Assessment of the Tres Palmas Marine Reserve

A review of the research and an evaluation of the management plan with recommendations

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Abbreviations and acronyms

USGS – United States Geological Survey
NCRMP – National Coral Reef Monitoring Program
PRCRMP – Puerto Rico Coral Reef Monitoring Program
NOAA – National Oceanic and Atmospheric Administration
CARICOOS - Caribbean Coastal Ocean Observing System
DNER – Department of Natural and Environmental Resources
ESA – Endangered Species Act
RMTP – Reserva Marina Tres Palmas
MPA – Marine protected area

Table of Contents

Executive Summary

The Tres Palmas Marine Reserve is an iconic fringing reef that flourishes with corals and is characterized by the presence of several commercially and ecologically important fish and invertebrate species. To determine if the goals and objectives of the reserve are being met, a long-term plan of research and monitoring was drafted but remains unimplemented. Even though the coral reefs of the reserve have been studied over time, the reports by different researchers had specific objectives and responded to multiple information needs that were not necessarily those expressed in the action plan. Thus, this review sought to compile all available research, identify if that research could be compared over time, and identify if those projects were addressing reserve goals. That information was then used to evaluate the management plan and identify recommendations for future work.

There was a total of 40 projects that were identified with relevance to the reserve, spanning the late 1990s (before reserve establishment) and early 2005 to the present. Very few projects had data available for public review and analysis. Overall, there was a lack of standardization in survey methodologies between projects as these had their own specific goals that did not overlap. Thus, only two data types could be compared in this review and only among their respective projects. The first was temperature data that the Schärer et al. team recorded during portions of their elkhorn demographic surveys. The second data set was from the Garcia-Sais PRCRMP team which included information on coral and fish communities. From those reports, it was evident that live coral cover in the reserve has been on a steady decline. This was exacerbated significantly by the appearance of Stony Coral Tissue Loss Disease in 2022, which has been estimated to decrease live coral cover to 15% across multiple species excluding elkhorn. The massive bleaching event of 2023 has further impacted corals including elkhorn.

The management plan for the reserve was created by the Centro Interdisciplinario de Estudios del Litoral of the University of Puerto Rico-Mayaguez and was accepted in 2008. The plan has not been updated or evaluated since its inception. Thus, this review also determined if the management plan, based on the biophysical indicators outlined in Pomeroy et al. 2004, is achieving its mission. Six management plan objectives for Biological Conservation and one objective for Sustainable Use are being addressed through scientific studies, or have been addressed even minimally through one, noncontinuous study. Of those objectives, four are being assessed at an acceptable monitoring level and with appropriate data. However, only two projects (PRCRMP and Surfrider water quality monitoring) have been standardized in their data collection that allow for actual evaluation of conditions and changes over time. The PRCRMP study summarizes trends for each of its monitoring reports. The water quality monitoring has yet to evaluate its data. The overall reserve goal to "*ensure the ecological integrity and biodiversity within the RMTP and surrounding areas*" is not being met. However, this is due to a combination of stressors, some of which are beyond the management control of the reserve. The goal to "*increase interdisciplinary scientific and technical knowledge applied to the management of natural ecosystems (principally the coral reef) and their sustainable use*" is not being addressed. There is a high volume of scientific studies that have been conducted within the reserve, producing valuable insight to assist with management, yet the management plan has never been adapted to consider these results.

Recommendations were created after analyzing all current project data and comparing that information with the biological indicators that are used to assess MPA health. The six recommendations direct future research to address the spillover of fishes and coral larvae, the recruitment success of restored corals, evaluate water quality, and improve awareness of the reserve's presence and purpose. Several of these recommendations are actions that can be implemented with little financial input or through inclusion in current or future monitoring actions that are already funded.

Part 1: Review of the Research in the Tres Palmas Marine Reserve

Introduction

Marine protected areas (MPAs) are designated to protect a natural ecosystem, a special historical location, or some other valuable component of the marine environment that deserves a level of protection from anthropogenic activity. In the same way that MPAs can vary in their purpose, they can also vary in their level of protection. For example, the most strictly protected MPAs are designated as marine reserves, where "no take" protocols may be in place, and some areas may even be closed to human activity altogether, including boating, snorkeling or scuba diving. Regardless of the purpose or intended enforcement level, all MPAs must have a management plan that defines the goals and regulations. This plan must be evaluated regularly to determine if those goals are being met. Without this due diligence, there is no way to know if the MPA is functioning as intended.

The Reserva Marina Tres Palmas (RMTP), or Tres Palmas Marine Reserve in English, located in Rincón (18°20'58.6"N 67°15'52.6"W) is an iconic fringing reef that flourishes with all seven Endangered Species Act (ESA)-listed corals and is characterized by the presence of several commercially and ecologically important fish and invertebrate species. The 89-hectare reserve was established by a grassroots effort in 2004 led by local non-profits, fishers, and other stakeholders. It is currently co-managed by the Puerto Rico Department of Natural and Environmental Resources (DNER), the municipality of Rincón and the NGO Amigos de Tres Palmas. This reef system boasts large, genetically diverse elkhorn coral (*Acropora palmata)* (38 genets, Mège et al. 2015) that grow in thickets to blanket much of the nearshore substrate. The reserve's location, just slightly tucked into a curve of the island's westernmost point, protects it from much of the river runoff that occurs north and south of the reserve. The prevailing currents typically carry terrigenous sediments away from the nearshore ESA coral colonies with some exceptions. The second and third reefs of the RMTP are a mix of star, boulder, and elkhorn corals. Before the arrival of Stony Coral Tissue Loss Disease (SCTLD) in July 2022, the reef was considered very healthy compared to others in Puerto Rico, with an estimated 47% (range of 27-63%) live coral cover (Garcia-Sais et al. 2014). However, that estimate is now around 15% live coral cover based on rapid assessments by local scientists (H. Ruiz, pers comm). The most notable threats to this ecosystem include septic tank leakage with contaminated waters, terrestrial runoff from adjacent watersheds, pollution by plastics and other debris, poaching of fish and invertebrates, impact to corals by snorkelers and divers as well as the climate change impacts such as increased water temperature, stronger and more frequent storms that affect the coral structure and rapidly emerging coral diseases.

The RMTP is guided by actions specified in a management plan approved by the Puerto Rico Planning Board in 2008 which established clear goals and objectives. To determine if the goals and objectives of the RMTP are being met, a long-term plan of research and monitoring was drafted but remains unimplemented. Even though the coral reefs of the RMTP have been studied over time, the reports by different researchers had specific objectives and responded to multiple information needs that were not necessarily those expressed in the action plan. The question of reserve effectiveness remains unanswered as it relates to coral reef condition in the RMTP given the no-take, no anchoring designation that should in theory help maintain the reef structure and ecological integrity. Previous research investigated corals in other contexts, ranging from coral reef characterization, elkhorn coral demographics, marine debris removal, fish assemblage condition, water quality, and human uses of the marine reserve. However, to determine changes over time in the condition of coral reef habitat and fish assemblages, a

robust baseline of the condition of the reserve was necessary. Unfortunately, there was no benchmark survey completed before the reserve designation.

Therefore, the purpose of this review is to compile a database of the research that has been performed in the reserve and to determine if any data collected from the various projects could be evaluated jointly to provide some overarching understanding of the functioning of the reserve to protect fish and coral species.

Methods

Information was collected and reported in an online spreadsheet (Google Sheets) that listed project metrics measured and data availability. Within the database, all evaluated research was divided into the following categories: Educational, Monitoring, Detection, Removal, and Conservation. Then, the project was further defined by its major focus on the scientific aspects of oceanography (Physical, Biological, Ecological, Chemical), or by its anthropogenic context (Social) or was labeled as a combination of those factors if multiple foci were addressed. The target interest of the project was then defined with one or two words, such as "Elkhorn" or "Water Quality" to provide a quick reference to the theme of the work. Other factors were also noted to generate a descriptive database entry for each project, including project duration, dates, date results were published, authors, affiliation, project title, contact, products, and if the product and data are available in the online database. The descriptive database can be accessed here and the collection of research can be accessed here. This digital record will serve to periodically update the research database with new projects or findings should additional review be necessary.

Results & Discussion

Overview

There was a total of 40 projects and/or project summaries that were identified with relevance to the RMTP, encompassing a date range of the late 1990s (prior to reserve establishment) and early 2005 to the present. Very few projects (n=3) have data available for public review and analysis. Each project is summarized below, categorized by the main themes used in the database. The projects are summarized in chronological order except where introducing certain projects ahead of others made sense for descriptive purposes.

By classification, there were a total of two (2) Educational projects, fifteen (15) projects and/or summaries focused on some element of Detection, nine (9) Conservation projects, twelve (12) projects and/or summaries that were long-term Monitoring, and two (2) Removal projects. A timeline of some of the key findings/focal points of these projects is visualized in Figure 1.

Although this represents an exhaustive search for relevant projects and data, it remains possible that some projects conducted in the RMTP were not discovered or reviewed in this report.

RESERVA MARINA TRES PALMAS

PROJECTS TIMELINE

1990s - 2000

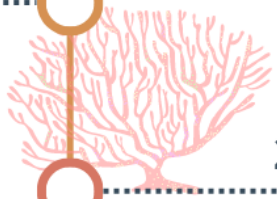
Early Monitoring

Elkhorn coral monitoring at the nearshore reefs of Steps Beach from 1994-2000. ***Low reports of disease or mortality***.

2004 - 2006

Reserve Founded

The Reserva Marina Tres Palmas was founded in 2004 and long-term monitoring of elkhorn coral begins. Water quality monitoring begins in 2005 and continues to present day. ***Live coral cover was estimated at 37%.***



2007 - 2009

Plan de Manejo

Other studies begin long-term monitoring and report on elkhorn status in 2007. Management plan is accepted in 2008. Coastal erosion is assessed. ***Live coral cover was estimated at 33%***

2010 - 2012

Debris Removal

Elkhorn coral sperm from RMTP collected and used in lab-based coral reproduction. ***Large scale marine debris removal takes 75 tires from the reserve and tons of garbage***.

2013 - 2015

Monitoring Boosted

NOAA joins monitoring effort for coral reefs in the RMTP in 2014. Swell patterns modeled to observe sediment transport. ***Thirty-eight genotypes of elklhorn coral identified in the RMTP***.

2016 - 2018

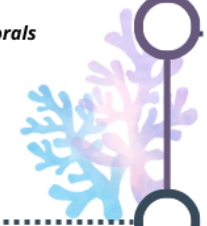
Coral Restoration

White pox in high incidence (>60% occurrence) on elkhorn in the reserve in 2016. A second marine debris removal effort takes >500 lbs of trash. ***Coral restoration plants >800 corals to the RMTP in 2018.***

2019 - 2021

Waste & Waves

Wave dynamics observed post-hurricanes in order to improve coastal hazard monitoring. ***RMTP found to be relatively clean of human waste pollution.***



2022

Disease Emerges

Restoration continues after boat grounding and hurricane (+360 corals planted). SCTLD first observed in the RMTP, treatment begins same month. Citizen Science program begins. ***Live coral cover estimated at 15%***.

2023

Monitoring Continues

SCTLD and coral reef restoration monitoring continue in the reserve to present day.

Figure 1. Key projects visualized on a timeline

Brief Project Summaries

Educational

Two (2) items were deemed strictly educational. The first was a presentation about the creation of the RMTP, while the second was a series of in-water trainings for visiting students that used the RMTP as a field station for learning fish and benthic reef assessment.

The conference presentation given by the Surfrider Foundation at the 20th International Conference of The Coastal Society (Nelson and Richter 2006) showcased the efforts of the Surfrider Foundation and its local partners in successfully establishing the RMTP in 2004. The document discusses the various issues that plague the RMTP (and, to date, continue to do so) including poor land-use decisions and the lack of an enforced management plan. The document also details the steps taken to produce a management plan and the outreach implemented to educate the Rincón community about the reserve's natural resources. This document provided an adequate summary of the multiple efforts undertaken to originally establish the reserve and provides solid background information on that effort.

The educational project conducted in the reserve from 2012, 2014 – 2019 was led by Isla Mar and Florida Institute of Technology as part of a Coral Reef Ecology field course by the latter institute. The project involved training students in Caribbean reef fish identification and fish survey techniques, whereby they collected data on fish species richness in the reserve at various fixed and random points. The data is available for comparisons, however, several caveats must be noted. First, the skill level of the surveyors varied considerably, severely affecting the reliability of the data. Second, the selected survey sites were not consistent over the years, which impacts long-term spatial comparisons. Third, the surveyors differed every year thereby introducing significant variability that further complicates the reliability of data. The goal of the activity was to provide an educational exercise in a field survey technique, thus the concern about data reliability was not considered in the project's goals.

Detection

There was a total of fifteen (15) projects that were characterized as *Detection*. This classification referred to a study that was performed for the purpose of detecting some physical, chemical, biological, social or another component that was not replicated over time in a long-term monitoring sense. These studies provide snapshots of occurrences or use time series data to produce an overview of the detection that was not intended to be further replicated by continuous or repeated monitoring.

A poster presentation given by CARICOOS presented the results of the use of satellite imagery to observe sediment loading around Puerto Rico. Total suspended sediment (TSS) was measured using 215 Medium Resolution Imaging Spectrometer (MERIS) images at 300 m resolution collected from 2005 to 2009. Suspended sediments were found at detectable concentrations at all stations including the RMTP. However, there were no significant levels of suspended sediments detected in the reserve.

An erosion study by Scott et al. (2011) found that extreme weather conditions do affect the coastline of the reserve, but that the coastline is able to recuperate. The study area was the entire length of the RMTP and stations were located 30 m apart, for a total of seven stations.

Measurements of the geology of the RMTP were determined from the line of vegetation perpendicular to the coastline. These measurements were taken in 2009 (April, September, November) and 2010 (January, March, April, May, and September). Changes in the shoreline were documented. Results indicated that sediment transport along the littoral zone provides growth and biodiversity in ideal conditions and the coastline remains relatively stable due to the presence of natural structures.

A study (Méndez Lázaro et al. 2012) used GIS methodology to determine the impact of bacterial contamination from non-point sources in coral reefs (specifically *A. palmata* thickets) in the RMTP. The project consisted of 12 field trips distributed throughout one year in which samples for coastal water quality were taken. To address this question, 5.6 m radial transects were used to assess the ecological impact of bacteriological contamination in various regions of the reserve. With this ecological data and the use of GIS, the researchers were able to identify sub-basins near the RMTP where septic tanks were faulty and where there was no wastewater service for sanitary sewage.

This septic waste issue was further evaluated by a later study that addressed the impact of septic waste leakage into the RMTP (Norat-Ramirez et al. 2019). This project delineated the different sub-watershed waterways that drained into the RMTP. They tested water quality at four locations within the RMTP and four control locations outside of the reserve (two north and two south). Results indicated that the RMTP is relatively clean of fecal coliform bacteria, likely the result of few direct river drainages into the reserve and a low density of residency along the boundary. However, the control sites did detect the bacteria. They remarked that the reserve is protected from contaminants from river runoff from the Rio Culebrinas to the north and the Rio Añasco to the south, mostly by the shadow of protection from the Rincón peninsula and the typical southerly current flow. They also observed that coral bleaching in the RMTP could be caused by pulses of freshwater/low salinity occurrences from runoff during storms that drain into the RMTP.

One study characterized wave patterns in the RMTP, a thesis from the Civil Engineering department of UPR-Mayagüez. Chardon (2013) deployed an acoustic doppler current profiler (ADCP) at the RMTP to record physical oceanographic information about the waves in the area, due to the interest in the large-scale waves that are generated during the swell season from November to April. Chardon sought to model the conditions at the reserve that occurred during Tropical Storm Isaac and Hurricane Sandy and the resulting sediment transport. Typically, swells with a north component result in energy being dissipated by the coral reefs of the RMTP. However, with northeast components to the swell, the alongshore sediment transport was found to move southeast.

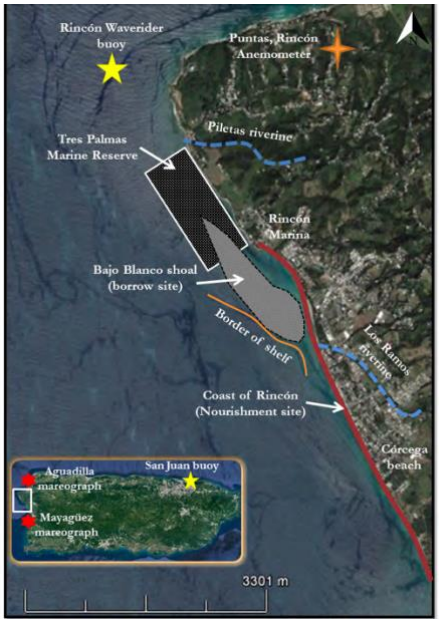


Figure 2. Map of sand shoal near RMTP, from Rojas 2016

Another thesis (Rojas 2016) from the Civil Engineering department of UPR-Mayagüez focused on evaluating simulated dredging at a nearshore sand shoal (Bajo Blanco) for the purpose of beach renourishment along the Rincón coastline from the marina to Corcega Beach (Figure 2, Rojas 2016). The study evaluated the impact that removing sand from this shoal would have on sites north and south of the removal area, which included the RMTP. This natural sand shoal is a likely deposit of sand to the beaches of Rincón, bringing sand to renew areas during specific wave events and wave directions. The simulated dredging models found that the associated changes in wave energy resulting from dredging this site would cause changes in the spatial structure of the wave-induced currents, especially the alongshore currents of the RMTP towards Bajo Blanco. This study built upon results obtained from Chardon (2013).

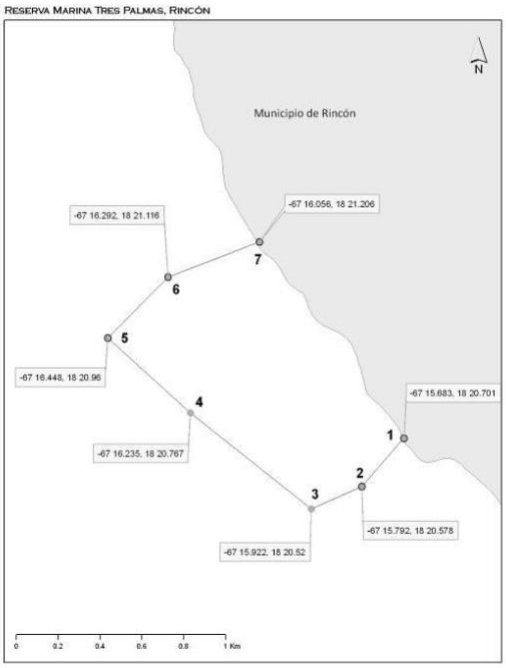


Figure 3. Location of the marker buoys in the RMTP

A report on the condition of the mooring buoys was performed by Isla Mar in 2016 as part of a NOAA NCRMP project monitoring fish and benthic organisms in the reserve. This action was completed to specifically address the Plan of Action for Sustainable Use under the Specific Objectives (Section 2.1.3) in the RMTP Management Plan. The management plan also states that the buoys should be monitored yearly, however no marker buoys currently exist in the RMTP as of the writing of this review. Results of the buoy report found that only two buoys were present at the time of the survey, the southernmost and northernmost buoys marking the western boundaries, and only one mooring block of the other three missing buoys was located at the central western boundary location. It was also determined that the GPS coordinates provided in the Reglamento de Pesca de Puerto Rico report (DRNA #7949) were accurate for buoy locations #2, 4 and 5 (Figure 3). The condition of the two buoys was deemed acceptable, however, only one had a stable line and mooring structure but was entangled with a trammel net and fishing line. The other present buoy (#5) showed weakness in the connection to the mooring blocks where the line appeared frayed. The mooring block for the missing buoy #4 was present. A complimentary fish and benthic survey was conducted at each mooring block to assess the composition of the benthic and fish communities, finding that the mooring blocks had attracted several fish species of commercial importance, particularly the red hind (*Epinephelus guttatus*). The report concludes with recommendations to replace the missing buoys, improve the condition of the buoy mooring block at #5, remove the trammel net on buoy #2, and add additional land-based signage along the shoreline portion of the reserve.

A doctoral dissertation (Beltran et al. 2017) from the Marine Sciences Department of UPR-Mayagüez addressed a biological detection issue of connectivity. The research focused on MPA connectivity between the RMTP and offshore marine reserves on the west coast of Puerto Rico (Desecheo Island, Mona Island) using the yellowhead jawfish (*Opistognathus aurifrons)* as the study organism. Specimens of this species were collected from the RMTP and the other study sites, then gene flow was compared using a distinct molecular approach of single nucleotide polymorphisms (SNPs) and microsatellites. The results of the study found that current MPAs on the West Coast, including the RMTP, are too far apart from each other to allow for connectivity. The effective dispersal of the studied small, benthic-dwelling reef fish was only 8.3 km while all MPAs were >50 km apart from each other. This study highlighted the importance of MPA buffer zones and MPA connectivity for the future of protecting biodiversity.

An ornamental fishery study used the RMTP as a control site to compare fished vs. non-fished reefs to evaluate the species listed on the allowed ornamental fish trade. The study was conducted from January to October 2010 (Ramos Alvarez 2011). The study observed that the heaviest ornamental fishing occurs on the west coast between Añasco, Rincón and Aguada, but observed no differences in species richness or abundance between the RMTP (control site) and the fished reefs of Rincón. The author suggests this could be because the two sites are relatively close and perhaps spillover is occurring from the reserve to the adjacent reefs.

Two studies were conducted that observed tourist interactions with the marine environment. The first study, led by Rosas Perez (2012) of UPR-Aguadilla, conducted direct interviews with visitors to the reserve to inquire about their knowledge of the area. Of the 40 people interviewed, 40% had visited the RMTP for some type of recreational activity. About 18% of these interviewees were vacationers. A vast majority of those interviewed (85%) knew about the reserve, and of that percentage, 44% commented that the purpose was to protect the coral while 24% did not know the purpose reserve and 26% knew the reserve was for conservation but did not know the specifics of that objective. Rosas Perez also documented that the primary activity performed at the RMTP was snorkeling. The second social study was more passive and observational within the RMTP and focused on observing actions and behaviors performed by tourists. This study led by Webler and Jakubowski (2016) found that tourists would often step on the reef (near and around the Steps Beach entrance) to enter the water if they were unsure where to enter from. This result indicates the need for detailed signage at the common entry/exit locations at the reserve to prevent damage to the reef and shoreline.

The wave dynamics at the reserve have been observed using stationary cameras designed to record and monitor the wave action (Canals and Storlazzi 2021). The information has been used to improve coastal hazard forecasting by CARICOOS. This two-year project was started in 2019 and was funded by the USGS. It concluded in 2021.

A report by NOAA (Kraus et al. 2020) focused on determining high-priority areas in Puerto Rico to focus future efforts with high-resolution imagery and habitat mapping. The goal was to identify and summarize spatial priorities for seafloor mapping, sampling, and visual surveys in coastal and offshore waters in the U.S. Caribbean. The report identified the RMTP as a high-priority area where additional high-resolution imagery and habitat information can help with questions of tourism and coastal development impacts, as well as provide detailed information to direct restoration.

A thesis from the Marine Sciences Department of UPR-Mayagüez was published that compared fish assemblages at various types of reef structures (restored reefs, transplanted reefs, natural reefs, artificial, etc). The study (Nieves-Ortiz et al. 2021) used the RMTP as a transplanted reef site, indicating that elkhorn coral had been transplanted to the area in the last 10 years. The results indicated that fish assemblages did not differ much (except in biomass) between natural reefs and transplanted reefs, which the authors suggest supports that transplanted reefs do provide some of the same function as natural reefs and should continue to be used as restoration and mitigation processes to help restore natural reef function.

Lastly, a recent study (Hernandez-Delgado and Florez-Ortiz 2022) provides a quick snapshot of some of the issues that could be harboring coral decline and lack of recovery in Puerto Rico. In the RMTP, water quality was monitored physically and through remote sensing to determine that the reserve was subject to high sediment concentrations and dissolved oxygen due to sewage runoff and plumes from the Añasco river outlet. These stressors impact coral recruitment to the area, potentially harming the overall growth of the coral reef in the RMTP. However, this study also recognized its limitations with a very limited sample size and survey time, thus indicating that additional sampling would help provide more insight.

Conservation

There was a total of nine (9) projects that were categorized as *Conservation*. This classification referred to projects that were focused on developing conservation tools or deploying conservation practices, such as citizen science and coral reef restoration. These projects could be one-time or replicated over time.

One unique study (Hagedorn et al. 2012) collected sperm from sexually reproductive elkhorn coral during its annual spawning event in August 2009 for four nights. The sperm was used to develop a cryofreezing method to store coral sperm for use in in-vitro fertilization (IVF) to reproduce the species in a laboratory setting for conservation. The results allowed for a methodology to be developed that could be used to test the IVF success for elkhorn corals. The same lead author performed another study in the RMTP. The collected sperm from five donor elkhorn colonies was used to test if cryopreserved coral sperm could be used to facilitate assisted gene flow between genetically isolated populations of Caribbean coral. The study (Hagedorn et al. 2018) successfully reproduced cross-population *A. palmata* between Florida, Curacao, and Puerto Rico (the RMTP) showing that assisted gene flow is possible in this endangered species and that regional *A. palmata* colonies are sexually compatible. The results showed that after one month from fertilization, there were 230 settlers from Curacao crossed with the Puerto Rico population that had survived. This was the first experiment of its kind and the genotypes of *A. palmata* from the RMTP were used for this purpose.

Thirty-eight different genotypes of the elkhorn coral in the RMTP were described from 52 coral colonies (Mège et al. 2015). From this project, it was determined that the RMTP has a high clonal cover (clones of the same genotype) for elkhorn, which is likely an effect of the extensively suitable shallow habitat nearshore in the reserve. This also means that this area could be subject to severe coral loss should a disease wipe out a particular genotype that is highly cloned throughout the reserve. However, 38 different genotypes are rather diverse for such a small area which is promising for the future of elkhorn in the reserve.

The Tres Palmas Citizen Science Program was started in 2022, led by Isla Mar, HJR Reefscaping, and Sea Grant, which trained 17 volunteer residents of Rincón and surrounding towns, to conduct coral reef restoration monitoring and seabird monitoring. The citizens perform three coral monitoring expeditions to their specific restoration areas, measuring coral growth of tagged colonies and monitoring for diseases and bleaching. They also perform three bird surveys, taking notes on species richness and abundance along the community trail adjacent to the reserve and the shoreline of the reserve. This program is currently in its infancy but has plans to continue. The first status report of the monitored corals will be due in December 2023.

A report on the health of the coral reef in the RMTP after Hurricanes Irma and Maria, and the major swell event of February 2018 was performed by HJR Reefscaping in collaboration with various partners around the island who performed the same damage assessment in other regions. The reserve was indicated to have damage to the reef ranging from minor to severe. Due to this, it was recommended that restoration continue in this area. Prior to this report, restoration had already begun at the reserve, led by HJR Reefscaping as part of an island-wide restoration effort funded by NFWF. In the reserve, 835 corals were outplanted over five days. For this, 14 volunteers contributed 272 man-hours towards the restoration. Volunteers assisted trained divers by mixing cement, transporting cement to the restoration sites by paddleboard (Figure 4), collecting data on the distribution and condition of fragments, photographing cemented fragments, and assisting in outplanting with scientists.

Figure 4. Aerial view of paddleboarder assisting coral reef restoration, photo by H. Ruiz

In January 2022, a FURA boat was grounded on the reef behind the Steps at the reserve. Isla Mar responded with an initial assessment of the damage shortly after, and HJR Reefscaping organized restoration efforts. The team, accompanied by two FURA officers and other volunteers, cemented 120 elkhorn coral fragments to a location near the grounding site. Ninety-two of those corals were part of an orthomosaic (aerial photograph), covering an area of 213 m^2, that will be used to follow the restoration effort over time. Ten of these corals were tagged and are currently being monitored as part of the Tres Palmas Citizen Science Program led by Isla Mar.

After Hurricane Fiona in 2022, an assessment of damage was performed by HJR Reefscaping. Most of the damage was concentrated in the *A. palmata* zone nearshore. It was estimated over 400 elkhorn coral fragments were generated in three areas of the reef. Marine debris was also observed tangled on *A. palmata* colonies. Many large colonies over 70 cm in length were detached from the reef bottom and laid upside-down on top of the reef. The restoration was conducted in this region, where 240 elkhorn corals were replanted to the reef at two locations in the nearshore area of the RMTP. These corals are also being monitored as part of the citizen science program.

Figure 5. Location of SCTLD treatment plots and control plots, from H. Ruiz

In July 2022, the first case of Stony Coral Tissue Loss Disease (SCTLD) was spotted in the RMTP by resident Raul Ortiz. Isla Mar responded by verifying the presence of the disease at the GPS coordinates provided by Ortiz. Thereafter, efforts have been made to treat various coral colonies and monitor their recovery, led by DNER and HJR Reefscaping. The antibiotic treatments began in July 2022. Six plots are being monitored – three treatment plots and three control plots (where no treatment is being given, Figure 5). At the time of writing this review, five antibiotic treatment events have been applied to the corals at the three plots. Thus far, it is inconclusive if the treatment has been successful.

Monitoring

There were twelve (12) projects and/or project summaries defined as *Monitoring*. This designation referred to projects that have long-term datasets, permanent monitoring sites within the RMTP, and intentions to replicate or continue monitoring, among other factors that indicate repeated measurements in the RMTP. These projects did not necessarily need to be ongoing at present to qualify for this category. *These projects were those that were assessed for any potential use in data comparison between or within projects. Also, some data reported here may be shared within the same project but is presented based on the separate reports that were generated – usually as final reports for specific monitoring seasons.*

Three (3) main long-term monitoring projects provided coral demographic data. The first was established by Garcia-Sais et al. which focuses on monitoring at three independent, fixed sites within the reserve at three different depth ranges representing three distinct habitat types in the RMTP. This project collects data on fish and benthic communities as part of the PRCRMP where data is publicly available and occasional final reports are provided that summarize the results. This project is still ongoing at the time of the review. The second program was established by Schärer et al. and focused specifically on monitoring coral demographics of elkhorn at three fixed sites within the RMTP. These are relatively the same depth range but spatially separated by region within the reserve (north, central, south). This program collected information on coral health, disease prevalence, growth, etc. for elkhorn in the monitored plots. The program concluded in 2014. The third and final long-term monitoring is conducted by NOAA as part of NCRMP. This program started in 2014 and continues to date. The number of sample sites within the reserve is not consistent between years and is randomly stratified by habitat, thus is not replicated at the same sites over time. Data collected include fish and benthic community information. Methodologies for collecting the fish community data changed in 2016, thereby rendering the initial monitoring in 2014 incomparable until a calibration assessment can be completed. All three programs are summarized below, in chronological order.

In 2001, Bruckner reported to NOAA about the condition of *A. palmata* within the RMTP, prior to its establishment as a reserve so the reference is indicated as Rincón rather than the RMTP. He commented that numerous broken colonies were observed after Hurricane Georges. Unlike La Parguera, most fragments remained near mother colonies and did not die. At the time of his report the RMTP populations of elkhorn coral were not facing a substantial threat from coral diseases or predators. Over the duration of the study (1994-1997), only six standing elkhorn colonies had been affected by groups of snails and associated predation was minimal. A low incidence of disease was observed in the RMTP. Isolated colonies were periodically observed with white band, and patchy necrosis may be relatively common after extended periods of terrestrial runoff (May-July, during the rainy season water visibility, may drop below 1 m and remain this way for several days). An outbreak of disease (patchy necrosis) was recorded on *A. palmata* at Steps Reef [*sic*] in 1996. Bruckner stated that the occurrence of the disease may be associated with high sediment loads from the construction of a residential structure across the street from Steps. The construction project involved the removal of all trees, and the land was bulldozed, exposing the underlying sediment. Unfortunately, this occurred during the rainy period in summer, and run-off was exacerbated. But fortunately, the amount of sediment run-off declined within a few weeks, and the disease outbreak subsided. However, this indicates that coral populations are very vulnerable in this location, and the development of the land immediately in front of Steps may seriously compromise elkhorn coral populations, especially if construction coincides with the rainy season.

The study by Garcia-Sais et al. (2006) involved monitoring natural communities from marine reserves in Puerto Rico, which included the RMTP. A total of five permanent 10-m long transects were surveyed at each of three permanent reef stations (5, 10 and 20 m depths). Monitoring surveys were performed during the period between April and July 2006. Rainfall-runoff with heavy loads of terrestrial sediments was observed to reach the fringing coral reef following a prevailing northerly alongshore current during the 2004 survey. Also, there were considerable amounts of garbage (cans, bottles, tires, etc.) on the reef. At the 5m site, live coral cover averaged 37.02% where elkhorn coral (*A. palmata*) was the dominant species with a mean substrate cover of 28.8 % thus representing 77.8 % of the total live coral cover. A total of 65 fish species were identified and no statistically significant differences in fish species richness or abundance were detected during the monitoring period (2004-2006). The author noted that large (adult) commercially important demersal fishes (snappers, groupers, hogfishes) were not observed. At the 10 m site, soft corals (gorgonians) were the most prominent feature and stony corals occurred mostly as encrusting colonies of typically small size and low vertical relief. Turf algae, a mixed assemblage of short filamentous red and brown macroalgae presented the highest percent of reef substrate cover with a mean of 64.51 %. A total of 109 fish species were identified. At the deepest 20 m site, there was substantial sediment transport down the shelf edge and most of the rocky substrate was covered by fine sand and silt. A total of 22 stony coral species (including two hydrocorals) were identified. A total of 76 fish species were identified. The author concludes that the deepest site had a well-balanced fish community except for the absence of large demersal predators, such as large snappers and groupers.

A continuation of this study, referred to as PRCRMP, reported on results from 2008-2009 monitoring season (Garcia-Sais et al. 2009) with comparisons to previous years' surveys. A trend of improving coral cover at their other study sites was observed, which was not observed at the RMTP due to the presence of white pox. There were varying abundances and species richness of fish and benthic organisms at each of these three sites, which was compared with

data from previous surveys to generate an estimate for the period from 2004-2009. At the 5m site, the dominant coral was the elkhorn, representing 25.9% of the bottom cover and accounting for 77% of live coral cover. The dominant fish was the blue tang (*Acanthurus coeruleus).* At the 10m site, the most dominant sessile-benthic organism was soft corals comprised of sea fans and sea rods, and the most dominant stony coral was great star coral (*Montastraea cavernosa),* but live coral cover was reduced to 19%. Benthic algae were also a dominant feature at this site. The dominant fish were equally the bicolor damselfish *(Stegastes partitus)* and the bluehead *(Thalassoma bifasciatum)*. Over time, there was a decrease observed in fish abundance and richness at this site during the study period. At the 20 m site, the boulder star coral (*Montastraea annularis)* was the dominant stony coral. Benthic algae were more dominant at this site than stony corals. Live coral cover was also found to be on steady decline. The dominant fish was an assemblage of six small-bodied species consisting of two gobies, a chromis, a damselfish, and two wrasses. Fish richness was constant at this site between years, but abundances varied which was driven by the swarms of the masked goby (*Coryphopterus personatus)* that showed significant temporal variability.

The authors later reported (Garcia-Sais et al. 2016) that the white pox incidence in the RMTP had increased with an infection prevalence of greater than 60%, anticipating that massive coral mortality could arise given the right conditions.

Schärer et al (2008) performed a study on the distribution of *A. palmata* throughout Puerto Rico, which included the RMTP. The study estimated 673 km^2 of potential habitat for elkhorn in Puerto Rico using GIS and measured the distribution, abundance, and condition with a random sampling approach at six sites (three east- and three west-coast MPAs). Average density ranged from 0.2 to 9.8 colonies/100m^2 and was highest on west coast sites (RMTP in Rincón and Cabo Rojo) and these sites showed lower predatory snail (*Coralliophila abbreviata*) prevalence and density. Overall, the prevalence of white band disease was low. Mortality caused by boring sponges (*Cliona tenuis*) was only observed at west coast sites. The results indicated that spatial variability must be considered when assessing trends at the regional level to clearly understand population status and responses to management actions.

Later, the same authors developed long-term monitoring sites for elkhorn coral around Puerto Rico (Schärer, Nemeth, Diez 2009). Of the areas identified around Puerto Rico, the RMTP was the smallest in hectares but the largest in the percentage of potentially available habitat for elkhorn (62% compared to 1-12% for other largest areas). In fact, the greatest densities of elkhorn were observed at the RMTP and Tourmaline, where the largest individual colonies were also observed. Mean live tissue cover in the RMTP sampled area was 77% and a total of 400 colonies were measured. At the time of the survey, no area that was sampled had exclusively dead elkhorn colonies. This study identified the RMTP as a long-term monitoring site and three representative plots were established in 2007. Thirty-six corals were tagged for monitoring within these plots at the RMTP.

Then, a report on the four-year study of elkhorn in the RMTP was conducted by Diez, Schärer and Nemeth (2011) at three monitoring stations that have been monitored since 2007. They observed a decrease in live coral cover (5.8%) that was on a steady decline since 2007 but most noticeably in the final monitoring year (2010) of the report. The incidence of white pox was linked to sewage discharge and fecal pollution that a separate study identified as the culprit on the west coast. The authors also note the impact of marine debris in the RMTP and suggest that frequent culling be used to remove this debris from the elkhorn. This project officially

ended monitoring in 2014 when the authors published the final report that included the monitoring season 2011-2013. Within their plots, live coral cover of elkhorn was averaged at around 50-60%, with some notice of an increase in live coral cover for this area during the study period. The site locations are listed below with their GPS coordinates and depths.

TP1 -- 18.350 67.267 13 ft.
TP2 -- 18.350 67.266 14 ft.
TP3 -- 18.347 67.264 10 ft.

Similarly, Garcia-Sais (2009) reported on their multi-year study that addressed the status of *A. palmata* specifically in the RMTP. The benthic community structure in the RMTP represents the highest live coral cover of those studied in the natural reserve systems of Puerto Rico. Coral cover ranged from 36-40% during the study from 2004-2007. Of that cover, *A. palmata* represented 80% of the live corals. In total, 18 species of coral were observed, most of which were encrusting corals. During the study, 74 species of fish were reported, including snappers and jacks. Later in the study, new developments were reported. A loss of coral cover in *A. palmata* was reported (19.5%) due to white pox disease. The prevalence was noted mostly in the southern portion of the RMTP. One recommendation from this study was to monitor the water quality in the reserve to locate any potential hazards that could affect this protected system.

Using this monitoring data from two of their sites (10 and 20 m) from their PRCRMP project, Garcia-Sais et al (2017) also published an article that discussed coral reef recovery after the massive regional bleaching event of 2005. The report indicated that depth, distance from shore, and reef location relative to riverine discharges were relevant factors influencing the resilience variability of corals, with faster recovery happening at nearshore reefs. They reported that the RMTP had recovered by 2008 and overall changes in live coral cover between pre- and post-bleaching surveys in the RMTP showed no differences.

Water quality monitoring has been conducted in the RMTP since 2005, but became a weekly activity in 2007, by the Surfrider Foundation Rincón Chapter and their Blue Water Task Force. Reports on the bacterial load from two sites within the RMTP can be founded reported online. Currently, this program performs weekly water quality monitoring with additional sampling if particular sources of pollution are being tracked. This program has involved the assistance of many volunteers since its inception but has since been led and organized by Steve Tamar of the chapter. Overall and in general, the water quality at Steps Beach (likely the most active site for snorkeling) is usually very clean and free of fecal bacteria.

The NOAA National Coral Reef Monitoring Program has historically been performing monitoring in the RMTP since 2014, however, the area covered and the number of sites has varied. The number of sites within the reserve was increased in 2016 when a separate citizen science-based project was conducted to increase the spatial coverage of sample sites in the reserve to 1) boost the data for the NCRMP program and 2) help create a baseline assessment of fish and benthic communities in the reserve using the NOAA NCRMP protocol for future comparisons. The results of this monitoring are available for public use but currently, the 2014 data cannot be compared with any subsequent years given the changes in fish survey methodology that occurred in 2016. The status report available for 2020 covers 2014-2017

monitoring years does not specify the RMTP but does note that live coral cover on average in Puerto Rico was on decline and had not rebounded from the 2005 bleaching event.

Removal

The removal of marine debris has been an ongoing effort in the RMTP, especially after natural disturbances like major swells and hurricanes. The river inputs both north and south of the reserve tend to deposit debris on the reef that gets tangled in the elkhorn coral branches. Additionally, the outflow from the agricultural land adjacent to the reserve that deposits at Steps Beach has also been observed to carry terrigenous debris (freshwater plants, animals) and anthropogenic debris to the nearshore elkhorn thickets. There have been two documented marine debris removals performed at the RMTP.

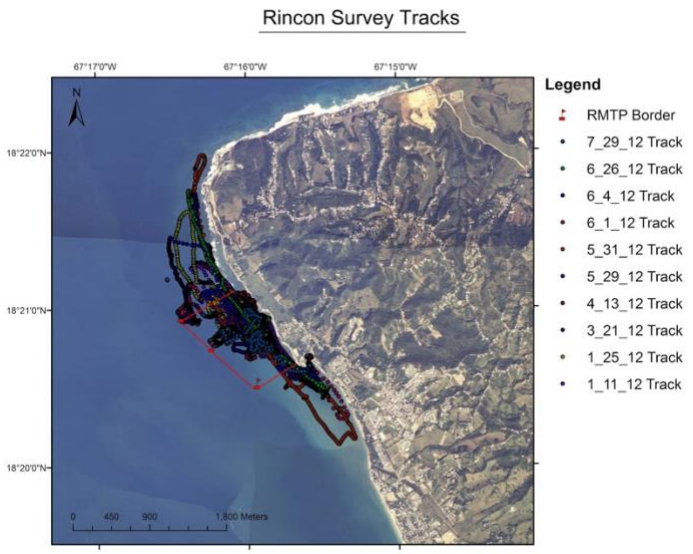


Figure 6. Location of the various debris search tracks performed for the debris removal, from Merten report.

The first was led by Dr. Wessley Merten in 2011 and involved the removal of boat debris and smaller debris (plastics, cables, pipes, clothing) from the reserve. This effort was noted to have built upon a 2009/2010 marine debris removal in the same area. The project reported using ten boat days to remove 75 tires (a total of 550 tires removed since the first effort in 2008) and copious amounts of the other mentioned smaller debris items. The project used volunteer assistance and a local fisher's vessel to perform the work and expanded the search and removal to an area of equal RMTP size outside of the reserve boundaries as well. Volunteers included residents, students, visitors, and municipal, state, and federal employees. Figure 6 shows the numerous GPS tracks that highlight the coverage area for the marine debris search and removal. Overall, this effort removed a significant amount of large-scale items that would generally be overlooked by smaller-scale removal efforts from the shore. The report stated that over 4,400 lbs. of trash were removed between the RMTP and a coral reef site in Mayaguez (Cayo Ron) but did not specify the amounts per site. Additionally, an outreach component of this project installed four recycling bins at the RMTP, however, these bins are no longer in use and have since been replaced with DRNA-provided trash receptacles.

A second debris removal effort occurred after 2017 Hurricane Maria and the major swell event of February 2018. This removal effort was led by Isla Mar and Sea Grant in April 2018. Over 64 volunteers assisted with the effort, contributing through paddleboarding, snorkeling, diving, and beachcombing to find and remove small-scale marine debris (clothing, fishing line, plastics, trash, tires). In total, this event removed 525 lbs. of trash, of which nine tires contributed 270 lbs. Although the entire reserve was open for exploration, the effort focused primarily on the first reef and the beach, resulting in about 12% of the reserve coverage being

surveyed for marine debris. Tires that could not be removed were documented by GPS points to be recovered later.

Data Comparisons and Analysis

Only biological data were considered for data comparison and analysis given that the purpose was to detect if the multiple projects conducted in the reserve that addressed coral and fish communities could be compared over time. During this review process, it became evident that there was a lack of standardization in survey methodologies between projects conducted in the RMTP. This is because the various projects had their own specific goals that did not overlap. Thus, only two data types could be compared in this review and only among their respective projects. The first was temperature data that the Schärer et al. team recorded during portions of their elkhorn demographic surveys in the RMTP which was not publicly available. The second data set was from the Garcia-Sais PRCRMP team which included information on coral and fish communities. This information is publicly available and is reported in periodic summaries with data analyzed specifically for the RMTP. Additionally, the program was originally recording annually but switched to biannual monitoring in 2011. Some of the data is reviewed and analyzed herein.

Temperature

Water temperature data was available for 2017, 2018, and 2019. These three years were assessed to provide some insight into temperature changes. The data loggers were initially placed at the three Elkhorn demographic sites used in the monitoring study, but data is not available for all sites in all years. For this reason, temperature was only compared for one site where data was consistently recorded (Figure 7). The years 2017 and 2019 had relatively similar temperature trends, however, 2018 recorded much cooler water temperatures. The temperature readings were analyzed with an ANOVA, which revealed a significant difference in mean water temperature between the years ($F=47.06$, $df=2$, $p = 1.95e^{-18}$). According to the National Weather Service, the early months of 2018 reported above-average rainfall which may have contributed to cooler sea surface temperatures.

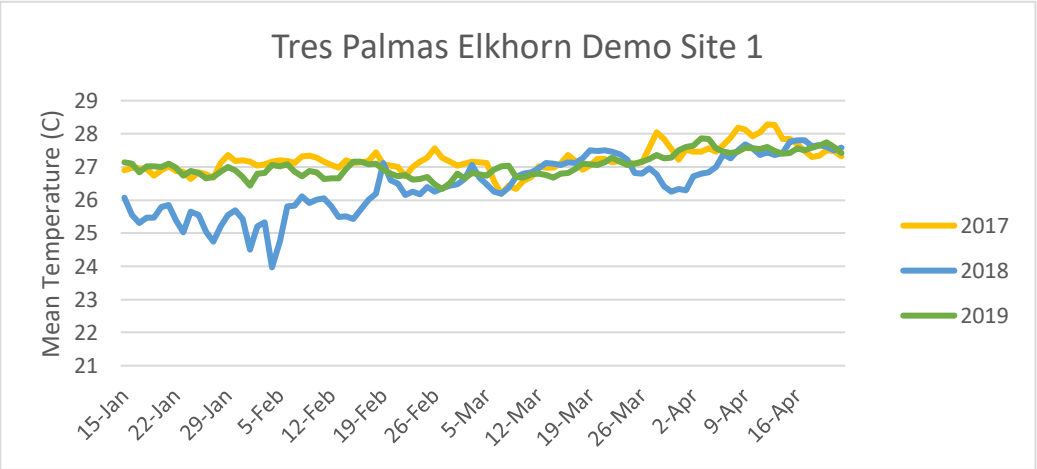


Figure 7. Mean water temperature at the Tres Palmas Marine Reserve elkhorn demographic site #1 for 2017-2019 during the first four months of the year.

Fish Biomass, Abundance and Size Frequency

Methodologies for recording fish biomass (as well as abundance and size frequency) were not consistent during the PRCRMP monitoring years. For example, fish biomass of certain commercially and/or ecologically important species was recorded. But starting in 2015, it appears that other fish were added to this selective list which again changed in 2017 with the addition of others and various deletions throughout. These changes were summarized in the PRCRMP Data Descriptor file *"Between 2004 - 2013 these estimates are based on size-frequency data annotated using the Active Search Census (ASEC) for 30 minutes per monitoring station and from 2015 – present estimates are based on five 60 m^2 band transects per station. The current (2015 - present) biomass data units are in grams per 60 meters squared (gr / 60 m^2), while previous data (2004-2013) units are in grams per 30 minutes per site."* It was also stated that biomass was calculated using the length/weight relationship variables available for certain species on Fishbase.org.

Interestingly, some species such as *Caranx crysos* were recorded in the first few years (2004-2013) but never seen again after the change in survey methodology, except for once at one site in 2021. This was similarly observed for other *Caranx* except for the appearance of *Caranx ruber* in 2021. Jacks are fast-swimming pelagic fish, except the bar jack which can be frequently found in nearshore reefs. Their disappearance from the surveys likely indicates that the change in survey methodology removed the ability to observe them, rather than their removal from the ecosystem. This trend of the decline in reporting biomass for commercially important species that are present in the RMTP was observed for other species that were commonly seen in the 2004-2013 monitoring years but not reported later.

Snappers and parrotfishes were used as a proxy for the reserve (given their general abundance) and biomass can be compared by separating the monitoring years' data by their survey methodologies. This strategy produces two biomass trends, one for 2004-2013 (Figure 8) for snappers and one for 2015-2021 (Figure 9) for parrotfishes. Since these data cannot be directly compared anyways, then the first grouping represents commercially important species, and the second grouping represents ecologically important species. The data for 2015-2021 was averaged for all five transects per site to produce one value for each of the three sites. The 2004-2013 data was presented as only one value, so standard deviation could not be calculated.

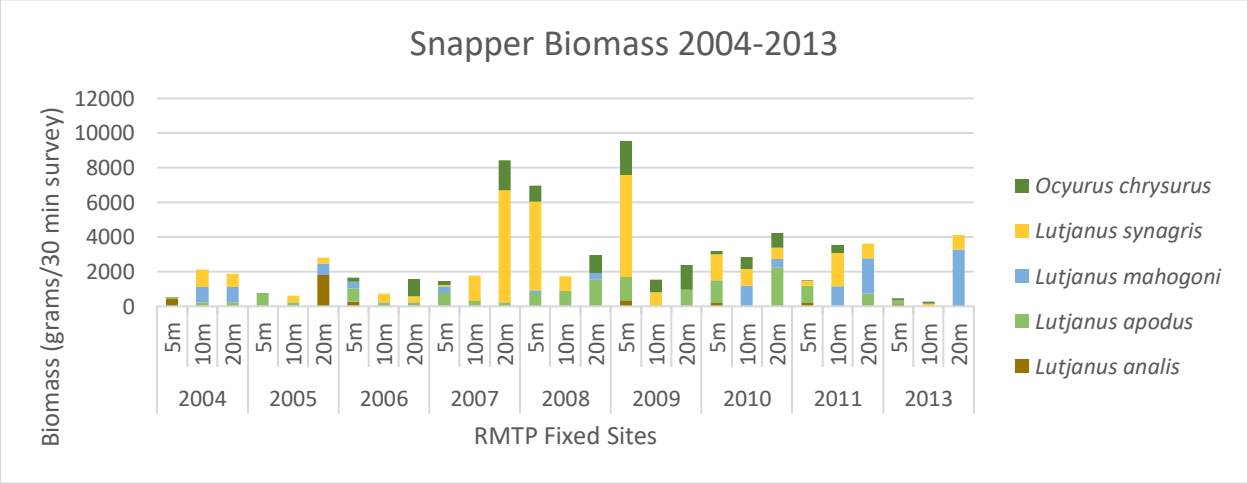


Figure 8. The biomass of snappers in the RMTP at three sites monitored by Garcia-Sais et al.

One species of snapper was particularly abundant in 2007-2009 – the lane snapper *(Lutjanus synagris)* where it was predominantly observed in the deepest site in 2007, while it later became more abundant in the shallowest site in the following two years.

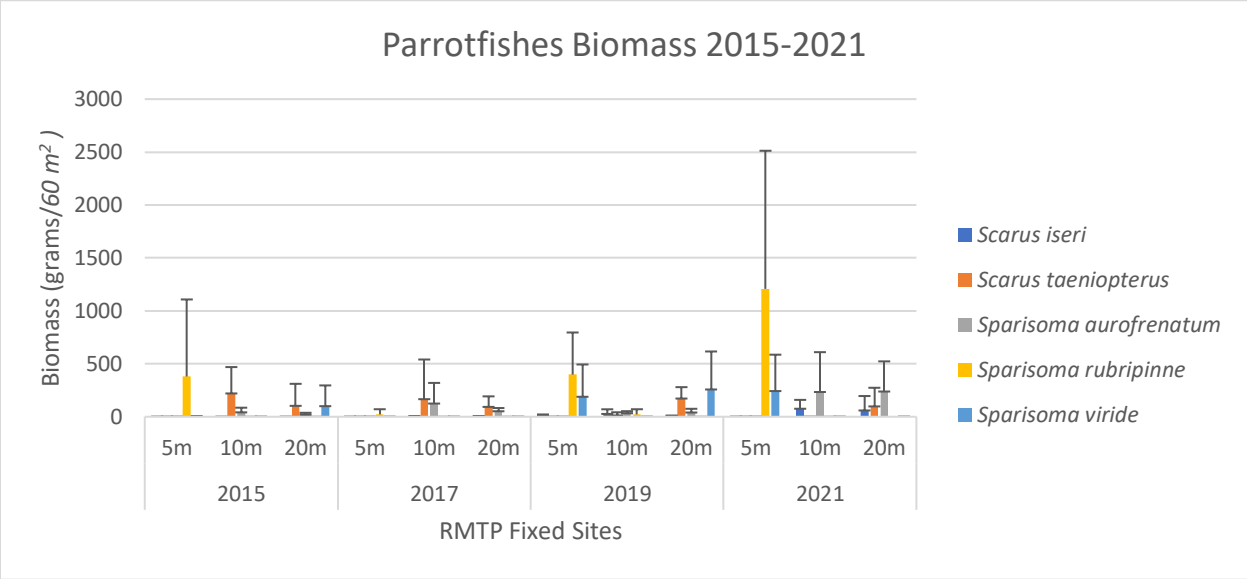


Figure 9. The biomass of parrotfishes in the RMTP at three sites monitored by Garcia-Sais et al.

Most of the parrotfishes surveyed are small to medium-bodied species, except for *S. rubripinne* and *S. viride* which can grow larger than the others and are relatively the same size as one of the largest parrotfish, *Scarus guacamaia*, for example, which has been observed in the reserve as well but in the 30 cm size class (pers obs). The most dominant species of parrotfish within the reserve is *S. rubripinne,* which appeared to be dominantly present in the shallowest site.

Conclusions

Only one monitoring project has allowed for limited fish and benthic community comparisons in the RMTP since its inception, but no baseline data of a similar nature was available to compare any trends before/after reserve establishment. However, despite this fact and the inconsistent use of survey methodologies, a story emerged that unveiled some biological dynamics of the reserve over time.

Based on the reports from Garcia-Sais et al. during the PRCRMP monitoring project at the reserve, it is evident that live coral cover has been on a steady decline. This was exacerbated significantly by the appearance of SCTLD in 2022, which has been estimated to decrease live coral cover to 15% (unpublished data, H. Ruiz) across multiple species excluding elkhorn. Also, in comparison to the Bruckner (2001) review of the elkhorn coral in the nearshore reef of the reserve, and the evaluation of elkhorn coral demographics by Schärer et al. team, there are now patches of completely dead elkhorn stands among the living. Other diseases are also evident in the reserve, including black band and patchy necrosis.

The PRCRMP monitoring program does provide a reliable long-term monitoring initiative in the reserve that measures multiple indicators of biological and ecological function. Thus, this program will be beneficial to monitoring reserve function over time in terms of these indicators (biomass, abundance, live coral cover, etc) especially given that these surveys are occurring across the seascape of the reserve and not strictly within the nearshore elkhorn-dominated first reef.

Part 2: Review of the Management Plan of the Tres Palmas Marine Reserve to Address Reserve Effectiveness

Introduction

This review highlights some of the key findings related to assessing reserve effectiveness by evaluating if the goals of the management plan are being met. This is a brief review designed to draw attention to major needs or questions, rather than an in-depth review of all potential MPA indicators identified by Pomeroy et al. (2004).

The current management plan can be accessed online. This plan was created by the Centro Interdisciplinario de Estudios del Litoral (CIEL) of the UPR-Mayaguez and was accepted in 2008. The plan has not been updated or evaluated since its inception. The focus of this review will be on Chapters 9 and 10 which describe the Plan of Action and the Implementation of the management plan. The mission of the plan states " *The management plan for the RMTP seeks to guarantee the conservation, preservation, and restoration of natural resources and natural ecosystems in such a way as to promote the rational use of their environmental goods and services that favors sustainable socioeconomic development and stimulates a better quality of life in Rincón and in the western area of Puerto Rico"*.

On page 59 of the management plan, the Plan of Action (translated from Spanish) states *"In order to make this vision a reality on which the entire management plan is based, we have established a series of achievable and measurable management objectives through individual strategies. By working on each of these strategies we will be able to achieve the defined objectives and, therefore, we will know that the main idea of the plan is becoming a reality. To know if the objectives are being achieved, we must monitor and evaluate the action strategies to find out what the weak points are and decide what we must reinforce to achieve our purpose (Pomeroy et al., 2004). At this point, we establish the basic conservation objectives that should be pursued by the management plan of the RMTP in order to achieve the main vision:"*

The objectives of the management plan (translated from Spanish) state that the plan aims to

1. Ensure the ecological integrity and biodiversity within the RMTP and surrounding areas.
2. Ensure that recreational, tourism or other activities are sustainable and do not negatively impact the natural resources of the RMTP.
3. Ensure the management and coordination of human and financial resources for the effective management of the RMTP and promote collaborative management.
4. Educate the general public (the community, visitors, and representatives of the municipal and central government and of the agencies responsible for decisions)

about the values and threats of the RMTP and achieve greater support for the establishment of collaborative management.
5. Increase interdisciplinary scientific and technical knowledge applied to the management of natural ecosystems (principally the coral reef) and their sustainable use.
6. Ensure compliance with the regulations established for the RMTP.

Thus, the purpose of this portion of the review is to determine if the management plan, based on the biophysical indicators, is achieving that mission through the objectives. However, the socioeconomic and governance aspects of a management plan review (Pomeroy et al. 2004) will not be evaluated as it is out of the scope of this current review project and its resources. As it relates to the RMTP management plan, the objectives that were evaluated include objectives 1 and 5, with some discussion regarding objective 4. This review also makes use of current scientific data available to answer the evaluation questions rather than implementing an entirely new research project to collect the data suggested by Pomeroy et al. (2004). This approach allows for a more cost-effective evaluation and condenses human resources, and financial resources, required to perform an initial evaluation of the management plan and effectiveness of the reserve.

Methods

To determine if the RMTP action plan is meeting its biological and ecological goals, a review of the research efforts was conducted to determine if this information is sufficient to address the management needs (Part 1). This type of evaluation is a critical step for monitoring all marine reserves and for applying adaptive management strategies, especially considering the dynamic environment with changing needs as suggested by the future of a changing climate. To conduct the evaluation (this part), the standardized assessment guidelines detailed by Pomeroy et al. (2004) that assess biological indicators, socio-economic components and governance were used to guide all aspects of this review.

Following an adaptation of the protocols outlined in Pomeroy et al. (2004), the management plan of the RMTP was reviewed for the following criteria (Table 1). The associated RMTP management plan objective was assigned to the respective biophysical indicator. A rationale, from Pomeroy et al. (2004), is provided to suggest why the indicator is a useful measurement tool for the effectiveness of the MPA. Data needs are defined as the anticipated metric that would be the most beneficial in addressing the indicator. This information is visualized in Table 1 and the same format is used to detail the results in the following section. The contractor first gathered all relevant reports and data, as presented in Part 1, and then used the information detailed in the summaries and through the available data to:

1. Determine if the appropriate types of data were being collected to allow for the ability to evaluate reserve effectiveness on the biological community.
2. Determine if these indicators had a correlating objective within the RMTP management plan.
3. Determine if current data could be used to answer the reserve effectiveness question or if further analyses would be needed.

Following the determination of #3 above, a summary of RMTP effectiveness was generated in Results. Finally, Part 3 of this report provides recommendations and proposed actions for continuing to monitor the RMTP and for further evaluation of effectiveness.

Table 1. The biophysical indicator (Pomeroy et al. 2004) used to evaluate the effectiveness of the RMTP and its management plan, along with the corresponding RMTP indicator, description of the indicator, and the data used to evaluate its performance or ability to achieve the corresponding objective in the management plan.

BIOPHYSICAL INDICATOR	RMTP BIOPHYSICAL INDICATOR	RATIONALE OF RMTP INDICATOR SELECTION	INDICATOR PURPOSE	DATA NEEDS	RMTP OBJ.
Focal species abundance	Elkhorn (*A. palmata)*	Based on the management plan's primary interest in protecting coral reefs, this review selected the elkhorn coral as the "focal" species indicator for the MPA. This decision was based on the prevalence of this ESA-listed coral and its relevance to several monitoring and detection projects performed in the RMTP.	Improved and sustained abundances of the focal species is a common indicator of an effective MPA.	Data should be collected annually or biannually and should include a control location outside of the MPA	1.3.1
Focal species population structure	Elkhorn (*A. palmata)*	Knowing the population structure (age, size classes) of the elkhorn population in the RMTP, as well as reproductive output, can provide an overview of current and future population status	Effectively managed MPAs have balanced populations of adults and juveniles to allow them to replenish themselves	Size of individuals inside and outside the MPA collected biannually at min, timing of spawning behavior and frequency of spawning events	1.3.1
Habitat distribution and complexity	Coral reef demographics at all three reefs	Characterization of all three reefs within the RMTP would provide an overview of this indicator	Maintenance of habitat complexity is considered a pinnacle of MPA success	Habitats should be characterized within the MPA, stratified by depth and substrate type, and re-surveyed annually or biannually	1.2.1 1.2.2
Composition and structure of the community	Fish and invertebrates	Species composition (richness, diversity, abundance) of fish and invertebrates	Measuring community composition through time indicates if MPA management is restoring or maintaining the natural community	Species inventories and habitat surveys conducted annually or biannually and especially after disturbances; should be spatially replicated	1.4.2
Recruitment success within the community	Fish or sexual reproduction of Elkhorn	Focal fish species recruitment success considered. Asexual reproduction (coral fragmentation) not considered under this indicator. Elkhorn spawning events can be considered.	Measures regularity and extent of larval settlement and recruitment, and survivorship	At minimum, size class information of focal species with particular focus on juveniles or recruits. Data should be collected annually.	n/a

Food web integrity	Composition of fish trophic guilds	Understanding how energy is transferred in the MPA system is critical to understanding function. For this indicator, fish will be used as a proxy of food web structure.	Indicate improved ecosystem function with a healthy balance of trophic levels (i.e. return to a natural state of predator-prey relationships)	Relative abundance and biomass of fish in each trophic guild, collected annually. *Important to note that changes occurring inside may be due to threats outside the MPA or from global issues unrelated to management.*	1.4.2
Type, level, and return on fishing effort	Commercially important fish abundance and biomass through catch data	Assessing the spillover effect outside of the RMTP by determining focal fish species abundance and biomass; fisheries-dependent assessment	Indicates if spillover from the MPA is occurring, since no fishing is allowed inside its boundaries	CPUE, landings of target fish species, other harvest data, collected weekly/monthly and reported annually	n/a
Water quality	Bacterial load at RMTP	Fecal coliform information collected at two sites at the RMTP	Key determinant of overall MPA health and viability; can indicate anthropogenic influence on the MPA, especially important to measure in MPAs linked with tourism	Sedimentation rates, temperature, salinity and freshwater inputs, oxygen content, turbidity, bacterial counts, pH levels and biological agents (chlorophyll, phytoplankton); all should be measured regularly at least seasonally or after disturbances	n/a
Area showing signs of recovery	Coral and benthic community structure and composition, fish community structure and composition	In theory, MPA protection would bring about increased live coral cover and diversity. Similarly, fish community structure and composition should be diverse and abundant.	Indicates the area within the MPA that has been restored to 'original' condition; *must have enforcement and compliance of regulations*	Focal species abundance and population structure, community composition and structure, habitat distribution and complexity, food web integrity, recruitment success. Measured every 2-5 years throughout the MPA.	1.2.2 1.3.1 1.4.2
Area under no or reduced human impact	Presence of humans and other non-marine animals	Farmland adjacent to reserve brings terrestrial impacts, human use of beach and reserve for recreational activities	Measures scale and pattern of human uses that could impact MPA success	Qualitative assessment of uses of the reserve (presence, level, threat)	2.1.1

Table 8 (Plan de Manejo, pg 61) and Table 9 (Plan de Manejo, pg 63) were used to identify the corresponding RMTP Management Plan objective that would align with that from Pomeroy et al (2004) in Table 1. Then, using Table 1, the results of Part 1 of this review were used to evaluate if the reserve is fulfilling its goals.

Results

Ten biophysical indicators can be used to assess MPA effectiveness (Table 1). Of those indicators, there was a corresponding RMTP management plan objective for seven of them. More than one RMTP objective could be assigned to one biophysical indicator in two cases. The indicators that were not considered in the RMTP management plan objectives included those that assessed direct **recruitment success** of focal species, type/level, and return on **fishing effort** (as evidenced by *spillover* to outside the MPA boundaries) and **water quality**.

Despite this lack of inclusion as a direct objective of the RMTP management plan, some of those indicators have still been assessed by independent research. For example, water quality has been monitored extensively within the RMTP since the reserve's inception by the Surfrider Rincón chapter. However, the data has not been evaluated for trends or changes over time. A report is made available on the Surfrider website. There have also been projects that have assessed coral reef fish abundance and richness at the reserve boundaries (NCRMP) and elsewhere near the reserve. This information could be used to evaluate spillover, although not directly evidenced as catch or fishing effort data.

Table 3 was used to assign actual studies and data to the objectives to address if, despite being included or not within the management plan, the scientific studies in the reserve have addressed these indicators.

Focal Species Abundance (RMTP 1.3.1) – The focal species of the RMTP is the Elkhorn coral. Abundance data is collected annually or biannually. The NCRMP and PRCRMP projects address this indicator, and the NCRMP project includes random sites outside of the reserve that could be used as a control. There is sufficient data collected over time, albeit using different methodologies, to address the abundance of this focal species in the RMTP.

Focal Species Population Structure (RMTP 1.3.1) – The focal species of the RMTP is the Elkhorn coral. The size of the population is assessed within and outside of the RMTP in both the Elkhorn demo (past) and PRCRMP (past and current) projects, which occur annually or biannually. There is sufficient data collected over time, albeit with different methodologies, to address the structure of this focal species population. However, no continuous data is collected regarding spawning regularity.

Habitat Distribution and Complexity (RMTP 1.2.1, 1.2.2) – The demographic of the coral reef at all three reefs within the reserve should be categorized and assessed over time, annually or biannually. The NCRMP and PRCRMP projects address this objective, especially the PRCRMP project which characterizes the habitat at all three reefs specifically. There is sufficient data, collected in a standardized way and repeated at sufficient intervals, to address this indicator.

Composition and Structure of the Community (RMTP 1.4.2) – The fish and invertebrate communities are characterized as inventories and repeated regularly. The PRCRMP and NCRMP projects are performed annually or biannually and are designed for this purpose. There is sufficient data over time to address this indicator.

Recruitment Success within the Community (RMTP n/a) – There is no corresponding RMTP management plan objective specific for addressing recruitment success. There have been no continuous monitoring projects within the RMTP that address the focal species recruitment. However, a past project has provided evidence of spawning, and occasional reports from scientists indicate that elkhorn spawning still occurs. There is not sufficient data to address this indicator.

Food Web Integrity (RMTP 1.4.2) - The biomass of fish in each trophic guild is assessed at regular intervals. The PRCRMP and NCRMP projects do collect biomass information that could be analyzed and interpreted based on trophic structure. There is sufficient data to assess this indicator.

Type, Level, and Return on Fishing Effort (RMTP n/a) – There is no corresponding RMTP management plan objective specific to addressing fishing efforts. This indicator is assessed to determine if spillover from the MPA could be occurring. Some past projects have addressed this topic, and the NCRMP project does collect fish abundance and biomass data at sites outside of the RMTP boundaries, however, this indicator does not have a project assigned for this specific purpose. Additionally, a few projects collect fishing effort data in Rincon. Although some data does exist, this indicator cannot be successfully assessed with the data that is available.

Water Quality (RMTP n/a) – There is no corresponding RMTP management plan objective for addressing water quality in the reserve. However, there has been continuous water quality monitoring occurring at the RMTP since its inception, but the data is not available for review and has yet to be analyzed for trends. Thus, there is not sufficient data to address this indicator currently.

Area Showing Signs of Recovery (RMTP 1.2.2, 1.3.2, 1.4.2) – The structure of fish and invertebrate communities should show signs of increased diversity and abundance, and this factor is assessed at regular intervals. The PRCRMP and NCRMP projects, among other cataloging scientific endeavors in the RMTP, have indicated a high diversity of fish and coral species compared to other sites in Puerto Rico. Some data would allow for comparison of these catalogs over time to assess if "recovery" is occurring. However, this indicator assumes that both enforcement and compliance are occurring, which is lacking on both counts for the RMTP. Thus overall, this indicator cannot be measured with the current data as it relates to the goal of the MPA.

Area Under No or Reduced Human Impact (RMTP 2.1.1) – This indicator is addressed as Sustainable Use in the management plan. Human activities and impacts have been identified, but not relayed into management actions or acted upon to alleviate stressors caused by human activities. There is not sufficient data to accurately address this indicator.

Table 3. The biophysical indicators, RMTP relevant indicator descriptions of the expected results or outputs that would be necessary to assess the indicator, the data available that can be used to address those needs, and then the actual outputs there are/were available for assessment. Finally, a Yes or No on if the indicator could be addressed with the information available.

BIOPHYSICAL INDICATOR	RMTP BIOPHYSICAL INDICATOR	EXPECTED RESULTS OR OUTPUTS	DATA EVALUATED	ACTUAL RESULTS	INDICATOR ADDRESSED?
Focal species abundance	Elkhorn	1. Abundance estimate (counts, area, or biomass) inside and outside the MPA 2. Estimated population density within and outside the MPA 3. Distribution of the population (uniform or clustered)	PRCRMP NCRMP	Focal fish and coral biomass, abundance, and changes over time within and around the MPA	Yes
Focal species population structure	Elkhorn	1. Estimate of how the population is structured by size 2. Graph of size/age distribution 3. Characterization of reproductive potential	PRCRMP Elkhorn Demo	Health and area of Elkhorn population	Yes
Habitat distribution and complexity	Habitat structure at all three reefs	1. Species, community composition; substrate and water conditions 2. Percentage live coral or substrate cover 3. Physical distribution of habitat (depth, location)	PRCRMP (all) Elkhorn Demo (priority areas)	Community composition of fish and benthic structure, assessed over time	Yes
Composition and structure of the community	Fish and invertebrate communities	1. Species richness and relative abundance data 2. Species evenness and habitat diversity 3. Trends of changes within the MPA of these factors for the long-term	PRCRMP NCRMP	Composition and changes over time of fish and invert/benthic community	Yes
Recruitment success within the community	Fish and sexual reproduction of Elkhorn	1. Validation of spawning occurrence 2. Presence and relative abundance of size classes 3. Spawning regularity and settlement regularity	Elkhorn Demo	Previous evidence of Elkhorn spawning	No
Food web integrity	Composition of fish trophic guilds	1. Relative abundance and biomass of fish categorized by their trophic position 2. Illustration of food web and interconnectedness 3. Trophic level index and changes over time	PRCRMP NCRMP	Biomass of fish that could be interpreted by trophic guild	Yes

Type, level, and return on fishing effort	Commercially important fish abundance and biomass through catch data	1. Level and return on fishing effort outside the MPA 2. Changes in size and species composition 3. Changes in volume/weight of target species	Data not specific to areas fished outside of RMTP	Fishing effort by region	No
Water quality	Bacterial load at RMTP, Temperature	1. Bacterial counts and changes over time 2. Temperature trends over time 3. Freshwater inputs and changes in salinity 4. Sedimentation rates 5. Influences from land-based uses	Surfrider Foundation Scharer temp logs	Temperature during few years, non-summarized; Water quality	Yes
Area showing signs of recovery	Restoration success	1. Area being restored to "original" condition (Elkhorn corals) 2. Fish communities returning to "original" population sizes	Ruiz et al. restoration initiatives	Restored coral growth, monitored 1 yr	No
Area under no or reduced human impact	Qualitative uses by humans	1. Defining uses and trends in use by humans, evaluating impacts and changes over time 2. Evaluating the total area not impacted by humans	Rosas Perez (2012) Webler and Jakubowski (2016)	Identified uses for a defined period; identified human stressors	No

Discussion

The Reserva Marina Tres Palmas was first established in 2004 based on tremendous effort and undertaking by a determined and concerned community to conserve a complex and diverse ecosystem at the shoreline of Rincón. A management plan was later established in 2008 but has never been evaluated or updated. The purpose of this report was to identify all scientific research that has been conducted in the reserve since its inception and to determine (using that data) if the reserve has been meeting its goals and could be deemed effective.

Six RMTP management plan objectives for Biological Conservation and one objective for Sustainable Use are being addressed through scientific studies, or have been addressed even minimally through one, noncontinuous study. Of those objectives, four are being assessed at an acceptable monitoring level and with appropriate data. However, only two projects (PRCRMP and Surfrider water quality monitoring) have been standardized in their data collection that allow for actual evaluation of conditions and changes over time. The PRCRMP study summarizes trends for each of its monitoring reports. The water quality monitoring has yet to evaluate its data.

Based on Garcia-Sais et al. reports available for this review, it is evident that live coral cover has been on a steady decline within the RMTP, despite its overall higher percentage compared to other reefs in Puerto Rico. This decline was exacerbated by the appearance of SCTLD in 2022, which has been estimated to decrease live coral cover to 15% (unpublished data, H. Ruiz) across multiple species excluding elkhorn. Since the initial writing of this report, there has also been a significant and widespread coral bleaching event (2023) that severely impacted the reserve, along with the continued presence and spread of SCTLD. The extent of mortality due to bleaching has yet to be determined. Given these stressors, the overall RMTP goal to "*ensure the ecological integrity and biodiversity within the RMTP and surrounding areas*" is not being met. However, this is due to a combination of stressors, some of which are beyond the management control of the reserve. For example, the warming of sea surface temperatures is impacted by global contribution to atmospheric temperature increases leading to the recent coral bleaching episode. This episode would occur with or without management, or even the presence, of the reserve.

Despite this, other stressors could be managed to help the reserve achieve this goal:

1. Enforce regulations to prevent anchoring, touching, or taking anything from the reserve. Anchoring and boat collisions damage corals and kill decades of growth. Re-establishing buoys and markers in the water would assist navigation around the reserve boundaries. Other buoys could mark shallow areas where boats and jet skis should avoid. Clear signage should be placed at all reserve entrances to alert visitors to the regulations. Regular enforcement should be present.
2. Water quality should be improved by reducing land-based runoff into the reserve, especially near the first reef at the Steps Beach entrance. Freshwater input, sediments, and agricultural waste are introduced to the reserve at these locations. These stressors significantly impact coral health.
3. Septic and sewage should be managed for all homes along the reserve borders, upstream and inland. Bacteria and other pathogens become introduced through these sources and lead to disease outbreaks that corals have not evolved to handle.

The RMTP goal to "*increase interdisciplinary scientific and technical knowledge* ***applied to the management of*** *natural ecosystems (principally the coral reef) and their sustainable use*" is not being addressed. There is a high volume of scientific studies that have been conducted within the reserve, producing valuable insight to assist with management, yet the management plan has never been adapted to consider these results. Some initiatives have been undertaken to improve coral reef condition in response to stressors – such as restoration and antibiotic application to SCTLD-infected corals – but the management of the reserve has not been reevaluated to address these new impacts and how they may impact the future goals of the RMTP.

Part 3: Recommendations for the Future Management of the Tres Palmas Marine Reserve

Introduction

An MPA management plan is a living document that should be dynamic and evaluated regularly. Without a proper plan to manage stressors, impacts, and uses of the MPA – combined with adequate enforcement and willing compliance – then the protected area is referred to as a "paper park", existing only on paper and not serving an actual purpose. Unfortunately, the Reserva Marina Tres Palmas as it stands to date is currently a paper park. There is very little enforcement or even enforcement presence, few types of signage, non-existent boundary markers, high impact from human use without mitigation or regulation, lack of visitor awareness about the reserve existence or purpose, few efforts to encourage community stewardship and thus little compliance as evidenced from poaching, standing on corals, and anchoring (pers. obs). All these factors could be addressed by evaluating the management plan and directing efforts and funds to those areas requiring the most attention.

The last section of this review has provided recommendations to build upon the biological conservation objectives of the RMTP management plan, while also suggesting two other initiatives tied to socioeconomic and community aspects that will further improve the effectiveness of the reserve.

Methods

Part 1 of this review did identify that two projects (PRCRMP and the Surfrider Water Quality monitoring) have been occurring in the RMTP since its inception and are generalized and standardized to allow for comparisons over time. Armed with that information, Part 2 sought to address whether the reserve was meeting its management objectives. Only two goals that related to the project information that was reviewed (i.e. biological conservation and sustainable use) could be evaluated. Unfortunately, it was determined that the reserve was not performing the service it was intended to provide. But Part 3 of this review (this section) was designed to provide solutions to aid in restarting and redirecting the purpose of the RMTP for the future.

Recommendations were created after analyzing all current project data and comparing that information with the biological indicators that are used to assess MPA health (Pomeroy et al. 2004). This allowed us to identify areas where data was lacking or not addressed. The list

created is not exhaustive and does not consider other governance or socioeconomic indicators that should also be evaluated (but see Recommendation #3). Some recommendations do go beyond the biological to include outreach improvement as well.

Results

The following six recommendations were generated:

1. **Assess recruitment success of elkhorn coral:** This study could include natural and restored elkhorn colonies to evaluate how often this endangered species is contributing to its local population through sexual reproduction, and then searching for evidence of recruitment and settlement of new elkhorn within the reserve. To best evaluate this factor, then areas directly outside of the reserve boundaries and within the natural depth range for elkhorn (but currently lacking the presence of elkhorn) should also be assessed to determine the spillover effects of the MPA. It would be particularly useful to know if the restored elkhorn corals are contributing to the reserve, which would be an indicator of successful restoration efforts.

2. **Assess fishing effort outside of the reserve:** This study would evaluate the level and impacts of fishing directly outside of the reserve boundaries to assess spillover. Assuming no fishing is occurring within the reserve, then the larger-than-normal abundances of fish should "spill over" to the areas outside of the reserve creating greater catch for effort. This would require dedicated port sampling in Rincon that specifically asks for GPS coordinates of fishing locations and documents catch and effort. The results could be compared with fishery-independent monitoring of fish abundance within the reserve.

3. **Evaluate the entire management plan:** This report should be further expanded by evaluating the other MPA-health indicators in Pomeroy et al. (2004) and identifying which, if any, of the RMTP management goals and objectives align with those indicators. It was out of the scope of this review to explore beyond the biological conservation indicators, but the governance and socioeconomic aspects are equally as important and oftentimes more convincing to use to influence stewardship of the reserve to local and state agencies (i.e. economic benefit to the community, tourism, etc).

4. **Evaluate water quality:** This study would involve analyzing the years of data from the Surfrider monitoring project and identifying trends. This information can be used to identify current and perceived impacts on the reserve by helping locate point sources of poor water quality and evaluating the frequency of poor water quality and its association with natural or human-made events.

5. **Support citizen science initiatives and neighborhood watch:** A neighborhood watch could improve compliance with the MPA regulations. The neighborhood watch would consist of a group of citizens from the area who have scheduled times to visit the reserve and inform beachgoers of the reserve's purpose and rules, while also reporting poaching and illegal activities to authorities. This same group could be involved in other citizen science initiatives, such as the current program designed to monitor

restoration efforts and other biological diversity elements. Support for these programs could be as simple as funding the workshops to train the citizens.

6. **Improve signage, boundary markers, and educational opportunities:** Funds should be directed to the immediate need for improved and additional signage to alert of the reserve regulations and purpose. This information should be placed at all entrances to the reserve. Boundary marker buoys should be reinstalled in the water to alert boaters and fishers to the reserve's boundaries. Furthermore, if a neighborhood watch is not created, then an "education station" at the Steps Beach entrance should be created to provide daily interaction with beachgoers through passive and active education. The station can be manned by volunteers and would improve visitor and community awareness of the reserve.

Discussion

The six recommendations suggested provide immediate direction to assist the reserve in achieving its goals. Although not an exhaustive list, these recommendations are actions that can be taken often with little financial input. For example, the recommendations that involve the community would require a training workshop and then rely on volunteer hours. Other aspects involve more intensive scientific studies, but the recommendation could perhaps be incorporated into ongoing or future projects that are aligned for complementary goals. Some aspects, like improving enforcement and signage, will require directed funding from DRNA but should be considered a priority, especially since this reserve is likely sustaining some of the last coral reefs with relatively high diversity around the island.

Unfortunately, many of these recommendations have been suggested in the past by other scientists/managers and concerned community members. It is the hope and goal of this review to generate interest and action by the agencies responsible for managing the reserve.

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