# STATUS AND CONSERVATION OF THE CORAL REEF ALONG THE PUERTO MORELOS REGION OF THE MESOAMERICAN BARRIER REEF SYSTEM

by
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**Abstract**

Coral reefs and reef communities are easily susceptible to degradation due to anthropogenic threats stemming from climate change. Coral reefs are under siege from effects like ocean acidification, ocean warming, sea level rise, and specific local threats. Conservation efforts are pursued in reef communities around the world to gather data and determine what can be done to protect the remaining corals. From January 22nd, 2021 through February 20th, 2021, I worked as a Marine Conservation Intern with Global Vision International (GVI) in Puerto Morelos, Mexico. I was educated on coral reef community biology and their threats. I was trained in multiple underwater monitoring methods to record data on coral bleaching, disease, and mortality. This training allowed me to gain valuable insight into the current state of the coral reef in Puerto Morelos and how it has changed over time with bleaching, disease, and death due to constant threat. I collected data and provided it to organizations that partner with GVI and use this information to analyze the overall health of the reef. This analysis is used to provide policymakers with up-to-date information on the status of the reef so that they can make the best policy and management decisions. This experience showed me how GVI is bettering the region through partnerships with federal organizations, NGOs, and community outreach.

**Primary Reader**: Dr. David Guggenheim

**Secondary Reader**: Dr. Jerry Burgess

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A special thank you to all of the GVI staff members. Sebastian Berenguer who mentored me and made sure all of my goals were attainable during the duration of my program. Aysha Pena who worked tirelessly to integrate us as GVI interns into community outreach and development projects in respectable and safe way during a global pandemic. Lara Birkart who was our dive instructor and taught us everything we needed to know to obtain the Advanced Open Water (AOW) certification and make sure we were safe and in the water in respect to each other and marine life that we interacted with. Kayla Moore who was also one of our dive instructors, but also our resident expert who conducted all of our lectures and taught us about the ecosystem of the reef. Miguel Angel Lozano and Alejandro Vasquez who operate the GVI base and work directly with local partners, your combined wealth of knowledge and passion has left a lasting impact on me. Together, your commitment to marine conservation, sustainable living, and educating others about the effects of climate change are an inspiration. Your combined knowledge and expertise created an experience that will live with me forever and will continue to drive me towards living sustainably.

Thank you to all of my fellow interns at GVI, some of which are still in Puerto Morelos continuing to record necessary data on the health of the coral reef. Without your friendship, support, encouragement, and teamwork it would not have been possible for me to complete this internship program and absorb as much information as I did. I wish you all the best of luck in your future careers.

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**List of Abbreviations**

| | |
|---|---|
| AGRRA | Atlantic and Gulf Rapid Reef Assessment |
| AOW | Advanced Open Water |
| CONANP | Comisión Nacional de Áreas Naturales Protegidas (National Commission of Protected Areas) |
| CRIAP | Coral Fragmentation and Restoration for the Northern Yucatan Peninsula |
| GVI | Global Vision International |
| HAB | Harmful Algal Blooms |
| HR4HP | Healthy Reefs for Healthy People |
| INAPESCA | Instituto Nacional de Pesca y Acuaculture (National Fisheries Institute) |
| MBRS | Mesoamerican Barrier Reef System |
| PADI | Professional Association of Diving Instructors |
| RHI | Reef Health Index |
| SCTLD | Stony Coral Tissue Loss Disease |

## Introduction

Coral Reefs are home to 25% of all marine life and provide many benefits to humans and marine animals alike. Coral reefs have high biodiversity and provide several services that are irreplaceable. Due to high biodiversity, many communities rely on fish as a means of protein and as a source of income through the fishing industry. Coral reefs provide shoreline protection from hurricanes as they dissipate the wave energy. Their chemical compounds are being used by pharmaceutical companies to fight diseases. The income generated in communities where there are coral reefs helps sustain the local economy and provides jobs. Coral reefs around the world provide roughly 375 million USD annually in these services. With the effects of climate change worsening each year, anthropogenic threats are taking their toll on coral reefs at global and local levels. If this continues, marine life and terrestrial life will have to suffer the catastrophic results of life without the services provided by coral reefs.

I've come to realize that the conservation and restoration of coral reefs is something that is vital to the marine ecosystem and it is something that I have developed a passion for. I sought out an opportunity to gain first-hand experience monitoring and researching coral through an internship with Global Vision International. This program provided me with necessary skills, methods, and techniques to conduct personal coral research in my future career. It taught me the biology and ecology of the coral reef ecosystem and the organisms that inhabit it. It also taught me more about how important our reefs are, what is threatening their existence, and what can be done to help. During this internship I recorded data on coral reef bleaching, disease, and mortality which will be used by Mexican federal organizations and NGOs like Healthy Reefs for Healthy people to analyze the overall health of the Mesoamerican Barrier Reef system.

This report will differ from other capstone reports as there is no specific research goal in which I set out to achieve. Instead, I planned to gain real research experience working in the field. This report is intended to discuss the knowledge and tools I gained through this internship, best practices for coral monitoring, as well as provide an update on the status of the coral reef in Puerto Morelos, Mexico and the conservation efforts being conducted in this region. I will discuss Global Vision International and their programs, coral reefs and their importance, how GVI prepared me to conduct coral research dives, how the data was collected and what it is used for, the state of the Puerto Morelos region of the Mesoamerican Barrier Reef System, and what other activities I participated in with GVI including beach cleanups, coral fragmentation lab assistance, and community projects.

## Background

### 1. Global Vision International and Puerto Morelos

Global Vision International (GVI) was formed to provide support and services in environmental research, conservation work, education, and community development. Since its creation in 1998, more than 25,000 participants have completed an internship or a volunteer program with GVI. GVI's 13 bases can be found in Mexico, Costa Rica, Fiji, Peru, Seychelles, South Africa, Ghana, Greece, India, Nepal, Cambodia, Laos, and Thailand. Each location focuses on and contributes to long term sustainable solutions for critical global issues that are faced locally by partner organizations and communities. The programs focus on one or more of the following efforts: teaching, marine conservation, wildlife conservation, construction, education and empowerment, gender equality, and global health.

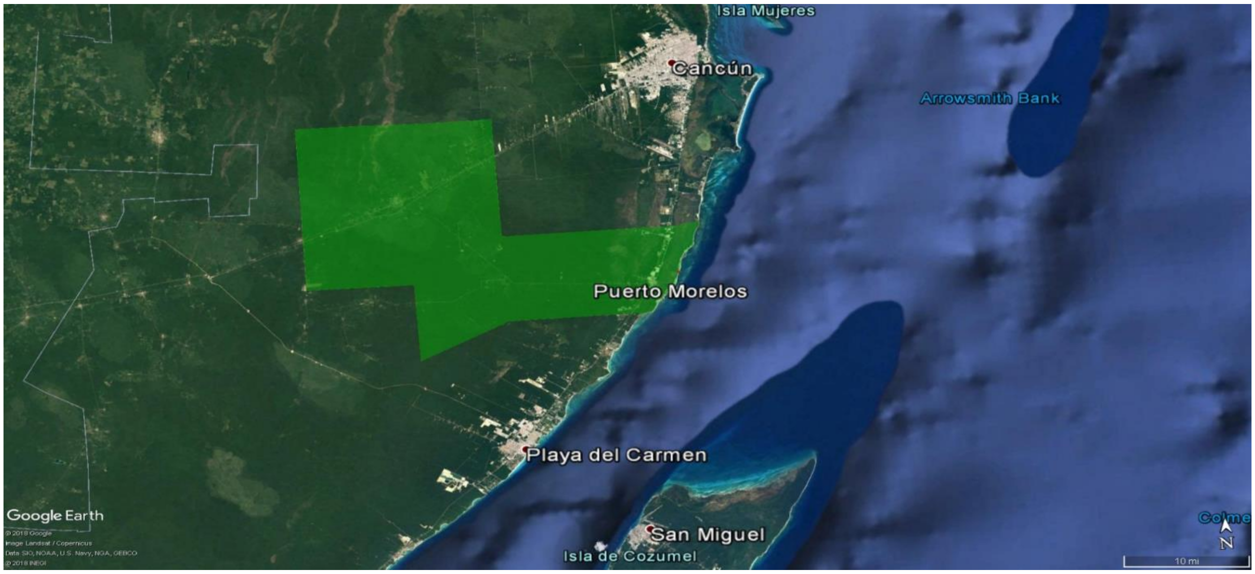
In order to make a lasting difference, GVI works on long term project that make a positive impact. Their projects use the UN Sustainable Development Goals as a framework to communicate their impact. Stakeholders in these projects are made up of local communities, NGOs, government agencies, partners, GVI staff members, volunteers, donors and fundraisers, and GVI interns. GVI applies 5 human empowerment principles to address the way that the collective of shareholders work together and support each other in their own empowerment.

1. *Collaboration*: In order to set and achieve project objectives, all stakeholders must collaborate together.
2. *Equal Partnerships*: Stakeholders work as both a student and teacher. As each stakeholder has varying and diverse skillsets, each stakeholder plays an equal part in the setting and achievement of project objectives.

3. *Support*: Stakeholders are all striving toward the same goal and support each other in an environment that promotes self-empowerment and independence.
4. *Sustainability*: All stakeholder collaboration works towards long-term sustainable outcomes.
5. *Representation*: Stakeholders come from varying backgrounds and are conscious and respectful of how they portray each other through all forms of communication.

GVI's Mexico base is in the town of Puerto Morelos which is located in the state of Quintana Roo, Mexico as seen in Figure 1. Quintana Roo is the youngest of Mexico's municipalities, with its founding date of November 6$^{th}$, 2015. Puerto Morelos is part of the Yucatan Peninsula and is situated halfway between Cancún and Playa del Carmen. While the state of Quintana Roo is relatively new, the town of Puerto Morelos is not. Puerto Morelos is the oldest port community in the Mexican Caribbean, and it dates back to use by Mayan civilizations. Mayan civilizations used Puerto Morelos to conduct fishing and trading activities as it is naturally protected by a barrier reef. In 1898, this region was selected by the Mexican government for the construction of a port because of the natural barrier reef protection, ample space for boat anchoring, and natural channels between the reefs that allow for boats and ships to access the port. Puerto Morelos, a small fishing town, currently has a population of 37,099 with a growth rate of 19.1% due to the popularity of tourism in the regions and development of transportation infrastructure. This rapid population expansion led to an increase in reef degradation as increased tourism was supported.

Figure 1. Location of Puerto Morelos (Google Earth)




Due to concern of reef degradation in tourist areas on the Yucatan Peninsula, Mexico began creating new laws and rules stipulated in the Cancún marine protected areas. In 1995, the Puerto Morelos community began to realize these new laws and regulations were driving various tour operators down the coast into their reef. The tour operators were using the reef in Puerto Morelos for their activities and had no regard for the conservation of this reef ecosystem. Implementation of Marine Protected Areas can have conflicting opinions in the affected communities, especially when fishing reliant communities could see a negative impact on their livelihood. However, because the Puerto Morelos community was able to witness the negative effects that tourist and tour agencies were having on a resource they depended on, they took it upon themselves to negotiate with the Mexican government and make the reef in Puerto Morelos a protected area and preserve their reef. After 3 years of negotiations, the marine coastal area of Puerto Morelos was declared a natural protected area for the conservation of ecosystems on February 2nd, 1998. The protected area is comprised of 22,404 acres of mangrove, coral reefs, and seagrass. The reef in Puerto Morelos in part of a larger reef called the Mesoamerican Barrier

Reef System (MBRS). The MBRS is the second largest barrier reef in the world, extending from the North of the Yucatan Peninsula, Mexico to the Bay Islands of Honduras.

In Puerto Morelos, GVI is partnered with several organizations including the Instituto Nacional de Pesca y Acuaculture (INAPESCA), Healthy Reefs for Healthy People (HR4HP), and the Comisión Nacional de Áreas Naturales Protegidas (CONANP). In their partnership with INAPECA, GVI assists researchers in the Coral Fragmentation and Restoration for the Northern Yucatan Peninsula (CRIAP) laboratory. In their partnership with Healthy Reefs for Healthy People, GVI monitors reef health and biodiversity and provides them with data. In their partnership with the CONANP, GVI monitors coral nurseries and restoration. With these partnerships, the Puerto Morelos base has cemented many long-term objectives. In a broad sense, GVI's long-term goals are to: aid in education and support of the local communities to support a sustainable future, reduce poverty, and reduce inequality; monitor and restore marine ecosystems and promote sustainable lifestyles reliant on these resources; and educate the community about climate change and the impacts of improper waste management.

GVI's long-term community-based objectives include building and maintaining relationships with the community, inspiring passion in the community and educating them to protect the local environment, working towards the United Nations Sustainable Development Goals, and educating the community to support a sustainable future. GVI's foremost long-term goal is marine conservation, where their primary responsibilities are monitoring the reef and recording data, teaching community members how to support a healthy reed ecosystem, and training interns to obtain additional help in their projects.

## 2. Coral Reefs and Their Importance

Coral reefs are extraordinarily diverse habitats. They are home to at least 25% of all marine life and yet they cover less than 0.1% of the marine environment (Burke et al., 2011). They are home to roughly 4,000 different coral reef-associated fish species and 800 different reef-building coral species (Burke et al., 2011). Located across tropical oceans around the world, coral reefs are temperamental and require particular conditions to facilitate growth and maintain their structures. The majority of reef building corals are found in tropical and subtropical oceans, between the 30°N and 30°S latitudes. These reef structures are built vertically from the seabed as calcium carbonate is deposited and then placed by reef-building corals over millions of years. Coral reefs are made up of coral colonies which are further comprised of many individual coral polyps.

Coral polyps are small, soft-tissue animals which have three tissue layers. The epidermis is the outer tissue and the gastrodermis is the internal layer which is used for digestion. In between the epidermis and gastrodermis is the mesoglea. The mesoglea, or hydrostatic skeleton, is the layer in which zooxanthellae live within the polyp. Polyps maintain a symbiotic relationship with the single celled dinoflagellate algae, commonly known as zooxanthellae. Coral polyps provide protection, carbon dioxide, and nutrients for these algae. The algae use the sunlight to photosynthesize and produce oxygen and sugar for the coral. Algae provides 90% of energy needed for coral survival. To supplement the energy received from the algae, corals are also equipped with nematocysts which have tentacles at their ends. The tentacles capture zooplankton floating in the water column for the polyp to eat. The coral polyps are housed in a continuous, hard, calcium carbonate skeleton structure, known as a corallite. These corallite structures continue to grow around the polyp as it secretes additional calcium carbonate.

Corallite structures are comprised of walls, septa, and costae. Large groups of polyps are called colonies, which form together to make larger coral reef structures.

Coral can reproduce in three different ways including asexual reproduction, sexual reproduction, and fragmentation. Asexual reproduction is when new coral polyp buds from a parent polyp and separates. The budding polyp can then attach to the existing colony to expand the colony, or it can attach to a substrate and begin its own new colony. In sexual coral reproduction coral larvae is fertilized in the water column through an event called spawning. The fertilized larvae will attach to a hard surface in the ocean and eventually create its own colony. Coral fragmentation varies greatly from asexual or sexual coral reproduction. When storms or other forces cause a coral to fracture, the fractured section of coral is able to attach itself to a hard surface and grow. The remaining portion of the original coral will continue to grow in its existing colony while the fractured portion will grow elsewhere.

In order for corals to survive and reproduce, their required conditions must be precise. Corals rely on energy output from the zooxanthellae which utilizes photosynthesis. It is because of this that corals generally do not live any deeper than 30 meters as they require sunlight for the photosynthetic processes to occur. Turbid waters can obstruct the sunlight and prevent photosynthesis which is why corals prefer clearer water.  Reef building corals are most often found in tropical and subtropical waters because these corals can only survive in water ranging from 23° to 29° C. Corals are also very sensitive to acidity and freshwater which is why the water they inhabit must maintain a specific salinity of roughly 35 ppt and a composition of 8.3 to 8.5 pH. Lastly, corals cannot survive in stagnant water and require constant water movement to refresh supplies of plankton and oxygen to sustain themselves.

These reefs provide a habitat for a wide range of species, but their value to humans and land-based organisms cannot be understated. Reefs provide food and livelihood, medicine, shoreline protection, and tourism revenue each year. Combining the value of the services in which coral reefs provide is estimated to value at roughly 375 billion USD annually (NOAA, 2011). Just over 12% of the world's population live within 100 km of a coral reef and over 275 million people live within 10 km of a reef (Burke et al., 2011). Coral reefs are a source of both food and livelihood for coastal communities in developing countries. Fishing provides jobs and a source of income while these regions also depend on fish as a primary source of protein. Corals reefs and some of the marine life that inhabits them have complex chemical compounds that are being explored by the pharmaceutical industry to treat cancer, HIV, and malaria to name a few (Burke et al., 2011). Across the world, coral reefs run the length of 150,000 km of shoreline in over 100 countries (Burke et al., 2011). Barrier reefs and fringing reefs along the shoreline naturally protect land from hurricanes as they dissipate wave energy and reduce wave damage. In tropical regions, coral reefs are vital to the tourism industry. Divers, snorkelers, beachgoers, and recreational fishers all visit these regions and spend money in these countries which help sustain the local economies. As we will see later, tourism is a double-edged sword as it is also a local threat to some coral reefs.

Coral reefs have proven themselves to be vital to marine and terrestrial lives. Their importance is irreplaceable, but there are many global factors that threaten to eradicate coral reefs. Climate change stressors like ocean warming, ocean acidification, and sea level rise make up some of the major global threats that impact all coral reefs. Anthropogenic threats to coral reefs are largely due to climate change. Use of fossil fuels have polluted the air trapped heat within the atmosphere, causing the earth's surface temperature to gradually increase over time.

The ocean is a carbon sink and absorbs much of the excess heat that we have created. This has caused the average ocean temperature to rise by 0.1° C between 1961 and 2003. It is projected that the surface air temperature will continue to increase by 1.8 to 4.0° C by the 2090's (Keller et al., 2009). The carbon dioxide that is emitted from the burning of fossil fuels remains in the atmosphere and mixes with water in the air to create carbonic acid which falls into the ocean as acid rain. Along with acid rain, the ocean absorbs roughly one-third of human caused carbon dioxide in the air which alters the pH levels of the ocean and increases the ocean acidity. Due to the calcium carbonate structure of coral skeletal structures, increased ocean acidity will slowly dissolve these structures. Estimates indicate that when the atmospheric carbon dioxide levels reach double or triple pre-industrialization levels, coral structures will erode faster than they can rebuild (Keller et al., 2009). With climate change heating the surface of the earth, ice sheets and glaciers have begun to melt which has increased the average global sea level rise by roughly 1 to 2 millimeters per year over the last 100 years (Keller et al., 2009). Increased sea level rise erodes shorelines and deplete mangrove forests which are integral to coral reef ecosystems. Another issue of sea level rise is the decrease of the ocean's salinity due to the introduction of freshwater via melting glaciers.

Pushing corals to live at or near their limits of survivable conditions causes significant stress. When coral becomes stressed, it may eject the zooxanthellae that live in their mesoglea which are responsible to providing the vibrant colors that coral is known for and are photosynthetic and responsible for providing nourishment to corals. When this happens, the coral becomes white as all that can be seen is their calcium carbonate skeletons. This phenomenon is known as coral bleaching and unless ocean conditions are restored within short period of time, the effect will become irreversible, and the coral will die entirely.

## Methods

### 1. Trainings and Lectures

Designed to provide a diverse range of knowledge, practical techniques, qualifications, and valuable experiences to support academic study and career development in the field of marine biology and conservation, several forms of trainings and evaluations were administered over the course of the internship. Upon arrival to base, we were trained in emergency first response primary and secondary care, risk assessment for all areas of work, emergency action plans and drills, emergency oxygen equipment, and child and vulnerable adult protection policy trainings in order to provide a focus on health and safety. Prior to any diving, we attended a lecture on hazards of the reef. This presentation taught us about the potential marine life injuries that could take place on a dive and how to attend to them if necessary. The lecture discussed stings from cnidarians like jellyfish and fire corals, envenomation from lionfish and scorpionfish, bites and stings from sharks, barracuda, stingrays, and sea urchins, as well as potential injuries from marine vessels. This lecture also discussed appropriate behavior underwater so that we were not hazards to aquatic life during our dives.

Interns holding an open water certification from the Professional Association of Diving Instructors (PADI) were required to perform a spot check dive for instructors to verify basic dive skills prior to beginning the PADI Advanced Open Water (AOW) certification course which was a requirement before scientific research dives could be conducted. The PADI AOW course consisted of self-learning modules and knowledge reviews. Following successful completion of knowledge reviews, we embarked on the following five certification adventure dives: Underwater Naturalist, Search and Recovery, Deep Dive, Underwater Navigation, and Peak

Performance Buoyancy. GVI's dive training objectives are focused on teaching PADI courses while improving existing skills and confidence in divers.

During the day between study sessions, we were provided with several in depth marine research program lectures on the following subjects: conservation research, incidental sightings, introduction to coral reefs, threats to coral reefs, lionfish[1] biology, sea turtle biology, beach cleanups, coral community tutorials, and monitoring methods and demonstrations.

In order to familiarize interns with the species of coral that would be monitored, the coral tutorial was provided to teach us the subtle differences between the many species. We needed to memorize the Latin genus and species of each coral and be able to distinguish one from another. In total there were 46 target coral species that needed to be memorized, all of which can be found in Table 1. In order to verify our knowledge, we were required to pass 3 visual identification exams with 95% accuracy. Each exam had 60 images and the exams increased in difficulty. Following successful completion of all 3 exams, underwater coral identification spots were necessary to further test our knowledge. We needed to complete 3 coral spot dives, with a pass rate of 97%. On coral spot dives, GVI staff would point out species of coral and we would write on our dive slate the genus and species names. A successful coral spot dive required a minimum of 20 species to be found on the duration of the dive.

[1] The lionfish is an invasive exotic fish species discussed later in this report.

Table 1. Target Coral Species List.

| **Mound & Boulder** | **Branching** |
|---|---|
| *Porites astreoides* | *Acropora cervicornis* |
| *Sidersastrea radians* | *Acropora palmata* |
| *Sidersastrea siderea* | *Acropora prolifera* |
| *Stephanocoenia intercepta* | *Madracis aurentenra* |
| *Montastrea cavernosa* | *Madracis decactis* |
| *Orbicella annularis* | *Madracis pharensis* |
| *Orbicella faveolata* | *Madracis sp.* |
| *Orbicella franksi* | *Oculina diffusa* |
| *Favia fragum* | *Porites divaricata* |
| *Dichocoenia stokesii* | *Porites furcata* |
| *Solenastrea bournoni* | *Porites porites* |
| *Solenastrea hyades* | *Porites sp.* |
| **Meandroid** | **Agariciid** |
| *Diploria labyrinthiformis* | *Helioseris cucullata* |
| *Pseudodiploria strigosa* | *Agaricia fragilis* |
| *Pseudodiploria clivosa* | *Agaricia lamarcki* |
| *Colpophyllia natans* | *Agaricia agaricites* |
| *Manicina areolata* | *Agaricia tenuifolia* |
| *Meandrina meandrites* | *Agaricia humilis* |
| *Meandrina jacksoni* | **Fire Corals** |
| *Dendrogyra cylindrus* | *Millepora alcicornis* |
| *Mycetophyllia lamarckiana* | *Millepora complanata* |
| *Mycetophyllia aliciae* | *Millepora striata* |
| *Mycetophyllia ferox* | *Millepora squarrosa* |
| *Isophyllia sinuosa* | *Millepora sp.* |
| *Isophyllia rigida* | *Stylaster roseus* |
| **Flower & Solitary** | |
| *Eusmilia fastigiata* | |
| *Mussa angulosa* | |
| *Scolymia sp.* | |

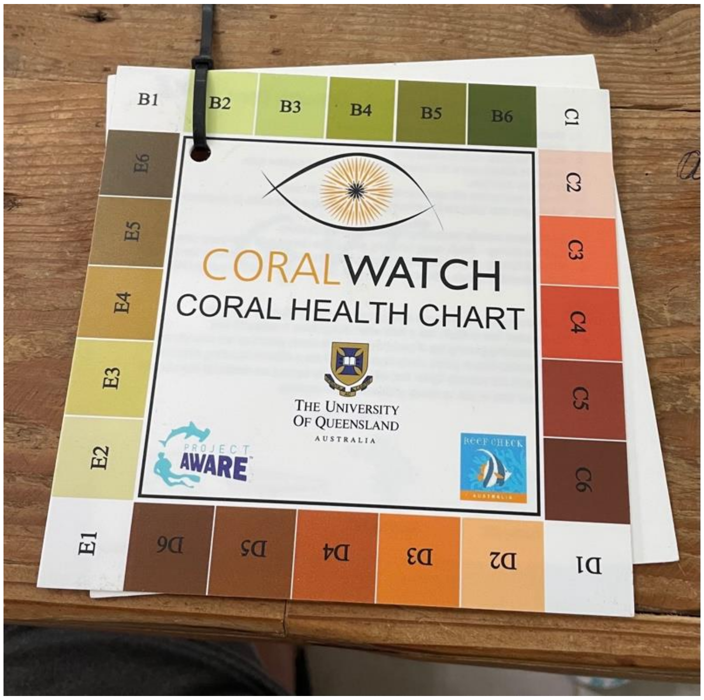
**2. Scientific Dives**

Once we had completed all the necessary exams and coral spots, we were eligible to start conducting research dives and gather data for GVI's partners. The conservation research lecture taught us the best practices for underwater monitoring. We were taught that during any scientific dives, we should never touch the coral or substrate. To best view the reef and observe the coral without risk of contact, divers should be hovering at a 45-degree angle with their fins up. We were also taught how to backfin and helicopter kick so that if they got too close to the reef, they could back out or turn around without the risk of reef contact. We completed a written exam and two certification dives demonstrating these research skills to earn their PADI Coral Reef Research Diver specialty certification.

We also learned that the most widely adopted surveying technique in the region for coral monitoring is the Atlantic and Gulf Rapid Reef Assessment (AGRRA) methodology, a guide of which can be found in Appendix A, which is used by GVI when conducting coral community research surveys as it allows data to be intercompared. The objective of the AGRRA coral survey method is to assess the size and health condition of coral. To conduct an AGRRA coral survey, a minimum of two divers is required. Diver A lays the weighted end of a transect at the edge of the reef, being sure not to lay the weights on any coral. Diver B then unreels the 10-meter measuring tape transect in a straight line across the reef. Diver A follows diver B and tucks the transect line around corals and gorgonians so as not to damage any species on the reef. Once the transect line is in laid out, diver B weighs down the other end of the transect to ensure that it does not move. At every 1-meter mark on the transect, divers hold a PVC quadrat measuring 25 cm x 25 cm to record data. Divers are equipped with an A4 underwater slate that have measurements along the sides and a pencil to record information. Rather than having a blank slate to record information, we copied AGRRA's Coral-UW-V5.4 datasheet onto our slates to record the proper information. At each quadrat, divers identify all species of coral that are larger than 4 cm and record them using the proper coral species code. Their size (length, width, and height) is recorded as well as how much of each species is bleached, what percentage of new, old, or transitional mortality are present on the coral, and what diseases (if any) are present. This information is recorded for all corals within the quadrat at each 1 m marking along the transect line. The AGRRA coral methodology assesses the species, colony size, and health of corals present at each of the GVI's 10 dive sites. This methodology identifies the diseases that are having the greatest impact on coral populations and the impact of bleaching events on the different species of local coral. It also helps to determine live coral cover and information about the population dynamics at the dive sites including species diversity, population changes, and the factors that affect them.

Separate from coral community monitoring, we utilized the CoralWatch methodology, a guide of which can be found in Appendix B, specifically for monitoring the severity of coral bleaching at GVI dive sites. CoralWatch is a program created by the University of Queensland, Australia that can be contributed to by anyone in an effort to help provide the university with data for use in their research. CoralWatch is not considered to be the standard practice for monitoring coral bleaching, and it is intended to be used by non-specialist observers to gain a better understanding of effective reef management while providing the University with accurate bleaching data from around the world. For GVI's purpose, CoralWatch bleaching monitoring also requires two divers to complete. Divers approach a coral and identify the species on their slates. Diver A will use a flashlight to illuminate the coral, while Diver B holds the CoralWatch health chart up to the species. They will compare the darkest and lightest colors of the coral and match them to the colors on the health chart, as seen in Figure 2, and record them. Divers make sure that they do not use two color indicators that are on the same side of the chart. Divers will continue to record this information until they have recorded a minimum of 20 corals. This data is submitted to the University of Queensland and is used to identify water temperature patterns. The data helps to understand the relationship between increasing water temperature and bleaching events. It also monitors the severity and species affected during bleaching events.

Figure 2. CoralWatch Coral Health Chart




At the conclusion of each dive with GVI, we record all megafauna and lionfish sighting they witnessed during the duration of their dive, and their estimated size. Data on incidental sightings of megafauna is used by GVIs partners to provide information on species that are difficult or expensive to monitor. This data provides a greater understanding of megafauna and lionfish population sizes, distribution, and biomass for these megafaunas. Additionally, the lionfish sighting information is also passed onto one of GVI's partners which helps uncover important information about the invasive species.

**3. Coral Fragmentation Lab**

GVI's Puerto Morelos base is on Mexican federal land and shares some spaces with the CRIAP coral fragmentation lab. Interns worked at the CRIAP laboratory to help the researchers with their work. When fragmented, corals can grow at up to 4 times their normal rate. In an effort to rebuild degraded areas of the reef, researchers at the CRIAP laboratory have been cloning corals by fragmenting them and allowing them to mature. We aided the researchers by assisting with the microfragments and coral nurseries. We were tasked with preparing and cleaning the coral fragments that are eligible to be replanted onto the reef. We also helped clean and maintain the tanks and equipment used by the researchers. On rare occasions, CRIAP researchers requested the aid of GVI interns to replant the cloned coral onto reef transplant sites.

The reefs in Puerto Morelos have become increasingly dominated by macroalgae rather than coral. This increase in macroalgae can be attributed to both overfishing as well as nutrient pollution (Sura et al., 2021). Overfishing has led to a decline in herbivorous fish populations which are responsible for controlling the growth of algae. Increased tourism has led to an increase in terrestrial runoff of nutrients such as nitrogen and phosphorus which aid in the growth of macroalgae. As a part of the reef restoration project in Puerto Morelos, CRIAP partnered with Healthy Reefs for Healthy People to create a marine aquaculture project for Caribbean king crabs. This species' primary diet is calcareous algae, but they prefer the fleshy macroalgae. The Caribbean king crab has per capita grazing rates that exceed those of most Caribbean herbivorous fish which make it an excellent choice to help consume competing algae on the Puerto Morelos reef. The Caribbean king crab has been shown to decrease algae cover by 50% to 80% on small reefs which led to an increase coral recruitment and abundance of reef fish (Spadaro & Butler, 2021). The Caribbean king crab occurs at low densities in this area, so the project aims to raise a large number of Caribbean king crabs to a sufficient size and use them to consume macroalgae at coral transplantation sites. Caribbean king crabs consuming the algae cover on these reefs will ensure higher survival rates of the transplanted corals. We aided the CRIAP researchers in the king crab project by feeding the juveniles, cleaning and maintaining the enclosures they are held in, and also collecting algae on dives that can be fed to the juveniles.

## 4. Beach Cleanups and Divers Against Debris

Marine debris represents a large threat to coral reef ecosystems and can harm or kill animals that reside in them. Debris floating on the surface can block sunlight to corals which prevents photosynthesis, while submerged debris can be consumed by or entangle fish or marine mammals. The presence of plastics specifically in coral reef ecosystems can increase the likelihood of disease from 4% to 89% (Lamb et al., 2018). Due to COVID-19 restrictions, many of the community engagement projects were not permitted as additional contact exposure for these projects was an unnecessary risk that could shut the base down. However, we were able to assist the community in weekly beach cleanups and Divers Against Debris (DAD) dives. Each week, we spent two hours walking along the beach recovering debris that washed up on shore or was left behind by beachgoers. We used mesh bags to carry the debris while filtering out sand that may have been unintentionally picked up. At the completion of each clean, we would work together to sort out all of the debris into the following categories: cigarette butts, bottle caps, plastic bags, foam micropieces, plastic micropieces, glass, tin and aluminum cans, recyclable plastics, and non-recyclable trash. Each category was bagged separately and weighed with the exception of bottle caps. Bottle caps were counted and sent to a charity who would take them and in exchange donate a wheelchair to a community member in need for every 10,000 bottle caps. Debris collection data was sent to Healthy Reefs for Healthy People to use for their analysis. The purpose of this exercise was to collect data for GVIs partners while also removing various kinds of debris from the beach in an effort to protect marine life. Occasionally, we would snorkel in the seagrass with bags and collect similar debris. We also participated in DAD dives where we would remove debris from the reef in Puerto Morelos.

For a more thorough beach and seagrass clean, interns partnered with a local volunteer conservation organization known as the Puerto Morelos Eco-Brigadas. Interns coordinated and executed a community engagement beach cleanup project during their time with GVI. Rather than participating in a typical beach or seagrass clean, interns conducted a dynamic ecosystem clean on a local community beach that utilized the assistance of community members. GVI divers combed the seagrass and collected debris in their mesh bags. Once the bags were full, they signaled to snorkelers overhead to trade the full bags for empty ones. Snorkelers would then signal to one of 2 kayaks to take the bag back to the beach. While divers were removing debris from the seagrass beds, other GVI interns and additional community members conducted an extended beach cleanup. The debris from the seagrass beds was combined with debris from the beach cleanup and then sorted like any other beach cleanup.

## Results

### 1. Trainings and Lectures

To gain a better understanding of the local reef ecosystem, we were provided with a lecture on the local threats to the coral reef. In Puerto Morelos, there is a wide range of natural and anthropogenic threats that lead to the degradation and devastation of reef. We learned that the following local factors lead to degradation of coral reefs: storms, nutrient run-off, sewage, plastic, overfishing, algae overgrowth, animal predation, invasive species, and tourism.

Storms, hurricanes, and earthquakes occur periodically and devastate large areas of the reef by increasing the amount of sediment suspended in the water and decreasing the light availability for photosynthesis. When the sediments settle following a storm, they smother the coral and recovery can take decades as it is inhibited by algal growth. Algae competition is another threat as algae has become a major competitor to coral in this region. In 1983 a waterborne illness wiped out 93% to 98% of the long-spined sea urchin population in one year. Before the disease there were 1 to 14 sea urchins per $m^2$. Following the disease there were only 0.02 sea urchins per $m^2$. As of 2021 this region currently has 0.12 sea urchins per square meter. Sea urchins live on reefs and help by grazing the algae covering the coral. With a mass decrease in sea urchin population, algae gained a competitive advantage and began to overgrow corals.

Diseases haven't only impacted sea urchins, however. Coral diseases have increased in frequency, intensity, and geographic range over that last few decades. Once a disease is present in a reef it spreads quickly, especially amongst species that share similar genetics. During the 1970's and 1980's there was an outbreak of white band disease in the Caribbean that killed a large portion of the live coral. Today, the most prominent coral disease is called the Stony Coral Tissue Loss Disease (SCTLD). This disease has ravaged the Caribbean by rapidly killing large coral colonies in a matter of days to weeks. SCTLD affects over 20 common species of coral in the Caribbean. Coral diseases are caused by infectious pathogens such as fungi and bacteria. They are commonly transmitted through coral predation where predators like the bearded fire worm acts as a vector and spreads the disease from colony to colony. The spread of coral diseases is exacerbated by tourism, an increase in turbidity and sedimentation, and elevated sea temperatures which impair coral defense mechanisms and increase the disease growth rate.

We learned that invasive species alter the population dynamic of an ecosystem and this is especially true for lionfish in the Caribbean. Lionfish are an invasive species that are specialized predators with no natural predators of their own in the area. Lionfish decrease fish recruitment in many herbivorous fish species which turns reefs into algae dominated areas.

Natural threats to coral reefs are difficult to prevent, but anthropogenic threats to coral reefs can be prevented but currently are not. Coral is harvested by humans for the coral trade which directly kills off coral. Coral is removed from the ocean using destructive and aggressive techniques to be sold as souvenirs or for use in aquariums. Similarly, reef fish are harvested for aquariums. Only 2% of marine fish are able to reproduce in captivity and most of the fish harvested for this trade die in transport.

Another important local anthropogenic threat to coral reefs that we learned about is overfishing. Commercial fishing in these regions grossly overfish which does not allow fish or marine mammals the opportunity to reach maturity. 80% of the world's fisheries are fully exploited and overfished. 90% of all large predatory fish such as tuna, cod, halibut, sharks, and swordfish are gone. If overfishing continues at the current rate, it is predicted that the world fisheries could collapse by 2050. Another problem with overfishing is bycatch. Over 250,000 loggerhead and leatherback turtles, 100 million sharks, and 300,000 dolphins and small whales have been unnecessary victims of bycatch. Overfishing contributes to the decrease in population of many herbivorous fish species. Without these herbivorous fish to control macroalgae growth rates, the macroalgae could overtake live coral cover.

We learned about many local threats to the reef that are related to urbanization. The state of Quintana Roo has significant water pollution issues that negatively impact coral reefs as well. Quintana Roo is home to many resorts to accommodate the growing number of tourists each year. With no sewage drainage systems in the area, mass amounts of sewage from these facilities are piped directly into the ground. This sewage finds its way into the local cenotes and eventually makes its way into the ocean. As indicated earlier, sewage can be a cause of diseases in coral that spread quickly. Agricultural runoff which is heavy in fertilizers, hormones, and cleaning products also find their way into the ocean. This nutrient based runoff provides excess amounts of nitrogen and phosphorus into the ocean which can accelerate the growth of algae and create harmful algal blooms (HAB). When HABs form, they block light from coral, preventing photosynthesis, and they use large amounts of oxygen which can suffocate the coral.

With new resorts frequently being built in Quintana Roo, urbanization, deforestation and sedimentation have become large local threats to the coral reef. The annual growth rate of Playa del Carmen is astounding at 25%. In order to build these resorts, mangrove forests are cut down in areas where they are not protected. In areas where they are protected there will occasionally by mangroves that are cut through corruption or lack of enforcement. Mangrove forests are rich feeding and nursery grounds for many marine species such as nurse sharks, barracuda, tarpon, shrimp, crabs, and many others. The mangroves act as a buffer that prevent sedimentation and nutrient runoff into the ocean and as additional shoreline protection from erosion and land loss. Without mangrove forests, increased amounts of nutrient runoff and sedimentation will find their way into the ocean and slow down or halt coral production. Mangrove forests are also carbon sinks and can absorb four times the amount of carbon dioxide than rainforests. The storage of carbon in marine and coastal ecosystems is commonly referred to as blue carbon (NOAA, 2021). Focusing on blue carbon through conservation of these ecosystems would help reduce the effects of climate change.

**2. Scientific Dives**

Data collected by interns on research dives is handed GVI staff who compiles it and provides it directly to GVI partners who analyze this data to generate reports, coastal zone management recommendations, and to inform decision makers so that they can make the best management decisions. The collected data that we as interns have access to are the lionfish and incidental sightings which can be found in Table 2 and Table 3 respectively.

Table 2. Incidental Sighting Data

| Species | Sightings | Frequency Spotted |
|---|---|---|
| Caribbean Reef Squid | 1 | 2.7% |
| Caribbean Stingray | 2 | 5.5% |
| Chain Moray | 0 | 0% |
| Goldentail Moray Eel | 4 | 11.1% |
| Green Moray Eel | 2 | 5.5% |
| Green Turtle | 5 | 13.9% |
| Hawksbill Turtle | 0 | 0% |
| Loggerhead Turtle | 0 | 0% |
| Nurse Shark | 1 | 2.7% |
| Octopus | 2 | 5.5% |
| Sharptail Eel | 0 | 0% |
| Southern Stingray | 22 | 61.1% |
| Spotted Eagle Ray | 14 | 38.9% |

Table 3. Lionfish Sighting Data

| Dive Site | # of Lionfish Spotted |
|---|---|
| La Pared | 6 |
| Cueva | 21 |
| Rodman | 4 |
| All Other Sites | 5 |
| Total | 36 |
| | |
| **Average Size (cm)** | 21 |
| **Maximum Size (cm)** | 4 |
| **Minimum Size (cm)** | 5 |

Healthy Reefs for Healthy People (HR4HP), an organization that encourage discussion and collaboration to strengthen efforts to protect the MBRS, use GVI's collected data to analyze overall reef health. This analysis is then used to promote the adoption and applications of their reef indicators, raise awareness to the state of the reef, and make recommendations to policy makers in the region who are worried about the integrity of the MBRS. HR4HP aims to standardize the analysis of this data to be used to improve reef ecosystem management. The data provided to them by GVI is analyzed along with data from other partners along the MBRS and used in an annual report card. The data gathered during this internship has not been used by GVI's partners yet, as their annual reports will be completed at the end of the year. However, by comparing previous years report cards, the value and importance in this internship program and the data collected can be demonstrated.

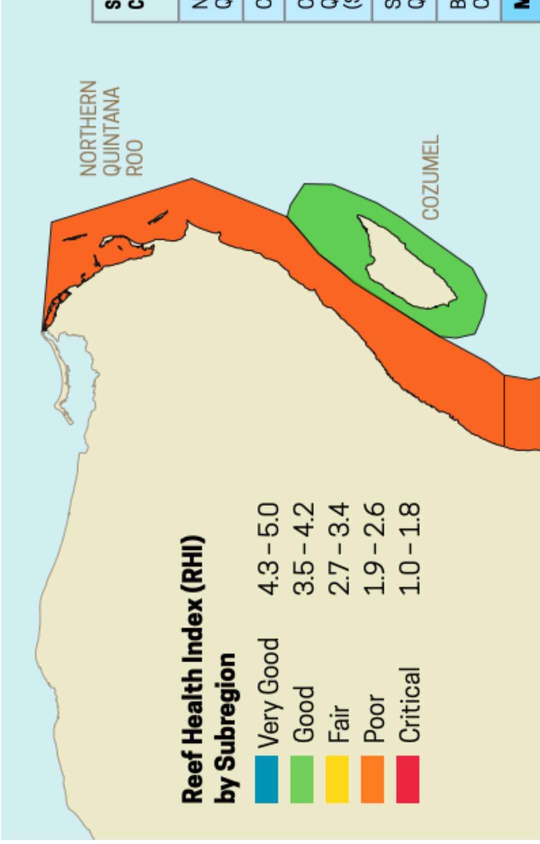
The annual report cards issued by HR4HP also provide recommendations to help restore the reef through such methods as enforcement of environmental regulations and engagement with the private sector to support and incentivize sustainability. Some Mexican federal agencies like the Natural Commission of Natural Protected Areas (CONAP) and the National Fisheries Institute (INAPESCA) use the recommendation from HR4HP reports and take action. Both of these agencies have worked to train coral first responder brigades to assess coral damage after storms and hurricanes and help repair the reef by reattaching overturned coral and re-stabilize the structure of the reef.

As noted previously, HR4HP uses the data collected by GVI to create their reef health metrics. They have created a metric called the Reef Health Index (RHI) that shows the health of the reef all regions of the MBRS. The subregional analysis for Mexico from their 2018 and 2020 reports can be seen in Figure 3. The subregional analysis includes data on herbivorous and commercial fish populations, coral cover, and algae cover. Noting that reefs take a long time to rebuild, drastic changes from year to year are not likely to be seen. Subtle changes in the Northern Quintana Roo subregion, where GVI's base is located, have occurred over the last couple of years.

Figure 3. Subregional Analysis of the Mexican Region of the MBRS in 2018 (left) and 2020 (right) (McField et al.)

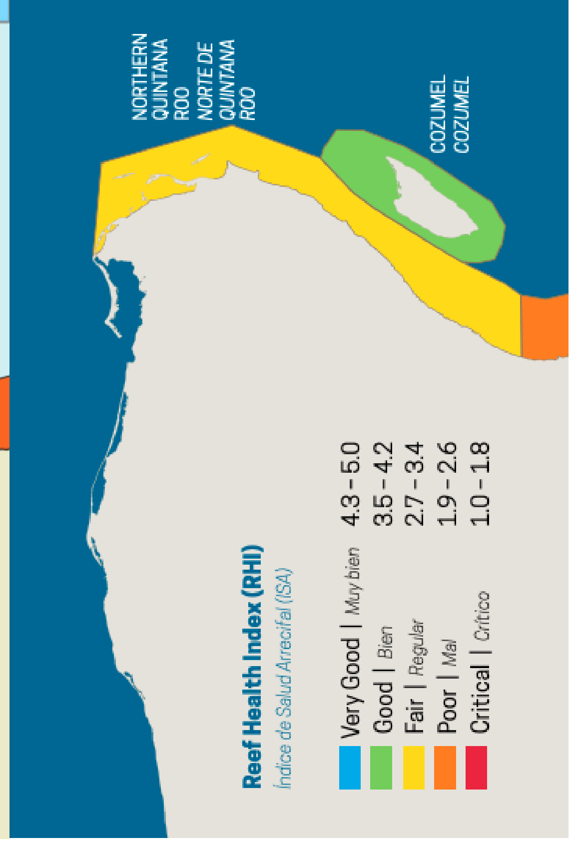
**SUBREGIONAL ANALYSIS**

| Subregion / Country | RHI | # Sites | Live Coral (% cover) | Fleshy Macroalgae (% cover) | Commercial Fish (g/100m²) | Herbivorous Fish (g/100m²) |
|---|---|---|---|---|---|---|
| Nothern Quintana Roo ▼ | 2.5 | 47 | 17 | 22 | 665 | 2521 |
| Cozumel | 3.5 | 18 | 17 | 17 | 3,226 ● | 2,851 |
| Central Quintana Roo (Sian Ka'an) ▼ | 2.3 | 40 | 13 | 26 | 988 | 1,555 |
| Southern Quintana Roo | 2.3 | 22 | 18 | 24 | 572 | 1,738 |
| Banco Chinchorro | 2.8 | 7 | 11 ● | 17 | 1,590 | 1,438 |
| **MEXICO** | **2.8** | **134** | **15** | **23** | **1,139** | **2,092** |




**SUBREGIONAL ANALYSIS | ANÁLISIS SUBREGIONAL**

| Subregion / Country Nombre de la Subregión / País | RHI ISA | # Sites Número de Sitios | Live Coral (% cover) Corales Vivos (% cobertura) | Fleshy Macroalgae (% cover) Macroalgas Carnosas (% cobertura) | Commercial Fish (g/100m²) Peces Comerciales (g/100m²) | Herbivorous Fish (g/100m²) Peces Herbívoros (g/100m²) |
|---|---|---|---|---|---|---|
| **MEXICO** *MÉXICO* | **2.8** | **99** | **16** | **18** | **939** | **2470** |
| North. Quintana Roo ▲ *Norte de Quintana Roo* | 2.8 | 39 | 14 | 19 | 534 | 2773 |
| Cozumel *Cozumel* | 3.8 | 18 | 22 | 15 | 2174 ● | 3024 |
| Central Quintana Roo *Centro de Quintana Roo* | 2.5 | 19 | 13 | 19 | 641 | 2217 |
| South Quintana Roo ▲ *Sur de Quintana Roo* | 2.8 | 7 | 14 | 20 | 898 | 2424 |
| Banco Chinchorro ▼ *Banco Chinchorro* | 2.5 | 16 | 16 | 16 | 906 | 1427 |



## 3. Beach Cleanups and Divers Against Debris

Beach cleanups were disheartening at times because even after spending hours removing debris from the sand, new debris washed ashore overnight, and the beach looked exactly as it did prior to a beach cleanup. The most common types of debris found on the beaches were fishing gear, packaging materials, personal hygiene items, and small and large pieces of trash. We covered a total of 4200 meters during the month-long internship and the amount of debris collected was concerning with 285 kilograms of non-recyclable trash being the feature of the results. Table 4 shows the breakdown of what debris was found over the course of the internship.

Table 4. Beach Cleanup Results

| **Item** | **# Collected** |
|---|---|
| Cigarette Butts | 44 |
| Plastic Bottle Caps | 1,029 |
| Plastic Bags | 293 |
| Foam Micropieces | 3,995 |
| Plastic Micropieces | 5,905 |
| | |
| **Item** | **Weight (Kg)** |
| Glass | 63.6 |
| Tin/Aluminum Cans | 8.14 |
| Recyclable Plastic | 9.02 |
| Non-recyclable Trash | 285.58 |

## 4. Professional Skills

Through this internship, we were tasked with a many responsibilities and assignments to contribute to research projects for GVI's partners. Through these assignments, we gained many professional skills that will aid them in their future careers. Through lectures and exams on an array of topics, we developed hard skills such as biological survey techniques and marine ecology expertise. Through day-to-day activities, we developed many soft skills as well. We learned patience, independence, collaboration, teamwork, flexibility, and adaptability through self-directed tasks, group work in a new environment, and exposure to different cultures. Lastly, we developed an intercultural competency by working in a foreign country. We learned about Latin American culture, language, and habits while also experiencing local challenges and a different way of living. Working with peers from different backgrounds, ages, cultures, and educations provided us with a new perspective on the world and the issues surrounding it.

**Discussion**

The research gathered by GVI is used directly to analyze the health of portions of the MBRS. Based on these analyzations, policy recommendations are made which influence the future of this reef system. Between 2018 and 2020 the RHI in the Northern Quintana Roo subregion has increased from 2.5 to 2.8. RHI is measured on a scale of 1 to 5 which currently labels the health of the reef in this region as “fair” Over the same period of time, live coral cover and fleshy macroalgae cover have decreased from 17% to 14% and 22% to 19% respectively. The other data in the report cards illustrates why the fleshy macroalgae cover has decreased. Herbivorous fish populations have increased from 2521 to 2773 grams per 100 square meters. The uptick in herbivorous fish likely explains the decrease in the fleshy microalgae cover. While the decrease in coral cover does stand out, it’s worth noting that the overall health of the coral in this region has still increased. The RHI has increased over this span likely due to disease, bleaching, and mortality levels decreasing. It is possible that corals in 2018 that were bleached or diseased have died which would explain the decrease in coral cover but increase in reef health. Some of the data for the Northern Quintana Roo subregion of Mexico is provided by the efforts of interns working with GVI.

Based on the reports created by HR4HP, policymakers and leaders are provided with factual data to show how these reef communities have been impacted by natural and anthropogenic threats in the region. With this information, leaders and policymakers have been able to make decisions that partially mitigate these problems. There are many ecosystem restoration projects taking place in this region such as herbivore population enhancement and reef-building coral transplantation. Without the constant supply of reef health data gathered by GVI, there would not be an accurate representation of the health of the coral reef in the Northern Quintana Roo region of the MBRS. Lack of information regarding the state of the reef would result in lack of changes and the coral would continue to suffer until they it was eradicated. The research methods and data gathering performed by GVI interns directly contributes to necessary policy reform and enforcement responsible for protecting and healing one of the Caribbean's greatest resources.

**Conclusion**

Climate change impacts all coral reefs in the world with indirect threats such as ocean acidification and direct threats including ocean warming and sea level rise. Mitigating these issues will take an international effort. Local threats to coral reefs can be addressed by local communities and national policymakers. In Puerto Morelos, the biggest contributor to coral reef degradation is urbanization. Construction of new resorts results in the deforestation of mangroves which are a vital part of the coral reef ecosystem due to their containment of sediments that would otherwise disturb the turbidity in the shallow ocean waters. Lack of waste processing allows sewage to pollute local waters that find their way into the ocean and block sunlight from the coral while also suffocating coral via harmful algal blooms (HABs). Overfishing occurs throughout Quintana Roo as there is lack of enforcement of these laws.

Conservation mitigation efforts can help immediately aid degrading coral reefs, but they are only a temporary fix. In order to eliminate local threats, local lawmakers need to create new laws and start enforcing existing ones. New laws should focus on including mangrove forests in the natural protected areas associated with coral reefs, creating wastewater processing plants while simultaneously creating guidelines for how residential facilities pipe their sewage systems. Local marine enforcement services need to begin enforcing regulations surrounding overfishing and develop incentive programs to ease the transition. GVI's federal partners should also use information on the lionfish populations to incentivize fisherman to catch the invasive species or create a program designed towards finding other solutions to the invasive species problem.

Even with the efforts of GVI, the reefs are not improving as quickly as one might hope. A constant stream of data continues to provide a real time look into the status of the reef, but in the Northern Quintana Roo subregion, the reef health is listed as 'fair'. The reef still needs a lot of help and many of the local threats can be removed if proper action is taken and communities are properly educated on what changes they can make to help.

## References


Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). *Reefs at Risk Revisited*. World Resources Institute.

CoralWatch. *CoralWatch Do It Yourself Kit*. University of Queensland, Australia.

Google. (2021). Google Earth [Computer software].

NOAA. (2011). Coral Reefs Support Jobs, Tourism, and Fisheries. National Ocean Service website, https://floridakeys.noaa.gov/corals/economy.html#:~:text=By%20one%20estimate%2C%20coral%20reefs,full%20and%20part%2Dtime%20jobs.

NOAA. (2021, February 26). What is Blue Carbon? National Ocean Service website, https://oceanservice.noaa.gov/facts/bluecarbon.html

McField, M., Drysdale, I., Peterson, A. G., Soto, M., Flores, M. R., & Craig, Nicole. (2020). *2020 Mesoamerican Reef Report Card: Evaluation of Ecosystem Health.* Healthy Reefs for Healthy People.

McField, M., Drysdale, I., Peterson, A. G., Soto, M., Flores, M. R., & Craig, Nicole. (2018). *Mesoamerican Reef Report Card: An Evaluation of Ecosystem Health.* Healthy Reefs for Healthy People.

Keller, B. D., Gleason, D. F., McLeod, E., Woodley, C. M., Airamé, S., Causey, B. D., . . . Steneck, R. S. (2009). Climate change, Coral Reef Ecosystems, and Management Options for Marine Protected Areas. *Environmental Management, 44*(6), 1069-1088. doi:10.1007/s00267-009-9346-0

Lamb, J. B., Willis, B. L., Fiorenza, E. A., Couch, C. S., Howard, R., Rader, D. N., . . . Harvell, C. D. (2018). Plastic Waste Associated with Disease on Coral Reefs. *Science, 359*(6374), 460-462. doi:10.1126/science.aar3320

Lang, J. C., Marks, K. W., Kramer, P. R., & Ginsburg, R. N. (2015). *A Guide to Methods & Training Materials*. Atlantic & Gulf Rapid Reef Assessment (AGRRA).

Spadaro, A. J., & Butler, M. J. (2021). Herbivorous Crabs Reverse the Seaweed Dilemma on Coral Reefs. *Current Biology, 31*(4). doi:10.1016/j.cub.2020.10.097

Sura, S. A., Bell, A., Kunes, K. L., Turba, R., Songer, R., & Fong, P. (2021, January 23). Responses of Two Common Coral Reef Macroalgae to Nutrient Addition, Sediment Addition, and Mechanical Damage. *Journal of Experimental Marine Biology and Ecology, 536*. doi:10.1016/j.jembe.2021.151512

# Appendix A

## AGRRA Monitoring Methodology

## Provided by the Atlantic & Gulf Rapid Reef Assessment Program

## Appendix B

## CoralWatch Monitoring Methodology

## Provided by the University of Queensland, Australia