TRAINING GUIDE FOR
CORAL REEF RESTORATION

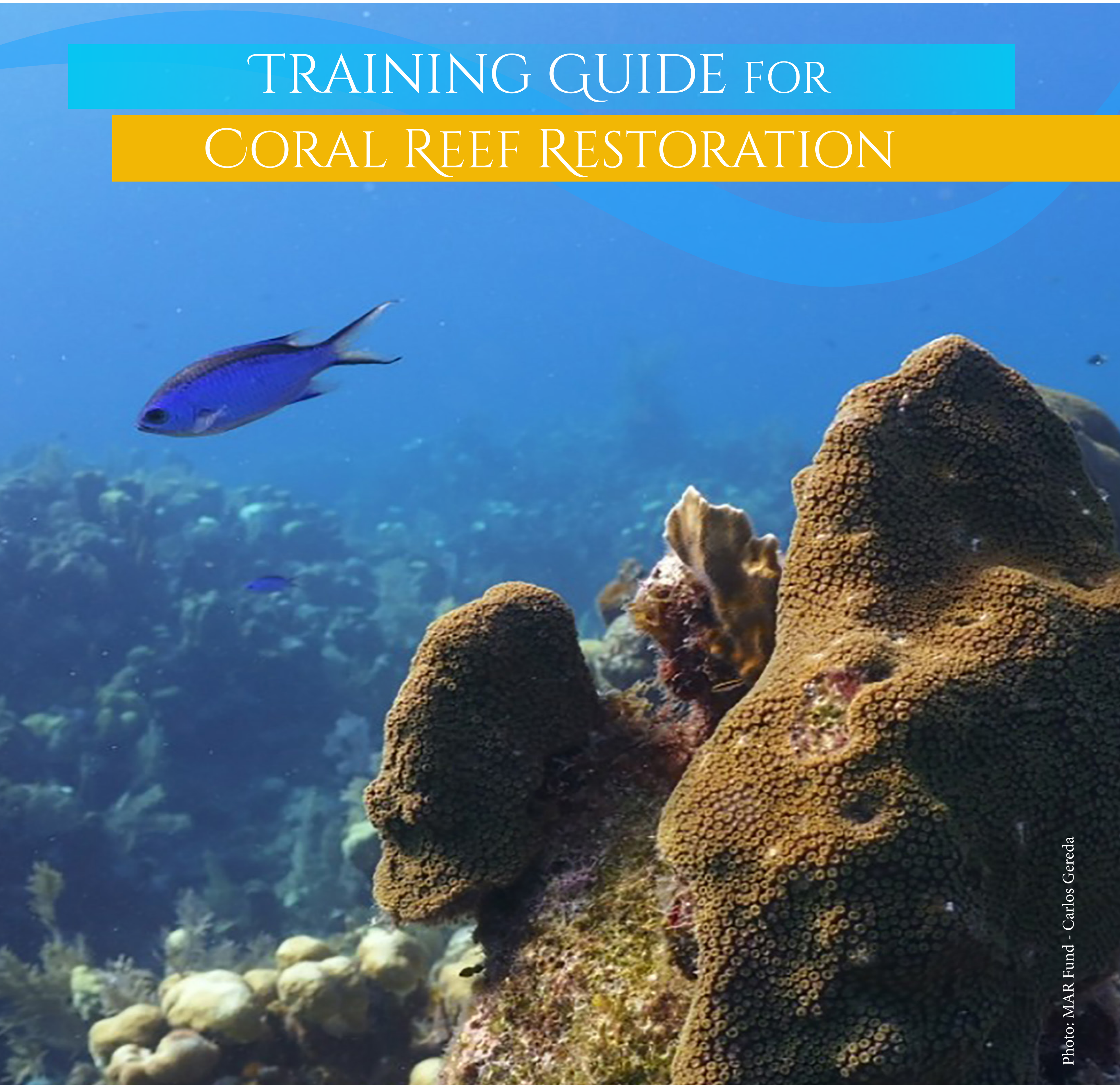

Photo: MAR Fund - Carlos Gereda

COMISIÓN CENTROAMERICANA DE AMBIENTE Y DESARROLLO

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DEUTSCHE ZUSAMMENARBEIT

Mesoamerican Reef System

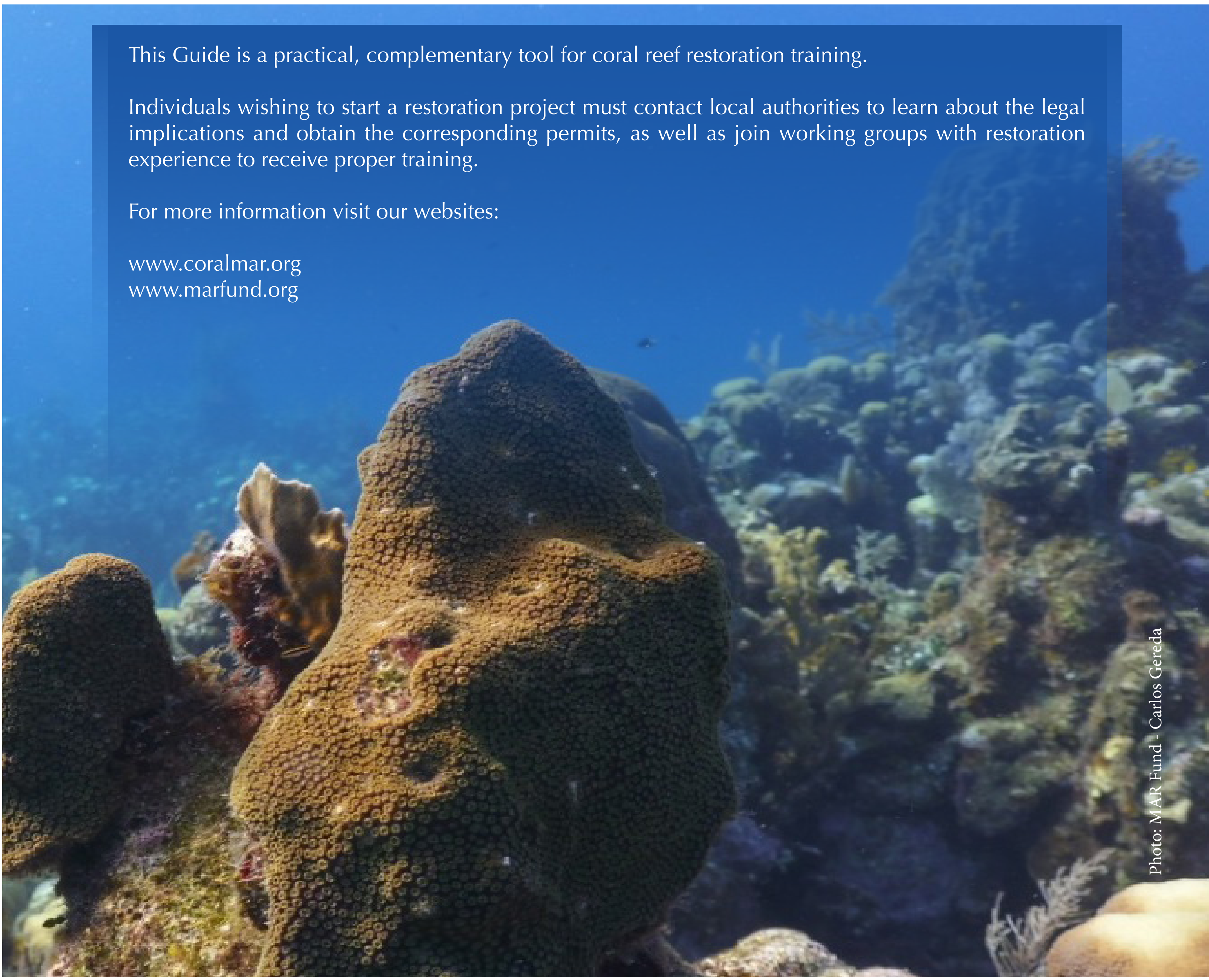
(MAR Fund) Reef Rescue Initiative

This Guide is a practical, complementary tool for coral reef restoration training.

Individuals wishing to start a restoration project must contact local authorities to learn about the legal implications and obtain the corresponding permits, as well as join working groups with restoration experience to receive proper training.

For more information visit our websites:

www.coralmar.org
www.marfund.org



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ICRI

UN environment United Nations Environment Programme

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This document was prepared by Mesoamerican Reef Fund (MAR Fund), Mesoamerican Reef Rescue Initiative (RRI) with the support of the International Coral Reef Initiative (ICRI) and the Small Grants Program for United Nations Environmental Programme (UN/UNEP).

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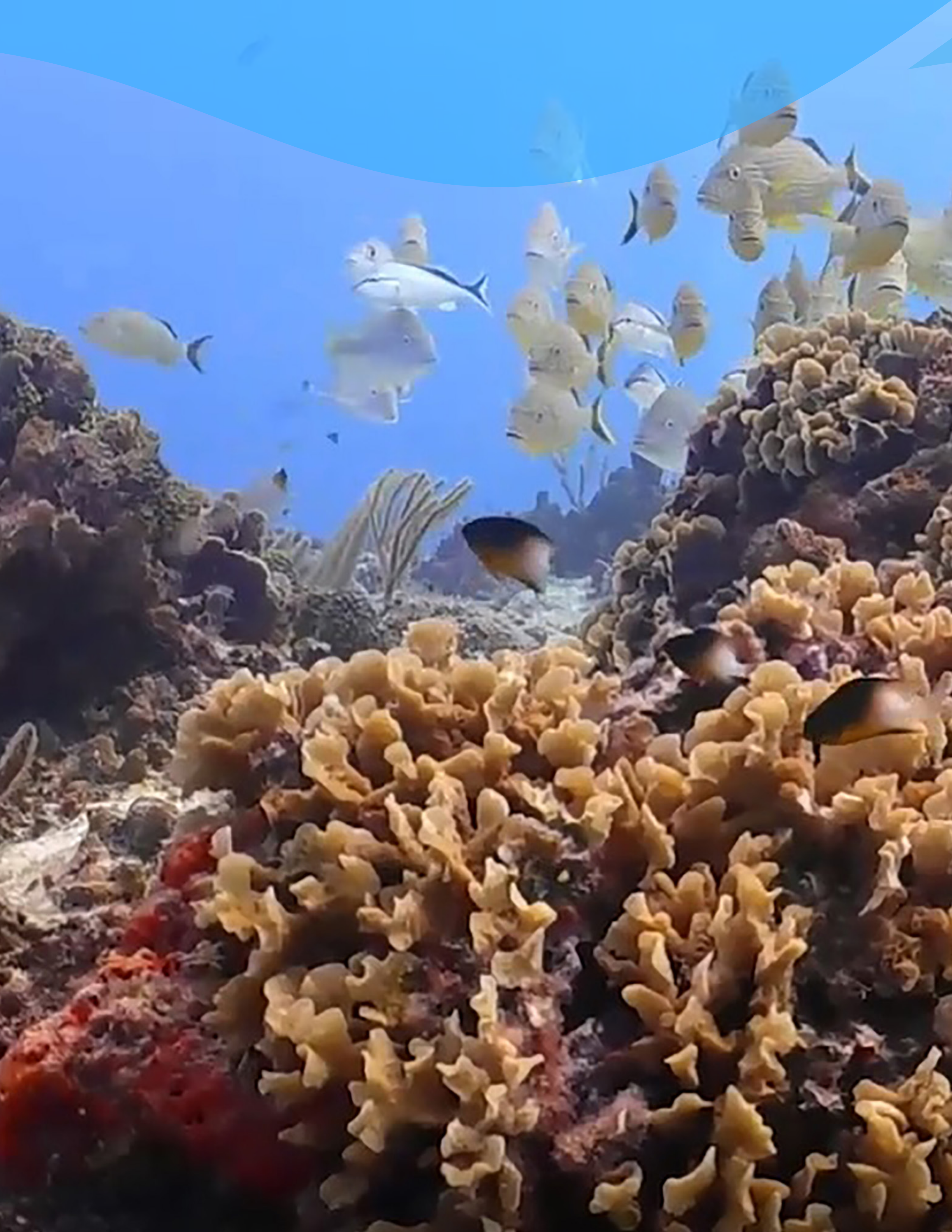


CHAPTER 1

THE MESOAMERICAN REEF SYSTEM

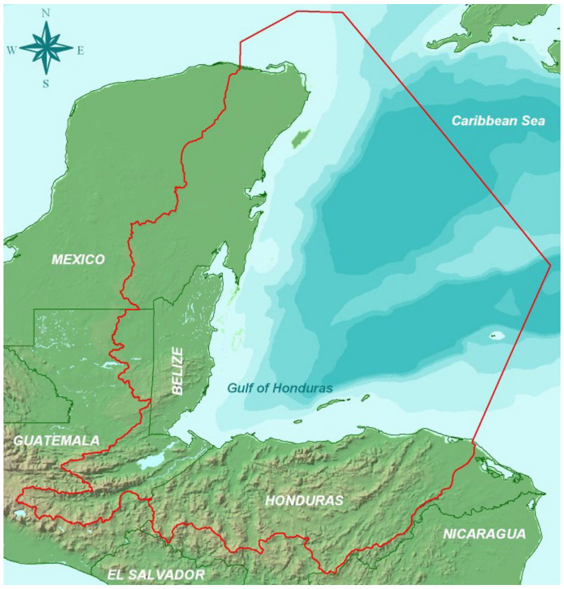
Photo: MAR Fund - Carlos Gereda

1.1 THE MESOAMERICAN REEF SYSTEM (MAR)

The Mesoamerican Reef System stretches over one thousand kilometers, from Isla Contoy in the Yucatan Peninsula, Mexico, down to the Bay Islands in Honduras, including the coasts of Belize and Guatemala.

It is the largest coral reef in the Western Hemisphere and the second largest in the world after the Australian Great Barrier Reef. It is home to more than 65 species of hard corals and has valuable concentrations of mangroves, as well as seagrass. It is the habitat for over 500 species of fish, more than 350 species of mollusks, and also to protected or endangered species, such as the manatee, the marine turtle, the whale shark, and acroporid corals, commonly known as elkhorn and staghorn corals.

That is why the MAR constitutes a vital place for the protection of biodiversity and the preservation of ecosystemic services that are essential to humankind.



1.2 BENEFITS OF THE MAR

The Mesoamerican Reef System supports over two million people who directly or indirectly depend on the resources it provides.

Millions of tourists visit the MAR region every year for the coastal and marine attractions. Tourism and recreational activities like diving generate a substantial source of employment to the residents of the coasts in the four countries that make up the MAR.

Photo: David Mejia Suansin

Fisheries provide food to all the populations of these countries and are the primary source of employment for local fishermen. The fisheries in the MAR, such as lobster, halibut, conch, and snapper, among others, are important at local, regional and international levels.

Additionally, the reef structure is the first barrier protection for the coast, because it absorbs up to 99 percent of the wave energy from surges, storms, and hurricanes.

1.3 THREATS TO THE MAR

The spectacular beauty of the MAR landscape makes it a tourism destination of high importance, while the availability of its natural resources attracts the presence of industrial and agricultural activities. Also, the abundance of aquatic species supplies the commercial fisheries of the region. Although many of these activities stimulate the local economy, they also compromise the integrity and health of coastal marine ecosystems of the MAR region.

The most relevant threats to the MAR include the following:

1. The most important fishery resources in the region have rapidly been depleted, given the excessive amount of traditional and commercial fishing vessels that compete in a poorly regulated environment with free access.
2. The high rate of coastal development has exceeded the capacity of the local infrastructure, which causes the spill of urban and industrial waste into coastal waters and the reef.
3. The exponential increase of cruises and development of hotel compounds, from the Yucatan Peninsula down to Belize and north of Honduras, is scaling up activities such as deep diving, snorkeling, and other aquatic sports, more than the system is able to support in the long term. This puts greater stress on the reef.
4. Large-scale agroindustry applies pesticides across thousands of hectares, and runoff drains into the Caribbean. Small farmers, on the other hand, do not have other options than to keep practicing slash-and-burn farming.
5. Manufacturing and textile processing plants depend on the water from the nearby rivers, which produces industrial runoff that spreads from the Atlantic coast of Guatemala and Honduras to the reef.

1.4 ABOUT THIS GUIDE

This guide is a practical tool for specialists, students, technicians, trainers, and the general audience, who are interested in implementing activities in the MAR or any other place where it is necessary to apply the appropriate techniques for coral reef restoration.

This guide combines knowledge and experiences of coral reef restoration and rehabilitation specialists. They have implemented restoration projects and strategies across the barrier reef in the four countries of the MAR region.

Photo: Claudia Ruiz

CHAPTER 2

INTRODUCTION TO CORAL REEF RESTORATION

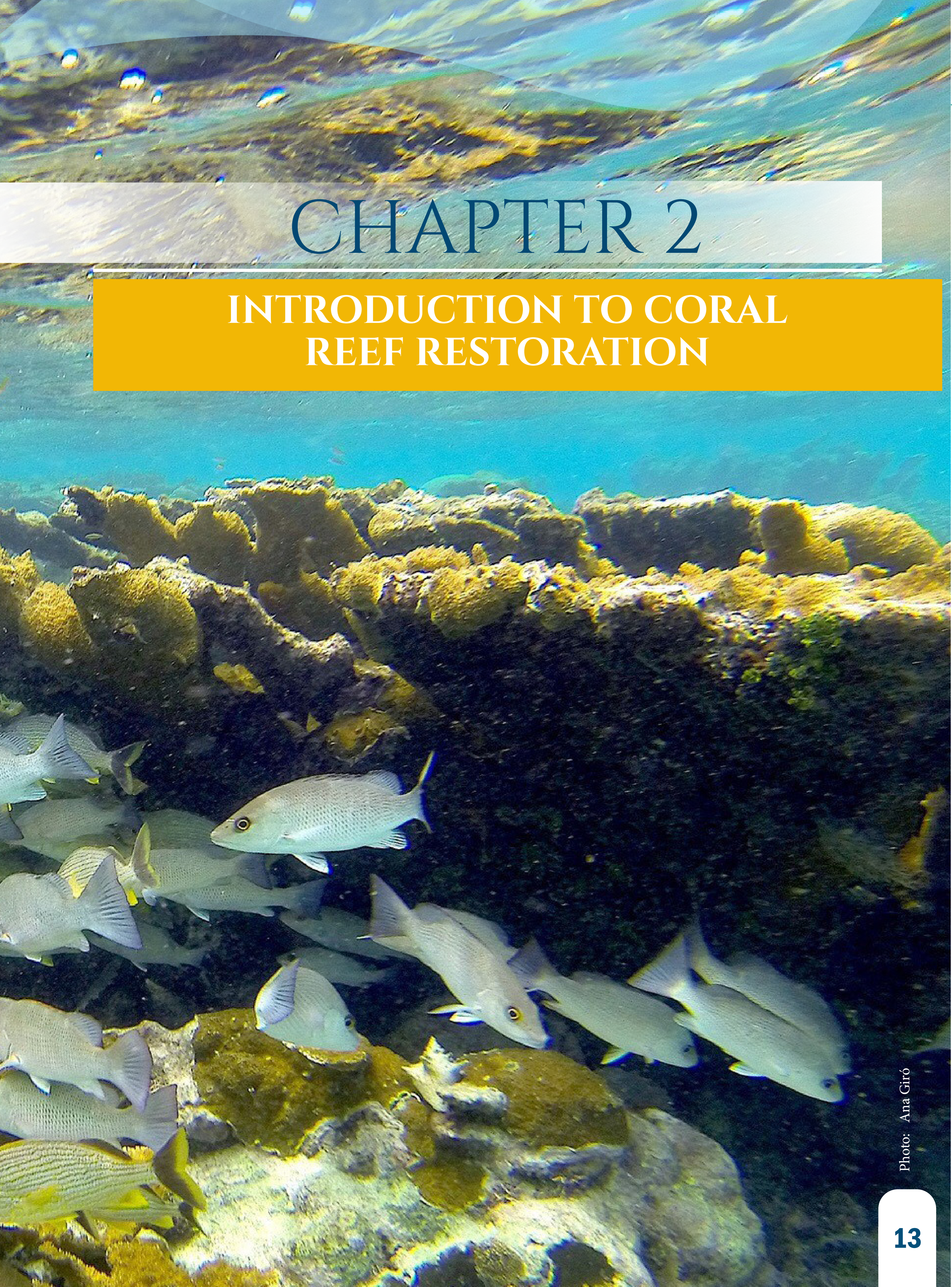


Photo: Ana Giró

2.1 THE BENEFITS OF RESTORATION AND CONSIDERATIONS PRIOR TO ITS IMPLEMENTATION

Global degradation of coral reefs has reached a critical point. Local conservation strategies and natural recovery processes alone can be less effective in preserving and restoring reef biodiversity and integrity over the long term. That is why researchers and managers are addressing reef restoration as a strategy focused on mitigating degradation patterns and increasing the recovery potential of damaged and depleted coral populations.

Coral restoration consists of the processes of recovering reefs that have been damaged or disturbed in their physical, biological, or functional integrity by implementing actions to revert it, as much as possible, to its original state.

Restoration actions may be passive. They involve management actions to control the activities that affect the reef indirectly (as when land-based contamination is mitigated). They can also be active actions when human intervention is involved in accelerating the recovery process (as outplanting coral onto the reef).

Coral reef restoration techniques are a tool in the attempt to respond to human impact on reef areas. If these techniques are used together with other interventions of local management, such as development and implementation of regulations and public policies, creation of natural protected areas, pollution management, good tourism practices, good fishing practices, good navigation practices, the maintenance and strengthening of technical capacities, among others, the resilience of the ecosystem could be improved. Thus, coral reefs could have at least a chance to survive as productive and functional systems in the face of global impacts, including the effects of climate change.

Due to the importance of reefs, any effort that may contribute to its resilience and ecosystemic services supplied to communities is reflected in the reasonable use of resources. It is important to have in mind that active restoration is not an alternative to effective coastal management. That is, there is no point

Photo: MAR Fund - Carlos Gereda

in implementing resources and work in places where there are no regulations for human-induced pressure and no adequate management plans.

In fact, restoration projects should be seen as one component of a comprehensive coastal management plan, agreed upon with all decision-makers of the area, and not just an isolated action. Ideally, a comprehensive management plan should be developed to address or solve aspects related to the quality of local environmental conditions (nutrient runoff, sedimentation, overfishing, tourism, etc.) that occur as a result of human activity, prior to the implementation of any active restoration project.

When an effective strategy has already been set up, all restoration efforts effectively contribute to recovering the reef. This ideal situation can be difficult to achieve. Finding the right moment where functional and sound management conditions coalesce with the requirements for restoration actions to be significant over a medium and long term can be complicated. Hence, the need to design a scheme for strategic planning that is conscientious and suitable for the target site in order to reduce the risk of failing or increasing the cost-effectiveness of interventions.

2.2 PLANNING

After understanding that the active reef restoration program is to be defined only as an option within a more comprehensive coastal management plan, we can move on to the planning phase.

2.3 INITIAL SCOPES

The early phase includes reviewing the initial scopes of the restoration project. To that end, the following questions should be answered in order to include key factors that make the active restoration a feasible option in ecological, social, economic, and political-legal terms.

What kind of coral community did the site support before it was disturbed?

What kind of coral community can survive today in this place?

What caused the deterioration of this place? Have the causes of degradation already been stopped?

Does the substrate require stabilization?

Photo: MAR Fund - Carlos Gereda

To answer these questions, it is essential to have or generate knowledge about the ecological condition of the reef, as well as the environmental conditions, in order to be able to identify the sources of damage. Once they have been identified, it is important to work on the necessary management context to keep them under control so that they don't compromise the corals outplanted on the degraded site.

Pay attention to the effects related to water quality, the condition of populations of herbivore fish, the components of the substrate cover focusing on macroalgae, and coral recruitment.

If the substrate of these zones which have suffered destruction, physical damage, or considerable loss of the structure has not consolidated well, it is probably necessary to stabilize it before beginning the active restoration. Stabilization processes are generally costly and complicated and depend on the level of exposure to currents and waves. However, once these measures are necessary, and there is proper funding, this is the initial action for an effective restoration process.

2.4 OBJECTIVES AND ACTIONS

Clear objectives allow evaluating the project's success and learn from the obtained lessons. The design of a detailed restoration plan and timeline allows identifying the participation of decision-makers on more specific objectives and when they will be achieved. These objectives need to be realistic and verifiable using indicators that help detect the scope of objectives, one by one, in the agreed time, and need to be monitored with adequate methods for each one of them.

For example:

Objective	Increase the live coral cover by 10 percent at the end of year 1.
Actions to execute	1. Implement campaigns to outplant fragments from donor colonies. 2. Monitor the survival and growth of fragments, including their maintenance.
Performance indicators	Outplanting 10,000 fragments from the pruning of donor colonies.
Verification means	Survival of 70 percent of colonies and increase the coral cover by 20 percent on the reef habitat.

2.5 FEASIBILITY STUDY

Additionally, it is essential to conduct a feasibility study of restoration projects, for which several factors should be taken into consideration, such as the geographic location, the site ecology, the available human resources, and financial resources. The first task is to quantify the scale to which the project is working in order to start the restoration, as well as the feasibility under such ecological conditions. This consists of making field visits to collect and systematize information of the site and neighboring reefs, in order to determine if it is possible or worth it to carry out intervention actions. This process allows linking restoration objectives with available resources and adjust them as appropriate (raise more funds or readjust objectives).

The next step is to identify which areas within the degraded site are likely to be restored, depending on the approach to address the damage, objectives, and available funding.

Once the sites for restoration have been selected, it is important to define the type of reef community to be restored. The presence of former and current colonies, their condition, and the diversity indicate what was there before. However, knowing the current ecological conditions determines how much these same coral communities are able to survive when they are outplanted onto the site.

If it is possible to find a "site of reference," that is, where live coral colonies are still found showing the type of community that used to live on this site, it can work as a guide to establishing which species to outplant, at what density, and the kind of combination, in order to achieve an optimum restoration of the area. Sometimes, when there are no points of reference, pilot experiments help define which species work best for these actions; however, this has a cost and time to determine their survival potential.

The cost of the intervention strongly depends on the area to be restored, which must be taken into consideration from the beginning because, again, it hinges on the scale, objectives, and available resources.

The selection of species to be used for restoration is subject, as mentioned above, to the presence of reference colonies surviving on the site. These reference colonies do not reproduce yet; they are only used as a guide. The use of branching corals of rapid growth (acroporids) helps to quickly generate a structural complexity, which provides shelter to small fish and invertebrates. Massive species such as Orbicella, Siderastrea, or Porites grow slower, yet they can be more resistant to diseases or predators. The idea is to outplant a diversity of species with those already present in the area to minimize risk and increase outplanting efficiency.

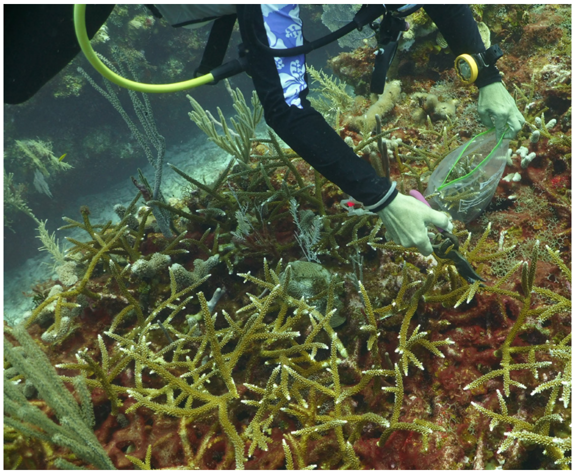


Photo: MAR Fund - Carlos Gereda

Strategies that include mapping of the existing coral colonies, which can be used as donors, and show genetic variability, help accelerate the natural recovery processes of the reefs. Make observations to detect coral slicks nearby restoration sites and nursery facilities, in order to ensure that corals can recover by themselves among resilient sites.

Experience suggests that the sites that contain donor colonies should be between 30 and 60 minutes away from restoration sites to be able to transport them in healthy condition. These colonies can be obtained from "fragments of opportunity" or fragments removed from intact colonies on sites of reference or similar reefs. To that end, the amount of material to be extracted without causing significant damage to donor areas must be estimated. It is often viable to remove 10 percent of fragments from the donor colony in the case of branching colonies.

2.6 POLITICAL AND LEGAL BASIS

This section may be very important when conducting the project's feasibility study. Many times, restoration projects would be using endangered coral species or under management restrictions due to their critical conservation status.

That is why it is essential to thoroughly review the status of coral species in the region where the project is to be implemented, to have in mind all the necessary processes for the application of special permits issued by government agencies in charge to enforce environmental legislation, especially, for managing restoration activities.

Occasionally, these permits can take too long to issue, depending on the requirements that each government has on each region or country. This delay can strongly influence the feasibility of the projects when they are being designed or implemented.

When taking into consideration all the points mentioned above, it is clear how feasible a project can be. If the project is affordable, then a detailed restoration plan can be developed, including the design of activities and requirements essential for its implementation. Human resources and available funding must be taken into account as well.

Photo: MAR Fund - Carlos Gereda

CHAPTER 3

RESTORATION OF CORAL REEFS

ASEXUAL REARING TECHNIQUES OF CORAL

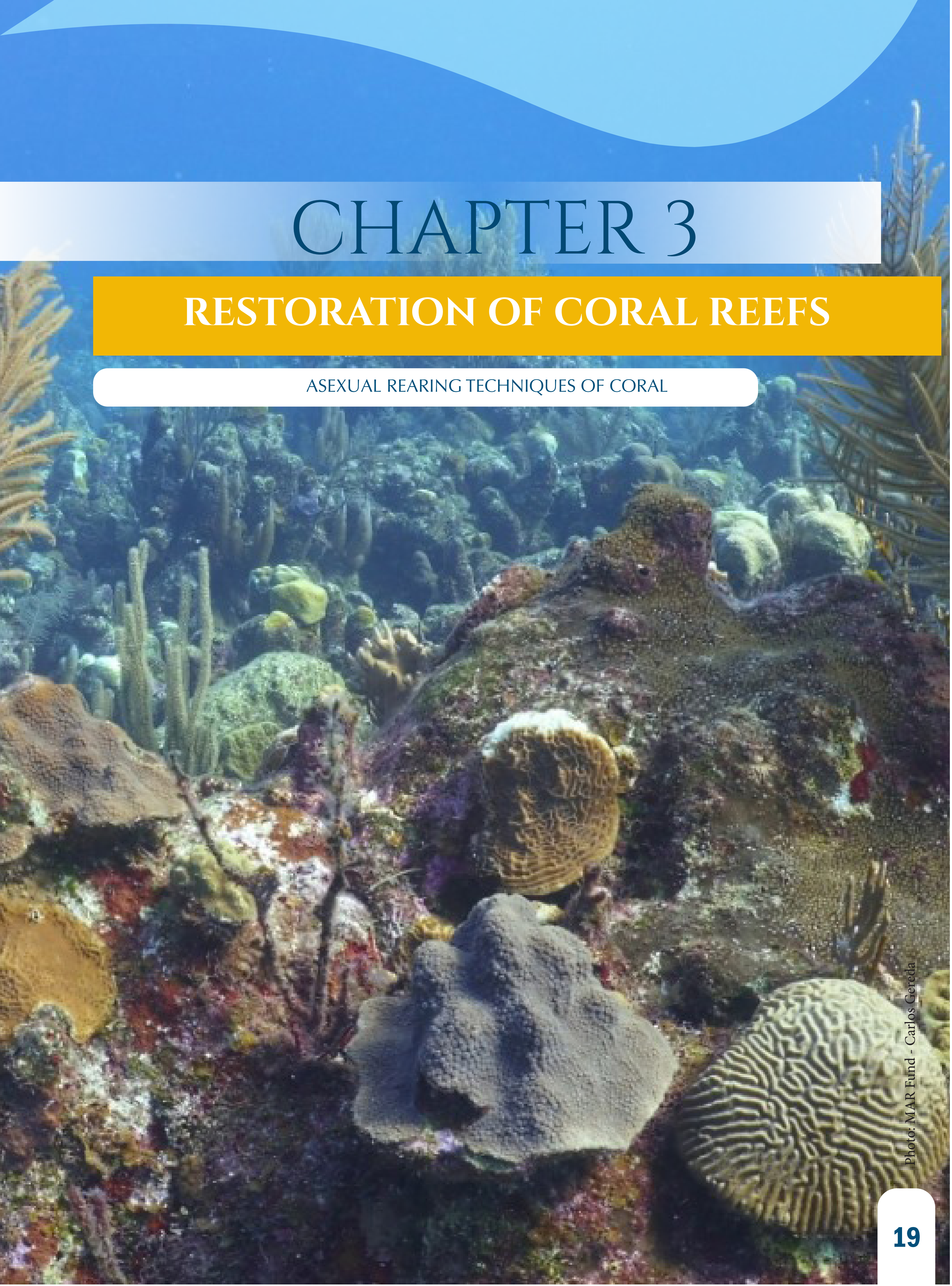


Photo: MAR Fund - Carlos Cereda

3.1 Asexual Reproduction

Asexual reproduction of corals can be either through budding (a process in which the coral polyp is divided into two identical polyps) or through fragmentation (in which a colony is broken off, and fragments grow as individual colonies genetically identical).

3.2 Asexual Reproduction Process through Coral Fragmentation

The implementation of coral restoration projects through asexual reproduction is becoming increasingly common. This method involves outplanting corals through fragmentation as a way to imitate and accelerate reef recovery processes.

This technique is appropriate when the goal is to help a population that has lost coral cover and is not able to recover naturally. The implementation of this technique allows corals to “avoid” critical recruit settlement stages, particularly onto substrates less favorable to coral larvae or their survival after they have been attached.

Coral fragments have an advantage over recently settled larvae due to its considerable size, allowing them to have more survival and growth skills, better capability to compete for space, and greater stability on a less consolidated substrate, among others. They also provide habitat faster for other organisms like small fish and invertebrates.

When a portion of coral is broken off, it is called “fragment of opportunity.” It can be taken into a nursery to have it stabilized and generate new coral colonies, which later can be placed back onto the reef in order to promote live coral cover on the substrate.

3.3 Coral Gardening (Rearing in Nurseries)

Coral nurseries are important because they provide a place for coral fragments to survive, propagate, and grow in great quantities. This technique allows to “grow coral seed” from smaller pieces that can be locally reintroduced or provide material for degraded areas in neighboring zones. It is important to mention that asexual fragmentation does not increase genetic diversity.

Photo: MAR Fund - Carlos Gereda

Photo: MAR Fund - Carlos Gereda

Therefore, it is necessary to understand the associated risks and reduce them during the gardening process.

There is a wide range of nursery structures successfully being used today, which vary in shape, size, and purpose. In order to select a suitable nursery, it is necessary to consider several factors, such as the following:

a. The site where the nursery will be established.
b. Environmental conditions of the site.
c. The available financial resources to build it.
d. Maintenance requirements.

The major differences of these nurseries are found in those that are far away from the site *(ex situ)*, or in the site *(in situ)*. Additionally, nurseries can be land-based or ocean-based.

3.4 LAND-BASED NURSERIES *(EX SITU)*

Land-based nurseries are located on the coast, in proper facilities (tanks), out in the open, or contained in laboratories. Some of the advantages of installing land-based nurseries are that coral fragments can be frequently monitored, are less exposed to diseases given the control of environmental conditions, and achieve optimum growth at any time of the year.

Some of the disadvantages include their high cost and requirement of skilled personnel.

Recently, a technique applied in land-based nurseries of some research centers, called microfragmentation, has allowed determining the minimum fragmentation sizes of coral colonies. The advantage is that it allows them to grow at a faster rate than in their natural environment. Micofragmentation is useful to reproduce massive coral species that grow slower and can be reared in land-based nurseries. This is an innovative technique because of a more efficient production of coral recruits to outplant them back onto the reef.

Technical advice for the installation of ex-situ nurseries:

1. For a successful distribution of the water system in the tanks, pumps, valves, pipes, tanks, and a drainage system must be installed.
2. Land-based facilities should be equipped with elements such as a shade using screens that can control light and temperature when the nursery is installed outdoors.
3. The water in the tanks must remain at optimal levels for coral growth.

Both corals and their environmental conditions must be monitored regularly by technical personnel, specialized in nursery management and maintenance.

3.5 OCEAN-BASED NURSERIES *(IN SITU)*

When selecting the optimum site to install an in-situ nursery, it is essential to address the following aspects: water quality, shelter, accessibility, and tide potential. The idea is to place fragments in these nurseries, which must have the appropriate and similar conditions (depth, water temperature, salinity, sedimentation, etc.) in order to survive at the outplanting sites.

Ideally, these nurseries should be installed in places where they require low maintenance and provide a better survival conditions for fragments. This means to ensure they are not subject to get pollution influx, and their water is clear enough to get sunlight and low sedimentation, as well as the conditions without significant changes throughout the seasons (salinity, solar radiation, temperature) in order to avoid additional stress. Although a good exchange of water is beneficial to nurseries, it is important to avoid areas subject to strong tidal currents that could damage the structures.

One of the advantages identified for ocean-based nurseries is their low-cost construction, which allows a greater number of people to take part in coral restoration, and thus reduce financial stress. However, the easy access to ocean-based nurseries is key to quantify visits to the site for maintenance and monitoring. These activities require a significant deployment of logistics (travel to the site, human resources, equipment, etc.). Again, that is why the selection of the implementation site is essential. Then, it is invaluable that local people know the reef site, mainly fishermen, when identifying potential sites to install nurseries.

Photo: MAR Fund - Carlos Gereda

3.6 CONSTRUCTION OF *IIN-SITU NURSERIES*

There is a wide array of nurseries installed in the ocean that have proven to be effective in many coral restoration projects in recent years. Usually, floating or fixed structures may be used to implement them, but it is important to stress that each type of nursery responds to particular objectives and scope of each restoration project, in terms of how easy the installation of nursery structures (and its cost) can be, the type of coral to be stabilized in the nursery, the number of fragments it can contain, the necessary level of maintenance, and how fast fragments can be outplanted onto the reef to improve cost-effectiveness.

Photo: MAR Fund - Carlos Gereda

3.7 FLOATING STRUCTURES

Floating nurseries can be useful when materials are limited, placing fragments at different depths for their photoacclimation. This depends on the outplanting area, when hundreds of corals are being considered for outplanting or if anchoring conditions are the best (coral massifs divided by sand furrows that allow the installation of several adjacent lines). This way, floating structures can be attached to marine soil with anchors or be placed onto old reef structures, or suspended at mid water using floats or on the surface. These structures should be in places where they do not represent a risk to boats, and at the depth where stabilized fragments are intended to be outplanted.

The following are examples of these structures:

a. Horizontal line nurseries
b. Floating frame nurseries
c. Coral tree nurseries

Technical advice:

1. PVC pipes, anchors, and floats may be used to build a coral tree. Anchors can be 25-kg concrete slabs or foundations, anchoring lines between 1.5 and 5 meters long. Buoys are made of 5 to 10 liter (L) plastic containers, with synthetic lines to connect buoys submerged at 2 to 3 m from the surface. The weight of the nursery can be estimated taking the weight of the colony and multiply it by the total weight of the nursery, or by adding buoys to the system until the nursery remains in a positive buoyancy and the structure maintains the tension. Fragments may be secured to the structure with tarred twine or plastic ties (although it is best to avoid less environment-friendly materials).

2. In line nurseries, rope is used, coated with plastic (to clean the line easily), as well as PVC to join the anchoring line. Or it is simply tied to concrete foundations in the reef, between the massif systems and furrows. Tension is adjusted, and buoyant structures are applied to keep it horizontal.

3. In nurseries with floating frames, a grid is used to support the coral fragments, fixed to the center with a plastic line, and buoyant elements are added at the edges, on lines approximately 1 to 2 m long, anchored down with stainless steel rings to concrete foundations of 20 to 40 kg, depending on the support requirement. The number of anchors and floatation devices to maintain a positive buoyancy depends on the number of grid frames.

3.8 FIXED STRUCTURES

Fixed structures are anchored to marine soil and are the best option for shallow-water settings. There is a wide range of these type of nurseries, which consist of modular structures with the capacity to hold hundreds and even tens of thousands of fragments.

These are some of the structures:

a. Block nurseries
b. Dome nurseries
c. Table nurseries

Technical advice:

1. Fixed structures are built from a metal grid, PVC structures, blocks, etc. The idea is that the structure is placed horizontally over a stable substrate, such as sand or limestone, and that the attaching surface (either with concrete or metal angle bars) is able to withstand the impact of waves and surges. PVC is commonly used to build tables or trays, as well as chimneys on which corals are attached at the top, embedded on a concrete "cookie," or attached onto limestone, in pipe systems over concrete slabs. Any species can be reproduced on these types of nurseries.

2. Other structures combine ropes with suspended lines like the line nursery, which are suspended in a structure such as a metal table, 10 m long by 1.15 m wide by 2 m tall.

Photo: MAR Fund - Carlos Gereda

Corals are placed onto the lines, separated 10 to 15 cm between them, either in the line twists or with tarred twine or plastic ties. Not all species can be placed in this type of nursery (for example, massive or slow-growth species), but branching species seem to do well. These nurseries can be more expensive than the previous ones. They also allow a faster transplant of corals because lines can be placed over the reef, as they are, with colonies growing on the rope.

3.9 STEPS TO ASEXUAL RESTORATION THROUGH FRAGMENTATION

Below is a specific list describing the steps to implement a restoration plan through fragmentation, taken from a research of some projects executed in the MAR, mainly with branching corals such as elkhorn *(Acropora palmata)*, staghorn *(Acropora cervicornis)*, and some massive corals *(Orbicella faveolata, Montastraea cavernosa, Porites astreoides, and Siderastrea siderea)*.

3.9.1 Site selection

The site selection process can help determine if active restoration is an appropriate management strategy and which methods are the most suitable for the project. Also, it helps quantify the scale required for the coral outplanting, as well as locating areas that can increase the chance of success of outplanted corals, and, finally, to determine the feasibility of the project.

Three main factors that help determine which areas should be restored:

a. The ecological history of the site
b. Biological and physical characteristics of the site
c. Restoration feasibility

Photo: MAR Fund - Carlos Gereda

Site history

Sites should be selected where there are coral species to be restored. When it is not clear what kind of natural communities existed before on the degraded site, it is important to look for reference sites or communities in the surroundings. These communities may help to determine how conditions of the site have changed as to no longer allow coral species to grow. If there are no reference sites, then poor environmental conditions could be an indicator preventing a successful restoration, besides being a strong factor for the feasibility of the project due to the potential difficulties of finding donor colonies.

Site conditions

If the main reason for restoration is to strengthen the population of a particular species, then it is essential to find indicators that suggest a suitable environment for this species. On the other hand, if the goal of the restoration is to improve ecosystemic services, such as fisheries or coastal protection, other indicators should be taken into consideration to select the sites. For outplanting activities, managers should select areas that provide optimum conditions for the health of coral communities, with the goal to make them more resilient to stressors, such as the rise in water temperature. With this purpose, a fact-finding mission is advised to compare potential sites and their environmental or ecological quality.

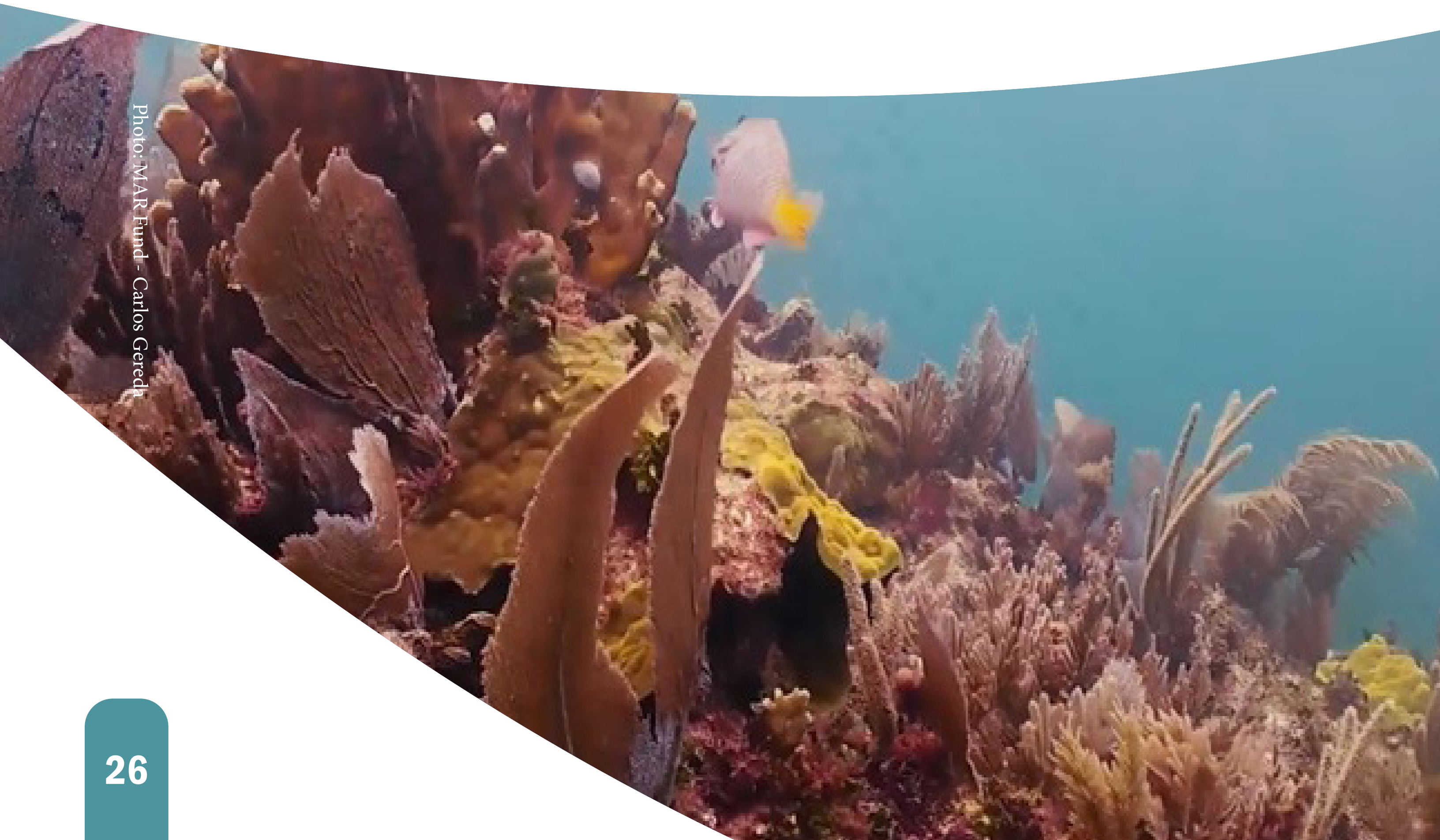


Photo: MAR Fund - Carlos Gereda

The following indicators are frequently used to evaluate the resilience of sites:

a. Existence of wild coral populations and their condition
b. Origin of parent or donor colonies
c. Depth of the site (similar to the restoration area)
d. Type of soil (substrate)
e. Water quality (light, sedimentation, and nutrients)
f. Biological stressors (predators and competitors)
g. Accessibility of the site (for easier intervention logistics)
h. Protected status (optimum in protected areas)
i. Resilience and overall health (conduct prior evaluations)

Site feasibility

In order to determine if the site is feasible, several factors should be considered, such as the size of the restoration area to establish operation costs (technical and scale), and which coral species are most suitable for outplanting. It should be taken into account that a mixed outplanting of branching and massive species allows minimizing risk and increasing the success of the restoration strategy, as well as to determine the local source of coral fragments for nurseries and outplanting. Proximity to intervention sites is important.

Photo: MAR Fund - Carlos Gereda

Photo: MAR Fund - Carlos Gereda

3.9.2 Collection

Either to stock natural material for stabilization at in-situ or ex-situ nurseries or outplant directly through assisted dissemination, active restoration actions must obtain material from parent or donor colonies. It is fundamental to ensure that the collection of fragments causes as little collateral damage as possible to healthy reefs.

Harnessing corals of opportunity

These are fragments found at the bottom, in separate colonies or recruits on unstable substrates, unlikely to survive naturally. However, they could survive if they are stabilized in the nursery. Commonly, they belong to branching species, but an abundance of fragments of opportunity of massive species can be found after damaging events such as boat grounding or storms.

Fragments of opportunity are easy to collect and can be transported to land- or ocean-based nurseries to be stabilized. Small fragments can be trimmed to remove dead, moribund, or diseased tissue. Larger pieces may need to be further fragmented by cutting with pliers to obtain the desired size. An approximate size of 5 cm is recommended.

Fragmentation of donor colonies

In branching colonies, branches should be carefully cut in 5-cm pieces approximately, and better yet if it has new branching at the tip. Also, cutting pliers must be used. As a cautionary measure, cutting more than 10 percent of the donor colony is not advised. This reduces the probability of the colony getting a negative impact. Wear cotton or surgical gloves, and be sure to hold part of the colony during the cutting, since a strong force might lead to breakage of other parts of the colony as well. Try to choose parts of the colony that already show signs of harm (tips of branches with the base covered by algae or colonies close to other neighboring colonies).

In order to collect fragments of massive, encrusting, or foliose species, it is advisable to use a hammer and chisel. Preferably, fragments must be taken from the edge of the colonies to minimize impact and facilitate healing. Cuts must be performed diagonally or vertically to the surface of the colony to minimize the amount of skeleton removed and the amount of surface exposed to the attack of encrusting or boring organisms. For example, in elkhorn corals *(A. palmata)*, cuts must be made in wedges, similar to a slice of pizza. And as for O. *faveolata*, cuts must be made at the lower skirts of the coral structure.

Technical advice:

1. Before starting any kind of collection, make sure to have all the locally current permits for the collection sites.
2. Collect, if possible, only from healthy coral colonies.
3. Collect less than 10 percent of the colony to minimize the damage.
4. Remove dead tissue before transportation and reduce the thickness of the skeleton as much as possible in massive species.
5. After cutting, remove tissue and skeleton debris by shaking them in fresh seawater.
6. Use plastic containers (resealable storage bags) but resistant, suitable for fragment collection and transportation.
7. Place each genotype in separate containers to avoid harmful interactions.
8. When coral is brought to the surface, be careful not to keep it more than 60 minutes on the deck of the boat, keep on the shade, and moisten it with clear seawater to avoid stress.

3.9.3 Transportation to the nursery or outplanting site

Coral fragments should always be transported in plastic containers to move them easily and safely to the nursery. Using large coolers with opaque lids is the most convenient way to carry them.

If corals need to be transported a long distance from the collection site or origin to the nursery or outplanting site, the containers must have the right size to fit the volume of fragments collected. Moreover, seawater in these containers should differ only one or two degrees from the temperature of the site where they were extracted.

If colony fragments are to be transported during a spawning event, it is important to bear in mind that keeping them in darkness may lead them to spawn prematurely. Therefore, it is recommended to expose them to the light of day by opening the lids of containers every 15 minutes approximately, and minimizing the time of transportation as much as possible. If the transportation takes too long, colonies must be aerated using a battery-operated aeration device, or, if possible, apply seawater exchanges for that purpose.

3.9.4 Attaching fragments for stabilization in nurseries

When fragments are transported from their original site (either collected from donor colonies or brought from other nurseries), they should be attached to nurseries to start the stabilization phase under the site's conditions.

How they are attached to a temporary substrate to maintain them for an adequate amount of time corresponds to the type of nursery used, so that they can adapt and grow. The selection should be based on the project's objectives and the target species. It is important to bear in mind that, depending on the time they are expected to spend in the stabilization phase, fragments require some space to spread out, according to their growth rate. This is to avoid contact between colonies, which can lead to physical stress by abrasion and cause bleaching situations, tissue loss, or unwanted fragmentation, derived from the collision between colonies due to currents or the effects of storm surges.

Reviewed experiences show that it is better to attach fragments in a modulated configuration, securing them with tarred twine or plastic ties, to keep different levels between fragments depending on their structure and size, in order to optimize the space between them and the potential number of colonies that are reared in the nursery.

Massive colonies can be attached to nursery substrates (PVC connectors, metal or plastic grids), using epoxy glues, acrylate adhesives, concrete, plastic ties, or nails.

It is fundamental to carefully classify fragments by origin and monitor their response in terms of survival success. This allows identifying and choosing the most resilient genomes and use them for outplanting in order to increase the efficiency of restoration efforts.

3.9.5 Nursery maintenance

The most common activities for regular maintenance in nurseries include the removal (cleaning) of overgrowth of competing organisms on structures or fragments, such as filamentous algae, macroalgae, cyanobacteria, hydroids, or mollusks, among others. It also covers the re-configuration of coral fragments and repair of structures that have been damaged by the effects of surges, currents, or storms.

Moreover, part of the maintenance work in nurseries is re-fragmenting colonies that, due to their rapid growth, it is necessary to trim them and reorganize them on the structure. The purpose is to follow a systematic identification plan of origin, and later determine and select the colonies with the best response to the site's environmental conditions for future outplanting onto the reef.

Technical advice:

1. Remove encrusting organisms that may damage or compete with corals, such as algae, sponges, fire corals, hydroids, tunicates, mussels, and barnacles.
2. Remove, as much as possible, corallivore predators or coral antagonists such as conches and fireworms. And, if necessary, isolate corals from damselfish, butterflyfishes, and triggerfish, etc., on the first days.
3. Stabilize or change damaged nursery structures, such as ropes, anchors, or grids, and adjust the buoyancy of structures in floating nurseries.
4. Re-attachment of fragments detached by physical alterations (surge, currents, fish, etc.).

3.9.6 Monitoring of coral nurseries

It is necessary to continuously monitor coral fragments to assess the project's progress and check the health and condition of reared corals. A regular visual check is usually enough to identify problems in nurseries (overgrowth, mortality rate, or diseases) that require adaptive management. However, systematic evaluations are also required (less frequently) to check the project's progress regarding the objectives of coral production in nurseries as outplanting material.

These actions also help define how frequently to implement nursery maintenance and analyze the feasibility of the project over time. Considering that the site's conditions favor the overgrowth of algae, the cost of the project would be too high because frequent cleaning is necessary more than the expected.

Photo: Marcio Aronne

Technical advice:

The following aspects must be monitored and evaluated:

1. The growth rate of colonies.
2. The coral health, in terms of the presence and percentage of bleaching incidence, disease, tissue loss, and increasing and transitional mortality.
3. The overgrowth of competing and predatory organisms.
4. The approximate size of colonies to determine when re-fragmentation or outplanting should occur in the reef.
5. Environmental variables such as temperature and, if possible, nutrients present on the surface, water column, and sediment.

3.9.7 Outplanting onto the reef

When fragments in nurseries are stabilized and meet the required conditions (size and condition), they can be outplanted back to the reef. This depends on the project's objectives. The outplanting process can be carried out directly without going through the nursery phase of fragments taken from donor colonies (such as the case of actions of assisted dissemination focused on A. palmata).

It is very important to take the necessary measures of reducing the stress on colonies as much as possible during transport and handling for their outplanting.

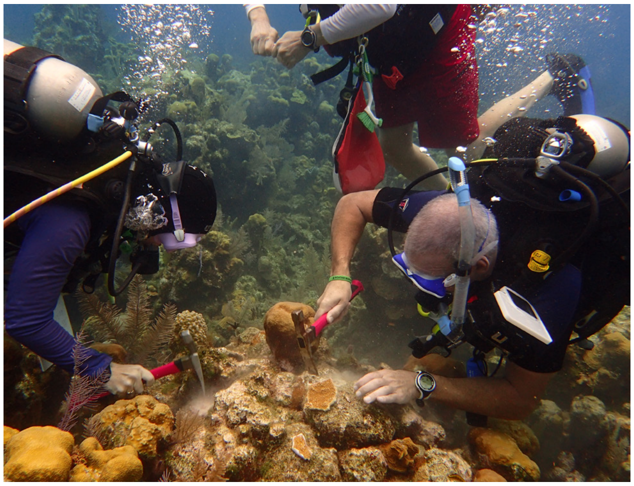
Outplanting methods

The most appropriate technique is determined based on 1) the species of coral to be outplanted, 2) the nature of the substrate of the outplanting site, and 3) the environment of the site.

For an effective method, a good outplanting survival and minimization of the likelihood of colonies becoming detached from the substrate and going adrift must be ensured. However, it depends on the characteristics of the site and substrate. It is common to lose 50 percent of transplants in exposed sites, such as the case of the reef crest.

Most of the corals require a hard and solid substrate to survive, although other species may thrive on sand or small debris. All efforts should be aimed at allowing corals to grow on the substrate (natural or artificial). The attachment of corals by any artificial method must be seen as a temporary measure allowing corals to attach themselves to the substrate through tissue growth. Therefore, attachment mechanisms must be as sound and durable as possible, isolating them from movement, because if they oscillate with the waves, they are not be able to get attached by themselves.

The surface of the substrate where fragments are placed must be as clean as possible from the overgrowth of algae, sponges, encrusting organisms, etc. Therefore, it is recommended to clean the surfaces with wire-bristle brushes. Only live tissue grows on the substrate, and that is why care should be taken when cutting the base of colonies and remove dead patches or areas of exposed skeleton. In general, if corals have few points of contact with the substrate, that should be enough to get attached and grow.



Photos: Roatan Divers

Based on the type of substrate and available materials, fragments could be attached to the substrate with a series of techniques, such as by tying them to the structures of old coral or artificial substrates with nails or wooden pegs. They can also be placed in holes on the reef boulder in sites with protective conditions or using artificial adhesives (epoxy) or support bases (metal or concrete) in zones with high tidal energy.

The most common outplanting method used in coral restoration projects is probably the use of cement and adhesives. This technique is labor-intensive because it involves a hand-made process to provide and mold the concrete base where fragments are to be placed. It is necessary to organize them in a configuration that promotes the fusion of fragments generating a colony with a structural complexity as soon as possible.

Cement, as an adhesive material, is much cheaper than epoxy glue, and it is usually the best choice to attach massive corals after grounding events or hurricanes, as well as in large outplanting operations of small colonies. It is advisable to clean the attachment area with a wire-bristle brush previously.

Photos: Marcio Aronne

Technical advice:

1. Aim to reduce stress on colonies by carefully manipulating and transporting during outplanting.
2. All the encrusting organisms and sediments must be removed from the substrate using wire brushes and scrapers before outplanting corals.
3. It is advisable to outplant branching corals of 5-15 cm in diameter, and massive corals of 4-5 cm in diameter.
4. Do not plant corals if they present abnormal conditions, such as tissue loss, discoloration, bleaching, or parasites.
5. Avoid outplanting corals right after a storm or during the months with the highest water temperatures, in order to prevent increasing the probability of bleaching and the prevalence of diseases.
6. Nails and cable ties often work properly with branching corals in zones protected from wave energy, while cement is a good option in exposed zones to attach both small colonies and massive corals.
7. It is important that corals attached to the reef substrate are securely fixed and in contact with a solid surface, to allow them to attach themselves through basal growth tissue.
8. Set concrete structures where microfragments of massive species will be attached, to provide them with a preconfigured support and help the reef recover the structural complexity as fast as possible.

3.9.8 Maintenance and monitoring of the reef

As in the nurseries mentioned before, intervention zones require maintenance and monitoring visits. They can be costly, given the high costs of coral outplanting. Visits prevent losing many outplanted colonies to predation or algae overgrowth.

It is advisable to tag the outplanted corals to record and identify them (different genotypes or origins) for future maintenance and monitoring activities.

Technical advice:

1. Observe coral growth and record its condition.
2. Clean planted colonies using toothbrushes, because it allows removing algae outbreaks in grooves and crevices between colonies.
3. Monitor the overall condition of the reef site and assess changes in coral cover, the abundance of fish, and the new coral recruitment.
4. Detect and record environmental changes that may compromise the outplanted colonies. Establish a systematic maintenance and monitoring scheme based on observations and recorded data.

The proper use of coral restoration techniques, concurrently with other local management interventions (regulation of fisheries, creation of protected areas, pollution control, etc.), could reduce human-induced impact, improve the ecosystem resilience, and eventually allow reefs to continue being productive and functional.

CHAPTER 4

RESTORATION OF CORAL REEFS

CORAL ASSISTED REPRODUCTION TECHNIQUE

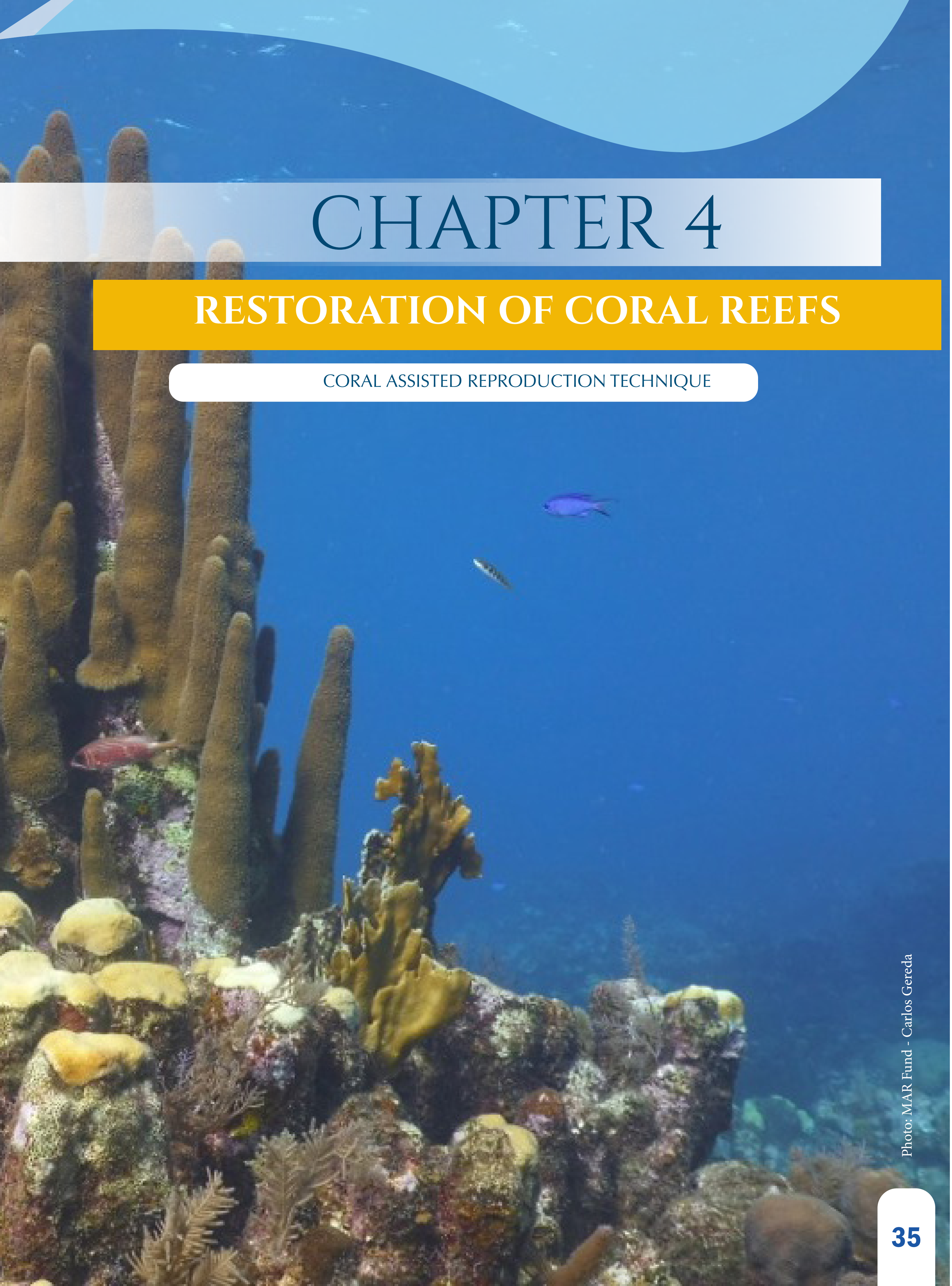


Photo: MAR Fund - Carlos Gereda

4.1 SEXUAL REPRODUCTION

Sexual reproduction is the most important process in the life cycle of corals because it provides genetic variation in order to survive environmental changes.

Sexual reproduction requires the combination of two gametes (sperm and eggs) to produce embryos that will develop into free-floating planula larvae, adapted to disseminate and settle, either in their original reef, in neighboring reefs, or in reefs that are a hundred kilometers away from their origin.

Most coral species reproduce mainly by night, during events of massive spawning, although some reproduce before sunset. Spawning occurs during the warm months of August, September, and October, with a two or three-day frequency, after a full moon.

Species like elkhorn and staghorn are suitable for sexual restoration because they are hermaphrodites. These corals release eggs and sperm from each polyp. Gametes drift in packages to the water surface, where they are easily collected.

In hermaphrodite species, a pink bundle appears at the mouth of the polyp, which is a sign that the colony is preparing to spawn.

For elkhorn coral, Acropora palmata, (one of the most studied species for assisted reproduction), spawning occurs between two and eight nights after a full moon, during summer (mainly in August and occasionally in July or September). Spawning occurs two hours following sunset, and it has been seen that, if there are two full moons in the same month (blue moon), it is possible that the spawning occurs in the same place during consecutive moon cycles.

Coral restoration through assisted reproduction is achieved by the collection of gametes from many colonies, fertilization, embryo development, larval phase, and settlement. The use of corals from sexual reproduction has three key advantages over techniques used in corals obtained through fragmentation. In the first place, there is no need for fragment donor colonies, which reduces collateral damage to reefs. In the second place, corals produced sexually are not clones, which increases the genetic diversity of corals to be outplanted, leading to a successful result in the long run


Photo: MAR Fund - Carlos Gereda


Photo: MAR Fund - Carlos Gereda

in terms of conservation of donor populations. In the third place, it is possible to get high levels of fertilization and settlement (millions of larvae obtained from a few colonies).

Before implementing a coral restoration plan with this technique, it is essential to obtain the necessary collecting permits, issued by the authorities, because the law often protects target species to their conservation status. Moreover, it is strongly advisable to previously consult with experts to know the details and implications of the processes thoroughly.

The method of coral sexual reproduction has particular technical requirements. And, although this method is well known, and it can become a very simple and routinely process, it still needs considerable systematic attention and intensive work. The general processes are described below. However, it is advisable to consult more technical documents with a detailed explanation about each phase of operation for these actions. Although significant progress has been made in the last years, the process of generating corals through sexual reproduction for restoration is still experimental. Therefore, the application scope and the diversity of species to be used is yet limited.

4.2 REQUIREMENTS FOR SEXUAL REPRODUCTION OF CORAL

Before beginning with the procedures to help corals reach their optimum sexual reproduction and the care of recruits in their early stages of development, it is necessary to understand the requirements. In general, the work area must have three basic requirements: work stations, incubators, and filtered seawater.

Technical advice:

1. Seawater must undergo a filtration process through cartridges with pores of 20, 5, and 1 micron, and if possible, with UV filter.
2. Work stations must have the necessary materials to handle embryos and larvae, such as hoses, pipettes, containers of different volumes, tapes, markers, filters, and containers.
3. Incubators in which to keep corals during their development. These must be plastic containers with smooth walls, of 90-L capacity, with drainage valves at the bottom.
4. All materials must be washed with plenty seawater to avoid toxicity in embryos and larvae (especially when using PVC adhesives).

4.3 SPAWNING OF CORAL

There are several methods to determine if corals are close to spawning. The simplest and quickest is to observe the pigmentation of eggs in polyps artificially fragmented in situ. Eggs of species that release gametes become pigmented as the time come to spawning. They become in hues of red, orange, pink, or brown, in some cases. The rule of thumb is that strongly pigmented corals spawn in the next full moon, as it happens with many Acropora species. Even for species with large mature eggs, divers are able to see them underwater with the naked eye.

Technical advice:

1. Conduct a prior recognition of the work site during the day to locate target colonies and anchoring procedures.
2. Locate 5 to 10 healthy colonies ready for spawning, preferably separated by 10 m between them.
3. The optimum sizes of colonies for gamete collection, in most reproductive species, is 30 cm or more.
4. Some 20- to 30-centimeter colonies also spawn.

Photo: Fabián Grageda

Photo: Fabián Grageda

4.4 COLLECTION OF GAMETES

For coral larvae rearing, it is necessary to collect gametes. There are three ways to do this: 1) collect gametes and embryos recently fertilized from the ocean surface where they form spawning bundles; 2) collect gametes in situ with collection devices over mature colonies, and 3) remove colonies from the reef and their maintenance in land-based aquarium tanks or on the boat's deck to allow them to spawn ex situ. This process is not advisable due to the stress on the colonies. Prior to setting out to collect gametes, it is necessary to organize logistics carefully and discuss the work plan so that all the participants understand their roles.

4.5 COLLECTION FROM THE SURFACE IN SPAWNING SLICKS

Following massive spawning events, slicks of eggs and embryos are formed on the surface. Ideally, embryos should be collected immediately when the bundles are produced because, two hours after being formed, they start to drift, then they lose viability and deteriorate.

Technical advice:

1. Collect gametes at the edges of the slick, just below the surface (less than 0.5 m deep) using plastic containers with a capacity between 2 to 10 L.
2. Dip the bucket slowly on the water surface to fill it with water and make sure it gathers a significant number of eggs, sperm, and embryos.
3. Clean the embryos with continuous water exchanges and transport them carefully to the laboratory to count and store them in rearing tanks.

4.6 COLLECTING FROM COLONIES *IN SITU*

EIn case you want to collect gametes in situ, it would be essential to place devices on several mature colonies just before the spawning event because the appearance of gamete packages have been identified ready to be released from the mouth of polyps.

The typical collection devices are plankton nets with an opening of at least 2 mm, including a half- or one-liter collection cup connected to the mouth of the net. Weights are attached to the base of the net or lines to secure it to the bottom and a buoy on the top to hold it vertically.

The nets should be placed by experienced divers to avoid damaging the coral colonies carefully. Packages of gametes have a high buoyancy. Therefore, when corals start releasing them, they can be collected in cups. The cups must have water exchanges until the end of the event, which lasts at least 20 minutes. A new cup must be replaced at least every 10 minutes to avoid packages breaking and releasing the eggs and sperm because they are diluted in water, and it complicates the assisted fertilization on the boat.

Photo: MAR Fund - Carlos Gereda

When spawning is over, it is critical to transport gametes immediately to fertilization tanks to combine them with gametes of other colonies and promote cross-fertilization.

Technical advice:

1. Assign at least two divers in charge of placing and removing the nets, monitoring the spawning, and replacing the collection cups. There should be two free divers to support the other divers and transport the cups to the boat, besides having a person on the boat to conduct the assisted fertilization.
2. Place the nets carefully and ensure the conical shape so that gamete packages can get to the collection cup. This should be happening around 9 pm for Acropora palmata, which is when corals are preparing for spawning.
3. Cups are replaced when they are filled with gametes, on a 1:10 ratio of the jar's volume or every 10 minutes.
4. During the diving, it is important not to shine a light directly to the collection cup, to avoid attracting predators that feed on gamete packages.
5. Handle collection cups with great care to avoid breaking the packages of gametes.
6. Take notes during spawning events, such as the conditions of colonies and the environment, to better understand the reproductive biology of corals and make decisions for future spawning events.


Photo: Roatan Divers

4.7 FERTILIZATION

Fertilization processes, the maintenance of embryos, and the rearing of larvae until they are ready to attach are similar, regardless of the methods used for gamete collection.

Assisted fertilization consists of promoting gametes of different colonies to be fertilized to form new individuals. This procedure must be conducted during two hours after spawning.

Collection cups with gametes are taken to the boat, where they are transferred to a bin of approximately 6 L of capacity. Care should be taken to carry as little water as possible. At the same time, predators (fish, shellfish, or worms) over 1 cm should be removed with pipettes.

When bundles of at least two colonies are in the bin, start mixing slowly and carefully, causing them to break and release sperm and eggs to begin the fertilization process. During the mixing, the pink-colored eggs can be seen floating on the surface,

while gray-colored sperms are in the bottom part of the bin. If they are turning white, filtered water should be added to the mixture to avoid anoxia, the oxidation of gametes, and polyspermy (many sperm cells fertilizing one egg).
In general, eggs and sperm are mixed 20 seconds approximately every 5 minutes, for 2 hours, so that degradation of sperm and the resulting anoxia does not limit the viability of fertilized eggs.

Water temperature should not exceed 4 ºC from where it was taken, to avoid minimizing the success of the fertilization.

When degraded sperm cells do not fertilize eggs, bacteria growth is promoted, as well as an anoxic environment, for which it is necessary to remove all sperm excess. Therefore, portions of the mixture are transferred to a separating jug and then are set aside until eggs float, clumping on the upper layer. Most of the eggs should be removed by using a transfer pipette. Later, the water containing sperm is decanted through the opening of the jug to avoid pouring out the eggs. Then, filtered seawater is added slowly on the brim of the jug. This process is repeated until the eggs are floating over the clear water. The entire process must be performed very carefully.

Approximately three hours after beginning the fertilization process, the early embryo developmental stages are observed. A sample is taken, and fertilized eggs are counted and compared to the number of unfertilized eggs in order to estimate the fertilization success, which is expected to be over 70 percent. Otherwise, care should be taken to clean the degraded material during the following hours.

Technical advice:

1. Handle embryos carefully because they are very fragile during the fertilization phase until 24 to 36 hours after fertilization.
2. Mix at least two colonies with genetically different gametes.
3. Stir the water several times until it becomes clear and optimum in a container, such as a jug with a funnel to remove the unfertilized gametes.
4. After three hours, fertilization can be seen under a stereomicroscope to identify the early phases of mitosis.

4.8 EMBRYO DEVELOPMENT IN AN INCUBATOR

After the cleaning process, embryos are transferred to incubators, where development takes place. Incubators must be kept at 28 ºC, and with 12-hour periods of light and 12 hours of darkness. Commonly, for A. palmata, 300 embryos are reared per liter or 40 embryos per cubic centimeter of surface. It is essential to prevent embryos from clumping on the walls of the incubator by applying filtered seawater with a wash bottle.

Embryo development has a high mortality, so it is critical to remove the waste with partial water exchanges. Frequency depends on the clarity of the water, which can be required every day or every third day.

Technical advice:

1. Solid waste is removed with wash bottles. Smaller waste is removed with a plastic film spread over the surface, and larvae are eliminated with a wash bottle filled with filtered water.
2. Cleaning procedures depend on the clarity of the water, through a filter (100-micron mesh) and a hose siphon of 5 mm in diameter, to remove 60 to 90 percent of the water and add new clean seawater, washing down the walls of the incubator to avoid larvae adhering to them.
3. Keep larvae at low densities (no more than 300 larvae per liter); clean seawater is critical for their survival and health.
4. In the case of bacteria growth, it is better to isolate infected incubators and use disposable materials or interrupt the rearing in such incubator.

4.9 SETTLEMENT OF LARVAE

Three to seven days after fertilization, the planula larva begins to explore the bottom in search of a suitable substrate to attach, continue with the metamorphosis, and become a polyp. That is how its sessile life begins.

The appropriate selection of the type of substrate and the right conditions are two key factors for larvae to settle successfully. It seems that tetrapod bases are more convenient for restoration activities because while they provide a wide range of settlement options (different sides and textures of tetrapod bases), they are also easy to handle due to their size, and their fairly simple insertion to the reef.

Before using settlement substrates, they should be 'conditioned' by introducing them near the reef for 60 days. This process allows forming a biofilm, essential to make the substrate more appealing for larvae. Settlement substrates should have a high number of calcareous crustose algae that enhance the settlement of coral larvae.


Photo: MAR Fund - Carlos Gereda

In *Acropora palmata*, it has been seen that the settlement period comes two to three days after the formation of the planula larva. Larvae start swimming down to the bottom of the incubator, which is the ideal opportunity to introduce the settlement substrates. These substrates must cover all the surface of the incubator to prevent larvae from clumping too much and not getting enough oxygen.

This phase lasts between two to four days so, during that time, handling the bases must be avoided so that larvae are able to adhere to the substrate properly.

For practical restoration purposes, the higher the number of settled polyps, the more likely it is to have at least one surviving recruit per substrate after six months.

Technical advice:

1. There is a variety of types and shapes of substrates. They can be purchased or manufactured using a mixture of ocean sand and cement to build them (50:50 ratio).
2. It is important to promote the formation of biofilm on the base of the substrate, as well as the removal of excess of sediment, filamentous algae, and possible predators.
3. In order to avoid the lack of oxygen, it is necessary to place a layer or two of the suitable substrate at the bottom of the incubator when the larvae are looking to settle. Soft additional aeration is suggested.
4. The metamorphosis from larvae to polyps may be confirmed by observing through a stereomicroscope and using fluorescent lamps.

Photo: MAR Fund - Carlos Gereda

4.10 DESTINATION OF CORAL RECRUITS: INTRODUCTION TO THE REEF OR REARING NURSERY

Basically, three methods that can be used to introduce recruits into an active intervention area of restoration:

1. When they are fixed on optimal substrates, their development is maintained in nurseries to later outplant them on the reef.
2. Complete rearing in systems with extreme control.
3. Direct introduction in high densities to reef areas.

Due to high coral mortality rates following settlement in nature, it may indicate that outplanting coral directly onto the reef is not the best option. Mortality can be minimized thanks to the care and protection provided by nurseries because they are kept under controlled conditions such as environmental factors. This method has a significant potential for coral restoration.

This predicament in decision-making regarding restoration objectives uses recruits obtained from sexual reproduction. This represents a key area of current research, from the cost and care efforts entailed. In addition to the assisted fertilization processes mentioned before, corals need to be inoculated with symbiotic algae, required for their subsistence.

Inoculation of symbionts can be done in three ways. The simplest consists of introducing coral fragments from colonies near the site where recruits will be finally outplanted; that is, the area to be restored. The second involves obtaining adult fragments of the same species and the same place where recruits will be introduced, extract symbionts, and immediately inoculate all the obtained recruits. And the third is a combination of the previous two. The introduction of recruits to the nursery, for future outplanting onto the reef or direct planting, does not need inoculation of symbionts, because recruits can acquire them from natural surroundings. Also, production costs are significantly reduced.

Given that coral recovery processes using the assisted fertilization technique requires unique and complex methodologies, it is advisable to request assistance from specialized biologists for proper implementation. The rearing of recruits in systems with extreme control is also a task that should be addressed by technical personnel and requires adequate infrastructure. Therefore, it is essential to work in collaboration and jointly among restoration projects and research and biotechnology development centers for coral restoration.

4.11 OUTPLANTING RECRUIT COLONIES AND MONITORING

When the cycle of obtaining recruits through fertilization and assisted rearing in ex-situ coral nurseries is concluded, the obtained coral colonies will be ready to introduce them back onto the reef and to form a part of the coral restoration process.

With this purpose, the processes described previously in Chapter 3 is basically followed for transportation, outplanting, maintenance, and monitoring of colonies obtained in situ. The success of survival rate must be analyzed, taking into consideration that their performance may be different because their development phases have been achieved under partially or fully controlled systems. And their reaction depends on their inherent response skills to environmental changes, under which they are subject based on this study of their life on the reef.

CHAPTER 5

EXPERIENCES AND ADVICE

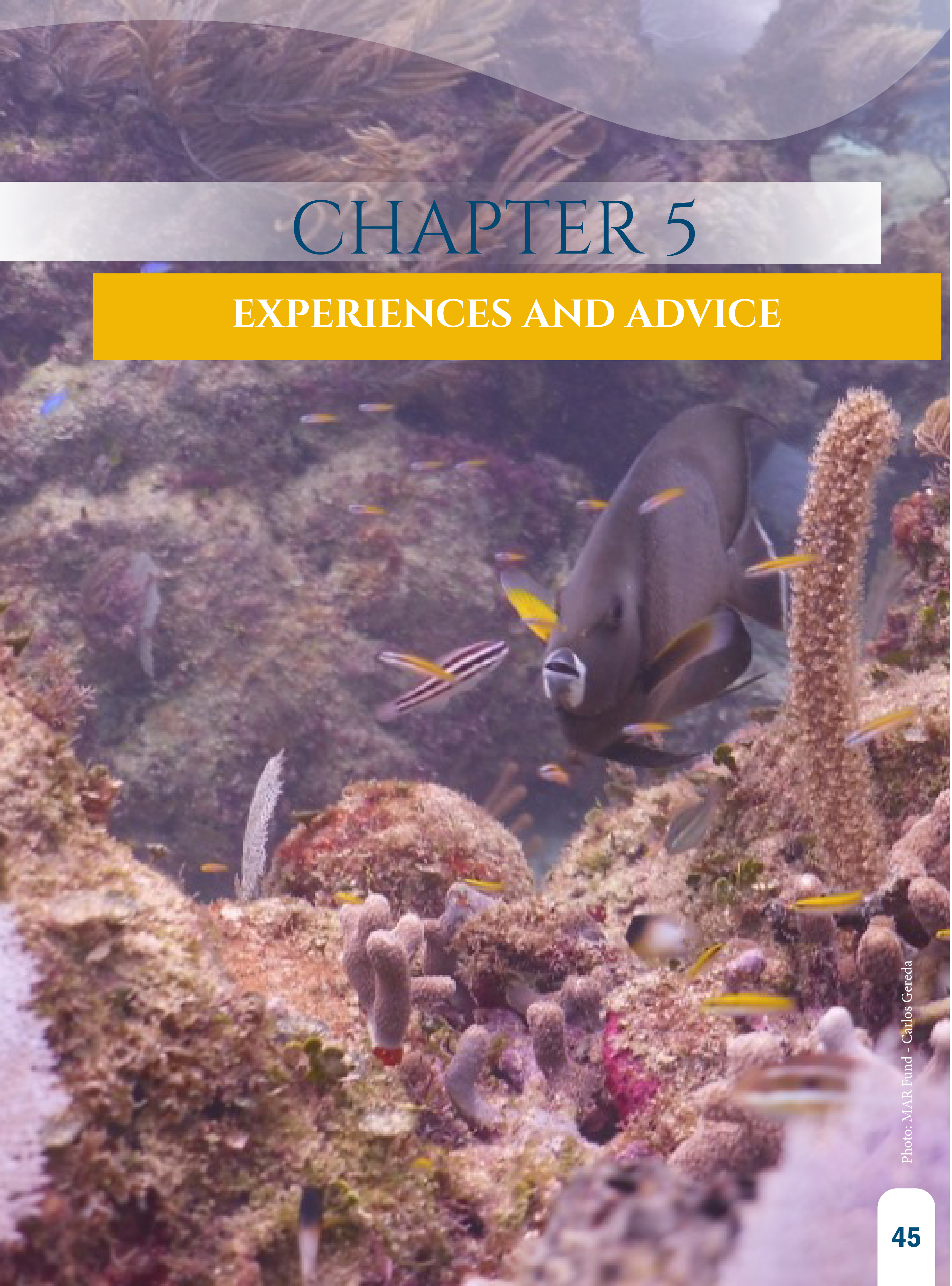


Photo: MAR Fund - Carlos Gereda

5.1 EXPERTS IN REEF RESTORATION OF THE REGION SHARE THEIR EXPERIENCES

Across the one thousand kilometers of the Mesoamerican Reef System, known as the Mesoamerican Reef, and commonly abbreviated as MAR, some groups of organized biologists work in projects to save, rebuild, and repopulate damaged coral colonies in the region. Some of their experiences evince that determination and dedication have been key to bring back the life to these systems which had disappeared as a result of the impact of hurricanes, variations in temperature, or human-induced activities.

Experiences compiled from the Caribbean coasts of Mexico to the Bay Islands in Honduras, share achievements and setbacks. However, the determination of those who fight every day is what undoubtedly is required to save, preserve, and protect one of the most complex marine systems of the world.

5.2 CHALLENGES

Claudia Padilla, a Ph.D. researcher of the National Fisheries Institute (INAPESCA), in Puerto Morelos, Mexico, works in 24 reef sites, from Contoy to Akumal, in coral restoration through fragmentation technique. Padilla is the INAPESCA's representative of the project in Mexico since 2009, that consists of developing biotechnology for coral production and the restoration of the natural ecosystem, with the goal to recover the structure of the reef.

Padilla has used several reproduction techniques for different coral species with which she works. Mostly, to increase the roughness and structure of sites with human-induced activities such as groundings. In these cases, Acropora species are used because they have a branching morphology that covers the structures of previous colonies. The expert proposes that by 2022, with the support of the Mexican government, 265,000 corals will be restored in 32 sites where they have been reduced or destroyed.

Padilla claims that to start working on coral restoration requires to understand the legal basis and other matters that need to be addressed for interventions to take place.

The implementation of restoration programs in the MAR region is a challenge, including the "lack of access to resources or administrative problems to manage resources," Anastazia Banaszak states, a Ph.D. researcher of the Universidad Autónoma de México and the Instituto de Ciencias del Mar y Limnología.

Banaszak has successfully implemented the reef restoration in sites like Cancun, Puerto Morelos, Sian Ka'an, and Xcalak, all located in the Mexican Caribbean. For Banaszak, it is important to understand the reproductive biology of coral species and their population genetics. Moreover, capacity building should be provided to the personnel to, in turn, teach students about the benefits of having a healthy system. "Internships, postgraduate degrees, and online courses should be created to disseminate the work guides." Of course, supported by public policy and awareness campaigns on the matter.

Lisa Carne, the executive director and founder of Fragments of Hope, in Belize, works on coral restoration since 2013. After hurricane Iris hit Laughing Bird caye, she says that the main factor that affects corals is climate change. "We documented the decline of the reef's health that began long before the hurricane hit. Diseases and bleaching are mostly due to the change in water temperatures." Carne claims that, although there are more people interested in engaging in coral restoration, one of the most significant problems is the influx of tourism in the work areas.

Others, like Tripp Funderburk, who is the director of the Coral Restoration Project in Roatan Marine Park, in Honduras, has had to fight against nature and relocate his coral nurseries. One of them was Mahogany Bay, located far from the expert's complex and which endured strong winds, surges, and currents that soiled the nursery. "It was hard to maintain it, and we weren't able to bring divers to help clean the nursery. We had to transfer the corals to Turquoise Bay (another nursery run by Funderburk).

Funderburk stresses that the challenges for the programs that he implements are transforming local fishermen into coral gardeners. They are taught to clean the corals and to ensure that they are not affected by fisheries.

In contrast, the Guatemala experience has been complicated. Ángela María Mojica, the co-founder of Pixan'Ja Guatemala, assures that she has conducted several trials to identify effective methods, but that one of the greatest challenges has been facing thefts in the nurseries. "We thought about building nurseries with cement blocks and towers… We saw that some of them were stolen." Keeping coral fragments adhered to the nurseries has also been a challenge. "We planned to work with epoxy adhesive to attach the fragments which didn't work, and the drying time was longer than expected." She also claims that due to the distance of reef sites from Guatemalan coasts, in the Caribbean, a bigger budget is necessary to carry out coral reef restoration.

In Guatemala, Ana Giró, the Guatemala coordinator for Healthy Reefs for Healthy People, states that they are working with learning centers of the region, the government, non-governmental organizations in Izabal, and the local community, using training guides on ecological reef restoration. And this coordination represents a challenge to carry out restoration programs.

As for Johanna Calle, from Change Iberostar, assures that working on three fundamental pillars can make coral restoration effective. First, the removal of single-use plastic in over 120 hotels in the area, generate a responsible consumption of shellfish and fish, and conduct trials with genotypes resilient to climate change.

5.3 Achievements and Recommendations

The efforts of this group of ecologists have raised greater awareness of the critical situation that the Mesoamerican Reef is going through. Their reef restoration techniques have become a working model in many parts of the world, and hundreds of organizations and people are joining their efforts with the same goal: to rescue the reef.

One of Banaszak's achievements is to have sexual recruits of up to eight years old and still reproductive. "We have sites with younger sexual recruits (from a few weeks old produced in August 2019) and cohorts outplanted each year since 2011."

Baruch Figueroa, the coordinator of the coastal ecosystems program of the Akumal center, also in Mexico, adds that first, it is necessary to define the ecological condition of reefs, "select sites and especially rely on the work of the local people to conduct a mass operation."

Moreover, he has been able to successfully determine the best ways to attach corals and has excluded those less effective. "The use of concrete turned out to be more efficient. The one using nails and clamps works, but fragments take longer to fuse naturally with the substrate."

For Mojica, of Pixan'Ja Guatemala, the experience has shown them to exclude methods and remove processes that resulted unsuccessful. "We have excluded options in order to seek more efficient and effective methods.

Meanwhile, Funderburk, in Roatan, claims that they currently have 20 coral trees, with nearly a thousand corals, and have outplanted 800 corals onto the reef, with a survival rate of 80 percent in the area of Turquoise Bay Resort. "We have received a donation from MAR Fund, and we are installing 20 trees in Seaquest Deep, in West Bay."

Lisa Carne, of Fragments of Hope in Belize, states that since 2013 to date, her work has improved and has achieved excellent results. "We began outplanting broken corals from one place to another. Now we are implementing nurseries from where we have managed to obtain 70,000 corals that we have outplanted.

As for Claudia Padilla, researcher of the National Fisheries Institute, in Puerto Morelos, she adds that before starting to work, it is important to be informed. "I recommend joining workgroups with more experience."

All the activists that work for the Mesoamerican Reef agree that the most important thing for a successful coral restoration is through nurseries. "Cleaning and maintaining nurseries is vital for the implementation of restoration programs."

Photo: MAR Fund - Carlos Gereda

BIBLIOGRAPHY

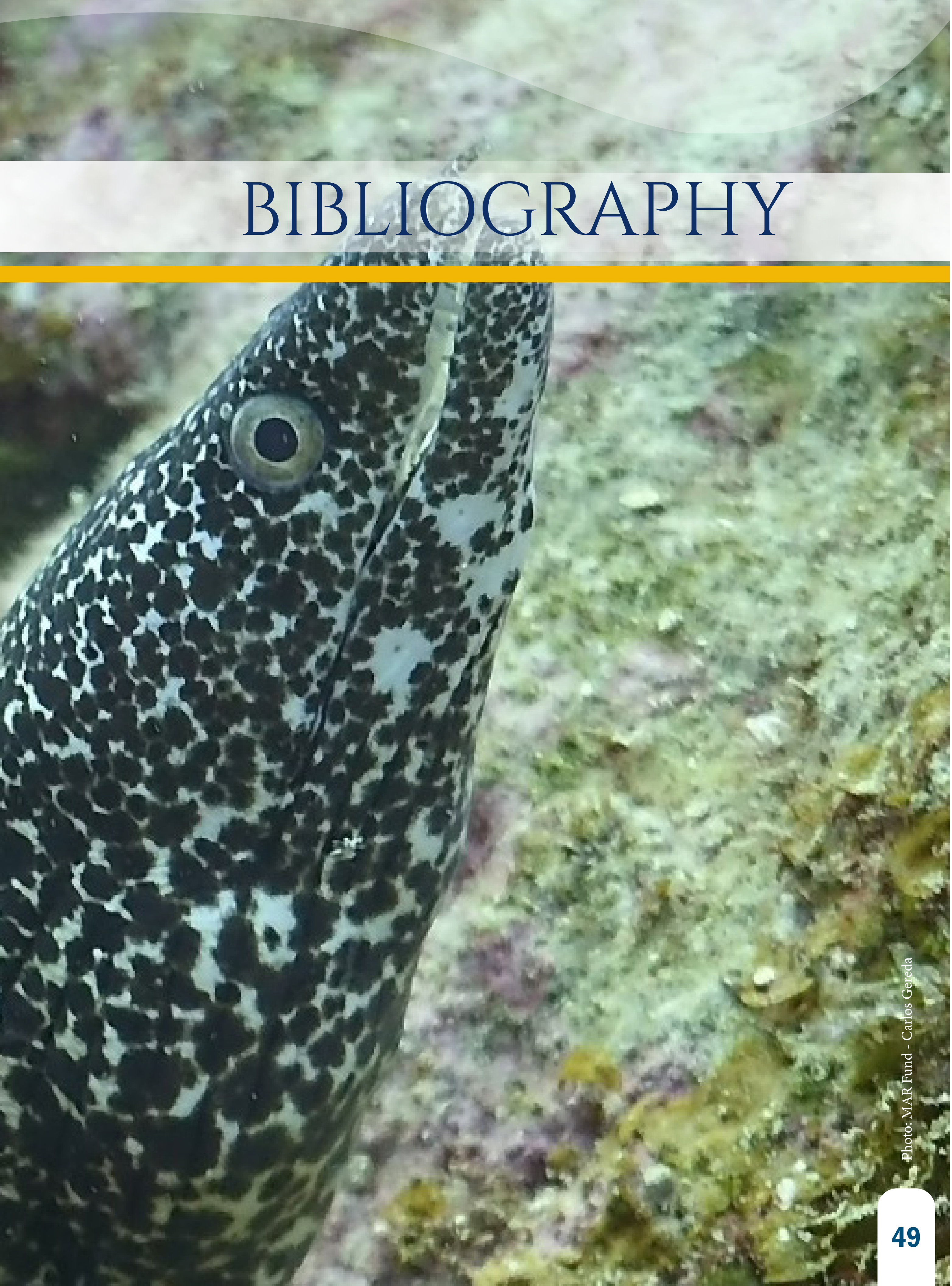


Photo: MAR Fund - Carlos Gereda

1. **Banaszak, Anastazia T.** (2019). Guía Práctica para la restauración coralina con base en la producción de reclutas sexuales con énfasis en Acropora palmata, Universidad Nacional Autónoma de México.

2. **Bowden-Kerby, A.** (2003). Coral Transplantation and Restocking to Accelerate the Recovery of Coral Reef Habitats and Fisheries Resources Within No-Take Marine Protected Areas: Hands- On Approaches to Support Community-Based Coral Reef Management. Paper presented at the Second International Tropical Marine Ecosystems Management Symposium (ITMEMS 2), Manila, Philippines. Mar. 24-27. pp.15.

3. **Bowden-Kerby, A. and L. Carne.** (2012). Thermal Tolerance as a factor in Caribbean Acropora Restoration. Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9-13 July 2012 20A Restoration of coral reefs.

4. **Cummings, K., A. Zuke, B. De Stasio, and J. Krumholz.** (2015). Coral Growth Assessment on an Established Artificial Reef in Antigua. Ecological Restoration Vol. 33, No. 1. 90-95 pp.

5. **Edwards A. J. and S. Clark** (1998). Coral Transplantation: A Useful Management Tool or Misguided Meddling? Marine Pollution Bulletin Vol. 37, Nos. 8±12, pp. 474±487.

6. **Edwards, A. J.** (ed.) (2010). Reef Rehabilitation Manual. Coral Reef Targeted Research & Capacity Building for Management Program: St Lucia, Australia. 166 pp.

7. **Edwards, A. J. Job, S., and Wells, S.M.** (2010). Learning lessons from past reef-rehabilitation projects. Pp. 129-166 in: Reef Rehabilitation Manual. Coral Reef Targeted Research & Capacity Building for Management Program: St Lucia, Australia.

8. **Edwards A. J. and S. Clark** (1998). Coral Transplantation: A Useful Management Tool or Misguided Meddling? Marine Pollution Bulletin Vol. 37, Nos. 8±12, pp. 474±487.

9. **Lohr K. E., S. Bejarano, D. Lirman, S. Schopmeyer, and C. Manfrino.** Optimizing the productivity of a coral nursery focused on staghorn coral Acropora cervicornis. Endang Species Res. 27: 243–250.

   Red de Restauración del Sistema Arrecifal Mesoamericano. Retrieved in May, 2020, from https://coralmar.org/

10. **Reef Resilience Network**, Coral Restoration Consortium.

11. **Ross A. M.** (2016). The efficacy of nursery head- starting in the culture and restoration of Acropora cervicornis. Proceedings of the 13th International Coral Reef Symposium, Honolulu: 306-324.

12. **The Nature Conservancy**, Conservation Training, Coral Reef Restoration.