. Common groupings of the fish community for surveys and how they can be used to assess reef condition.

Common fish groupings	Information about reef condition
Herbivores	Important indicators of reef resilience. They keep algae levels low to prevent them from outcompeting corals for space
Carnivores	A high number may indicate a healthier reef system as it suggests a healthy prey community. The species or size of carnivores present can also provide useful information about level of fishing or type of prey present
Corallivores	An abundant and diverse community likely indicates healthy corals
Coral-dwelling species	Inhabit the reef matrix and are heavily reliant on the coral structure therefore, loss of structural complexity will impact this group
Fishery-targets	Can indicate whether a reef is overfished and needs management restrictions

Box 4: Data handling – field data entry

Whether conducting surveys on land or underwater it is essential that due consideration is given to data entry and storage until you have returned to the office and it can be entered into the computer.

Datasheets
The use of waterproof datasheets is strongly recommended for all field surveys. This allows you to create and print a uniform datasheet that can be used by all observers and on future surveys to maintain consistency in data collection. If waterproof paper is not available data can be entered on to an A4 size dive slate. The slate should be setup in the same format as a datasheet.
Datasheets should be created before starting fieldwork. The layout should be clear with bold lines and boxes large enough to write in legibly. They should be easy to navigate so the observer knows where to enter the data each time. Space should be included for metadata (Box 2). Example datasheets are provided for each survey method in the sections below.

Recording data
Observers should familiarise themselves with the datasheet before recording data to make sure data is entered into the correct sections. Data should be recorded in a clear enough manner that anyone should be able to read. The use of data codes (Box 3) is recommended. This will speed up data entry and save space on the datasheet. If necessary additional notes can be made elsewhere but should be clearly linked to the raw data where it applies.

Common issues	Solution
Data fades or rubs off over the course of fieldwork, particularly when using slates.	Use a 2B or softer grade pencil. Periodically check data to make sure it is still clear. Once data collection is completed, take a photo of the datasheet/slate
Datasheets are lost during surveys. Particularly during marine surveys.	Datasheets should be securely attached to slates/clipboards. When not entering data, slate/clipboard should be securely attached to the surveyor or stowed in a bag.
Data written is illegible	Datasheet should be designed so the enough space is available to clearly record data. Using data codes (box 3) allows concise clear names to be used. Writing in capital letters aids clarity.

2.4 Manta tow

This method involves towing an observer behind a boat at a set speed and stopping at regular intervals to record observations on the reef condition. This method allows surveys to cover large areas of reef and is best used to describe areas on a broad scale. However, it only allows for relatively simplistic observations and is generally restricted to shallow (< 10 m) reef areas. It is typically used to determine general reef type and condition using estimates of substrate cover. To ensure the validity and reliability of the data collected, the observer(s) should undergo training in cover estimation. This is especially important where multiple observers are used.

Manta tows can only be used on shallow (<10 m) continuous reef areas where visibility is greater than 10 m. If visibility is poor or the reef is too deep it may not be possible to identify small areas of cover or differentiate between substrate types. The large area covered by these surveys means sample design is not such an issue; a large part of the survey area can be covered by this survey and survey track will be determined by a combination of the in water conditions, reef contours and boat driver.

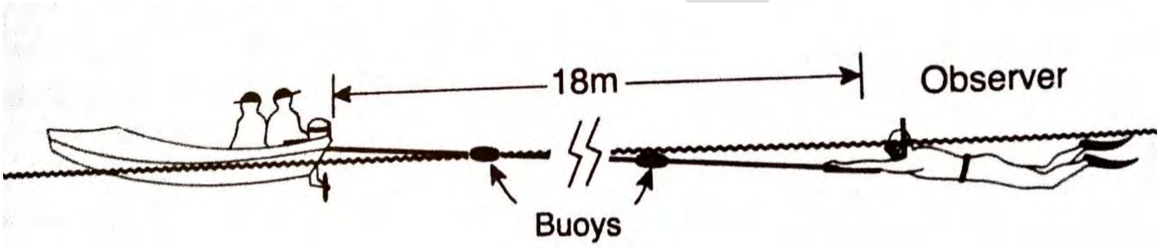


Figure 3. Diagram of a manta tow

2.4.1 **Equipment**

- Strong towing rope – minimum 15 m long
- Cleat or similar solid area on the boat to attach the rope
- Mask and snorkel
- Mantaboard – a wooden or plastic board that can attach to the rope and hold a slate/paper for data recording
  - If unavailable a handle can be attached to the rope e.g. such as used for water-skiing, provided a slate can be securely attached to the rope/handle
- Slate with datasheet attached to the mantaboard and pencil for writing
- GPS for marking survey start and end points
- Stopwatch for timing surveys

2.4.2 Personnel

- o 1 boat driver trained to maintain boat speed and navigate around a shallow reef area
- o 1 surface support to time surveys, record gps points and communicate with observer where necessary
- o 1 trained observer

2.4.3 Data collected

The primary focus of this method is to assess the composition and proportionate cover of the benthos. It is difficult to visually identify reef organisms to a high level from a distance and the observer must remember all observations during the tow. Therefore, the data collected should be limited to level 1 substrate classes (Table 1) in large percent categories e.g. 10 % bins.

Manta tows can also be used to determine the abundance of key macro-invertebrates such as crown-of-thorns starfish (COTS), giant clams (*Tridacna sp.*) and urchins; impacts such as bleaching and disease; or megafauna such as sharks, turtles, dolphins and large schools of fish.

- Macro-invertebrates recorded as abundance counts
- Bleaching and disease recorded as present/absent and percent of corals bleached if present.
- Mega-fauna recorded as abundance counts or presence of schools of key fish species e.g. fisheries targets such as jacks or snapper

2.4.4 Procedure

- o Prior to setting out on the boat an aerial image of the reef should be used to discuss the tow area and proposed route.
- o Substrate categories and level of detail should be agreed beforehand.
    - ▪ Categories during manta tows should be limited to low-level groups such as hard coral, soft coral, rock, rubble and sand
    - ▪ To ensure reliable estimations of cover it should be in 5 – 10 % bins

- Once the boat has reached the agreed starting point securely attach the tow rope to the boat at one end and the manta board at the other. Feed the rope out to ensure the observer is a safe distance from the engine and the rope does not get caught in the propeller.
- Metadata (Box 2) should be recorded by both the personnel on the boat and in-water surveyor.
- Once the observer signals, the boat should begin towing at a constant speed approximately 3 – 5 km/hr (1.5 knots), the surface support should record the GPS point at the survey start and begin the stopwatch.
- Tow path should aim to keep the observer parallel to the reef crest over a depth of 5 – 10 m.
- The observer should scan a belt of 10 – 12 m width depending on depth, reef contour and visibility. The observer should use hand signals to keep the boat on a suitable path.
- After 2 minutes surface support must tell the boat driver stop, signal the observer by pulling sharply on the rope, and record the end GPS point. The observer should then note down estimated percentages of the substrate categories and counts of any organisms being recorded.
- This process is then repeated until the agreed reef area has been surveyed.

2.4.5 **Safety**

Signals between the boat and person being towed must be agreed to allow continuous communication during the survey. The team on the boat will need to notify the observer at the end of each survey period, at the end of the surveys and in case of any dangers. This can be done through 2 – 3 sharp tugs on the towing rope to get the observer's attention, followed by loud, clear instructions where necessary. Hand signals should be used by the observer to communicate with the team on the boat. Signals should include O.K. proceed/understood, stop, slow down, speed up, move left/right, come back/pick me up and emergency/help.

Care should be taken in turbid conditions or where strong currents may be present and surveys may need to be abandoned if conditions become dangerous. Danger may also come from marine life where aggressive fish or swarms of jellyfish can harm the observer.

2.4.6 **Advantages**

- Can cover a large area of reef in a short period of time
- Easy to follow methods that requires minimal training
- Identifies broadscale patterns and changes in reef type and condition
- Appropriate for remote locations with limited support as surveys are conducted using simple equipment (mask and snorkel)
- Useful for identifying sites for more detailed surveys

2.4.7 **Limitations**

- Method lacks precision as estimates must be in broad categories of cover (e.g. 10 % bins) and organisms (e.g. hard coral, algae etc.)
- Few variables can be used as it reliant on observer remembering all things observed during the two minute survey
- Limited to surveys of shallow reef areas with good visibility
- Survey track is reliant on boat driver which may lead to unsuitable sections being covered e.g. deep slopes or large sand patches.

MANTA TOW SURVEY								Tow No.		
Date:					Surveyor :					
Island:					Surveyor :					
Start Time:			End Time:							
	Substrate									
Tow No.	Live coral	Dead rock	Soft coral	Algae	Rubble	Sand	Complex	Depth	COTS	Remarks
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										
31										
32										
33										
34										
35										

Figure 4. Example manta tow datasheet

2.5 Roaming surveys

This method uses paired observers who swim at a constant speed and depth for a set time, recording data on the benthic and fish communities. This survey can be performed whilst snorkelling in shallow (<10 m) areas or SCUBA diving depending on training, equipment available and site conditions. The method can be adapted to suit the goals of the survey but will always follow a similar general procedure. This approach can be used to determine reef type and condition over an area of 100 m – 1 km. It can also be used to examine the fish community and presence and/or abundance of rare or endangered species of fish or coral and key macro-invertebrates such as COTS or giant clams. Benthic observers should undergo training in cover estimation and species identification for endangered or key species to be included in the surveys. Fish observers must be trained in fish identification to the level required for the survey.

Roaming surveys can be used for a range of habitats and conditions, including reef flats and slopes, isolated reefs and channels between reefs. They are particularly useful for challenging survey conditions such as deep habitats or areas of high currents where manta tows or reef transects are unsuitable.

Depending on the exact method used and the aims of the survey, different sample designs may be used, or a combination of approaches may be most appropriate. For example, reefs around an island may be divided (stratified) into oceanward, atollward and channel sub-groups, all of which may need to be surveyed. The to avoid survey overlap within the sub-groups survey sites may need to be separated systematically. Where multiple samples are conducted during a SCUBA dive this may be the only way of sampling as it is not possible to navigate to randomly assign sites underwater.

2.5.1 **Equipment**

- Snorkelling or SCUBA equipment
- Slate, waterproof datasheet and pencil for recording data

- GPS for marking survey start and end points
- Waterproof (to at least 50 m) stopwatch for timing surveys
- Camera in underwater housing

2.5.2 **Personnel**

- 1 person to survey the benthos
- 1 or more surveyor(s) for the fish community
- 1 boat driver if required to access the site

2.5.3 **Data collected**

Roaming surveys can be used to collect substrate and fish data to a medium level of precision (level 2 progression: Table 1). Substrate surveys are based on estimates of percent cover over the survey time and number of categories should be limited as the observer must remember what they observed over the entire survey period. However, the observer can take longer over assessing the substrate, get closer to the surface to help identification and make notes. Therefore, it should be possible to estimate cover within 5 % bins. Though it is still unlikely that the observer will be able to record a high level of taxonomic detail, it is possible to record morphology of the substrate or coral growth from. This can be done by estimating the proportion of each substrate category in different growth form categories e.g. hard coral – branching. It is also possible to use the estimated measure of structural complexity during these surveys.

The fish community can be assessed by one or more observers. With multiple trained observers it may be possible to identify abundance to species level, however a single observer will likely need to focus on a lower taxonomic level or specific fish group. Time of first observation can be used as a proxy for fish abundance where the quicker a species or family is observed the more abundant it is likely to be. For example, a single trained observer should be able to record the presence and time of first observation for all fish families present or all species of the herbivore group. It is also possible for the fish surveyors to record observations of mobile, charismatic or endangered species such as sharks or large groupers using this method.

2.5.4 **Procedure**

- o An aerial image of the reef should be used to discuss the survey area and local conditions (waves, current etc.) assessed to decide survey direction.
- o Based on the expertise and aim of the project, the level of detail and length of survey time should be agreed beforehand.
- o A GPS point should be taken at the start of the survey (start of descent for SCUBA surveys).
- o Once observers are ready the stopwatch should be started, and observers begin recording.
- o Surveyors should aim to swim at a constant speed and depth. Observers recording fish should lead.
    - During SCUBA surveys an area 5 m above and below the diver should be surveyed.
    - During snorkel surveys the observer should scan a belt of 10 – 12 m width depending on depth, reef contour and visibility.
- o Metadata (Box 2) should be recorded by benthic and fish surveyors. This should include general descriptions of the site.
- o Photographs should be taken along the survey area as a record of the site
- o At the end of the survey period a GPS point should be taken. This can be as soon as surfacing for dive surveys.
- o Where snorkel surveys are used, surveyors can return to the boat and use GPS to navigate to the next assigned survey site
- o Where SCUBA surveys are used, surveyors should continue swimming for a minimum of 1 minute before beginning a new survey

2.5.5 **Safety**

In water conditions should be checked before surveys to assess currents and visibility. Surface support should be aware of survey direction and length of survey time. Dive safety protocols should be agreed and followed during all dives and surveyors should remain within visual distance.

1.5.1. Advantages

- Can cover a relatively large survey area
- Versatile method that can be used to survey a range of reef habitats including areas with strong currents or deeper reefs.
- Can be performed with minimal training, though more detailed information can be provided by experienced surveyors.
- Provides greater accuracy and detail than manta tows since the surveyors can spend more time examining the area and get closer to the reef or fish.

2.5.6 **Limitations**

- Relies on estimates of benthic communities which can be subject to biases and vary between individuals.
- Limits to the level of detail
- Time to first observation of fish only provides an estimate of abundance.
- Where abundance is recorded for the fish, data cannot be calculated as density since it is not possible to determine area surveyed.

Site:	Date:	Start GPS:			Start Time:	Surveyor:	
Survey Comments:							
	S1	S2		S3		S4	
End Time							
End GPS N							
End GPS S							
Complex	Depth	Comp	Depth	Comp	Depth	Comp	Depth
Family	Time	Family	Time	Family	Time	Family	Time
Red List	Abundance	RedList	Abun	RedList	Abun	RedList	Abun

Figure 5. Example roaming fish survey datasheet

Site:		Date:		Start GPS:					Surveyor:	
Survey Comments:									Start Time:	
	Survey 1								RedList	Abundance
End Time										
End GPS										
Depth										
Complexity										
Visibility										
	Growth Form/Type									
Substrate	%	TB	BR	MA	EN	FIN	FOL	OTHERS		
HC										
RC										
SC										
SP										
SD										
AL										
RB										
RKC										
OT										
Galax. astreata					Pac. rugosa					
Tur. mesenterina					Pav. venosa					
Phy. lichtensteini										

Site:		Date:		Start GPS:					Surveyor:	
Survey Comments:									Start Time:	
	Survey 2								RedList	Abundance
End Time										
End GPS										
Depth										
Complexity										
Visibility										
	Growth Form/Type									
Substrate	%	TB	BR	MA	EN	FIN	FOL	OTHERS		
HC										
RC										
SC										
SP										
SD										
AL										
RB										
RKC										
OT										
Galax. astreata					Pac. rugosa					
Tur. mesenterina					Pav. venosa					
Phy. lichtensteini										

Figure 6. Example roaming benthic datasheet

2.6 Transect surveys

Transect surveys are used to provide quantitative information about a reef area with a high level of precision using a transect tape to provide a unit of reef area that can be accurately surveyed using a range of methods. This approach can only cover a small area of the reef due to the time required to complete the survey. It also means they must be conducted at relatively shallow depths to allow divers enough time to complete the surveys. Because of this, transects are likely to be unsuitable for deeper reef areas such as thilas or channels in the Maldives. Strong currents or wave action will prohibit transect surveys, as the transect must remain as still as possible and divers must be able to tightly control their position along the transect. At least three replicate transects should be conducted at a site to ensure the validity and robustness of the data.

Sampling design will depend on the aims of the project and the area being surveyed. If the aim of the survey is to compare between different areas or the area can be dived into sub-groups, stratified sampling may be the most appropriate. Where the aim is to develop an understanding of the habitat or species and little is known about the survey area, then either random or systematic sampling may be most appropriate.

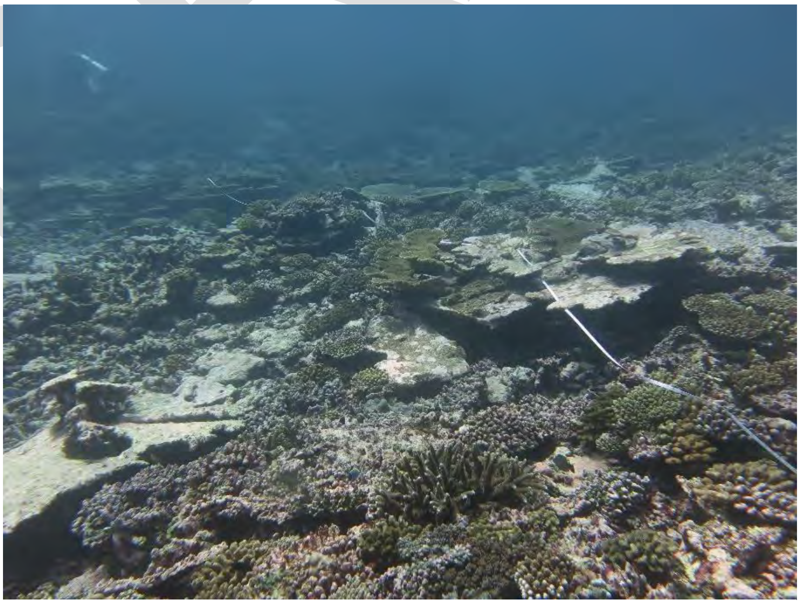


Figure 7. Transect laid over reef area

2.6.1 Equipment

- o SCUBA equipment
- o Slate, waterproof datasheet and pencil for recording data
- o GPS for marking survey site
- o High quality 50 m transect tape
- o Camera in underwater housing
- o Small quadrat (25 cm x 25 cm)
- o PVC pipe (1 m) for photoquadrat
- o Digital camera
- o Callipers and/or small tape measure for measuring coral colony size

2.6.2 Personnel

- o 1 or more surveyor(s) for the benthos
- o 1 or more surveyor(s) for the fish community
- o 1 boat driver if required to access the site

2.6.3 Data collected

Transect surveys can tailored to collect a range of data using different methodologies. Based on the experience of the surveyor any of the benthic progression levels (Table 1) can be used to determine substrate cover. Fish surveys can also focus on the fish groups (Table 2) or the entire fish community if multiple surveyors are available.

2.6.4 Point intercept transect

Point intercept transects (PITs) are used to determine the percent cover of different substrate categories. The surveyor swims along the transect line recording the benthic category directly below the transect at specific points along the line e.g. every 50 cm. Because this approach uses points along a transect and does not rely on observer estimation it is quantitative and robust than other methods. PIT length can vary depending on the goals of the survey, but common lengths include 10 m, 30 m and 50 m. Longer transects will increase the chance of observing rare or highly mobile species, however they take significantly longer to complete, reducing the number of replicates. Coral recruits can be surveyed with the addition of a small quadrat (25 cm x 25 cm). This is placed beside the transect at specific points along the transect, and corals less than 5 cm within the quadrat are counted and identified to genus or family. Structural complexity can be measured by estimating complexity along the transect or calculating the rugosity index (see Section 2.2)

Figure 8. Point intercept transect being performed

2.6.5 **Photoquadrat**

Photoquadrat is a commonly used method to survey benthic habitats. This method is conducted by photographing the substrate along each transect. To standardize the area captured in each image, 1 m long PVC stick is placed at the benthic structure and a photograph is taken at every 2 m along the transect at alternate side of the tape. The stick is used to ensure that the camera was kept at the right distance from the substrate. This method minimalizes the time in the water, yet gathers a wide range of data.

Reef-building coral genera and benthic life forms in the photos are identified using Coral Point Count (CPCe) or Coralnet program. Both these programs generate a spatially specified random points (as much point as the analyser needs) and then identify each point to growth form (eg. coral, sand, algae) or to the lowest taxonomic level possible (eg. genus or species).

Figure 9: Photoquadrat being taken

2.6.6 **Belt transect for substrate**

Belt transects use a belt of set width along a transect to determine coral community and health metrics. The surveyor swims along the belt and counts, measures and identifies each coral colony in the belt area. For each colony counted, health of the coral should also be classed as healthy, diseased or bleached. In the case of bleached or diseased colonies, percent of colony affected should also be recorded. A 10 m long transect with a 1 m belt width is commonly used however, width and length should be based on the goals of the survey and the coral community present. If there are many colonies, searching, measuring and identifying can take significant amounts of time.

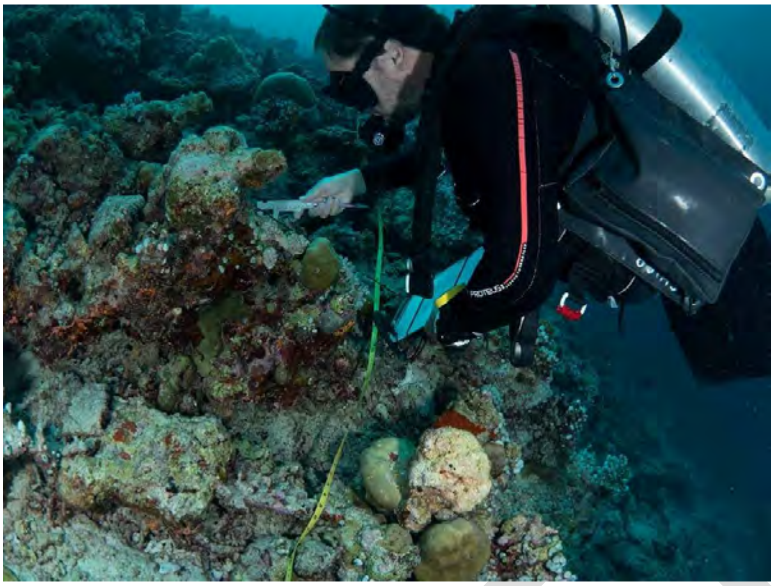


Figure 10. Coral being measured on a belt transect

2.6.7 **Belt transect for fish**

This method uses a belt transect to quantify composition and abundance of the fish community. The surveyor moves at a steady speed along the transect recording fish within the belt area. Belt length and width can vary depending on the aims of the survey. Larger, mobile fish should be surveyed using longer (50 m) transects with 5 m wide belts, whereas smaller, site attached species can be surveyed using 2 m wide belts and shorter transects if required. Larger belt areas are more challenging to survey and are more likely to result in missed fish and errors in the data, therefore it is important to use the width most suitable to the survey aims. Fish should be counted, identified and their size estimated to the nearest 1 cm or 5 cm depending on surveyor training.

Due to the challenges of surveying a mobile and diverse fish community, it is common to use multiple surveyors or to make consecutive swims along the same transect. Large, mobile fish should be counted by the first surveyor, or on the first swim. Fish decreasing in size and mobility should be counted by successive surveyors or on successive swims.

Fish surveyors should undergo training in identification, rapid counting of large groups and underwater size estimation prior to surveys. Fish identification training can be done using slide shows of pictures. To train rapid counting of large groups the surveyor can use grains of rice scattered over a flat surface. To practice estimating size underwater the surveyor should have a partner hold up lengths of wire or pre-cut cable ties during a training dive. The surveyor must then estimate the size of these. Only after the whole team are capable of accurately identifying, counting and estimating size to the nearest 5 cm should the surveys begin

Figure 11. Counting fish on a belt transect

2.6.8 **Procedure**

- An aerial image of the reef should be used to discuss the survey area and local conditions (waves, current etc.) assessed to decide survey location.
- Based on the expertise and goal of the study, the level of detail and length of survey time should be agreed beforehand.
- A GPS point should be taken at the start of the dive.
- The transect should be set at the agreed depth and follow this depth contour.
    - The transect should be carefully attached to an area of dead reef to avoid damaging coral and prevent the tape from coming loose during the survey.
    - Care should be taken while setting the transect to keep it tight and close to the substrate.
    - Where both fish and substrate surveys are both being performed the surveyor counting large, mobile fish should set the transect whilst surveying the fish.

- Metadata (Box 2) should be recorded by benthic and fish surveyors. This should include a general site description.
- The fish surveyor should move at steady speed along the transect counting all relevant fish within the belt.
    - If the survey includes small and cryptic species the surveyor must take care to search the reef habitat fully and evenly as they move along the transect.
- PIT or substrate belt surveyor follows the final fish surveyor, recording substrate present under transect at pre-determined intervals.
- Quadrat for coral recruits should be placed beside the transect at set intervals and the number of recruits counted and identified to genus where possible.
- Photographs should be taken along the transect to record the survey area

2.6.9 **Safety**

In water conditions should be checked before surveys to assess currents and visibility. Surface support should be aware of length of survey time. Dive safety protocols should be agreed and followed during all dives and surveyors should remain within visual distance.

2.6.10 **Advantages**

- Transects can be used to combine several approaches in a quantitative manner
- Can be designed for all levels of surveyors
- Fish surveys on transects can be used to quantify density and biomass of fish per unit area.
- Standard of data required for statistical analysis, management recommendations and scientific publications

2.6.11 **Limitations**

- Only covers a limited area of reef
- Not good for rare species
- Time consuming

Date:	Site		Transect #		Start Time:		Depth:	Surveyor:	
Notes:									
Species	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40+

Figure 12. Example datasheet for transect fish survey

Date:			Site:					GPS:				Surveyor:			
Depth T1:				Direction T1				Depth T2:				Direction T2			
Time T1:				Visual Grade T1				Time T2:				Visual Grade T2			
Substrate		Genus	Note	Substrate		Genus	Note	Substrate		Genus	Note	Substrate		Genus	Note
0.5				20.5				0.5				20.5			
1				21				1				21			
1.5				21.5				1.5				21.5			
2				22				2				22			
2.5				22.5				2.5				22.5			
3				23				3				23			
3.5				23.5				3.5				23.5			
4				24				4				24			
4.5				24.5				4.5				24.5			
5				25				5				25			
5.5				25.5				5.5				25.5			
6				26				6				26			
6.5				26.5				6.5				26.5			
7				27.0				7				27.0			
7.5				27.5				7.5				27.5			
8				28.0				8				28.0			
8.5				28.5				8.5				28.5			
9				29				9				29			
9.5				29.5				9.5				29.5			
10				30.0				10				30.0			
10.5								10.5							
11				Q	No. Recruits			11				Q	No. Recruits		
11.5				Q1				11.5				Q1			
12				Q2				12				Q2			
12.5				Q3				12.5				Q3			
13				Q4				13				Q4			
13.5				Q5				13.5				Q5			
14				Q6				14				Q6			
14.5				Q7				14.5				Q7			
15				Q8				15				Q8			
15.5				Q9				15.5				Q9			
16				Q10				16				Q10			
16.5				Q11				16.5				Q11			
17				Q12				17				Q12			
17.5				Notes:				17.5				Notes:			
18								18							
18.5								18.5							
19								19							
19.5								19.5							
20								20							

Figure 13. Example datasheet for transect benthic survey. This datasheet is for a 30 m transect where substrate is recorded at 50 cm interval. Two coral recruit quadrats are performed every 5 m

Box 5: Data handling – digital data entry

Once data has been recorded on your datasheets (Box 4) the next step is to enter the data into appropriate computer software for analysis and storage. Digital data entry should be done as soon after data collection as possible. This minimises the chance of data loss and makes sure you remember any codes or additional notes made during data collection.

Errors during digital data entry

Mistakes made during digital data entry are the most common cause of errors in a dataset. Common errors include misspelt species names, inputting incorrect numbers and entering data into the wrong sections of a table. These errors can have serious repercussions on data analysis and interpretation and great care should be taken to minimise these.

1. Check datasheet carefully before digital data entry to make sure you understand the data and no numbers or species appear questionable.
2. Enter data slowly and methodically
3. Perform regular checks on the data to look out for different spellings of the same words e.g. species name. This can be done by filtering columns and checking for multiple versions of a word. Where software allows, apply rules to columns so only names from a pre-determined list with correct spellings are allowed.
4. Perform regular checks on the numbers entered. For percent cover data, formula can be used to check data from a sample always adds up to 100.
5. Perform a final check on the data using appropriate filters and formulae for spellings and numbers – you can never check the data too carefully.
6. Add your name to all data you have entered so you can be contacted regarding any future queries about the data.
7. Photograph and save digital images of all datasheets. This protects against data loss and allows you to quickly refer to the raw data if necessary.

Digital data entry software

Microsoft Excel (or similar spreadsheet software)

Entering data into spreadsheets is the most common approach to data entry. This simple to use software allows you to create your own table formats and is widely accessible. Using multiple sheets means you can create tables for metadata and data from different sections of the survey on different sheets which can all be saved in one file. However, tables are not easily linked and extracting and combining data from different tables requires copy and pasting which can lead to errors.

Microsoft Access (or similar database software)

Database software can be used in a similar way to spreadsheets with multiple tables in one file. However, you can link multiple tables through primary keys in a database. This allows you to query a database to extract and combine data without copy and pasting and creating additional tables and files. It is also simple to apply rules to cells which can help prevent data entry errors. However, databases can be challenging to use and require a reasonable amount of training before using.

Online platform

There are organisations that have created open-source data entry platforms. These are easy to use databases where all the hard work of database design is done for you. You just download the tables and follow the format for your data entry and upload the data when you have finished. Many of these have pre-determined rules for data entry to prevent errors and data is saved to the cloud when you have internet to prevent data loss. Examples of these are the Maldives National Coral Reef Monitoring Framework CoralDatabase (https://coraldatabase.gov.mv/) and the WWF Mermaid (https://datamermaid.org/) platform.

3 Terrestrial surveys

3.1 Site selection

As with marine surveys, site selection is an important first step in surveying terrestrial habitats. It must ensure that the survey can meet the aims of the project, but also that suitable and accurate data can be collected. The site chosen should be representative of the area of interest. This can be easier with terrestrial sites as aerial images can provide the exact locations of the habitats of interest. Where available a drone can be used to provide high resolution images of surveys areas making it possible to precisely target survey sites. However, dense vegetation or swampy areas can be challenging to move through and are difficult to identify from aerial images.

Accessibility is an important consideration for terrestrial surveys as unlike marine surveys a boat cannot simply drop you on top of the survey site. Aerial images and local knowledge should be used to understand access to the survey area. Though the aim when designing surveys is often to randomly assign survey sites, it is more important to be able to access the site than it is to select truly random sites.

Site selection should consider the following:

- Are sites are representative of the habitat you want to survey?
- The range of physical and social influences on the sites
- Safety of the survey team. Is it safe to survey given the habitat, weather or wildlife?

To navigate to survey sites a handheld gps or smartphone with suitable app. e.g. SWMaps™ should be used. The advantage of smart phones apps is they allow the use of satellite images to help guide observers through the area. It is also possible to take georeferenced images of vegetation or areas of interest, track routes through the habitat and in some cases enter data directly to the app which can easily be downloaded to a computer at the end of the surveys. Utilising advances in this technology will improve the accuracy and efficiency of surveys and attempts should be made to incorporate future advances into survey protocols.

3.2 Flora community

Depending on the goals of the survey, experience of the surveyors, time available and survey area, the method and detail used for surveying the flora community will vary. A detailed assessment of the plant community that examines size and abundance of individual species will require experienced surveyors, take longer and will usually cover a smaller proportion of the survey area. Where detailed surveys are required training must be undertaken to ensure correct species identification and accurate measures of size. Identification guides should be carried during surveys. Information about the type of habitat should be recorded as part of all surveys. These habitats can be categorised into coastal fringe, mangrove bay, mangrove pond, mangrove basin, pond, island interior and farmland.

3.2.1 **Abundance**

Plant abundance can be estimated using percent cover or counted to provide individual species densities. Estimates of the cover of different vegetation species within a small plot are used to rapidly survey sample points. More detailed surveys may count the number of individual plants of each species within a plot or along a transect, this will give you the density of each species in the sample area.

3.2.2 **Canopy cover**

Canopy cover describes the density of leaf growth around the trees and how much light reaches the lower levels of the canopy. Three approaches can be used to measure this. The first is to use a light meter to record the amount of light that reaches the surveyor. This is a standardised approach that is not subject to observer differences, however a light meter can be an expensive and fragile piece of equipment that must be used correctly to ensure accurate results. The second method is to use a quadrat held directly above the observer's head. The observer then estimates the proportion of the quadrat covered by the canopy above. This approach requires training to improve the accuracy of estimates and may also vary between observers, however it can be performed without specialised equipment. The third method requires the use of a smartphone app. e.g. CanopyApp™ for Apple phones or Canopeo™ for Android phones. This is a relatively new technology that uses the phone's built-in camera to take an image of the canopy and estimates the leaf cover. The reliability of this data is uncertain, but it may be a useful future technology for gathering this data.

3.2.3 Height

There are several methods that can be used to measure tree height. The most accurate method is to use a clinometer. This approach requires training to use the device correctly and some maths to calculate the tree height based on angles. The simplest method is to estimate the height by comparing the tree to other things of a known height. One way to do this is to stand one observer beside the tree and to estimate how many times that person would be stacked to reach the top of the tree. The error around this method can be significant and height should only be estimated to the nearest 0.5 m. A challenge of working in dense vegetation is identifying the top of a tree and being far enough away from the tree to utilise height estimation methods.

3.2.4 Diameter at breast height

Diameter at breast height (DBH) is a standard method of measuring the size of a tree. The measurement is taken at 1.37 m from the ground. The measure can be made quickly using a specially calibrated tape measure that displays the diameter measurement when wrapped around the circumference of a tree. Where a special tape is not available diameter can be calculated by measuring the circumference of the tree and dividing by pi (3.14).

3.2.5 Health

Recording information on the health and condition of plants in the survey area is essential to understanding the management needs of the area. The most basic measure of tree health is using categorical groups to classify tree condition e.g. good, fair, poor, dead. Discoloured

Figure 14. Measuring diameter at breast height

(yellowing) leaves or pealing bark are indicators of declining plant health. The plant should also be inspected for the cause of any deterioration in heath such as insects or disease. This can be determined by marks on the leaves from feeding or infection and damage to the stem or trunk of a tree. The underside of leaves can also be checked for insect eggs. The number of trees in the survey area affected by any disease or insect damage should be recorded.

3.2.6 **Aerial surveying**

Aerial surveying of vegetation is an ever advancing area. Drones can be used to capture high resolution images of a habitat that can be stitched together to give a detailed mosaic of the survey area. These can be used to accurately map the area of interest, group similar vegetation types, determine vegetation density and in some cases the health of areas. This approach can also be combined with measures of island elevation to determine vegetation height and machine learning techniques to accurately determine vegetation species. The approach does require ground truthing to ensure accurate data. This field of research is the subject of many books and courses, so the methods are not covered here. It should be noted that even without the ability to analyse the data from aerial surveys, they provide an exceptional resource for observing changes over time, particularly where human encroachment is a problem for the area.

Figure 15. Aerial image of terrestrial habitat

3.3 Faunal community

Dense vegetation and turbid water bodies can make surveys of faunal communities challenging. The extra time and equipment required can also be quite significant. Often different methods must be used to survey each part of the community and different groups can be active at different times of the day – night cycle therefore, to accurately survey the fauna surveys should target specific time periods. Because of this, in cases where time is short, and the fauna is not the primary aim of the surveys the simplest approach is to make observations about the fauna concurrently with vegetation surveys. Though this will likely result in significant under sampling, it can provide enough information to meet simple survey goals.

3.3.1 **Insects and arachnids**

During vegetation surveys it should be possible to record information about arachnids and nest making insects where they are encountered. Many insects are more active at sunset or at night therefore setting insect traps at these times are often the best approach to surveying this group. Light traps use light to attract insects that can then be counted. There are two relatively simple approaches to light trap design:

1) A light source is placed inside a box of known surface area made using white fabric This creates a surface for the insects to land on while also allowing the light to pass through. The trap is left in place for a set time, after which all insects on or inside the trap are counted and identified to highest level of classification possible.
2) A light source is suspended over a funnel which tappers into a chamber beneath it. Once the insect enters the chamber through the funnel it is trapped. At the end of a set period all insects in the chamber are counted and identified to the highest classification possible. In more complex traps a fan can be place above the light to blow insects down through the funnel to increase the number of insects attracted to the light that are counted.

An advantage of light traps is that they can be set up in a range of habitats allowing a comparison of incest communities. Once set up they require minimal effort to survey. However, they are only useful for insects that are attracted to light, which is often only a small proportion of the insect community.

For insects that have an aquatic larval stage e.g. mosquitoes, samples can be collected from water bodies within the survey area and examined for the abundance of larvae. Water samples should be collected from multiple points within each area. 100 ml from each sample is then filtered through a fine mesh to separate out the larvae. These are then counted and identified to give density of larvae per 100 ml.

Figure 16. Light trap (top) and aquatic larvae sampling (bottom).

3.3.2 **Birds**

Bird surveys will be most effective at either sunrise or sunset as the birds depart to forage in the morning or return to roost in the evening. Observers should find a suitable point from which to observe birds as they enter/exit the survey area. All individuals should be counted and identified to species. Surveys should be for a set period e.g. 30 minutes. Binoculars and a camera with a telephoto lens should be used to improve identification accuracy and catalogue the species present. Surveys can also be conducted alongside vegetation surveys. However, this is unlikely to be during the optimum window for surveying birds and the noise made while moving through the habitat can scare them away.

3.3.3 **Crabs**

Crabs are quick moving and shy and making it difficult to accurately count individuals. However, number of burrows has been widely used for estimating the population of mangrove crab species. At each site a plot should be set up – the same plots used to sample the vegetation would be sensible – and the number of burrows within the plot area counted. This will give an estimate of the density of crabs at the site. Where burrows may be submerged at high tide counts should be conducted at low tide. Care should be taken to search the area thoroughly, including at the base of trees and around root networks.

3.3.4 **Fish**

This section applies to surveying fish within a mangrove water body, if it is possible to conduct underwater visual surveys utilise one of the methods described in the marine section. The simplest approach is to catalogue species as they are observed during other terrestrial surveys. This can be done whilst moving around the edge of the water bodies. It is most effective in clear, undisturbed water. This approach can determine whether mangrove bays are valuable for juvenile sharks and rays, or whether invasive fish species are present in terrestrial waterbodies. However, it will under sample the fish community, providing no measure of abundance and it will likely miss many of the species present, especially in large, deep or turbid water bodies. In a mangrove bay if the water is deep enough it is also possible to do these surveys from a boat or whilst snorkelling. Provided care is taken and the limitations are understood and acknowledged during data analysis, this can be a useful approach when there are few other options.

3.4 Habitat variables

3.4.1 **Water quality**

Water quality can be measured in situ using a portable meter. The simplest version of these can collect data on temperature and salinity. More advanced meters can collect a range of additional data. Measurable parameters include pH, temperature, dissolved oxygen, conductivity, RedOx, ammonia, ammonium, chloride, fluoride, nitrate, and sodium. Collecting this data with probes is a quick and efficient way to get valuable data. Manufacturer instructions must be followed and may include calibration before and during surveys. The cost of meters may also be prohibitive. The most complete data about water quality will come through laboratory testing of water samples. Labs can test for a broad range of water quality parameters. The accuracy of this data depends on following correct procedures for collection, storage and transportation of the sample before reaching a lab. This can be challenging in remote locations particularly where samples are required from multiple sites. Depending on the goals of the survey different water quality parameters will be required.

3.4.2 **Soil quality**

Data collection for soil quality is similar to water quality. Measures can be taken in situ using a portable meter or samples can be taken to a lab for detailed analysis. Meters can collect measure pH, temperature, salinity, water content and RedOx. Collecting this data with a meter is a quick and efficient way to get valuable data. Manufacturer instructions must be followed which may include calibration before and during surveys. The cost of meters may also be prohibitive. To collect the most accurate information about soils measures should be taken from approximately 10 cm below the surface, this can be achieved by digging a small hole or using a corer. The most complete data about soil quality will come through laboratory testing of water samples. Collection of samples will require a corer. Labs can test for a broad range of soil quality parameters. The accuracy of this data depends on following correct procedures for collection, storage and transportation of the sample before reaching a lab. This can be challenging in remote locations particularly where samples are required from multiple sites. Depending on the goals of the survey different soil quality parameters will be required.

Soil or sediment type influences the presence and type of vegetation at a site and it is important to include measures of this in surveys. Soil can be divided into three major groups depending on size: gravel (>2 mm), sand (0.062 – 2 mm) and mud (<0.062 mm). At sites where vegetation surveys are conducted the soil type should be recorded in one of these categories. These three groups can be further subdivided where possible/relevant, though for smaller sizes this requires particle fractionation which is a long and complicated task.

3.4.3 **Rubbish**

At each site, a plot should be set up – the same plots used to sample the vegetation would be sensible – and the number of items of rubbish within the plot area counted. This will give an estimate of the density of rubbish at the site. Rubbish should be split into categories such as plastic, glass, cans etc. If a site is being used as a waste disposal area this should be noted as well. Care should be taken to search the area thoroughly, including at the base of trees and around root networks.

3.5 Point survey

The point survey approach uses multiple pre-determined points to rapidly survey an area. The method can be adapted to suit the goals of the survey but will always follow the same general procedure. It is particularly useful where little is known about the habitat, the area is challenging to move through, or large area needs to be covered in a short period of time. The approach can be used to determine habitat type, diversity and condition over a large area. It can also be used to create habitat maps and ground truth aerial surveys. Observers should undergo training in flora and fauna species identification, area cover estimation and should practice with any water/soil meters that will be used. Identification guides should also be used during surveys.

Depending on the exact method used and the aims of the survey different sample designs may be used, or a combination of approaches may be most appropriate. For example, where multiple habitat types are present the area may be divided (stratified) into the different habitats, and random points assigned to each habitat based on size, time available and accessibility. Alternatively, if a large area needs to be surveyed and little is known about the habitat a systematic approach may be more suitable. Points should be assigned a beforehand using GIS or other similar software and entered into a handheld GPS or smartphone with a suitable app.

Figure 17, Data collection at a point survey site

3.5.1.1 Equipment

- Computer with GIS or mapping software
- Handheld GPS or smartphone
- Slate, waterproof datasheet and pencil for recording data
- Camera
- Identification guides
- Bag for sample collection
- Appropriate clothing and shoes for moving through dense vegetation and muddy pools.
- Optional equipment for more detailed surveys:
    - Tape measure
    - Water/soil quality meter
    - Small shovel or corer for soil samples
    - Bottles for water sample collection
    - Clinometer
    - Quadrat, light meter or smartphone with suitable app for canopy cover

3.5.2 **Personnel**

- Survey team should consist of a minimum of 2 people who can work together to complete the surveys.

    - A smaller survey team limits the amount of equipment that can be carried and therefore the data that can be collected.
- 1 vehicle driver if required to access the site

3.5.3 **Data collected**

Point surveys can be used to collect a range of data depending on the equipment available and the knowledge of the surveyors. The method described here is a rapid survey approach, relying on estimates of vegetation variables and observations of fauna as you move through the habitat.

3.5.4 **Procedure**

- An aerial image of the survey area should be used to create survey sites using the decided sampling approach. The coordinates of these sites should then be entered into a handheld GPS device or smartphone with appropriate app.
- Based on equipment, expertise and aims of the project, the level of detail should be agreed beforehand.
- Survey team should then navigate to the survey point. If the point is inaccessible due to dense vegetation, hazardous conditions or any other reason the survey should be performed as close to the original site as possible and the new coordinates recorded.
- At the survey site a 2.5 m radius circle should be estimated (or measured with tape measure if available).
- Metadata (Box 2) should be recorded. This should include notes about the survey area e.g. time of survey, flora habitat category, proximity to water, tide (if relevant), density of vegetation, presence of bird/turtle nests.
- Dominant, secondary and tertiary plant species should be identified, and the percent of the survey area covered by each species should be estimated. Where identification is not possible, pictures should be taken, and samples collected if necessary.
- Any additional species or notes should be recorded.
- Height of the tallest plant estimated to the nearest 0.5 m.

- Canopy cover recorded
- Soil categorised
- Rubbish identified and counted
- Crab burrows counted
- A picture taken of the survey site with GPS tag if possible
- If part of the survey design, sample soil quality parameters and/or collect soil samples
- If water is present and part of the survey design, sample water quality parameters and/or collect water samples
- Whilst moving between survey points record species of fauna observed, including birds, fish and insects.

3.5.5 Safety

Sensible procedures should be followed to avoid getting lost in dense vegetation. Care should be taken in deep water or muddy areas. The depth of these should be tested before advancing through dangerous areas. Mangrove root systems and crab burrows create uneven ground that can lead to foot or ankle injuries. Enough water to stay hydrated throughout the day should be carried to avoid dehydration. Legs and arms should be covered, and insect repellent used to limit mosquito bites. Care should be taken to avoid stinging or biting insects such as wasps and ants that are common in terrestrial habitats.

3.5.6 Advantages

- Can cover a relatively large survey area
- Versatile method that can be used to survey a range of habitats including areas with limited accessibility.
- Can be performed with minimal training, though more detailed information can be provided by experienced surveyors.
- Useful for ground truthing aerial surveys.

3.5.7 **Limitations**

- Relies on estimates which can be subject to biases and can vary between individuals
- Not an absolute catalogue of species present at a site
- Does not differentiate between ages/sizes of species present

Island:			Date:			Surveyors:					
General observations:											
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	
Point No	GPS	Hab. Cat.	Sp. 1	Height	Sp. 2	Sp. 3	Location	Soil	Disturbance	Rubbish	Crab burrows
	Notes:				Fauna:		Water quality:			Soil quality:	

Figure 18. Example datasheet for terrestrial point survey data collection

3.6 Transect - plot survey

Transect surveys are used to provide quantitative information about an island area with a high level of precision using a transect tape to provide a unit of area that can be accurately surveyed with a range of methods. This approach can only cover a small area of the habitat due to the time required to complete the survey. Transects can be setup to examine a relatively uniform area or the transition from one habitat to another e.g. outside to inside a mangrove area. Understanding these transition areas and edge communities can often be key to understanding habitat dynamics.

Where the aim of the project is to survey a specific habitat, transects should be set so the length of the transect is entirely within the habitat, and repeat transects should be performed in different areas of the habitat. For these surveys, a 20 m transect with five 2.5 m x 2.5 m plots, set every 5 m along the transect will be sufficient. Where the aim is to examine the transition from one habitat another (e.g. farmland to mangrove), transects should be long enough so they stretch between the two habitats with enough plots so there are replicates in each habitat.

Sampling design will depend on the aims of the project and the area being surveyed. If the aim of the survey is to compare between different habitats or the area can be dived into sub-groups, stratified sampling may be the most appropriate. Stratified random sampling will also be most appropriate for surveying habitat transitions. Where the aim is to develop an understanding of the habitat and little is known about the survey area, then either random or stratified sampling may be most appropriate.

3.6.1 **Equipment**

- Computer with GIS or mapping software
- Handheld GPS or smartphone
- Slate, waterproof datasheet and pencil for recording data

Figure 19. Transect set through mangrove habitat

- Transect tape x 2
- Tape measure for DBH measurement
- Quadrat, light meter or smartphone with suitable app for canopy cover
- Camera
- Identification guides
- Bag for sample collection
- Appropriate clothing and shoes for moving through dense vegetation and muddy pools.
- Optional equipment for more detailed surveys:
  - Water/soil quality meter
  - Small shovel or corer for soil samples
  - Bottles for water sample collection
  - Clinometer

3.6.2 **Personnel**

- Survey team should consist of a minimum of 3 people who can work together to complete the surveys.
  - A smaller survey team limits the amount of equipment that can be carried and therefore the data that can be collected.

- 1 vehicle driver if required to access the site

3.6.3 **Data collected**

Transect-plot surveys are used to collect detailed information about a habitat and should be accurate and robust enough to be used for statistical analysis. Therefore, the more information that can be collected the better. We would strongly advise the collection of soil and water quality data wherever possible as these are key in understanding the condition of the habitat and can be used to provide targets for management goals. The abundance, height, DBH (for trees) and health of all species of vegetation within the survey area are recorded. Where relevant, species can be divided into classes based on size (height or DBH). This is particularly valuable for mangrove species which can be divided into seedling, sapling and adult trees. This will provide valuable information on health and resilience of the habitat as well as plant community dynamics.

Counts of fauna are likely to be limited to crab burrow counts or site attached insects and arachnids, as most mobile animals will leave the area due to human presence. Where relevant tidal range should also be recorded and where the transect/plot lies in relation to this range.

Diagram with 3 drawings:

1. transect in the middle of a habitat,

2. round the perimeter of a mangrove bay

3. across a transition zone

3.6.4 **Procedure**

- An aerial image of the survey area should be used to create survey sites using the decided sampling approach. The coordinates of these sites should then be entered into a handheld GPS device or smartphone with appropriate app.
- Based on equipment, expertise and aims of the project, the level of detail should be agreed beforehand.

- Survey team should then navigate to the survey point. If the point is inaccessible due to dense vegetation, hazardous conditions or any other reason the survey should be performed as close to the original site as possible and the new coordinates recorded.
- At the survey site the transect should be set in accordance with the project aims – habitat vs. transition zone sampling
- Metadata (Box 2) should be recorded. This should include notes about the survey area e.g. time of survey, flora habitat category, proximity to water, tide (if relevant), density of vegetation, presence of bird/turtle nests.
- Take a picture of the transect with GPS tag if possible
- Second transect tape should be laid perpendicular to measure a 2.5 m x 2.5 m plot starting at 0 m
- In this plot:
    - All flora classified as adult should be counted, measured for height and DBH and identified to species. The health of each tree should be categorised and any additional notes about disease or damage should be recorded.
    - All flora classified as saplings should be counted and identified to species
    - Canopy cover recorded
    - Soil categorised
    - Soil depth measured
    - Rubbish identified and counted
    - Crab burrows counted
    - If part of the survey design, sample soil quality parameters and/or collect soil samples
    - If water is present and part of the survey design sample water quality parameters and/or collect water samples
- Within the 2.5 m x 2.5 m plot a smaller 1 m x 1 m plot should be measured out. In this plot:

- All flora classified as seedlings should be counted and identified to species

o These plots should then be repeated every 5 m along the transect or at a suitable distance if a longer transect is being used

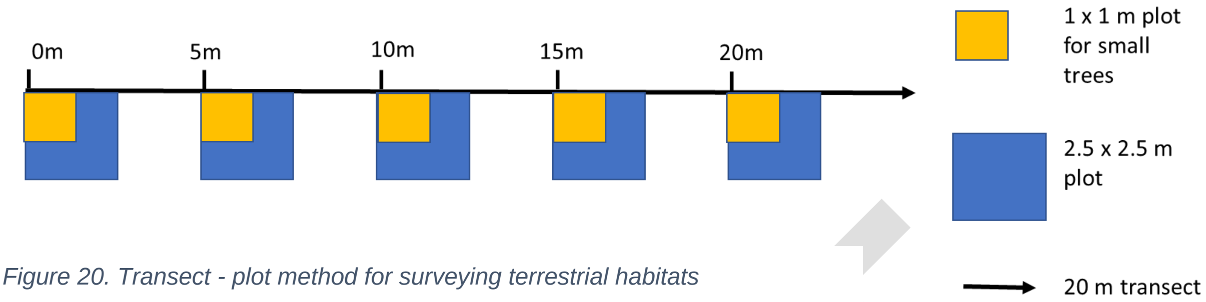


Figure 20. Transect - plot method for surveying terrestrial habitats

3.6.5 Safety

Sensible procedures should be followed to avoid getting lost within dense vegetation. Care should be taken in deep water or muddy areas. The depth of these should be tested before advancing through dangerous areas. Mangrove root systems and crab burrows create uneven ground that can lead to foot or ankle injuries. Enough water to stay hydrated throughout the day should be carried to avoid dehydration. Legs and arms should be covered, and insect repellent used to limit mosquito bites. Care should be taken to avoid stinging or biting insects such as wasps and ants that are common in terrestrial habitats.

3.6.6 Advantages

- Can be designed for all levels of surveyors
- Flora surveys on transects can be used to quantify density and diversity of vegetation
- Standard of data for required statistical analysis, management recommendations and scientific publications

3.6.7 Limitations

- Only covers a limited area
- Not good for rare species
- Time consuming

Date:		Surveyors:				GPS	N
Zone:	Transect:		Direction:				E
Notes:							
				2.5m2			
		1	2	3	4	5	
Habitat cat.							
Rubbish							
Canopy cover							
Crab burrows							
Disturbance							
Soil quality							
Water quality							
Tree 1	Sp						
	DBH						
	Height						
	Health						
Tree 2	Sp						
	DBH						
	Height						
	Health						
Tree 3	Sp						
	DBH						
	Height						
	Health						
Tree 4	Sp						
	DBH						
	Height						
	Health						
Tree 5	Sp						
	DBH						
	Height						
	Health						
Tree 6	Sp						
	DBH						
	Height						
	Health						
Tree 7	Sp						
	DBH						
	Height						
	Health						
Tree 8	Sp						
	DBH						
	Height						
	Health						
Tree 9	Sp						
	DBH						
	Height						
	Health						
				1m2			
		1	2	3	4	5	
Leaf litter							
Sp1	Sp						
	Abund						
	Height						
	Health						
Sp2	Sp						
	Abund						
	Height						
	Health						
Sp3	Sp						
	Abund						
	Height						
	Health						
Sp4	Sp						
	Abund						
	Height						
	Health						

Date:		Surveyors:				GPS	N
Zone:	Transect:		Direction:				E
Notes:							
				2.5m2			
		1	2	3	4	5	
Habitat cat.							
Rubbish							
Canopy cover							
Crab burrows							
Disturbance							
Soil quality							
Water quality							
Tree 1	Sp						
	DBH						
	Height						
	Health						
Tree 2	Sp						
	DBH						
	Height						
	Health						
Tree 3	Sp						
	DBH						
	Height						
	Health						
Tree 4	Sp						
	DBH						
	Height						
	Health						
Tree 5	Sp						
	DBH						
	Height						
	Health						
Tree 6	Sp						
	DBH						
	Height						
	Health						
Tree 7	Sp						
	DBH						
	Height						
	Health						
Tree 8	Sp						
	DBH						
	Height						
	Health						
Tree 9	Sp						
	DBH						
	Height						
	Health						
				1m2			
		1	2	3	4	5	
Leaf litter							
Sp1	Sp						
	Abund						
	Height						
	Health						
Sp2	Sp						
	Abund						
	Height						
	Health						
Sp3	Sp						
	Abund						
	Height						
	Health						
Sp4	Sp						
	Abund						
	Height						
	Health						

Figure 21. Example datasheet for terrestrial transect - plot survey data collection

4 References

Ministry of Environment and Energy. (2015). *Fifth national report to the United Nations convention on Biological Diversity*.

Naseer, A., & Hatcher, B. G. (2004). Inventory of the Maldives' coral reefs using morphometrics generated from Landsat ETM+ imagery. *Coral Reefs*, *23*(1), 161–168.

Risk, M. J. (1972). Fish diversity on a coral reef in the Virgin Islands. *Atoll Research Bulletin*.

Wilson, S. K., Graham, N. A. J., & Polunin, N. V. C. (2007). Appraisal of visual assessments of habitat complexity and benthic composition on coral reefs. *Marine Biology*, *151*(3), 1069–1076.

5 Decision tables

Table 3. Table to guide in marine survey design and method selection. The methods used should match up with the survey objectives and the habitat being surveyed.

Method	Data collected	Level of detail	Suitable for survey objectives	Suitable habitat	Justification
Manta tow	Qualitative estimate of substrate cover and condition in low resolution categories	Low	2. Habitat mapping, 3. Impact of disturbance, 6. Improving environmental management	Fringing reef or shallow submerged reef	Provides information about a large area. Determines habitat locations and boundaries. Used to detect bleached corals or COTS outbreaks. Limited to shallow reef areas. Useful to scope conditions and target more detailed surveys. Does not require dive qualifications.
Roaming survey for substrate cover	Qualitative estimate of substrate cover and condition in medium resolution categories	Medium	1. Baseline assessment, 2. Habitat mapping, 3. Impact of disturbance, 5. Education and awareness, 6. Improving environmental management	Fringing reef, shallow submerged reef, channel or thila	Provides a reasonable level of information about habitat type and condition over a large area. Can detect changes in coral and other substrate cover. Snorkel surveys can be used to educate and engage others. Flexible method that can be used in a range of environments. Useful to scope conditions and target more detailed surveys. Surveys can be done whilst snorkelling.
Point intercept transect (PIT)	Quantitative measure of substrate cover in high resolution categories	Medium - High	1. Baseline assessment, 3. Impact of disturbance, 4. Impact of human activities, 6. Improving environmental management, 7. Scientific study	Fringing reef or shallow submerged reef	Provides precise detail about small areas of reef. Can detect small changes in benthic communities. Used alongside other transect surveys and limited to shallow reef areas.
Coral size class	Quantitative measure of coral colony size and abundance	High	1. Baseline assessment, 3. Impact of disturbance, 4. Impact of human activities, 6. Improving environmental management, 7. Scientific study	Fringing reef or shallow submerged reef	Provides precise detail about small areas of reef. Can detect changes in coral community composition. Used alongside other transect surveys and limited to shallow reef areas.
Coral recruits	Quantitative measure of coral recruit community	High	1. Baseline assessment, 3. Impact of disturbance, 4. Impact of human activities, 6. Improving environmental management, 7. Scientific study	Fringing reef or shallow submerged reef	Provides precise detail about small areas of reef. Can detect changes in coral recruit composition. Used alongside other transect surveys and limited to shallow reef areas.
Visual estimate	Qualitative estimate of whole reef complexity	Medium	1. Baseline assessment, 2. Habitat mapping, 3. Impact of disturbance, 5. Education and awareness, 6. Improving environmental management, 7. Scientific study	Fringing reef, shallow submerged reef, channel or thila	Provides a reasonable level of information about reef complexity. Can detect changes in complexity. Snorkel surveys can be used to educate and engage others. Flexible method that can be used in a range of environments
Rugosity index	Quantitative measure of reef surface area	Medium	1. Baseline assessment, 3. Impact of disturbance, 6. Improving environmental management, 7. Scientific study	Fringing reef or shallow submerged reef	Provides detail about small areas of reef. Can detect changes in complexity. Used alongside other transect surveys and limited to shallow reef areas.
Roaming survey for fish	Quantitative or qualitative measures of limited components of the fish community	Low - Medium	1. Baseline assessment, 5. Education and awareness, 6. Improving environmental management	Fringing reef, shallow submerged reef, channel or thila	Provides a reasonable level of information about fish community composition across a large area. Snorkel surveys can be used to educate and engage others. Flexible method that can be targeted towards survey goals and used in a range of environments.
Belt transect survey for fish	Quantitative measure of fish community. Can include size, abundance and species data for whole fish community	Medium - High	1. Baseline assessment, 3. Impact of disturbance, 4. Impact of human activities, 6. Improving environmental management, 7. Scientific study	Fringing reef or shallow submerged reef	Provides precise detail about small areas of reef. Can detect changes in fish communities. Used alongside other benthic transect surveys and limited to shallow reef areas.

Table 4. Table to guide in terrestrial survey design and method selection. The methods used should match up with the survey objectives and the habitat being surveyed.

Method	Data collected	Level of detail	Suitable for survey goals	Suitable habitat	Justification
Point survey for flora	Qualitative estimate of plant cover and condition	Medium	1. Baseline assessment, 2. Habitat mapping, 3. Impact of disturbance, 4. Impact of human activities, 5. Education and awareness, 6. Improving environmental management	All terrestrial habitats	Rapid surveys can be used to provide information about a large area. Determines habitat locations and boundaries. Can build multiple surveys into this survey design.
Transect survey for flora	Quantitative measure of plant community composition	Medium - High	1. Baseline assessment, 3. Impact of disturbance, 4. Impact of human activities, 6. Improving environmental management, 7. Scientific study	All terrestrial habitats - particularly mangrove habitats	Provides precise detail about plant communities and can detect small changes or variations. Can be used to understand transitions between habitats. Can build multiple surveys into this survey design.
Bird survey	Qualitative measures of bird community	Low	1. Baseline assessment, 5. Education and awareness, 6. Improving environmental management	All terrestrial habitats	Provides low level information about bird communities. Surveys can be used to educate and engage others. Flexible method used in a range of environments. Can be used with point or transect surveys.
Crab survey	Quantitative measure of crab burrow abundance	High	1. Baseline assessment, 3. Impact of disturbance, 4. Impact of human activities, 6. Improving environmental management, 7. Scientific study	Coastal and mangrove fringe habitats	Provides precise detail about mangrove crab burrows, a useful proxy for abundance. Detects changes in crab abundance. Limited species that build burrows. Can be used with point or transect surveys.
Fish survey	Qualitative estimate of fish community	Low	1. Baseline assessment, 5. Education and awareness, 6. Improving environmental management	Ponds and mangrove bays	Provides low level information about fish communities in water bodies. Surveys can be used to educate and engage others. Flexible method used in a range of environments.
Insect survey	Quantitative measure of a small proportion of the insect community	Medium	1. Baseline assessment, 4. Impact of human activities, 5. Education and awareness, 6. Improving environmental management	All terrestrial habitats	Provides reasonable level of information about insect communities. Only targets nocturnal species attracted to lights. Detects changes in the insect community because of habitat changes. Flexible method used in a range of environments.
Water quality	Quantitative measure of water quality	Medium - High	1. Baseline assessment, 3. Impact of disturbance, 4. Impact of human activities, 6. Improving environmental management, 7. Scientific study	Ponds and mangrove bays	Provides precise detail about water quality within the survey area. Number of indicators measured depends equipment available. Can detect changes in water quality caused by changes in the environment. Can be used with point or transect surveys.
Soil quality	Quantitative measure of soil quality	Medium - High	1. Baseline assessment, 3. Impact of disturbance, 4. Impact of human activities, 6. Improving environmental management, 7. Scientific study	All terrestrial habitats	Provides precise detail about soil quality within the survey area. Number of indicators measured depends equipment available. Can detect changes in soil quality caused by changes in the environment. Can be used with point or transect surveys.
Rubbish counts	Quantitative counts of rubbish and other dumped items	High	1. Baseline assessment, 4. Impact of human activities, 5. Education and awareness, 6. Improving environmental management, 7. Scientific study	All terrestrial habitats - particularly coastal and mangrove fringe habitats	Provides counts of rubbish per unit area. Can determine human impacts on the habitat. Can be used with point or transect surveys.

6 External resources

Table 5. Additional resources to assist with survey design and data collection

Resource	Description	Link
IUCN RedList	Critical indicator of conservation, status and threat of the species	https://www.iucnredlist.org
NOAA Coral Reef Watch	Real time satellite models to monitor the sea surface temperature. Predict the acceleration of heat stress that causes coral bleaching	https://coralreefwatch.noaa.gov
Allen Coral Atlas	Coral reefs maps. Habitat classification	https://allencoralatlas.org
Maldives Conservation Portal	Information on the research and publications about Maldives which can be found in a single platform	http://maldivesconservationportal.org/home
Maldives Marine Research Institute	Latest updates on marine research in the Maldives. Also contains some of the survey protocols for megafauna	https://www.mrc.gov.mv
Ministry of Environment	Latest updates on environment in the Maldives	https://www.environment.gov.mv/v2/en/
Environmental Protection Agency of Maldives	Latest updates on the laws and regulations. Environmental Impact Assessment reports, monitoring reports of various projects	http://www.epa.gov.mv
Corals of the world	Information, identification, distribution and taxonomy of reef building corals	http://www.coralsoftheworld.org/
FishBase	Information, identification, distribution and taxonomy of fish	https://www.fishbase.se/home.htm
Algae Base	Information, identification, distribution and taxonomy of algae	https://www.algaebase.org
Trees and Shrubs	Information about trees and shrubs of Maldives (including Mangroves)	http://www.fao.org/3/ai387e/AI387E00.htm
AIMS Survey Manual	Survey manual for tropical marine resources	https://www.aims.gov.au/sites/default/files/Survey%20Manual-sm01.pdf
Coral Point Count	Windows based software to analyse benthic composition (photoquadrats)	https://cnso.nova.edu/cpce/index.html
CoralNet	Online platform to analyse benthic composition (photoquadrats)	https://coralnet.ucsd.edu
Mermaid	An open source database platform for coral reef data collection and visualisation	https://datamermaid.org/
Maldives CoralDatabase	Database platform for data entry to the Maldives National Coral Reef Monitoring Framework	https://coraldatabase.gov.mv/
Tide and Weather	Information about the tides and weather of Maldives	https://www.tideschart.com/Maldives/
Greenfins	Environmental friendly diving and snorkelling guidelines	https://greenfins.net

7 Commonly observed taxa in the Maldives

Table 6. Genera of corals commonly observed in The Maldives

Family	**Genus**
Acroporidae	*Acropora*
Acroporidae	*Alveopora*
Acroporidae	*Astreopora*
Acroporidae	*Isopora*
Acroporidae	*Montipora*
Agariciidae	*Gardineroseris*
Agariciidae	*Leptoseris*
Agariciidae	*Pachyseris*
Agariciidae	*Pavona*
Coscinaraea	*Coscinaraea*
Dendrophyllidae	*Tubastrea*
Dendrophyllidae	*Turbinaria*
Diploastreidae	*Diploastrea*
Euphylliidae	*Galaxea*
Fungiidae	*Ctenactis*
Fungiidae	*Fungia*
Fungiidae	*Heliofungia*
Helioporidae	*Heliopora*
Lobophyllidae	*Echinophyllia*
Lobophyllidae	*Lobophyllia*
Lobophyllidae	*Oxypora*
Lobophyllidae	*Symphyllia*
Merulinidae	*Cyphastrea*
Merulinidae	*Echinopora*
Merulinidae	*Favites*
Merulinidae	*Goniastrea*
Merulinidae	*Hydnophora*
Merulinidae	*Leptoria*
Merulinidae	*Merulina*
Merulinidae	*Mycedium*
Merulinidae	*Platygyra*
Milleporidae	*Millepora*
Mussidae	*Favia*
Paramontastraea	*Montastrea*
Pocilloporidae	*Pocilliopora*
Poritidae	*Goniopora*
Poritidae	*Porites*
Psammocoridae	*Psammocora*

Table 7. Species of coral reef associated fish commonly observed in The Maldives

Family	Species	Common name
Acanthuridae	*Ctenochaetus striatus*	Fine-lined bristletooth
Acanthuridae	*Acanthurus leucosternon*	Powder-blue surgeonfish
Acanthuridae	*Ctenochaetus truncatus*	Gold-ring bristletooth
Acanthuridae	*Zebrasoma scopas*	Brown Tang
Acanthuridae	*Acanthurus nigrofuscus*	Dusky surgeonfish
Acanthuridae	*Acanthurus thompsoni*	Night surgeonfish
Acanthuridae	*Naso hexacanthus*	Sleek unicornfish
Balistidae	*Odonus niger*	Redtooth triggerfish
Balistidae	*Balistapus undulatus*	Striped triggerfish
Balistidae	*Melichthys indicus*	Indian triggerfish
Caesionidae	*Pterocaesio pisang*	Ba fusilier
Caesionidae	*Pterocaesio tile*	Bluestreak fusilier
Caesionidae	*Caesio varilineata*	Thin-lined fusilier
Caesionidae	*Pterocaesio trilineata*	Threestripe fusilier
Carangidae	*Caranx sexfasciatus*	Bigeye trevally
Carangidae	*Caranx melampygus*	Bluefin trevally
Carangidae	*Elagatis bipinnulata*	Rainbow runner
Carcharhinidae	*Triaenodon obesus*	Whitetip reef shark
Carcharhinidae	*Carcharhinus melanopterus*	Blacktip reef shark
Chaetodontidae	*Hemitaurichthys zoster*	Black pyramid butterflyfish
Chaetodontidae	*Heniochus diphreutes*	Schooling bannerfish
Chaetodontidae	*Forcipiger flavissimus*	Long-nose butterflyfish
Chaetodontidae	*Chaetodon kleinii*	Brown butterflyfish
Chaetodontidae	*Chaetodon trifasciatus*	Pinstriped butterflyfish
Chaetodontidae	*Chaetodon triangulum*	Triangular butterflyfish
Cirrhitidae	*Paracirrhites forsteri*	Forster's hawkfish
Cirrhitidae	*Cirrhitichthys oxycephalus*	Spotted hawkfish
Ephippidae	*Platax boersii*	Tall-fin batfish
Haemulidae	*Plectorhinchus vittatus*	Oriental sweetlips
Holocentridae	*Sargocentron caudimaculatum*	White-tail squirrelfish
Holocentridae	*Myripristis kuntee*	Epaulette soldierfish
Holocentridae	*Myripristis murdjan*	Crimson soldierfish
Holocentridae	*Neoniphon sammara*	Spotfin squirrelfish
Holocentridae	*Sargocentron spiniferum*	Sabre squirrelfish
Kyphosidae	*Kyphosus cinerascens*	Snubnose rudderfish
Labridae	*Thalassoma lunare*	Moon wrasse
Labridae	*Thalassoma amblycephalum*	Two-tone wrasse
Labridae	*Cirrhilabrus exquisitus*	Exquisite wrasse
Labridae	*Labroides dimidiatus*	Blue-streak cleaner wrasse
Labridae	*Pseudocheilinus hexataenia*	Six-line wrasse
Labridae	*Halichoeres hortulanus*	Checkerboard wrasse
Lethrinidae	*Gnathodentex aureolineatus*	Gold-spot emperor
Lethrinidae	*Monotaxis grandoculis*	Bigeye emperor
Lethrinidae	*Lethrinus olivaceus*	Long-nose emperor

Family	Species	Common name
Lutjanidae	*Lutjanus kasmira*	Blue-striped spper
Lutjanidae	*Lutjanus gibbus*	Humpback spper
Lutjanidae	*Lutjanus bohar*	Red spper
Lutjanidae	*Macolor macularis*	Midnight spper
Lutjanidae	*Macolor niger*	Black spper
Mocanthidae	*Oxymonacanthus longirostris*	Long-nose filefish
Mullidae	*Parupeneus macronemus*	Longbarbel goatfish
Mullidae	*Parupeneus barberinus*	Dash and dot goatfish
Muraenidae	*Gymnothorax javanicus*	Giant moray
Muraenidae	*Gymnothorax flavimarginatus*	Yellow-margin moray
Pinguipedidae	*Parapercis hexophtalma*	Black-tail grubfish
Pomacanthidae	*Centropyge multispinis*	Many-spined angelfish
Pomacanthidae	*Pygoplites diacanthus*	Regal angelfish
Pomacanthidae	*Pomacanthus imperator*	Emperor angelfish
Pomacanthidae	*Apolemichthys trimaculatus*	Three-spot angelfish
Pomacentridae	*Chromis ternatensis*	Swallow-tail puller
Pomacentridae	*Pomacentrus philippinus*	Philippine damsel
Pomacentridae	*Chromis viridis*	Green puller
Pomacentridae	*Pomacentrus indicus*	Indian damsel
Pomacentridae	*Dascyllus aruanus*	Humbug damsel
Pomacentridae	*Dascyllus carneus*	Indian humbug
Pomacentridae	*Amblyglyphidodon leucogaster*	White-breasted sergeant
Pomacentridae	*Chromis weberi*	Weber's puller
Pomacentridae	*Chromis atripectoralis*	Blue-green puller
Pomacentridae	*Chromis dimidiata*	Two-tone puller
Pomacentridae	*Amphiprion nigripes*	Blackfoot anemonefish
Pomacentridae	*Amphiprion clarkii*	Clarks anemonefish
Scaridae	*Chlorurus sordidus*	Shabby parrotfish
Scaridae	*Scarus niger*	Dusky parrotfish
Scaridae	*Scarus scaber*	Five-saddle parrotfish
Scaridae	*Scarus psittacus*	Rosy-cheek parrotfish
Scaridae	*Scarus tricolor*	Three-colour parrotfish
Scaridae	*Chlorurus strongylocephalus*	Sheephead parrotfish
Scaridae	*Scarus rubroviolaceus*	Ember parrotfish
Scaridae	*Scarus frenatus*	Bridled parrotfish
Scaridae	*Hipposcarus harid*	Longnose parrotfish
Scaridae	*Cetoscarus bicolor*	Two-colour parrotfish
Scorpaenidae	*Pterois antennata*	Spotfin lionfish
Scorpaenidae	*Pterois volitans*	Common lionfish
Serranidae	*Pseudanthias squamipinnis*	Orange basslet
Serranidae	*Pseudanthias evansi*	Yellow-tail basslet
Serranidae	*Pseudanthias ignitus*	Flame basslet
Serranidae	*Cephalopholis argus*	Peacock rock cod
Serranidae	*Aethaloperca rogaa*	Redmouth grouper
Serranidae	*Cephalopholis nigripinnis*	Blackfin rock cod

Family	Species	Common name
Serranidae	*Cephalopholis leopardus*	Leopard hind
Serranidae	*Anyperodon leucogrammicus*	Slender grouper
Serranidae	*Cephalopholis miniata*	Vermilion rock cod
Serranidae	*Variola louti*	Lunar-tailed grouper
Serranidae	*Plectropomus laevis*	Black-saddle coral grouper
Serranidae	*Cephalopholis sexmaculata*	Six-spot rock cod
Siganidae	*Siganus stellatus*	Starry rabbitfish
Siganidae	*Siganus puelloides*	Chin-strap rabbitfish
Siganidae	*Siganus corallinus*	Coral rabbitfish
Tetraodontidae	*Canthigaster valentini*	Saddled pufferfish
Zanclidae	*Zanclus cornutus*	Moorish idol

Table 8.Species of terrestrial flora commonly observed in The Maldives

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

Table 9. Species of avifauna commonly observed in The Maldives

Family	Species	Common name	Dhivehi name
Accipitridae	*Elanus caeruleus*	Black-winged Kite	Fiyakalhu Baazu
Ardeidae	*Ardea cinerea*	Grey heron	Maakanaa
Ardeidae	*Ardeola grayii phillipsi*	Maldivian Pond heron	Huvadhoo Raabondhi
Ardeidae	*Casmerodius albus*	Great Egret	Lagana
Ardeidae	*Nycticorax mycticorax*	Black-crowned night heron	Raabondhi
Charadriidae	*Charadrius mongolus*	Lesser Sand Plover	Kuda Bondana
Corvidae	*Corvus splendens*	Crow	Kaalhu
Cuculidae	*Eudynamys scolopacea*	Asian Koel	Koel
Phaethontidae	*Phaethon lepturu*	White-tailed tropical bird	Dhan'dhifulhu
Rallidae	*Amaurornis phoenicurus maldivus*	Maldivian water hen	Dhivehi Kambili
Scolopacidae	*Arenania interpres*	Ruddy turnstone	Rathafai
Scolopacidae	*Numenius phaeopus*	Whimbrel	Bulhithun'bi
Scolopacidae	*Tringa hypoleucos*	Common sandpiper	Findhana