CORAL REEF RESTORATION MONITORING MANUAL

Maldives

Edited by Simone Montano, Federica Siena and Fathimath Hana Amir

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

MARINE RESEARCH CENTRE

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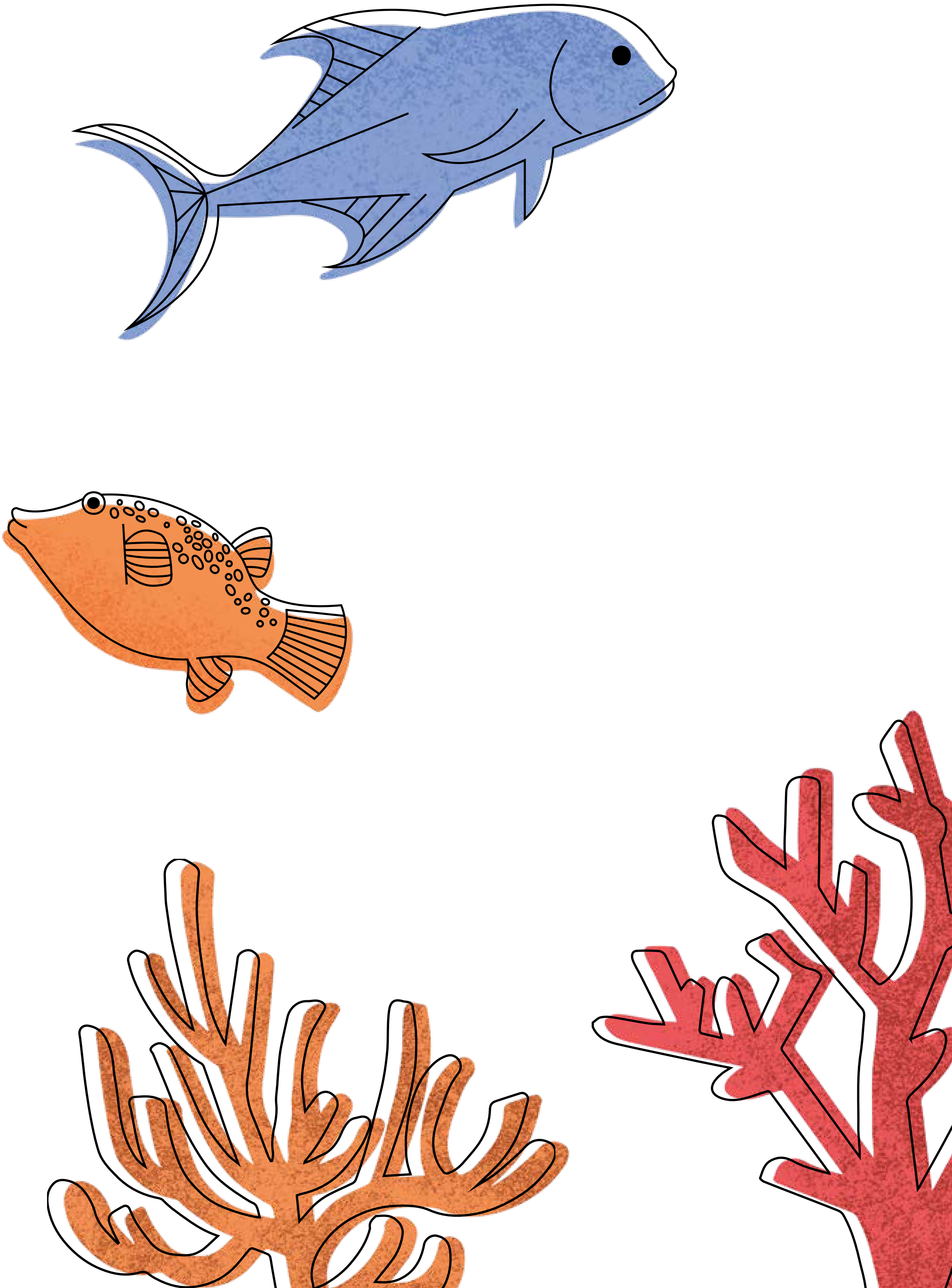

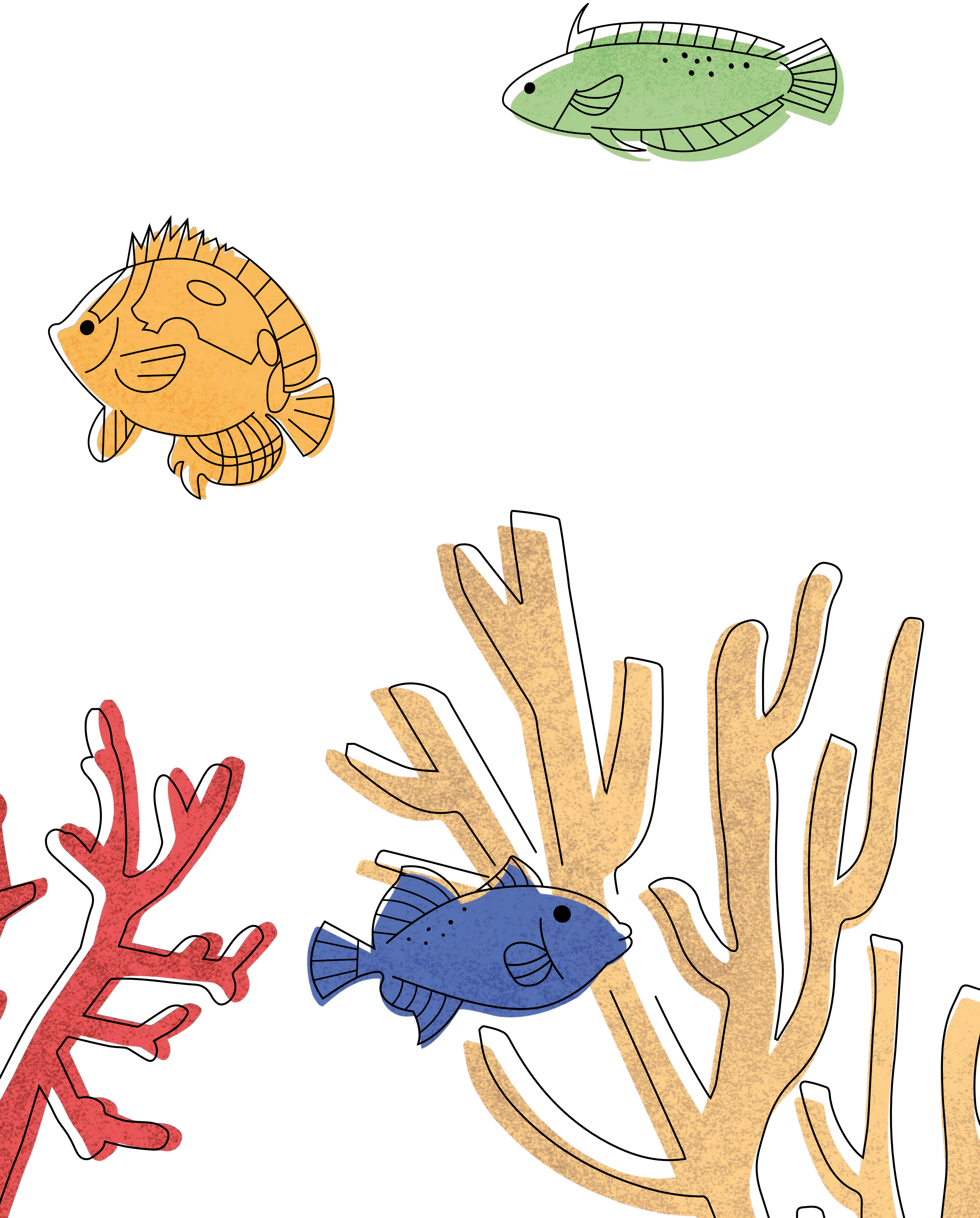

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Disclaimer

Monitoring of restoration projects may require the use of SCUBA diving. As such, only certified SCUBA divers with training in scientific diving should perform this activity, following up-to date standards.

Graphics Concept & Illustrations

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Acronyms

BBD	Black Band Disease
BrB	Brown Band Disease
COT	Crown of Thorns (*Acanthaster planci*)
CPCe	Coral Point Count with Excel extensions
DCQA	Data-centred quadrants approach
DISAT	Department of Earth and Environmental Sciences
EIA	Environmental Impact Assessment
EV	Ecological Volume
GPS	Global Positioning System
IPA	Importance-Performance Analysis
MaRHE	Marine Research and High Education Center
MMRI	Maldives Marine Research Institute
NCRMF	National Coral Reef Monitoring Framework
NOAA	National Oceanic and Atmospheric Administration
PIT	Point Intercept Transect
PQ	Point Quadrat
SCTLD	Stony Coral Tissue Loss Disease
SCUBA	Self Contained Underwater Breathing
SEB	Skeletal Eroding Band
SER	Society for Ecological Restoration
SQM	Square Metre
UW	Underwater

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Foreword

Coral reefs are quintessential to the survival of the Maldives, not just because of their function as providers and provisioners of food, protection, and livelihoods, but also as a cornerstone of Maldivian identity and culture. Climate change and its impacts, particularly the increasingly frequent and severe thermal events and consequent bleaching, pose a critical threat to the very reefs Maldivians are so dependent upon. To mitigate coral reef loss and bolster the chances of their survival, there is a growing interest in active coral reef restoration and rehabilitation in the Maldives with methods of asexual propagation currently being the most practiced. These endeavors differ in scale and effort and are scattered throughout the country with limited connectivity – the latter proving to be a significant barrier in upscaling projects and evaluating their effectiveness not just locally but also on a national scale. A prime objective of this protocol is to provide a tool that can be utilized to overcome some of the challenges that reef restoration practitioners face by harmonizing data collection, enabling information exchange, and facilitating the comparison of progress and success in different areas. Through this, it is hoped that the efforts scattered throughout the Maldives can help achieve a national scale reef restoration, benefiting all.

“Restoration ecology really requires two tools: the ability to manipulate ecosystems to recreate a desired community and the ability to evaluate whether the manipulations have produced the desired change”

Keddy P, 2000

How to use this manual

This manual is organized in 4 parts:

1. OBJECTIVE AND SCOPE OF WORK

Identifies why this manual is needed and useful.

2. INTRODUCTION

Provides a background on Maldivian Coral Reefs and a description of Coral Reef Restoration main drivers and components.

3. MONITORING

Specifies the goals and through which tools they can be achieved.

4. MONITORING PROTOCOL

Indicates protocols, indicators, tools, procedures, and a schedule to collect data.
Suggests datasheets and questionnaires for data collection and submission.

Within each chapter the reader will find boxes that highlight additional general information concerning coral restoration as well as monitoring.
This information will be divided into 3 mains categories:

INSIGHTS

Which provide additional theoretical information.

RECOMMENDATION

Which provide suggestions on how to successfully conduct certain processes.

TECHNICAL ADVICE

Which illustrate practical aspects of the operations.

Preface

The National Coral Reef Restoration and Rehabilitation program was established by the Government of Maldives in 2019. Hosted by the Maldives Marine Research Institute [MMRI] under its coral reef research body of work, the program aims to develop a nationwide plan to address degraded coral reefs under natural and anthropogenic pressure, combined with the development of mitigation tools to withstand those impacts. The program will address and identify specific information gaps within this research field for the Maldives, in addition to developing effective sustainable methods and management practices based on the latest available knowledge, tools, and technologies.

The Marine Research and Higher Education [MaRHE] Centre is an outpost of the University of Milano-Bicocca involved in research related to several topics, including environmental science, tourism science, human geography, and marine ecology with special focus on the tropical marine biology of coral reefs. As a teaching outpost, the Centre has for many years developed and taught field skills necessary to investigate coral reefs which include development and research related to coral reef restoration and rehabilitation. As part of this work, MaRHE Centre began the development of monitoring protocols that could be used for coral propagation, restoration and rehabilitation efforts.

Figure 2 - Maldives Marine Research Institute outpost in Maniyafushi.

The absence of a nationwide plan regarding the monitoring and reporting of restoration and rehabilitation efforts within the nation has been recognized as the key limiting factor for the coordination and effectiveness of efforts in these activities. Therefore, MaRHE Centre and MMRI have developed this document as a tool to guide and lead the parties within this field in order to cope with and overcome this limitation.

Figure 3 - MaRHE Center on the island of Magoodhoo, Faafu Atoll.

1.
OBJECTIVE AND SCOPE OF WORK

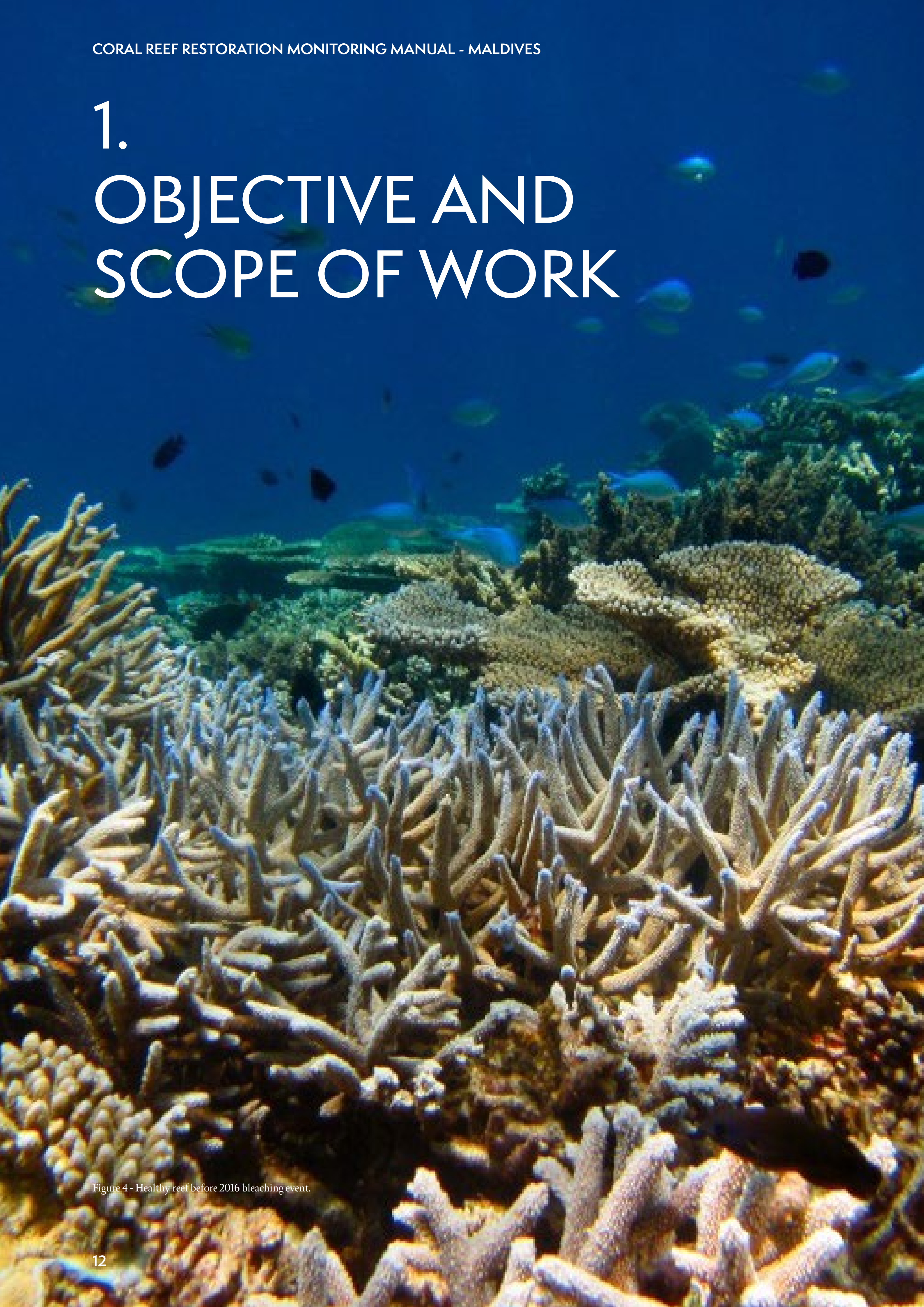

Figure 4 - Healthy reef before 2016 bleaching event.

1.1 Purpose of this Manual

In recent years, an increasing number of reef managers and practitioners have started to share successes, failures, and challenges of coral restoration projects due to the urgency to act in response to the impacts of climate change (See BOX 1.1. “Insights – Further Reading”).

In the Maldives, coral restoration projects, particularly those following asexual coral propagation methods, are now popular with both public and private sector commonly taking initiative. Resorts consider these initiatives to fund conservation and involve tourists in activities to raise awareness on environmental issues and therefore an increased effort in this discipline can be observed. Similarly, local NGOs and communities wish to preserve their local coral reefs, create engagement opportunities, and spread environmental awareness. Despite the numerous efforts, a lot of the data and information currently available on these projects is shared via symposiums, grey literature, non-technical reports, or Facebook groups, and unfortunately all of these are rarely compiled together.

As a consequence, a lot of practitioners are struggling to assess the multitude of techniques available to determine what is most suitable to achieve their envisioned goal. Furthermore, practitioners lack a way to benchmark or compare project successes, even if similar techniques and time frames are applied. Moreover, despite the common desire to share success, failures and results, the lack of common protocols to collect data only provides a partial overview of the current situation. Consequently, this disconnection has slowed down the progress towards large-scale restoration within the Maldives.

The guidelines provided in this manual are not exhaustive and applicable to all tenets of coral restoration and rehabilitation, rather they are applicable to the practice of asexual coral propagation and coral gardening for restoration purposes – the type of coral restoration and rehabilitation that is currently most commonly practiced in the Maldives.

The creation of national guidelines allows for consistent spatial and temporal data collection. Recognising the importance of a holistic approach, these guidelines incorporate a set of ecological indicators associated with sociocultural and economic indicators to allow practitioners to perform a comprehensive analysis of their projects. By offering a tool to report nation-specific, comparable, and science-based data on the performance of the various projects, the manual provides an important instrument to elevate the credibility of coral restoration and determine cumulative efforts and impacts of projects carried out in the Maldives.

Therefore, the manual provides information and guidance on:

- what to survey
- ecological indicators and how to measure them
- how to collect data and input them in datasheets and database
- the early detection of problems for a timely implementation of corrective measures
- consistent and complementary collection of information on a national level
- the creation of science-based restoration projects which serve as a strategy to increase the resilience of reefs and work on a large-scale basis
- benchmarking performance against goals and assess effectiveness
- measuring socio-economic aspects of coral restoration

BOX 1.1 - INSIGHTS FURTHER READING ON MONITORING

For more information we suggest consulting

- Goergen EA, Schopmeyer S, Moulding A, Moura A, Kramer P, Viehman S. 2020. Coral Reef Restoration Monitoring Guide: Best Practices for Monitoring Coral Restorations from Local to Ecosystem Scales.
- Frias-Torres S, Montoya-Maya P, Shah N. 2019. Coral Reef Restoration Toolkit: A Field-Oriented Guide Developed in the Seychelles Islands.
- Hein MY, Birtles A, Willis BL, Gardiner N, Beeden R, Marshall NA. 2019. Coral restoration : Socio-ecological perspectives of benefits and limitations. Biological Conservation 229: 14–25.

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1.2 Target audience

1.2
Target Audience

This manual is carefully designed for anyone already working on a coral restoration project or attempting to start a new one using methods of asexual propagation. The manual aims to offer restoration practitioners in the Maldives (e.g., resorts' marine biologists and independent organisations and persons) a common monitoring protocol to survey their coral restoration projects, gauge success and effectiveness, and create a national database. The protocol is designed to be adaptable to different scenarios whilst providing standard procedures. It is also a flexible tool in terms of the quantity and quality of the data collected (see below "Ecological monitoring: Indicators, Tools, and Procedures" chapter 3.2).

Figure 5 - Team effort to restore a degraded reef.

1.3
What Does Coral Reef Restoration Mean?

There are several terms used to indicate the possible interventions on a reef either aimed at producing long-term outcomes (restoration and rehabilitation) or short-term results (mitigation and remediation)[2] (see BOX 1.2 "Insights - Definition of Terms"). This manual will use the general term restoration as intended by the Society for Ecological Restoration (SER)[3]: "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed". This definition of Ecological Restoration covers projects aimed at assisting a reef, not creating a brand new one. To achieve this, anyone planning to establish a new project must have clear understanding of the goals and objectives and acknowledge the complexity of the task.

BOX 1.2 - INSIGHTS DEFINITIONS OF TERMS

It is important to provide a bit of background on what terms are often used with regards to interventions on the reef as, despite looking like synonyms, they have specific connotations[2].

Restoration: is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed[3]. It focuses on recreating a pre-existing ecosystem in terms of organisms' composition and community.

Rehabilitation focuses on the model offered by historical data or a reference ecosystem concentrating efforts on processes, productivity, and services. It aims at replacing the structural or functional characteristics of an ecosystem that have worsened or have been lost. In some cases, it includes the replacement of some characteristics with others of a higher social, economic, or ecological value.

Remediation: the process of remedying or repairing damage occurred in an ecosystem. Often refers to an acute source of degradation which, once removed, allows the ecosystem to recover, albeit through man-made efforts.

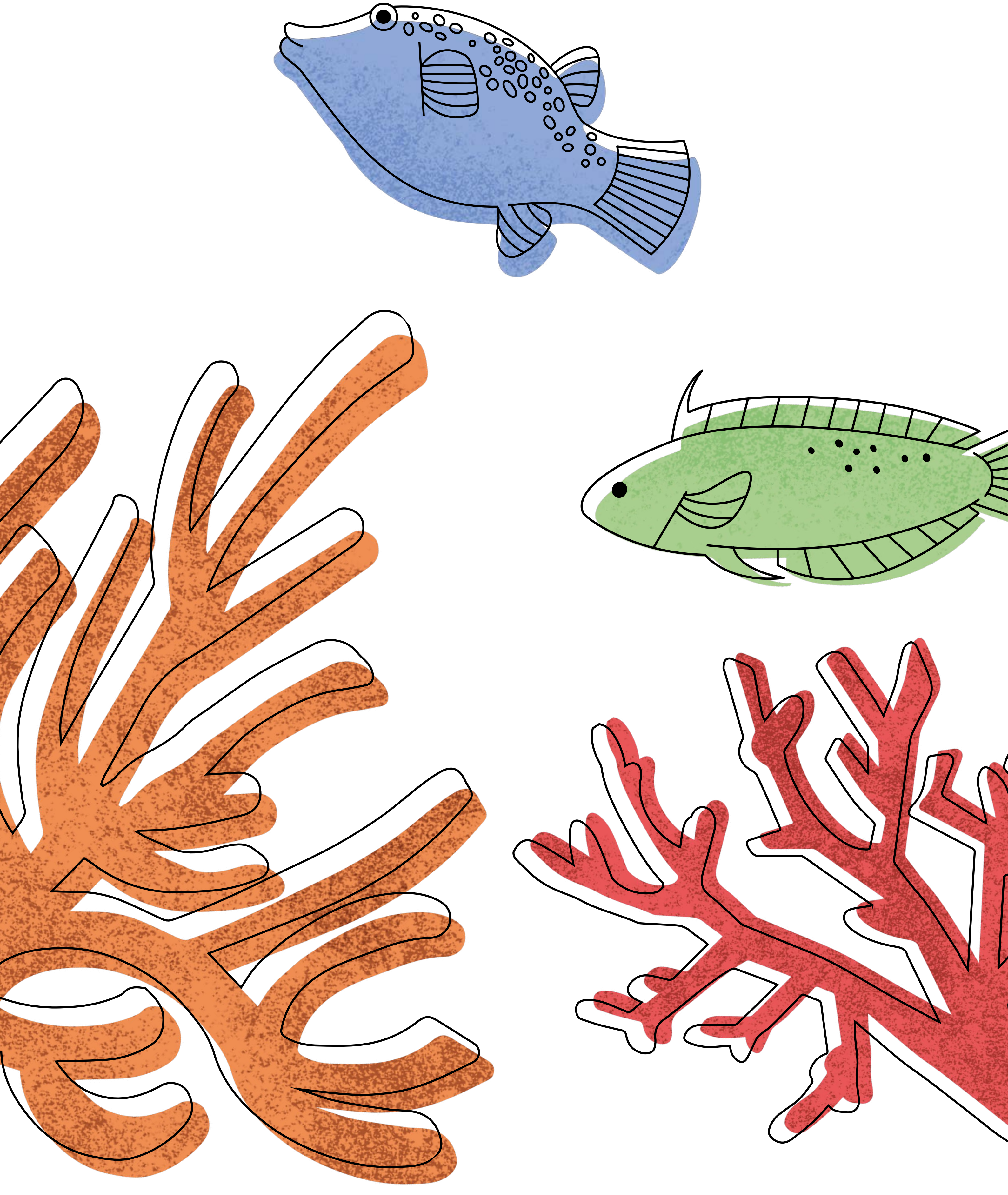
Mitigation represents an effort to ensure the reduction or control of the adverse environmental effects of a project.

Compensation can take a myriad of forms and is often project and location specific. Commonly, it can include the creation of a habitat in one area to compensate for loss in another.

Outplanting is the process of planting corals from a nursery to a chosen area (e.g., restoration site). The term is used instead of transplantation.

Transplantation refers to the process of relocating corals from an area to another area without any intermediate phase (i.e., direct transplantation).

›› Next chapter:
2. INTRODUCTION



2. INTRODUCTION

Figure 6 - Aerial view of a typical Maldivian area.

2.1

Impacts on the Reefs of the Maldives

The Republic of Maldives encompasses a chain of atolls forming a coral reef system, crucial to the nation survival and vulnerable to both global and local challenges. With over 250 reported species [4,5], the coral cover of the Maldives before the 1990s ranged between 40-80% [6–9]. However, due to two mass bleaching events (the first in 1998 and the latter in 2016) and minor bleaching episodes in between (e.g., in 2003, 2005 and 2010) coral cover across the archipelago has been severely affected [10,11].

During the 1998 bleaching event, mass mortality was recorded with the overall coral population declining to less than 3% [6–8,12]. The composition of coral reef communities shifted towards massive corals like Poritids, Faviids (now Merulinids) and Agariciids, with branching corals showing >98% mortality [6,7,13]. This shift in composition, however, has proven not to be permanent, as shown by a slow and partial recovery of the Acroporid and Pocilloporid communities by 2015 and reaching a coral cover of average 50% by 2015 [14].

Further recovery of Maldivian coral reefs was impeded by the 2016 bleaching event that affected reefs across the nation. Much like reported in 1998 [15], branching corals like Acroporids were differentially and more severely affected compared to massive corals like Poritids. Following this bleaching event, coral cover remained low with declines in reef rugosity associated with bleaching [16]. Today, coral reef cover continues to persist around an average of 20% with Poritids being now the dominant genera.

Climate change and bleaching impacts aside, the coral reefs reefs of the Maldives have been and continue to be subject to natural and anthropogenic stressors that affect their health [17]. Coastal development on both local and resort islands impact reef health via several processes. Land reclamation, beach replenishment and seagrass removal can compromise reef health by moving sediment and silt away from the source to other areas [18] and can have negative impacts on the ecosystem by increasing the movement of fine particulate [19] as well as by removing important species and habitat.

Natural stressors include coral diseases which, since the first official report in 2012, have been identified in many areas [20]. Outbreaks of *Acanthaster planci* (Crown of Thorns Starfish - COT) have been reported from the Maldives with reefs affected by outbreaks being majorly compromised by coral mortality reaching up to 70% [21,22]. Additionally, predation by the Pin-Cushion Starfish (*Culcita* sp.) [23,24] and *Drupella* sp. [25] had impacts on already affected areas.

Figure 7 - Conditions of reefs before 2016 bleaching event.

Figure 8 - Coral bleaching in the Maldives, 2016.

Figure 9 - Conditions of reefs after 2016 bleaching event.

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2.2 Need for Coral Reef Restoration

2.2
Need for Coral Reef Restoration

It is still uncertain how long it will take reefs to naturally recover and what approaches should be taken to support reef recovery and improve their resilience. With an everchanging marine environment along with competing interests and needs in terms of anthropogenic developments as well as growing sentiment towards marine stewardship, any restoration and rehabilitation project will need to account for numerous factors to be effective in the long run, return the desired results and achieve pre-described objectives.

Nevertheless, in response to the state of the coral reefs of the Maldives, researchers and concerned parties have turned to restoration and rehabilitation techniques as a tool to mitigate and reverse those impacts. While some scientists argue that frequent short-term interventions like coral gardening are necessary to counteract the increasing impacts of climate change and facilitate the long-term recovery of coral reefs [26–28], others argue these measures should remain a last resort intervention, especially if the stressor causing the degradation is not alleviated [2,29,30].

With the ambiguity of success involved with restoration and rehabilitation efforts and the magnitude of resources required for long-term and large-scale programs, the protection and management of coral reef areas should be prioritised, and any prospective restoration and rehabilitation site(s) must be thoroughly evaluated through a comprehensive ecological assessment before pursing any restoration or rehabilitation activity. Whenever the causes of degradation have not been identified and addressed, any attempt to restore an ecosystem is likely to fail to achieve the desired outcomes[31]. Baseline ecological surveys should include assessments of habitat, environmental conditions, various characteristics of reef state, stressors, suitability of intervention type (passive vs active vs combination), sustainability of the project, consequences etc. Moreover, they should indicate the need for a project, inform of the objectives, and set a baseline to compare the progress and results of the project. Procedures to measure many of the parameters and indicators are provided within this manual.

2.3
Goals of Restoration Programs

Ecological Restoration requires the formulation and identification of clear goals that allow the assessment of the effectiveness of a project against the main objective of bringing a degraded ecosystem as close as possible to original condition or at minimum to improve its resistance or resilience. Although it might require decades for this to fully occur, the common goal of all the projects should be to assist the functional and structural recovery of the ecosystem by putting it on the right trajectory [2].

It is important that goals are relevant to the area, realistic and measurable to ensure feasibility and engagement. Goals might be defined for different timeframes and might comprise several smaller objectives. Moreover, nowadays it is recognized that the value of restoration should be analysed both with reference to the ways it helps the recovery of the ecosystem and account for the human perspective by including socio-economic aspects. Similarly, research goals can be incorporated into a project, based on both local and global needs.

Goals and objectives are specific to each coral restoration and rehabilitation project and although they should be determined before the start of a project, they could be adjusted later in case of need.

Project goals and objectives, as well as the degree to which they are met are required metrics to assess the success of a project.

2.3.1
Ecological Goals and Objectives

Ecological restoration goals broadly target supporting/improving the structural and functional capacity of the ecosystems that are being restored or rehabilitated. These are often project and site-specific. Their specificity is derived from pre-project evaluations that include ecological and socio-economic surveys among others.

Some examples of goals and objectives include:

- Goal: Improve functional and structural complexity
  - Objective: Increase coral abundance and cover by x% in the project site
- Goal: Improve reef biodiversity
  - Objective: Increase abundance of slow growing coral by x%

2.3.2
Socio–economic Goals and Objectives

Socio-economic goals should also be incorporated into restoration or rehabilitation projects as these efforts may create job opportunities, promote educational activities, increase coastal protection, or provide locals and tourists with a healthier reef to visit among other benefits. While the socio-economic aspects may be extremely relevant for the project, they should always complement an ecological restoration to avoid compromising the foundational doctrine of such projects. Similar to ecological goals, socio-economic goals can be general with specific targets or smaller objectives.

For example:

- Goal: Create stewardship for ocean conservation amongst the young generations of a local community
  - Objective: hold a presentation for each school grade and lead a snorkelling session to the restoration site

Figure 10 - SCUBA diving can serve as an educational activity to raise awareness of the need for reef conservation.

Socio-economic goals might be directly linked to ecological goals, e.g., coastal protection might benefit greatly the communities and could be obtained by an increase in coral cover and thus structural complexity.

2.3.3 Research-based Goals and Objectives

Much like ecological and socio-economic goals, research goals can also be incorporated into a project.
Coral reef restoration is a developing discipline, with many experiments regularly being conducted to improve the performance of the structures, ameliorate the structural stability (e.g., consolidate rubble), increase the resilience of the reef and much more. A project might focus on studying new techniques, the response of less commonly used species, the use of assisted evolution, the selection of genetic traits associated with particular features and so on.

For example:

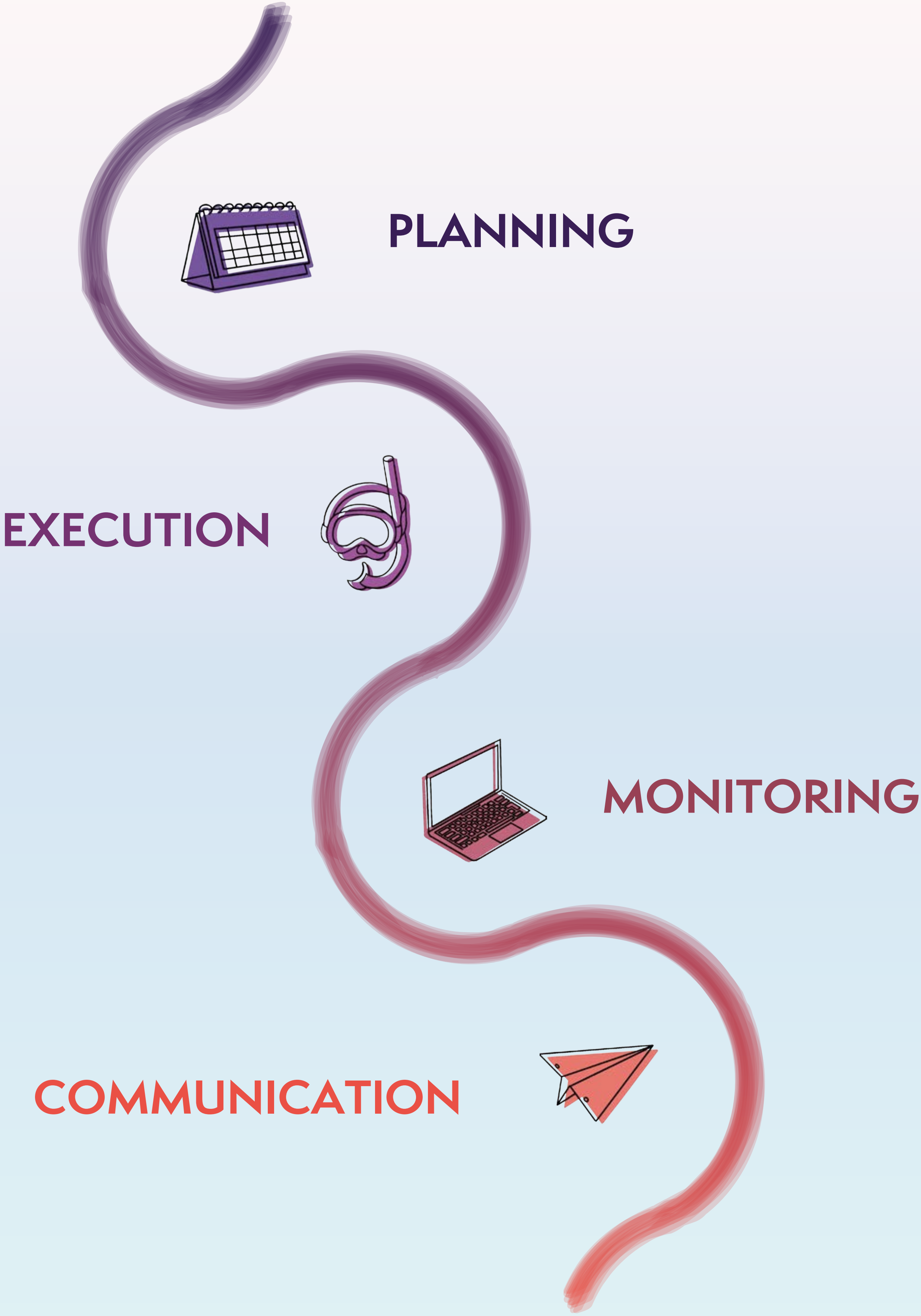
- Goal: Assess how to speed-up corals self-attachment to reduce outplants mortality
  - Objective: Trial X different gluing materials with the same coral genet in the same environmental conditions

2.4 Components of the Project

The development of a coral restoration project lies outside the scope of this manual (see BOX 2.1. “Insights - Further Reading”), however, as the monitoring of a restoration project begins even before restoration physically starts, we provide here a list of the main steps, describing some in more detail and offer some useful references.

BOX 2.1 - INSIGHTS FURTHER READING

- Frias-Torres S, Montoya-Maya P, Shah N. 2019. Coral Reef Restoration Toolkit: A Field-Oriented Guide Developed in the Seychelles Islands.
- Shaver EC, Courtney CA, West JM, Maynard J, Hein M, Wagner C, Philibotte J, MacGowan P, McLeod I, Boström-Einarsson L, Bucchianeri K, Johnston L, Koss J. 2020. A Manager ’s Guide to Coral Reef Restoration Planning and Design. NOAA Coral Reef Conservation Program. Silver Spring: NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP 36.
- Edwards AJ, Gomez ED. 2007. Reef Restoration Concepts and Guidelines: making sensible management choices in the face of uncertainty. The Coral Reef Targeted Research & Capacity Building for Management Program.
- Edwards AJ. 2010. Reef Rehabilitation Manual. St Lucia, Australia: Coral Reef Targeted Research & Capacity Building for Management Program.


PLANNING
EXECUTION
MONITORING
COMMUNICATION

2.4.1 Planning

Planning a coral reef restoration project requires practical and theoretical skills. While these steps can be applied for any type of project, the guidance provided here is specific to the tenet of asexual coral propagation for coral restoration.

The steps include:
- Baseline assessment of sites suitability for a project
- **Site selection and description**
- Organization of the activities for the construction of the nurseries and the outplantation of the corals
- Involvement of stakeholders
- Definition of goals and objectives (see "Goals of Restoration Programs")
- **Technique selection**
- **Team formation**
- **Budget creation and securing of funding**
- Creation of standard operating procedures
- **Management of permits**
- Development of the monitoring plan (see chapter 4: "Monitoring Protocol")
- Development of the communication strategy.

The main steps highlighted in bold in the list above will be described in more detail in the following paragraphs.

The development and implementation of a monitoring plan are comprehensively discussed within the manual.

Figure 11 - Planning sessions for the management of a project.

2.4.1.1 Site Selection and Description

A coral restoration project is not limited to where the restoration physically occurs (i.e., the restoration site), it also includes the reference and the donor sites. All these sites must be assessed through surveys to establish a baseline and determine any impact, positive or negative.

Restoration site

A restoration site is a site that requires intervention. It is important to emphasize that prime criteria for choosing a restoration site are: a- that a reef must have existed before, and b- that the pressures which caused the degradation must have been either eliminated or reduced to a minimum to facilitate success. Some of the features that help selecting a site are[2,31]:
- Distance from facilities and donor sites
- Presence of consolidated substrate
- Low hydrodynamic conditions and low sedimentation
- Likelihood of no disturbance during critical phases (e.g., recreational anthropogenic activities or exposure to storms and strong currents)
- Size of the area in relation to funds available

Reference sites

Reference sites are used as a proxy to assess the performance of a restoration site comparing it to communities with different conditions.
Ideally there should be two reference sites: a "healthy" site and a "degraded" site.
The **healthy site** is the community that best resembles the conditions prior to degradation[2,31] and represents a long-term reference for the restoration site, especially when historical data are unavailable. The aim is not to replicate the reference site, but rather to use it as guidance to choose the species composition and the density of the outplants.
Reference **degraded sites** represent a way to benchmark the success of a restoration project comparing it to similarly degraded sites where no intervention took place. This could be an area of the reef that is further away from the restored area but presents similar features.

Donor site

A donor site represents the area where coral fragments are collected to stock up nurseries for the restoration project.
Once species have been selected (see BOX 2.2. "Technical advice - Species Selection") and the number of fragments needed has been estimated, the next step is to locate potential sources of outplant material, i.e., the donor sites. These sites should be close enough to the restoration site to allow the corals to be transported in good health.

Fragments could be pruned from colonies and/or could derive from "corals of opportunity" (natural fragments found on the reef that have a poor chance of survival) or collected from areas destined to be dredged or reclaimed. In case of pruning methods, it is important to assess how much source material can be collected from an alive coral without causing significant damage to the donor colonies (see BOX 2.3. "Technical Advice - Fragment Sourcing").

A donor site could be a site of its own unless coral fragments are obtained from the healthy reference site. In this latter case donor colonies that are pruned should lie outside the ecosystem monitoring area and should be tagged to be regularly monitored. The choice of donor sites therefore depends on many variables, not fully discussed here, which should all be considered during the planning process (for some references see BOX 2.1. "Insights – Further Reading").

BOX 2.2 - TECHNICAL ADVICE SPECIES SELECTION

Monitoring the abundance and diversity of species is one of the first steps of a restoration project as it provides key information useful during planning. The use of historical data might not always be possible and therefore a reference site often becomes the best proxy. Baseline data on the sites should be collected from the beginning of the project as they influence the choice of techniques, materials, and strategies to be implemented.

Although the majority of current projects focuses on fast growing species[32], these might show immediate results at the expenses of a more diverse and resilient community. It is, therefore, always suggested to outplant as many species as possible. Each coral has its own role on the reef: fast growing branching species (e.g., acroporids and pocilloporids) can act as "engineering species" as they quickly generate a three-dimensional environment and provide shelter for other organisms.

Massive and sub-massive framework builders (e.g., poritids and faviids - now merulinids) tend to be slower growing but also less susceptible to bleaching[2].

Some important questions during the planning phase are:

- What are the different species and what is their relative abundance in the area?
- What are the coral conditions, survival, and growth rate of the different species?
- Do we know what coral gardening techniques are the most successful with the species and habitat we are working with?

BOX 2.3 - TECHNICAL ADVICE FRAGMENT SOURCING

Corals might be obtained from different sources: they could be rescued from areas destined to be impacted by development (e.g., land reclamation, dredging or constructions), corals of opportunity (found already fragmented on the reef) or pruned from colonies.
Whenever collecting fragments for projects, practitioners should ensure minimal damages to donor sites and colonies and swift transportation to the nursery sites.
As scars constitute a possible point of entrance for diseases[64] (see BOX 3.6 "Technical advice - Predation and Diseases"), it is recommended to reduce the lesions on donor colonies by fragmenting them in as few points as possible and then creating nubbins (Fig. 50).

In the case of slow growing species, which are difficult to fragment, it has also been suggested to either collect fragments from protruding areas (never the core) or to rather collect an entire colony and then compensate for its loss with some outplant in the donor site[31]. To have an idea of the suitability of the area in terms of species abundance, we should keep in mind that it is suggested to prune from alive corals no more than 10% of the colony to avoid irreversible damages to the donor colony[31].
A further consideration is to be made regarding genetic diversity. In order to maintain adaptive variation and avoid inbreeding, it is suggested to collect fragments from different genets (see BOX 3.7 "Technical advice - Genotype diversity").

Corals of opportunity could be chosen from various locations and source material might vary from fragments to entire colonies. Practitioners should perform surveys to estimate the availability of fragments.
Experience suggests that the source sites should be no more than 30–60 minutes away by boat unless special facilities are available to hold the corals during transportation.

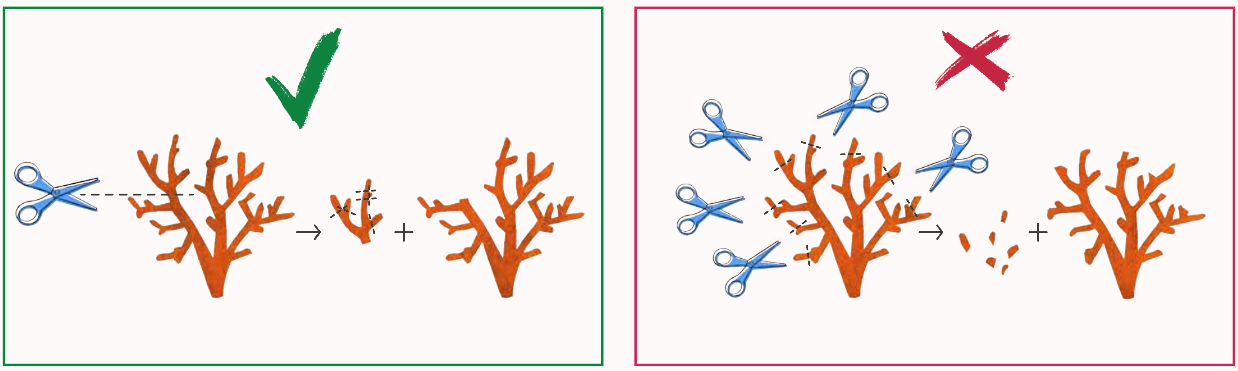


Figure 12 - Suggested vs. non-suggested way of pruning donor coral colonies. The first method leaves only one scar to the donor colony and thus decreases the chance of a decrease in health conditions. By contrast, the non-suggested method may increase the susceptibility to disease.

Figure 13 - Fragment collection from a donor site. Similar sites might provide numerous fragments of "opportunity".

2.4.1.2 Technique Selection

As coral restoration is a discipline in development, there are regularly new techniques being experimented and producing interesting results.
Below some of the most common coral reef restoration methods are briefly described (adapted from Boström-Einarsson et al. 2020[32]).

Coral gardening

Coral gardening is the most common technique used worldwide. The concept of coral gardening introduced by Rinkevich[33] represented a breakthrough in coral reef restoration by adapting the theory of silviculture to corals. It is a two-step method using ex-situ or in-situ nurseries (BOX 2.4. "Insights – Nurseries) to grow fragments in sheltered favourable conditions until they are ready to be outplanted on degraded reefs. This technique allows the production of a larger number of colonies using smaller fragments and therefore it becomes an applicable methodology at larger scales, whilst also reducing the damages to wild colonies.

Direct transplantation

Direct transplantation occurs when parts or whole colonies, or micro-fragments are directly secured to the reef substrate without an intermediate phase.

Substrate stabilisation

Substrate stabilisation is applied in conditions where the substrate is so damaged that it is impossible for corals and recruits to grow naturally. The most common technique is cur-

BOX 2.4 - INSIGHTS NURSERIES

Nurseries allow for the growth of coral fragments in an environment which presents enhanced or even ideal conditions compared to the natural environment.
Nurseries can be generally grouped into two major categories: ex-situ nurseries and in-situ nurseries.
Ex-situ nurseries are increasing in popularity as they offer the opportunity of controlling the environmental parameters and the interactions (including positive ones) with other organisms, increasing genetic diversity (through sexual reproduction and larval rearing) and/or coral survival when working with slow-growing species.
Ex-situ nurseries sometimes represent the first step of a restoration programme, followed by in-situ nurseries or in some cases by direct transplantation.
In-situ nurseries have been used for large-scale coral restoration as they have shown enhanced growth and survival of the nubbins[32,152,153].
For the purpose of this monitoring protocol, we will be considering as nurseries only those structures that are used to temporarily host corals until they reach a size suitable for outplant.

›› Next page: Figure 14

Figure 14 A - Table nurseries, 14 B - Direct transplantation, 14 C - Mid-water rope nursery, 14 D - Substrate stabilisation through “spiders”.

rently represented by the use of modular ‘spiders’[34] which help to stabilise the rubble unlike randomly shaped iron frames which are generally used in artificial reefs (see BOX 2.5. “Insights – Iron Frames”). This technique is considered “direct transplantation" as the structures permanently host corals.

Novel techniques

Amongst the research currently being conducted around the world, we find experiments on larval rearing, reef seeding, 3D printing, rubble consolidation, coral-carpets and so on.

BOX 2.5 - INSIGHTS IRON FRAMES

Coral frames are iron structures of various shapes commonly used in the Maldives as artificial substrate to permanently host corals. In some cases, the frames are used as source of corals for the replication and maintenance of the projects. Frames are often coated with sand to favour the self-attachment of corals after being artificially secured for the first period of time; the structures are generally placed on a sandy or rubble substrate. Unlike coral spiders, whose role of rubble and substrate stabilization has been studied[34], iron frames are created with the purpose of providing a safe and stable environment (i.e., away from rubble and sand) for corals to permanently grow. They often create reefs in places where they were not naturally occurring to achieve aesthetic and educational purposes. We consider therefore iron frames as artificial reefs.

Figure 15 - Iron frames used for artificial reefs.

2.4.1.3
Team Formation

Coral reef restoration projects require several skills often complemented by the different team members. Along with theoretical expertise which might have been acquired through academic courses, team members should have some practical skills [31,35].

They should be able to:
- plan all the steps of the projects
- timely source materials and equipment
- secure funds
- adapt to alternative solutions and challenging situations
- possess good technical and in-water skills
- create accessible databases with sharable data
- understand and analyse data
- analyse the effects of the project within the socio-economic sphere
- involve stakeholders and communicate with them using a scientific language with the technical audience and an informal one with everyone else
- produce reports and documents to communicate and keep track of results

Figure 16 - assessment of each member's in-water skills

2.4.1.4
Budget Creation and Securing of Funding

An important process in coral restoration is the long-term financial viability for the execution and monitoring of the activity as reduced availability of funds has appeared to be one of the major reasons for projects' interruption or short-term monitoring [27,36]. Currently, cost estimates within the Maldives are ambiguous and difficult to account for. However, regular monitoring of the projects and shared information regarding performance, financial viability and success of new start-ups may increase in the future producing cost reductions to manage and maximise results.

Many projects in the Maldives have been sponsored by the tourism industry with visitors supporting a certain activity with financial contributions (e.g., acquiring a frame or a line, sponsoring the restoration of a certain amount of sqm of reef, adopting a coral), whilst in other countries a major contribution derives by "volunteers" paying to join a project in exchange of field-experience and training [37]. Several financial aids from governments, research institutions and the private sector have been put in place around the world to fund a variety of projects.

Depending on the project and the location, some costs might be in-kind or provided free of charge, whilst in other situations funding should account for SCUBA gear, boat rentals, accommodations, transfers, and consultancy of experts. A comprehensive budget list should be drafted during the proposal. Funding must be allocated to include costs to obtain a permit for coral reef restoration project (when necessary) and to ensure its long-term maintenance and monitoring (See BOX 3.12 "Technical Advice – Cost Analysis").

2.4.1.5
Management of Permits

Currently there is a lack of laws that specifically regulate the undertaking of coral restoration activities; however, the pursuit of the restoration and rehabilitation can fall under multiple other regulations.

Nowadays, these activities can fall under the purview of EIA (2012/R-27), Marine Research (2013/R-34), and Protected Area (2018/R-78) regulations – this list is not exhaustible, exhaustive and situation-based. Depending on the scale, aim, locations and methods of the project, the practitioners pursuing these efforts will be required to lodge permits with the relevant government bodies before the beginning of the activity. The Government and administrative bodies that may be responsible for such authorisations are the Ministry of Fisheries, Marine Resources and Agriculture for research permits, the Environmental Protection Agency for EIA and related permits, and the Local Councils (Island/Atoll) which can guide on what permits may be required and receive approvals on specific locations of the project.

2.4.2
Execution

After the development of a strategic plan, the following step is its execution.

The execution of a project occurs over a period of time that could span several years during which projects are regularly assessed, techniques may be adjusted, and nurseries scaled up.

While within this phase the team members play a significant role, involvement of multiple stakeholders could contribute to the expansion of the project, so as to enhance a conservation mindset and the long-term sustainability of the project.

The main component of the execution phase involves the implementation of planned ideas at the right times. Execution sched-

Figure 17 - Placing of coral fragments in a rope nursery.

ules should also consider environmental factors such as avoiding rough weather for certain activities, taking corrective measures, and eventually even halting activities during stressful periods.

Adjustments, delays, and last-minute changes to the plans are quite common and must be accounted for.

The outplantation of nursery-grown or collected corals should be carefully planned to implement the chosen techniques through the standards established and then monitored to assess the long-term results.
Monitoring should begin even before the beginning of the project as highlighted below.

2.4.3 Monitoring

> "The science of restoration requires two basic tools: the ability to manipulate ecosystems to recreate a desired community and the ability to evaluate whether the manipulations have produced the desired change"[1].

The success and effectiveness of restoration projects can only be assessed through exhaustive baseline studies and the regular monitoring of nurseries, coral outplants, and sites.

Monitoring begins before any "restoration" activity by conducting baseline surveys which will determine the feasibility of the project and will be the starting point to track efforts. After the definition of the project goals and objectives, it is important to start collecting a series of data to assess the success of the project.
Once a project starts, though often the main focus will be on the performance of the techniques (e.g., tracking the fate of corals, suitability of methods chosen), it is extremely important to plan the long-term monitoring for the evaluation of effects on the ecosystem[38–41] in line with the chosen goals.

This can be achieved through regular assessment of project sites. E.g., the goals "increasing the complexity of a reef" or " restoring a healthy fish community" both require a starting point to assess changes over time.

Since changes to the biological community should be expected to occur in medium term (<5 years) and long term (>5 years)[42,43], it is strongly recommended to allocate time, effort, and funds for extended and repeated monitoring.

Monitoring is comprehensively described and discussed in the following sections within this manual.

Figure 18 - Assessment of coral growth. through Vernier calipers.

2.4.4 Communication

Communication is a key component of the projects as it enables practitioners to disseminate vital information to partners and the public. Engagement with stakeholders can create stewardship, ownership, and secure funds while the regular sharing of achievements can increase the life of a project in the long-term [44]. Reports should be accessible to both scientific and non-scientific audiences , with the latter requiring a more visual communication and different media to convey goals, objectives, as well as progress and current results.

2.4.5 Project Timeline

Every project should include a guideline to assist in the planning, implementation, and assessment of a project's effectiveness.

The figure below illustrates an example of a timeline that broadly accounts for multiple steps within a project and can be adjusted on a project basis depending on the needs of the project and of those implementing it.

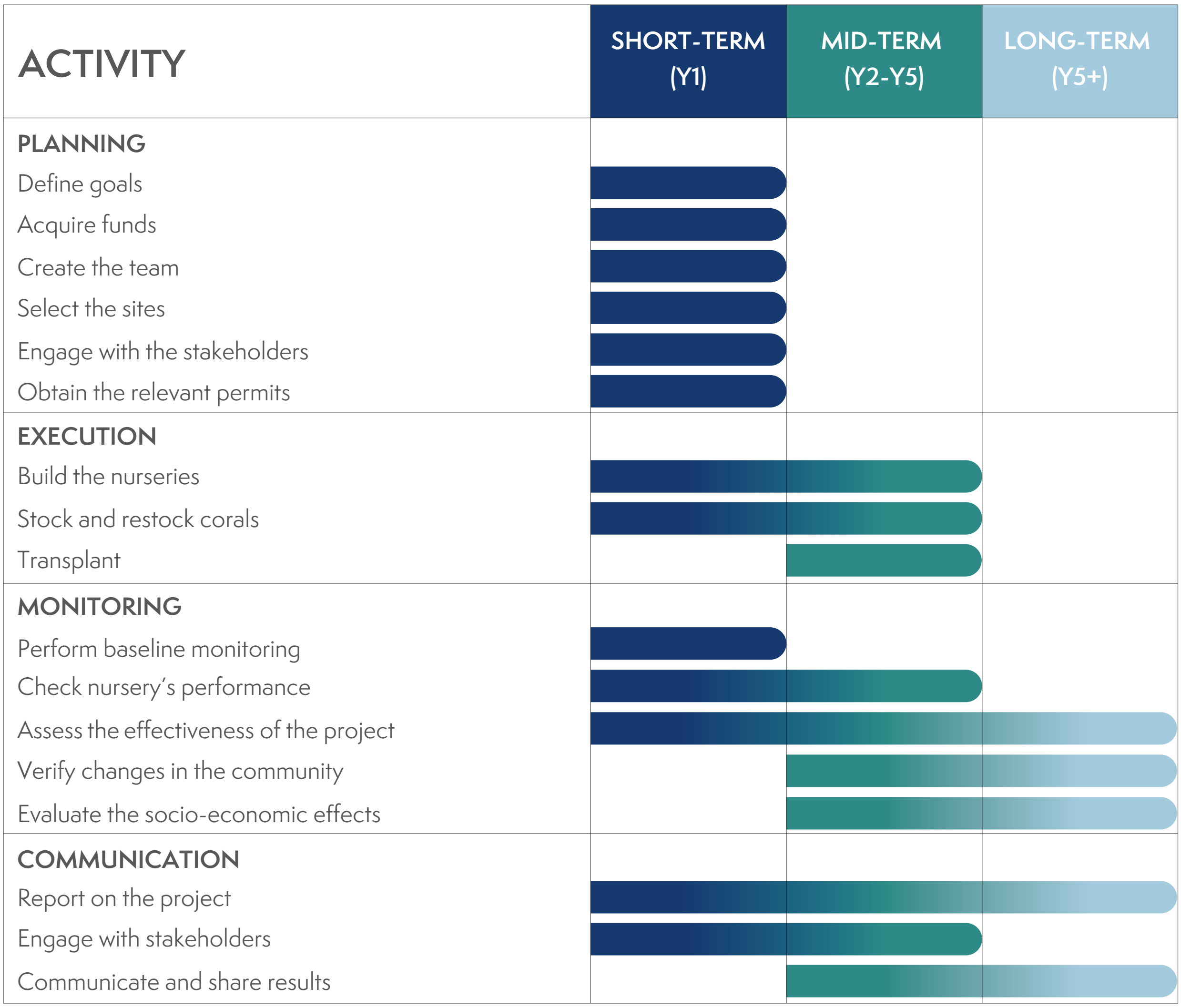


Figure 19 - Project timeline.

›› Next chapter:
3. MONITORING

3. MONITORING

Figure 20 - Monitoring of a coral nursery.

The need to conduct baseline surveys is emphasized throughout the manual to ensure the feasibility of the projects and to obtain key information to track results. Monitoring should apply to all phases and sites of a project: donor site, reference sites, nurseries (ex-situ and in-situ) and restoration site. Currently, most restoration programs monitor only few ecological factors, often limited to coral growth and survival of fragments for the first year[45]. However, evaluation of recent efforts have made it clear that projects' success should account for both ecological and sociocultural-economic factors over longer timescales.

3.1 Project Specifics

Each project will have some features which influence its performance and characterise the project. These include:

- the source of fragments (i.e., corals of opportunity or pruned from wild or reared colonies),
- the technique chosen for the nursery (e.g., trees, mid-water rope nursery)
- the material and the media used to secure corals and fragments
- the number and density of corals outplanted
- the depth where activities are carried out
- the location of the project and the different sites
- the environmental aspects (e.g., current, time of the year, weather)
- the size of the restored area (see BOX 3.1. "Technical Advice – Ecological Footprint").

BOX 3.1 - TECHNICAL ADVICE ECOLOGICAL FOOTPRINT

An important consideration should be made on the size of the restoration area as this represents a measurable way to assess the scale of intervention. The need to include this information derives from the different methodologies and coral densities used while outplanting, which create very unique communities and results.

Although 4-8 colonies per square meter is a commonly suggested density of outplants[31], this may vary according to the goal/s of the project and the techniques used. Some projects occurring on denuded reefs with unconsolidated substrate (for example after the construction of an infrastructure) might use artificial structures that need a denser outplant design to both cover the structures and be cost-effective.

The ecological footprint, in combination with density, growth forms and size-frequency distribution of the corals has been considered a tool to provide an idea of the extension and the type of reef likely to result from the efforts[48].

Moreover, reefs are expected to naturally change over time. As a result of a storms, branching species might naturally fragment, creating new colonies even in a relatively short period of time, potentially increasing the size of the restored area.

To assess the extension of the restored area (ecological footprint), we recommend following the same criteria established for the Caribbean by Goergen *et al.*[48]. This approach will allow consistency of basic data across the globe.

The ecological footprint is the areal sum of restored plots. A single plot is considered to be each zone where corals are less than or around 2 meters apart from each other. When there are more than 2 meters between 2 outplanted colonies, the areas should be considered as two unique plots. The ecological footprint is then the areal sum of all plots which are no more than 10 meters away from each other or which are not separated by an unsuitable habitat (e.g., a physical barrier, a seagrasses patch, or a sandy groove between two spurs). The different plots should be connected by the shortest boundary. A project might comprise several ecological footprints.

The margins of each area could be georeferenced (e.g., with temporary surface buoys to identify the GPS coordinates) and ideally even visually marked underwater (e.g., with small floats) to allow for detection of changes over time.

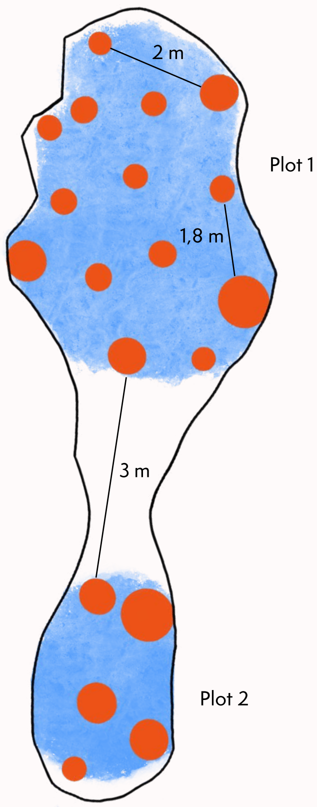


Figure 21 - Visual rapresentation of the Ecological Footprint.

3.2
Ecological Monitoring: Indicators, Tools, and Procedures

Within this protocol, the term "**indicator**" will be used for key variables which are used to detect changes and assess the evolution of a system[46]. The term "**parameter**" will instead refer to the different measures of an indicator. For example: temperature, light conditions, sedimentation are some of the parameters used to assess the indicator "Environmental conditions".

From an ecological perspective, indicators should range from those related to water quality (paramount in areas where degrading conditions might be a limiting factor if not removed), to those related to the development of nubbins and outplants, to those allowing the evaluation of the responses of the community to the enhancement of the coral population.

The protocol offers a set of '**mandatory**' indicators and '**discretionary**' indicators, all of them monitored depending on time availability, goals of the projects and skills of the surveyors. Whenever possible, each indicator presents two level of complexity in terms of data collection: **simple** and **advanced** expertise.

Indicators and parameters are mandatory and discretionary relatively to the different phases e.g., water chemistry is mandatory in ex-situ nurseries but discretionary in in-situ nurseries and the following phases/sites (see chapter 4 "Monitoring Protocol").

Mandatory indicators are selected to achieve the common goal of having basic sharable data and comparable results in different locations to understand the cumulative impact of the projects on a regional scale. The discretionary indicators, despite not being mandatory, are important measures, especially in the long-term, to assess the effectiveness of a project from an ecosystem perspective and offer a more comprehensive evaluation (see BOX 3.2. "Recommendations – Adaptive Monitoring").

This manual recommends that all the procedures, codes and methods should be recorded while working under the assumption that data should be available and easily accessible in the long-term as it is extremely important to retain information on the corals, techniques, and procedures throughout the monitoring programme.

The indicators and associated parameters are listed below along with the tools and procedures required for their assessment. Common tools for general monitoring are not listed for each section but include diving equipment, UW slates and pencils, UW paper (if needed). The manual provides examples of datasheets which are key tools for an effective monitoring.

BOX 3.2 - RECOMMENDATIONS ADAPTIVE MONITORING

Despite careful and precise planning, the occurrence of events which suddenly change the conditions of a reef might require adjustments of in the plans which should be dealt with.

During these sudden events practitioners might decide to use several additional monitoring indicators, which are not part of the regular plan, and schedule tighter monitoring intervals to be able to capture changes as they occur.

These situations might require shifting efforts from restoration activities to monitoring activities or temporarily focus all the efforts into minimizing the damages to nurseries.

On the other hand, sudden events such as ship groundings and storms might require a temporary concentration of energies on restoration (direct transplantation of broken colonies), maintenance (securing of structures and nubbins) and in some cases even stabilization of the substrate[152].

Adaptive management allows therefore to concentrate efforts from monitoring to restoring and vice versa depending on the needs, whilst at the same time not compromising the main plans.

3.2.1
Survival

Coral survival is probably the most important component of a coral restoration project.

Survival indicates the performance of the corals and the corrective measures to be adopted in order to ensure the effectiveness of the project, whether through changing techniques or materials, removing diseased fragments or making a more comprehensive analysis of possible mortality causes.

This indicator also grants that fragments are restocked, when necessary, within a nursery to ensure maximum yield from a structure.

Survival of nubbins and outplants might be linked to different reasons and evaluation and exclusion of mortality causes is fundamental for the success of nurseries and generation of nubbins.

The analysis of survival, expanded to the degree of live tissue, and associated to distinct causes, allows practitioners to allocate resources towards vital phases of the restoration.

Figure 22 - Dead coral colony.

Figure 23 - Alive coral colony.

PROCEDURES

Survival is measured through **the use of UW cameras and visual observation** of selected nursery fragments at least as a binary condition (alive vs. dead). A coral is considered alive until all the tissue has been lost.

Further details (advanced method) can be provided on the percentage of live tissue by using categories (see Table 1). The advanced method provides the degree of "aliveness" of fragments in addition to survival.

Figure 24 - Example of coral colony showing 1-25% alive tissue. The same colony is considered "alive" in the simple survey.

EXPERTISE		
SIMPLE	ADVANCED	
Dead Alive	0%	alive tissue (dead)
	1–25%	alive tissue
	26–50%	alive tissue
	51–75%	alive tissue
	76–99%	alive tissue
	100%	alive tissue (alive)

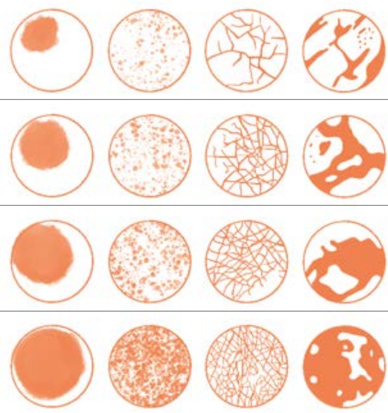


Table 1 - Level of complexity for monitoring of 'survival'. Advanced method based on a readaptation of the classes proposed by Berzins et al. [47]) and those used by NOAA in the Caribbean [48].

Figure 25 - Examples of equal percentages of alive tissue. The drawings represent the upper limit of the range.

3.2.2
Growth

One of the aims of nurseries is to speed up the growth of coral fragments which is species-specific [49]. There is limited data on growth within nurseries for corals specific to the Maldives [50] which can make it hard to set objectives and plan activities, two critical aspects in the management of restoration projects. During the initial phases, corals use a lot of energy to heal their wounds or attach to the substrate which might reduce the colony growth [51,52] and make them vulnerable during this critical stage [53,54].

The growth is estimated through the use of **Vernier callipers and/or UW cameras** calculating the area or the "Ecological Volume" [EV] over time, which represents an approximation for the growth of a colony of irregular shape and is an indicator of the structural complexity of the coral community [55].

The "Ecological Volume" is considered to be the space the space occupied by the coral colony and, in the case of branching forms, it includes the water volume between and below the branches [56]. Depending on the growth of the colony this can be estimated as the volume of a cylinder or a half sphere [55].

The analysis of coral growth can be conducted also on a sample of the colonies within the reference sites.

BOX 3.3 - TECHNICAL ADVICE DIGITAL MONITORING
(Photomosaics, images and image processing)

It is possible to perform certain measurements (e.g., corals' growth and fate, the project area) through digital assessments by taking pictures which will be later processed in the office. To be able to obtain comparable results with analogic measurements, several pictures for each colony might need to be taken, often with the use of reference markers for sizing. Digital photos are later analysed through software like ImageJ [154] or CPCe [155] which allow the extrapolation of data and measurement that can even be more precise than estimation through analogous shapes [156].

In recent times, the use of digital techniques such as photomosaics have become a very common to analyse sites.

Although this methodology requires an investment in capacity building and tools (e.g., cameras, computers, software), it provides a long-term visual reference of the status of the reefs through time, and it also allows rapid-assessments of large-scale projects reducing the need for in-water hours.

The explanation of the execution of photomosaics lies outside the purpose of this manual, but it is highly encouraged as photomosaics have shown to provide images detailed enough for benthic assessments [157]. For further information the Reef Resilience Network has produced a webinar on the topic (https://reefresilience.org/photomosaics-as-a-tool-for-monitoring-coral-restoration-success/).

Figure 26 - Photomosaics on an area restored through spiders.

PROCEDURES

Depending on the growth forms of the corals, measurements will be carried out by area (table corals or nubbins) or by ecological volume (branching and massive colonies). Measurements are linear extensions and can be taken with Vernier callipers or images, however the methodology should be specified (see BOX.3.3. "Technical advice – Digital monitoring").

Growth should be calculated through the Ecological Volume when corals exhibit a three dimensionality.

Ecological volume is calculated with the following formulas:

CYLINDER → $EV=\pi r^2 h$

HALF SPHERE → $EV= 4/6\pi r^3$

Where 'h' is the longest dimension and 'r'= (w+l)/4 with 'w' being the width perpendicular to the height and 'l' the length perpendicular to both height and width (see Fig. 28-29).

In the ex-situ phase, it may be more appropriate to use the Area instead of EV for massive, encrusting, and tabular colonies. The area should be approximated to the most similar shape:

CIRCLE → $Area = \pi r^2$

ELLIPSE → $Area = \pi ab$

(with r being the radius, a and b being the two axis calculated from the centre of the shape, and π the constant pi=3.14159).

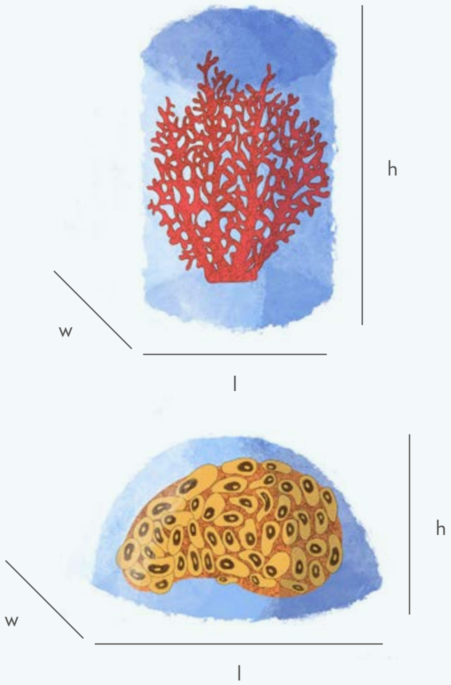


Figure 27 - How to measure a coral nubbin.

Figure 28 - EV Measurement of a coral nubbin (height).

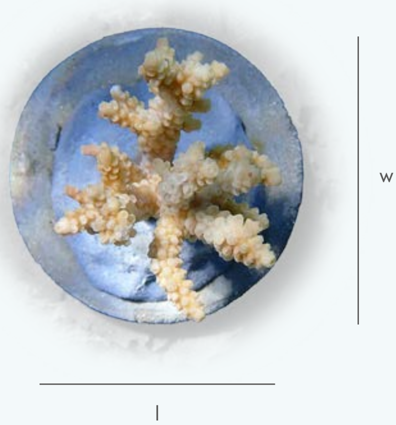


Figure 29 - EV Measurements of a coral nubbin (width and lenght).

Figure 30 - Growth measured with Area for a bidimensional nubbin.

3.2.3 Health Conditions

This indicator provides information on how the fragments and outplants are doing and provide guidance for corrective measures. It can be extended to colonies within the reference sites to allow for statistical analysis. Many different factors may cause stress in corals, e.g. physical damages from debris [57], predation, snorkelers and divers, and pollution from chemicals and nutrients [39,58,59] which result in coloration changes or diseases [60,61]. Although not all the diseases have a known pathogen, it is known that in some cases they have caused high mortality due to rapid distribution, high prevalence or high virulence [62] (e.g., see BOX 3.4 "Insights – Stony coral tissue loss disease"). Hence timely identification of a disease within a nursery is critical to a project's success.

Predators have been reported to have several effects on corals: they can cause direct complete or partial mortality of colonies [63], be the vector of a disease or even open up the way to infections through the lesions [64].

Common predators in the Maldives include the gastropod *Drupella* spp. and the echinoderms *Acanthaster planci* and *Culcita* sp. (see "Associated fauna", and "Non-associated fauna" and BOX 3.6. "Technical advice – Disease and predation") which leave characteristic marks on colonies.

Whereas the identification of a coral disease requires specialised training [65], its manifestation or the effects of unspecified stress result in changes in the usual coloration or patterns which can be easily identified. This indicator may alert practitioners of the need to introduce adaptive measures e.g., to avoid diffusion of the disease through removal of infected fragments [31] or the removal of predators, thus ensuring a successful management of nurseries.

PROCEDURES

Health conditions are **analysed visually and with the use of UW cameras** through several physical parameters that can be identified on the corals:

- Coral bleaching
- Signs of stress
- Predation
- Physical damages

In terms of loss of **coloration**, a distinction should be made between 'pale' corals and 'bleached' corals with the first one showing an 'evident loss of colouration, but not white' and the latter 'being stark white with no obvious pigmentation and possible tinge of iridescent colours' [66,67]. Since the determination of coloration state has been considered to be partly biased by the surveyor's experience and personal opinion [68], in case of doubt, the **use of Coral Watch cards** [68,69] through time allows a more reliable collection of data (see BOX 3.5. "Technical Advice – Coral Bleaching").

The presence of **signs of stress** in corals can be assessed following a standardised procedure [65], which depending on the level of expertise, allows for the basic identification of the presence of stress or even the identification of the disease. (see BOX 3.6. "Technical Advice – Disease and Predation").

Figure 31 - Coral Bleaching assessment with Coral Watch cards.

The presence of a **physical damage** on the fragment (e.g., lack of parts, smothered surface) should be recorded with specific information on the type and dimension of the physical damage when possible.

Figure 32 - The table coral in the center of the photo (*Acropora* sp.) is considered "pale".

Figure 33 - Bleached coral.

» Next page: Procedures

The damages inflicted to corals by **predators** can be identified even in the absence of predators by looking at the scars ([65]) or by spotting the organism, although in some situations it might not be possible to determine the cause of the injury.

A basic level of data collection and a more advanced one are presented below. A combination of both can be used (see Table 2).

PARAMETER	EXPERTISE	
	SIMPLE	ADVANCED
Coral bleaching	OK, Pale, Bleached	OK, Colour code (Coralwatch), Bleached
Signs of stress	Presence / Absence	**Type of lesion** (tissue loss, discoloration, growth anomaly) **Lesion description** (Host affected; acute / sub-acute / chronic; Focal / multi-focal/ coalescing; location on colony; lesion margin) **Disease nomenclature**
Predation	Presence / Absence	Predator name and scar size
Physical damage	Presence / Absence	Type of debris and effects

Table 2 - Parameters and level of complexity for monitoring of 'Health conditions'.

BOX 3.4 - INSIGHTS
STONY CORAL TISSUE LOSS DISEASE

Stony Coral Tissue Loss Disease (SCTLD) is a disease first reported in Florida in 2014 which affects over 20 species of corals in the region and spreads quickly, has high prevalence and causes rapid mortality of colonies. Since the first report, the disease, which cause is yet unknown, has spread across the Caribbean. In Florida 66% of the colonies surveyed were infected (aggra.com) and the disease has caused a reduction in coral density by 30% and a loss of tissue by 60% [161] even within coral restoration programmes [162]. Treatments are being experimented and implemented to preserve vulnerable species and sites, yet the disease is rapidly spreading.

Figure 34 - Stony Coral Tissue Loss disease.

BOX 3.5 - TECHNICAL ADVICE
CORAL BLEACHING

Coloration of corals is generally evaluated through visual assessment as a sign of stress in colonies. The term "Pale" refers to corals showing an 'evident loss of colouration, but not white' and the term "Bleached" refers to corals 'being stark white with no obvious pigmentation and possible tinge of iridescent colours' [66,67]. Bleached corals have their tissue, whilst "recently killed corals" do not. Since the determination of coloration might be subjective, we recommend the use of Coral Watch cards [68,69] through time as it allows a more reliable collection of data.

BOX 3.6 - TECHNICAL ADVICE
DISEASE AND PREDATION

Coral disease outbreaks have become a major threat to coral reefs and may couple with other stressors causing large coral loss and changes in the community structure and composition. Since the first report of coral disease in the Maldives [20] five disease have been found in the region [158,159]. Key to effective management is an early detection of the disease; here we offer a tool edited from Beeden *et al.*[65] to help with the task.

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PREDATION

- **Crown Of Thorns Starfish - COTS** *(Acanthaster planci)* are up to 80 cm in diameter with max 21 arms. They leave scars with scalloped borders on table corals, often corals strings of tissue and mucus.

Figure 35 - *Acanthaster planci* juvenile.

Figure 36 - Adult *Acanthaster planci*.

- **Drupella** *(Drupella cornus)* are up to 40 mm, between pink and red in colour and often found in large numbers. They leave scars with irregular borders and strings of tissue. Scars tend to be from the base upward.

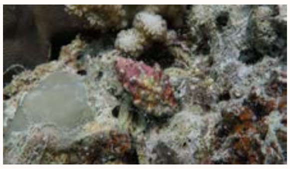

Figure 37 - *Drupella* sp.

Figure 38 - Signs of *Drupella* sp. predation on an *Acropora muricata* colony.

- **Pin-cushion starfish** (*Culcita* sp.) measure up to 30 cm in diameter and tend to have a pentagonal shape and various colours. They feed on coral tissue by everting their stomach and not impacting the skeleton.

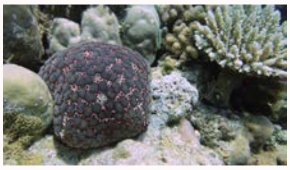

Figure 39 - Pin cushion starfish (*Culcita* sp.).

Figure 40 - Pin cushion starfish (*Culcita* sp.) next to coral colonies showing signs of predation.

- *Terpios hoshinota* [160]. It is an encrusting cyanobacteria sponge which kills and overgrows alive corals. It can last for years preventing the recruitment of corals.

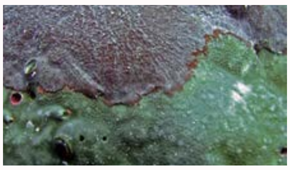

Figure 41 - *Terpios hoshinota*.

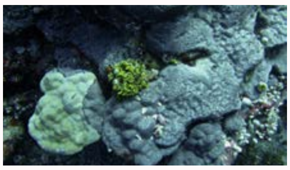

Figure 42 - *Terpios hoshinota*.

DISEASE

- **Skeletal Eroding Band (SEB)**. Recognised by black specks clustered within corallites. Shows exposed skeleton and has a relatively slow rate of progression (~0.6 mm/day)

- **Black Band Disease (BBD)**. Shows a dark band between live tissue and exposed white, not speckled skeleton, at times over live tissue. Rate of progression (-4-8 mm/day on staghorns; ~1-4 mm/day on plates).

- **Brown Band Disease (BrB)**. Brown band between live tissue and white skeleton. Narrow white band may be present between live tissue and brown band. It shows a rapid rate of progression (20-100 mm/day)

Figure 43 - Skeletal eroding band.

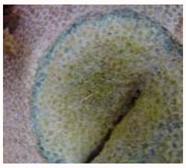

Figure 44 - Black Band Disease.

Figure 45 - Brown Band Disease.

COMMONLY CONFUSED

Some of the causes of damages to corals might be difficult to tell apart, especially without adequate tools and to practitioners who have not been specifically trained. In particular, White syndromes, bleaching, and predation are often confused with each other.

- White syndrome causes fast and extended tissue loss (≤20 mm/day) whilst Ulcerative White Spots presents small spots (≤1 cm of diameter)

- Bleaching is distinguished by the presence of tissue

- Predation might cause lesions to the skeleton and predators tend to be nearby

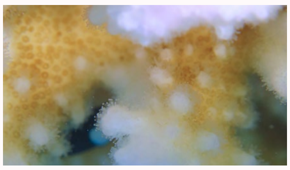

Figure 46 - First signs of bleaching.

Figure 47 - Damselfish bites on an *Acropora muricata* coral.

3.2.4
Self-attachment

Self-attachment is the time required by each fragment to grow tissue over the substrate and attach itself partially or fully to it[70,71].

It ensures the survival of corals, even with rough weather or strong currents[72,73].

Nubbins within nursery are generally placed on artificial substrates[74] and attached either mechanically or with chemical substances thus allowing them to be stable and to grow[75,76]. Knowing and predicting the time required by the nubbin to self-attach has some practical implications. This allows practitioners to:

- understand the time needed for stabilization during which corals should be handled with particular care (e.g., if in needs of cleaning from fouling organisms, or whether positive organisms need to be added for assisted algae removal)
- plan outplantation to avoid particularly stormy seasons[71].
- use biodegradable substances which should not degrade before corals have stabilised.

Depending on the coral species and conditions, self-attachment of the coral nubbins has been recorded to be vary variable (from few days to 24 weeks)[76–79].
During this delicate period, it is recommended to conduct close surveys to proceed with timely interventions of re-attachment should detachment occur.

PROCEDURES

This indicator should be **analysed visually and with the use of UW cameras** considering the total time required by the corals to attach completely. Coral fragments should be visually inspected to assess the moment when the tissue starts growing over the substrate or the media used to secure them. As for the other indicators a set number of nubbins/colonies per species might be chosen. Observations should be made with different intervals according to the phase.

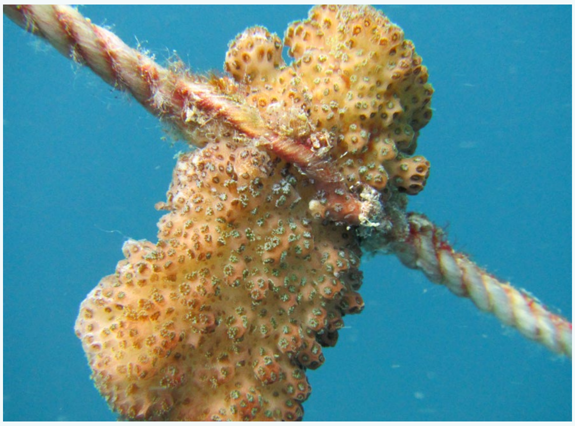

Figure 48 A - No attachment.

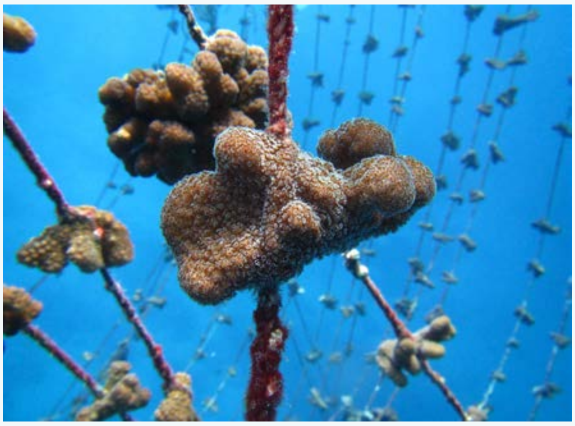

Figure 48 B - Full attachment on a rope nursery.

Figure 48 C - Full attachment on a 'spider'.

3.2.5 Genotype

Genetic diversity is considered a driver of resilience[80]. A "genet" is defined as a single colony or several ramets (fragments) of the same colony which derive from sexual reproduction.
(see BOX 3.7. "Technical advice – Genotype Diversity")
Genotypic diversity therefore depends on the number of different genets, whilst genetic diversity depends on the variation between genets[81]. To ensure genetic diversity, it is important to ensure that projects are planned to use as many genotypes per species as possible[81].

Generally, it is not recommended to collect fragments from reared colonies to avoid outplanting several generations of the same genotype, yet in case of particularly vulnerable donor sites or species, this procedure can be envisaged.

PROCEDURES

Since genetic analyses are costly and require specialized facilities, it is common practice to use geographical distance as a proxy for genetic differences[81]. In the absence of genetic analysis for the Maldives we will consider as different genets corals collected at least 5m apart from each other[81] calculated with **UW measuring tapes**.

For each hypothetical source genotype, the location (if possible, with **GPS** coordinates) and species/genus of the donor colony should be documented. This information should be retained from the collection phase throughout the project when fragments are added to the nursery or whenever these are re-fragmented. Donor corals can be tagged and genetical diversity will be estimated by measuring the distance between genets through waterproof measuring tapes.

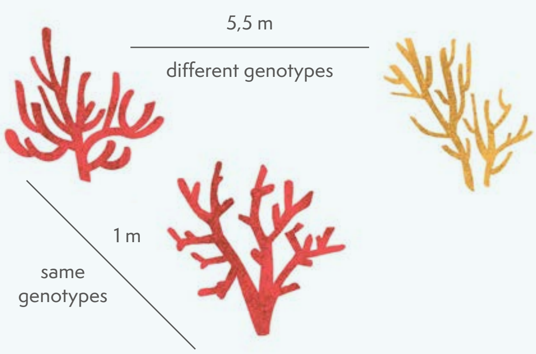

Figure 49 - Genotypes defined through geographical distance.

BOX 3.7 - TECHNICAL ADVICE GENOTYPE DIVERSITY

Considering the costs connected to genetic analysis and the different reproductive methods of corals (sexual and asexual by fragmentation), geographical distance is often used as a proxy for genotype diversity. According to the different species and their frequency of fragmentation, clonemates have been found at different distances from the parent colony. Currently there are different and equally accepted recommendations to ensure genotypic diversity in the absence of genetic analysis based on the geographical distance:

- collecting ramets from 3 to 6 colonies per patch with morphological differences and at least 5m apart[81]
- propagate 20-25 genets for each species in the nursery[81]
- using no more than 10% of each coral colony to reduce the number of propagated clonemates[31,36]
- using fragments of opportunity[36]
- collecting from donor colonies at least 100m apart to ensure the likelihood of having different genotypes[48,163]
- collect corals from at least 35 spaced colonies to retain over 90% of the genetic diversity[164]
- use at least 5 unique genets per species at each restoration site[48]
- use at least 20 different genotypes within nurseries to ensure genetic diversity[48]
- collect corals more than 7 m apart to avoid clonemates[163]
- collect corals 100 m apart to avoid inbreeding of colonies and increase genetic diversity[165]

›› Next page:
3.2.6 Reproductive Capacity

3.2.6
Reproductive Capacity

Reproductive capacity might be dependent on fragment size [82]. It is also possible that coral relocate energy from reproduction to self-attachment, and survival once outplanted on the reef. In some cases, corals might not release gametes for one to several years after outplantation [82,83]. The knowledge of size maturity and timings of spawning is fundamental in reducing negative impacts on wild coral colonies through a mindful planning of activities to avoid fragments collection during critical moments of their life cycle [82,83].

PROCEDURES

The reproductive capacity will be assessed through a non-invasive method with corals being **visually inspected** to avoid damages to the colonies. Surveyors will install **3 collection cups** for each coral species at each location following the procedure from Horoszowski-Fridman *et al.* [84] for few consecutive days before the new moon and full moon of March and April [85] and October-December based on information from marine biologists working in the Maldives. Given that a qualitative analysis is being conducted (**presence or absence** of gametes or planulae), only a small quantity of material for each coral species can be brought to the lab to study with a **stereomicroscope**, but this is not mandatory.

Figure 50 A - Non-destructive method through collection cups.

Figure 50 B - Visual inspection by breaking fragments.

BOX 3.8 - RECOMMENDATIONS REPRODUCTIVE CAPACITY

Reproductive capacity is generally measured through both invasive and non-invasive methods.

It is known that corals which have undergone a stress (i.e., fragmentation and outplantation) might not reproduce for some time and therefore we recommend the use of non-invasive methods.

The invasive method, which we do not recommend, requires the breakage of the colonies to visually assess the presence of gametes.

A non-invasive method and applicable on a larger scale due its non-damaging nature, consists in placing collecting cups (similar to plankton nets) above a certain number of fragments during the predicted days for reproduction.

We also recommend to visually inspect collection cups for the presence of gametes within one hour from the release to avoid the loss of their viability and release them in the water as soon as possible.

The Reef Resilience website https://reefresilience.org/management-strategies/restoration/coral-populations/larval-propagation/collecting-spawn/ offers an overview of how the process can be carried out.

3.2.7
Benthic Cover

The analysis of the benthic community focuses on sessile benthic organisms which contribute to the formation of the substrate and characterize the community with constant and often long-lasting interactions. In the long-term the spatial distribution of benthic organisms should also shift a more diverse and richer ecosystem e.g., from a bare rocky and algal-dominated environment to a coral-dominated one.
As there are numerous crucial interactions between the various organisms that occupy the benthos, changes in the abundance of benthic categories may provide an indication of whether an ecosystem is recovering from or undergoing stress.

Figure 51 - Benthic surveys.

PROCEDURES

Benthic assessments have been standardized the by the National Coral Reef Monitoring Framework [NCRMF]. Instructions and datasheets are included in the following chapter of this manual. Protocols can follow the Point Intercept Transect [PIT] protocol briefly described below or the Photo Quadrat [PQ] protocol.

Four replicates of PIT, each 20 m long or 20 replicates of PQ in each restoration site and reference sites are used. Sedentary organisms and substrate should be identified every 50 cm using a **waterproof measuring tape** and each transect should be at least 5 m apart from each other. An **UW camera** will allow taking photos, 1m above the substrate and 1 m apart, alternating on either side of the transect line for each transect (20 images per transect) and annotated using an **annotation tool** to assess benthos.

At the time of the first survey, transect lines should be randomly placed. In the restored area the inclusion of outplanted corals should not be forced as these are specifically analysed through other indicators (See above "**Survival**", "**Growth**", "**Health Conditions**").

This indicator collects data both on substrate and organisms and, as for the other indicators, we propose two methodologies, simple and advanced.

<table>
<tr><th colspan="3">EXPERTISE</th></tr>
<tr><th colspan="2">SIMPLE</th><th>ADVANCED</th></tr>
<tr><td rowspan="4">Algae</td><td>Macro algae (> 3cm)</td><td rowspan="10">All the organisms encountered at the highest taxonomic level possible including life conditions</td></tr>
<tr><td>Turf (< 3cm)</td></tr>
<tr><td>Coralline Algae</td></tr>
<tr><td>Halimeda sp.</td></tr>
<tr><td colspan="2">Seagrasses</td></tr>
<tr><td colspan="2">Sponges</td></tr>
<tr><td colspan="2">Tunicates</td></tr>
<tr><td colspan="2">Molluscs (Giant Clam)</td></tr>
<tr><td rowspan="2">Cnidarians</td><td>Hard corals, include:
• Anthozoans of the orders: Scleractinia, Helioporacea, Alcyonacea (only family Tubiporidae)
• Hydrozoans of the families: Milleporidae and Stylasteridae</td></tr>
<tr><td>Soft Corals, include:
• Anthozoans of the orders: Actiniaria, Antipatharia, Alcyoncea (except family Tubiporidae), Corallimorpharia, Zoantharia
• Hydrozoans (sedentary) of all the other families</td></tr>
<tr><td rowspan="3">Substrate</td><td colspan="2">Sand</td></tr>
<tr><td colspan="2">Rock</td></tr>
<tr><td colspan="2">Various rock-rubble granule sizes</td></tr>
<tr><td colspan="3">Other</td></tr>
</table>

Table 3 - Level of expertise for Benthic Cover utilising the PIT survey.

3.2.8
Fishes Community

With restoration it is expected that the additional habitat provided and the increase in refuge and food should have an impact on the abundance and diversity of reef fish [86–91].

Furthermore, fishes can have positive, negative, or indirect interactions with corals and the whole reef community, which are important to monitor. For example, herbivores influence the resilience of the reef[92–94] or impact the reef by feeding on or breaking corals (e.g. corallivores and invertivores) [95].

Coral nurseries often become hubs for the aggregation of several species of fishes [96], which either feed on the organisms settling down on the nurseries or use them for protection. In either case they can provide a positive contribution to the success of the projects by consuming biofouling and reducing the amount of time required for cleaning the nurseries [97,98].

PROCEDURES

Ideally, fish species will be identified to the highest taxonomic level possible (family, genus, or species) to understand feeding preferences and make inferences on coral-fishes relationship and the impact they have on the reef and consequently on the project.

Changes in the fish community should be assessed in the short-medium and long-term as it may require several years before certain fish species make their appearance at the restored site.

EXPERTISE	
SIMPLE	ADVANCED
Presence / Absence of the different families	Abundance class of each species/genus/family

Table 4 - Level of expertise for Fishes community surveys.

ABUNDANCE CLASSES			
1 (+)	2 (++)	3(+++)	4(++++)
Rare, few residents	Uncommon, but always found	Commonly recorded, >10 individuals	Highly abundant, >50 individuals

Table 5 - Abundance classes for the advanced survey of Fishes community [96].

Different procedures should be followed for different phases of the project.

In-situ nurseries

Fishes found within and in the near proximity of the nurseries will be calculated at least as presence/absence (Table 4) or through abundance classes (Table 5) in each nursery. Fishes should be identified to the highest taxonomic level possible (family, genus, or species).

In case of uncertainty about the species, fishes should be identified to the family level (e.g., Butterflyfishes, Groupers, Sweetlips, Parrotfishes, Snappers, Surgeonfishes).

Restoration sites and reference sites:

Basic fish assessments have been standardized the by the National Coral Reef Monitoring framework. Datasheets are included in the following chapter.

Fish surveys should be done through 4 belt transects measuring 5x20x5 m (Fig. 52 – Example of Fish belt transect).

Surveyors should lay the **waterproof transect line** (ideally 1 line of 100 m) and wait 15 mins before starting the survey to allow all the fish that have been startled to return to the area or exit their burrows. Between each transect there will be a 5 m gap.

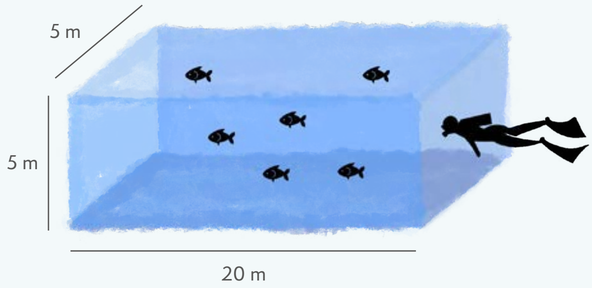

Figure 52 - Example of Fish belt transect.

The surveyor will start swimming into the current to keep a slow steady pace and have sufficient time to detect smaller fish. They will tally on the datasheet the number of fish identified based on the level of detail decided. It is important not to count fish twice as they exit and re-enter the monitoring area. The one exception is that surveyors should include larger and uncommon fishes (i.e., Napoleon Wrasse, Sharks, Rays, Bumphead Parrotfish) in their notes (not the actual count), even if they are outside the area.

As proposed for other indicators the survey can be conducted at different level of detail based on the expertise of the surveyor. Fishes will be either classified at family-level (Simple) or by genus/species level.

EXPERTISE	
SIMPLE	ADVANCED
Butterflyfish	Genus or species level of the fish
Groupers	
Sweetlips	
Parrotfish	
Snappers	
Surgeonfish	
Damselfish	
Triggerfish	
Filefish	
Pufferfish	
Napoleon Wrasse, Sharks, Rays, Bumphead Parrotfish (even outside the area)	Napoleon Wrasse, Sharks, Rays, Bumphead Parrotfish (even outside the area)
Other	

Table 6 - Levels of expertise for "Fishes community".

3.2.9
Associated Fauna and Non-associated Fauna

Associated Fauna

Exosymbionts are common in corals and some may have a positive influence on their host [99,100], thus some studies have suggested [101–104] the beneficial effects on corals and nurseries of fauna that settles or is deployed on them. Conversely, certain organisms found within coral colonies may be predators causing quick mortality of the colony and eventually spreading to the area.
This manual suggests a list of organisms which might have a positive or negative impact, but any additional species encountered may provide interesting insights on the performance of restoration projects (see BOX 3.9 "Insights – Organisms' interactions with corals").

This indicator refers to the organisms living within a coral colony which may have positive or negative impacts.

›› Next page:
BOX 3.9 - Insights
Organism's interactions with corals

BOX 3.9 - INSIGHTS
ORGANISMS' INTERACTIONS WITH CORALS

Organisms are known to have neutral, positive, or negative interactions with each other. We highlight the role of some common and uncommon creatures found on coral nurseries or restoration sites which might promote or endanger projects.

- The gastropod *Drupella* spp. is an obligate corallivore that has caused substantial damages to reefs [63] and might impact coral recovery after bleaching events [25].
- *Acanthaster planci* is a dangerous predator that might even cause mass mortality of entire reefs [21,63,166].
- *Culcita* sp. has been recognised as a coral predator widespread in the Maldives with dietary preferences which may cause local shifts in coral community composition [24] and reduce coral recovery after a bleaching event [23].
- *Trapezia* spp. is generally associated with corals from the family Pocilloporidae and beneficially protects the host from predation [167–172], from negative impacts of sedimentation [173,174], or enhances corals' calcification rates under reduced pH [175].
- The shrimp *Alpheus* spp. is often found in association with *Trapezia* spp. and enhances the protection of corals, especially pocilloporids [173,174,176,177].
- *Tetralia* spp. crabs have a similar role but in association with coral of the Acroporidae family [167,170].
- Tiny hydrozoans of the genus *Zanclea* living in association with scleractinians have been demonstrated to be able to protect their host from predation and disease [178].
- Recent studies [179] have also associated the presence of the crab *Cymo melanodactylus* with reduction in prevalence of White Syndrome disease.

Other than the commonly encountered predators we would like to bring the attention to two organisms which have been spotted in the Maldives and, although not particularly common, they might get overlooked and pose a threat to corals.

- *Waminoa* sp. is an organism belonging to the phylum Xenacoelomorpha which lives in association with corals and might reduce the host's photosynthesis capacity by shading it, and it also might make corals more susceptible to disturbances by feeding on their mucus [180] or even cause tissue loss [181]. Despite their relatively small size (0.5-10 mm) [182], in certain areas *Waminoa* sp. have been found in such large numbers to change corals' aspect and make them appear spotted [183].
- *Phestilla* spp. are one of the largest groups of Nudibranchia feeding only on scleractinian corals [184,185], they tend to be host-specific [186,187] and camouflage with their host [188]. *Phestilla* spp. might cause coral tissue loss and act as vectors of coral disease [189]. Since species within this genus are still being described with a growing number of associations being witnessed and studied in recent years [190,191], and due to their cryptic lifestyle and potential negative impact, it is important to keep an eye out for their presence within nurseries and restoration sites.

Positive interactions (+)	Negative interactions (-)
Trapezia spp. (Arthropoda, Crustacea)	*Culcita* sp. (Echinodermata, Asteroidea)
Tetralia spp. (Arthropoda, Crustacea)	*Acanthaster planci* (Echinodermata, Asteroidea)
Alpheus spp. (Arthropoda, Crustacea)	*Drupella* spp. (Mollusca, Gastropoda)
Cymo melanodactylus (Arthropoda, Crustacea)	*Coralliophila neritoidea* (Mollusca, Gastropoda)
Zanclea spp. (Hydrozoa, Zancleidae)	*Phestilla* spp. (Mollusca, Gastropoda)
Diadema spp. (Echinodermata, Echinoidea)	*Waminoa* spp. (Xenacoelomorpha)
Echinotrix spp. (Echinodermata, Echinoidea)	*Chalinula nematifera* (Porifera)
	Terpios hoshinota (Porifera)

Table 7 - Examples of Associated fauna and its interactions.


Figure 53 - *Trapezia* sp. in a *Pocillopora* sp. colony.

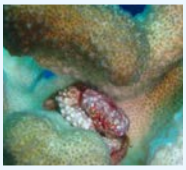
Figure 54 - *Cymo* sp. in a *Pocillopora* sp. colony.


Figure 55 - *Tetralia* sp. crab within a *Pocillopora* sp.

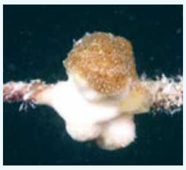
Figure 56 - *Phestilla* sp. settling and preying on a coral nubbin in a nursery.


Figure 57 - Symbiosis of *Zanclea* sp. with a scleractinian coral.


Figure 58 - *Alpheus* sp. in a *Pocillopora* sp. colony.

PROCEDURES

Between 30 and 100 colonies per species should be **visually inspected** while checking survival and health to verify the presence of organisms which should be identified in loco to the highest taxonomic level of confidence or later through pictures.

The organisms should be measured either as a **presence/absence** or as **number of individuals per colony** the latter allowing the calculation of the **frequency of occurrence: number of individuals of a species over colonies surveyed.** The presence of organisms of smaller dimensions like *Zanclea* sp. should be assessed as a binary presence / absence.

Special attention should be paid during this monitoring process for the possible presence of predators (which might have not yet inflicted a scar) to eventually remove them.

EXPERTISE	
SIMPLE	ADVANCED
Highest taxonomic level: presence / absence	Highest taxonomic level: n° of individuals per colony

Table 8 - Level of expertise for "associated fauna".

Non-associated Fauna

Even if it is not considered as a major indicator of reef resilience, a rich and diverse invertebrate population is generally an indication of the health and maturity of a coral community [94] and plays an important role in assessing the recovery of an ecosystem. On the other hand, numerous organisms compete with corals for space or inhibit their growth (e.g., sea urchins, boring sponges, worms).
This manual suggests recording species with known interactions provided in the list here, even if it is not comprehensive and others can be included. In line with the Protocol of the National Coral Reef Monitoring Framework the presence of additional species should also be ascertained (*Stenopus hispidus* - Banded coral shrimp; *Charonia tritonis* – Triton shell).

Non-associated fauna includes those mobile organisms found in the proximity of corals but not within them.

PROCEDURES

General information on the non-associated fauna living in the sites will be collected through **4 Belt Transects of 20x5 m** per site identifying mobile or sedentary invertebrates from the groups listed below, choosing the adequate level of expertise (Table 9). Please note that to comply with the National Coral Reef Monitoring Framework protocols we request you to identify certain organisms to a higher taxonomic level even with the simple methodology.

	EXPERTISE	
	SIMPLE	ADVANCED
Crustacea	All together	*Stenopus hispidus* (Banded Coral Shrimp)
		Panulirus versicolor (Lobster)
		Other
Mollusca	*Drupella* spp.	*Drupella* spp.
	Other	*Charonia tritonis* (Triton Shell)
		Other
Echinodermata	*Acanthaster planci* (Crown of Thorn)	*Acanthaster planci* (Crown of Thorn)
	Culcita sp. (Pin-Cushion sea star)	*Culcita* sp. (Pin-Cushion sea star)
	Other	*Asteroidea* (Sea stars)
		Crinoidea (Feather stars)
		Echinoidea (Sea urchins)
		Holothuroidea (Sea cucumbers)
Tunicata	-	All together

Table 9 - Level of expertise for "non-associated fauna".

›› Next page:
3.2.10 Recruitment

3.2.10 Recruitment

A healthy reef should present growth in coral recruitment as a result of the increased abundance of corals [105,106] in the years following a restoration programme, but not necessarily in the first year after outplanting [82,83].
Even though it is not uncommon for corals to recruit in a relatively short distance from their parent colony [107,108], this generally happens beyond the area where colonies have been outplanted. Therefore, it is recommended that surveys to assess coral recruitment (including the baseline survey prior to outplant) extend to a wider area to ensure capturing potential changes in values.

PROCEDURES

Young corals can be considered those that are settling on the reef and then starting to grow and they can be differentiated by size category.
This manual defines "recruits" those corals that are less than 5 cm in diameter, while the ones that are between 5 cm and 20 cm are defined as "juveniles" [109].
They can be measured using **Vernier callipers**. Recruits can be counted within **quadrats of 50x50 cm** with at least 10 repetitions per site. Experienced surveyors can identify the recruits following Baird & Hughes [110] and distinguishing only between Acroporidae, Pocilloporidae, Poritidae and others (Table 10, Fig. 59-61)

EXPERTISE	
SIMPLE	ADVANCED
Number/m^2	Number/m^2 of Acroporidae, Pocilloporidae, Poritidae and Other

Table 10 - Level of expertise for "Recruitment".

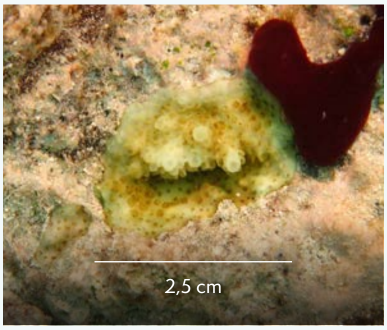

Figure 59 - *Acropora* sp. recruit.

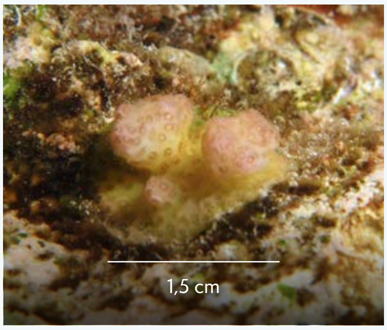

Figure 60 - *Pocillopora* sp. recruit.

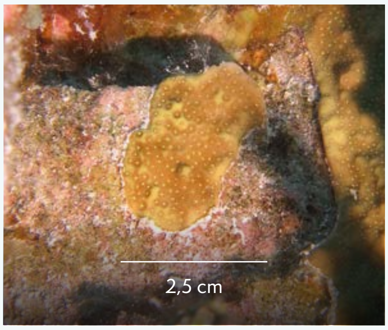

Figure 61 - *Porites* sp. recruit.

3.2.11 Reef Rugosity

Rugosity reflects the three-dimensional structure of a reef and improves biodiverse and abundant communities [111–114].
Massive and sub-massive species such as poritids and merulinids are the framework builders because of their shape, their slow growth and low susceptibility to bleaching [115].
Branching species such as acroporids and pocilloporids are instead considered "engineering species as they grow faster and create habitats with their complex shapes which provide a quick shelter for organisms" [116].
The role of corals three dimensionality in coastal protection through the dissipation of wave energy [111,117,118] is also widely recognised and is poorly described by only analysing changes in coral cover [119].
It is therefore important to understand if and to which degree outplanted corals contribute to the enhancement of the three-dimensionality of reefs by studying their rugosity.

PROCEDURES

Substrate rugosity can be measured through at least 3 repetitions of **10 m chain transects (1.5 cm links)**, laid following the contour of the reef (above corals and crevices) **next to a 10 m transect laid straight on the ground** (Fig. 62) [46,113].

The rugosity index is given by the ratio between the length of the chain divided by the length that it covers (see caption of Fig. 62).

The straighter the chain, the less complex the reef, with values of 1 indicating a flat surface and higher values indicating a more complex reef, although rarely going above 3 [120].

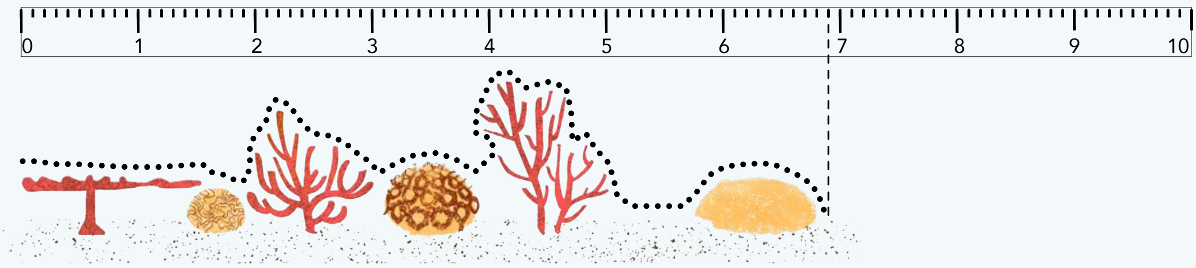

Fig. 62 - Chain intercept transect. Rugosity index is 10/6.9=1.45

3.2.12
Environmental Conditions

It is commonly recognised that if the initial causes of degradation are not eliminated, restoration might be ineffective becoming a waste of resources and a diversion from real threats [121].

"Environmental conditions" is a comprehensive expression that indicates a series of parameters describing the chemistry of the water and the environment in which corals are growing.

The analysis of these parameters allows an early detection of changes which might negatively influence the projects and, when the cause is known or suspected, timely act on it.

In each of the phases of the project we might consider as extremely important important certain parameters rather than others and even require their assessment at very different intervals.
The main parameters which we will consider are:

- **Sea temperature**: Corals are known to be able to live in a certain range of temperatures, generally dependent on the local mean. Increased temperature is one of the most influential factors triggering coral bleaching [39,122,123], which in turn has in some cases caused mass mortality of corals.

- **Light** affects the resistance of corals and their growth. The interaction between light and growth is known to be positive [124,125], yet if excessive it might cause paling of corals [126–128], whilst turbid waters might reduce corals susceptibility to coral bleaching [129].

- **Sedimentation** is known to smother coral surface and change light conditions which reduces photosynthesis capacity in corals [130]. It might be a temporary condition (due to sand dredging during constructions) but nonetheless can reduce coral survival in a relatively short time and at relatively high distances from the source [130–132].

- **Water chemistry** comprehends salinity, pH, Nitrate, Nitrite, Phosphate, Total Ammonia, Calcium, Magnesium, and Total Alkalinity. These parameters are particularly important in ex-situ nurseries where the control of the environment is crucial, but they can also be analysed in the field to understand whether any land-activity might influence restoration projects, e.g., unexpected sewage discharge, artificial nutrients from islands practicing agriculture [133]. Degraded water quality connected to other not entirely defined factors may be one of the causes of the increased virulence, geographic distribution, and occurrence of some diseases [62]. Being salt-water organisms, corals in ex-situ projects require a value of salinity as similar as possible to those of the natural environment, which for the Maldives is around 36‰ [134]. A variation in the pH of the water might affect the ability of corals to perform certain biological functions. It is believed that a decrease in pH causes a reduction in coral growth [135] and productivity, and might even cause local bleaching [136]. Although some studies demonstrated a regulating mechanism of some species that facilitates adaptive responses of corals to ocean acidification [137,138] it is nonetheless a good practice for ex-situ project to keep the pH around the ideal values of the pH of the natural reef waters (the value of 8.28 is an average between values for offshore and lagoon areas from over 20 years ago [134]).

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- **Sea temperature**: install a temperature logger with logging interval of 30 minutes or 1 hour or collect temperature manually **with a dive computer or UW thermometers during any survey**.
- **Light** should be monitored continuously with **loggers** recording either every 30mins or every hour and the data or the functioning of the logger should be retrieved or checked on a regular basis. (see BOX "3.10. Technical Advice – Tools for Environmental Conditions Assessment")
- **Water chemistry** should be measured through **probes** such as those for large aquariums or by **collecting samples** to be sent to the local laboratories. In the latter case, the procedure for water collection should follow the indications from the lab (e.g., Male Water and Sewerage Company or Maldivian Food and Drugs Authority).
- **Sedimentation** can be assessed using sediment traps placing **3 jars** straight with open top at the same height of the corals for a maximum of 14 days. The recommended size of the cups is 10 cm in height and 8 cm in diameter. After 14 days the jars will be covered and removed **weighting the sediments deposited inside after filtration**. Following Rogers *et al.*[139] values obtained will be mg of sediment per cm^2 per day. (see BOX "3.11. Technical Advice – Measuring sedimentation")

BOX 3.10 - TECHNICAL ADVICE TOOLS FOR ENVIRONMENTAL CONDITIONS ASSESSMENT

Environmental conditions can be assessed through various tools. We suggest here some which are commonly used for these purposes.

Location: coordinates can be recorded through portable GPS systems, some of which are also waterproof. We are not looking at systems with precisions of centimetres, yet we also don't want several meters discrepancies. Some waterproof cameras also collect GPS data when on the surface and can be used to associate coordinates with physical images.

Water temperature and light: temperature loggers are some of the best tools to record water temperature (and light) at regular intervals. Commonly used tools are UA-002-64 -HOBO® Pendant Temperature/Light 64K and U22-001 HOBO® Water Temperature Pro v2 by ONSET with different characteristics, accuracy and both requiring additional tools for data retrieval.

BOX 3.11 - TECHNICAL ADVICE MEASURING SEDIMENTATION

The procedure for measuring sedimentation rates (edited from Rogers *et al.*[139]) are the following:

1. Use 3 straight-sided jars at each depth and at each location (suggested size of the jars: 10 cm high and 8 cm in diameter). Depending on the type of nurseries the jars will be placed at the same height or the average height of the structures; on the reef (i.e., restoration or reference sites) jars will be placed at each location at 2 depths, 10 cm and 50 cm from the ground.
2. After no more than 14 days remove any organism, close them underwater and take them to the lab.
3. Weigh 2 Whatman filters and flow the water through the filters using a Buchner funnel. Rinse the filters well using distilled water.
4. Dry the filters in an oven at 70°C until they reach a constant weight.
5. Calculate the sedimentation rate as mg of sediment per cm^2 per day. The sediment weight is the total weight minus the filter weight (see "4.2 Data Analysis for Ecological Indicators").

3.3 Socio-economic Indicators

The socio-economic analysis includes any aspect which relates to the restoration project and doesn't have only an ecological connotation but also human, financial, and subjective features relating to the concept of ecosystem services. Reef ecosystems have a financial value that depends also on the benefits provided to the communities through direct activities conducted within the reef[34] as well as the indirect effects of a healthy ecosystem on the environment through, for example, increased fisheries or shoreline protection[140–143].

Considering the Maldivian Climate Change Adaptation and Mitigation Programmes, it is paramount to have a wider assessment of the value of restoration projects. Apart from the practitioners, there can be several people directly or indirectly involved in coral restoration projects such as grant donors, government bodies, tourists, locals, volunteers participating in activities or just visiting the restored areas as a leisure or awareness-raising activity.

A socio-economic analysis depends on the goals and background of the project; however, we suggest studying three main indicators: Reef-User Satisfaction, Outreach, and Financial Sustainability[144, 145, 146].

Since the socio-economic part is analysed by engaging different stakeholders, it is important to consider the language used during surveys as problems may arise when unclear or scientific terms are used. Moreover, the approach should avoid bias, we therefore discourage the use of leading or emotionally charged words [144], such as the terms "restored" or "artificial" which might induce people to attribute a value in a non-objective way. It is recommended to describe components in an unambiguous way by using other distinctive features.

3.3.1 Reef-user Satisfaction

Reef-user satisfaction allows to distinguish divergences between what the user perceive as an important component of a specific service and their actual perception of how well the service is being managed, i.e., their satisfaction with it. Amongst the many ways to assess this indicator we propose the use of a recognized tool: the Importance-Performance Analysis (IPA)[145, 146].

The assumption is that satisfaction provides essential information for judging performance, then comparing importance and satisfaction provides critical information on where limited resources can be allocated or saved. Another assumption is that the conditions of natural features, such as the presence of marine life, are central to what people experience in natural areas. Furthermore, this method has already been tested in the Maldives on coral restoration projects[147].

Figure 63 - Involvement of people in coral reef restoration

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To analyse Reef-user Satisfactions through IPA, stakeholders are provided a questionnaire with several sections.

The first part analyses the **demographic** data of the respondents. This information allows to understand if some categories need to be more informed or involved. For example, language barriers might identify indicate that certain nationalities are receiving very little information. The inability of swimming instead might mean some people believe they can't visit the restoration sites and so on.

The second section focuses on the **importance and satisfaction** of several attributes on a **scale from 1 to 5**, where 1 indicates "not important" and "not satisfied" and 5 indicates "extremely important" and "extremely satisfied". This section allows us to understand whether there are areas where practitioners should concentrate their efforts on.

Here below we provide the main points to assess reef-user satisfaction:

- size of the "x" reef area (please remember to use clear and non-leading language)
- size of the corals in the "x" area
- quantity of corals in the "x" area
- variety of corals on the "x" area
- quantity of fish in the "x" area
- variety of fish in the "x" area
- aesthetics of the nurseries (the structures where corals are left for a short period of time)
- aesthetics of other structures (excluding the nurseries, i.e., permanent structures where coral grow indefinitely)

The following chapter will provide an example of questionnaire which could be used to assess Reef-user Satisfaction (see 4.3 Socio-economic Monitoring).

3.3.2 Outreach

This indicator allows the evaluation of the effects of projects on people offering suggestions on how the ecosystem services might have been influenced.

Recorded information should include at least:

- How the fisheries have benefitted
- How tourism has changed
- The willingness of visitors to be actively involved
- The total number and demographics of people involved in coral restoration
- The type and number of related activities run e.g., educational presentations
- The demographic of people reached with educational activities

Additional questions could be focusing on the communication sphere:

- Which information has been provided on the project
- How stakeholders have received updates on the development of the project

PROCEDURES

This indicator is analysed through information that can be recorded, binary, and short-answer open questions which can be posed to stakeholders. Results can then be compared with other projects or point out changes deriving from the project through pre- and post-activity surveys.

3.3.3
Financial Sustainability

From a management point of view, it is important to ensure the financial sustainability and execution feasibility of projects which start with the set-up of a clear budget (see BOX 3.12. “Technical Advice - Cost Analysis”) prepared during planning (not analysed in this manual).

Nonetheless, the successful management of coral restoration may induce changes in the available finances which might have further positive outcomes on the long-term performance of projects. As applied with the other indicators, the Financial Sustainability should be measurable to obtain useful information. This indicator includes information on funders and funds received.

PROCEDURES

This indicator is analysed through information retained from the planning phase and analysed on a regular basis, at least yearly.

These are:

- The number of sponsors
- The number of sponsors who renew their commitment
- The number of sponsors who abandon the projects
- The size of financial aids
- The type of financial aids received (investors, programmes, sponsors...)
- The willingness of visitors to actively contribute to coral restoration

The analysis of these parameters through time allows practitioners to visually present the financial performance through graphics and thus in a measurable way.

BOX 3.12 - TECHNICAL ADVICE COST ANALYSIS

Cost is a fundamental component which shapes decisions throughout the whole restoration project. Having a precise costing framework tailored for the Republic of the Maldives allows to:

- help new practitioners in making realistic budgets to determine scale and scope of the programme
- understand where resources are mostly spent (and eventually try to reduce costs)
- compare costs of different techniques and factor whilst making decisions
- separate setting up and operational costs and allocate funds accordingly
- ensure the long-term sustainability of projects

Five main components shape the costs of a programme during its set-up and running:

- Manpower
- Equipment
- Transportation
- Consumables
- Time required to perform tasks

Whilst we are quite comfortable assuming that it won’t be necessary to fully set-up facilities (i.e., a diving centre) in the context of the Maldives, we can’t and shouldn’t assume that some of the components might be free of charge (as already owned or borrowed). We suggest making a detailed list of all the components at the beginning of the projects including estimates that account for the time required to obtain goods and to perform activities. Experience and shared information will help practitioners achieve the desired outcomes without exceeding budgets.

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4. MONITORING PROTOCOL

4. MONITORING PROTOCOL

Figure 64 - A team of divers getting ready to monitor a "Restored" area.

The scheme presented below provides an overview of the mandatory and discretionary indicators that should be used in the different phases of ecological monitoring of coral reef restoration projects in the Maldives.

DONOR SITE

Mandatory indicators
- Survival of donor colonies
- Health conditions of donor colonies
- Environmental conditions: sea temperature

Discretionary indicators
- Genotype

Project specifics

IN-SITU NURSERIES

Mandatory indicators
- Survival
- Growth
- Health conditions
- Associated fauna
- Environmental conditions: sea temperature

Discretionary indicators
- Self-attachment
- Genotype
- Reproductive capacity
- Fishes community
- Environmental conditions: sedimentation, light, water chemistry

Project specifics

EX-SITU NURSERIES

Mandatory indicators
- Survival
- Growth
- Self-attachment
- Health conditions (coral bleaching and signs of stress)
- Environmental conditions: water temperature, light, water chemistry (salinity, pH)

Discretionary indicators
- Genotype
- Environmental conditions: Water chemistry (Nitrate, Nitrite, Phosphate, Total Alkalinity, Total Ammonia)

Project specifics

RESTORATION & REFERENCE SITE

Mandatory indicators
- Survival
- Growth
- Health conditions
- Benthic cover
- Fishes community
- Non-associated fauna
- Recruitment
- Environmental conditions: sea temperature

Discretionary indicators
- Self-attachment
- Genotype
- Reproductive capacity
- Associated fauna
- Reef rugosity
- Environmental conditions: light, sedimentation, water chemistry

Project specifics

4.1
Ecological Monitoring

4.1.1
Donor Site

Figure 65 - Healthy reefs provide an opportunity as donor and reference sites.

4.1.1.1
Preliminary Operations

Before starting the monitoring process, tags (see box 4.1. "Technical advice - How to Tag Coral Colonies") and floating markers (if needed) should be applied to the selected pruned colonies to assess their fate over time. Once monitoring has ended, the tags and markers should be retrieved. Some of the information collected during this phase are used to assess the effects of pruning on the colonies others should be retained for the following monitoring steps (e.g., genotype).

4.1.1.2
Project Specifics

- The location (with GPS coordinates if possible or through Google Earth)
- The depth of the location
- The source of corals (fragments of opportunity or pruned from colonies or full colonies),
- The species and number of colonies per species
- The number of cuts per colony

4.1.1.3
Ecological Indicators

Mandatory indicators

- Survival of donor colonies
- Health conditions of donor colonies
- Environmental conditions: sea temperature

Discretionary indicators

- Genotype

4.1.1.4
Monitoring Schedule

INDICATOR	FREQUENCY		
	T_0 (during collection)	30 mins / 1 hour	weekly
Environmental conditions: Sea temperature		• (logger)	• (computer)
Survival			•
Health conditions			•
Genotype	•		•

Table 11 - Monitoring schedule for donor sites.
• Mandatory indicators
• Discretionary indicators

Datasheets

The following are examples of datasheets with the information which need to be collected at T_0 during coral stocking and later on to assess the effects of pruning (when this was the chosen technique) on the donor colonies.

BOX 4.1 - TECHNICAL ADVICE
HOW TO TAG CORAL COLONIES

Tagging coral colonies is one of the key elements that allows monitoring.
It is recommended to keep a record of which corals have been chosen and to use a standardised procedure for tagging them as, despite any best effort, tags might get lost. Generally speaking, it is suggested to avoid tags touching corals and proceed by placing them always before or after, above or below a reference point.
Tags can be made with several materials and codes engraved or printed, they will be attached to structures and substrate through cable ties, ropes, nails, or glue (Fig. 66).
Additionally, coral colonies within the donor, reference and restoration area can be marked with small buoys which allow their detection in a larger and less organised space.

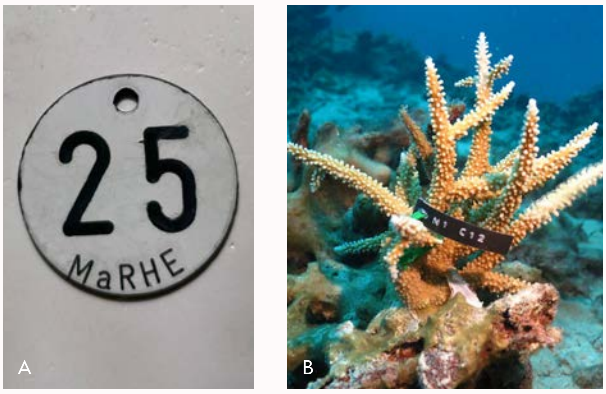


Figure 66 - Different type of tags,
A Engraved tags, B Low cost tags.

Coral Reef Restoration Monitoring - Maldives
Donor site - Monitoring at T_0

Surveyor	Date	Depth	Sea temp
Location	Site	GPS coordinates	

Colony #	ID	N° of cuts	N° of frags	Genotype ID

Coral Reef Restoration Monitoring - Maldives
Donor site (ADVANCED)

Surveyor	Date	Depth	Sea temp
Location	Site	GPS coordinates	

Colony #	ID	Survival 0% alive tissue (dead) 1–25% alive tissue 26–50% alive tissue 51–75% alive tissue 76–99% alive tissue 100% alive tissue (alive)	Health conditions					
				Predation	Ph. damage	Signs of stress		
			Bleaching (color code)	Predator - Scar size	Type od debris - Effect (detached, smothered, broken)	Type of lesion (tissue loss, discoloration, growth anomaly)	Description (host affected, acute/sub-acute/chronic, Focal/multi-focal/coalescing, location on colony, lesion margin)	Disease nomenclature

<u>**Simple survey**</u>: **Survival** (Alive/Dead); **Bleaching** (Ok/Pale/Bleached); **Signs of stress** (Presence/Absence); **Predation** (Presence/Absence); **Physical damage** (Presence/Absence)

4.1.2 Ex-situ Nurseries

Figure 67 -Ex-situ nurseries. Water tanks are used both indoor and outdoor.

4.1.2.1 Preliminary Operations

Before starting the monitoring process, each coral should be permanently marked or tagged without damaging the coral itself. It is important to keep in mind that fouling organisms might hamper the tags and regular cleaning needs to be planned.

If corals are divided in trays, each of the trays should have a progressive number. The numbering should follow a logical order e.g., from top left to bottom right and the direction should be described (Fig. 68 and Fig. 69).

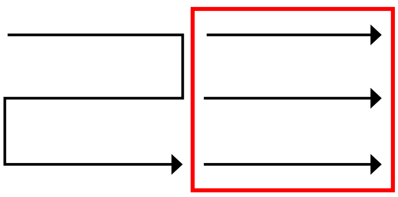


Figure 68 -Example of direction for progressive numbering.

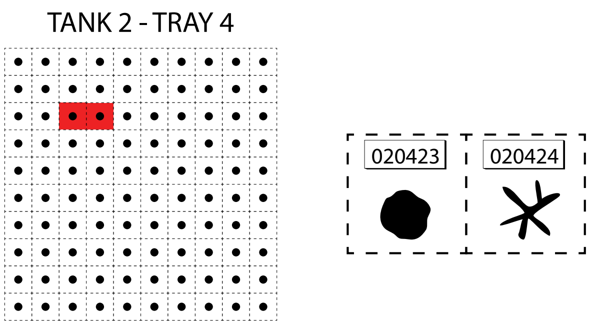


Figure 69 -Example of nubbins numbering.

The code should reflect the tank number, tray number, fragment number with as many zeros preceding a single figure as the quantity of digits of the highest number i.e., in a project with 10 tanks, 10 trays per tank, 100 corals per tray; the coral in Tank 2, Tray 4, Fragment 23 and 24 will be 0204023 and 0204024 (Fig. 69). The name of the species should be recorded to the highest taxonomical level possible following Veron 5, Rowlett [148] and Wallace *et al.* [149]. In case of doubt, a certain family level is preferred to an uncertain genus or species.

Sample selection

In case of large ex-situ projects, a significant number of nubbins might be chosen to assess all the indicators and allow possible statistical analyses. It is important to select a sufficient sample for each species and to select them randomly.

4.1.2.2
Project Specifics

For each nursery the following information should be specified:

- The **material** used as a support (e.g., plastic, cement),
- The **media** used to attach the coral (e.g., glue, epoxy)
- The **source of fragment** (e.g., sexually reared, corals of opportunity, fragments from an alive colony).

4.1.2.3
Ecological Indicators

Mandatory indicators

- Survival
- Growth
- Self-attachment
- Health conditions (coral bleaching and signs of stress)
- Environmental conditions: water temperature, light, water chemistry (salinity, pH)

Discretionary indicators

- Genotype
- Environmental conditions: Water chemistry (Nitrate, Nitrite, Phosphate, Total Alkalinity, Total Ammonia)

4.1.2.4
Monitoring Schedule

INDICATORS		FREQUENCY				
		At T_0 during nursery stock-up	30 mins / 1 hour	Daily	Weekly	Fortnightly / Monthly
Survival						•
Growth		•			•	
Self-attachment		•		•		
Health conditions (coral bleaching and signs of stress)					•	
Genotype		•				
Environmental conditions	Water temperature & light	•	•			
Environmental conditions	pH	•		•		
Environmental conditions	Salinity	•		•		
Environmental conditions	Water chemistry	•		• (probes)		• (lab)

Table 12 - Monitoring schedule for ex-situ nurseries.
• Mandatory indicators
• Discretionary indicators

» Next page:
Table Ex situ

Datasheets

The following are examples of datasheets with the information which need to be collected at T_0 while stocking up nurseries and during the periodical assessment of the nubbins' performance.

Coral Reef Restoration Ex situ - Monitoring at T_0
Ex situ (ADVANCED)

Surveyor		Date	Location	Tank
Water temp	Light	pH	Salinity	

Water chemistry				
Nitrate	Nitrite	Phosphate	Total Ammonia	Tot Alkalinity

Fragment code	Support material	Attaching material	Frag source (sexually reared, opportunity, from an alive colony)	Genotype

Coral Reef Restoration Monitoring - Maldives
Ex situ (ADVANCED)

Surveyor		Date	Location	Tank
Water temp	Light	pH	Salinity	

Water chemistry				
Nitrate	Nitrite	Phosphate	Total Ammonia	Tot Alkalinity

Frag code	Survival 0% alive tissue (dead) 1–25% alive tissue 26–50% alive tissue 51–75% alive tissue 76–99% alive tissue 100% alive tissue (alive)	Size (EV or Area)	Self-attachment (Y-N)	Health condition			
				Bleaching (color code)	Signs of stress		
					Type of lesion (tissue loss, discoloration, growth anomaly)	Description (host affected, acute/sub-acute/chronic, Focal/multi-focal/coalescing, location on colony, lesion margin)	Disease name

Simple survey: **Survival** (Alive/Dead); **Bleaching** (Ok/Pale/Bleached); **Signs of stress** (Presence/Absence)

4.1.3 In-situ Nurseries

Figure 70 - Nurseries anchored independently on the substrate have different identification codes.

4.1.3.1 Preliminary Operations

If several nurseries exist, each nursery anchored independently on the substrate should have its own code. If more techniques or supports are used, each one should have its own code as well.

If corals are divided in trays, nets, or ropes, each of them should have its own progressive number.

The numbering should follow a logical order e.g., from top left to bottom right or the geographical position (North-East to South-West...) and the direction should be described, i.e., with a continuous line through a row-by-row basis (Fig. 71).

For each supporting structure the total number of fragments should be recorded (e.g., 23 nubbins in rope 1 of nursery 1).

For tagging methods see BOX 4.1. "Technical Advice – How to Tag Coral Colonies".

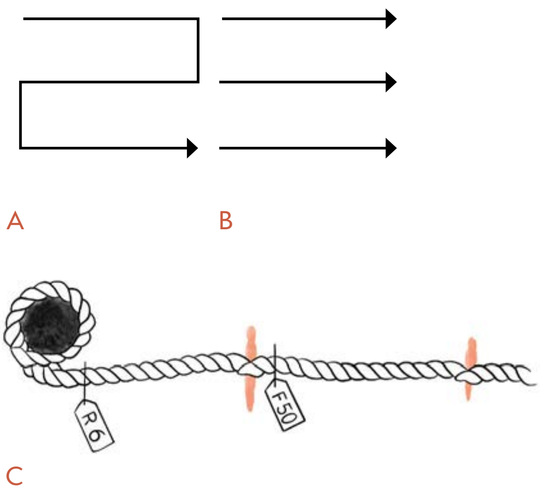


Figure 71 - Example of direction for progressive numbering:
A Continuous line,
B Row by row,
C Rope and fragments numbering.

The code of each fragment should be reflecting the structure number, technique/support code, tray/rope/net, number, fragment number with as many zeros preceding a single figure as the number of digits of the highest number of that category. For example, in a project with 2 nurseries, 10 ropes each and 1 net each, 50 corals per rope and 100 per net; the coral in nursery 1, Rope 6, Fragment 50 will be N01R06F050; the coral on nursery 1, net 1 coral 99 will be N01N01F099.

The name of the species should be recorded to the highest taxonomic level possible following [5,148,149]. In case of uncertainty family level is preferred to an uncertain genus or species level.

It is recommended to decide on a procedure to be to keep track of the numbering system (if fragments are not singularly tagged), in case coral fragments die or get lost.

Tags should be kept clean of biofouling and the position of the corals should be recorded for future reference in case of tags breakage or loss.

Please make sure not to lose track of any information deriving from the donor site (i.e., genotype) or the ex-situ phase (when present).

4.1.3.2
Project Specifics

For each project practitioners should note the basic features of the nurseries:

- The **technique/s** used for in-situ nurseries:
    - Mid-water rope nursery
    - Trees
    - Trays
    - Other (specify)
- The **substrate** where corals are anchored if any
- The **media** used to secure corals e.g., nylon ropes, epoxy glue, cement, biodegradable or plastic cable ties, PVC pipes.
- The **source of fragment**, whether coral of opportunities or portions from alive colonies.
- The **depth** at which nurseries are placed (real or average).

4.1.3.3
Ecological Indicators

Mandatory indicators

- Survival
- Growth
- Health conditions
- Associated fauna
- Environmental conditions: sea temperature

Discretionary indicators

- Self-attachment
- Genotype
- Reproductive capacity
- Fishes community
- Environmental conditions: sedimentation, light, water chemistry

4.1.3.4
Monitoring Schedule

INDICATORS		FREQUENCY				
		At T_0 (at nursery installation)	30 mins / 1 hour	weekly	monthly	at need
Survival					•	
Growth		•			•	
Health conditions					•	
Associated fauna					•	
Genotype		•				
Fishes community		•			•	
Reproductive capacity						•
Self attachment				•		
Environmental conditions	Sea temperature	•	•			
Environmental conditions	Sedimentation	•		•		•
Environmental conditions	Water chemistry	•		•		•

Table 13 - In-situ nurseries monitoring schedule.
• Mandatory indicators
• Discretionary indicators

Datasheets

The following are examples of datasheets with the information which need to be collected at T_0 while stocking up nurseries and during the periodical assessment of the nubbins' performance and the performance of nurseries.

Coral Reef Restoration Monitoring - Maldives
In situ - Monitoring at T_0

Surveyor			Date		Technique	
Sea temp			Light		Sedimentation	
Water chemistry						
Nitrate	Nitrite	Phosphate	Total Ammonia	Tot Alkalinity	Size of the nursery	Nursery n°
					L1: L2:	

Frag code	ID	Media to secure coral	Frag source (Sexually reared, Opportunity, Pruned)	Substrate	Depth	Size (EV or Area)	Genotype

Fishes Community (ID/Abundance Class)			Lenght and width surveyed:		
Fish ID	Fish n°	Fish ID	Fish n°	Fish ID	Fish n°

Coral Reef Restoration Monitoring - Maldives
In situ (ADVANCED)

Surveyor			Date		Technique	
Sea temp			Light		Sedimentation	
Water chemistry						
Nitrate	Nitrite	Phosphate	Total Ammonia	Tot Alkalinity	Size of the nursery	Nursery n°
					L1: L2:	

Frag code	Survival	Size (EV or Area)	Health conditions						Self-attachment (Y-N)	Reproductive capacity
				Signs of stress			Predation	Ph.damage		
	0% alive tissue (dead) 1–25% alive tissue 26–50% alive tissue 51–75% alive tissue 76–99% alive tissue 100% alive tissue (alive)		Bleaching (color code)	Lesion type (tissue loss, discoloration, growth anomaly)	Description (host affected, acute/ sub-acute/ chronic, Focal/ multi-focal / coalescing, location on colony, lesion margin)	Disease nomenclature	Predator - Scar size	Type of debris, Effect (detached, smothered, broken)		

Associated fauna (ID - individuals)				Number of colonies surveyed:				
coral ID	fauna ID	fauna #	coral ID	fauna ID	fauna #	coral ID	fauna ID	fauna #

Fishes Community (ID/Abundance Class)			Lenght and width surveyed:		
Fish ID	Fish n°	Fish ID	Fish n°	Fish ID	Fish n°

Simple survey: **Survival** (Alive/Dead); **Bleaching** (Ok/Pale/Bleached); **Signs of stress** (Presence/Absence); **Predation** (Presence/Absence); **Physical damage** (Presence/Absence); **Fishes community** (ID by family and Presence/Absence); **Associated fauna** (ID and Presence/Absence)

4.1.4
Restoration and Reference Site

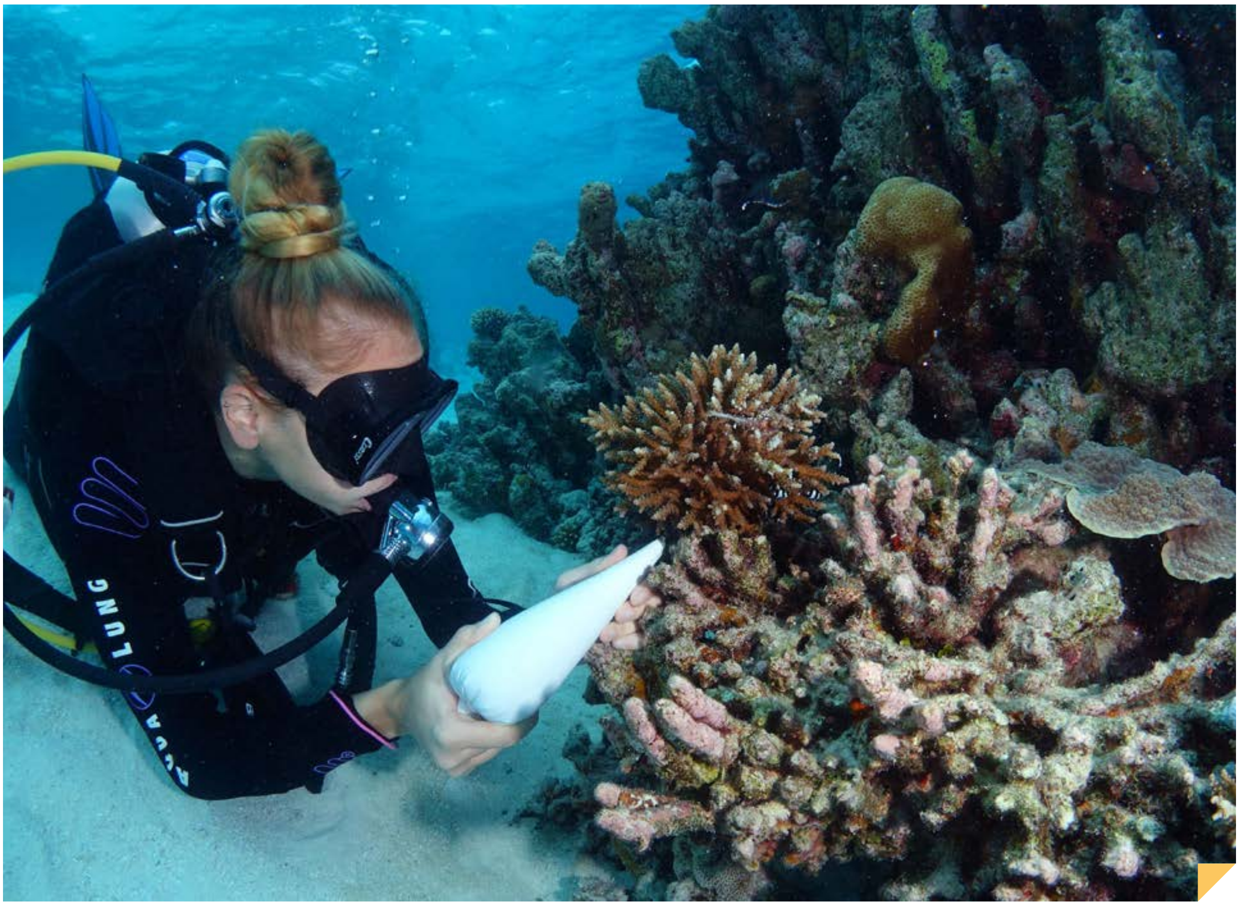


Figure 72 - Outplantation of a coral colony by cementing it on the substrate.

4.1.4.1
Preliminary Operations

Before starting the monitoring process, colonies that were selected to be monitored should be tagged (possibly through a non-invasive method) and the restoration area indicated through markers and GPS coordinates.

A map with these coordinates should be created for reference (see BOX 3.1. "Technical Advice – Ecological Footprint" and BOX 3.3 "Technical Advice – Digital Monitoring"). Within the reference sites several colonies can be selected to make comparisons on indicators of the coral condition (i.e., survival, growth, health conditions, reproductive capacity, associated fauna).

Please keep in mind that the sampled colonies should be representative of all the species used and significative from a statistical point of view.

4.1.4.2
Project Specifics

For each project practitioners should note down the basic features of the sites (restoration and reference sites) and the techniques used:

- The **habitat** (e.g., reef flat, crest or slope)
- The **depth**
- The **source of the corals**: whether coral of opportunities, from nurseries or portions from alive colonies
- The **total number** of outplanted corals
- The **substrate** on which corals are attached to (e.g., rock, spiders)
- Any **treatment** applied (i.e., cleaning substrate from fouling organism or leaving it uncleaned)
- The **media** used to secure corals (e.g., epoxy glue, cement, biodegradable or plastic cable ties, nails)
- The **density** of outplanted corals (e.g., 4 corals per sqm)
- Any **other** information which might have an impact on the success of the project

4.1.4.3
Ecological Indicators

Mandatory indicators

- Survival
- Growth
- Health conditions
- Benthic cover
- Fishes community
- Non-associated fauna
- Recruitment
- Environmental conditions: sea temperature

Discretionary indicators

- Self-attachment
- Genotype
- Reproductive capacity
- Associated fauna
- Reef rugosity
- Environmental conditions: light, sedimentation, water chemistry

4.1.4.4
Monitoring Schedule

INDICATORS	FREQUENCY					
	SHORT TERM (1 Year)			MID – TERM (Y2 – Y5)	LONG-TERM (>5Y)	
	baseline + $time_0$ – (at the time of outplant)	fortnightly (until self-attachment)	once (1) or twice a year (2)	once (1) or twice a year (2)	yearly surveys	at need
Survival	•	•	• (2)	•		
Growth	•		•	•	•	
Health conditions	•		•	•	•	
Benthic cover	•		•	•	•	
Fishes community	•		•	•	•	
Associated fauna	•		•	•	•	
Non-associated fauna	•		•	•	•	
Recruitment	•		• (1)			
Self-attachment		•				
Genotype	•					
Reproductive capacity			• (1)	• (1)		• (before reproduction)
Reef rugosity	•			• (1)	• (1)	
Environmental conditions: Sea temperature	Suggested continuous logging					• (weekly manual) • (every 2 months – loggers)
Environmental conditions: Light	Suggested continuous logging					
Environmental conditions: Sedimentation	•					•
Environmental conditions: Water chemistry	•					•

Table 14 - Monitoring schedule of Restoration and Reference sites. • Mandatory indicators • Discretionary indicators

Datasheets

Restoration and reference sites should be monitored on a regular base and in the long-term. The following are examples of datasheets with the information required at T_0 during outplant and during the periodical assessment of the coral performance and the effects on the community.

Restoration / Reference site - Monitoring at T_0

Surveyor		Date		Depth	Location		Site
Habitat		GPS				Sea temp	
Light	Nitrate	Nitrite	Phosphate	Tot Ammonia	Tot Alkalinity	Sedimentation	

Frag code	ID	Genotype	Substrate	Attaching material	Substrate treatment	Frag source (sexually reared, opportunity, from alive colony)	Size	Depth

Rugosity lenght rep 1	Rugosity lenght rep 2	Rugosity lenght rep 3

Fishes Community (ID/Abundance Class)			Lenght and width surveyed:		
Fish ID	Fish n°	Fish ID	Fish n°	Fish ID	Fish n°

Non-associated fauna		
Location	Site	Date
GPS	Observer	Depth
Measures of the transect	Transect n°	

Stenopus hispidus	*Culcita* sp.
Panulirus versicolor	Other Sea Stars
Other crustaceans	Feather Stars
Drupella spp.	Sea urchins
Charonia tritonis	Sea cucumbers
Other molluscs	Tunicates
Acanthaster planci	

Benthic Cover					
Date		Location		Site	
GPS		Observer		Depth	
Dist	ID code	Dist	ID code	Dist	ID code
0,5		7,5		14,5	
1		8		15	
1,5		8,5		15,5	
2		9		16	
2,5		9,5		16,5	
3		10		17	
3,5		10,5		17,5	
4		11		18	
4,5		11,5		18,5	
5		12		19	
5,5		12,5		19,5	
6		13		20	
6,5		13,5			
7		14			

Recruitment	
Acroporidae	Acroporidae
Pocilloporidae	Pocilloporidae
Poritidae	Poritidae
Other	Other

Simple survey: **Survival** (Alive/Dead); **Bleaching** (Ok/Pale/Bleached); **Signs of stress** (Presence/Absence); **Predation** (Presence/Absence); **Physical damage** (Presence/Absence); **Fishes community** (ID of main families and Presence/Absence); **Associated fauna** (ID and Presence/Absence); **Non-associated fauna** (Presence/Absence of: Crustacea, *Drupella* sp., Other mollusks, *Acanthaster planci, Culcita* spp., Other echinoderms, Tunicates -); **Benthic community** (Substrate: RK (rock), RB (rubble), SA (sand) - Algae: MA (macroalgae), TA (turf algae), CCA (crustose coralline algae), HA (*Halimeda* spp.) - SG (Seagrass), Invertebrates: GC (*Tridacna* spp.), OY (Oyster), SP (sponge), TU (tunicates) - SC (soft coral) - HC (hard corals) - OT (Other)); **Recruitment** (number of recruits)

Coral Reef Restoration Monitoring - Maldives
Restoration/ Reference site (ADVANCED)

Surveyor		Date		Depth	Location		Site
Habitat		GPS				Sea temp	
Light	Nitrate	Nitrite	Phosphate	Tot Ammonia	Tot Alkalinity	Sedimentation	

Rugosity lenght rep 1	Rugosity lenght rep 2	Rugosity lenght rep 3

Frag code	Survival 0% alive tissue (dead) 1–25% alive tissue 26–50% alive tissue 51–75% alive tissue 76–99% alive tissue 100% alive tissue (alive)	Size (EV or Area)	Health Conditions			Self-attachment (Y-N) Reproductive capacity (Y-N)	Associated Fauna (ID -N°individuals)
			Bleaching (color code)	Predation Predator- Scar size Ph. damage Type od debris - Effect (detached, smothered, broken)	Signs of stress 1)Type of lesion (tissue loss, discoloration, growth anomaly) 2) Description (host affected, acute/sub-acute/ chronic, Focal/multi-focal/coalescing, location on colony, lesion margin) 3) Disease nomenclature		

Fishes Community (ID/Abundance Class)			Lenght and width surveyed:		
Fish ID	Fish n°	Fish ID	Fish n°	Fish ID	Fish n°

Non-associated fauna		
Location	Site	Date
GPS	Observer	Depth
Measures of the transect	Transect n°	

Stenopus hispidus	*Culcita* sp.
Panulirus versicolor	Other Sea Stars
Other crustaceans	Feather Stars
Drupella spp.	Sea urchins
Charonia tritonis	Sea cucumbers
Other mollusks	Tunicates
Acanthaster planci	

Benthic Cover					
Date		Location		Site	
GPS		Observer		Depth	
Dist	ID code	Dist	ID code	Dist	ID code
0,5		7,5		14,5	
1		8		15	
1,5		8,5		15,5	
2		9		16	
2,5		9,5		16,5	
3		10		17	
3,5		10,5		17,5	
4		11		18	
4,5		11,5		18,5	
5		12		19	
5,5		12,5		19,5	
6		13		20	
6,5		13,5			
7		14			

Simple survey: **Survival** (Alive/Dead); **Bleaching** (Ok/Pale/Bleached); **Signs of stress** (Presence/Absence); **Predation** (Presence/Absence); **Physical damage** (Presence/Absence); **Fishes community** (ID of main families and Presence/Absence); **Associated fauna** (ID and Presence/Absence); **Non-associated fauna** (Presence/Absence of: Crustacea, *Drupella* sp., Other mollusks, *Acanthaster planci, Culcita* spp., Other echinoderms, Tunicates -); Benthic community (Substrate: RK (rock), RB (rubble), SA (sand) - Algae: MA (macroalgae), TA (turf algae), CCA (crustose coralline algae), HA (*Halimeda* spp.) - SG (Seagrass), Invertebrates: GC (*Tridacna* spp.), OY (Oyster), SP (sponge), TU (tunicates) - SC (soft coral) - HC (hard corals) - OT (Other)); **Recruitment** (number of recruits)

4.2 Data Analysis of Ecological Indicators

An important component of a monitoring programme is the subsequent ability to read, understand and analyse data. A robust design of the monitoring plan allows the project to be ecologically and statistically meaningful.

In terms of sample size, there is no unique size fitting all solution as it depends on the goals of the projects, the size of the population and the analyses to be performed.

It is recommended to select at least 30 fragments per species[31] and, depending on the research question, samples could be taken for each technique, habitat or condition to reach a goal of at least 3 to 5% of corals monitored for each setting.

Having enough samples, without excess, increases the level of precision of the surveys and allows to assess changes over space and time[46].

It is important to remember to select a random sample both within nurseries and in the restoration/reference sites.

The main basic analyses to be performed on the data are:

- Mean
- Standard deviation and standard error
- Data distribution
- Parametric and non-parametric tests
- Further correlations and inferences through a statistical software

Furthermore, some of the indicators allow the assessment of specific indexes useful in ecology:

- Density (the number of individuals of a species in the area) (individuals/m^2)
- Species diversity – Shannon-Wiener Index (the number of species and the evenness of their abundance)[150]

$$H' = -\sum_{i=1}^{s} p_i \log_e p_i$$

With s=number of different species in the area,

p_i= the proportion of the ith species in a sample (total number of individuals in the i species / total number of individuals in all species)

$\log_e p_i$= the natural logarithm of p_i

The minimum value of H' is 0 representing a community with a single species; the increase in H' describes a community with higher richness and evenness.

Sedimentation will be calculated as mg of sediment per cm^2 per day through the following formula:

$$W / d \pi r^2$$

where "W" is the weight of sediments in mg,

"d" the number of days of deployment,

"r" the radius of the jar in cm (to measure the area over which sediments have deposited)

Rugosity index indicates how three-dimensional a community is:

R_i = Chain length/length that the chain covers (see Fig. 62)

A value of 1 corresponds to a flat area, higher values correspond to more complex substrates.

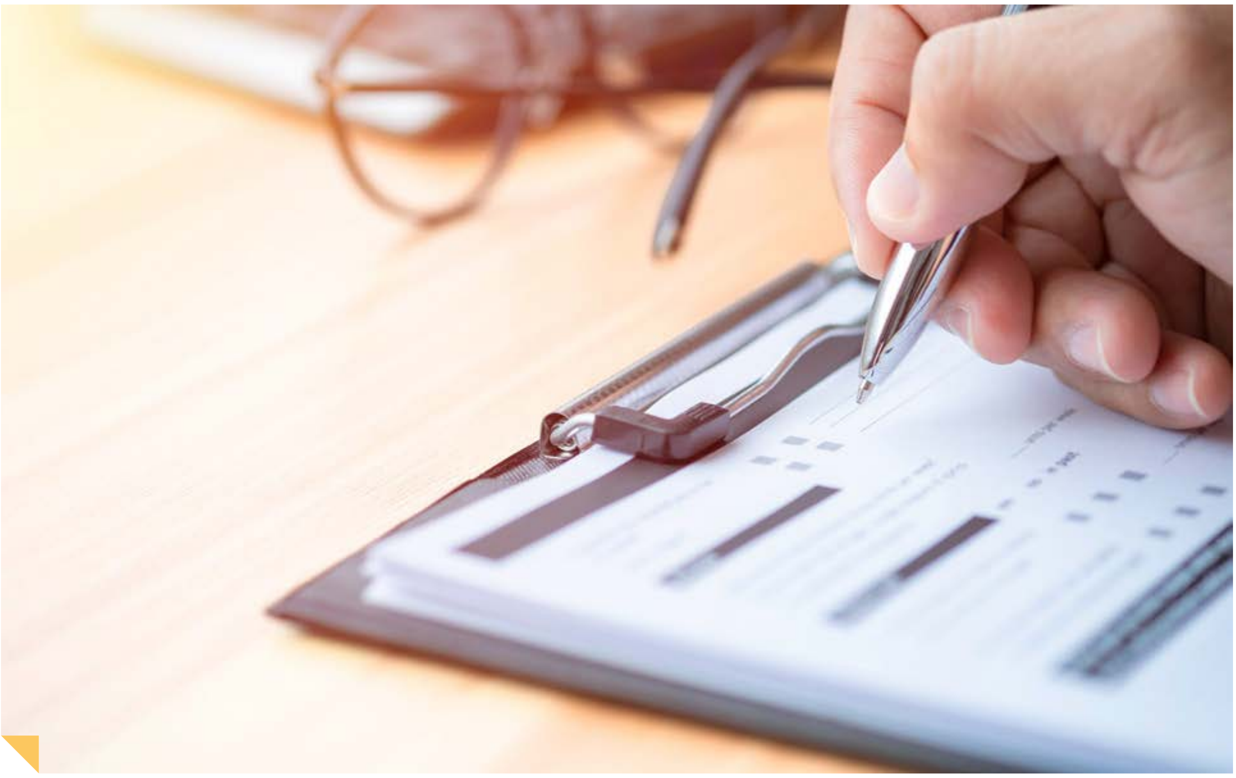


Figure 48 - Questionnaires can be filled out by different stakholders.

4.3

Socio-economic Monitoring

Unlike the ecological survey where a comprehensive list of mandatory and discretionary indicators was provided, here we propose a number of indicators and parameters, but we recognise that each project may formulate additional questions to investigate the socio-economic sphere.

Given that each project might have different stakeholders and purposes, the questions should be tailored to the specific goal of the activity. The questionnaire provided below is an example and adaptation of what already tested for the Maldives [147].

›› Next page:
4.3.1 Questionnaire

4.3.1
Questionnaire

4.3.1.1
Reef-user Satisfaction

Thank you for making some time to help us understand how well our Coral Restoration Project is doing in your opinion. Answering these questions is not mandatory but will provide us a more comprehensive picture of our activities and insights on various levels.

Location:	Date:
Name (optional):	Age:
Occupation (optional):	Gender:
Email (optional):	Nationality:

	YES	NO	I don't know
Can you swim?	☐	☐	☐
Can you dive?	☐	☐	☐
Do you know anything about Coral Restoration Projects	☐	☐	☐
Would you like to receive more information on our coral restoration project?	☐	☐	☐
Would you be interested in participating in our coral restoration project?	☐	☐	☐
Are you interested in educational and outreach activities?	☐	☐	☐
Are you interested in visiting or diving in the restoration sites?	☐	☐	☐

Please state your level of **satisfaction** with respect to the following items, on a scale of 1 to 5:

	Not Satisfied	Slightly Satisfied	Moderately Satisfied	Satisfied	Highly Satisfied	N/A
Size of the "x" reef area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Size of the corals in the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Quantity of corals in the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Variety of corals on the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Quantity of fish in the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Variety of fish in the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Aesthetics of the nurseries (the structures where corals are left to grow for a short period of time)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Aesthetics of the artificial structures (excluding the nurseries, i.e. All the artificial structures where corals grow indefinitely)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Information provided on the project	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Updates on the development of the project	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Information provided on the marine environment (e.g., through marine biology presentation or school lectures)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐

Please state how **important** are, in your opinion, the following items, on a scale of 1 to 5:

	Not Satisfied	Slightly Satisfied	Moderately Satisfied	Satisfied	Highly Satisfied	N/A
Size of the "x" reef area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Size of the corals in the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Quantity of corals in the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Variety of corals on the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Quantity of fish in the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Variety of fish in the "x" area	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Aesthetics of the nurseries (the structures where corals are left to grow for a short period of time)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Aesthetics of the artificial structures (excluding the nurseries, i.e., all the artificial structures where corals grow indefinitely)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Aesthetics of the artificial structures (excluding the nurseries, i.e. All the artificial structures where corals grow indefinitely)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Information provided on the project	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Updates on the development of the project	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐
Information provided on the marine environment (e.g., through marine biology presentation or school lectures)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	☐

4.3.1.2
Outreach

Surveys might be conducted involving several stakeholders with precise binary questions and some short-open questions to provide yearly reports.

FISHERMEN

	YES	NO	I don't know
Have you seen any change in the fish community in the last year?	☐	☐	☐
Have you seen any increase in fish catches in the last year?	☐	☐	☐

TOURIST OPERATORS

	YES	NO	I don't know
Have you seen any increase in tourism due to an interest in the reef in the last year?	☐	☐	☐
Has any tourist commented on the reef status?	☐	☐	☐
If the answer to the previous question was "Yes", were comments positive?	☐	☐	☐

Additional data should include the following:

What type of outreach activity was conducted? (Awareness session, visits to the sites, hands-on restoration)	
How many sessions of each type of activity was conducted in the last year?	
How many non-experts have been involved?	
How old were the people involved?	
Where did they come from?	
What was their occupation?	
What was their gender?	
What type of information have participants been provided? (Leaflets, verbal, social media, presentations)?	
How did stakeholders (donors and funders) receive updates on the development of the project?	
What was their feedback? (Rate 1-5 where 1 is "Not satisfied" and 5 is "Highly satisfied")	

4.3.1.3
Financial Sustainability

Data should be collected on a regular basis to provide yearly reports.

How many sponsors have funded the project this year?	
How many new sponsors have funded the project this year?	
How many sponsors have renewed their commitment after the first pledge?	
How much did each sponsor provide?	
How many visitors are willing to contribute financially to the project?	
Is the project self-funded?	
To which extent (percentage) does the project rely on donations (rather than on activities which fund it?)	
Where did the funds come from? (Tourist operators, Government bodies, Private sector, Tourists, Local funders, Volunteers projects)	

4.4
Data Analysis of Socio-economic Indicators

Once a questionnaire has been created and questions have been filled in by a representative number of respondents, we propose the visualisation of the results of the IPA through a bidimensional matrix to analyse the answers and identify areas of focus.

First, values should be tested for normality through histograms or boxplot, then a formal test of normality is required to confirm the conclusion from graphical methods. If some of the attributes don't result normally distributed, these should be removed from the analysis [146].

It is important to find the means of the values, the gap between satisfaction and importance and calculate its significance. Given the common problem of "ceiling effect" with respondents often using the highest values of the scale-rating, it is possible to elaborate data (e.g., with multivariate regression) to remove the "ceiling effect".

Values are then represented in a matrix with 4 quadrants having different meaning:

- **Quadrant I high importance, low performance**: Concentrate Here
- **Quadrant II high importance, high performance**: Keep Up the Good Work
- **Quadrant III low importance, low performance**: Low Priority
- **Quadrant IV low importance, high performance**: Possible Overkill

We suggest the use of a 'data-centred quadrants approach' DCQA [151] already adopted in many studies (cited in Lai & Hitchock [146]) setting the cross-points from the calculation of the empirical means of the data (Fig. 74). The means of the importance and satisfaction values (either direct ratings or elaborated data) are therefore used to identify the axis of the matrix with importance in the y-axis and satisfaction in the x-axis and values are then represented in the matrix. This enables practitioner to identify areas of focus.

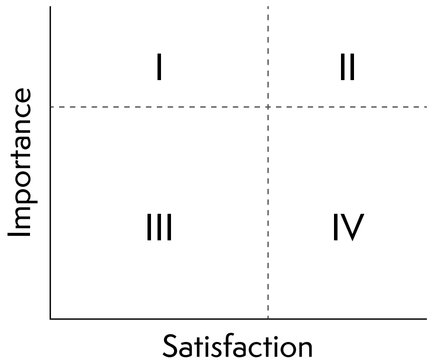
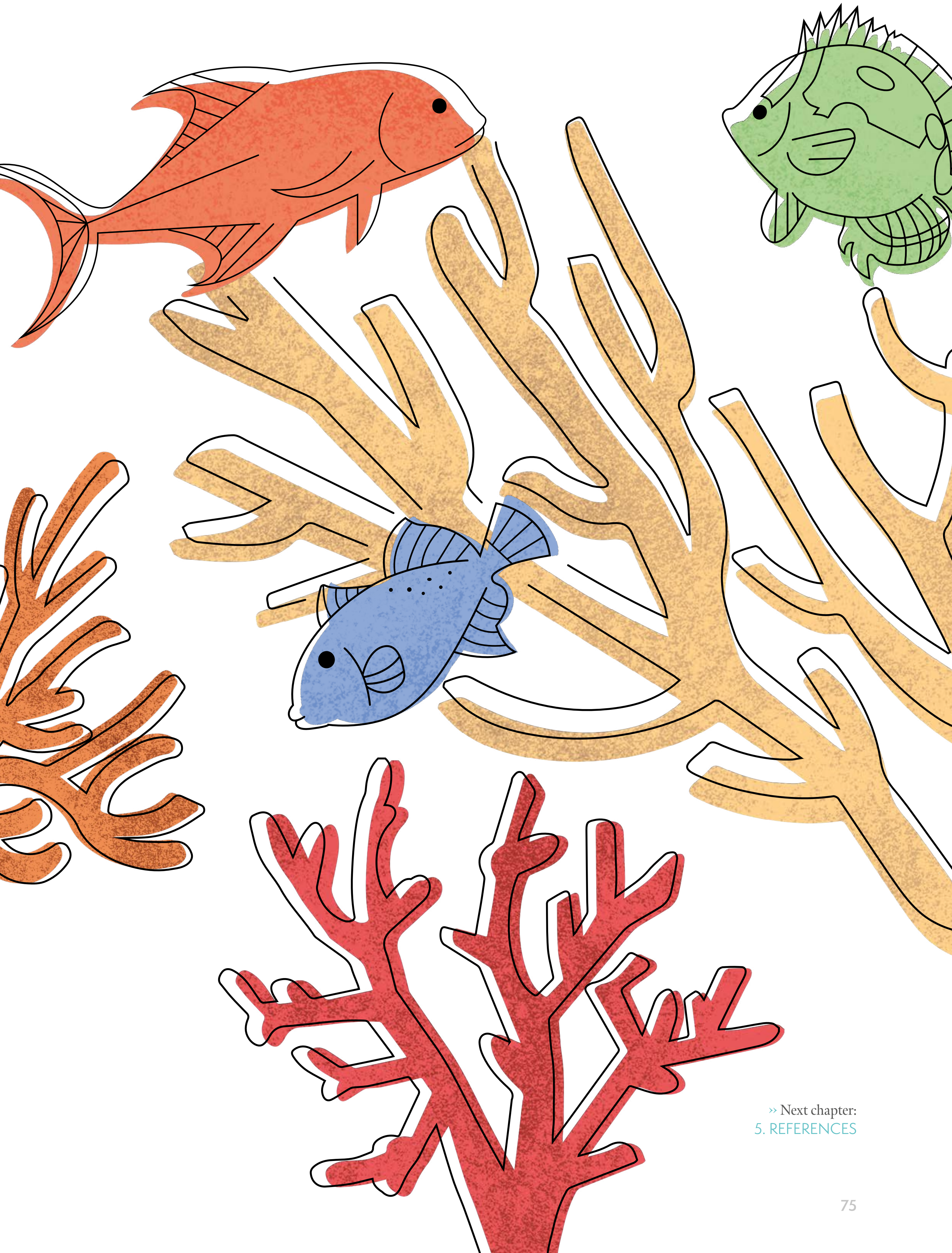


Figure 74 - Data-centered quadrants approach.

The questions on outreach and economic impact can be analysed directly (e.g., through histograms) to understand single responses (e.g., nationalities or skills of the respondents) and make comparison and statistical correlations which can provide insights that might become helpful from a management point of view (e.g., identify certain category of people more prone to get involved in projects). All of this information will allow practitioners to create an annual report for all the stakeholders and thus communicate efficiently and consistently their results.

4.5
Database

As highlighted in the whole manual, once data have been collected for each project, it is important to gain an understanding of the cumulative efforts in coral reef restoration in the Maldives.
On the Maldivian National Coral Reef Monitoring Framework website (https://sites.google.com/view/coraldatabase/home?authuser=1), it is possible to download the most up to date version of the protocol and datasheets, and submit data after surveys, thus providing an active contribution.



›› Next chapter:
5. REFERENCES

5. REFERENCES

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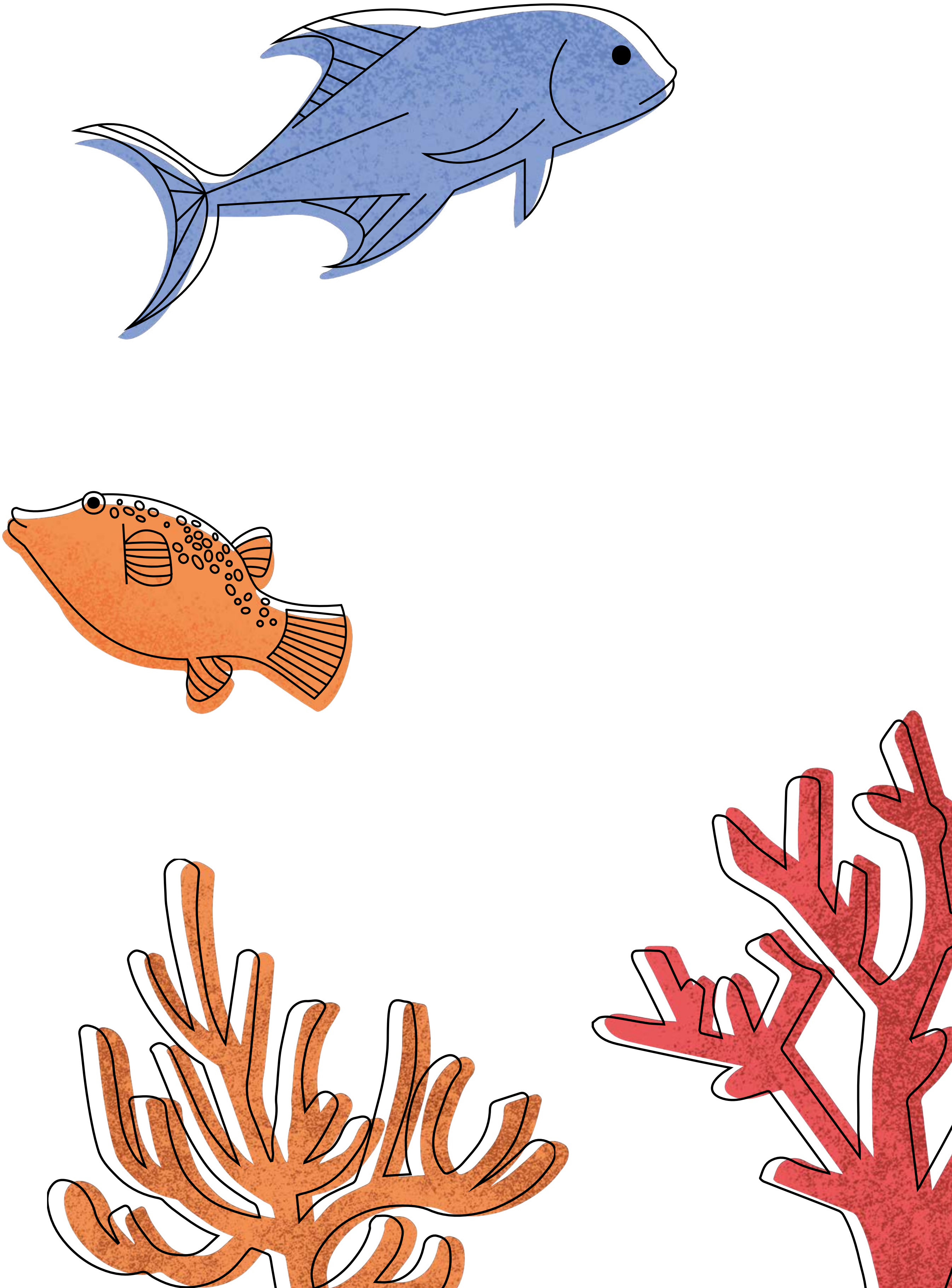
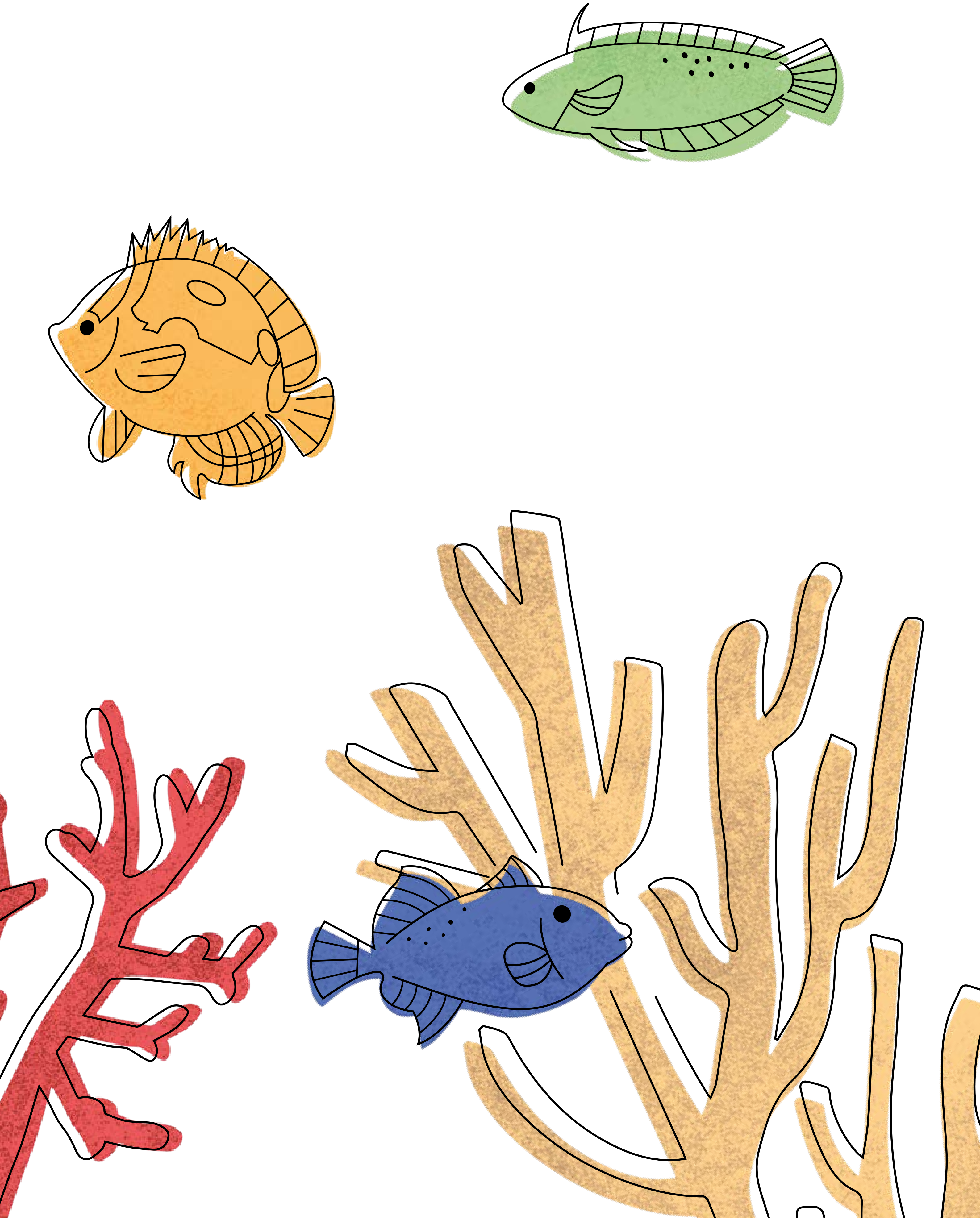
NOTES





Coral Reef Restoration
Monitoring Manual
Maldives

University of **Milano-Bicocca**

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