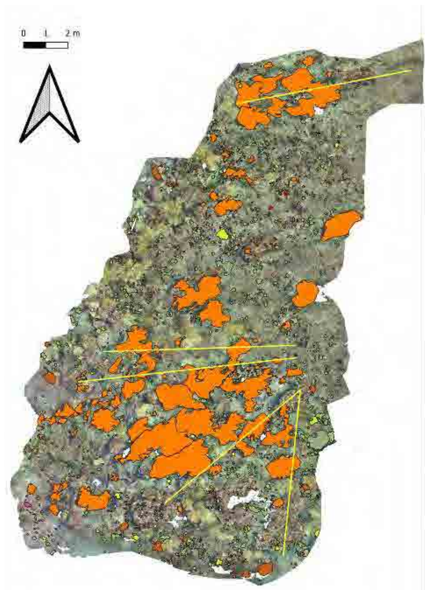
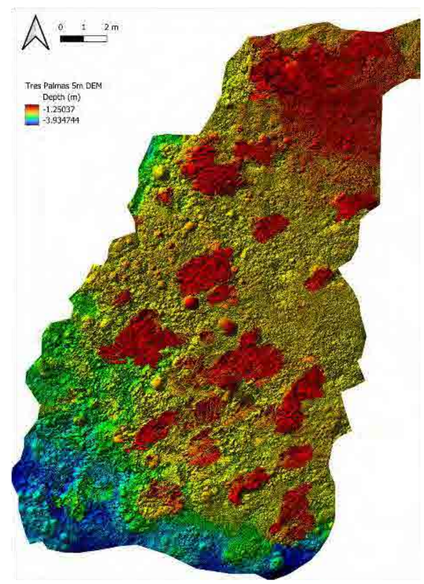
Integrating Photogrammetry into the Puerto Rico [long-term] Coral Reef Monitoring Program: Part 2

Field Case Study





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Contents

Executive Summary

Data from the Puerto Rico Coral Reef [Long Term] Monitoring Program (PRCRMP) has been used to assess significant events and processes as part of the natural history of Puerto Rican reefs. Despite the incredible contributions of the PRCRMP, several areas of improvement have been identified by local stakeholders. One of the major limitations is the small area of PRCRMP benthic surveys (Example: 0.6 m^2 at Tres Palmas 5m station) which limits the capacity to detect change in coral cover on degraded reefs. Photogrammetry is a technique that given recent advances in photography and computing hardware and software components allows us to make quantitative measurements of coral populations at unprecedented large spatial scales and high image resolution. This report focuses on the implementation of a photogrammetry survey at one of the PRCRMP stations. The main goals of this effort are to (1) document the effort involved in the field to complete a photogrammetry survey, (2) understand what resources it would take to integrate this methodology, and (3) compare the data we gather from this process with the traditional (legacy) methods used in the PRCRMP. The PRCRMP field team completed the benthic chain-intercept method in June 2023. Concurrently, a 278m^2 plot was established at the PRCRMP Tres Palmas 5M station from which 3,000 images were collected and further processed in Agisoft Metashape to produce a 3D model, orthomosaic, and digital elevation model (DEM). The orthomosaic was processed in TagLab and QGIS to extract stony coral species and major benthic components data using a combination of segmentation tools and random point counts. Sampling and processing effort metrics were compiled and compared between methods to estimate costs associated with each. Photogrammetry provided higher equipment costs than the chain method and also higher data processing and managing time efforts. However, when integrating the sampling and processing effort per unit of area, Photogrammetry had between two orders of magnitude less effort in the field sampling and half the processing effort. Therefore, Photogrammetry was the most effective and least expensive method to assess coral species and major benthic categories parameters per unit of sampled area. It is presented that projects that aim at assessing coral populations with the chain intercept for a given amount of area can expect costs up to five times higher than using photogrammetry. This information is relevant to managers who aim at expanding the spatial scale of coral monitoring routines, a common and necessary goal of restoration efforts and managing resilience.

Introduction

The Puerto Rico Coral Reef Monitoring Program (PRCRMP)

Monitoring of coral reefs in Puerto Rico has been a priority for the Department of Natural and Environmental Resources (PR-DNER) due to severe changes occurring in fish and benthic communities and the relevance of these changes to socioecological systems. After Law 147 was passed in 1999 to reinforce the management of coral reef ecosystems, the PR-DNER created the Coral Reef Conservation and Management Program (PR-CRCMP). One of the first tasks of the PR-CRCMP, which has been funded through a cooperative agreement with the National Oceanic and Atmospheric Administration (NOAA) was to establish a baseline characterization of coral reef communities in marine protected areas (MPAs) through the Puerto Rican archipelago. After the baseline surveys in several MPAs between 1999-2004, this project became a programmatic task of the PR-CRCMP funded by NOAA's Coral Reef Conservation Program and implemented through a fieldwork contractor team, led by Dr. Jorge García Saís. As continuous funding allowed the assessment to expand through time and space, the monitoring project became the Puerto Rico [Long-Term] Coral Reef Monitoring Program (PRCRMP).

Overall, the methods used by the PRCRMP can be considered traditional coral reef research methods (in-situ-based observations over belt and chain transect replicates) and were adapted from previous regional efforts such as CARICOMP. Currently, 42 permanent stations are visited every other year. Most stations are located in the major reef development regions in the archipelago (Western Platform, Guanica-Lajas Corridor, and the NE Marine Corridor) (Figure 1). In each station, a set of 5 permanently marked transects are used to collect benthic and fish data. Benthic data is collected over a 10m-long chain transect from which cover % and colony counts and recorded. A detailed description of the PRCRMP field methodology and access to the entire time series data can be found in NOAA's National Center for Environmental Information (NCEI) at the following link: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0204647

Figure 1. Map of PRCRMP stations in Puerto Rico. Green markers represent the 42 stations currently visited every other year. Red markers represent past stations no longer visited.

Data from the PRCRMP has been used to assess significant events and processes part of the natural history of Puerto Rican reefs such as the mass mortalities and recovery related to the thermal anomaly and disease event in 2005 (García-Saís et al., 2017), spatiotemporal patterns in the distribution of reef fishes (Esteves, 2013; Melendez, 2020), the emergence of nuisance species (Williams and García-Saís, 2020), and detection of disease outbreaks

(Williams et al., 2021). Over 20 years of monitoring, more than 80 reef sites have been visited at least once, and almost 300 benthic species and categories and 250 fish species have been documented. This highlights the wealth of information and expertise currently involved in the PRCRMP.

Despite the incredible contributions of the PRCRMP, several areas of improvement have been identified by local researchers and managers to better fulfill the conservation and management needs of the PR-DNER under an adaptative management cycle framework (Leon, 2018). So far, no demographic data or coral density data has been collected as part of the PRCRMP. Coral recruitment is not considered in surveys due to limited bottom time. There are few sites deeper than 20m surveyed which data is extracted from photo quadrats using random point count analysis due to reduced diver bottom time as well. The current methodology has been regarded by some interviewees as field-time and labor-intensive, while chain transects don't represent the benthic reef community. Temporal changes in coral cover are becoming harder to detect in stations with low coral cover with current methods. Fish data is collected over a 1m band along the same 10m long benthic transect. To record fish species of economic importance that tend to move, an expansion of another 10m is surveyed. All fish densities, sizes, and biomass are estimated in situ by diver observations. Some stakeholders have identified these transect sizes (limited spatial coverage) as not ideal for all fish and benthic species and the negative effect of divers on fish abundance estimates during surveys as potential reasons to dismiss PRCRMP data.

The PRCRMP current methodology has another limitation that has been more evident with the loss of coral cover in most stations. The site average cover % for PRCRMP stations was 15 % in the 2022-2023 cycle, with 30 % of all stations below 10% live coral cover. With low coral cover, the five-chain transect array becomes less capable of detecting coral species and changes in abundance over time due to its limited spatial coverage. With the reduction in live coral cover, the loss of species is another important trend. Over the last two decades, the PRCRMP has lost the detection of between 3 and 4 species per site. This further limits the capacity to assess the status of less abundant species that might be present in some sites, some of which have a priority conservation status such as ESA-listed species.

In summary, the current methodological limitations and challenges of the PRCRMP justified the evaluation of integrating new approaches to survey such as photogrammetry including:

- Limited spatial coverage of the chain method.
- Low coral abundance in many PRCRMP sites.
- More coral species are becoming "rare".
- No coral density and demographic data is collected.
- Structural complexity and functionality are poorly represented and visualized with the chain method.

Uses of Photogrammetry

Photogrammetry is a technique based on the extraction of measurement data from images. This has a lot of potential to address some of the limitations faced by the PRCRMP methodology. Photogrammetry isn't a new technology; it's not a recent science—it's been around for a long time, even for baseline characterizations of coral reefs in Puerto Rico since the 1980s (Weinberg, 1981). Today improvements in data management systems, photography equipment, and visual computing software have increased tremendously the capacity of field ecologists to extract data from images. Therefore, we can measure changes over time and space at resolutions down to sub-centimeter scales over hundreds to thousands of square meters. It is now possible to create precise Digital Elevation Models (DEMs) of coral reefs that are much higher resolution than Lidar and side-scan sonar to study the structural complexity and reef habitat functionality. Photogrammetry is now widely used today to monitor and characterize the impact of bleaching events and disease outbreaks. This helps us gauge the impact of these events, which is key for identifying areas that might be resistant or resilient to them. We can analyze objects captured in 2D and 3D. One important application of photogrammetry and monitoring, in general, is assessing management activities. By increasing the scale and resolution we can monitor management intervention such as restoration. For example, it's been used by NOAA in Puerto Rico since 2006 to study the impact of restoration efforts on major vessel grounding events, and it's something that's being adopted to evaluate how restoration is affecting our environment and the outcome of projects more broadly across the globe.

Scope of this report:

This report will is the Part 2 of an effort to evaluate the integration of photogrammetry into the PRCRMP. Part 1 was a literature review of the known uses, advantages, and disadvantages of photogrammetry in coral reef monitoring (available here: https://drive.google.com/file/d/17Jm_miwJA9abYsJJcEkAIj94OrxYp0Lm/view?usp=drive_link). Part 2 is a field case study to implement this technique and evaluate its use from a logistical and data approach. The main goals of this effort (Part 2) is to conduct a photogrammetry survey at one of the PRCRMP stations with the objective of (1) documenting the effort involved in the field, (2) understanding what resources it would take to integrate this methodology, and (3) compare the data we gather from this process with the traditional (legacy) methods used in the PRCRMP.

Methods

Site

The site selected for this pilot was an accessible station within the Tres Palmas Marine Reserve, west Puerto Rico (Figure 2). The station is located at a shallow fringing reef at an average depth of 1.3 meters, which provided some challenges to capture the photographic samples. That makes it difficult to collect images, especially if there's a significant swell surge and currents. This station has been monitored by Dr. Jorge García Saís since 1999. It represents an Acropora palmata biotope, so the structural complexity is relatively high, but coral species diversity was expected to be low. For this study, Dr. García-Sais's team visited the station to collect the PRCRMP 2023 survey data on June 13, 2023. The photogrammetry survey was conducted 12 days later on June 25, 2023. During the time between surveys, no major disturbance that might have caused a change in the benthic structure and composition was known to occur at the site.

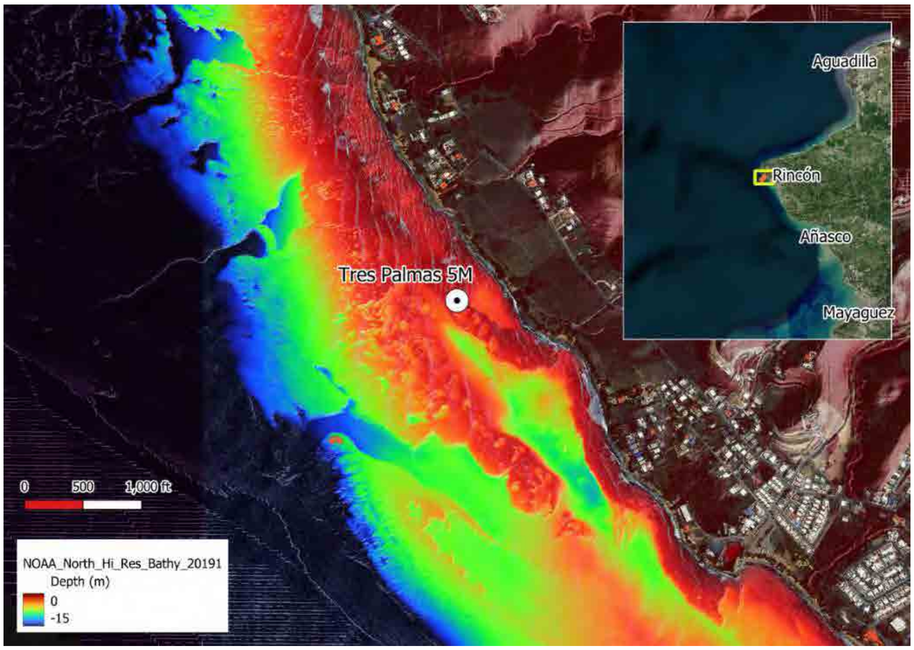
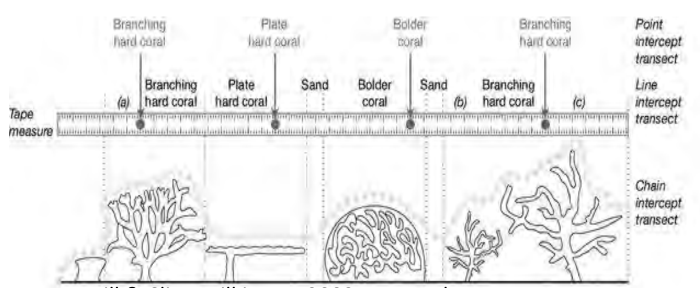


Figure 2. The site where both chain-intercept and photogrammetry surveys were conducted in June 2023. This Site (Tres Palmas 5M) is a PRCRMP station with a baseline established in 1999.

PRCRMP Chain Point Intercept

The traditional PRCRMP methodology uses the continuous chain intercept method. This method is similar to the continuous intercept transect (Hill & Wilkinson, 2003), but instead of a measured transect tape, a chain is used. The chain is placed between two permanent markers (rebars), and then it's dropped over the different organisms and structures between those two chains. The PRCRMP field team collects data by counting how many links of the chain



Jos Hill & Clive Wilkinson, 2003: Researchgate:

Figure 3. Diagram of a continuous line intercent transect. A chain-intercept transect would be represented by the gray dots over the benthic features in the diagram.

Figure taken from Jos Hill & Clive Wilkinson, 2003. Available at: https://www.researchgate.net/publication/242384503_Methods_for_Ecological_Monitoring_of_Coral_Reefs cover each category or species. To get the cover percentage of benthic species and categories, the total number of links for each benthic category/species is divided by the total number of links in the chain that spanned the 10-meter horizontal distance between the transect rebars. All benthic species and categories are identified in the field. Since 2015 the taxonomic ID of benthic variables is led by Dr. Stacey Williams. Rugosity is the only structural complexity parameter gathered from the chain-intercept method. This is achieved by dividing the total chain distance between the two transect rebars, given by the number of links overlaid in the reef (# of total links X link length), by the horizontal distance between the rebars (10 meters). The closer the rugosity value to 1, the flatter the reef profile.

The PRCRMP station at Tres Palmas 5M has 5 chain-intercept transect replicates. Each was installed over areas of relatively high coral cover, not randomly. No fish data was used in this effort. All benthic data is published in the NOAA National Centers for Environmental Information at the end of each PRCRMP cycle. For more details of the PRCRMP Field Methodology please refer to the supporting documentation online at: https://www.ncei.noaa.gov/data/oceans/archive/arc0147/0204647/5.5/data/0-data/PRCRMP_Field-Methodology_(11-30-2023).pdf

Photogrammetry survey (Structure From Motion - Sfm)

We implemented a standard photogrammetry survey following a common workflow used in the field. A visual representation of this workflow is presented in Figure 4.

Plot establishment and image collection

The plot was established by outlining the area using the start and end rebars of all five chain-intercept transects already installed by the PRCRMP team at Tres Palmas 5M. This gave an asymmetrical polygon of 278 m^2. A transect tape was placed around this outline for visual aid of the plot. Inside the plot, 3 scale bars were placed flat to scale the plot later on in the photogrammetry software. Scale bars consisted of 8 cm PVC pipes and an underwater slated place flat in the benthos across the plot. Transect rebars were used as control points to georeferenced the plot. GPS coordinates and depth was recorded for all ground control points (rebars and scale bars) using a handheld Garmin GPS on the surface directly above the control points. One diver collected roughly 3,000 images swimming 1 meter above the substrate in a “maw-the lawn” pattern making sure different angles of the reef structure were captured to accurately represent the A. palmata biotope.

Hardware and software used

The following components were used in the camera system:

- Olympus EM-10 camera
- Olympus M.Zuiko Digital ED 9-18mm f/4-5.6 Lens. Micro fourth thirds, 16MP
    - Focal length used = 10mm (20mm equivalent)
    - Settings: time-lapse at 1 frame/sec., ISO auto, F-stop at f/7.1, shutter speed at 1/320 sec.

- Meikon EM10 underwater housing

The following components were used in the computer system:

- Operative System: Windows 10
- CPU: AMD Ryzen 9 3900X 12-Core Processor, 4.00 GHz
- GPU: NVIDIA GeForce RTX 3060 Ti
- RAM: 64 GB, DDR4 3,600Mhz

The following software was used to process images and extract data:

- Agisoft Metashape:
  - Processed images in Agisoft Metashape to build orthomosaic, 3D model, and Digital elevation Model (DEM)
  - Georefferenced orthomosaic and exported as GeoTIFF
- TagLab:
  - Python-based tool for the AI-assisted segmentation of corals and other benthic features
  - Segmented all corals colonies in the 278 m^2 photomosaic per species to get coral density, diversity, demographics, and cover percentage.
  - Exported sementation data (annotations) as .csv and shapefile.
- QGIS:
  - Used to measure cover percentage by measuring the area of the imported orthomosaic GeoTIFF and the area of each annotated coral from the imported annotations shapefile.
  - A total of 558 random points were placed on the orthomosaic to estimate the cover percentage of major benthic categories (totals, not by species) assessed by the PRCRMP. This was done to reduce the processing time to extract benthic category data which is extremely time consuming over hundreds of meters squared.

Metrics for comparison

The metrics used to compare both methods can be classified as benthic variables, sampling and processing effort, and costs.

Benthic Variables

Benthic variables (Table 1) were compared between two methods: chain intercept (PRCRMP current method) and photogrammetry (Figure 5). Photogrammetry or Structure from motion (Sfm) was divided into two routines: “random point count” for the major benthic categories and “segmentation” for the stony corals. The difference between methods for each variable was calculated by subtracting the cover % given by PRCRMP chain data to the values given by the Sfm data.

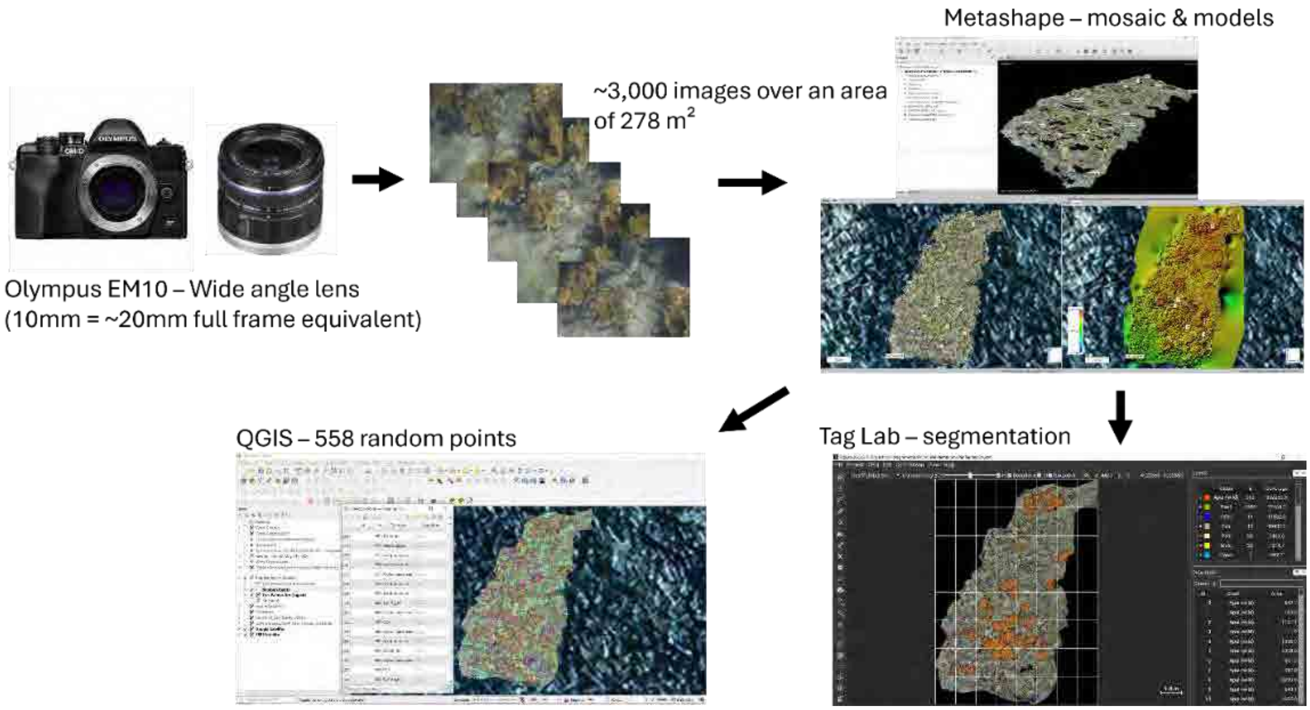


Figure 4. Steps implemented to conduct the Sfm survey and extract benthic data. Stony coral species were measured in TagLab segmentation tool, while major benthic categories were assessed using random points in QGIS.

Table 1. Benthic variables of interest available for the Tres Palmas 5M PRCRMP chain-intercept and Sfm survey. Variables that are available for both methodologies were used for comparison.

	PRCRMP Chain-Intercept	Photogrammetry Sfm
Stony Coral Species Cover %	Yes	Yes
Stony Coral Species Colony Counts	No*	Yes
Stony Coral Species Colony Sizes (cm²)	No	Yes
Stony Coral Species Density (col/m²)	No	Yes
Benthic Category Cover %*	Yes	Yes
Species Richness - Stony Corals	Yes	Yes
Species Richness - Other Benthic Categories	Yes	No*

***Notes**: The variable “stony coral colony counts” were compared between methods as a total, not by species because the PRCRMP currently does not collect counts per species. PRCRMP could take note of counts per species given more field and data processing time but it is not currently done. “Species Richness -Other Benthic Categories” was not documented using photogrammetry in this particular effort, but it could be done when analyzing mosaics given adequate taxonomic expertise, image resolution, and human processing time. The Benthic Categories annotated in the Sfm survey matched those included in the PRCRMP 2019-2023 Benthic Database Compilation.

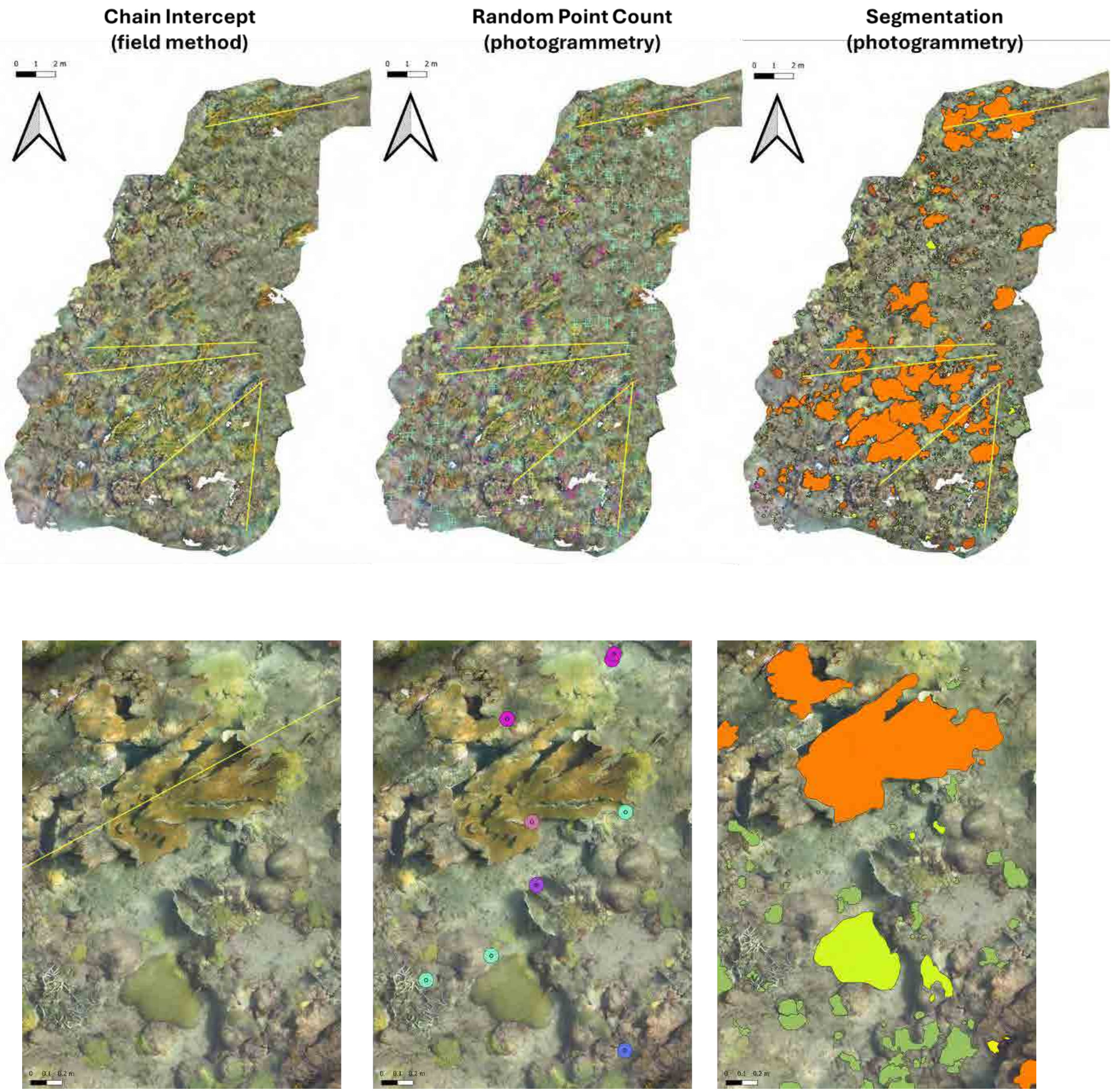


Figure 5. Visual representation of the methods compared. Top panel shows 278m² orthomosaic at Tres Palmas 5M. Yellow lines are current PRCRMP transects. Lower panel shows zoomed-in portions of the mosaic equivalent to a few square meters.

Sampling and Processing Effort

The following field and laboratory (office) effort and logistical parameters were used to compare the sample and processing effort between the methods. The parameters estimated here are based on the stony coral benthic variables only, which are the main focus of this study:

- **Area Sampled (m²)**: The total coral reef area sampled either by a visual census or a photographic sampling from which stony coral data was extracted.
  - In the case of the PRCRMP chain-intercept this area was calculated based on 2023 benthic data submitted by the PRCRMP field team and using the following formula:
    - Area = (# of total chain links in site) x (length of chain links) x (width of chain links)
    - Where the # of total chain links was 4,316, the length of the chain links is 0.014m and the width of the chain links is 0.01m.
  - In the case of the Sfm survey, the total area was given by the polygon outlining the scaled orthomosaic. This was done by importing the orthomosaic GeoTIFF into QGIS, drawing a polygon around the plot and measuring the area in m².
- **# of divers**: The number of divers needed to collect the benthic data.
  - This does not include additional divers that the PRCRMP employs to locate transects and conduct fish surveys.
  - For both methods, 2 divers were assigned (one for data collection and another for support)
- **# of dives:** The number of dives needed to complete the field sampling for each method.
- **Dive bottom time (hours)**: Total bottom time in hours to complete the field stony coral cover sampling for each method. Indicates time in the field required for the in-water collection of the stony coral data or photographic samples used for the comparison between methods.
  - In the case of the PRCRMP chain method the total benthic survey (5 transects) bottom time was estimated at 90 minutes (1.5 hours) in an interview with the PRCRMP principal investigator, Dr. Jorge García-Saís, and benthic lead, Dr. Stacey Williams. To maintain comparability between methods, a fraction of the total benthic survey bottom time was used. The fraction used was the 2023 average live stony coral cover % value (26%) for Tres Palmas 5M. Although the time spent per benthic category using the chain method can vary depending on the diversity, size, and abundance of individuals (benthic "fragmentation" or "heterogeneity"), it was assumed that the time spent completing the chain-link counts for a given benthic category is directly proportional to its cover %. This assumption was taken as a compromise to maintain an objective comparison. This was done because the PRCRMP benthic

    diver spends more time annotating other benthic species and categories not assessed in the Sfm survey due to limitations in the photogrammetry segmentation process.
    - The Sfm dive bottom time was obtained from the dive computer log for the date of the survey.
- **Bottom time per sampled m² (hours)**: This represents a standardized metric to compare the fieldwork time spent diving to complete the Tres Palmas 5M stony coral benthic survey over an entire 1 m^2.
    - Bottom time per sampled m^2 = [Dive bottom time (hours)] / [Area Sampled (m^2)]
- **Processing/Data management time (hours)**: Represent the time spent in the office entering, extracting, and processing the stony coral data only. Does not include data analysis or reporting, and other benthic categories are not included in this analysis. Indicates time in the office required for extracting the stony coral data and putting the data in an analysis-ready format and structure the collection of the stony coral variables used in the comparison between methods.
    - In the case of the PRCRMP chain data includes time spent doing the following tasks: data entry (from paper field sheet to digital matrix), data management, QAQC, and data compilation. In an interview with the PRCRMP benthic lead, Dr. Stacey Williams, this time was determined to be a small fraction of the total benthic data processing/management time, estimated to be an average of 15 minutes for all 5 transects.
    - In the case of the Sfm survey this includes photo sample processing and data extraction done in Agisoft Metashape, QGIS processing, TagLab segmentation, exporting data, QAQC, and data compilation.
- **Processing/Data Management time per sampled m² (hours):** This represents a standardized metric to compare the officework time spent processing and managing data to complete the Tres Palmas 5M stony coral benthic survey over an entire 1 m^2.
- **Processing/Data Management time per sampled m² (hours)** = [Processing/Data management time (hours)] / [Area Sampled (m^2)]

Costs

The following metrics were used to assess the costs of both methods.

- **Bottom time cost per sampled m² ($USD)**: [Bottom time per sampled m^2 (hours)] X [$120]
    - We assumed an hourly rate of 60$/hr for two AAUS or equivalent level coral reef scientific divers
- **Processing/Data Management time cost per sampled m² ($USD)**: [Processing/Data Management time cost per sampled m^2 (hours)] X $60

- We assumed an hourly rate of 60$/hr for one photogrammetry specialist and coral taxonomy expert

Additionally, a hypothetical proposal budget [1] was also developed based on the results of the benthic sampling effort metrics to exemplify the significance of each method in the associated costs of projects that aim to gather coral community data in a given amount of area. The goal of this hypothethical project is to collect the benthic variables (with an emphasis on stony coral variables) across 1,125 m^2 across the 45 PRCRMP sites, including remote stations at Mona Island (one 5 x 5m plot per site). The hypothetical budget was prepared for each method (Chain-Continuous Intercept and Sfm survey) and contained the following items:

- **Processing/data management time (hours)**: Estimated hours to pay needed to complete the office work based on the results of the sample and processing effort metrics.
- **Field sampling equipment**: Costs associated with equipment necessary to conduct the fieldwork for both methods such as transect tapes, diver underwater slate, underwater paper, pencils, scale bars, rebars, hammers, nails, GPS, cameras, and underwater housing.
    - Does not include SCUBA diving equipment
- **Data management equipment cost**: Costs associated with office equipment needed for data entry, processing, etc., unique for each method including computer hardware and software licenses. Dependent on the method.
- **Marine transportation days**: Number of days to pay for rental for a full (5-7 hour) boat days on a 20-25 foot vessel, including gasoline and captain service. Estimated at $750, independent of the method. Allows for a total dive bottom time average of 120 minutes (2 hours).
- **Diver days**: Number of days to pay for coral reef scientific divers for a fieldwork day. Allows for a total dive bottom time average of 120 minutes (2 hours). Estimated at $600 per diver, independent of the method.
- **Project Management fee (10%)**: 10% of the sum of previous budget items for project administrative tasks, independent of the method.

[1] This is a hypothethical model created to compare the methods discussed in this study and does not represent a formal proposal to the PR-DNER or NOAA. The budget amounts are hypothethical and does not necessarily indicate real costs associated to the implementation a coral reef monitoring project. Nevertheless, the difference of costs between methods should be considered as a result of the calculations explained in this report.

Results

Photogrammetry output

The final orthomosaic at Tres Palmas (Figure 6) was built from 3,000 images over 278m² and encompassed a reef volume of 98 m³. The mosaic resolution is 0.4mm per pixel.

The final orthomosaic outputs can be downloaded as a high-resolution JPEG and GeoTIFF at the following link: https://drive.google.com/drive/folders/1jDdmBHoa1uixm2k_0JUnJLselIQFfVTb?usp=drive_link

A video animation of the 3D model can be watched on the Coral PR Youtube page at: https://www.youtube.com/watch?v=jmLD1xCzIN0

A webinar on this report was recorded and is available on the Coral PR Youtube page at: https://www.youtube.com/watch?v=EupkuqNhre4&t=1439s

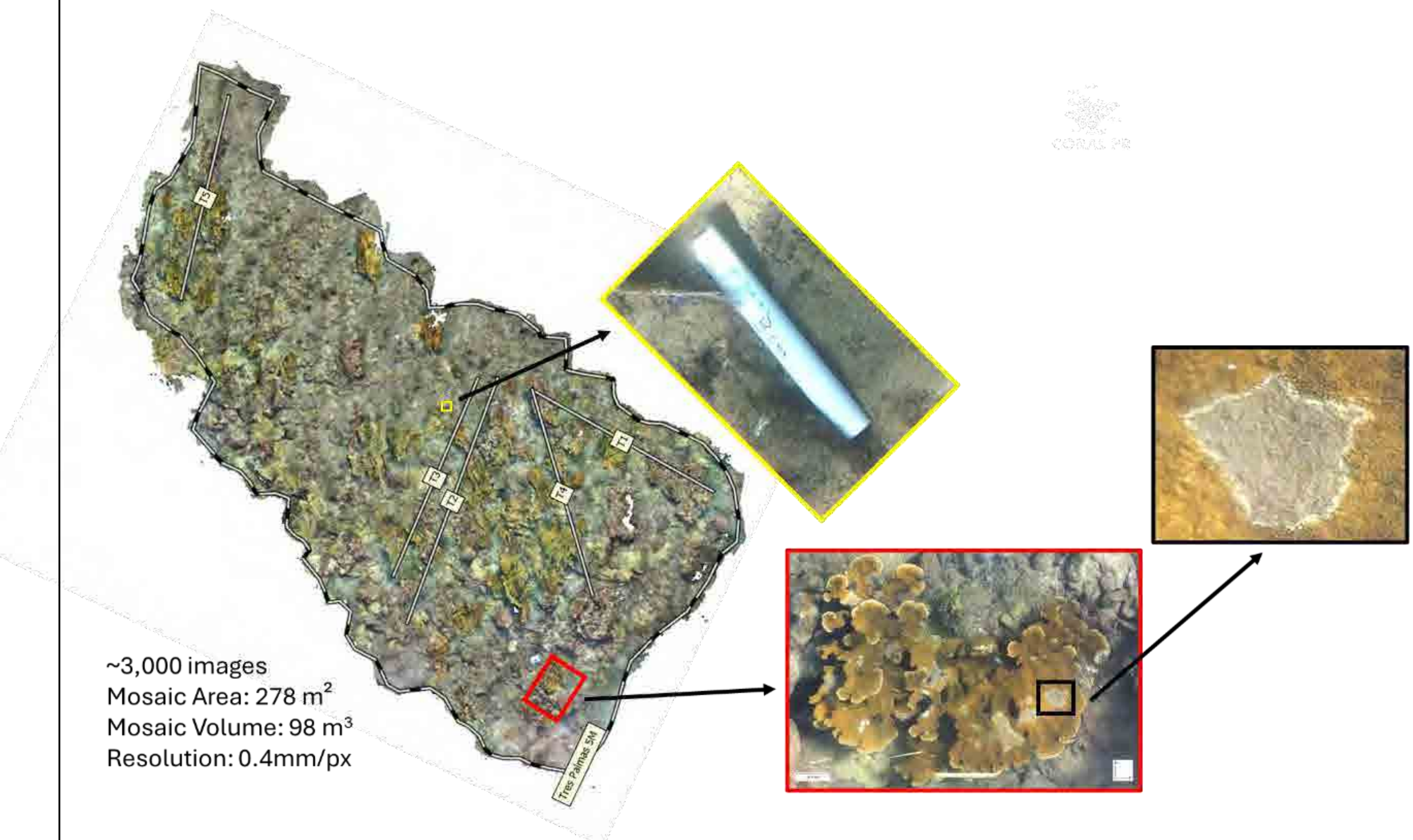


Figure 6. Final orthomosaic output. Close up portions are highlighted to see details captured using the Olympus OMD EM10 camera system.

Benthic Variables

The main differences between methods for major benthic categories were observed between the dominant "Abiotic" and "Turf Algae" categories, with a cover % difference (PRCRMP – Sfm) of 23% and -20%, respectively (Table 2, Figure 7). Although in < 1 % cover, the random point count method showed presence of three benthic categories that the chain method did not detect. These were octocorals, sponges, and macroalgae. The chain method data and Sfm random point count showed similar stony coral and peyssonneliaceae cover with differences of 4% and 3%, respectively. CCA and zoanthids were relatively underestimated by the chain method, with a cover % difference of 4%. In terms of species richness in the benthic categories level, the PRCRMP data recorded 4 species of stony corals, one species of zoanthid, and 1 species of peyssonneliaceae for a total species richness of 6 species. No species-level data was extracted from the Sfm random point count analysis for the major benthic categories.

Table 2. Cover percentage values for major benthic categories estimated using the PRCRMP chain method and the Random Point Count Sfm routine in QGIS.

Benthic Categories Cover %			
Benthic Categories	**Chain Intercept**	**Random Point Count**	**Difference**
Abiotic (total)	24.14	1.08	23.07
Peyssonneliaceae (total)	17.25	13.08	4.17
Stony Corals (total)	25.97	22.94	3.03
Octocorals (total erect)	0.00	0.18	-0.18
Sponges (total)	0.00	0.36	-0.36
Macroalgae (total)	0.00	0.90	-0.90
Zoanthids (total)	3.32	7.53	-4.21
CCA (total)	1.02	5.38	-4.35
Turf Algae (total)	28.30	48.57	-20.27

Within the stony coral assemblages, there was a difference in the total stony coral cover percentage of 6% (26% chain method vs. 20% Sfm segmentation = 22% change) both methods were able to detect the relative dominance of *Acropora palmata* at Tres Palmas 5M (Table 3, Figure 8) with 23% for the chain method and 16% for the Sfm segmentation. However, if we consider the Sfm segmentation as the most exact or "true" representation of the area cover percentage data, the chain method overestimated the abundance of A.

palmata by almost 8% (a 33 % change). The other species of stony corals detected by the chain method included *Pseudodiploria strigosa*, *Pseudodiploria clivosa*, and *Porites astreoides*. All these species combined made up less than 4% of the benthic cover in both methods. Most remarkably, the Sfm segmentation method detected almost three times more stony coral species than the chain method (11 species vs 4 species). All of the species detected only by the Sfm segmentation added up to <1% benthic cover.

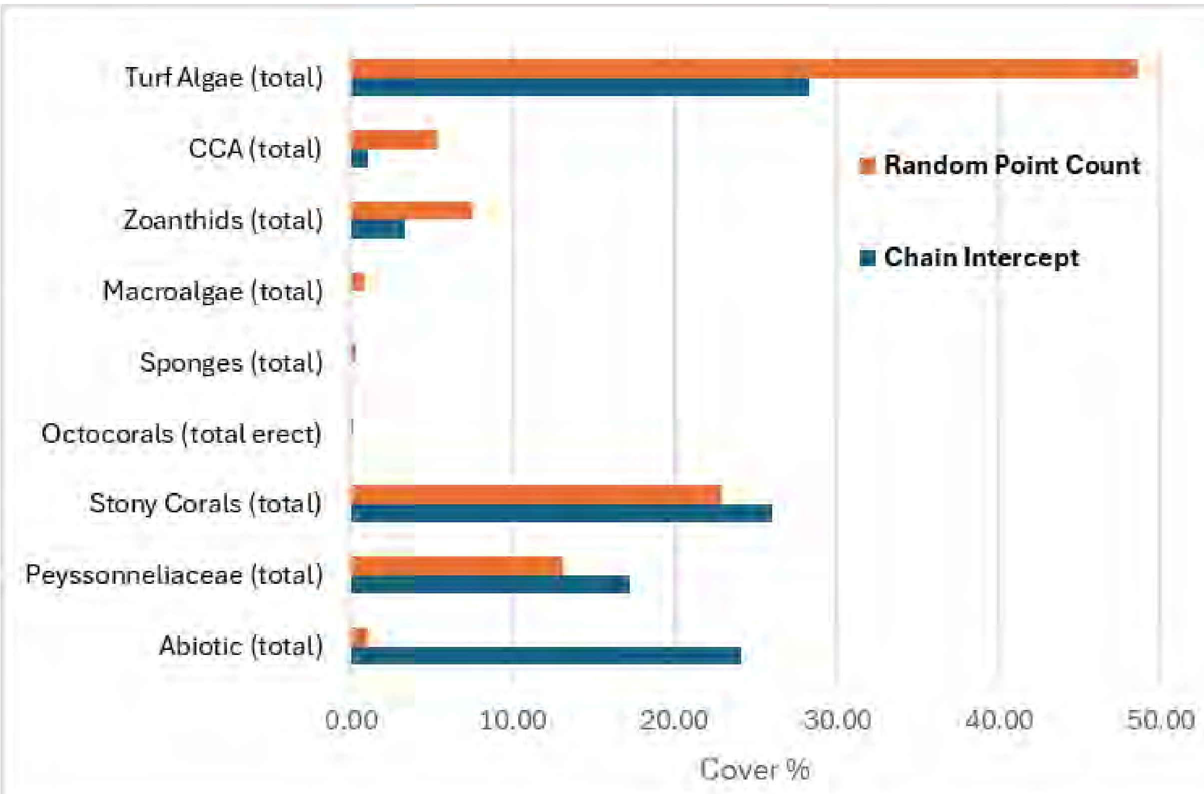


Figure 7. Bar graph of Benthic Category cover percentage based on the PRCRMP chain method and the Sfm random point count.

Other metrics of relevance that were not possible to assess between methods due to limitations of the chain-intercept included coral colony counts, density, and size (Table 4). Counts of coral colonies resulted in very different values between methods. Although the PRCRMP chain method did not provide for species-specific coral counts it was possible to compare the total coral counts between methods. The PRCRMP chain method recorded 25 colonies while the Sfm segmentation recorded 1,695 coral colonies. This resulted in a coral density of 6 coral colonies per meter squared, a metric not possible to estimate currently with PRCRMP chain method data.

Table 3. Estimated cover percentage values for stony coral species using the PRCRMP chain method and the segmentation Sfm routine in TagLab.

Stony Corals Cover %			
Species	**Chain Intercept**	**Segmentation**	**Difference**
Acropora palmata	23.2211	15.5211	7.70
Pseudodiploria clivosa	0.9338	0.4823	0.45
Stephanocoenia intersepta	0.0000	0.0004	0.00
Porites porites	0.0000	0.0138	-0.01
Siderastrea siderea	0.0000	0.0241	-0.02
Montastraea cavernosa	0.0000	0.0428	-0.04
Orbicella annularis	0.0000	0.0436	-0.04
Millepora alcicornis	0.0000	0.0576	-0.06
Pseudodiploria strigosa	0.2163	0.3278	-0.11
Orbicella faveolata	0.0000	0.4867	-0.49
Porites astreoides	1.5967	3.1700	-1.57
ALL SPECIES	**25.97**	**20.17**	**5.80**

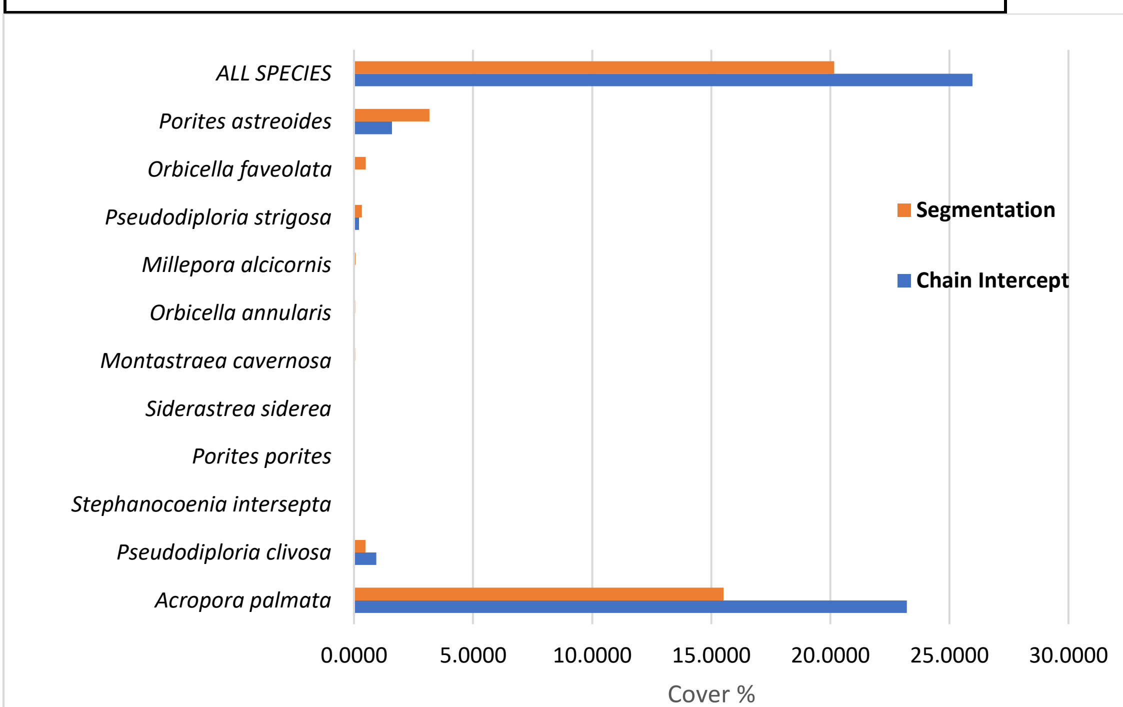


Figure 8. Bar graph of Stony coral cover percentage based on the PRCRMP chain method and the Sfm segmentation.

Table 4. Coral demographic metrics obtained integrating the Sfm segmentation in TagLab.

	Coral Counts		Coral Density (col./m²)		Coral Mean Size (cm²)	
Species	**Chain Intercept**	**Sfm**	**Chain Intercept**	**Sfm**	**Chain Intercept**	**Sfm**
Porites astreoides	n/a	1292	n/a	4.65	n/a	68
Acropora palmata	n/a	263	n/a	0.95	n/a	1638
Pseudodiploria strigosa	n/a	53	n/a	0.19	n/a	172
Millepora alcicornis	n/a	28	n/a	0.10	n/a	57
Pseudodiploria clivosa	n/a	15	n/a	0.05	n/a	892
Orbicella faveolata	n/a	14	n/a	0.05	n/a	965
Montastraea cavernosa	n/a	12	n/a	0.04	n/a	99
Porites porites	n/a	9	n/a	0.03	n/a	42
Orbicella annularis	n/a	5	n/a	0.02	n/a	242
Stephanocoenia intersepta	n/a	2	n/a	0.01	n/a	5
Siderastrea siderea	n/a	2	n/a	0.01	n/a	334
TOTAL	**25**	**1695**	**n/a**	**6.10**	**n/a**	**410**

Sampling and processing effort

Table 5 includes the calculated metrics of sampling and processing effort for both methodologies. The most remarkable evidence of the big difference between methods lies in the total area sampled in this case study at Tres Palmas. The difference in the area sampled is the most influential factor in estimating other cost-effectiveness metrics.

Processing time for the Photogrammetry office workflow resulted in the following general steps:

- Agisoft Metashape processing for Sfm outputs: 12 hours
- Tag Lab stony coral segmentation: 8 hours
- QGIS benthic groups random point count: 5
- Data management: 2 hours

Table 5. Sampling and processing effort obtained for the chain method and Sfm at the PRCRMP station Tres Palmas 5M. For details on how these numbers were calculated please refer back to the methods section of this report. Time units are provided in hours and not minutes for ease of cost estimates.

	PRCRMP Chain-Intercept	**Photogrammetry Sfm**
Area Sampled (m^2)	0.61	278.00
# of divers	2	2
# of dives	1	1
Dive bottom time (hours)	0.39	1.33
Bottom time per sampled m^2 (hours)	0.64	0.005
Processing/Data management time (hours)	0.17	27.00
Processing/Data Management time per sampled m^2 (hours)	0.27	0.10

Costs per m^2

The results on the costs of the area-standardized field sampling and office processing effort metrics are provided in Table 6. This data is provided per 1 m^2 of sampled coral reef area to maintain comparability between both methods' cost to measure stony coral metrics. The amounts are based on an hourly rate of scientific divers of $60/hr for both field and office work The chain method resulted in more expenses per unit of area for both fieldwork and office work. The chain method was two orders of magnitude more expensive than Sfm in the field and one order of magnitude more expensive in the office due to the limited spatial scale of chain method surveys.

Table 6. Calculated costs based on the sampling and processing effort units and a scientist $60/hr rate.

	PRCRMP Chain-Intercept	Photogrammetry Sfm
Bottom time cost per sampled m^2 ($USD)	$76.36	$0.58
Processing/Data Management time cost per sampled m^2 ($USD)	$16.32	$5.83
Field and Lab Cost per M^2 to measure coral cover (SUM)	**$92.68**	**$6.40**

The hypothetical project scenario consisted on doing 45 stations across the Puerto Rican archipelago and sampling stony corals over 25m² in each (5 x 5m plots). Using the chain method showed savings over Sfm under the needed equipment for field sampling ($75 vs $5,000) and office processing ($1,000 vs $6,000). However, the limited reef area coverage resulted in elevated units for fieldwork days (marine transport days, diver days) and office processing (hours). This led the chain intercept method to cost almost five times more than Sfm despite using lower-cost equipment. The total project cost was estimated at $491,933 for the chain method and $115,836 for the Sfm using the data obtained in this pilot study (Table 7).

Table 7. Parameters used in the hypothetical project scenario to evaluate implication of each method sampling and processing effort and costs.

Goal: Assess Corals at 45 sites, 25m² in each = 1,125m² total	**Needed Units**		**Cost per Unit**		**Total Cost**	
	PRCRMP Chain-Intercept	Sfm	PRCRMP Chain-Intercept	Sfm	PRCRMP Chain-Intercept	Sfm
Processing/data management time (hours)	306	109	$60	$60	$18,356	$6,556
Field sampling equipment	1	1	$75	$5,000	$75	$5,000
Data management equipment	1	1	$1,000	$6,000	$1,000	$6,000
Marine transportation days	219	45	$750	$750	$164,531	$33,750
Diver days	439	90	$600	$600	$263,250	$54,000
Project management fee (10%)	1	1	$44,721	$10,530	$44,721	$10,530
				TOTAL	$491,934	$115,836

Discussion

Benthic Variables

One of the main priorities in coral reef monitoring programs is to characterize stony coral population dynamics due to their role as foundation species. Given the loss of coral cover across the Caribbean, measuring coral parameters requires expanding the spatial scale of surveys. The photogrammetry outputs we generated for the Tres Palmas 5M station provided a permanent visual representation of the reef condition and increased the spatial scale covered by the current PRCRMP methodology by three orders of magnitude.

Differences in benthic cover percentage between methods depended on the benthic category. The large difference in the Abiotioc category is likely related to the "Overhang" abiotic variable currently in the PRCRMP database. Overhangs are only captured in the field by the chain method and do not represent live cover categories, rather than gaps or empty spaces in between benthic physical structures which the chain does not make contact with. Turf algae, as a dominant category was greatly underestimated by the chain method. This is likely due to the non-random positioning of PRCRMP transects which are established over areas of higher coral cover. Random point counts over a larger area provided much higher values of Turf algae, likely providing a more accurate representation of the benthic group dominance in the site. This can be effectively observed in the final orthomosaic imagery. The importance of benthic categories such as CCA should not be overlooked as well. Random point sampling over a large area provided much higher CCA values, allowing to identify potential substrates adequate for outplanting or restoration efforts. Both methods, chain and random point counts, seemed to provide similar estimates of coral cover. The consistency of this similarity should be explored by replicating this effort in different PRCRMP stations with more diverse and heterogeneous coral assemblages. The low coral diversity and relative dominance of *Acropora palmata* at Tres Palmas 5M probably allowed both methods to provide similar estimates of stony coral cover percentage.

The use of segmentation in Taglab provided an efficient and accurate way to extract abundance data of stony corals. Apart of 3D segmentation, segmentation of 2D orthomosaics is the most accurate way to estimate the live cover of benthic categories. Stony corals pose an advantage for this approach due to the conspicuous pixel signature characterized by distinct colors, shapes, and discrete margins. This is in contrast to highly heterogeneous and fragmented categories such as turf algae, cca, abiotic substrates, etc. which are not recognized well by the convolutional neural networks (CNN) employed in Tag Lab segmentation tools. However, the role of segmentation for other benthic groups with “colony-type” growth forms should be explored. Segmentation of sponges, zoanthids, and octocorals likely involves a similar effort to stony coral segmentation.

Compared the segmentation of the 278m^2 plot, the chain method provided an overestimation of stony coral cover, despite estimating similar relative abundances. This is likely due to the non-random positioning of the transects which aim at higher coral abundance areas. This is an important design consideration since the inception of the PRCRMP. Today, measuring coral continues to be a priority. However, recent coral mortality events might limit the capacity of current transects to measure coral. In this regard segmentation of a broader area not only provided more accurate estimates for the sampled reef in terms of abundance, but also in terms of diversity. For example, the Sfm survey conducted at Tres Palmas 5M confirmed the presence of 1 additional ESA-listed coral species and 2 major reef framework builders on the site. In this regard, management decisions that need to consider the presence/absence of ESA-listed species can be inaccurate based on PRCRMP chain coral data. Sfm surveys are not completely exempt from this spatial scale limitation but offer a substantial increase in the area observed from which quantitative demographic information is gathered.

Relevance for management

Recently, coral reef management priorities of the PR-DNER Recent have included coral reef emergencies due to the physical impacts of storms, diseases, thermal anomalies, and restoration of coral reef habitat. These management priorities require thorough data-based planning for the identification of priority reef units (sites) and biological criteria such as species compositions and demographics. The Sfm survey conducted at Tres Palmas 5M provided critical baseline data in terms of the density of corals and sizes, information not available for the PRCRMP station until now. The coral density and sizes per species data collected in June 2023 can now be compared with a post-2023 mass bleaching event survey to assess the demographic status of Acroporids at this important marine protected area. This information could greatly complement the analysis of reef conditions and coral populations using PRCRMP stations. For example, the location of resilient corals to bleaching events based on their abundance and size is possible with density and demographic data. Furthermore, with further analysis, the physical structural characteristics of the Tres Palmas 5M station, which are paramount to assess their functionality as natural coastal barriers can be further investigated with the photogrammetry outputs gathered from the Tres Palmas 5M station. This information can them be used by agencies such as NOAA, DNER, and FEMA to better understand the status of critical infrastructure and therefore, strategically plan response efforts.

Cost-effectiveness

However, this statement would be inaccurate without clearly identifying the main goals of the PRCRMP or any given monitoring program. The primary goals of the PRCRMP are to (1) characterize the coral reef benthic and fish communities of high-value reefs, (2) detect temporal change in these communities related to natural and anthropogenic factors, and (3) support the strategic management of drivers of change. Thus, coral reef monitoring is much more than measuring stony corals. The results from this study show that per unit of area, the current PRCRMP chain method can be between one and two orders of magnitude more expensive method than Sfm to assess coral abundance and demographics. Therefore it could be argued that the chain method is not a cost-effective methodology due to the limited spatial coverage it provides, resulting in the need for increased fieldwork units and inefficient office work per unit of area. If the assessment of stony corals would be the main target of a monitoring program, then it could be confidently stated that the PRCRMP chain method is not cost-effective.

The cost-effectiveness of Sfm as presented in this study is limited to the assessment of stony corals at the species level (using segmentation) and major benthic category components (using random point counts) at a functional group taxonomic resolution. As stated, office processing times for Sfm surveys are very demanding and can exponentially increase as more fragmented and diverse benthic functional groups are included in the segmentation of large-area imagery. Nevertheless, the assessment of stony coral populations at the species level is often a main priority for coral reef monitoring programs. Scleractinian coral cover, density, diversity, and demographic data is a major indicator of coral reef health in general and serves as a proxy to prioritize multiple management activities. Given the power of this technology to assess coral at large spatial scales, it can be stated that it is more suited for programs with that scope of work (coral restoration monitoring, disease dynamics, exploratory surveys, remote location surveys, etc.), rather than for programs that aim to assess multiple assemblages (fish and benthic) at small spatial scales. A realistic cost-effective solution to the spatial limitations of legacy methods can probably involve a combination of traditional visual and Sfm censuses to collect priority datasets that provide meaningful information to managers.

There are factors that can further decrease the costs of Sfm surveys. For example, faster and wider angle cameras can be used to speed up the image acquisition per unit of area in the field. Likewise, with larger one-time investments, more expensive and advanced computer hardware components can significantly reduce office processing time by up to 30-50% when producing the Sfm outputs (mosaics, 3D models, etc.). When extracting data from Sfm outputs, whether through segmentation or random point count, using visual computing algorithms is another venue of potential to reduce operational costs. However, making use of these algorithms have shown usefulness mostly with some specific benthic species that have very consistent and predictable pixel signatures across different locations, habitat types, lightning conditions, and depths (Ex. *Acropora palmata*). Available platforms such as CoralNet and TagLab currently offer the opportunity to train neural network algorithms with this application. Training algorithms are most useful for monitoring programs with permanent stations over time because they allow the trained networks to detect patterns in benthic categories pixel signatures given that the depth and other lightning conditions remain consistent.

Conclusions and recommendations

- The PRCRMP has been a major source of information to managers regarding the status and trends of coral reef fish and benthic communities. However, major limitations in the spatial scale of its benthic methodology challenge the capacity to accurately detect temporal changes in coral abundance and demographics.
- The photogrammetric survey implemented in this study increased the area sampled by the PRCRMP benthic survey from 0.6 m^2 to 278m^2. We showed relevant differences in the bethic assemblages at both major categories and coral species levels between the chain method and the Sfm survey. These differences are mostly due to the spatial scale sampled between methods.
- No statistical analyses were performed to test for significant differences by the end of this report. However, it is recommended that before doing formal statistical analyses to test the effect of "methodology" on stony coral community structure and

composition, this pilot project should be replicated at additional PRCRMP stations to add ”sites”. Site characteristics are a key factor in the model and the potential interactions between “sites” and “methodology” should be explored.

- The Sfm workflow requires training personnel, but it can be learned by established and upcoming staff given capacity-building opportunities. Students should be given these opportunities to continue integrating these technologies that help field ecologist to face the challenges of detecting change in highly variable biological communities.
- We showed data that highlights that the cost of sampling and processing per unit of area is between one and two orders of magnitude higher for chain intercept vs. the Sfm workflow presented here. However, this study applied mostly to the assessment of stony coral species and major benthic components. Further analysis of the mosaics produced for Tres Palmas 5M are needed to assess the office processing effort and costs if all benthic components need to be identified to the species level using the TagLab segmentation tools.
- Despite higher sampling and processing equipment costs of Sfm surveys, when the field effort per unit of area of the chain intercept method is considered, operational budgets to survey corals at multiple stations using the current PRCRMP are almost five times more expensive than using the Sfm method discussed here.
- It is highly recommended to consider the implementation of Sfm in future PRCRMP surveys especially if the following coral-based goals are sought after:
    - Monitoring the effectiveness of coral interventions at population and community levels such as:
        - Disease treatment
        - Coral outplanting and resilience-based restoration, especially with *Acropora palmata*
        - Artificial reef buildup and colonization
    - Assessment of distant or remote coral populations such as Mona Island
    - Assessment of physical structural parameters related to wave attenuation
    - Assessment of impacts of natural disturbances to target resistant or resilient populations.

References

Please make use of references cited in Part 1 of this effort – Literature Review available at: https://drive.google.com/file/d/17Jm_miwJA9abYsJJcEkAIj94OrxYp0Lm/view?usp=drive_link

PUERTO RICO CORAL REEF MONITORING PROGRAM: CHANGES IN CORAL REEFS SINCE THE EARLY 2000s.

Miguel G. Figuerola
Coral Reef Specialist
Coral Reef Conservation and Management Program
Department of Natural and Environmental Resources

NOAA CORAL REEF CONSERVATION PROGRAM

GOBIERNO DE PUERTO RICO
DRNA
DEPARTAMENTO DE RECURSOS NATURALES Y AMBIENTALES

PROGRAMA DE ARRECIFES DE CORAL DE PUERTO RICO
DRNA

PRCRMP

Programa de Conservación y Manejo de Arrecifes de Coral

Objetivos del *PRCRMP*:

1. Conocer la condición de las comunidades arrecifales con valor socioecológico.
2. Identificar las tendencias de cambio ante presiones ambientales y antropogénicas.
3. Ayudar a determinar las estrategias más efectivas de manejo.

Ley 147 de julio 15, 1999 – Ley para la protección, conservación y manejo de los arrecifes de coral de Puerto Rico https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0204647

DATOS

- Comunidades bentónicas - Transectos de cadena de 10 m (5 por sitio)
  - Porciento de cobertura
  - # de colonias
  - prevalencia de enfermedades de coral
- Peces y macroinvertebrados – transectos de banda 10 x 3 m
  - Densidad (individuos / 30 m^2)
- Especies de importancia comercial – Censos visuales de búsqueda activa (2004-2013). Transectos de banda 20 x 3 m (2015-2023)
  - Densidad (individuos / 60 m^2)
  - Largo total estimado
  - Biomasa (gramos / 60 m^2)

1999-2023

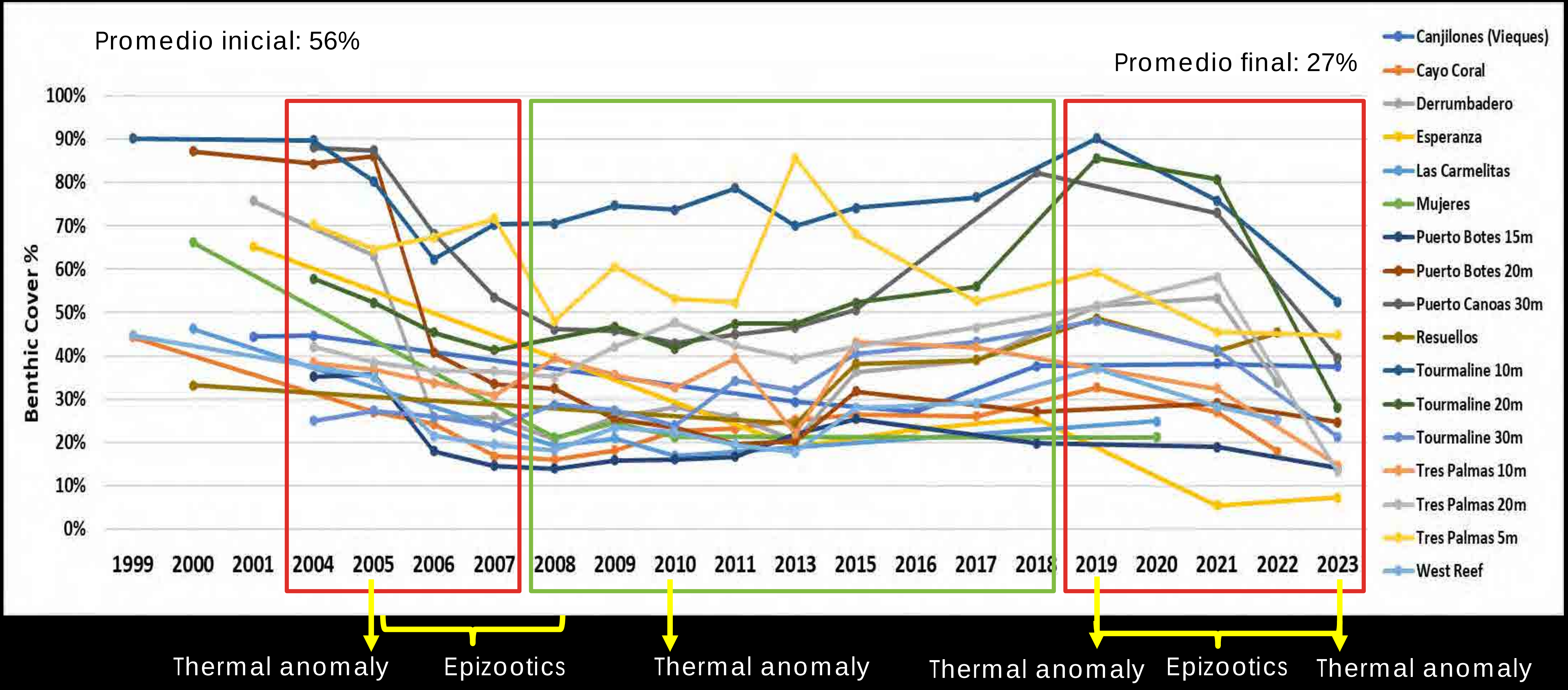
- En las últimas 2 décadas:
  - 88 estaciones muestreadas por lo menos 1 vez
  - 56% (49 out of 88) dentro de ANPs
- Actualmente (2015-presente):
  - 42 estations visitadas cada dos años (21 cada año)
  - 62% (26 out of 42) dentro de ANPs

TENDENCIAS 1999-2023

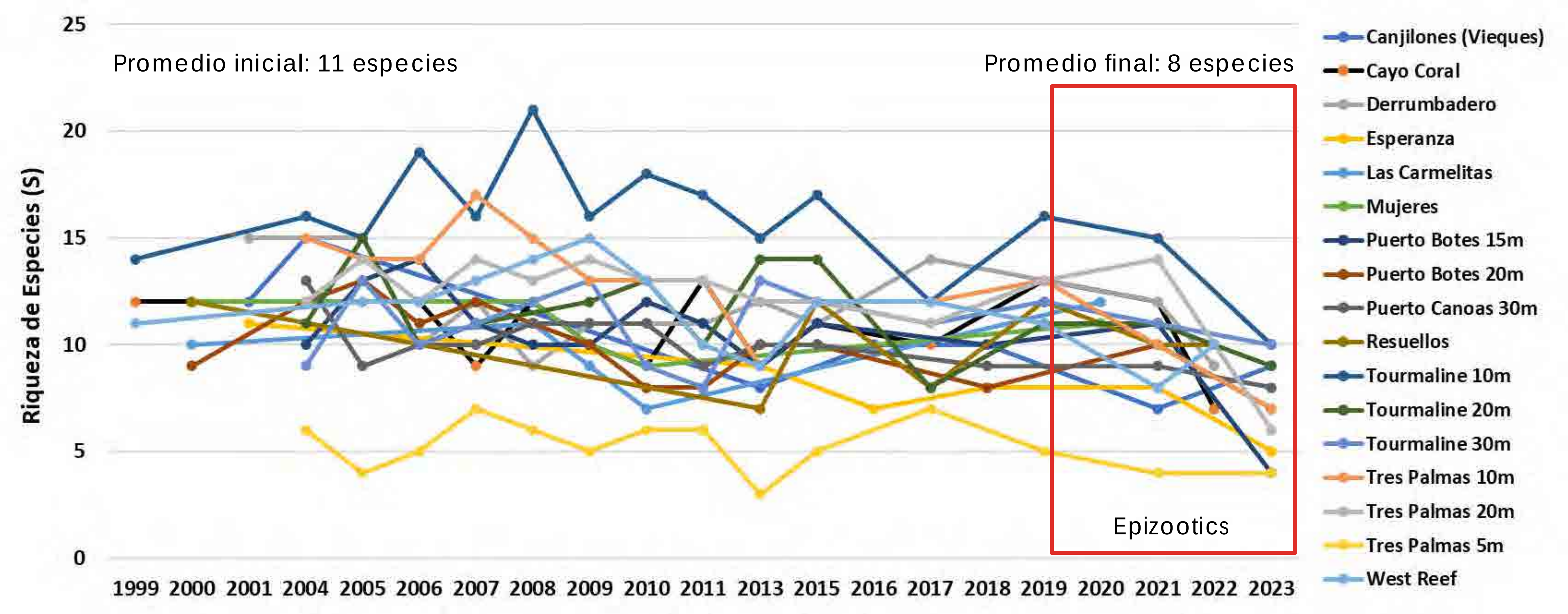
- 17 estaciones
  - Muestreo inicial : 1999 - 2004
  - Muestreo final : 2020 - 2023
  - ≥ 5 muestreos

Estación	Región
Las Carmelitas	Mona/Desecheo
Mujeres	
Puerto Botes 15m	
Puerto Botes 20m	
Puerto Canoas 30m	
Derrumbadero	South
West Reef	
Cayo Coral	Southwest
Canjilones (Vieques)	Vieques/Culebra
Esperanza	
Resuellos	West
Tourmaline 10m	
Tourmaline 20m	
Tourmaline 30m	
Tres Palmas 10m	
Tres Palmas 20m	
Tres Palmas 5m	

TENDENCIAS 1999-2023 COBERTURA DE CORAL



TENDENCIAS 1999-2023 DIVERSIDAD DE CORALES



TENDENCIAS 1999-2023

SCTLD – Especies Susceptibles

D. cylindrus

C. natans

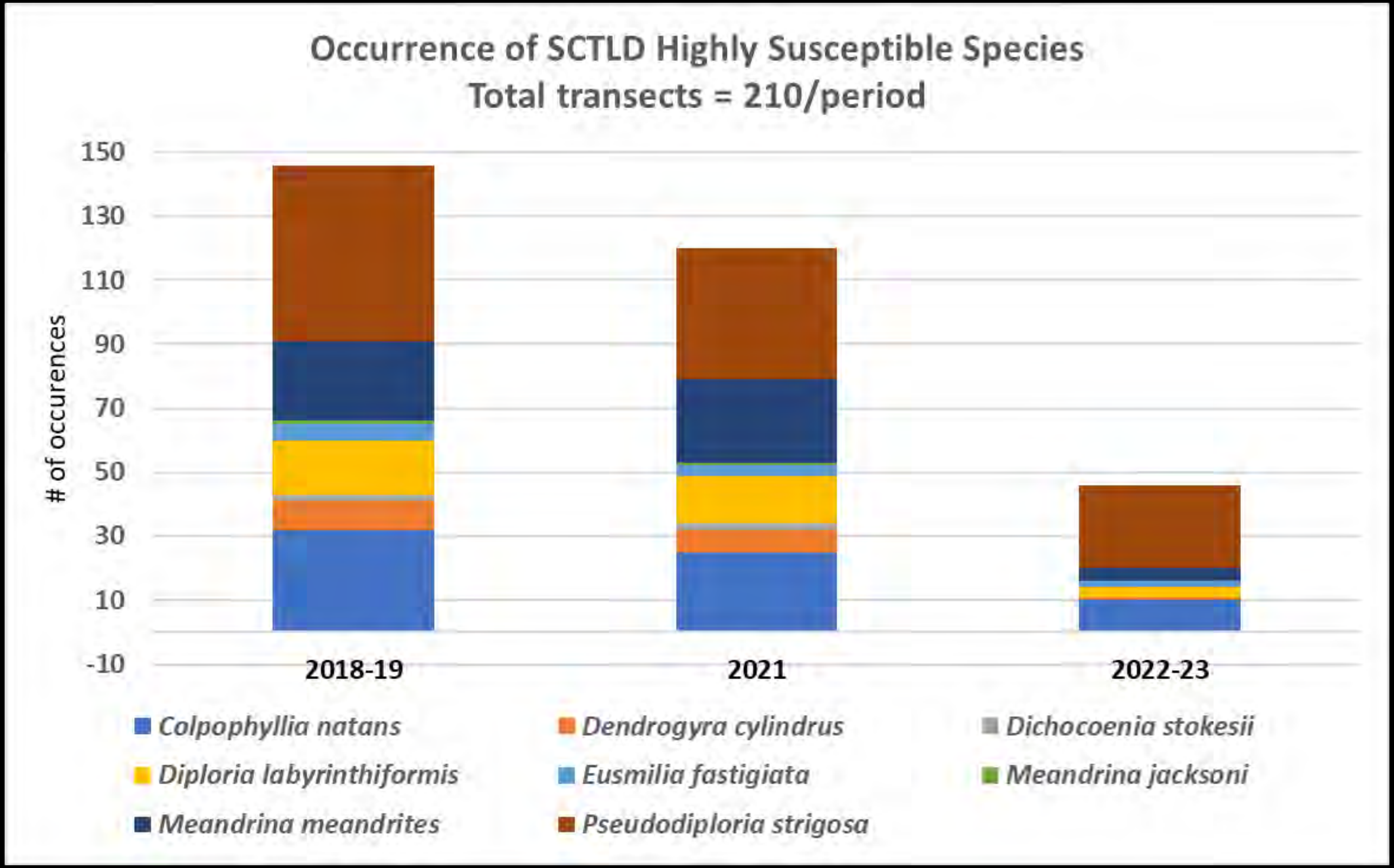
D. labyrinthiformis

M. meandrites

P. strigosa

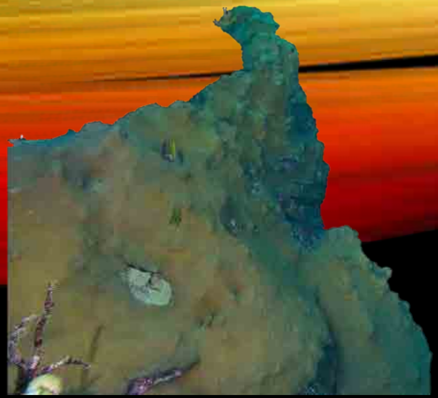
D. stokesii

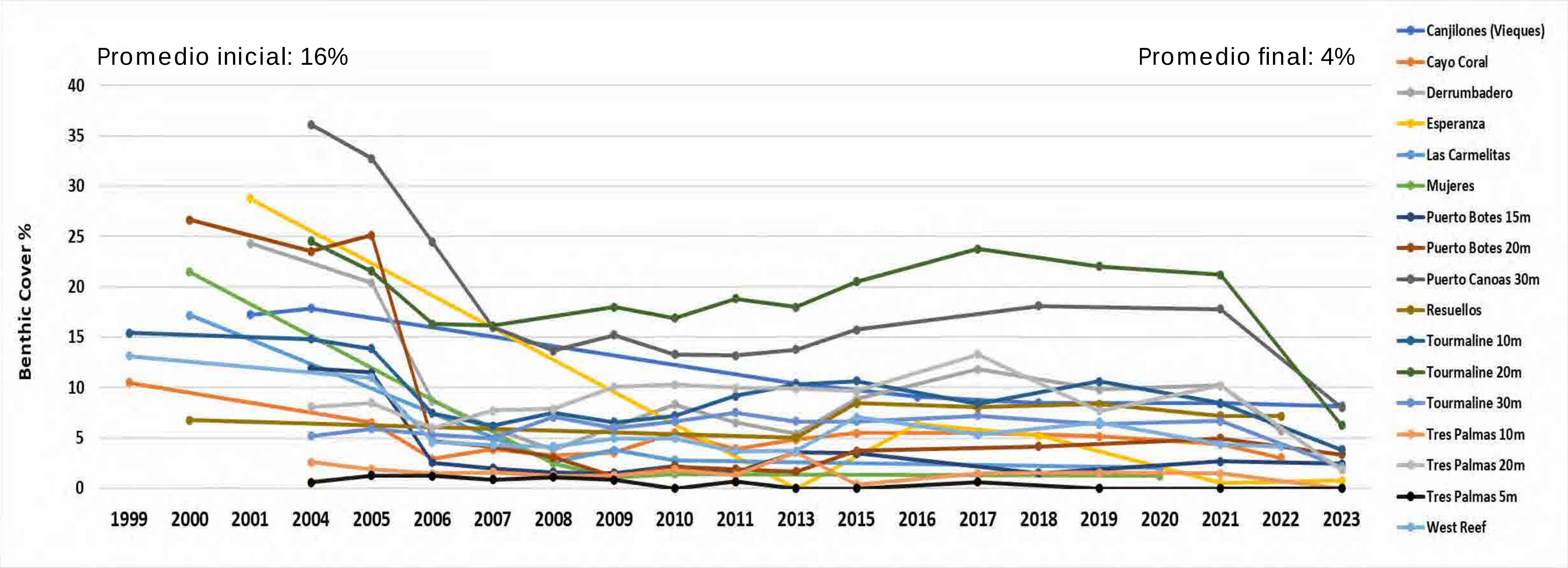
E. fastigiata



TENDENCIAS 1999-2023

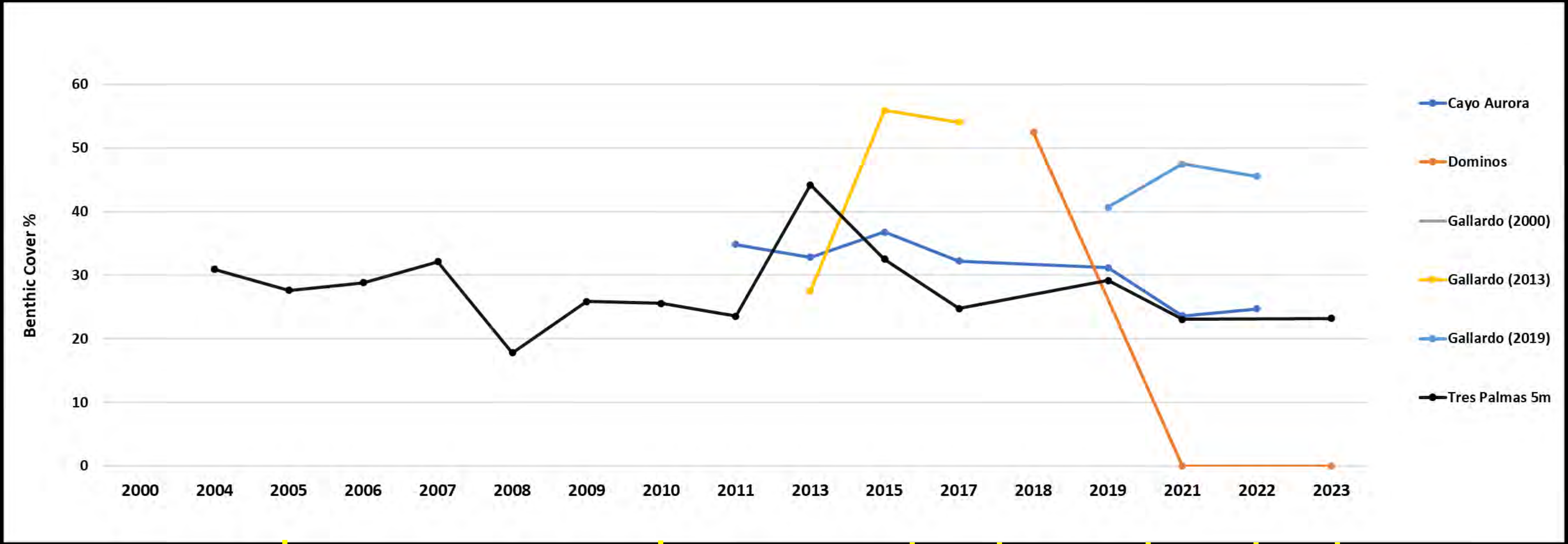
Orbicella annularis complex





TENDENCIAS 1999-2023

Acropora palmata



Thermal anomaly
Thermal anomaly
Matthew
María
Isaías
Thermal anomaly
Fiona
Thermal anomaly

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Patterns of spatial and temporal variation of fish assemblages associated with coral reefs of Puerto Rico: The story of 20 years of continuous monitoring

‹ PeerJ

Mortality, recovery, and community shifts of scleractinian corals in Puerto Rico one decade after the 2005 regional bleaching event

Research article | Biosphere Interactions | Ecology | Marine Biology | Natural Resource Management

Jorge R. García-Sais[1], Stacey M. Williams[2,3], Ali Amirrezvani[1]

Published July 25, 2017

marine ecology

ORIGINAL ARTICLE

A potential new threat on the coral reefs of Puerto Rico: The recent emergence of *Ramicrusta* spp.

Stacey M. Williams, Jorge R. García-Sais

First published: 20 April 2020 | https://doi.org/10.1111/maec.12592

Coral Reefs (2010) 29:277–288
DOI 10.1007/s00338-009-0582-9

REPORT

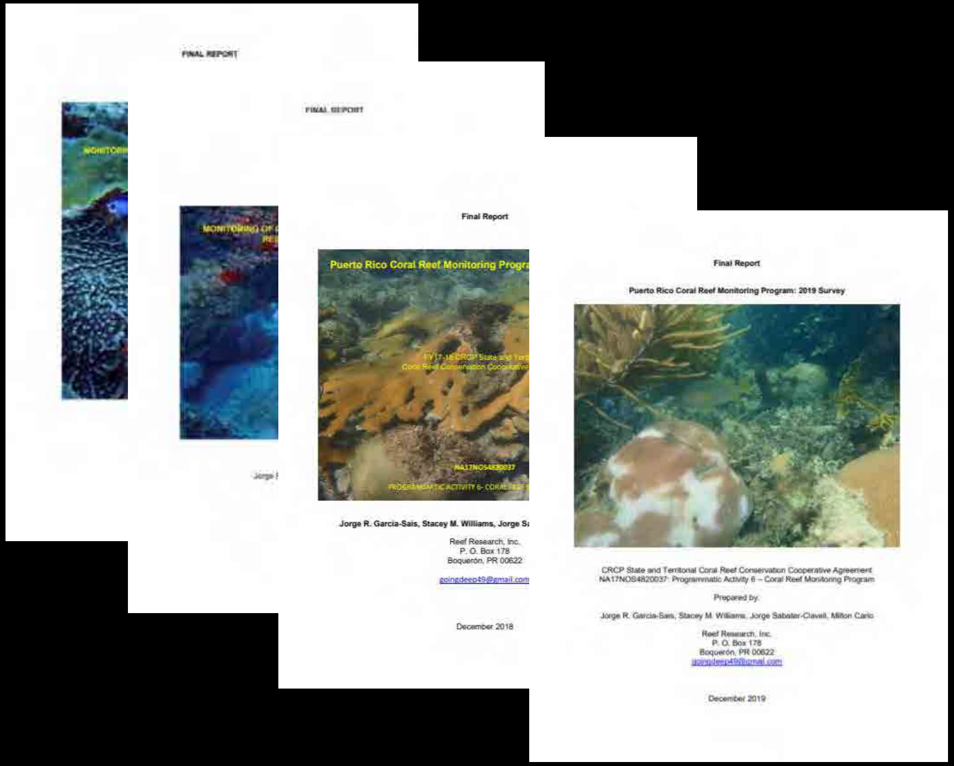
Reef habitats and associated sessile-benthic and fish assemblages across a euphotic–mesophotic depth gradient in Isla Desecheo, Puerto Rico

Jorge R. García-Sais

Received: 15 April 2009 / Accepted: 27 December 2009 / Published online: 7 February 2010

REPORTES ANUALES

- https://www.drna.pr.gov/coralpr/monitoreo/



Informes anuales del ciclo del Programa de Monitoreo de Arrecifes de Coral

- Informe del monitoreo de corales 2001- Volumen 1
- Informe del monitoreo de corales 2001- Volumen 2
- Informe del monitoreo de corales 2001- Volume 3
- Informe de monitoreo de corales 2001- Baseline Characterization for Vieques
- Informe de monitoreo de corales 2002
- Informe de monitoreo de corales 2004
- Monitoring of Coral Reef Communities from Isla de Vieques Puerto Rico- 2004
- Informe de monitoreo de corales 2005
- Informe de monitoreo de corales 2006
- Informe de monitoreo de corales 2006-2007
- Informe de monitoreo de corales 2007-2008
- Informe de monitoreo de corales 2008-2009
- Informe de monitoreo de corales 2009-2010
- Informe de monitoreo de corales 2010-2011
- Informe de monitoreo de corales 2012-2013
- Informe de monitoreo de corales 2015
- Informe de monitoreo de corales 2016
- Informe de monitoreo de corales 2017
- Informe de monitoreo de corales 2018
- Informe de monitoreo de corales 2019
- Informe de monitoreo de corales en Mona 2019

¿PREGUNTAS?

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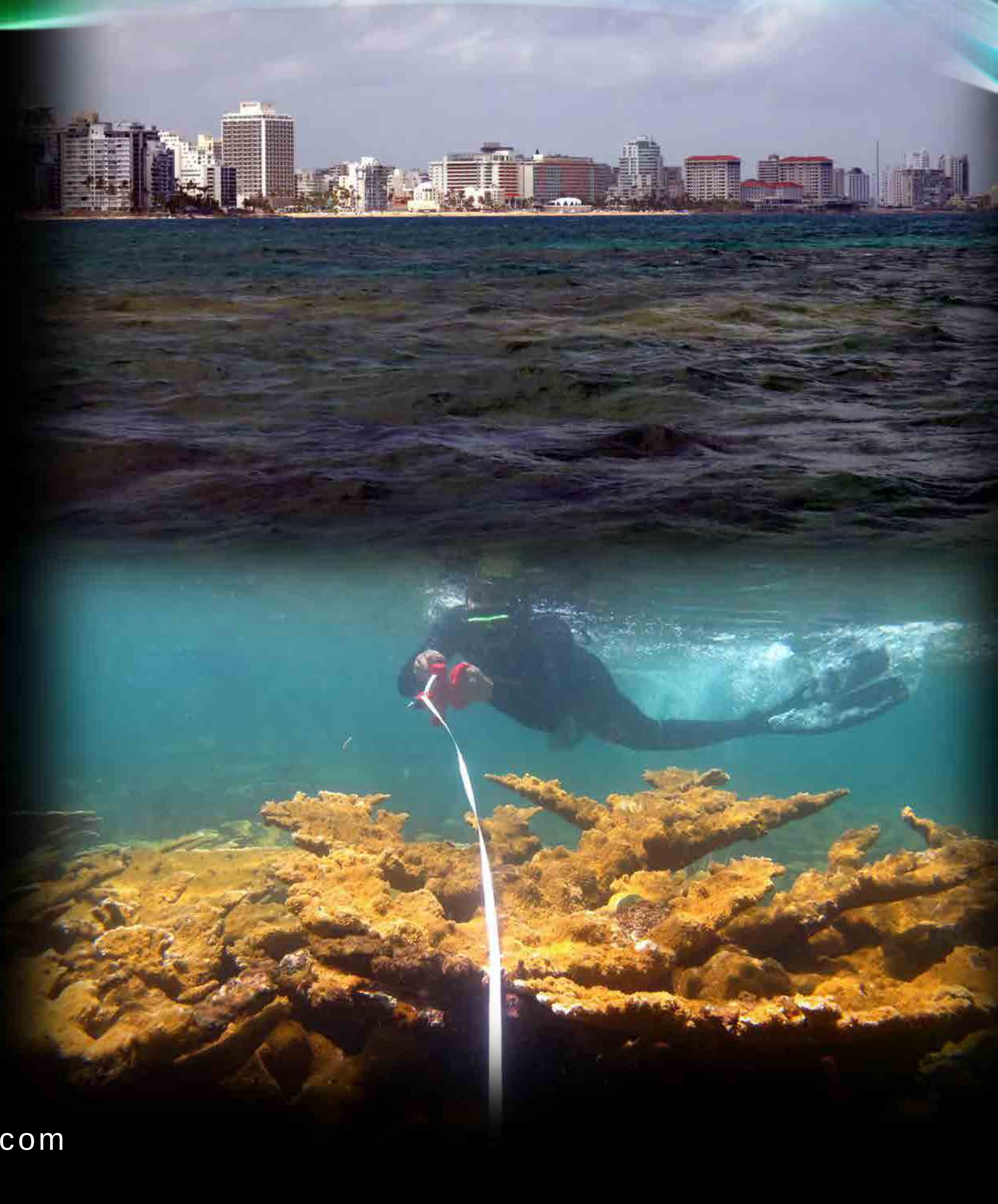

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Coral Reef Specialist

Capsulas noticiosas

Sometido al Programa de Corales del DRNA

Septiembre 2024

Cápsula Informativa: Respuesta a Emergencias Múltiples en los Arrecifes de Coral de Puerto Rico

Los arrecifes de coral de Puerto Rico han enfrentado una serie de emergencias naturales y biológicas en la última década, poniendo a prueba la capacidad de respuesta de las agencias manejadoras y la resiliencia de estos ecosistemas vitales. Entre las crisis recientes más significativas se encuentran los Huracanes Irma y María en 2017, la enfermedad de pérdida de tejido de coral pétreo (SCTLD, por sus siglas en inglés) desde 2019 hasta el presente, la mortalidad masiva de erizos en el 2022 y la anomalía térmica del 2023 que resultó ser la más severa en récord para Puerto Rico y el Caribe. Aquí te contamos un poco más sobre estas emergencias y como se ha respondido a ellas.

Huracanes Irma y María (2017)

Los huracanes Irma y María, ambos de categoría 5, devastaron los arrecifes de coral de Puerto Rico. Los fuertes vientos y oleaje impactaron gravemente la estructura física de los arrecifes, causando fracturas y desplazamientos de corales. En respuesta, la Oficina Nacional de Administración Oceánica y Atmosférica (NOAA, siglas en inglés) entró en negociaciones con la Agencia Federal de Manejo de Emergencias (FEMA, siglas en inglés) para hacer una evaluación exhaustiva del impacto que tuvieron estos huracanes en los arrecifes de Puerto Rico. Este proyecto evidenció el gran daño a corales listados bajo la Ley de Especies en Peligro de Extinción, especialmente en arrecifes llanos de la zona este de la Isla. Esto a su vez justificó una respuesta de emergencia para replantar y estabilizar grandes cantidades de corales sueltos.

Para recopilar las lecciones aprendidas de esta respuesta, el Departamento de Recursos Naturales y Ambientales de Puerto Rico (DRNA) desarrolló **el Protocolo de Respuesta a Emergencias de Alta Energía Oceánica**, un plan estratégico que guía las acciones inmediatas de restauración y rehabilitación de los arrecifes afectados. Este protocolo incluye la reubicación de corales fragmentados, la estabilización de grandes bloques coralinos y el monitoreo de la recuperación natural de los ecosistemas. Para conocer más detalles del protocolo de respuesta a emergencias sobre los arrecifes de coral puedes visitar el siguiente enlace: https://www.drna.pr.gov/wp-content/uploads/2023/06/2021-Protocolo-respuesta-rapida-ESPANOL.pdf

Enfermedad de Pérdida de Tejido de Coral Pétreo (SCTLD) (Desde 2019 hasta el presente)

La SCTLD es una de las amenazas más graves que han enfrentado los corales en Puerto Rico en los últimos años. Esta enfermedad altamente contagiosa ha afectado a más de 20 especies de corales pétreos, con tasas de mortalidad extremadamente altas. Desde que se detectó por primera vez en la Isla de Culebra en el 2019, se han implementado intervenciones en el campo, así como un exhaustivo proceso de coordinación y planificación.

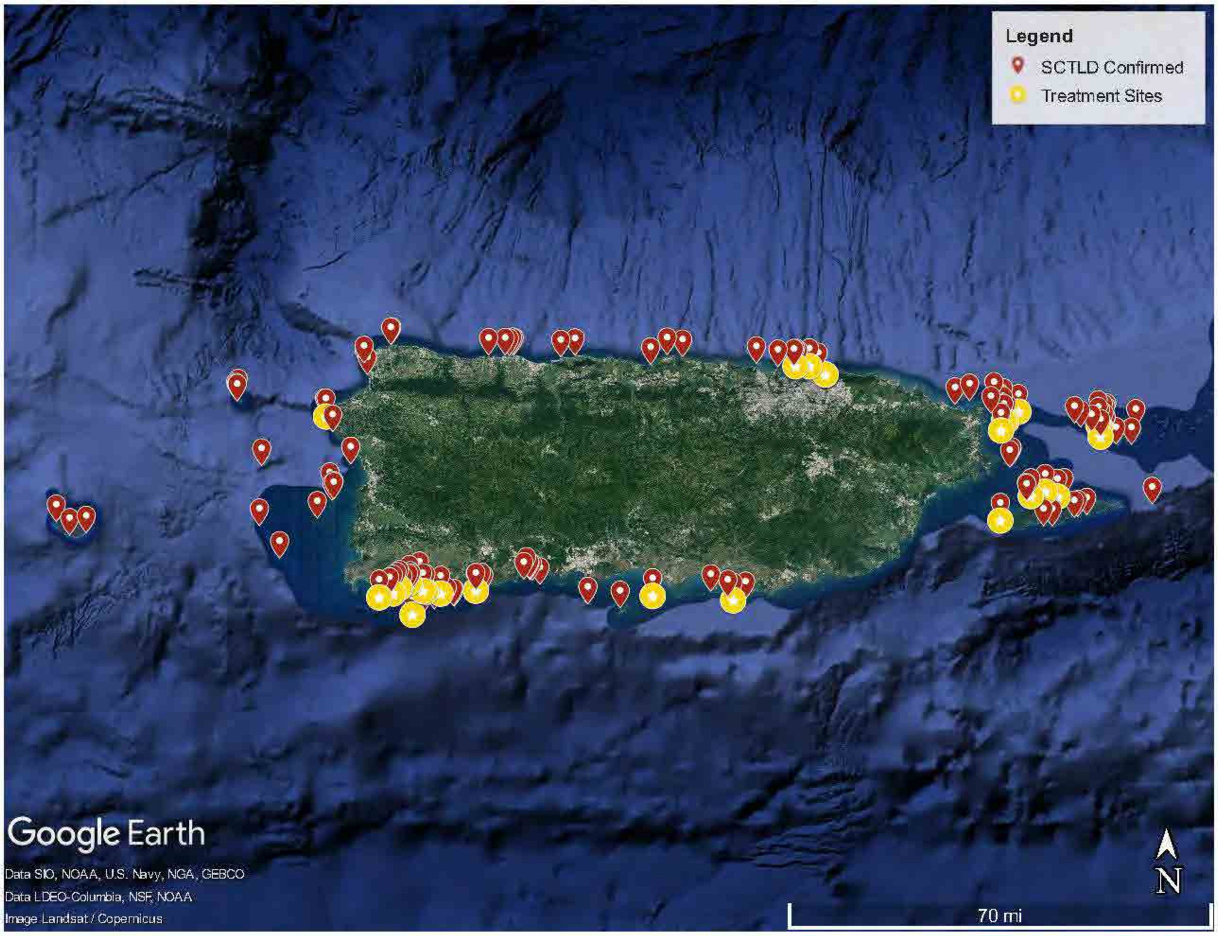
Fotos por Miguel Figuerola

Inmediatamente tras los primeros reportes de la enfermedad en el año 2019, en la Isla Municipio de Culebra, esta emergencia ha servido para reforzar la comunicación y colaboración del DRNA con diferentes entidades que se dedican a la investigación, conservación y manejo de recursos arrecifales. Mensualmente el DRNA ha sido anfitrión de reuniones donde se discute el estado de la enfermedad, se actualizan mapas de observaciones, se comparten datos de intervenciones y se coordinan esfuerzos de educación y alcance. El entrenamiento del público con fines de reclutar voluntarios en la respuesta ha sido una gran tarea para la cual se han desarrollado currículos educativos en colaboración con jurisdicciones afectadas (Florida e Islas Vírgenes). Para conocer un poco más sobre el tratamiento utilizado para combatir la enfermedad de coral SCTLD en Puerto Rico entra al siguiente enlace: https://www.youtube.com/watch?v=QkG_oHRT_0o.

El primer plan de respuesta elaborado por el DRNA y la NOAA fue en el 2021. Este pasó a ser un **Plan de Intervención para SCTLD**, que incorpora lecciones aprendidas de otras jurisdicciones que enfrentaban una emergencia similar desde el 2014. El Plan de Intervención incluye las directrices y criterios de priorización de sitios para la aplicación de un tratamiento experimental. Este tratamiento consta de un antibiótico y polímero, conocido como Coral Cure B2B, que es aplicado directamente sobre los corales infectados. El Plan de Intervención también sentó las bases para el monitoreo constante del tratamiento para prevenir la propagación de la enfermedad y evaluar su efectividad. Este Plan puso en marcha esfuerzos de intervención con una subvención de la NOAA por 80 mil dólares anuales, la primera aportación formal para atender este asunto en Puerto Rico.

Gracias al inmenso esfuerzo de entidades colaboradoras este evento sin precedente propulsó que el Gobernador de Puerto Rico aprobara la Orden Ejecutiva OE-2021-066 la cual declara una emergencia ecológica en nuestros arrecifes y se asignaran 1 millón de dólares al DRNA para continuar la respuesta a SCTLD. Bajo esta Orden, el DRNA rápidamente desarrolló un **Plan Estratégico de Respuesta a SCTLD**, que coordina los esfuerzos de diferentes agencias gubernamentales, organizaciones, científicos, voluntarios y miembros del programa de ciencia ciudadana para abordar la crisis de manera integral. Nunca antes el DRNA había recibido un apoyo de esta magnitud de parte de La Fortaleza para atender una emergencia ecológica, lo cual subrayó la importancia del excelente trabajo que se realiza en el Programa de Corales del DRNA y de la influencia de sus colaboradores.

Entre los resultados de esta respuesta se han documentado más de 9,500 tratamientos a colonias aplicados, más de 170 salidas de campo, unas 27 especies de coral tratadas en más de 30 arrecifes, así como el entramiento de más de 100 voluntarios a nivel Isla.



Mapa con los sitios donde se ha reportado la enfermedades desde el 2019 (puntos rojos) y sitios donde se han aplicado tratamiento a corales (puntos amarillos).

Mortalidad de Erizos (2022)

Durante el 2022, se reportó una nueva mortalidad del erizo de espinas largas *Diadema antillarum* en muchas islas alrededor del Caribe. Este evento preocupante recordó un brote similar que ocurrió en la década de 1980, que tuvo efectos devastadores en los ecosistemas de arrecifes de coral, ya que estos animales son fundamentales para el control de algas en los arrecifes de coral. Sin los erizos, las algas pueden crecer sin control, sofocando a los corales. En respuesta a esta emergencia, en Puerto Rico se invitó a la comunidad científica y de manejadores a participar de reuniones mensuales donde se compartían

Foto tomada de https://www.agrra.org/sea-urchin-die-off/

observaciones de campo y se le daba seguimiento y documentar la extensión del problema. Las observaciones más severas fueron para la Isla Municipio de Culebra y otras localidades en la costa Norte. Las colaboraciones de la Dra. Stacey Williams fundadora de la organización ISER Caribe y la Dra. María Vega, manejadora del Programa de Corales del DRNA, desembocaron en una publicación científica donde se describió este evento de mortalidad y comparó con el evento histórico de los 1980s.

Debido a las emergencias que ocurren constantemente con los organismos arrecifales, desarrollar estrategias de restauración, como la cría y reintroducción de erizos en áreas afectadas es de crucial importancia, en Puerto Rico la organización ISER Caribe y CIROM son pioneros en la propagación de erizos. Si te interesa aprender mas sobre los erizos y su situación actual, dales clic a los siguientes enlaces: https://www.youtube.com/watch?v=OAMrdU8baBc

https://www.agrra.org/sea-urchin-die-off/

https://www.instagram.com/reel/C8rb77Tg3a8/?igsh=MWJ5aWkycXN3ejBneQ==

Evento de Blanqueamiento Coralino (2023)

En el 2023 se registró la peor anomalía histórica en las aguas arrecifales de Puerto Rico en record. Específicamente el programa Coral Reef Watch de la NOAA reportó cerca de 20 semanas de altas temperaturas en las aguas de Puerto Rico. Esto resultó en uno de los eventos de blanqueamiento coralino más mortíferos en la historia moderna de nuestros arrecifes. Los monitoreos realizados por PRCRMP (Programa de Monitoreo de Arrecifes de Coral de Puerto Rico) y NCRMP (Programa Nacional de Monitoreo de Arrecifes de Coral), y monitoreos realizados por la comunidad científica y local de Puerto Rico, han sido cruciales para documentar el impacto de este evento y orientar las acciones de manejo y mitigación. Estos esfuerzos han permitido recolectar datos valiosos sobre la resistencia y recuperación de los corales blanqueados, como también información de mortalidades masivas como la ocurrida con las poblaciones del Coral Cuerno de Alce (*Acropora palmata*) y Cuerno de Buey (*Acropora cervicornis*) en el sur oeste de la Isla. Por ejemplo, una de las poblaciones de A. palmata más grandes en el Suroeste, el arrecife Cayo Aurora, sufrió 100% de mortalidad. Una historia similar ocurrió en el Cayo San Cristobal de La Parguera. Sin embargo, colaboradores han documentado la recuperación de varios arrecifes donde abundan especies de coral de alto valor ecológico como el coral masivo Orbicella faveolata. El DRNA continúa monitoreando estos eventos en el 2024 para documentar aquellas poblaciones que logran mantenerse vivas a pesar de estar expuestas a altos niveles de temperaturas. Para esto, la respuesta a blanqueamiento incluye la integración de tecnologías de monitoreo utilizando fotomosaicos y la

instalación de sensores de temperatura en arrecifes de prioridad.

Fotos: Miguel Figuerola

Esfuerzos de Respuesta y Monitoreo Continuo

Las respuestas a estas emergencias han sido respaldadas por una combinación de ciencia rigurosa, cooperación comunitaria y políticas de manejo adaptativo. Los monitoreos de la Respuesta a SCTLD y otras crisis han sido fundamentales para ajustar las estrategias de manejo en tiempo real. Los esfuerzos de los miembros del programa de Ciencia Ciudadana y los voluntarios han permitido a las comunidades locales involucrarse directamente en la protección de sus arrecifes, aumentando la conciencia y la capacidad de respuesta ante futuras emergencias. En el siguiente enlace te puedes enterar sobre los esfuerzos del programa de ciencia ciudadana:

https://linktr.ee/CoralPR?fbclid=IwY2xjawFFgH5leHRuA2FlbQIxMAABHZoofWA0Ql5ZMZ_9yQJcUtQb8T1KWT1DDap52kb7uOBlcDN3U1uldt0xPw_aem_dW0qjziz5w8dX--vZ9udAA

En conjunto, estos planes estratégicos y esfuerzos de monitoreo destacan la importancia de una respuesta coordinada, basada en la ciencia para enfrentar las múltiples amenazas que desafían estos ecosistemas.

Cápsula Informativa: "Nauta, cógelo suave: Navega con Calma"

Navegar es una experiencia que nos conecta con la naturaleza y nos permite disfrutar de la belleza del mar. Sin embargo, es esencial hacerlo con conciencia y respeto hacia el medio ambiente y la vida marina que habita en él. En esta cápsula informativa, te recordamos la importancia de navegar con calma y de estar siempre atentos a las restricciones de velocidad en ciertas áreas.

Respeto a la Vida Marina

Al navegar, es crucial tener en cuenta la presencia de animales marinos, especialmente especies vulnerables como los manatíes. Estos gentiles gigantes son conocidos por su lento movimiento y pueden ser gravemente heridos por embarcaciones que no respeten las normas de velocidad o que no están atentos observando sus alrededores. En los últimos años, se han reportado sobre 13 muertes de manatíes anualmente, muchas de estas debido a impactos de embarcaciones. Reducir la velocidad en áreas donde se sabe que habitan los manatíes no solo es una cuestión de seguridad, sino también de respeto y conservación de la vida marina.

Manatí bebe muerto por impacto de embarcación. Foto por Nilda Jiménez

Por otro lado, la navegación irresponsable puede culminar en encallamientos. Los encallamientos no solo representan un peligro a la vida y propiedad, sino que también causan daños mecánicos y/o estructurales a valiosos ecosistemas como los arrecifes de coral y praderas de hierbas marinas. Estos pueden tardar décadas en recuperarse y contribuye a la pérdida de servicios y funciones socioecológicas.

Uso de Cartas de Navegación y GPS

Tomado de Navionics® Boating

Para evitar encallamientos y otros accidentes que pueden dañar los ecosistemas marinos, como los arrecifes de coral y las praderas de hierbas marinas, es fundamental utilizar cartas de navegación con batimetría actualizada, sistemas de GPS y monitorear la profundidad en zonas con arrecifes. Sin embargo, no se debe depender únicamente de estas herramientas para la navegación ya que errores en los mapas y fallas de los instrumentos electrónicos pueden llevar a accidentes. El nauta debe mantenerse alerta observando, obedecer la señalización, estudiar las cartas náuticas y guiar con precaución para poder reaccionar de manera adecuada y a tiempo. La negligencia en la navegación no solo pone en riesgo tu embarcación y tu vida, sino que también puede causar daños irreparables a estos frágiles ecosistemas.

Evitar el Consumo de Sustancias psicoactivas y aglomeraciones en embarcaciones en los ecosistemas

Fotografía aérea en los cayos de la Parguera. Foto por: Omar López

Además de ser ilegal, conducir una embarcación bajo la influencia de sustancias psicoactivas, como por ejemplo el alcohol, es extremadamente peligroso. Estas sustancias afectan el juicio y los reflejos, aumentando el riesgo de accidentes. Las aglomeraciones de embarcaciones cerca de ecosistemas como los manglares, praderas de hierbas marinas y arrecifes, pueden afectar gravemente estos ecosistemas dejando daños que tardarían muchos años en repararse. Mantente en control, con una mente clara y en calma. Así podrás controlar la embarcación para garantizar la seguridad de todos a bordo y proteger el entorno marino, evita las aglomeraciones y dale un respiro al ecosistema.

Respuesta a Encallamientos

Durante los últimos cinco años en Puerto Rico se han reportado un promedio de 27 encallamientos anuales, lo que conlleva consecuencias tanto económicas como ecológicas y requiere una respuesta coordinada de varios sectores. En caso de un encallamiento, es vital la rápida intervención de las autoridades competentes, como el Departamento de Recursos Naturales y Ambientales (DRNA), la Administración Nacional Oceánica y Atmosférica (NOAA), las Fuerzas Unidas de Rápida Acción de la Policía (FURA), la Guardia Costanera de los Estados Unidos (USCG) y otras organizaciones no gubernamentales que colaboran en la respuesta. En conjunto, estas entidades evalúan el impacto del encallamiento y desarrollan un plan de respuesta que incluye la remoción de las embarcaciones y la reparación de los corales que fueron desprendidos por el impacto.

En estas respuestas se busca documentar el daño causado por la embarcación, evaluar la gravedad de este y generar un plan que busque no sólo remover la embarcación sino también mitigar de la mejor manera posible el daño causado a ecosistemas de vital importancia como lo son los arrecifes de coral y las praderas de hierbas marinas. En ocasiones se debe relocalizar colonias de corales para evitar ser impactados durante la remoción de la embarcación y/o estabilizar el sustrato impactado. Dependiendo del daño causado y la escala, la respuesta puede conllevar litigación en corte donde las agencias encargadas buscan una indemnización por daños ambientales. Estos pueden requerir inversiones significativas para la restauración de los arrecifes de coral y/o hierbas marinas afectadas. Por ejemplo, en el caso de encallamientos de grandes buques de carga esto ha requerido años de litigación y millones de dólares en la restauración de los ecosistemas. En casos de pequeñas embarcaciones, los seguros de responsabilidad pública juegan un rol fundamental en cubrir los costos de la respuesta. Esto debido a los daños causados a los arrecifes, los cuales son infraestructura crítica y barreras costeras naturales. Cuando una embarcación encallada no se remueve, permanece en la costa abandonada. Gradualmente se va deteriorándose, contaminando la calidad del agua y actuando como un riesgo para la navegación. Además, puede ser un proyectil durante huracanes, tormentas o marejadas fuertes, causando daños adicionales. Es responsabilidad del dueño de la embarcación tener un seguro y de no tenerlo debe cubrir los gastos de remoción de la embarcación y restauración, los cuales pueden ser de decenas de miles de dólares, dependiendo del tipo de embarcación y la magnitud del daño causado.

Este proceso es crucial para minimizar el daño ambiental y preservar la salud de nuestros océanos. Como navegantes responsables, debemos hacer todo lo posible para evitar situaciones que requieran este tipo de intervenciones y, en caso de que ocurran, cooperar plenamente con las autoridades.

Para más información visita el siguiente link: https://www.drna.pr.gov/wp-content/uploads/2015/05/brochure_encallamiento.pdf

Reporten los Encallamientos

Si usted encalla su embarcación o motora subacuatica, es su responsabilidad notificar al Cuerpo de Vigilante en un periodo de no más de 8 horas. El incumplimiento de esta accion conlleva una multa de $250.00.

Los Nautas y Usuarios del mar pueden apoyar al Cuerpo de Vigilantes reportando los encallamientos que observen, aun cuando sean removidos al momento dado que los mismos pudieron haber causado impacto en los arrecifes de corales o praderas de hierbas marinas. Para notificar puede llamar al XXX XXX-XXXX, mencionar el incidente y compartir el número PR de identificación de la embarcación que encalló, coordenadas del lugar de incidente y fotos.

Embarcación encallada en el arrecife Atravesado en La Reserva Natural La Parguera.

Navegar con calma y respeto no solo asegura una experiencia más segura para todos, sino que también contribuye a la protección y conservación de los ecosistemas marinos que tanto valoramos. ¡Nauta, cógelo suave y navega con conciencia!

Embarcación encallada luego de una tormeta frente al Conquistador, Fajardo. Foto por Sandra Schleier.

Embarcación abandonada en Puerto Ferro, Vieques. Foto por Sandra Schleier.

Cápsula Informativa: Poblaciones sobrevivientes de Acropóridos en Puerto Rico tras la Anomalía Térmica de 2023

En el año 2023, Puerto Rico experimentó la anomalía térmica más intensa jamás registrada, un evento que ha puesto a prueba la resiliencia de las poblaciones de corales, específicamente las especies Cuerno de Alce (*Acropora palmata)* y el coral Cuerno de Ciervo (*Acropora cervicornis)*. Estos corales, esenciales para la estructura y función de los arrecifes, han prácticamente desaparecido de nuestros arrecifes debido una variedad de factores. Los efectos del cambio climático en los arrecifes se pueden observar en el aumento de la intensidad y frecuencia de eventos de blanqueamiento y enfermedades. A nivel local, el deterioro en la calidad del agua, fenómenos de alta energía oceánica como huracanes y la sobrepesca son procesos adicionales que contribuyen a la muerte masiva de estos organismos marinos y la falta de recuperación. Esto resulta en la pérdida de la estructura vital para todo un ecosistema.

El cambio climático ha generado un incremento en la temperatura del agua, provocando episodios más frecuentes y severos de blanqueamiento coralino. Este fenómeno ocurre cuando los corales, bajo estrés por el aumento de temperatura, expulsan las algas simbióticas que les proporcionan nutrientes y su color característico. La pérdida de estas algas no solo provoca el blanqueamiento, sino que también debilita a los corales, haciéndolos más susceptibles a enfermedades y a la muerte.

Fig 1. Poblaciones de *A. cervicornis* y *A. palmata* que lucían saludables antes del blanqueamiento del 2023 en la Reserva Natural La Parguera

Los Acroporidos y su trayectoria

La importancia de los Acroporidos yace en su morfología ramificada y de gran tamaño, lo cual ecológicamente le confiere un mayor éxito creciendo en las partes llanas del arrecife donde rompen las olas. Al dominar en un ambiente alta energía crean un hábitat sumamente complejo estructuralmente, el cual sirve de refugio para grandes poblaciones de peces e invertebrados de importancia comercial. A su vez, el crecimiento de estas estructuras ramificadas promueve la absorción de la energía del oleaje, protegiendo nuestras costas del embate de tormentas y marejadas. Sin embargo, los Acroporidos han mostrado ser muy susceptibles a las anomalías térmicas y eventos de enfermedades. Desde los 1980s existen récords del Caribe, incluyendo a Puerto Rico, de la mortalidad masiva de Acroporidos por estas razones. Tanto así que en el año 2006 la Oficina Nacional de Administración Oceánica y Atmosférica (NOAA, siglas en inglés) incluyó a las dos especies de Acroporidos en la lista de especies amenazadas a extinción de la Ley de Especies en Peligro de Extinción federal. Hoy día, a casi 20 años de esta la designación, no se ha documentado una recuperación significativa de estas poblaciones, pues los eventos de mortalidad han continuado.

El evento de mortalidad más reciente – Octubre 2023

El Programa de Monitoreo de Arrecifes de Coral de Puerto Rico (PRCRMP, por sus siglas en inglés) y el Programa Nacional de Monitoreo de Arrecifes de Coral (NCRMP), más esfuerzos locales como los realizados por diferentes agencias y organizaciones locales como, DRNA, HJR Reefscaping, Sea Ventures MRU, Sociedad de Ambiente Marino, Isla Mar, ISER Caribe, Grupo VIDAS, entre otras, han estado monitoreando de cerca estos eventos y registrando datos cruciales sobre la salud de los corales en la isla. Las observaciones realizadas en el suroeste de Puerto Rico revelaron una mortalidad masiva en las poblaciones de *A. palmata* y *A. cervicornis*, una zona particularmente afectada por las intensas temperaturas en el mar durante el 2023. El Programa de Vigilancia de Arrecifes de Coral de la NOAA (NOAA Coral Reef Watch) registró temperaturas sostenidas sobre los 86 grados F por dos meses. Esto se combinó con condiciones muy calmadas en el mar debido una caida en la velocidad de los vientos alicios y la falta del paso de sistemas tropicales al sur de la Isla, lo cual empeoró la exposición al calentamiento e irradiación solar. Estos factores resultaron e una acumulación de estrés mortal para los Acroporidos del corredor marino ecológico Guánica-Parguera. Se documentó entre un 90-100% de mortalidad en las poblaciones de Acroporidos más grandes conocidas en Guanica (Cayo Aurora) y La Parguera (San Cristobal).

Para una mejor visualizacion de como eran algunas de las poblaciones de estas especies en la reserva natural la Parguera en el 2020 ver el siguiente video de Coral PR: https://www.youtube.com/watch?v=ZmLrt_AMmnY&t=36s

Fig 2. Poblaciones de *A. palmata* durante el episodio de blanqueamiento del 2023 en la Reserva Natural La Parguera.

Video por Sea Ventures sobre blanqueamiento masivo de Acropora palmata en Cayo Aurora, Guánica, 2023: https://www.youtube.com/watch?v=hmXyJZI5_r8

Sobrevivencia

A pesar de la devastación en el suroeste, se han observado poblaciones sobrevivientes en otras áreas de la isla. Una pregunta relevante es si las poblaciones sobrevivientes son más resistentes a las altas temperaturas o que tuvieron condiciones menos estresantes en el 2023. Estas áreas con poblaciones sobrevivientes de Acroporidos incluyen las costas del este, norte y algunas zonas del oeste. Datos de la NOAA sugieren que algunas de estas poblaciones estuvieron expuestas a menos semanas de acumulación térmica, sobre todo en la costa norte de la Isla. Esto fue posiblemente debido a la exposición al oleaje y fuertes viento que ayudan a la circulación y oxigenación del agua. También es posible que el paso de huracanes dentro de las 200 millas náuticas del Noreste de la Isla (Huracán Lee y Huracán Tammy) refrescaron las aguas del Norte y Noreste de la Isla, recordándonos que el rol que juegan estos sistemas en la regulación de la temperatura del océano. Estas regiones presentaron una sobrevivencia mayor de Acroporidos. Este comportamiento sugiere que, aunque algunas poblaciones están al borde del colapso, otras podrían tener la oportunidad de adaptarse o resistir mejor las condiciones cambiantes dependiendo de su localidad. Por otro lado, es posible que algunas

Cayo Largo, Fajardo

Foto: Sea Ventures MRU 2024

Gallardo, Cabo Rojo

Foto: DRNA 2024

poblaciones tengan cierto grado de resistencia debido a su genética o las comunidades de algas simbióticas que albergan. Este asunto es una gran incógnita en la comunidad científica debido a la rigurosidad científica necesaria para poder determinar las verdaderas causas detrás de la resistencia de los corales. El monitoreo constante de la temperatura con instrumentos de campo nos dará una mejor idea

sobre los niveles de estrés por temperatura al cual están expuestas estas poblaciones sobrevivientes. Para Puerto Rico cuenta con unas 80 estaciones de monitoreo de temperatura mantenidas por varias organizaciones ya sea mediante uso de datos satelitales como datos de sensores de campo.

Figura. 4. El monitoreo de temperatura con sensores en el campo será crucial para determinar con precisión los niveles de estrés a los cuales están expuestas las poblaciones de Acroporidos sobrevivientes.

La pérdida de corales no solo representa una disminución en la biodiversidad marina, sino que también pone en riesgo los servicios ecosistémicos que proporcionan, como la protección costera, la pesca y el turismo. Los arrecifes de coral son barreras naturales contra las tormentas y la erosión, y su desaparición podría tener consecuencias devastadoras para las comunidades costeras de Puerto Rico. La anomalía térmica de 2023 ha sido un recordatorio de la urgencia de abordar el cambio climático. Si bien algunas poblaciones de corales muestran signos de resiliencia, la tendencia general es alarmante. Los esfuerzos de monitoreo y conservación deben intensificarse para proteger estos ecosistemas críticos y asegurar su supervivencia a largo plazo.

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Coral Reef Specialist

Puerto Rico Marine Temperature Sensors Inventory

Submitted to the DNER Coral Reef Conservation and Management Program (CRCMP)

Summary

This product details the list of temperature sensors compiled for Puerto Rico by September 2024. It includes a description of each sensor data group including location, sensor types, points of contact, and other important metadata for the follow-up of this data. A total of 81 temperature marine stations were identified in this effort. A combination of web data mining, interviews, and fieldwork was implemented to compile the information about each temperature sensor. Raw data from each station was compiled when available and referenced if available on an online repository. The distribution of current temperature sensor stations is across all regions of the Puerto Rican archipelago and spans multiple temporal scales, from long-term to recently deployed (Figure 1). There are two main types of stations: virtual stations and field stations. Virtual stations are those that serve satellite sensor data derived from sea surface temperature (STT) readings, they are strategically distributed with input from local coral reef managers and experts, and provide the longest-term data available. Virtual stations represent a subset of the satellite SST data extracted based on the sub-sampling of pixel units which coincide with locations of coral reef management and conservation importance. There are two sources of virtual stations: NOAA's Coral Reef Watch (CRW) and the CariCOOS virtual buoys created in collaboration with the University of South Florida's Optical Oceanography Laboratory Virtual Buoy System (VBS). The field stations can be found in most regions of the Island, but are not as evenly distributed as the virtual stations. Most field stations are located in specific coral reefs where different entities currently work. Most field stations are located in the southwest region, between Guayanilla and Cabo Rojo, as well as in the

Northeast region between San Juan and Culebra Island. Entities use different field sensors but the most common are Onset HOBO temperature loggers. Data from temperature stations is available on demand, and only NOAA's CRW real-time data is available through a web server platform in a reliable way. The rest of the temperature stations require communication with data providers to get a copy of the raw data. Nevertheless, there are visualization tools or reports that can be obtained more readily to explore the datasets.

A matrix with the Puerto Rico Marine Temperature Stations was prepared for this product and can be downloaded at the following link: https://drive.google.com/file/d/1-BBMeusAXWw-1-zZsvvoiSJpMilV4Cou/view?usp=sharing

Figure 1. Distribution to temperature virtual and field station in the Puerto Rican archipelago. A shapefile with this data can be downloaded at: https://drive.google.com/drive/folders/1GWweBkI29XQiLwFjr5vMbB3aJJmz5yKe?usp=drive_link

Temperature Station List

Virtual Stations

NOAA's Coral Reef Watch

- List of stations:

Station	Region	Location	Depth(ft)	Latitude	Longitude
La Parguera(CRW)	South	La Parguera	0	17.925	-67.075
Guanica(CRW)	South	Guanica	0	17.925	-66.875
Guayanilla(CRW)	South	Guayanilla	0	17.925	-66.725
Salinas(CRW)	South	Salinas	0	17.925	-66.225
Maunabo(CRW)	South	Maunabo	0	17.975	-65.875
Vieques(CRW)	East	Vieques	0	18.075	-65.475
Culebra(CRW)	East	Culebra	0	18.275	-65.275
Fajardo(CRW)	East	Fajardo	0	18.325	-65.575
San Juan(CRW)	North	San Juan	0	18.475	-66.025
Vega Baja(CRW)	North	Vega Baja	0	18.525	-66.425
Arecibo(CRW)	North	Arecibo	0	18.525	-66.675
Isabela(CRW)	North	Isabela	0	18.525	-67.125
Aguadilla(CRW)	West	Aguadilla	0	18.425	-67.175
Rincon(CRW)	West	Rincon	0	18.325	-67.275
Cabo Rojo(CRW)	West	Cabo Rojo	0	18.175	-67.225

Station	Region	Location	Depth(ft)	Latitude	Longitude
Isla de Mona(CRW)	West	Isla de Mona	0	18.075	-67.925

- Sensor: Satellite (multiple): For more information on the satellite data sources visit: https://coralreefwatch.noaa.gov/product/5km/index_5km_sst.php
- Data availability: Real-time 5km resolution data is available via ERDDDAP using the graph page and data page:
    - ERDDAP Graph pag: https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.graph
    - ERDDAP Data page : https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html

CariCOOS-USF VBS

- List of stations:

Station	Region	Location	Depth(ft)	Latitude	Longitude
Rio Fajardo(EPR03)	East	Fajardo	0	18.33161	-65.5966
Rio Grande de Anasco(WPR03)	West	Añasco	0	18.26511	-67.2087
Guanica Bay(WPR06)	South	Guanica	0	17.92138	-66.9029
La Parguera(WPR05)	South	La Parguera	0	17.92069	-67.0366
Tres Palmas(WPR02)	West	Rincon	0	18.35209	-67.2886
Mona Island(WPR01)	West	Isla de Mona	0	18.09118	-67.9657

Station	Region	Location	Depth(ft)	Latitude	Longitude
JBNERR(WPR10)	South	Salinas	0	17.8912	-66.2426
El Seco Vieques(VIE02)	East	Vieques	0	18.12376	-65.1906
Vega Baja(WPR09)	North	Vega Baja	0	18.51275	-66.4096
Boca de Cangrejo SJBE(EPR02)	North	Isla Verde	0	18.47735	-66.0076
Ocean Park(EPR01)	North	Isla Verde	0	18.48439	-66.0513
Vieques(VIE01)	East	Vieques	0	18.26117	-65.464
Boya Ponce(WPR08)	South	Ponce	0	17.86317	-66.5103
Canal Luis Pena Culebra(CUL01)	East	Culebra	0	18.28163	-65.3149
Rio Culebrinas(WPR04)	West	Aguada	0	18.42215	-67.1845
Rio Grande de Arecibo(WPR07)	North	Arecibo	0	18.49007	-66.7111

- Sensor: Satellite (multiple, MODIS / VIIRS): For more information on the satellite data sources visit: https://optics.marine.usf.edu/projects/vbs.html
- Data availability: Data is currently available to be visualized at both the USF Optical Oceanography Laboratory and CariCoos websites.
    - USF Optical Oceanography Laboratory: https://optics.marine.usf.edu/cgi-bin/vb?area=PRICO&station=EPR01
    - CariCOOS: https://www.caricoos.org/virtual-buoys

Field Stations

Arrecifes Pro Ciudad Water Quality Monitoring Program ("De la Playa al Laboratorio") – Isla Verde

- List of stations:

Station	Region	Location	Depth(ft)	Latitude	Longitude
Esquina Sureste RMAIV_P01	North	Isla Verde	3	18.4448	-66.0072
Playa Pine Grove_P02	North	Isla Verde	3	18.4445	-66.0123
Kiosko Informativo_P03	North	Isla Verde	3	18.4459	-66.0151
Esquina Suroeste RMAIV_P04	North	Isla Verde	3	18.4462	-66.0171
Boca de Cangrejos_P05	North	Isla Verde	3	18.458	-65.9931

- Sensor: YSI ProDSS. For more information on Isla Verde's water quality program: https://www.arrecifeislaverde.com/proyectos-calidad-agua
- Data availability
  - Data from the project was requested on March 2023 to Mr. Francisco "Paco" Lopez. A series of raw data files organized by Mr. Paco were compiled into a unified database with all water quality parameters from 2018 to 2022.

- The compiled database can be downloaded here: https://drive.google.com/drive/folders/1J3WXaEfGpoWR8XV5W6ErRaq76UEIwXVx?usp=drive_link

NOAA's National Coral Reef Monitoring Program Subsurface Temperature Recorders (STRs)

- List of stations:

Station	Region	Location	Depth(ft)	Latitude	Longitude
PR_east_25b	East	Fajardo	82	18.3368	-65.5646
PR_east_15b	East	Fajardo	65	18.337	-65.5646
PR_east_1b	East	Fajardo	7	18.3377	-65.5659
PR_east_5b	East	Fajardo	24	18.3374	-65.5653
PR_east_15a	East	Culebra	61	18.3307	-65.3337
PR_east_1a	East	Culebra	8	18.3312	-65.333
PR_east_25a	East	Culebra	99	18.2776	-65.252
PR_east_5a	East	Culebra	26	18.3311	-65.3333
PR_north_5	North	Arecibo	15	18.4797	-66.721
PR_north_1	North	Arecibo	6	18.478	-66.7179
PR_north_15	North	Arecibo	65	18.4823	-66.7212
PR_north_25	North	Arecibo	101	18.4845	-66.7218
PR_south_15b	South	Jobos Bay	65	17.9105	-66.2316
PR_south_1b	South	Jobos Bay	6	17.9122	-66.2308
PR_south_25b	South	Jobos Bay	84	17.9104	-66.2316
PR_south_5b	South	Jobos Bay	23	17.9117	-66.231
PR_south_15a	South	La Parguera	62	17.9536	-67.0507

Station	Region	Location	Depth(ft)	Latitude	Longitude
PR_south_1a	South	La Parguera	5	17.954	-67.0507
PR_south_25a	South	La Parguera	85	17.8852	-67.016
PR_south_5a	South	La Parguera	16	17.9538	-67.0507
PR_west_15	West	Rincon	66	18.3444	-67.2692
PR_west_25	West	Rincon	97	18.3443	-67.2692
PR_west_5	West	Rincon	27	18.3429	-67.2607
PR_west_1	West	Rincon	6	18.3438	-67.2599

- Sensor: SBE56, SeaBird Electronics. For more information on the NCRMP Temperature sensors visit: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:NCRMP-STR-PR
- Data availability: Data is currently available upon request. On March 2023, 2015-2017 data was downloaded from the above link in NOAA NCEI. However, currently the data is no longer available directly from that link. Via email communication with Ian Enochs (ian.enochs@noaa.gov) and Nicole Besemer (nicole.besemer@noaa.gov) more recent data was requested (2019-2021). Data files were received individually through a Google Drive link and compiled to have all NCRMP STR data (2015-2021) in one matrix, with daily multivariate parameters (Average, Max, Min, StdDev, Variance). The NCRMP STR data compilation is not an official NOAA data product but it is based on individual data files either downloaded from the NOAA NCEI link or received directly from NOAA staff. The compilation was prepared for this product and can be downloaded at the following links:
    - Files received from Nicole Besemer on March 2023 – include raw individual files from the sensor (20172021): https://drive.google.com/drive/folders/189UfIZPlOGHMhjIRSKo4bw5nidWl7WZz?usp=drive_link
    - PR NCRMP STR Compilation (2015-2021): https://docs.google.com/spreadsheets/d/1hfOm7w_lLC8sNO7MWUzVMLU1v2qiWUcC/edit?usp=drive_link&ouid=109134763654269750667&rtpof=true&sd=true

Department of Natural and Environmental Resources Coral Reef Program

- List of stations:

Station	Region	Location	Depth(ft)	Latitude	Longitude
Turrumote	South	La Parguera	30	17.9345	-67.018
Gallardo	West	Cabo Rojo	18	18.0016	-67.3299
Tres Palmas 5M	West	Rincon	5	18.35066	-67.2669

- Sensor: HOBO MX2204.
- Data availability
  - Data from the project is available upon request. The sensors were deployed in the summer of 2024 in response to the 2024 expected thermal anomaly. The sensors were in the field by the time of this report. For data points of contact:
    - Miguel Figuerola – DNER Coral Program (former) Coral Reef Specialist
      - mfiguerolahernandez@gmail.com
    - Erik Appeldoorn – DNER Coral Program Coral Reef Specialist
      - eric.appeldoorn1@upr.edu
    - María Vega – DNER Coral Program Manager and POC
      - maria.vega@drna.pr.gov
    - Darimar Dávila – DNER Coral Program Emergencies Coordinator
      - darimardavila@gmail.com

HJR Reefscaping

- List of stations:

Station	Region	Location	Depth(ft)	Latitude	Longitude
Cayo Largo	East	Fajardo	15	18.3151	-65.5795
Tres Palmas	West	Rincon	20	18.3469	-67.2637
El Negro	West	Cabo Rojo	30	18.1452	-67.2537
San Cristobal	South	La Parguera	4	17.9439	-67.0785
El Ron	West	Cabo Rojo	30	18.1052	-67.2848
Palominos Seabass	East	Fajardo	30	18.3549	-65.5708
Muelle Eco Electrica	South	Guayanilla	unkown	17.97375	-66.761
Beril Guayanilla	South	Guayanilla	unkown	17.945	-66.7305
Maria Langa	South	Guayanilla	unkown	17.9649	-66.7519
Cayo Caribe	South	Guayanilla	unkown	17.9653	-66.7354
Cayo Rio	South	Guayanilla	unkown	17.98058	-66.7382

- Sensor: HOBO UA-002-64.
- Data availability
  - Data from the project is available upon request. The sensors have been deployed at various periods, depending on the project. Several sensors were in the field by the time of this report. Data points of contact:
    - Hector Ruiz – HJR Reefscaping Executive Director
      - astreoides@gmail.com

NOAA Restoration Center & Sea Ventures MRU

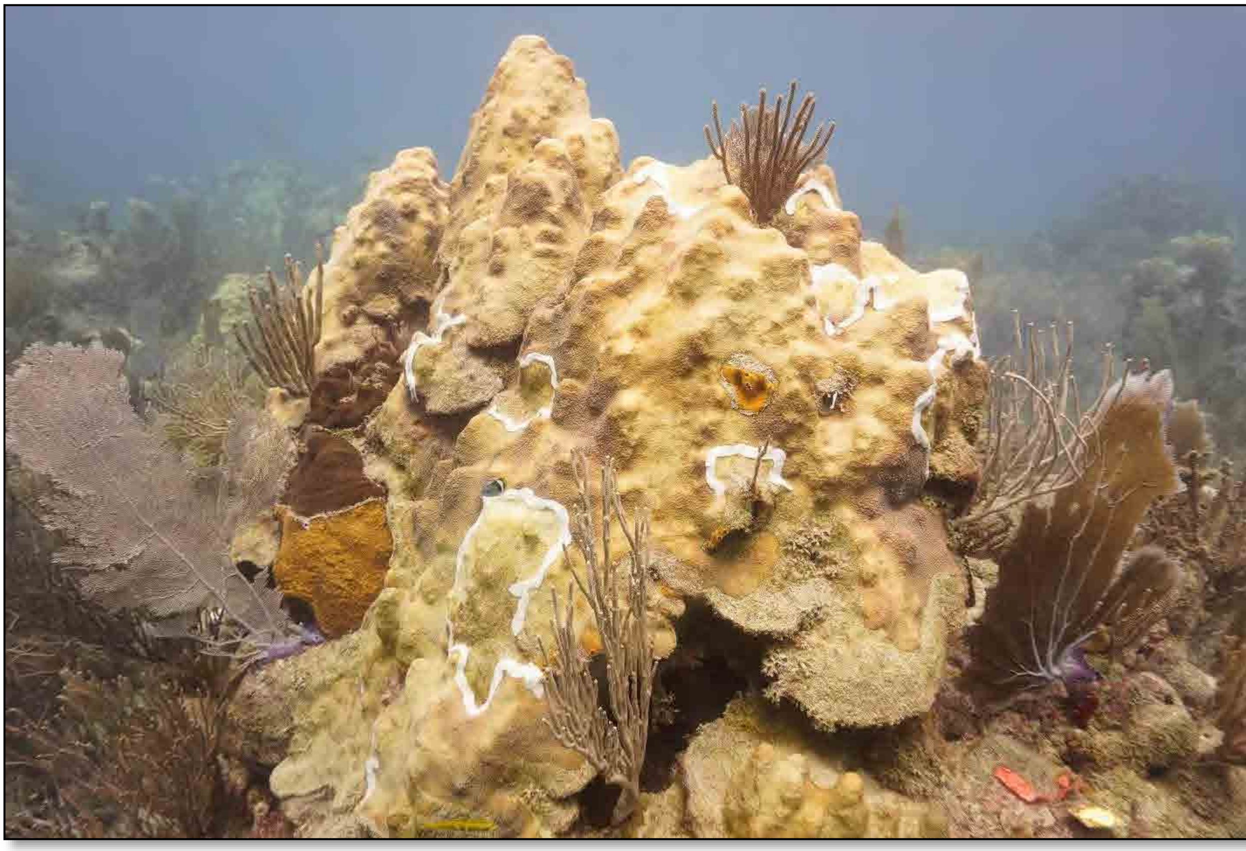
- List of stations:

Station	Region	Location	Depth(ft)	Latitude	Longitude
Cayo Largo	East	Fajardo	15	18.3151	-65.5795
Tres Palmas	West	Rincon	20	18.3469	-67.2637
El Negro	West	Cabo Rojo	30	18.1452	-67.2537
San Cristobal	South	La Parguera	4	17.9439	-67.0785
El Ron	West	Cabo Rojo	30	18.1052	-67.2848
Palominos Seabass	East	Fajardo	30	18.3549	-65.5708
Muelle Eco Electrica	South	Guayanilla	unkown	17.97375	-66.761
Beril Guayanilla	South	Guayanilla	unkown	17.945	-66.7305
Maria Langa	South	Guayanilla	unkown	17.9649	-66.7519
Cayo Caribe	South	Guayanilla	unkown	17.9653	-66.7354
Cayo Rio	South	Guayanilla	unkown	17.98058	-66.7382

- Sensor: HOBO MX2204
- Data availability
    - Data from the project is available upon request. The sensors were deployed in the summer of 2024 at various coral outplanting and nursery sites currently managed by Sea Ventures under a support contract with the NOAA Restoration Center. Sensors were in the field by the time of this report. Data points of contact:
        - Pedro Rodriguez – Sea Ventures Director of Marine Operations
            - pedrocoralrestoration@gmail.com
        - Michael Nemeth – NOAA Restoration Center
            - michael.nemeth@noaa.gov

SCTLD Efforts in Puerto Rico

Final Report: February 2024



By Miguel Gerardo Figuerola Hernandez

Coral Reef Specialist, PR-DNER Coral Program

Period: November 2019 - February 2024

Prepared under Award #: NA21NOS4820014 and submitted to the

NOAA Coral Reef Conservation Program

and the PR-DNER Coral Conservation & Management Program

Contents

Summary

SCTLD response efforts in Puerto Rico have been initiated since 2019 with the input gathered from FL and USVI jurisdictions. Since then, the Coral Reef Conservation and Management Program of the Puerto Rico Department of Natural and Environmental Resources (PR-DNER) had led a response with collaboration of multiple stakeholders. In the beginning of 2024, the PR-DNER continues to hold monthly meetings with local stakeholders to keep track of field observations and implements a local emergency response plan. A map with the distribution of SCTLD outbreaks and treatment sites has been maintained showing a total of 128 sites reported as with SCTLD outbreaks across all regions in Puerto Rico. Reporting timeline suggested a dispersion patterns from east to west and in the southwestern and western shelf an invasion pattern from the shelf edge to the inner shelf over time. Of sites reported with SCTLD, 36 were prioritized for interventions consisting of the application of B2B + Amoxicillin treatments. Several intervention site selection priority criteria were developed with input from local experts and managers as well as partners from NOAA, Florida, and the USVI. Criteria included biological and logistical considerations such as coral community structure and composition, demographics, distance to boat ramps, available groups, and disease status (prevalence, etc.). Seven entities have participated in a total of 173 field trips between November 2019 and February 2024 during which a total of 9,640 colony treatments have been applied. Most treatments (87%) have been applied to five susceptible species. Monitoring of treatment effects on a subset of tagged colonies has shown high levels of survivorship, except on a few highly susceptible species. However, the appearance of new lesions makes reapplication of the treatment necessary to maintain high survivorship over time, likely until the disease prevalence levels go below 5%. Interventions data is being processed in collaboration with PR Sea Grant to develop an Arc GIS online Data Dashboard. Other projects currently on the island include several research efforts regarding the etiology and epidemiology of the disease as well as expanding interventions and training volunteers.

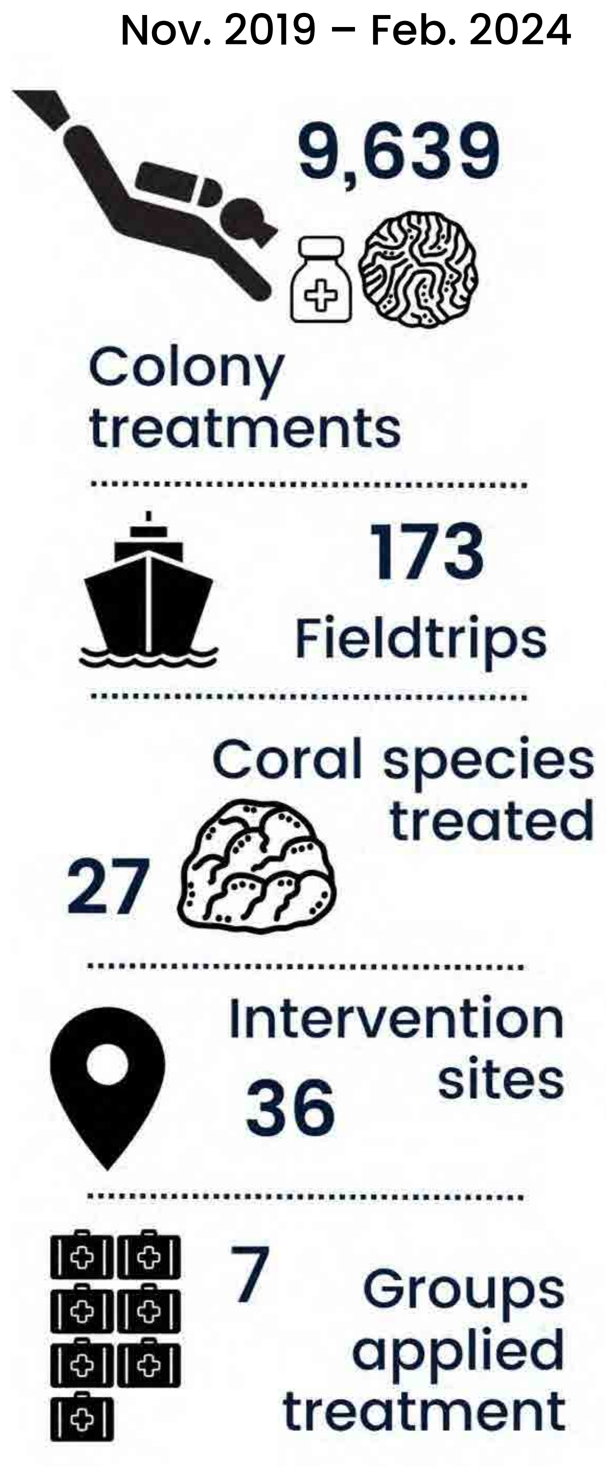


Figure 1. *Field summary metrics of SCTLD response efforts in Puerto Rico since 2019.*

Current Status: SCTLD Distribution and Intervention Mapping

Updating a map with reported sites with SCTLD and interventions has been a priority of monthly SCTLD calls coordinated by the Coral Program of the Puerto Rico Department of Natural and Environmental Resources since the disease was first reported by Sociedad Ambiente Marino in Culebra, east Puerto Rico, back in Fall 2019. During monthly jurisdictional SCTLD meetings, these maps are presented, and participants provide input regarding recent confirmation of SCTLD sightings and new intervention sites. This map is updated monthly, and it is published on the PR-DNER Coral Program website using the Google My Maps application (Figure 2). The map can be found and downloaded at the following link: https://www.drna.pr.gov/coralpr/enfermedades/. Map data files can be requested from the PR-DNER Coral Program Manager at maria.vega@drna.pr.gov.

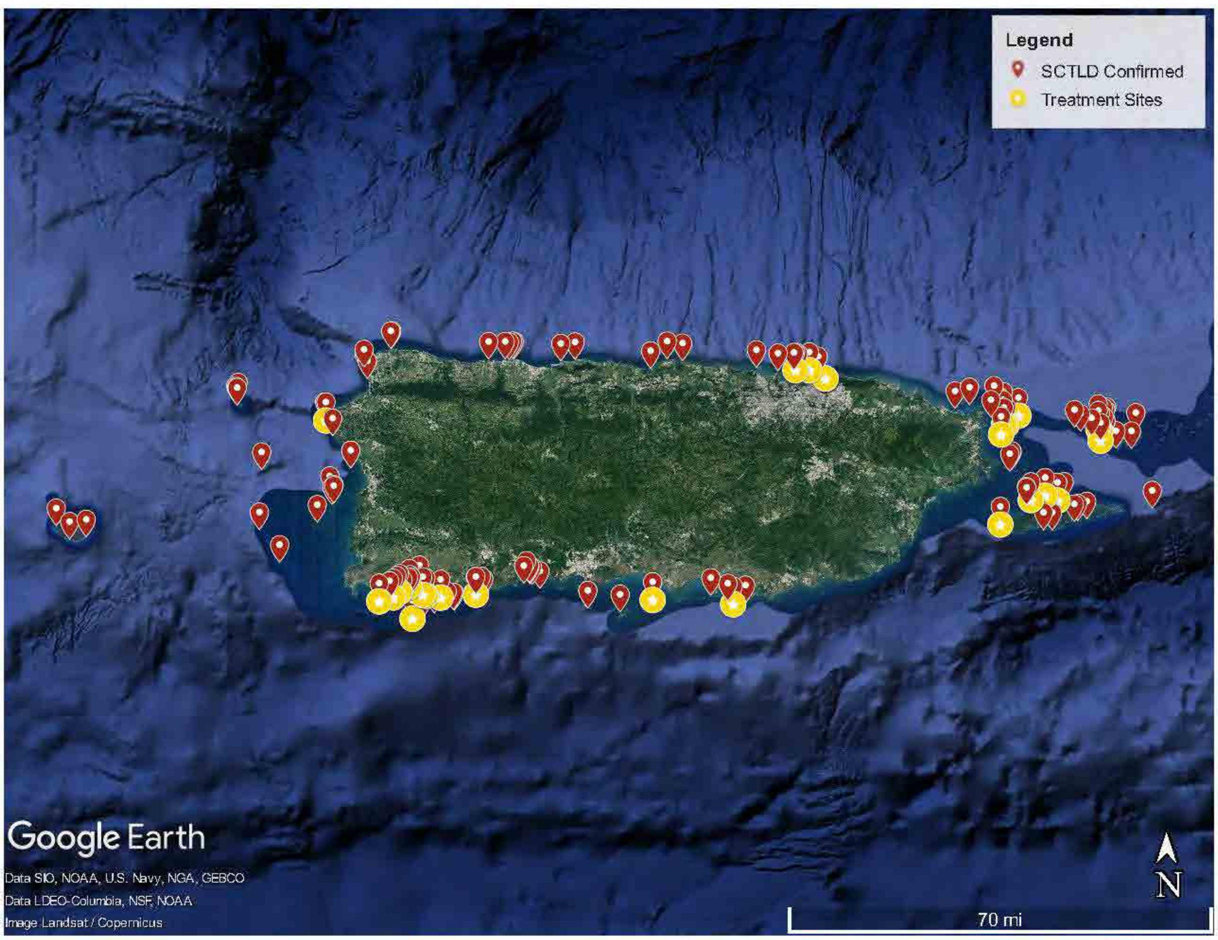


Figure 2. *SCTLD map maintained by the PR-DNER Coral Program for monthly updates of SCTLD distribution, intervention sites, and presence of highly susceptible species.*

Map updates in February 2024 provide the following highlights:

- A total of 128 sites have been reported as with SCTLD outbreaks in Puerto Rico
- SCTLD is well established in all regions (i.e., East, North, South, West) of the archipelago, including the oceanic islands of Vieques, Culebra, Caja de Muertos, Desecheo, and Mona.

- A total of 36 sites have been subject to antibiotic interventions, but not all have been consistently visited, and neither all have tagged colonies to track treatment effectiveness.
- Several data-deficient areas can be identified including:
    - Southeast, from Guayama to Ceiba municipalities
    - Northeast, from Carolina to Luquillo municipalities
    - North, gaps between Isabela and Arecibo,
    - West, nearshore environments in Cabo Rojo
- New sites with SCTLD have not been reported since summer 2023.

The maps don't include data on disease prevalence by species nor time series of the number of corals infected. This type of data is not being collected systematically across reported sites and only a few projects might provide such data for a few sites (see Recent and Ongoing SCTLD Projects section). However, local stakeholders share monthly updates regarding the severity of the disease in visited sites. The status of SCTLD, as of February 2024, appears to be more severe in southwest and western regions where the initial reports are more recent (2021-present). Qualitative reports from partners from Sea Ventures and the UPRM Marine Sciences Department have described that in the first sites affected in La Parguera and Guanica (SW Puerto Rico), the diseases have moved from the epidemic stage to a more endemic stage in about 12-15 months, with mass mortalities of highly susceptible corals and significant mortality in intermediate susceptibility species at intervention sites such as Pinnacles and Turrumote in La Parguera. Most interestingly, a distance from shore patterns in the timing of SCTLD reporting has been observed, with shelf-edge deeper sites (Ex. Black Wall) being reported by November 2021 and sites in the inner shelf (Ex. San Cristobal) first being reported in August 2022. In the eastern region, where Sociedad Ambiente Marino (SAM), the PR-DNER, and Sea Ventures conduct SCTLD efforts, it has been reported that the prevalence of SCTLD has dropped significantly (below 5%), suggesting the disease is now in an endemic stage. SAM's researchers have reported sporadic sightings of localized increases in prevalence in the Canal Luis Peña Reserve in 2023.

Photo Archiving

Following recommendations from the Puerto Rico SCTLD Intervention Plan, groups applying for treatments are encouraged to take photos of each treated colony. These photos are used to corroborate colony conditions, sizes, species, and the number of treatment applications, serving as a permanent record of interventions and a data source in case no datasheets are taken into the field. An archive compiled by the PR-DNER Coral Program and Sea Ventures interventions is available in these Google Drive Folders. These archives include all photos taken per site and dates in the compiled SCTLD interventions database:

- PR-DNER SCTLD interventions Photo Archive: https://drive.google.com/drive/folders/1pnjPwXyhIfr4V58P6iuwaoywPXX21Tx_?usp=share_link
- Sea Ventures Interventions Photo Archive: https://drive.google.com/drive/folders/1mYXESezmvAQ893g7RHf8cl9ow12NDqUL?usp=sharing

Interventions Data

The SCTLD intervention data managed by the PR-DNER focuses on antibiotic interventions. This data is provided by a few partners with resources to apply antibiotic treatments. The data is updated every other month and has been shared and discussed with Puerto Rico Sea Grant staff to be integrated into an ArcGIS Online Data Dashboard. Data on interventions is received by the PR-DNER from various groups since the beginning of SCTLD outbreaks in 2019 (Table 1). Seven organizations involved in applying B2B+amoxicillin treatments have participated in a total of 212 intervention field trips between November 28, 2019, through February 28, 2023. Many of these field trips have been joint efforts where two or more organizations provide different resources (marine transportation, treatment materials, mentorship, etc.) to complete the fieldwork. Data collected during each field trip, if any, is shared with the PR-DNER Coral Program and either the Coral Reef Emergency Response Coordinator or the Coral Reef Specialist has overseen the revision of the data and entered it in a compiled database. This database is currently being managed by the PR-DNER emergency response coordinator. To receive a copy of this database please contact darimardavila@gmail.com and/or maria.vega@drna.pr.gov.

***Table 1**. Organizations that have implemented SCTLD interventions in Puerto Rico.*

Organization / Entity	*Intervention Fieldtrips*
Sea Ventures	87
DRNA	80
HJR Reefscaping	32
Volunteers (on their own)	6
Crystal Clear Vieques	4
SAM	2
Paradise Scuba	1

The following highlights summarize key aspects of the SCTLD interventions in Puerto Rico extracted from the Puerto Rico SCTLD Treatment Database.

- Interventions data have been received for 30 sites across 6 geographic regions (see PR SCTLD Map at: https://www.drna.pr.gov/coralpr/enfermedades/)
- Colonies have been tagged for monitoring treatment effects in a subset of 19 sites, while only 8 sites have 5 or more sampling events.
- A total of 9,640 colony treatments have been applied across 25 identified scleractinian coral species (Figure 3). Of these, 73% represent five species (*Orbicella faveolata, Pseudodiploria strigosa, Montastraea cavernosa, Orbicella franksi, and Colpophyllia natans*).

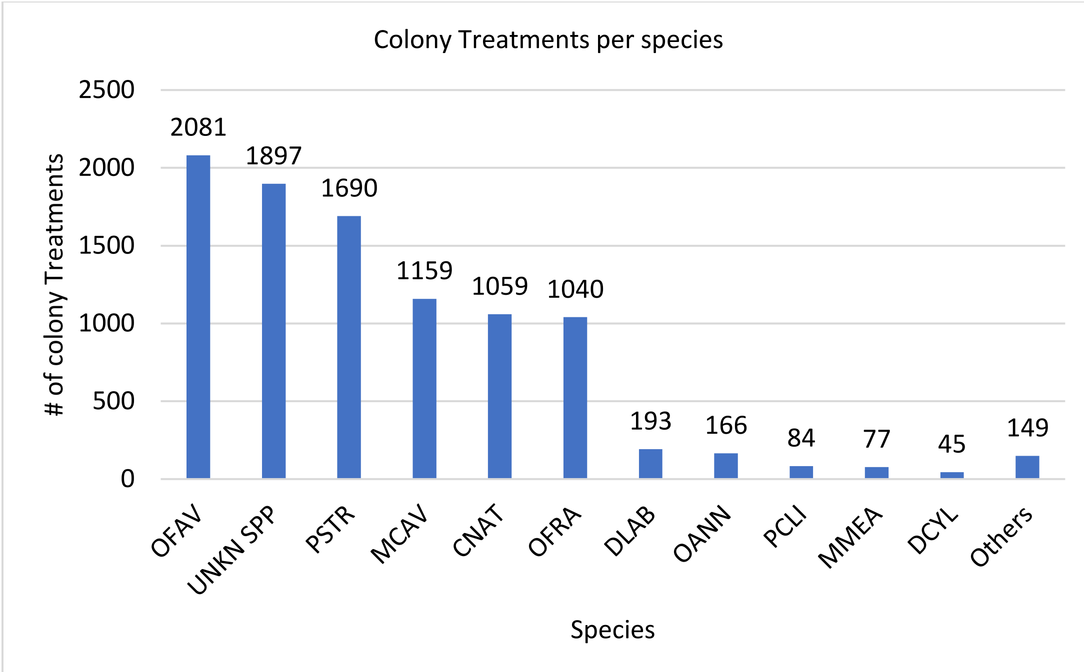


***Figure 3**. Colony Treatment counts per species between 2019 – 2024. These include tagged and non-tagged colonies. Unkn spp. refers to species that could not be identified and the other category refers to all species that had less than 40 colonies treated in the period between 2019 and 2024.*

- Tagged colonies for monitoring reveal a mean survivorship of 70% or higher across all sites during their last visit. However, this varies significantly by species with highly susceptible species such as *Meandrina meandrites* and *Dendrogyra cylindrus* with 90-100% mortality despite multiple treatments. These species only represent a few samples since intervention groups have not been targeting these species for treatment due to their low survivorship and limited intervention resources.
- The number of interventions has changed significantly over time and space according to the severity of the disease and its spread across regions (Figure 4). Currently, until February 2024, almost all intervention data is coming from the South and west regions, specifically from La Parguera Natural Reserve.
- Intervention data is currently being processed by PR Sea Grant to make an ArcGIS online Data Dashboard. Also, a master's thesis project from the UPR-Mayaguez Department of Marine Sciences is focusing on analyzing data from two sites at La Parguera to test differences in treatment effectiveness between *Orbicella faveolata* and *Colpophyllia natans*.

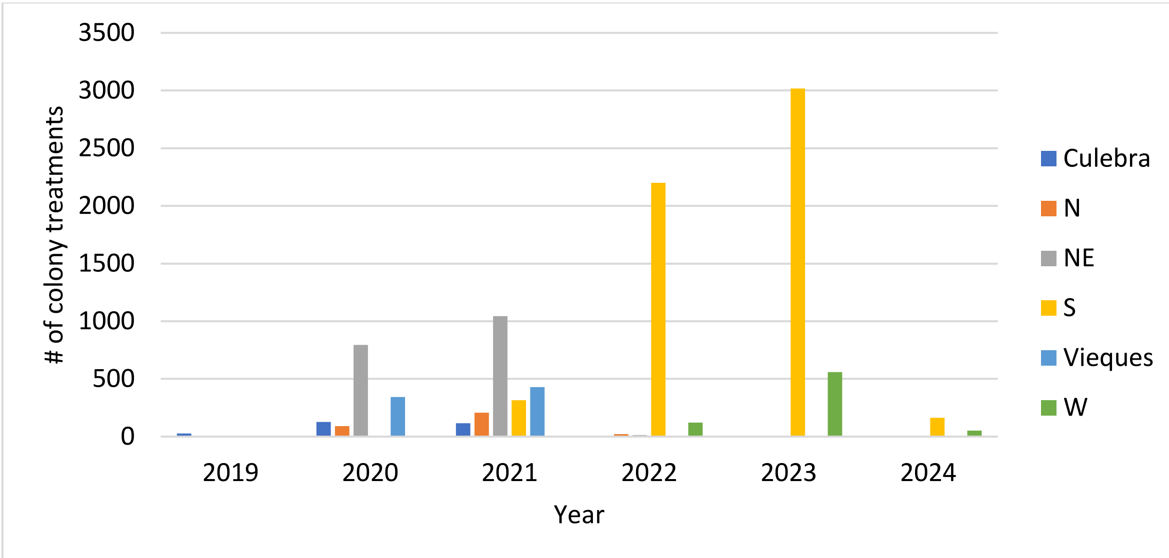


Figure 4. *Number of colony treatments across regions and years.*

SCTLD and the 2023 mass bleaching event

In 2023 Puerto Rico's coral reefs endured the most extensive and intensive thermal anomaly recorded in the NOAA Coral Reef Watch CoralTemp satellite-derived temperature dataset (1985-present). Almost 20-degree heating weeks were registered for the Island. Local intervention teams and researchers (SAM, Sea Ventures, HJR Reefscaping, PR-DNER, and University of Puerto Rico Department of Marine Sciences) reported mass coral bleaching affecting more than 20 species of scleractinian corals throughout the archipelago. By November 2023 mass mortalities were reported in the southwestern and western insular shelves with more dramatic impacts on Acroporid populations. During intervention outings it was reported that SCTLD prevalence collapsed during the onset of the bleaching event. It was reported that the lesions were difficult to detect given the lack of contrast between recently exposed skeleton and bleached tissue. However, upon careful inspection of bleached colonies in La Parguera, where several treatment monitoring sites were located, the absence of tissue-loss lesions was more evident. Intervention efforts such as the NOAA-funded implementation of the Puerto Rico SCTLD Intervention Plan and the ARPA-funded implementation of the Puerto Rico SCTLD Emergency Response Strategic Plan showed very little treatment applied during September - November 2023 due to lack of diseased colonies. By mid-November 2023 temperatures decreased abruptly, decreasing by 2 degrees Celsius. In late December 2023 field teams reported a dramatic increase in tissue-loss prevalence at intervention sites after the colonies started recovering their symbionts. These observations were captured in the intervention data provided to the PR-DNER (Figure 5 and 6).

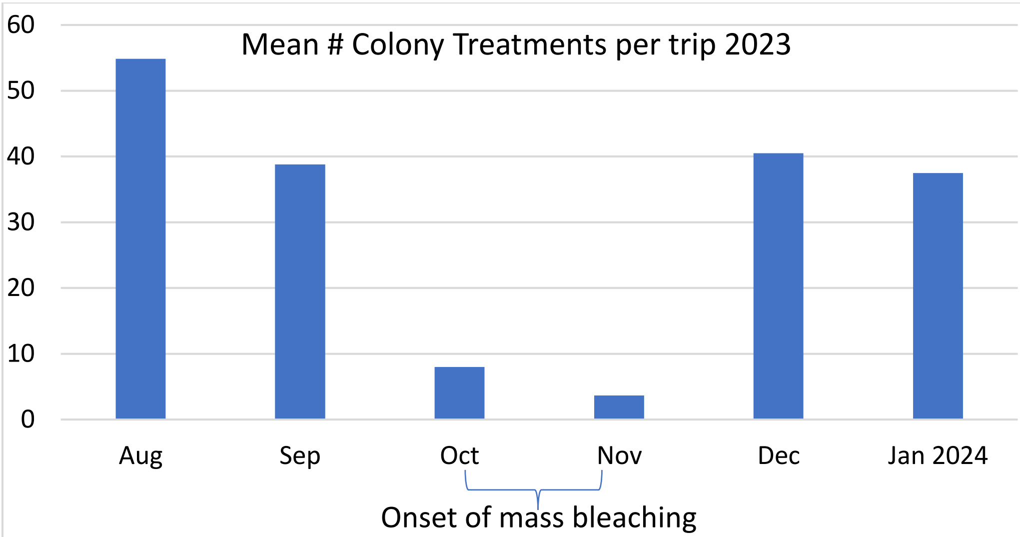


Figure 5. *Mean of number of colony treatments per fieldtrip during 2023 until January 2024*

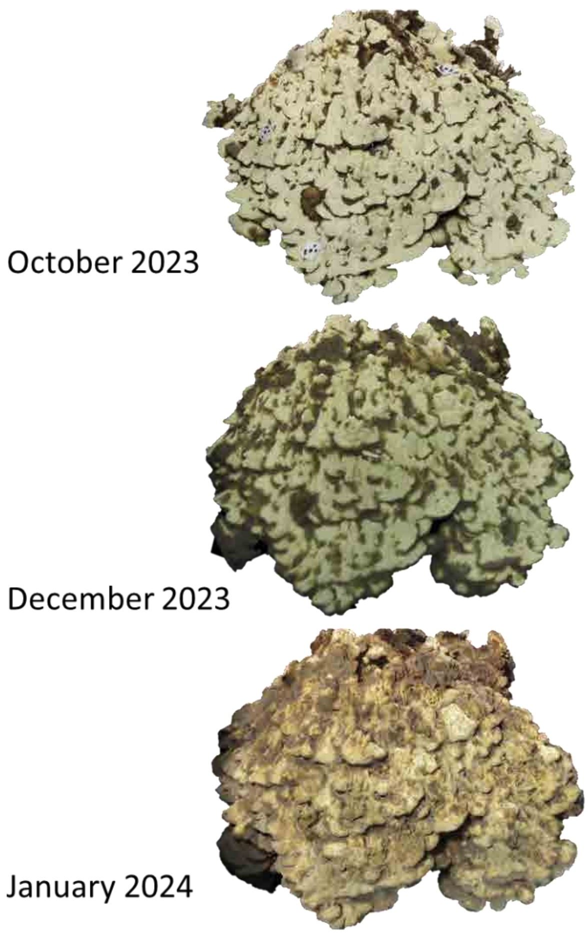


Figure 6*. Large O.faveolata monitored by Sea Ventures to show bleaching recovery at Pinaculos Reef, La Parguera. Once temperatures started to cool off and colonies started recovering their symbionts the divers saw a spike in SCTLD lesions. Photo by Sea Ventures.*

Recent and Ongoing SCTLD Projects

In addition to SCTLD treatment interventions, other local entities are engaging in research and outreach efforts in response to this event. The following is a list of projects and points of contact for projects recently implemented and/or currently ongoing:

1) Project title: Microbiome and population dynamics in Stony Coral Tissue Loss Disease (SCTLD) infected corals
    a. Timeline: 2019-present
    b. Sponsor: NSF
    c. Entity: University of Puerto Rico – Mayaguez, Department of Marine Sciences
    d. POC: Ernesto Weil (Ernesto.weil@upr.edu)
    e. Description: This project aims to describe the microbial community shifts and population dynamics on various SCTLD susceptible species associated with SCTLD to detect potential pathogens and population impacts of this event. Colonies have been tagged and sampled before and after SCTLD infections appear. The area of study is La Parguera in southwest Puerto Rico.
2) Project title: Modeling the demographic impacts of Stony Coral Tissue Loss Disease (SCTLD) in the brain coral *Pseudodiploria strigosa*.
    a. Timeline: 2019-2022
    b. Sponsor: NOAA
    c. Entity: Sociedad Ambiente Marino
    d. POC: Edwin Hernandez (edwin.hernandezdelgado@gmail.com)
    e. Description: This project aims to describe the demographic impact of SCTLD on *Pseudodiploria strigosa* as a model species. Project data has been used to model the population trends of *P. strigosa* based on observed patterns of disease progression and condition transitions. The area of study is Culebra Island and Vega Baja in the northeast and north of Puerto Rico.
3) Project title: Volunteer Training
    a. Timeline: 2021-2022
    b. Sponsor: Medalla Light, NOAA, PR-DNER
    c. Entity: HJR Reefscaping
    d. POC: Hector Ruiz (astreoides@gmail.com)
    e. Description: This effort is a collaboration with support from various sponsors to support the training of volunteers to apply antibiotic treatments to corals. A couple of field outings have been done in southwest Puerto Rico to treat corals. Between September 2022 and February 2023, a total of 53 participants attended in-person training and 105 participants in virtual workshops coordinated between the PR-DNER and HJR Reefscaping.
4) Project title: Stony Coral Tissue Loss Disease Puerto Rico Emergency Response Strategic Plan
    a. Timeline: 2021-present
    b. Sponsor: PR-DNER
    c. Entity: Multiple (Sociedad Ambiente Marino, Miguel Gerardo Figuerola Hernandez, HJR Reefscaping)
    d. POC: maria.vega@drna.pr.gov

e. Description: This Strategic Plan was created in response to the Governor's Executive Order 2021-66 in 2021. The Plan aims to implement several efforts to research, manage, and educate the public about the ongoing SCTLD event. Currently, there are three contracts under effect: (1) to expand monitoring of SCTLD demographic impacts, (2) to continue the evaluation of treatment effectiveness across ecological gradients and species, and (3) to train volunteer groups and expand SCTLD interventions.

5) Project title: Puerto Rico SCTLD Treatment Monitoring and Intervention Plan
   a. Timeline: 2019-Present
   b. Sponsor: NOAA
   c. Entity: Sea Ventures
   d. POC: Pedro Rodríguez (pedrocoralrestoration@gmail.com)
   e. Description: Since the first reports of SCTLD in 2019 the NOAA Restoration Center has supported the response efforts via interventions using amoxicillin treatments in Puerto Rico. This expanded in 2021 with the PR SCTLD Intervention Plan. Several sites have been prioritized to treat corals and monitor a subset of these to track treatment effectiveness. Sea Ventures have been supplying the PR-DNER with B2B+Amoxicillin treatment as well as requested by Dr. Nilda Jimenez.