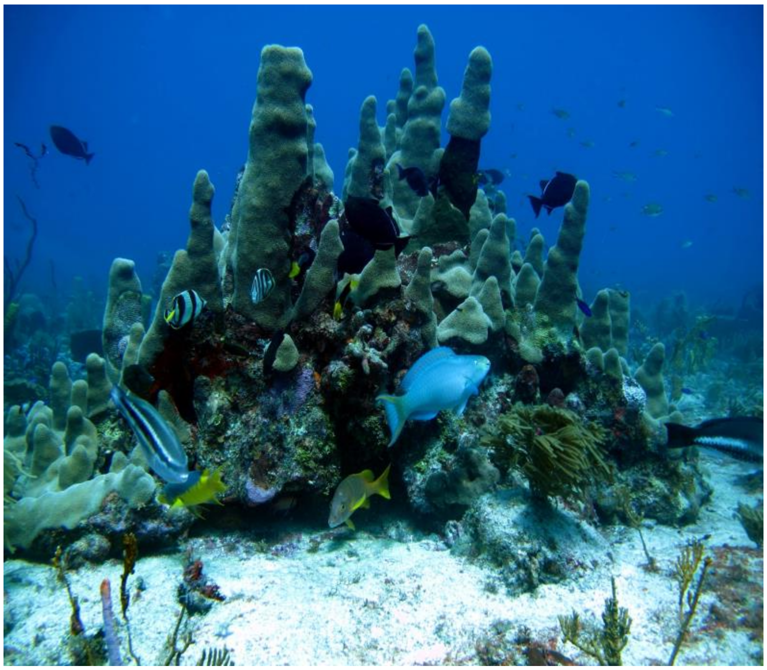

Resilient Assessment for PRCRMP's reef sites

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Cover photo: Miguel Figuerola

EXECUTIVE SUMMARY

This report presents the results of a resilience assessment done for the reef sites of the Puerto Rico Coral Reef Program (PRCRMP). The resilience assessment was done using the tool developed by United nations Environmental program (UNEP), and used by NOAA as a standard resilience assessment instrument (Maynard et al. 2017). The original objective was to compare differences in relative resilience of PRCRMP's reef sites before and after the arrival of hurricane Maria to Puerto Rican coasts. However, the structure of the data also allowed to do historical analyses (1999-2019) on selected PRCRMP's sites. The tool that was used in this assessment is a relative measure of resilience and not an absolute indicator of the health of the reef. In other words, it compares the relative resilience among selected sites or across time for a given reef site. That tool involved the selection of indicators, stressors and variables related to connectivity, which were identified and selected through a collaborative effort with various stakeholders who include 75% of managers of the different MPAs administered by Department of Natural and Environmental Resources (DNER). In addition to PRCRMP data on benthic and fish assemblages, data was extracted from available databases on 8 different stressors and 4 variables related to connectivity.

To do the resilience assessment, this project compiled and curated all existing PRCRMP data that at the date in which this project started was not readily and easily available. As part of that compilation and curation work, the entire dataset has been handed over to DNER who has made it public through NOAA's National Center for Environmental Information (NCEI). As an indirect outcome of this effort, the database constructed in this project was translated following the Darwin-Core Standard by CARICOOS with support from NOAA IOOS and published in the Global Biodiversity Information Facility (GBIF) and the Oceanographic Biodiversity Information System (OBIS). PRCRMP data is also available for web map visualization in the Marine Biodiversity Observation Network (MBON) data portal at: https://mbon.ioos.us/?ls=h5ELVXyv#map.

In terms of resilience assessment, this study showed that most reef sites that were analyzed for historical trends (1999-2019), showed a significant decrease of resilience scores (from high to low). These trends were observed using uni and multivariate approaches. Resilience indicators related to this decrease varied between sites and locations, however, percentage of coral cover and percentage of Peyssonneliaceae consistently showed in all analyses. At the site scale, there was not a clear effect of Hurricane Maria on the resilience scores, as the comparison before and after Maria was highly variable between sites, locations and regions. Overall, patterns of spatial and temporal variation of resilience scores were different across sites, locations and regions. Similarly, and despite some commonalities, indicators associated with those changes also varied across locations and sites. Despite these differences, coral and macroalgae cover such as *Lobophora* and the nuisance encrusting algae Peyssonneliaceae were the main resilience indicators across most sites. When stratified by depth, however, decreases of resilience were evident for shallow and deep strata but not for the very shallow stratum, which was unexpected since effects of hurricane are more likely to affect shallow areas of the reef. Resilience indicators related to benthic fauna and flora were more important than those related to fish assemblages.

This supports the fact that habitat-building invertebrates are key to target in resilience-based management. However, fish species like parrotfishes and damselfishes were important indicators explaining differences in overall resilience for some sites in Guanica, Ponce, and Tourmaline. Stressors related to observed spatial and temporal patterns of resilience scores were Degrees Heating Weeks (DHW) and Productivity; as they both were related to sites classified as low and medium-low resilience sites. The only connectivity variable related to high resilience sites was distance to nursery (i.e., mangroves and seagrasses).

This report contains a recent resilience classification of most PRCRMP sites (Table 10), which can be used by managers to answer questions about a wide array of management actions and or plans. Specific questions, which were identified during the stakeholders' workshops, are detailed, and answered in the conclusion section of this report. As an example, it was important for DNER's managers to identify "ideal" reefs to be used as restoration sites. In that sense, sites identified in this study as having high resilience, can be the target of such restoration efforts. This study also showed that, even though all regions had sites with high or -medium-high resilience, it is also important to consider that lower values of stressors were identified in the west and southwest. Our results also suggest that selection of sites should take into consideration those with low productivity and DHW but close to nursery habitats (mangrove and seagrasses).

1. INTRODUCTION

1.1. Resilience Assessments:

On Earth, 100% of the surface of the ocean is either directly or indirectly affected by some type of human intervention (Mora et al. 2008, Halpern et al. 2008). Detrimental anthropogenic practices like overfishing, pollution, and accelerated climate change are just some of the leading practices responsible for the recorded adverse effects on marine environments (Jackson et al. 2001, Mora et al. 2008, Halpern et al. 2008). The Caribbean appears to be one of the most susceptible regions due to its geographic location (hurricane corridor), habitat diversity, and over a 100 million people that live less than ten miles from the coast (Burke & Maidens 2004, Mora 2006; Roff & Mumby 2012, Lefcheck et al. 2019). The economic exploitation of the coastal areas, including excessive overfishing (Jackson et al. 2001 have resulted in extensive unfavorable impacts manifested in the sharp declines in species richness in different communities observed in this region and their associated loss of functionality and resilience (Vellend et al. 2013, Dornelas et al. 2014, Lefcheck et al. 2019) and resilience (Maynard et al. 2015).

Marine coastal ecosystems of the Caribbean and Puerto Rico are dominated by the interdependence of mangrove, seagrass, and coral reef habitats, from which coastal communities around Puerto Rico rely heavily on services provided by those systems (Pendleton 2002). Consequently, assessing the resilience of these systems is of paramount importance if proper management plans and strategies are to be set in place (Maynard et al. 2010). Understanding the resilience of a coral reef for example, or any ecosystem in general, must take into consideration the biological and ecological dimension of the problem (e.g., diversity, abundances, function, complexity, structure, etc.,) as well as the human dimension (e.g., socio-economic benefits and impacts and management actions) (Norton et al., 1992).

For the purpose of this report, the UN's definition used in their guide to assess resilience of coral reefs was adopted (Maynard et al. 2017): “Coral reef resilience is the capacity of a reef to resist or recover from degradation and maintain provision of ecosystem goods and services” (Mumby et al., 2007). Coral reefs that resist or recover after disturbances like hurricanes, diseases, or bleaching events are considered highly resilient, while coral reefs that exhibit low resilience are generally not able to recuperate as quickly or as effectively after similar disturbances (Maynard et al. 2017). This, in turn, will lead the reefs to lose its intrinsic functionality and the associated ecological and socio-economic services (Gibbs & West 2019). Current management trends are moving to a more ecosystem focused approach (Pikitch et al. 2004, McLeod & Leslie 2009, Anthony et al. 2015) with resilience-based management proposed as one of the methods to implement such an ecosystem-based approach. (Bellwood et al. 2004, Hernández-Delgado et al. 2018, Gibbs & West 2019, Mcleod et al. 2019). However, to implement such management practices, the managers should be able to assess the relative resilience of the different reefs within the area they manage and track changes in resilience through time (Anthony et al. 2015, Mcleod et al. 2019). The identification of resilient and non-resilient areas in a particular space can be achieved through a resilience assessment (Hernández-Delgado et al. 2018, Gibbs & West 2019). With a coral reef resilience assessment, a manager can appropriately target a site to implement management actions, evaluate the effectiveness of processes implemented to increase resilience in a managed area, examine spatial variations of the indicators used, and identify which indicators contribute the most to resilience in that particular area (Maynard et al. 2017, Gibbs & West 2019).

Marine coastal ecosystems in the Puerto Rico region were severely impacted after the passage of the major hurricanes Irma and Maria (https://www.oceannews.com/news/science-technology/scientists-get-early-look-at-hurricane-damage-to-caribbean-coral-reefs). Short-term consequences of hurricanes on local and regional socio-ecological systems were unquestionable, as interviews with local merchants within coastal towns quickly demonstrated. However, our understanding of medium to long term consequences, and very importantly, the resilience of these systems (i.e., ability and time to recover from the impact, Mumby et al. 2007) are not well understood, especially when there are many other anthropogenic and environmental drivers operating at the same time. Consequently**, the main goal of this study was to evaluate the potential effect of the major hurricane Maria on the resilience of coral reefs around Puerto Rico**. Focusing on resilience and based on the available PRCRMP database, we also explored historical trends (1999-2019) of resilience in selected reefs. In addition, we had the opportunity to engage managers (DRNA), NGOs working on co-management of coastal areas, and experts; to contextualize this resilience assessment within the framework of management actions and plans currently conducted in Puerto Rico. In this study, the resilience approach that was being used was the one developed by the United Nations Environment Program (UNEP) group on coral reef resilience, which involves measuring or assessing the attributes ("resilience indicators") that contribute to making a coral reef resilient, and also collecting measures of the stress related to human activities that can reduce reef resilience (Maynard et al., 2017).

1.2. Puerto Rico [Long-Term] Coral Reef Monitoring Program (PRCRMP):

On July 15, 1999, Puerto Rico established the Law for the Protection, Conservation, and Management of Coral Reefs in Puerto Rico (Law 147). As a response to this law, the DNER established the Puerto Rico Coral Reef Conservation and Management Program (DNER Coral Program, hereafter). With support from NOAA, the first initiative of the DNER Coral Program was the PRCRMP (DRNA.pr.gov), which has been operating since 1999 covering 86 coral reef communities around the island that have been sampled at various times and frequencies (although currently a subset of 42 sites are being surveyed every two years, Figure 1). The main goals of this program include: 1) Finding more about the conditions of the species that live in coral reefs that have both ecological and economic importance; 2) Identify spatial and temporal tendencies of the coral reef communities in response to anthropogenic stress; 3) Finding out what are the most effective management methods for the marine protected areas of Puerto Rico (DRNA.pr.gov). This massive effort has resulted in an important amount of data, leading to multiple technical reports and scientific publications (DNER, in prep.). This program has produced yearly reports that have provided detailed descriptions of several coral reefs around Puerto Rico (see the full list of reports at http://drna.pr.gov/programas-y-proyectos/coralpr/) and peer-reviewed publications on temporal trends of these reefs (e.g., Garcia-Sais et al., 2017); however, up to the start of this project, the data of the program was not compiled and publicly available in a single database. Nevertheless, given this program's spatial and temporal extension is an ideal source of information to conduct the resilience assessment mentioned above. In particular, the data collected under PRCRMP allowed to fulfill the **general objective** of the project that was *to conduct a resilience assessment "Before" and "After" September 2017*, which involved the following **specific objectives**:

1.3. Specific objectives:

- Consolidate DNER's PRCRMP data which was provided to the public in the form of technical reports (pdf files) at the beginning of this project.
- Obtain and consolidate databases related to stressors and connectivity for the sites where PRCRMP is being conducted.
- Identify, in collaboration with DNER managers, the management actions and plans that will be targeted for this resilience assessment.
- Describe patterns of temporal and spatial variation of "resilience indicators" and identify historic drivers of those patterns.
- Assess relative resilience of different coral reefs around Puerto Rico
- Inform managers and stakeholders of results and incorporate recommendations.

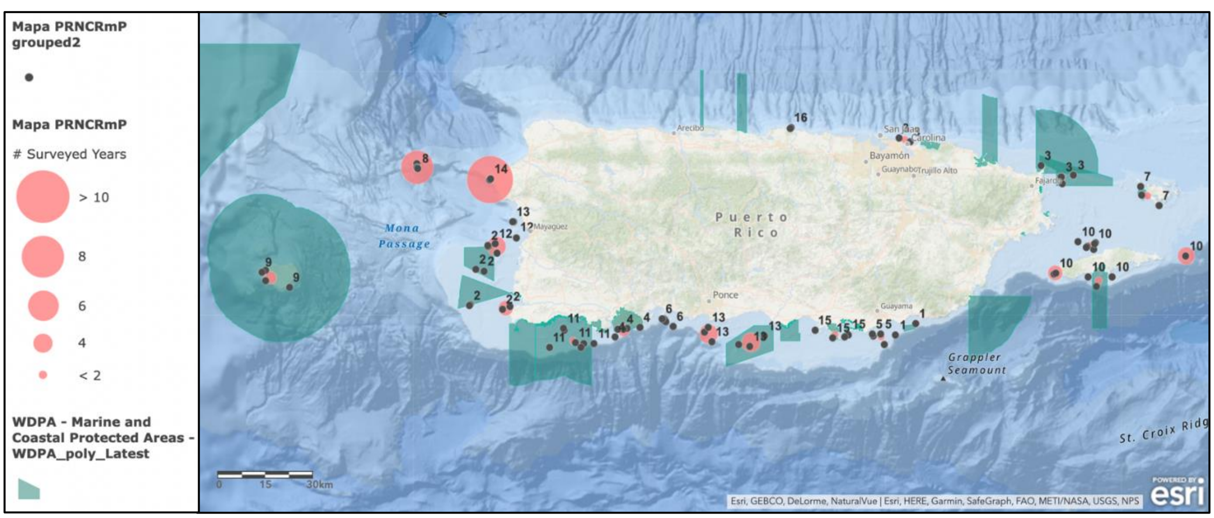

Figure 1. Sites and frequency of sampling of coral reefs around Puerto Rico. Source: Puerto Rico Coral Reef Monitoring Program (DRNA). Number of sites are identified and described in Table 3.

2. METHODS

2.1. Resilience assessment:

An integrative analysis of the PRCRMP data was done using the resiliency assessment framework developed by UNEP's group on coral resilience (Maynard et al., 2017), consisting of ten steps (Table 1). Once the objective of the resilience assessment is well defined, the core of the assessment is based on the identification and estimations of indicators (of resilience) and stressors that might affect that resilience. The resilience assessment guide used in this study is very explicit and comprehensive and was designed to be used by local managers to help them decide on actions and plans related to coral reefs. Furthermore, it is fully endorsed by NOAA and the Coral Reef Conservation Program. Details of these steps can be found in (https://www.coris.noaa.gov/activities/projects/climate/https://www.coris.noaa.gov/activities/projects/climate/), whereas specifics for this study are detailed in subsequent sections.

Table 1. List of steps to perform a resilience assessment. Summarized and adapted from Maynard et al. 2017.

Step	Description	Type of data/action
1	Identify management actions and plans that the assessment will evaluate/influence	Involve managers/stakeholders through public/targeted workshops
2	Select resilience indicators and anthropogenic stressors	Based on results of step 1.
3	Compile data for resilience indicators	Database compilation of what's available in Puerto Rico
4	Analyze data (normalized across variables and standardized across sources of data)	Analysis of data
5	Identify drivers of patterns of spatial and temporal variation (multivariate analyses)	Analysis of data
6	Assess anthropogenic stress	Database compilation and available databases
7	Review climate exposure	Remote sensing and climate models publicly available
8	Review connectivity information	Obtain from scientific literature
9	Formulate management actions	Workshops with managers
10	Inform and share data/results	Involve managers/stakeholders through public/targeted workshops (back to the start where the process can start again)

2.2. Stakeholder engagement (steps 1 and 2):

To receive the input of stakeholders, four workshops were organized (2 in the west and two in the east region of Puerto Rico to reach stakeholders from around the island), and a total of 158 persons were invited (Appendix 1). Out of those invited, thirty-eight (38) people assisted the workshops (Table 2). In addition to those workshops, 5 key stakeholders that could not participate and were identified as key informants were interviewed individually (Table 2). Most of the participants were either Scientists/consultants (42%) or Managers of marine coastal areas around Puerto Rico (39%), with a smaller representation of NGOs and State/Federal employees (Table 2). It is important to note that managers that attended the workshops covered 75% of Marine Protected Areas (MPAs) around Puerto Rico. To achieve the following objectives: i) to identify management actions/objectives that a resilience assessment could inform, ii) to identify and prioritize indicators, iii) to identify and prioritize stressors, iv) to identify new databases; the following questions were asked to all stakeholders during the workshops and interviews:

i. What do you think are the indicators you would use to assess the resilience of coral reefs of Puerto Rico? And how would you estimate those?
ii. What do you think are the main stressors affecting coral reefs in Puerto Rico (in general) and in your specific area of interest/influence?
iii. What would be the questions/issues that you would like to address using the resilience approach presented here?

It is important to note that resilience assessments must be done in relation to a particular stressor or disturbance event (in this case, Hurricane María). However, we left the first question open to allow for maximum flexibility in the answers of the people we engaged. Similarly, we opened the opportunity for stakeholders to come up with additional issues that perhaps could benefit from the current exercise. As a comparative reference, indicators and stressors identified by stakeholders were tabulated in relation to the indicators proposed by the UNEP manual (Maynard et al. 2017) and other resilience studies done in Puerto Rico (Hernández-Delgado et al. 2018, Gibbs & West 2019). In addition to these three main questions, stakeholders were also asked about: iv) databases that they might be aware of and that could be used for this resilience assessment and v) key stakeholders not present in the workshops but that we should contact directly.

Table 2. Names, positions, organizations, date of assistance and emails of the workshop's participants.

Name	Organization	Email	Position	Date
Miguel Figuerola	DNER	mgfiguerola@drna.pr.gov	DNER Employee	26-Apr-19
Fernando Melendez	Department of Marine Sciences UPRM	fernando.melendez1@upr.edu	Scientist	26-Apr-19
Juan Cruz Motta	Department of Marine Sciences UPRM	juan.cruz13@upr.edu	Scientist	26-Apr-19
Catalina Morales	Department of Marine Sciences UPRM	catalina.morales1@upr.edu	Scientist	26-Apr-19
Hector Ruiz Torres	HJR Reefscaping	reefscaping@gmail.com	Consultant	26-Apr-19
Michelle Scharer	HJR Reefscaping	michelle.scharer@upr.edu	Consultant	26-Apr-19
Ernesto Weil	Department of Marine Sciences UPRM	ernesto.weil@upr.edu	Scientist	26-Apr-19
Roy Armstrong	Department of Marine Sciences UPRM	roy.armstrong@upr.edu	Scientist	26-Apr-19
Jorge Garcia	Reef Restauration	goingdeep49@gmail	Consultant	26-Apr-19
Berliz Morales	Sea Grant	berliz.morales@pr.edu	Outreach	26-Apr-19
Clark Sherman	Department of Marine Sciences UPRM	clark.sherman@upr.edu	Scientist	26-Apr-19
Ian Maldonado	FEMA	ian.maldonado1@upr.edu	Federal	26-Apr-19
Suhey Ortiz	Department of Marine Sciences UPRM	suhey.ortiz.pr@gmail.com	Scientist	26-Apr-19
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Nikolaos Schizas	Department of Marine Sciences UPRM	nikolaos.schizas@upr.edu	Scientist	26-Apr-19
Robert Matos	DNER	matosreservas1@gmail.com	Manager	2-May-19
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Aitza Pabon	DNER	apabon@drna.pr.gov	Manager	2-May-19
Alfredo Montanez	Sociedad Ambiente Marino	alfredo.a.montanez@gmail.com	NGO	3-May-19
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Vanessa Marrero	DNER	vimarrero@drna.pr.gov	Scientist	3-May-19
Angel Dieppa	JoBaNERR	adieppa.jbnerr@gmail.com	NGO	3-May-19
Miguel Nieves	DNER	tonyamona@yahoo.com	Manager	16-May-19
Darien Lopez	DNER	dlopezocasio@drna.pr.gov	Manager	16-May-19
Gretchen Cordero	DNER	gretchen.cordero@yahoo.com	Manager	16-May-19
Jenny Vazquez	DNER	gretchen.cordero@yahoo.com	Manager	16-May-19
Harold Diaz	DNER	N/A	Manager	16-May-19
Edwin Avila	DNER	eavila@drna.pr.gov	Manager	16-May-19
Julio Feliciano	DNER	N/A	Manager	16-May-19
Maria Chardon	DNER	mchardon@drna.pr.gov	Manager	16-May-19
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Gaspar Pons	DNER	gpons@drna.pr.gov	Manager	16-May-19
Ernesto Diaz	DNER	ediaz@frna.pr.gov	Director CMCC	Jun-Sep-19
Ruperto Chaparro	SEAGRANT	ruperto.chaparro@upr.edu	Director Sea Grant	Jun-Sep-19
Rene Estevez	SEAGRANT	rene.esteves@upr.edu	Outreach	Jun-Sep-19
Edwin Hernandez	Faculty of Natural Sciences, UPR	edwin.hernandezdelgado@gmail.com	Consultant	Jun-Sep-19
Stacey Williams	Institute for Socio Ecological Research	stcmwilliams@gmail.com	NGO	Jun-Sep-19

2.3. PRCRMP data (step 3):

PRCRMP has surveyed a total of 86 coral reef sites (Table 3) around Puerto Rico over the last 20 years (Figure 1). The reefs range in depths from 3-35 meters, with more than half (62%) of them located inside marine protected areas. Within the available data, 58 reefs have only been visited once, while 26 have been visited annually or bi-annually for specific periods. Currently, the PRCRMP is surveying 45 coral reef sites surrounding Puerto Rico and the outlying islands (Culebra, Vieques, Mona, and Desecheo). To obtain the data, PRCRMP implements a variety of visual census techniques, including five 10m long chain transects for benthic surveys, five 30m2 belt transects for fish and megabenthic invertebrates, followed by 30-minute long ASEC size class survey for commercially important fishes (changed to five 30m2 belt transects after 2015). The transects are permanently placed on each location so that the area surveyed remains consistent during the years. In this study, a site was defined as a particular area where the permanent transects were deployed. Consequently, if a set a 5 transects replicates (for benthic and fish surveys) were established at different depths within the same reef, those depths were considered different sites. As such, an additional factor was created (see below) that was named "Location" that identified a particular reef and contained different sites (if more than one depth was sampled in the same reef).

At the beginning of the project, PRCRMP consisted of isolated (one per year of monitoring) files (either .xls or pdf.). Data were extracted from those single files and compiled in a single data matrix that consisted of variables (rows) and observations (columns). Variables corresponded to the different benthic and fish categories/taxa/species, and observations corresponded to each individual sampling unit in each site at each year (Table 4). Three types of matrices were obtained: Benthic, Fish Abundances, and Fish Biomass. The following factors were considered (and added) for the analysis of data: year on which the census was performed, region (cardinal point), location (municipality), site name, depth (categorized as very shallow, shallow, intermediate, and mesophotic), transect number, and a match index correlating multiple data on different sheets for a specific point. This match index allowed correlating indicators with stressors that were extracted from different databases (see below). Additionally, for every species identified, a taxonomic indicator was assigned to each, which included trophic guild, phylum, class, order, family, genus, and species. Once the data was compiled, data bases were evaluated for consistency in several of their properties before statistical analyses, starting with variable names, format of values, units, typographical errors, missing data, and finally, for anomalous values. All these procedures were done using the statistical software R, and the family of packages included in the metapackage tidyverse (Wickham et al. 2019). Specifically, all the text issues (i. e., format of scientific names, consistency of style of values in categorical variable) were supervised using the stringr package. The format of dates was standardized using the lubridate package. Evaluation of typographical errors in scientific names, as well as anomalous values, were explored with the rfishbase package (Boettiger et al. 2012). Then, all data bases were merged adequately using the tidyr package. Finally, statistical issues (i.e., missing values, summary of data, transformation of data, and exploratory analyses) were done using the dplyr package and the ggplot2 package (Wickham, 2016). Once this compilation and control quality was finished, the data matrix was provided to the Coral Reef Program of DNER (Miguel Figuerola, Tania Metz and Ernesto Diaz) for further review, publication, and dissemination.

From these curated databases, 23 resilience indicators were extracted (Table 5) to estimate the overall resilience scores. The rationale used by stakeholders for selecting those indicators is explained in the results section related to the stakeholders' workshops (Section 3.1) as the final decision was dependent on the stakeholders' perceptions of what indicators were important.

Table 3. PRCRMP sites and general characteristics. Category column indicates sites used for different resilience analysis: Spatial (S), Depth (D), and Temporal (T).

#	Group # on map	**Site Name**	**Location**	**Depth Zone**	***Category**	**# Surveyed Years**	**Latitude**	**Longitude**
1	13	Bertería	Ponce	very shallow (0-8m)		1	17.91985	-66.45317
2	10	Black Jack	Isla Vieques	mesophotic (28-35m)		1	18.05532	-65.46323
3	13	Boya 2	Ponce	intermediate (15-21m)		1	17.93025	-66.63023
4	10	Boya 6	Isla Vieques	shallow (8-14m)		1	18.17852	-65.51913
5	11	Boya Vieja (2000)	La Parguera	intermediate (15-21m)	S, D	1	17.89751	-66.99030
6	11	Boya Vieja (2015)	La Parguera	intermediate (15-21m)	S, D	2	17.88837	-66.99810
7	3	Cabezas de San Juan	Fajardo	very shallow (0-8m)	S, D	1	18.38544	-65.62972
8	4	Caña Gorda	Guanica	shallow (8-14m)		1	17.93967	-66.86088
9	7	Canal Luis Peña	Isla Culebra	very shallow (0-8m)	S, D	2	18.30493	-65.32772
10	11	Canjilones (Parguera)	La Parguera	shallow (8-14m)		1	17.89985	-67.01651
11	10	Canjilones (Vieques)	Isla Vieques	intermediate (15-21m)	S, D	5	18.08967	-65.59022
12	5	Canjilones Las Mareas	Guayama	intermediate (15-21m)		1	17.91805	-66.12708
13	7	Carlos Rosario	Isla Culebra	shallow (8-14m)	S, D	2	18.32779	-65.33200
14	4	Cayo Aurora	Guanica	very shallow (0-8m)	S, D	4	17.93690	-66.87380
15	15	Cayo Caribes (2013)	Salinas	shallow (8-14m)	S, D	1	17.92292	-66.20331
16	15	Cayo Caribes (2016)	Salinas	shallow (8-14m)	S, D	2	17.91533	-66.21410
17	4	Cayo Coral (1999)	Guanica	very shallow (0-8m)	T, S, D	8	17.93622	-66.88838
18	4	Cayo Coral (2013)	Guanica	very shallow (0-8m)	T, S, D	3	17.93620	-66.88840
19	3	Cayo Diablo (1999)	Fajardo	shallow (8-14m)	S, D	1	18.36003	-65.53237
20	3	Cayo Diablo (2016)	Fajardo	very shallow (0-8m)	S, D	2	18.36033	-65.53089
21	15	Cayo Ratones	Salinas	very shallow (0-8m)	S, D	2	17.93458	-66.30247
22	12	Cayo Rodriguez	Mayagüez	very shallow (0-8m)	S, D	2	18.18930	-67.19190
23	15	Cayos de Barca	Salinas	shallow (8-14m)		1	17.91383	-66.24776
24	16	Cibuco (2011)	Vega Baja	very shallow (0-8m)	S, D	1	18.48917	-66.37360
25	16	Cibuco (2013)	Vega Baja	shallow (8-14m)	S, D	3	18.48910	-66.37420
26	10	Comandante	Isla Vieques	very shallow (0-8m)		1	18.15775	-65.47045
27	7	Dakiti	Isla Culebra	intermediate (15-21m)	S, D	2	18.27587	-65.27730
28	13	Derrumbadero	Ponce	intermediate (15-21m)	T, S, D	11	17.90400	-66.60860
29	8	Desecheo North Reef	Isla Desecheo	shallow (8-14m)		1	18.39027	-67.48715
30	3	Dominos	Carolina	very shallow (0-8m)	S, D	1	18.46222	-66.05170
31	11	Efras Wall	La Parguera	intermediate (15-21m)		2	17.89760	-66.95990
32	2	El Negro 10m	Cabo Rojo	very shallow (0-8m)	S, D	2	18.14653	-67.24803
33	2	El Negro 5m	Cabo Rojo	very shallow (0-8m)	S, D	2	18.14658	-67.24758
34	2	El Palo	Cabo Rojo	very shallow (0-8m)		3	18.00057	-67.21117
35	10	El Seco	Isla Vieques	mesophotic (28-35m)	S, D	4	18.13869	-65.19714
36	10	Esperanza	Isla Vieques	shallow (8-14m)	S, D	4	18.08053	-65.48795
37	2	Gallardo (2000)	Cabo Rojo	shallow (8-14m)	S, D	1	18.00498	-67.32975
38	2	Gallardo (2013)	Cabo Rojo	very shallow (0-8m)	S, D	1	18.00140	-67.32990
39	2	Gallardo (2015)	Cabo Rojo	very shallow (0-8m)	S, D	2	18.00138	-67.32993
40	12	Guanajibo	Mayagüez	intermediate (15-21m)	S, D	2	18.17202	-67.25297
41	4	Guanica Wall	Guanica	intermediate (15-21m)		1	17.91750	-66.89700
42	5	Guayama Outer Shelf	Guayama	intermediate (15-21m)		1	17.89445	-66.09446
43	5	Guayama Patch Reef	Guayama	very shallow (0-8m)		1	17.92379	-66.10539

Table 3 (continuation).

#	Group # on map	Site Name	Location	Depth Zone	*Category	# Surveyed Years	Latitude	Longitude
44	1	Guayama Reef	Arroyo	shallow (8-14m)		1	17.92255	-66.06125
45	11	La Margarita	La Parguera	shallow (8-14m)		1	17.88884	-67.09250
46	9	Las Carmelitas	Isla Mona	shallow (8-14m)		4	18.09872	-67.93833
47	2	Las Coronas (Cabo Rojo)	Cabo Rojo	shallow (8-14m)		1	18.09727	-67.28708
48	10	Las Coronas (Vieques)	Isla Vieques	shallow (8-14m)		2	18.16493	-65.49090
49	5	Las Mareas Ridge	Guayama	intermediate (15-21m)		1	17.92319	-66.13206
50	12	Manchas Exteriores 10m	Mayagüez	shallow (8-14m)	S, D	2	18.23353	-67.20057
51	13	Manchas Exteriores 20m	Mayagüez	intermediate (15-21m)	S, D	2	18.23350	-67.20092
52	6	Maria Langa 10m (2001)	Guayanilla	shallow (8-14m)	S, D	1	17.96703	-66.75103
53	6	Maria Langa 10m (2016)	Guayanilla	shallow (8-14m)	S, D	2	17.96093	-66.75292
54	6	Maria Langa 20m (2001)	Guayanilla	intermediate (15-21m)	S, D	1	17.96234	-66.74920
55	6	Maria Langa 20m (2016)	Guayanilla	intermediate (15-21m)	S, D	2	17.95953	-66.74698
56	6	Maria Langa 5m	Guayanilla	very shallow (0-8m)	S, D	2	17.96488	-66.75647
57	2	Media Luna (Cabo Rojo)	Cabo Rojo	shallow (8-14m)		1	18.10132	-67.31218
58	11	Media Luna 10m (Parguera)	La Parguera	shallow (8-14m)	S, D	2	17.93470	-67.04800
59	11	Media Luna 5m (Parguera)	La Parguera	very shallow (0-8m)	S, D	2	17.93940	-67.05090
60	10	Monte Pirata	Isla Vieques	intermediate (15-21m)		2	18.09187	-65.58352
61	10	Mosquito	Isla Vieques	shallow (8-14m)		2	18.16213	-65.49477
62	9	Mujeres	Isla Mona	intermediate (15-21m)		4	18.07170	-67.93692
63	10	North Caballo Blanco	Isla Vieques	very shallow (0-8m)		1	18.17605	-65.46715
64	9	Pajaros	Isla Mona	shallow (8-14m)		1	18.05280	-67.86658
65	3	Palominitos (1999)	Fajardo	shallow (8-14m)	S, D	1	18.33570	-65.56573
66	3	Palominitos (2016)	Fajardo	shallow (8-14m)	S, D	2	18.33537	-65.56555
67	3	Palominos (1999)	Fajardo	shallow (8-14m)	S	1	18.35555	-65.57112
68	3	Palominos (2016)	Fajardo	intermediate (15-21m)	S	2	18.35466	-65.56711
69	8	Puerto Botes 15m	Isla Desecheo	intermediate (15-21m)	T, S, D	11	18.38200	-67.48833
70	8	Puerto Botes 20m	Isla Desecheo	intermediate (15-21m)	T, S, D	12	18.38158	-67.48860
71	8	Puerto Canoas 20m	Isla Desecheo	intermediate (15-21m)	T, S, D	1	18.37832	-67.48377
72	8	Puerto Canoas 30m	Isla Desecheo	mesophotic (28-35m)	T, S, D	11	18.37747	-67.48400
73	10	Puerto Ferro	Isla Vieques	shallow (8-14m)		1	18.08075	-65.41762
74	1	Punta Guilarte Shoal	Arroyo	shallow (8-14m)		1	17.95365	-66.00186
75	4	Punta Ventana	Guanica	intermediate (15-21m)		1	17.94140	-66.82300
76	3	Reserva Isla Verde	Carolina	very shallow (0-8m)		1	18.45063	-66.01835
77	2	Resuellos	Cabo Rojo	intermediate (15-21m)	S, D	4	17.99117	-67.23312
78	9	Sardinera	Isla Mona	mesophotic (28-35m)		3	18.09474	-67.94926
79	6	Tallaboa Reef	Guayanilla	shallow (8-14m)		1	17.94598	-66.72467
80	13	Tasmania	Ponce	shallow (8-14m)		1	17.94273	-66.61912
81	2	Tourmaline 10m	Cabo Rojo	shallow (8-14m)	T, S, D	12	18.16323	-67.27363
82	2	Tourmaline 20m	Cabo Rojo	intermediate (15-21m)	T, S, D	11	18.16517	-67.27520
83	2	Tourmaline 30m	Cabo Rojo	mesophotic (28-35m)	T, S, D	11	18.16642	-67.27635
84	14	Tres Palmas 10m	Rincon	shallow (8-14m)	T, S, D	11	18.34720	-67.27010
85	14	Tres Palmas 20m	Rincon	intermediate (15-21m)	T, S, D	11	18.34650	-67.27080
86	14	Tres Palmas 5m	Rincon	very shallow (0-8m)	T, S, D	11	18.35060	-67.26690
87	10	West Caballo Blanco	Isla Vieques	very shallow (0-8m)		2	18.17162	-65.46877
88	13	West Reef	Ponce	very shallow (0-8m)	T, S, D	11	17.89502	-66.52838
89	13	Windward Reef	Ponce	shallow (8-14m)		1	17.88902	-66.49683

Table 4. Example of data matrix (Fish and Invertebrates Abundances).

SAMPLE CODE	1999Berbería1	1999Berbería2	999Berbería	999Berbería	999Berbería	9Caña Gor	9Caña Gor	9Caña Gor	9Caña Gor	9Caña Gor	99Cayo Cor	99Cayo Cor	99Cayo Cor	99Cayo Cor	99Cayo Cor
Abudefduf saxatilis	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Abudefduf taurus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acanthemblemaria aspera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acanthemblemaria chaplini	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acanthemblemaria maria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acanthemblemaria spinosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acanthostracion polygonius	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acanthostracion quadricornis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acanthurus chirurgus	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	2.00	0.00
Acanthurus coeruleus	0.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Acanthurus tractus (bahianus)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	0.00	3.00	1.00	0.00	2.00	1.00
….															
….															
….															
….															
Synodus saurus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thalassoma bifasciatum	5.00	8.00	7.00	6.00	8.00	0.00	9.00	11.00	7.00	5.00	0.00	6.00	0.00	0.00	5.00
Tripneustes ventricosus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unidentified spp.(fish)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urobatis jamaicensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xanthichthys ringens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
YEAR	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**	**1999**
REGION	**South**	**South**	**South**	**South**	**South**	**Southwest**	**Southwest**	**Southwest**	**Southwest**	**Southwest**	**Southwest**	**Southwest**	**Southwest**	**Southwest**	**Southwest**
LOCATION	**Ponce**	**Ponce**	**Ponce**	**Ponce**	**Ponce**	**Guanica**	**Guanica**	**Guanica**	**Guanica**	**Guanica**	**Guanica**	**Guanica**	**Guanica**	**Guanica**	**Guanica**
SITE NAME	**Berbería**	**Berbería**	**Berbería**	**Berbería**	**Berbería**	**Caña Gorda**	**Caña Gorda**	**Caña Gorda**	**Caña Gorda**	**Caña Gorda**	**Cayo Coral**	**Cayo Coral**	**Cayo Coral**	**Cayo Coral**	**Cayo Coral**
DEPTH ZONE	**Shallow**	**Shallow**	**Shallow**	**Shallow**	**Shallow**	**Shallow**	**Shallow**	**Shallow**	**Shallow**	**Shallow**	**Very Shallow**	**Very Shallow**	**Very Shallow**	**Very Shallow**	**Very Shallow**
TRANSECT	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Fish-Benthic Match	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**	**Si**

Table 5. Final list of indicators, method of estimation and description.

Indicators	Estimators (variable)	Category
Resistant Coral Species	Proportion resistant species cover/total coral cover	Benthic
Temperature	Variation of temperature during the warm season	Environmental
Total Biomass of predators	Total biomass predator/sampling unit	Fish
Herbivore biomass	Total biomass herbivore/sampling unit	Fish + Invertebrates
Coral disease	Prevalence (proportion disease/total).	Benthic
Habitat/structural complexity	Ratio of reef surface contour distance to linear distance	Environmental
Total coral cover	% live cover corals	Benthic
Degrees Heating Weeks	As estimated by NOAA	Environmental
Relative abundance of parrotfishes	proportion number parrot fishes/total	Fish
Abundance of *Diadema antillarum*	Number of individuals per sampling unit	Invertebrates
Coral Reef Builders	Proportion of coral reef builders/total coral	Benthic
Cover of Cliona tenuis	% cover of the species	Benthic
Cover of Ramicrusta and Peysonnelia spp.	% cover of the species	Algae
Cover of CCA	% cover of the species	Algae
Cover of Lobophora	% cover of the species	Algae

2.4. Other databases to assess stressors and connectivity (steps 6 and 8):

Using available information on the web and based on ongoing efforts of the Laboratory of Experimental Ecology (LEE) of the Department of Marine Sciences (DMS) of the University of Puerto Rico at Mayaguez (UPRM), the listed stressors below were estimated for all PRCRMP's sites. This work was subcontracted to Dr. Iliana Cholett under ongoing collaboration between Dr. Cholett and LEE. Most of the stressors listed below were estimated once (i.e., one value per site), with the exemption on DHW, Turbidity and Production, for which historical data existed (1999-2019).

- *Population*: Estimates of human population density (number of persons per square kilometer) based on counts consistent with national censuses and population registers. A proportional allocation gridding algorithm, utilizing approximately 13.5 million national and sub-national administrative units, was used to assign population counts to 30 arc-second grid cells. From this dataset the amount of people inside a 50 km radius circle around the site was extracted. Estimations were done for all available censuses and from those the trend in population increase was used as it has been shown that is the best predictor for population effect (Chollett et al. 2017).

- *Water pollution*: It is a proxy for sediment, nutrient, and pollutant delivery to coastal ecosystems given limited data. Relative erosion rates were estimated across the landscape based on slope, land cover type, precipitation, and soil type. Sediment delivery at the river mouth was estimated based on total erosion in the watershed, adjusted for the sediment delivery ratio and sediment trapping by dams and mangroves. Sediment plume dispersion was modeled using a linear decay rate from the river mouth and was calibrated against actual sediment plumes observed from satellite data. Data was then split into categories (low=10, medium=100, high=1000). Sites without data (that fell inside Puerto Rico's land mask) were assigned the highest impact (1000). Analysis and data extraction of were conducted in QGIS 3.10.

- *Distance to major river*: An image showing main rivers in Puerto Rico was supplied by Dr. Miguel Canal (DMS). Then river mouths were identified and digitized in Google Earth. Calculation of distances, while avoiding land, were calculated over raster of 100 m resolution and an approach considering 8 neighbors and based on minimizing cost distances. Coastline was extracted from the GSHHS dataset v 2.3.7 (Wessel and Smith 1996). Analyses were implemented in R using the packages raster, rgdal, gdistance and maptools.

- *Distance to ports*: Same procedure as above but distances were estimated in relation to ports, especially those related to fishing activities. Data on ports location was directly provided by Daniel Matos from the Fisheries Laboratory of DNER. This variable was used as a proxy for fishing pressure.

- *Inorganic Pollution:* Modeled as runoff into the sea using information on watersheds, land-use categories and data for land-based drivers (nutrient input, non-point source pollution and direct impact of humans) (Halpern et al. 2008). "Sites without data (that fell inside land mask) were replaced with values from the closest pixel. Analysis and data extraction were conducted in QGIS 3.10."

- *Degree's heating Weeks (DHW):* data produced by NOAA's Coral Reef Watch (CRW) program and is part of their suite to monitor coral bleaching heat stress in near real-time (https://coralreefwatch.noaa.gov/satellite/). Estimations were based on the CoralTemp version 1.0 dataset available in ERDDAP, produced from a blend of several inputs. The DHW value is an accumulated averaged thermal anomaly over a rolling period of 12 weeks (Strong et al. 1997) reflecting the number of days the temperature was 1 ^{o}C above the temporal average. For this data monthly and yearly averages were used per site and associated standard deviations. Analyses were conducted in R with the aid of the packages dplyr, geosphere, raster, and rgeos.

- *Turbidity (K490)*: Diffuse Attenuation Coefficient at 490 nm (Kd490) wavelength data from NASA's Aqua satellite. Measurements were gathered by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor carried aboard the spacecraft Aqua. Kd490 indicates the turbidity of the water column - how visible light in the blue to green region of the spectrum penetrates within the water column. Data available in ERDDAP (https://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMH1kd4901day.html. For this data monthly and yearly averages were used per site and associated standard deviations. It is important to note, however, that Kd490 estimates in reef areas are not very accurate, as reef areas present several challenges for ocean color instruments (Hendley et al. 2016; Zheng and DiGiacomo 2017), Consequently, values from pixels over adjacent deeper waters were used for those reefs located in shallow waters. Analyses were conducted in R with the aid of the packages dplyr, geosphere, raster, rgeos and rgdal.

- *Productivity (net primary production):* was calculated using the Vertically Generalized Production Model (VGPM). The VGPM is a "chlorophyll-based" model that estimates net primary production from chlorophyll using a temperature-dependent description of chlorophyll-specific photosynthetic efficiency. For the VGPM, net primary production is a function of chlorophyll, available light, and the photosynthetic efficiency using as input satellite MODIS data (http://sites.science.oregonstate.edu/ocean.productivity/index.php). For this data monthly and yearly averages were used per site and associated standard deviations. Analyses were conducted in R with the aid of the packages R. utils, plyr, geosphere and raster.

In addition to the stressors listed above, the following estimators related to connectivity were also calculated for all PRCRMP's sites:

- *Reef area:* it was estimated using NCCOS habitat maps for Puerto Rico (*https://products.coastalscience.noaa.gov/collections/benthic/e95usvi_pr/).* Mapped areas encompassed the insular shelf between the shoreline and shelf edge, except where turbidity prevented visualization of the bottom. For each site, the amount of reef habitat was calculated (habitat= "Coral Reef and Colonized Hardbottom" in source file) in km^2 within 6 km of the site. 6 km was selected because this value encompasses most home ranges for reef associated species (Green et al. 2015, 2018). Analyses and data extraction were conducted in QGIS 3.10.

- *Habitat heterogeneity:* same data set as above was used. For each site, the number of different "habitat type" within 6 km radius of the site was calculated. Analyses and data extraction were conducted in QGIS 3.10."

- *Nursery habitat:* same data set as above was used. For each site, the amount of nursery habitat (habitat = submerged vegetation, and type = Mangrove) in km^2 within 6 km of the site. Analyses and data extraction were conducted in QGIS 3.10."

- *Connectivity:* Data for this estimator was directly provided by Dr. Lysel Garavelli which consisted of connectivity matrices for spiny lobster (Chollet et al. 2017) and yellowtail snapper (Chollett 2017) along coral reef habitat identified by the UNEP. For each connectivity site, the strength of the site as a sink was calculated which is the proportion of larvae arriving at a site, including larvae from within the site or retention. Each site was characterized by the closest connectivity value. Analyses were conducted in R and QGIS 3.10.

2.5. Data analyses (steps 4 and 5):

Resilience analyses aim to compare sites (or times) in relative terms (e.g., which site is the most resilient or the least). As detailed in Maynard et al. 2017, the calculation of relative resilience scores (or stressors) involves the following steps:

• All scores for resilience indicators (or stressors) were normalized to a scale of 0-1 per site. Since all indicators were in different units and ranges (e.g., total coral cover is estimated as a percentage, but the density of parrotfish is estimated as counts/transect), they had to be normalized to a common scale (0-1). This was achieved by dividing all values of a specific variable (e.g., total coral cover) by the maximum value registered for that particular variable.

• All scales were made uni-directional, where a high score means high resilience (or stress). For example, a high value of *Ramicrusta spp.* was considered a negative indicator of resilience. In cases like this, the normalized value of cover (step 1) was subtracted from 1, so a high value of the indicator (100 - % cover *Ramicrusta spp.*) was related to high resilience.

- All indicators (or stressors) for a given site were averaged to produce a raw resilience score (or stress score).

- Average resilience (or stress) scores were normalized to a scale of 0-1 as in step 1.

- Sites were ranked from highest to lowest score.

- Sites were categorized into four relative categories: 'Low', "Medium Low", "Medium High" and 'High'. This was achieved by estimating the standard deviation and using +1 stdv. to differentiate "High" from "Medium High" values and -1 stdv. To differentiate "Low" vs "Medium Low" values.
- In this study, no weighting was applied to the different indicators (or stressors) as recommended by Maynard et al. (2017).

Based on the description above, it is of paramount importance to define the maximum value by which a particular indicator (or stressor) will be divided. For example, if times are to be compared for a specific site, the maximum value must be selected from that specific time series associated with that site. If, on the other hand, different sites are to be compared for a specific year, the maximum value for an indicator must be selected from the group of sites surveyed during the same year. Consequently, it is important to define the specific questions that the resilience analysis will answer (see section 3.1 on stakeholder's workshops) because it will affect what are the sites or times that need to be compared. In this sense, and based on the objectives of the study (i.e., comparison before and after Maria) and perceptions of stakeholders, the following comparisons were made in this study:

- Historical comparisons (1999-2019) for 11 selected sites where more than 10 surveys were available. In this case, relative resilience scores were estimated using the maximum value for the time series of the specific site that was analyzed through time. A subset of 3 stressors (KD490, DHW, and Productivity) were plotted per location to evaluate historical temporal trends. Sites within the same location with close proximity which represented different depths gave the same stressor values and thus, were plotted as one series in time series plots.

- Temporal comparisons (Before and After September 2017) for sites/locations (see definition of site and location in section 2.3) that were surveyed between 2015 and 2019. The sampling survey design was (and still is) highly unbalanced and asymmetrical, which hinders options available to test multifactorial, non-pseudo replicated, and unconfounded hypotheses. Consequently, for the specific purpose of comparisons before and after hurricane Maria, only sites that were consistently sampled between 2015 and 2019 (32 sites) were selected as all indicators could be used for these analyses. Two sites that were sampled only once: Dominos and Cabezas de San Juan, were included in the overall analyses as managers and local NGOs showed (during stakeholder's workshops) particular interest on those two sites. It is important that some 10 sites currently monitored, were not included in the final analyses because had no consistent data. Analyses had to be differentiated between these two periods because biannual sampling is segregated by regions. Odd years (15, 17, and 19), only locations in the south, south-west, and west were sampled, whereas during even years (16 and 18), most locations in the north, north-east, and islands were sampled (Tabl3 3). PRCRMP (between 2015 and 2019) works on a two-year cycle. The first year of a monitoring cycle, 18 of the sites used in this temporal comparison were sampled (mainly in the south, southwest, and west), whereas, in the second year, 16 sites were sampled (mainly in the east, north, and the rest of the west). Consequently, and from a sampling design point of view, sampling times should be considered as t1 = 2015-2016, t2 = 2017-2018, and t3 =2019-2020. Unfortunately, that structure could not be incorporated in this study to formally test for the effect of Hurricane Maria (Before vs. After Maria) because: a) Hurricane Maria occurred between sampling 2017-2018, splitting in two what was supposed to be t2; b) 2020 sampling was partially done (only 3 sites) due to unprecedent sanitary measures (i.e., lockdown) related to the COVID-19 pandemic. Consequently, the approach used in this study was to: i) temporally compare those sites that were sampled in even years independently of those sampled in odd years (Table 3), and ii) compare all before times (averaged) vs. all the time after (averaged).

- Depth comparisons: Since different sites are located at different depths, and that's a factor that could influence enormously the estimations of the relative resilience scores, spatial comparisons described above were also done considering a stratification of three categories based on depth: "very shallow" (< 10 m), "shallow" (10-19 m) and "deep" (>20 m).

Based on all comparisons and considerations described above, not all available PRCRMP data were used for the different comparisons. It is important to note that indicators were estimated at the transect level; consequently, there were five estimations of relative resilience score per site, whereas estimations of stressors were done at the site level, so these were not replicated at the site level. Permutational Multivariate Analyses of Variance (PERMANOVA) were used to test for various hypotheses associated with the comparison described above whenever formal hypothesis testing was possible. The models for these analyses depended on the comparison being made (see above). All analyses were done using 9999 permutations of residuals under a reduced model. These analyses were done for univariate (i.e., resilience or stressors scores) and multivariate data (i.e., indicators). Euclidean distances were used as the resemblance matrices in all cases because all data was previously normalized and were in the same scale (0-1). The routine "RELATE" was used to estimate multivariate correlations of temporal patterns across sites. For multivariate data, patterns of spatial (or temporal) distribution were illustrated by means of unconstrained multivariate ordinations (i.e., metric Multidimensional Scaling = mMDS). In addition, for the specific purpose of identifying drivers of the resilience scores, Canonical Analysis of Principal Coordinates (CAP), a constrained ordination, was used on the indicators' matrix using the category of resilience (Low, Medium Low, Medium High, and High) as discriminant factors. In all ordinations (constrained and unconstrained), original variables were correlated with the first two axes of the ordination, and those highly correlated (> 0.7) were graphed as vectors in the ordinations. All ordinations were done on the centroids per site and year. All multivariate analyses were done with the program PRIMER-E (Clarke and Gorley, 2015).

3. RESULTS and DISCUSSION

3.1. Stakeholder's workshops:

- *Indicators*: A total of 54 potential indicators were identified by various stakeholders (Table 6), which included most of those initially proposed by the UNEP resilience manual (Maynard et al. 2017), and those used in previous resilience assessments in Puerto Rico (Gibbs & West 2019). This long list reflects the heterogeneity associated with the perceptions of various stakeholders on the island. It also reflects the different needs and realities that each manager faces in the particular reefs they are trying to manage and preserve. Despite this long list, some indicators (3) originally proposed by Maynard et al., 2017; were not considered by any of the participants of the workshops and interviews (Table 6). These indicators were: Mature colonies, Coral Size-class distribution, and substrate suitability. The reasons for excluding these three indicators were: i) data is limited (e.g., coral size distribution), ii) loose definition of indicator (e.g., Substrate availability), or iii) not relevant for resilience assessments (e.g., Mature colonies).

The most frequently mentioned indicators (> 20 times) were: resistant coral species, temperature, the total biomass of predators, recruitment, and herbivore biomass. All those indicators, except the total biomass of predators, are considered in the list proposed by Maynard et al., 2017. A second group (12) of moderately mentioned indicators (> 13, < 20, times) consisted of coral disease (prevalence), habitat/structural complexity, total coral cover, degrees heating weeks, proportion of loose vs. consolidated substrate, fish recruits, relative abundance of parrotfishes, relative abundance of *Stegastes planifrons* (damselfish), biomass of commercially important species, coral disease (Incidence), abundance of *Diadema antillarum*, and coliform presence (Table 6). Very interestingly, in these two groups, the following indicators originally considered by Maynard et al., 2017 were mentioned only few times (< 5 times): Macroalgal cover, light penetration and coral diversity (Table 6). The reasons for this outcome were: i) too broad categories (i.e., Macroalgae), ii) there was no data for Puerto Rico to assess it (i.e., light penetration) and iii) summary index that loses a lot of ecological information (i.e., Shannon diversity index). It is also important to note that there was a group of indicators related to the human dimension of coral reefs in Puerto Rico, that even though they were mentioned few times (< 5 times), they were important for managers and DNER personnel such as enforcement levels, number of personnel associated to a particular area or MPA, community organizations involved in a particular area, population density, governance, recreational activities, among others (Table 6). These indicators, however, could also be considered as stressors (e.g., population density). However, there was no general agreement among stakeholders on how to classify these variables/factors. Consequently, some of these aspects will be reviewed in the following section (i.e., stressors).

Based on this outcome and available data, a total of 15 indicators were finally selected for the resiliency analysis (Table 5). This is a greater number of indicators than those originally selected in Maynard et al., 2017 because the categories: percentage cover of macroalgae and herbivore biomass were further split into sub-groups. Stakeholders, and especially managers, considered that this detailed information could be more informative in terms of future management decisions. From this final list, there was a group of indicators that, even though were commonly mentioned (> 13 times) by stakeholders, were excluded because there was no data available to assess them (Appendix 2).

Table 6. List of indicators mentioned by participants to workshops and interviews. Number of participants supporting a given indicator is also provided. Highlighted (green) indicators are those originally proposed by Maynard et al., 2017.

Indicators	Estimators (variable)	Support
Resistant Coral Species	Proportion resistant species cover/total coral cover	26
Temperature	Variation of temperature during the warm season	26
Total Biomass of predators	Total biomass predator/sampling unit	26
Recruitment	ind/m2 of corals less than 2 years old (4 cm)	24
Herbivore biomass	Total biomass herbivore/sampling unit (Note: could be total or per group)	23
Coral disease	Prevalence (proportion disease/total). Note: could be total (adding up all corals) or per group	16
Habitat/structural complexity	Ratio of reef surface contour distance to linear distance	16
Total coral cover	% cover corals	16
Degrees Heating Weeks	As estimated by NOAA	16
Proportion of loose vs consolidated substrate	Proportion of these two substrates	16
Fish recruits	proportion juveniles/total individuals	16
Relative abundance of parrotfishes	proportion nuimber parrot fishes/total	16
Relative abundance of S. planifrons	proportion number planifrons/ total	16
Commercially important species	Proportion of commercially Important species (# ind)/ total # ind	16
Coral disease (Incidence)	New cases of disease/time/area	16
Abundance of *Diadema antillarum*	UNUmber individuals/sampling unit	15
Bacterial presence	Concentrations of harmfull bacteria (e.g. E. coli)	15
Abundance vulnerable	Proportion of vulnerable coral colonies(ind)/total colonies	13
Builders	Proportion of coral reef builders/total coral (measured as cover or numl	13
Cover *Cliona tenuis*	% cover of the species	13
Cover *Ramicrusta*	% cover of the species	13
Cover CCA	% cover of the species	13
Cover *Lobophora*	% cover of the species	13
Cover *Chrysocystis*	% cover of the species	13
Heavy metals	Concentration of heavy metals (ppm)	10
Groundings	# reported groundings/ year	10
Oil and chemical spills	volumen of accidental discharges/year	10
Number of concesionaries	Absolute number per reef	10
Genetic Diversity of corals	Any index of genetic diversity	8
Turbidity	Concentration per ml (estimated in situ). No good re,mote sensing proc	7
Distance to natural juvenile nursery	Distance to mangroves or seagrass	7
Size Class structure of fish assemblages	Frecuency distribution of individuals acroos size classess per species.	6
Enforcement	# patrols/week	6
Macroalgal cover	% cover macroalgae	5
Cover indicator species (algae) eutrophication	% cover group	5
Density bioeroders	# bioeroders/area	5
Number of fines/arrests/complaints	#/year	5
Number of personnel	# personnel per MPA. If outside MPA then = 0	5
Community organizations	# communities associated with the area	5
Population density	# persons living within xx radius of the reef	5
Public Policy execution	??	5
Proportion of calcifying substrate	%cover of calcifying organisms/total cover sampling unit	4
Light penetration	Light/area	3
Coral diversity	Shannon or Simpson.	3
Chlorophyll a	Concentration per ml (estoimated with remote sensing)	2
Distance to shore	meters	1
Water quality	Not specified	1
Current direction	Prevailing direction (ocenpgraphic data)	1
Soundscape diversity	Diversity information extracted from hydrophones	1
Coral Mortality	Proportion of dead colonies/total	1
Invasive species	Proportion individuals invasors/total individuals (fish)	1
Number of turtles	Absolute number of turtles counted per site	1
Trophic complexity	Connectance (number of trophic links/total possible links)	1
Gas price	Us dolar gallo gasoline	1
Number of boats	#/year	1
Number of buoys	#/year	1
Distance to AAA emisaries	kilometers	1
Herbivore diversity	Shannon or Simpson.	1
Mature colonies	Proportion of old colonies (>10 years)/total	0
Coral size-class distribution	Corals size classes	0
Substrate suitability	Ratio of suitable substrate/total available substrate	0

- ***Stressors:*** A total of 17 stressors were identified by the stakeholders, which included 3 of the original stressors recommended by Maynard et al., 2017 (Table 7). The stressor "Physical human impacts" was not selected by the stakeholders because they considered it a broad category that included several different physical impacts that were included in the list of 17 stressors (e.g., groundings, boat usage, recreational activities, etc.). It is important to note that some of the stressors were also mentioned as indicators (e.g., enforcement or lack of it), which was the result of different stakeholders' perceptions on what were the direct vs. indirect causes of impacts in Puerto Rico's reefs. Another relevant piece of information was the fact that managers found that an important source of stress to coral reefs in Puerto Rico include aspects related to governance which were not considered in any previous resilience assessment of Puerto Rico (Hernández-Delgado et al. 2018, Gibbs & West 2019). It was the overwhelming view of all managers that any other management action, plan, or decision will not have any effect if those actions/decisions were not applied or enforced.

Out of the 17 stressors, eight were commonly mentioned (>10 times) by all stakeholders, including the three most important of those originally reported by Maynard et al., (2017): nutrients (pollution), fishing pressure, and sedimentation (Table 7). Other stressors included in this list of eight were: thermal anomalies, lack of enforcement, coastal development, boat groundings, and recreational activities. Based on this outcome and availability of data, a final list of 7 stressors were selected (Table 8), which included 3 anthropogenic, 3 environmental, and 1 related to governance. Out of those selected, data was not available for 2: recreational activities and lack of enforcement.

Table 7. List of stressors and their categories, mentioned by participants to workshops and interviews. Number of participants supporting a given stressor is also provided. Highlighted indicators are those originally proposed by Maynard et al., 2017.

Stressor	Estimator	Support	Type
Nutrients (pollution)	Concetration of nutrients	37	Environmental
Fishing Pressure	Frequency and intensity of extraction of reef associated fishes	24	Anthropogenic
Sedimentation	Concenration of heavy and fine sediments in the water column	21	Environmental
Thermal anomalies	Number of days surpassing 2 SD of year average	19	Environmental
Lack of enforcement	Presence/Absence of patroling and interventions	17	Governance
Coastal development	Distance to populated areas	16	Anthropogenic
Groundings	Number of groundings per unit of area	15	Anthropogenic
Recreational activities	Number of visitors/unit area	12	Anthropogenic
Invasive species	Abundance/Biomass of invasidve species per area	10	Biological
Acidification	Water pH	9	Environmental
Boat usage	Number of boats per unit area	9	Anthropogenic
Sargassum blooms	Percentage cover per/time unit/area unit	8	Biological
Marine litter	Weight/area	6	Anthropogenic
Coral Trampling	Number of visitors/unit area	4	Anthropogenic
Dredging	Distance to dredging projects and frequency of ocurrence	4	Anthropogenic
Hurricanes	Number and intensity of hurricanes per unit area	1	Environmental
Swells	Average montly or yearly wave height	1	Environmental
Physical Human Impacts		0	Anthropogenic

Table 8. Final list of stressors selected for the resilience analysis grouped by categories.

Stressor	Estimator or Proxy	Type
Nutrients (pollution)	Productivity (proxy)	Environmental
Fishing Pressure	Frequency and intensity of extraction of reef associated fishes	Anthropogenic
Sedimentation	Distannce to rivers and water discharges (proxy)	Environmental
Thermal anomalies	Number of days surpassing 2 SD of year average	Environmental
Lack of enforcement	Number of patroling and interventions and/or number of enforcement personnel	Governance
Coastal development	Distance to populated areas and population density	Anthropogenic
Recreational activities	Number of visitors/unit area	Anthropogenic

- ***New databases:*** From the workshops and interviews, no new databases were identified to conduct a resilience analysis at the scale of the entire archipelago of Puerto Rico. Consequently, the assessment was conducted using PRCRMP data. Nevertheless, several stakeholders identified datasets for particular areas of Puerto Rico (e.g., La Parguera Natural Reserve, Caja de Muertos, and Corredor Ecológico del Noreste), which could be used in future for more focused resilience assessments.

- ***Management questions:*** apart from the original purpose of this assessment which is to compare resilience indicators before and after Hurricane María, stakeholders pointed out that the following questions would also be interesting to be addressed:

- Identify ideal reefs (those with higher resilience) to be used as restoration sites. For this, small-scale assessment should be conducted around the island as ideal places for restoration might vary at the scales of 10's of kilometers (Gibbs and West, 2019).
- Evaluate the effectiveness of MPAs in maintaining or increasing resilience indicators. This evaluation could be done by comparing temporal trends of resilience indicators inside and outside MPAs.
- Identify places where new MPAs should be located. This could be achieved by identifying places of high resilience which are not currently located inside MPAs.
- Resolve the priority disparities that exist among different government and federal organizations in terms of their management and conservation efforts. This resilience assessment could be used as a quantitative tool to homogenize the priorities among different organizations.
- Identify the percentage of high resilient reefs that are currently located within an MPA. This is the inverse of point 3 above and could be done along the same process.
- Use patterns of spatial variation of resilience status within MPAs to develop a list of possible uses for particular localities, reefs or habitats – a user-zonation classification. This cannot be done within this exercise as it would require smaller scale assessments within different MPAs.

- ***Other outcomes – Conservation challenges identified:*** workshops and interviews provided a forum for all stakeholders to ventilate many other issues/problems related to their perception of the health of coral reefs around Puerto Rico. Independently on whether they relate to a resilience assessment, we considered it necessary to mention them here as they might provide a broader framework against which we can discuss the results of our resilience assessment. To organize these various aspects, we categorized those issues as follows:
    - General issues:
        - Overwhelmingly, all managers and DNER personnel emphasized that the overarching problem affecting coral reefs in Puerto Rico is the implementation and enforcement of environmental policies. They all believe that without enforcement, all other aspects of management and conservation are rendered useless.

- The population needs and expectations are not aligned with conservation efforts. Most stakeholders' opinions stated that people need (e.g., recreational use of natural reserves) are in clear conflict with most conservation objectives.

- **Management issues**:
  - Lack of resources, human and material. They claim that it is evident that every year resources dedicated to management and conservation of coral reefs decline, at least those funds given to DNER.
  - There are many stakeholders that are not currently engaged in conservation efforts of coral reefs around Puerto Rico that could effectively contribute.
  - Current management practices are reactive, and they should be moved towards a more adaptive and proactive approach.
  - Ideally, there should be special places designated as coral reef recovery zones, where access should be restricted. A small-scale resilience assessment within a specific MPA could help to indemnify such places.
  - Some areas of high interest (e.g., MPAs like Tres Palmas) have been created by community initiatives with limited ecological/scientific evidence to justify their spatial designation over other areas. However, areas of interest that may host diverse and productive habitats lack the necessary data for effective management and data driven MPA designations.
  - Most MPAs do not have management and/or zoning plans, which renders them more difficult to enforce.

- **Outreach**:
  - There is the need to expand education/outreach initiatives to help the public understand the underlying issues that affect our ecosystems, especially with key stakeholders like fishers. This will help align people needs and expectations with conservation goals.
  - Lack of outreach/education funding.
  - Lack of concrete results to show to the community. Results from previous management action that could have affected the local community.

- **Operational**:
  - Different governmental organizations (and other stakeholders) need to start working together as two antithetic processes are occurring: overlap of efforts and jurisdictions, but at the same time in other places, there is a total absence of authority. A typical example of this is related to agencies such as the Puerto Rico electrical agency (AEE) issuing permits/connections on protected areas such as "Camino del Indio" mangrove forest.
  - Lack of government-community collaboration and trust.

- **Research and monitoring**:
  - Lack of monitoring programs and studies in areas of interest. This perception, however, was also accompanied by the perception that current monitoring programs are not designed to address the particular needs of managers.
  - There is common agreement that stressors vary around the island and consequently it is very important to identify which stressors are important depending on the specific site to be managed.
  - Water quality and water discharges needs to be incorporated in the monitoring programs routinely being conducted.
  - Vulnerability studies on local communities are lacking. What are the impacts on local economies after mayor climatic disturbances?
  - Environmental variables must be incorporated into the monitoring programs.
  - Collection of basic statistics related to recreational fisheries must be resumed.
  - Prevalence and incidence of coral's disease must be incorporated into the PRCRMP.
  - Data is not accessible, and sometimes, there is duplicity of data. Consequently, studies are rarely directly used for management. Please note that it was not until recently that PRCRMP data was made available. It was thanks to this project (NA18NOS4820105) that the PRCRMP data was compiled, organized, and curated so that DNER could make it available.

- **Governance**
  - There is too much bureaucracy with no positive results.
  - Managers do not have jurisdiction over “vigilantes” (i.e., DNER Rangers corps), and there is little consistency on collaborations between them. Several agencies involved that are not coordinated, don’t have cooperation plans which results in a waste of the little resources available.

- ***Conclusions stakeholder’s engagement*:**
  - A total of 15 indicators and 7 stressors were selected to conduct resilience assessments with data available before and after the occurrence of Maria (September 2017).
  - It was extremely important for managers and DNER personnel to include aspects related to enforcement in this resilience assessment.
  - The high number of indicators and stressors was the consequence of splitting categories originally proposed by Maynard et al., (2017). In this sense, the indicator “macroalgae cover” was split into four categories (Peysonnelids, Crustose Calcareous Algae, *Lobophora*, and other macroalgae) and the stressor “human physical impacts” was split into three categories (recreational activities, coral trampling, and groundings). These three categories, however, were not estimated due to lack of data.
  - Several conservation issues were identified during workshops and interviews. These represent challenges to integrate the results of this resilience assessment into an effective resilience-based management approach. Without proper attention to mitigate or resolve these issues, future management and conservation efforts may render useless.

3.2 PRCRMP database:

- *Variables:* Detailed information on the variables considered by PRCRMP and how they have changed through time can be found in https://www.drna.pr.gov/coralpr/monitoreo/. Variables estimated by the PRCRMP are divided into two major groups: benthic and fish assemblages. Our final compilation showed 295 variables in the benthic group and 247 in the fish assemblages’ group.

- *Benthic:* Benthic variables consisted of 5 abiotic categories and 290 biological categories. Those biological categories consisted of taxonomic groups that were mostly identified to species level (72%). The rest of the biological variables were grouped into genera (22%), Family (4%), or broad taxonomic groups (2%). (Appendix 3). It is important to note that all corals were identified to the species level (or species complex in the case of *Orbicella*).

- *Fish assemblages:* Fish information was further subdivided into two groups: variables associated with abundances = 247 and fish biomass = 64. Sharp differences in the number of variables between these two sub-matrices were related to the methodology used to estimate biomass and abundance, which were briefly described in the methods sections and further detailed in https://www.drna.pr.gov/coralpr/monitoreo/. For the fish abundance matrix, most of the variables were related to fish taxa (86%), whereas the rest (14%) were invertebrates. Fish taxa were identified to species (93%) or genera (7%). (Appendix 4).

- *Spatial and temporal structure:* The data compilation work (up to 2019) resulted in a data matrix that contained information about 86 coral reef sites around Puerto Rico over the last 20 years. The reefs ranged in depths from 3 to 35 meters, with more than half of them (62%) located inside some marine protected areas (Figure 1). Within the available data, 58 reefs were visited once, while 26 were visited annually or bi-annually over variable time spans (3 to 11 years, Table 3). Out of the original 86 sites, 40 are still being monitored around Puerto Rico and the outlying islands (Culebra, Vieques, Mona, and Desecheo) with 2 additional sites added in 2018 after Hurricane María for a total of 42 sites currently being monitored (Figure 1, Table 3). Out of those 42 sites, only 11 have been consistently sampled since 1999 or 2000 (Table 3) until 2019. In this report, historical analyses of the resilience of those sites were included in addition to the resilience analyses originally aimed at analyzing the effect of Hurricane Maria. It is important to note, however, that resilience scores for historical analyses (i.e., sites sampled between 11 and 13 times) were calculated using only benthic indicators because fish assemblages were not monitored until 2004, and then the methods changed in 2015. Consequently, indicators related to fish assemblages were not consistent through time and did not allow for historical analyses.

- *Data access*: The DNER has made public all PRCRMP raw data used in this project in NOAA's National Center for Environmental Information (NCEI). The most updated data files along with supporting documentation (field methods, data dictionary, etc.) can be found at NCEI accession 204647: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0204647. PRCRMP annual reports, from which raw data was extracted for the creation of the database, submitted by the field work team lead by Dr. Jorge García Saís (Reef Research, Inc.) can be found in the DNER website at: https://www.drna.pr.gov/coralpr/monitoreo/. As an indirect outcome of this effort, the database constructed in this project was translated following the Darwin-Core Standard by CARICOOS with support from NOAA IOOS and published in the Global Biodiversity Information Facility (GBIF) and the Oceanographic Biodiversity Information System (OBIS). PRCRMP data is also available for web map visualization in the Marine Biodiversity Observation Network (MBON) data portal at: https://mbon.ioos.us/?ls=h5ELVXyv#map

3. 3 Historical Analyses:

- *Resilience scores*:

Out of the 86 coral sites monitored by the PRCRMP, 11 had continuous (annual, by-annual) data that allowed for a historical analysis of relative resilience (Table 3). These 11 sites were grouped into 5 Locations over the west and southwest coasts of Puerto Rico (i.e., Rincon, Tourmaline, Ponce, Desecheo, and Guánica, Table 3). Sampling sites of Ponce, Desecheo and Guánica, showed consistent decreasing trends from High values ($\approx$ 0.9) of relative resilience at the beginning of the data series (1999-2005) to Low values ($<$ 0.65) or relative resilience towards the end of the data series (2018-2019) (Figures 2 a to c). Sampling sites in Tourmaline and Rincon did show significant temporal variations (Pseudo F = 2.07; p = 0.028; d.f. = 10, 132). However, there were no clear trends of change

(Figures 2 d and e). For those two sites located in Desecheo and Guánica, temporal trends were similar, whereas sites in Tourmaline and Rincon were different and showed different trends (Figure 2). In Rincon and Tourmaline, the three sampling sites were at different depths of the same reef. Consequently, those differences represent known differences between depth habitats. For the Tourmaline, the sampling site located at 10 meters deep showed consistently a higher relative resilience than sites located at 20 and 30 meters, whereas patterns of temporal variation at deeper sites were not statistically significant (except for the period 2004-2007 Figure 2 d). As per sites in Rincon, patterns of temporal variation were not different between shallower depths (5 and 10 m), but these differed from that of the deeper depth (20 m). Out of all these sites, those in Rincon showed the highest temporal source of variation, which might have been due to changes of permanent transects in 2005 and 2012 due to physical impacts given significant exposure to high period groundswells during the winter months. On the other hand, sites in Desecheo and Guánica were located at different reefs about 80 kilometers apart but at similar depths. Similarities in their temporal changes might indicate that processes determining those temporal changes of resilience operate at large scales (i.e., island scale). The sharp decline in resilience in most sites coincides with the consequences of the extensive and intensive bleaching event and disease outbreaks (Yellow Band = CYBD, White Plague =WPD, White Band = WBD, and other minor diseases) that occurred between 2003 and 2007 (Weil et al 2009). Several species showed significant bleaching-related mortalities (i.e., Agaricids, Mycetophyllia, Siderastrea, Stephanocoenia, etc.). CYBD for example, was at epizootic prevalence levels (> 25 %) for several years (until around 2019). CYBD affected the most abundant reef building genus, the Orbicella species complex across all reefs in the south-west coast from 2002-03 until 2009-11 depending on reef sites and abundances of these species (Weil and Croquer, 2009). The significant declines in coral cover were essentially reflecting the mortality of the Bleaching, WPD, WBD and CYBD susceptible species which included the most important and abundant reef-building genera (Orbicella, Pseudodiploria, Diploria, Colpophyllia, Montastraea, Siderastrea, agaricids, acroporids, etc.) (Weil and Rogers, 2011).

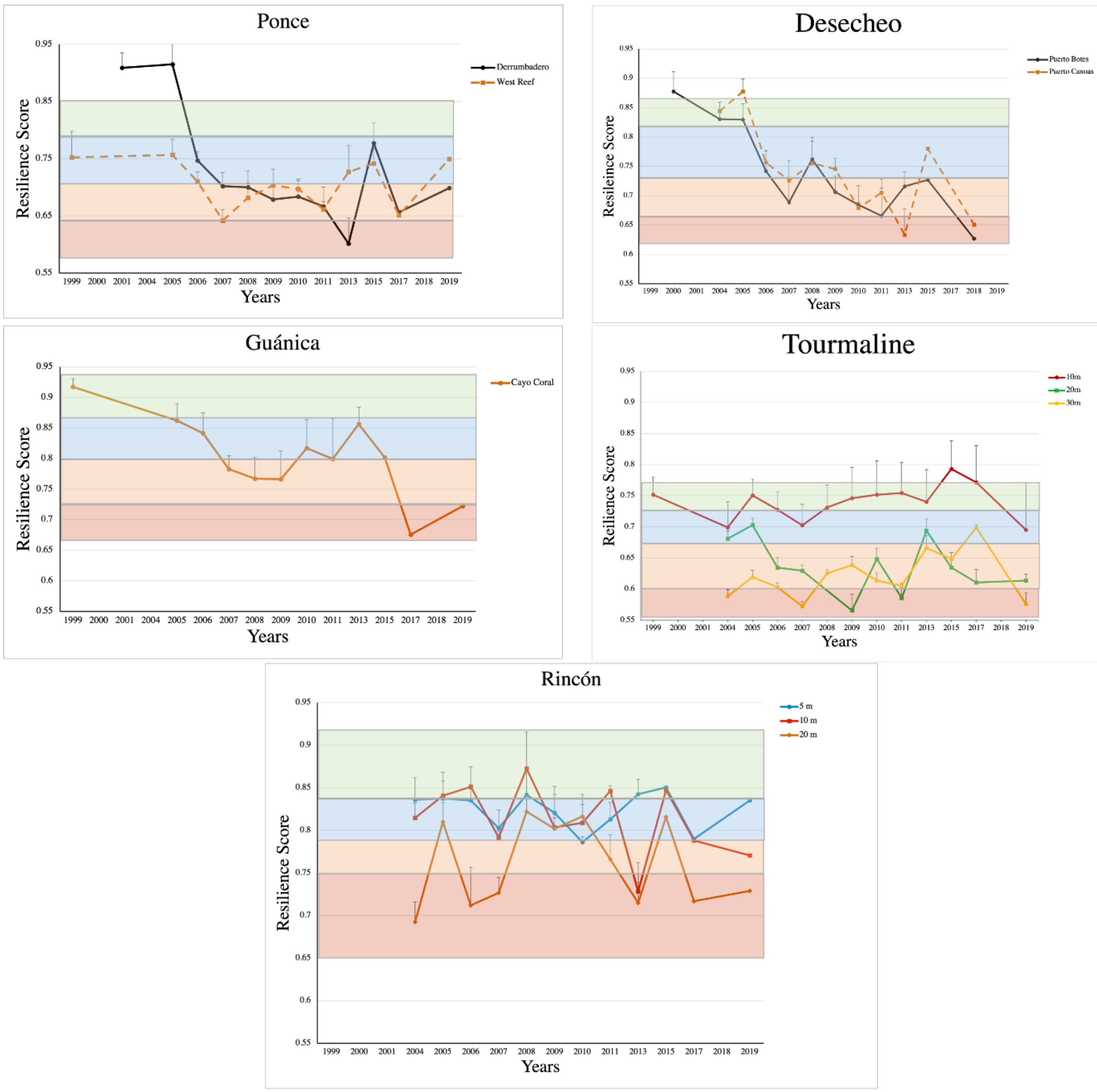


Figure 2. Temporal trends of average (+/- S.E.) resilience scores in 11 sites belonging to five different locations. A = Ponce, B = Desecheo, C = Guanica, D = Tourmaline, E = Rincon. Color bands represent resilience categories: Green = High, Blue = Medium High, Orange = Medium Low, Red = Low.

- *Multivariate (indicators)*:

To understand which indicators were related to temporal changes in each location, multivariate metric ordinations (mMDS) of sampling years in each location were done (Figures 3 to 10). From those analyses, it can be concluded that patterns of temporal variation in different sites and locations were driven by different indicators. Sampling sites in Ponce (two different reefs) showed conspicuous differences in terms of indicators (Figure 3) as West reef had a higher relative habitat complexity than Derrumbadero, but lower relative percentage of macro algae, *Lobophora*, and densities of damselfishes. In addition, it can be noted that patterns of temporal variation in each site were different and responded to different indicators (Figures 4 a, b). In both sites, there were clear temporal changes from 1999/2001 to 2019, but indicators associated with those changes were not the same in each site. At West Reef, changes in resilience scores obeyed to decreases of *D. antillarum* (densities) and increases of Damselfishes (densities and total abundances) (Figure 4 a). On the other hand, temporal changes in Derrumbadero were related to increased relative cover of *Lobophora* and other macroalgae (Figure 4 b). In this site, other indicators, such as relative percentage of coral cover and relative abundance of parrotfishes were associated with observed between 2001 and 2006 and then 2013 and 2015 (Figure 4 b). These two indicators (parrotfishes and coral cover) appeared to have been negatively correlated (Figure 4b).

Sampling sites in Desecheo, showed significant temporal variations (Pseudo $F = 8.57$, $p = < 0,001$, $df = 10, 144$); but, unlike Ponce, those patterns of variations were similar ($Rho = 0.49$; $p = 0.009$) and were related to the same indicators (Figure 5). In both cases, declines in resilience scores were related to consistent declines of relative coral cover (especially those that are resistant to sedimentation) and diversity of corals (Simpson index), and increases of *Lobophora* and other macroalgae. These results are consistent with what is widely known for the Caribbean (Bruckner and Hill, 2009; Weil et al. 2009, Weil and Rogers, 2011). Sampling site in Cayo Coral (Guánica), also showed significant and consistent temporal variations (Pseudo $F = 3.31$, $p < 0.001$, $df = 11, 48$). In this particular case, declines in resilience scores were mainly related to relative increases of Peyssonneliaceae and a decrease of other CCA (Figure 6). It is possible that increases of Peyssonneliaceae were facilitated by the open spaces left by dead corals during the 2005 and 2010 events. Other indicators that were related to important changes between 2009 and 2019 were: damselfishes and macroalgae, which were negatively correlated with changes in parrotfishes (Figure 6).

Sampling sites at Tourmaline showed very distinctive characteristics based on resilience indicators (Figure 7), which was not surprising as those three sites represented distinctive depths. In addition, patterns of temporal variation were different, but in all three depths/sites, resilience indicators seemed to have changed conspicuously after 2015 (Figure 7). Even though patterns of temporal variations were not the same in each site and related to different indicators, there were some commonalities. In all three sites, temporal changes between 1999/2001 and 2019 were related to decreases in habitat complexity and macroalgae increases (Figure 8). These changes were not translated into an overall decrease of the resilience score (Figure 2d) because some resilience indicators showed some improvements, like densities of *D. antillarum* (10 and 30 meters, Figure 8 a and c) or relative percentage coral cover (30 m, Figure 8 c). Nevertheless, and except for the indicators already mentioned, different indicators were related to temporal changes in each site (Figure 8). Sampling sites at Rincon showed very distinctive characteristics based on resilience indicators (Figure 9), which was not surprising as those three sites represented distinctive depths and most probably, different species composition and abundances. As per most of the other sites and locations, patterns of temporal variation were not the same across the three depths (Figure 10). In particular, it can be noted that changes at 5 m were not as large as those observed at 10 and 20 m. Despite these differences, in all three cases, it can be observed that after 2013, changes were larger than any year before (especially at 5 and 10 m; Figure 10 a and b). Also, and per most sampling sites, indicators associated with changes were not the same at each depth (Figure 10). However, in all three depths, changes between 2004 and 2019 were related to increases in the variation of the summer temperature (something that was not observed for any of the sites described above) and increases of macroalgae. (Figure 10).

Despite all the differences among sites, depths, and locations described above, there are two commonalities that were found across all cases: indicators related to coral cover went down, and those related to algae, increased. These variable trends evidence the community shift from coral dominated to algae dominated after the coral mortalities over time that were triggered by the thermal anomalies and the bleaching and disease-associated mortalities from 2005-06 and 2010, and the lack herbivory in those reefs.

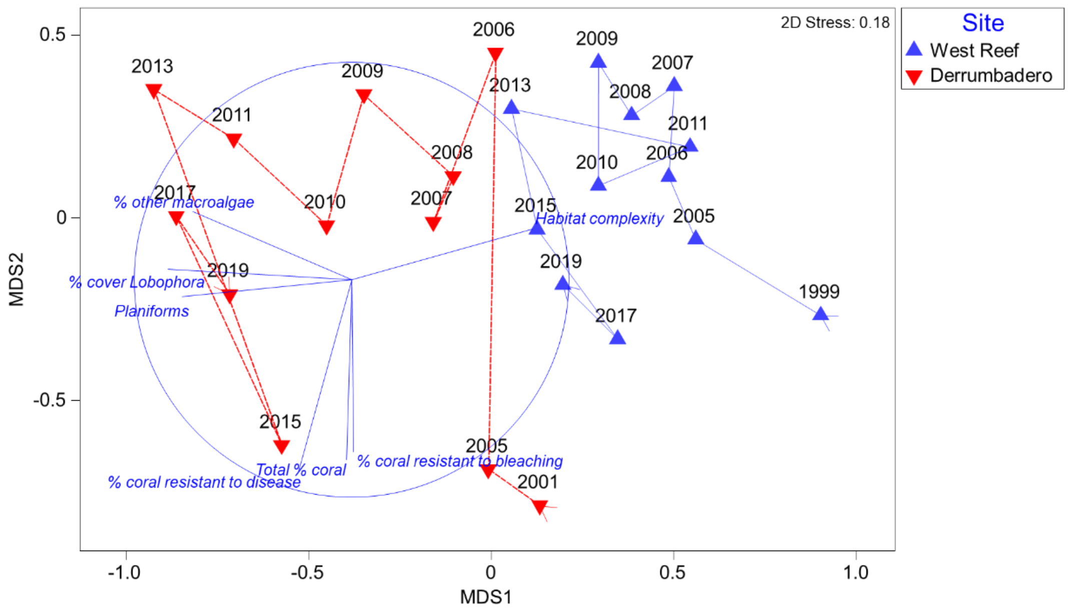


Figure 3. mMDS of centroids per site and year based on resilience indicators comparing two sites (West Reef and Derrumbadero) at Ponce. Continuous lines show temporal trends for each site, whereas vectors show indicators best correlated (>0.7) with the first two axes of the ordination.

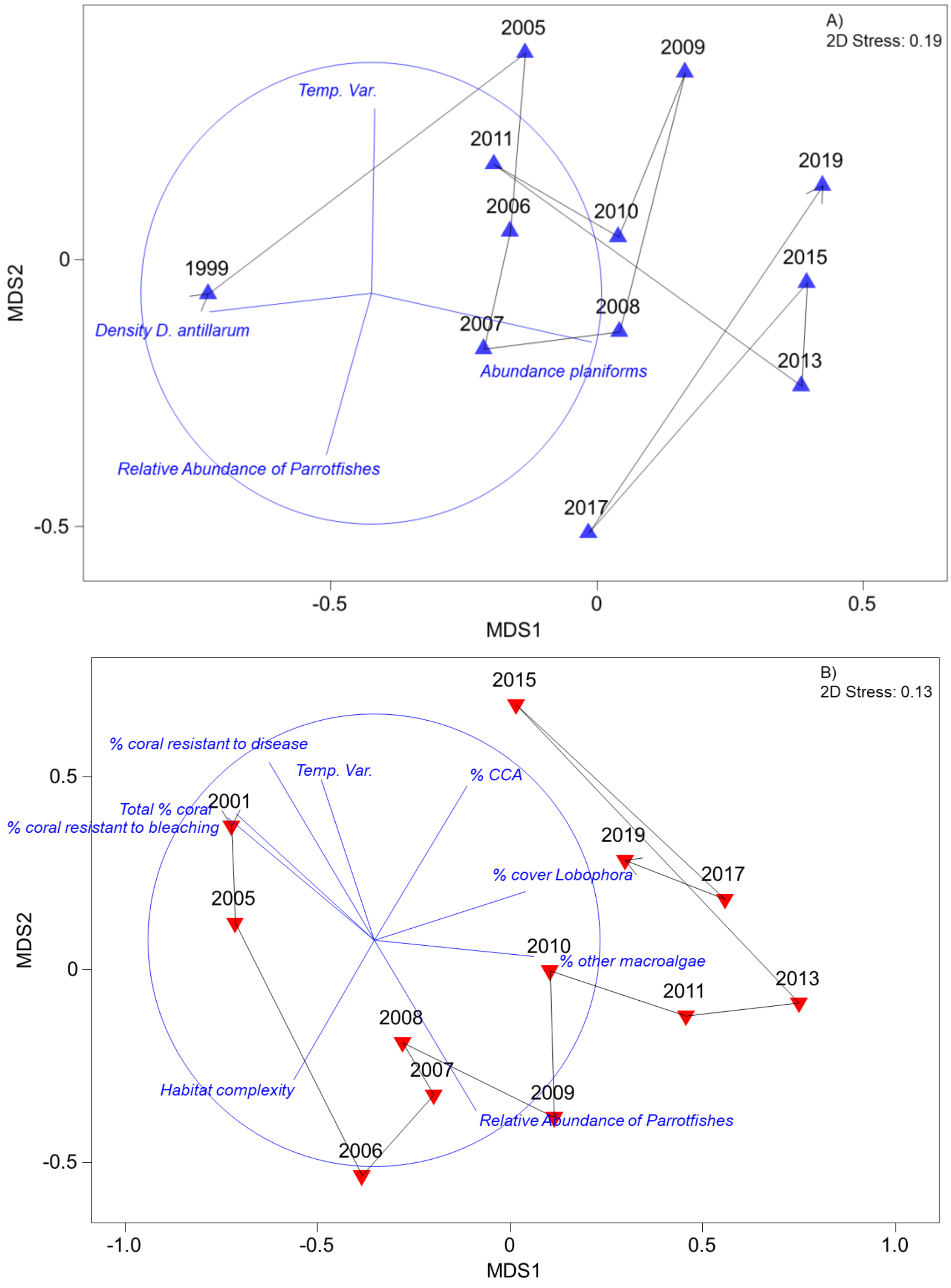


Figure 4. mMDS of centroids per site and year based on resilience indicators comparing in two different sites of Ponce: A) West Reef and B) Derrumbadero. Continuous lines show temporal trends for each site, whereas vectors show indicators best correlated (>0.7) with the first two axes of the ordination. A = West Reef, B = Derrumbadero.

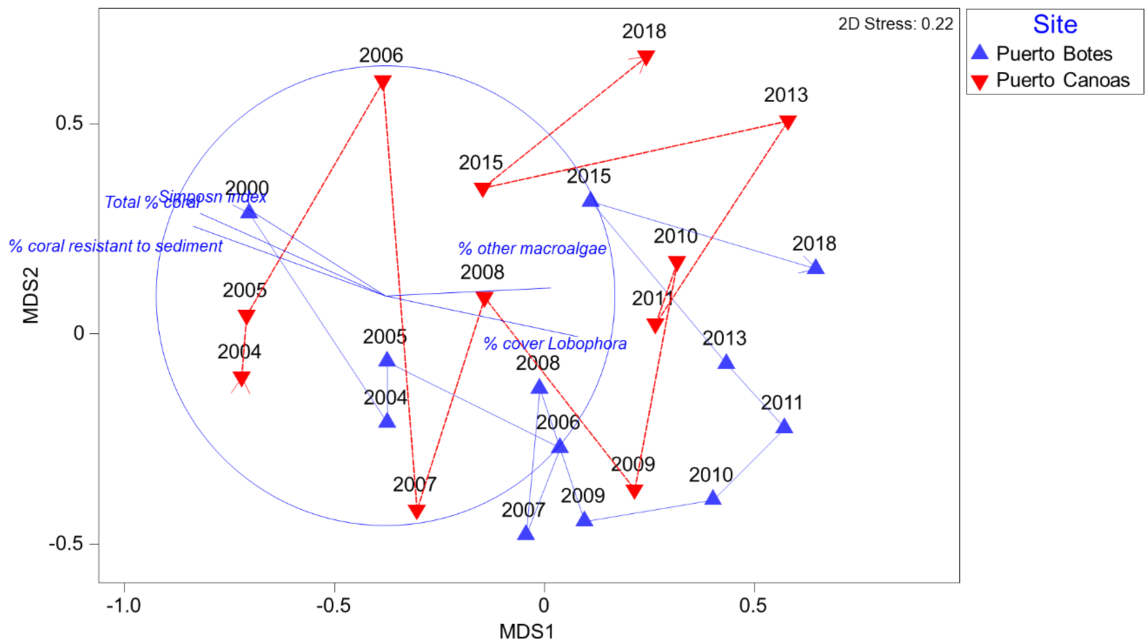


Figure 5. mMDS of centroids per site and year based on resilience indicators comparing two sites (Puerto Botes y Puerto Canoas) at Desecheo. Continuous lines show temporal trends for each site, whereas vectors show indicators best correlated (>0.7) with the first two axes of the ordination.

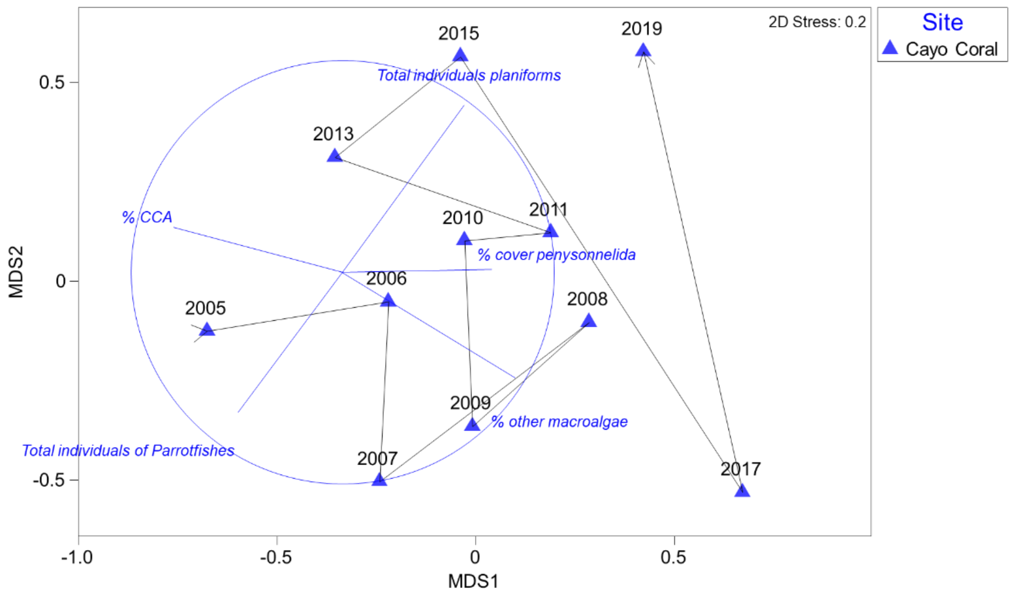


Figure 6. mMDS of centroids per site and year based on resilience indicators at Cayo Coral (Guanica). Continuous lines show temporal trends for each site, whereas vectors show indicators best correlated (>0.7) with the first two axes of the ordination.

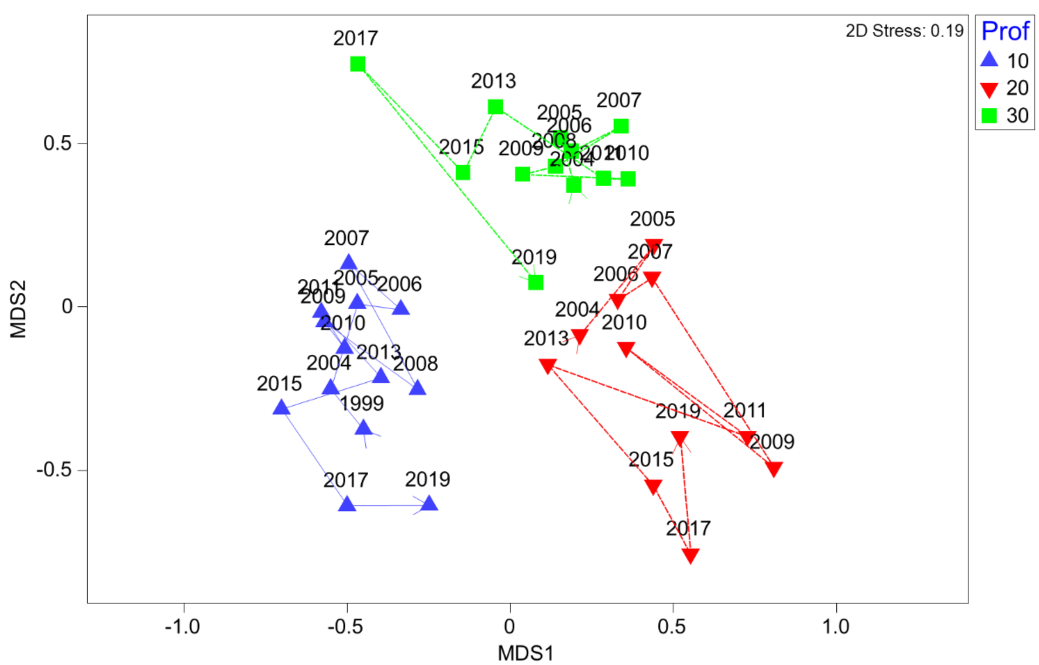


Figure 7. mMDS of centroids per site and year based on resilience indicators comparing three sites (in this case depths = 10, 20, and 30 m) at Tourmaline. Continuous lines show temporal trends for each site.

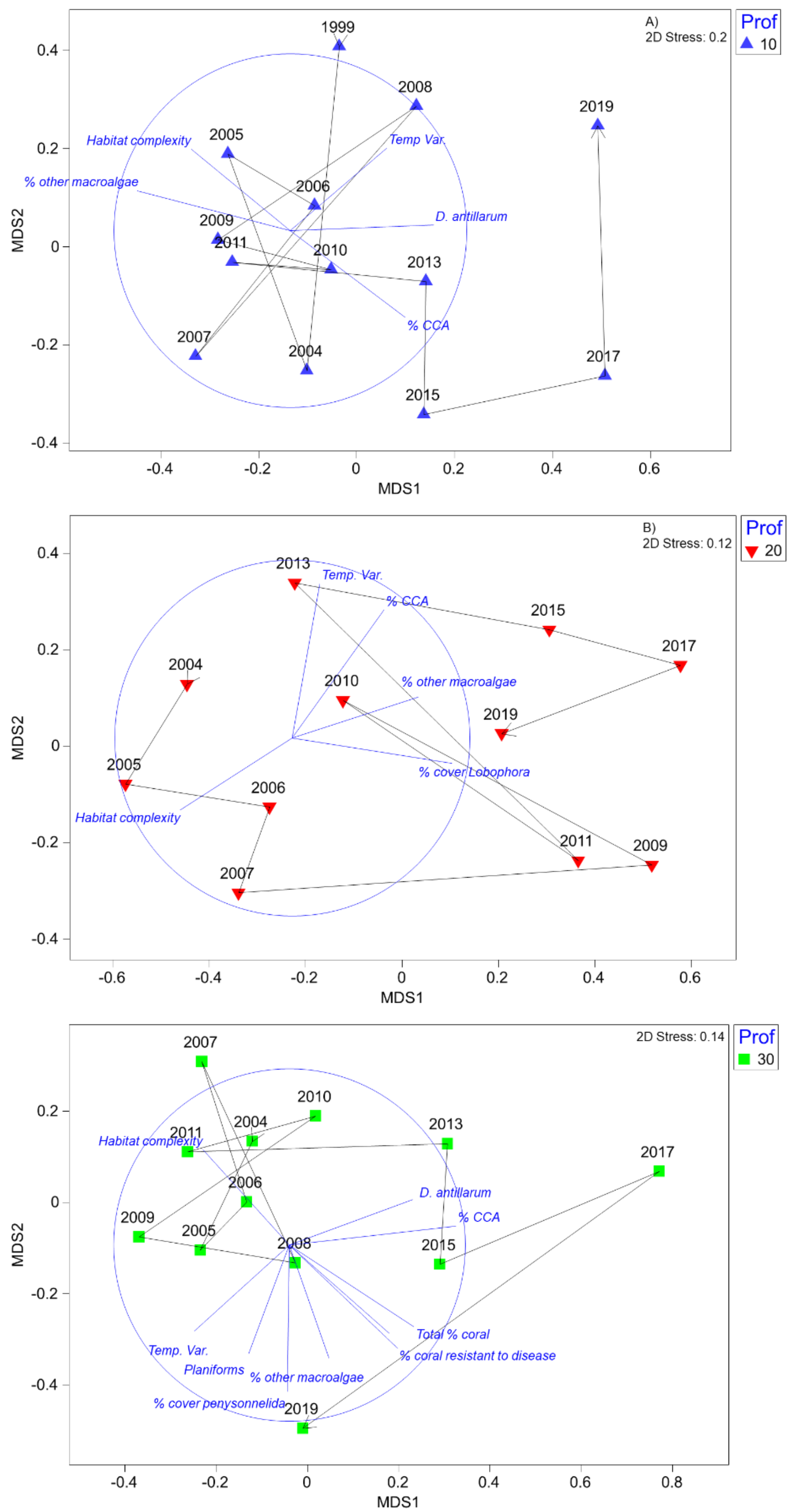


Figure 8. mMDS of centroids per site and year based on resilience indicators comparing three different sites (depths in this case) of Tourmaline: A) 10 m and B) 20 m and C) 30 m. Continuous lines show temporal trends for each site, whereas vectors show indicators best correlated (>0.7) with the first two axes of the ordination.

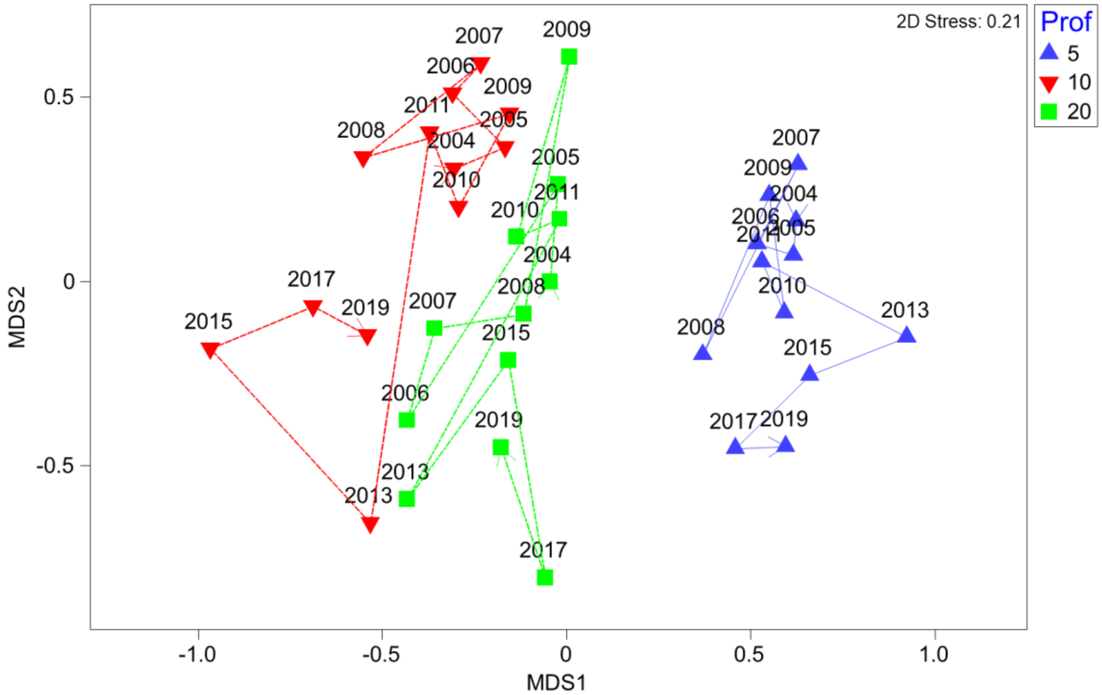


Figure 9. mMDS of centroids per site and year based on resilience indicators comparing three sites (in this case depths = 10, 20 and 30 m) at Rincon. Continuous lines show temporal trends for each site.

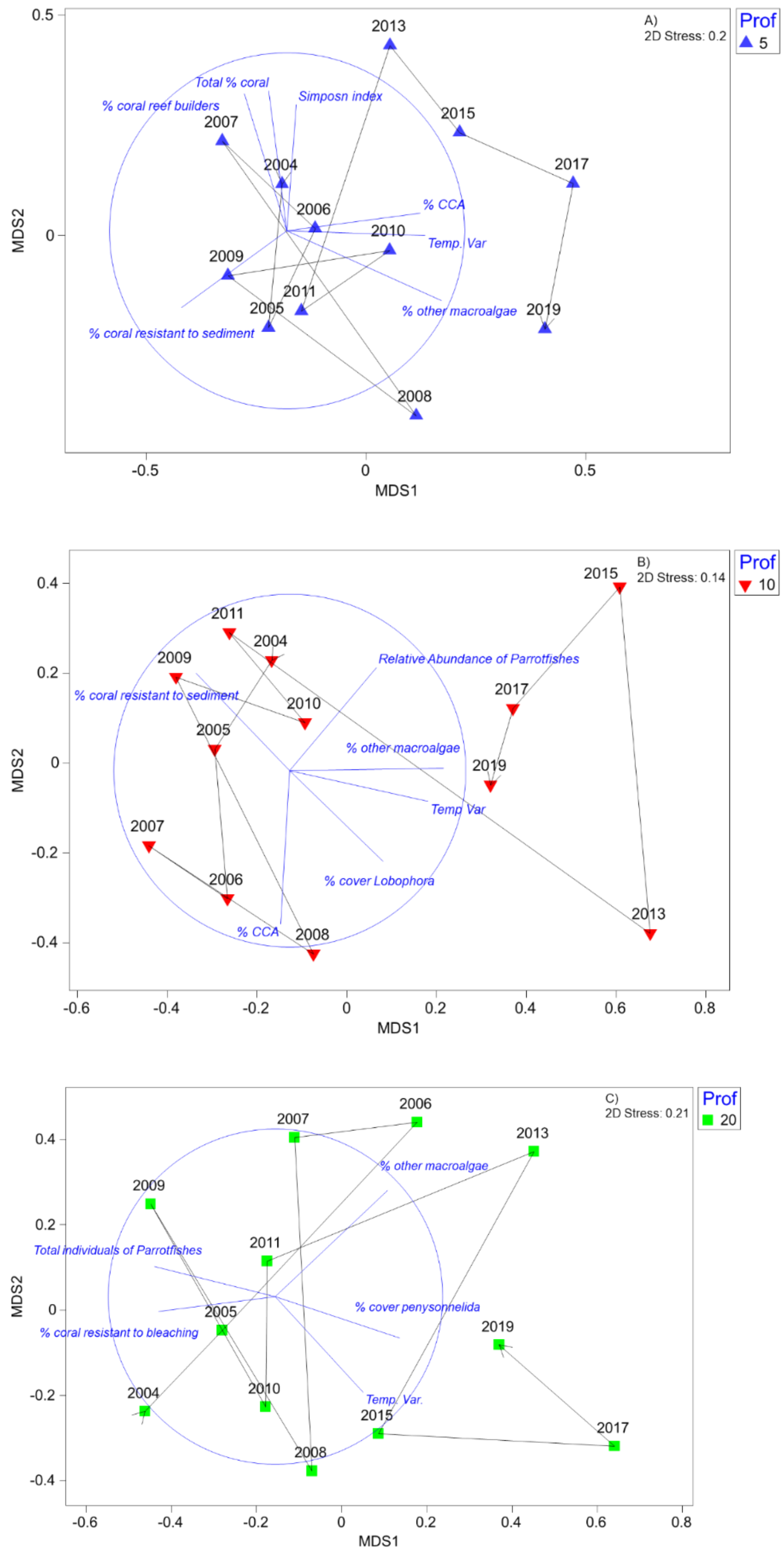


Figure 10. mMDS of centroids per site and year based on resilience indicators comparing three different sites (depths in this case) of Rincon: A) 5 m and B) 10 m and C) 20 m. Continuous lines show temporal trends for each site, whereas vectors show indicators best correlated (>0.7) with the first two axes of the ordination.

- *Stressors*: Although 9 different stressors were estimated for this study, only three allowed for historical analyses: Degree heating weeks (DHW), Turbidity (K490), and Productivity (as proxy for eutrophication). As Such individual stressors were analyzed separately instead of calculating an overall "stressors indicator".

    - *DHW*: Patterns of temporal variation for this parameter were consistent across localities and sites (Figure 11). In all locations and sites, the sharp increases of this parameter were evident for 2005, 2010, and, to a minor degree, 2019. These high temperature anomalies induced the two most intensive bleaching events in the northeastern and southern Caribbean in recorded history, and also induced epizootic outbreaks of virulent coral/octocoral diseases which brought about high levels of coral mortality and therefore, open space for macro- and turf algae to colonize (Weil et al. 2009, 2017; Rogers et al. 2009; Croquer et al, 2009a, b, Eakin et al. 2010; Bastidas et al. 2011). The magnitude of the 2005 event was the same across all locations and sites, however, they were different across locations for the 2010 event. (Figure 11). It can be noted that the increase of DHW was sharper (and seemed to last for longer) in Guánica (Cayo Coral), the two sites at Desecheo (Puerto Botes y Puerto Canoas), and the two sites of Ponce (West Reef and Derrumbadero); in comparison with Tres Palmas and Tourmaline (Fig. 11). The 2019 thermal anomaly produced an extensive bleaching event but without any associated disease outbreaks or mortalities.

    - *Turbidity (K490):* As per DHW, patterns of temporal variation of this potential stressor were similar in all locations and sites, except for Derrumbadero in Ponce and Tourmaline (Figure 12). In all cases, K490 showed consistent increases starting around 2013-2015 except at Derrumbadero (Ponce) and Tourmaline, where patterns of temporal variation of this parameter seemed constant (Derrumbadero) or variable. This could be potentially correlated with increases in rain and river discharges, and possibly bottom sediment resuspension by surge and currents. Similar results have been observed in La Parguera Natural reserve where visibility has decrease consistently (increase in turbidity) over the last 20 years (Weil, Unpub. Data).

    - *Productivity:* This parameter showed variable patterns of temporal variation depending on location, with no clear tendencies of increase or decrease through the data series (Figure 13).

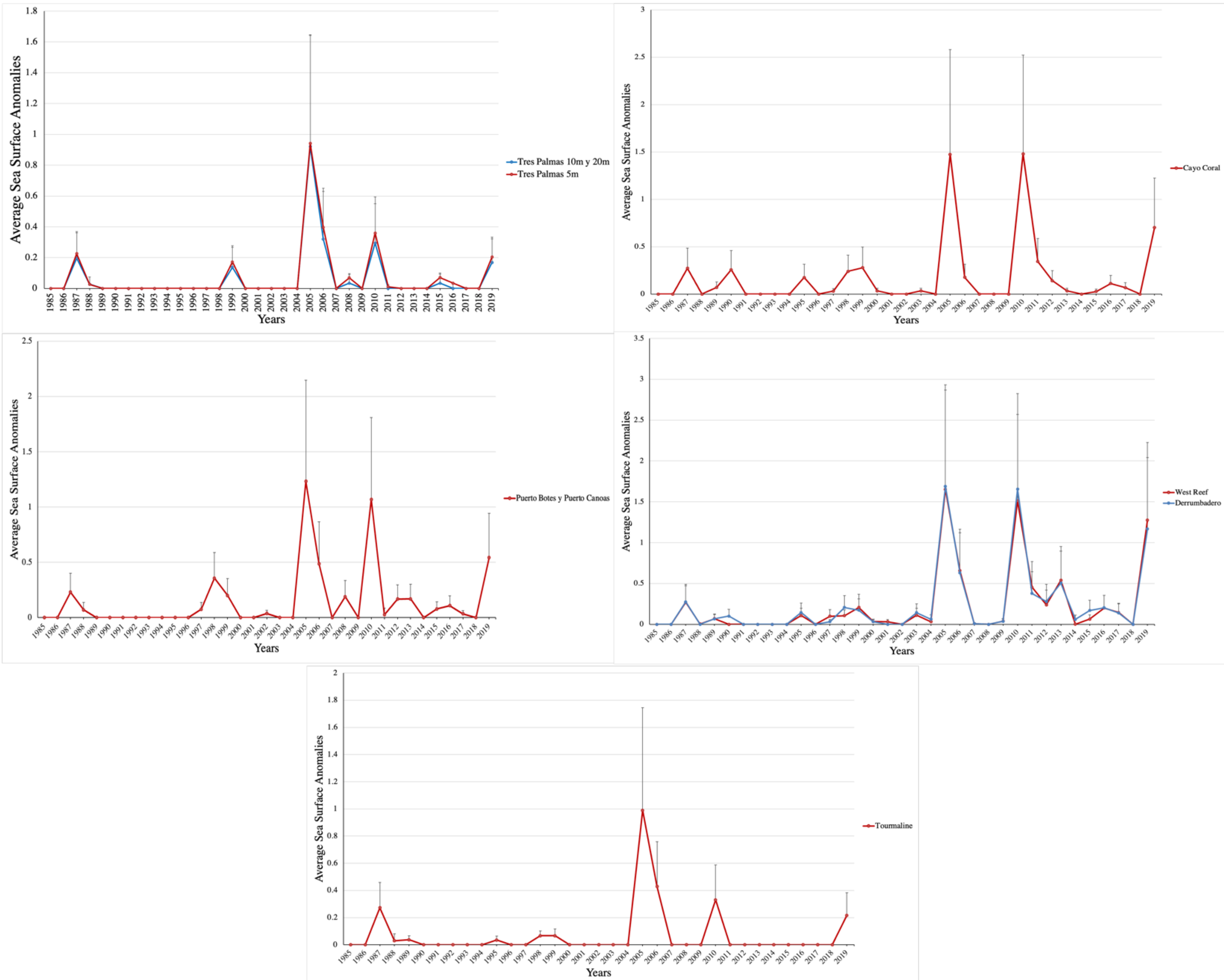


Figure 11. Average DHW (+/- S.E.) per year at five different locations.

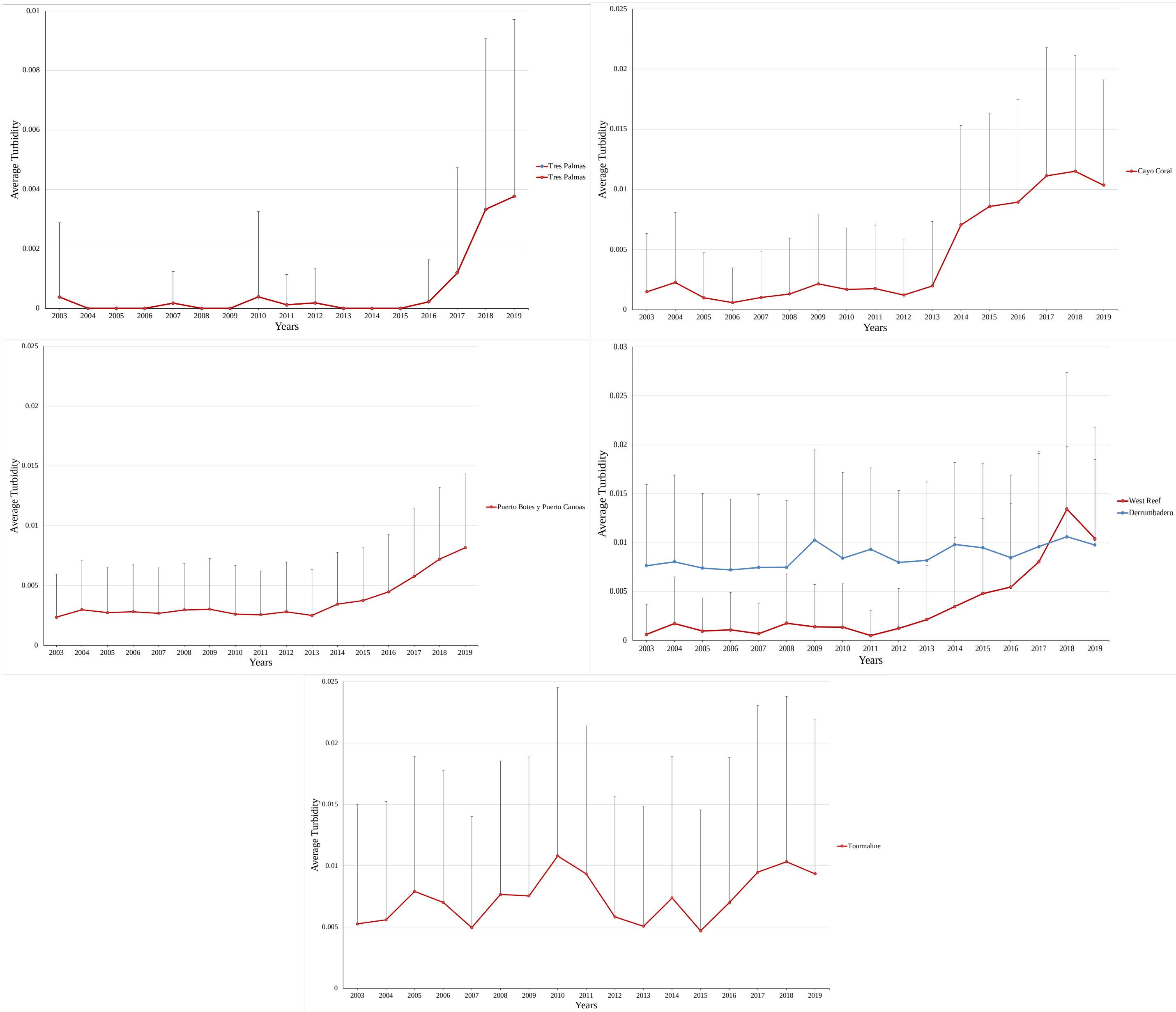


Figure 12. Average K490 (+/- S.E.) per year at five different locations.

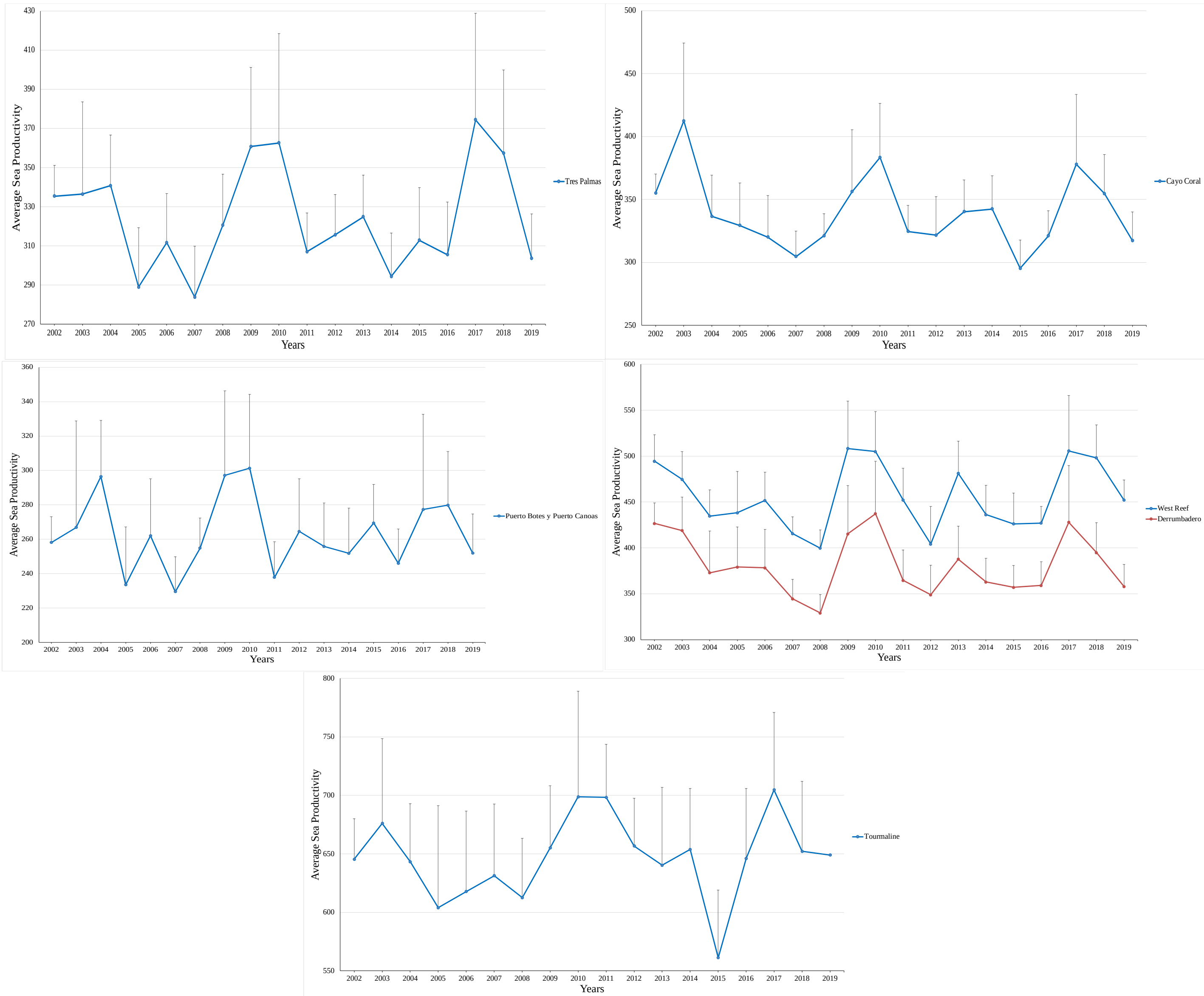


Figure 13. Average productivity (+/- S.E.) per year at five different locations.

3.4 Spatial and temporal analyses:

- *Resilience scores (Univariate)*: When comparing initial years (15-16) vs. final years (18-19), statistical analyses showed a significant interaction between sampling site and time (Table 9). This interaction was because changes in resilience scores were not consistent across sites, locations, or regions (Figure 14). Out of 32 sites used for this specific comparison, 11 showed an increase of their relative resilience score, whereas 18 showed a decrease, and 3 remained constant (Table 10, Figure 15). In general, the rate of change was relatively low (average of absolute change 4.4 %), ranging between – 14.14 % (the highest decrease observed at Gallardo) and 11.8 %, the largest increase at Cayo Coral. As per the last cycle (2018-2019), relative resilience scores varied between 0.53 (Canal Luis Peña) and 0.75 (Boya Vieja). Within that range, 7 sites were identified as having a high resilience score, 12 Medium High, 9 Medium Low and 4 had a Low resilience Scores (Table 10). Despite the fact, those relative scores were standardized by their maximum; the highest value was 0.75 because there was high variability among sampling units within each site. In addition, this analysis is averaging across different depths for reefs that had various sites located at different depths. These overall results suggest that there was not a generalized effect of Hurricane Maria on the relative resilience of sites studied under the PRCRMP. A potential explanation for this is that reefs around Puerto Rico (as well the wider Caribbean) have shown a continuous deterioration through the years, reaching such a state that the potentially deleterious effects of a hurricane could not be detected (Edmunds, 2019). In particular, hurricanes impact mostly shallow-water communities that are usually dominated by branching, fast growing species such as *Acropora palmata and A. cervicornis*. These species are no longer the dominant component of these communities after being decimated by diseases and bleaching (Weil et al., 2017, Edmunds, 2019). The remaining species are mounds and crusts that are barely impacted by waves and surge. Most marine communities on the southwest coast had some impact in shallow areas, but, deeper than 10 m, there were no extensive visible impacts (Weil, unpublished data). Alternatively, these results could support the idea that hurricanes *per se* do not have a significant negative effect on the resilience of reefs (Manzello et al., 2007). At local level the effect of hurricanes is obvious as they generate destruction of the structure of the reef (turnover and dislodgement of colonies), however, at a larger scale they can alleviate the thermal stress that corals are suffering during the summer months (Manzello eta al, 2007), which could ultimately be reflected in the resilience of reefs. A third alternative is that the time scales used in the analyses do not capture important changes that occur at slower rates in coral communities. For example, successful recruitment and survivorship will not show in surveys until colonies grow to sizes that are visible and cover some substrate.

A similar conclusion can be reached when sites were discriminated in those that were sampled in odd years and those sampled in even years (Figure 16). Changes in resilience score were not consistent across sites, locations and regions. In particular, for those sites that were sampled three times (2015, 2017, and 2019, odd years), it can be noted that 4 sites (Boya Vieja, Cayo Coral, Media Luna and Resuellos) showed constant increases in terms of resilience scores, whereas 3 sites showed constant decreases of resilience scores (3 Palmas, Gallardo and Cayo Aurora, Figure

16 B). These results further support the idea that there was not a generalized effect of hurricane Maria on the resilience of Puerto Rico's coral reefs.

Since depth can play an important role on the potential effect of a hurricane on a particular reef, spatial-temporal comparisons between sites and years were also made using a depth stratification (Figure 17). By doing this stratification, indicators were standardized by their totals for those particular strata, which had the advantage of taking into consideration known depth differences in reefs. Very interestingly, and contrary to our previous conclusions, these comparisons showed that patterns of temporal change depended on the strata that were considered. In this sense, very shallow sites (5 m) did not show a generalized pattern as half of the sites considered showed a decrease, whereas the rest maintained their relative resilience scores. On the other hand, most sites at shallow (5 -15 m) and deep strata (> 16 m) showed reductions of the resilience score (shallow = 12 of 15 sites and deep = 13 of 14 sites, Figure 17). These results, support the historical trend of resilience decrease that was previously described in this report.

Table 9. PERMANOVA analysis based on Euclidean distances of resilience scores using a mixed lineal model (Time: Fixed, Region: Fixed and Site: random nested within region. The probabilities associated at each pseudo-F value were obtained with 9999 permutations of residuals under a reduced model.

Source	*d.f.*	M.S.	*Pseudo-F*	*p*	C.V. (%)
Ti	1	9.84E-05	0.03	0.856	0.00
Re	4	7.25E-02	2.46	0.069	18.32
Si(Re)	25	3.43E-02	16.37	> 0.001	35.07
TixRe	4	4.25E-03	1.29	0.308	3.85
TixSi(Re)	25	3.51E-03	1.67	0.028	10.39
Res	340	2.10E-03			32.38
Total	399				

Table 10. Resilience scores and ranks for various reef sites at two different times Before = Initial (2015-2016) and After = Final (2018-2019).

Site	Initial	Rank Initial	Final	Rank Final	Region	Locality
Tourmaline	0.68	5	0.69	6	W	Cabo Rojo
El Negro	0.64	12	0.64	10	W	Cabo Rojo
Gallardo	0.72	3	0.62	17	W	Cabo Rojo
Resuellos	0.56	25	0.59	23	W	Cabo Rojo
Dominos			0.74	2	N	Carolina
Puerto Canoas	0.68	5	0.71	4	W	Desecheo
Puerto Botes	0.62	16	0.67	8	W	Desecheo
Palominos	0.66	9	0.63	12	E	Fajardo
Palominitos	0.58	21	0.61	19	E	Fajardo
Cayo Diablo	0.55	26	0.58	24	E	Fajardo
Cabezas de S. Juan			0.54	29	E	Fajardo
Beril	0.58	21	0.63	12	SW	Guanica
Cayo Aurora	0.66	9	0.63	12	SW	Guanica
Cayo Coral	0.51	28	0.58	24	SW	Guanica
Maria Langa	0.54	27	0.54	29	S	Guayanilla
Guanajibo	0.76	1	0.74	2	W	Mayaguez
Manchas	0.64	12	0.63	12	W	Mayaguez
Cayo Rodriguez	0.59	20	0.60	22	W	Mayaguez
Media Luna	0.61	17	0.63	12	S	Parguera
Boya Vieja	0.70	4	0.75	1	SW	Parguera
Derrumbadero	0.61	17	0.67	8	S	Ponce
West Reef	0.60	19	0.61	19	S	Ponce
3 Palmas	0.63	14	0.61	19	W	Rincon
Cayo Ratones	0.63	14	0.62	17	S	Salinas
Cayo Caribes	0.58	21	0.58	24	S	Salinas
Cibuco	0.75	2	0.71	4	N	Vega Baja
Dakiti	0.67	8	0.65	9	E	Vieques/Culebra
Carlos Rosario	0.66	9	0.64	10	E	Vieques/Culebra
Canjilones	0.58	21	0.57	27	E	Vieques/Culebra
Esperanza	0.50	29	0.55	28	E	Vieques/Culebra
Canal Luis Pena	0.50	29	0.53	31	E	Vieques/Culebra
El Seco	0.68	5	0.69	6	W	Vieques/Culebra

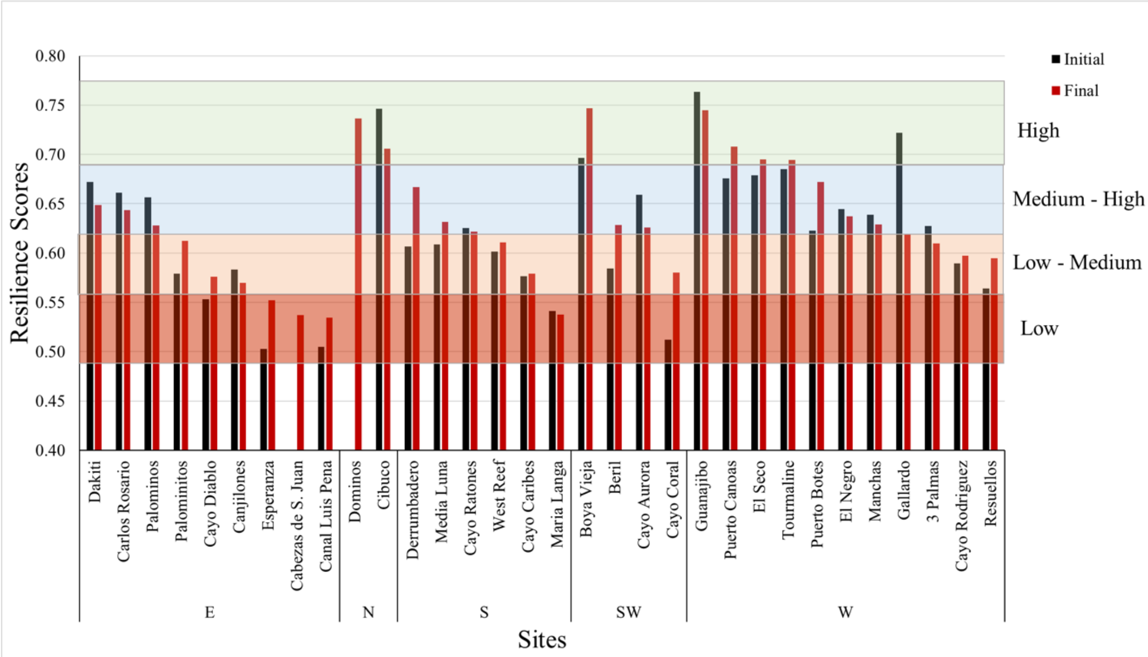


Figure 14. Initial (Before September 2017) and Final (After September 2017) resilience scores at 32 reef sites around Puerto Rico discriminated by regions.

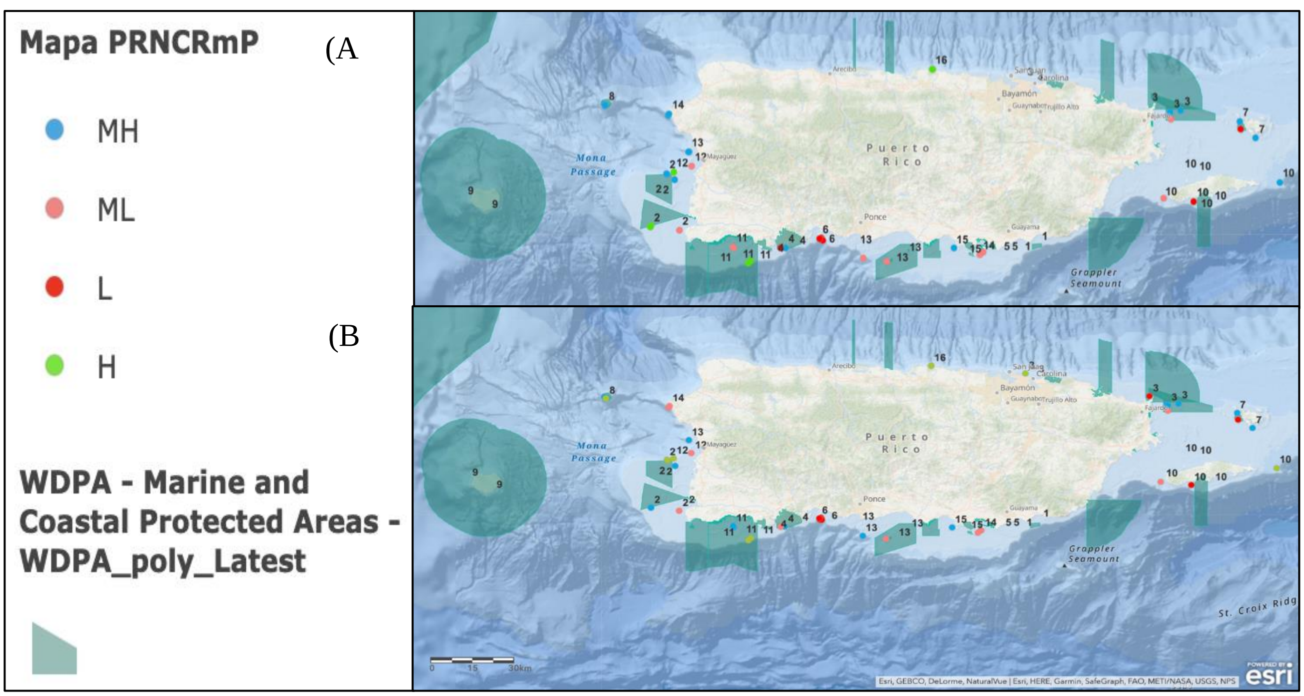


Figure 15. Resilience categories before (2015-2016) = A and after (2018-2019) = B across different PRCRMP sites.

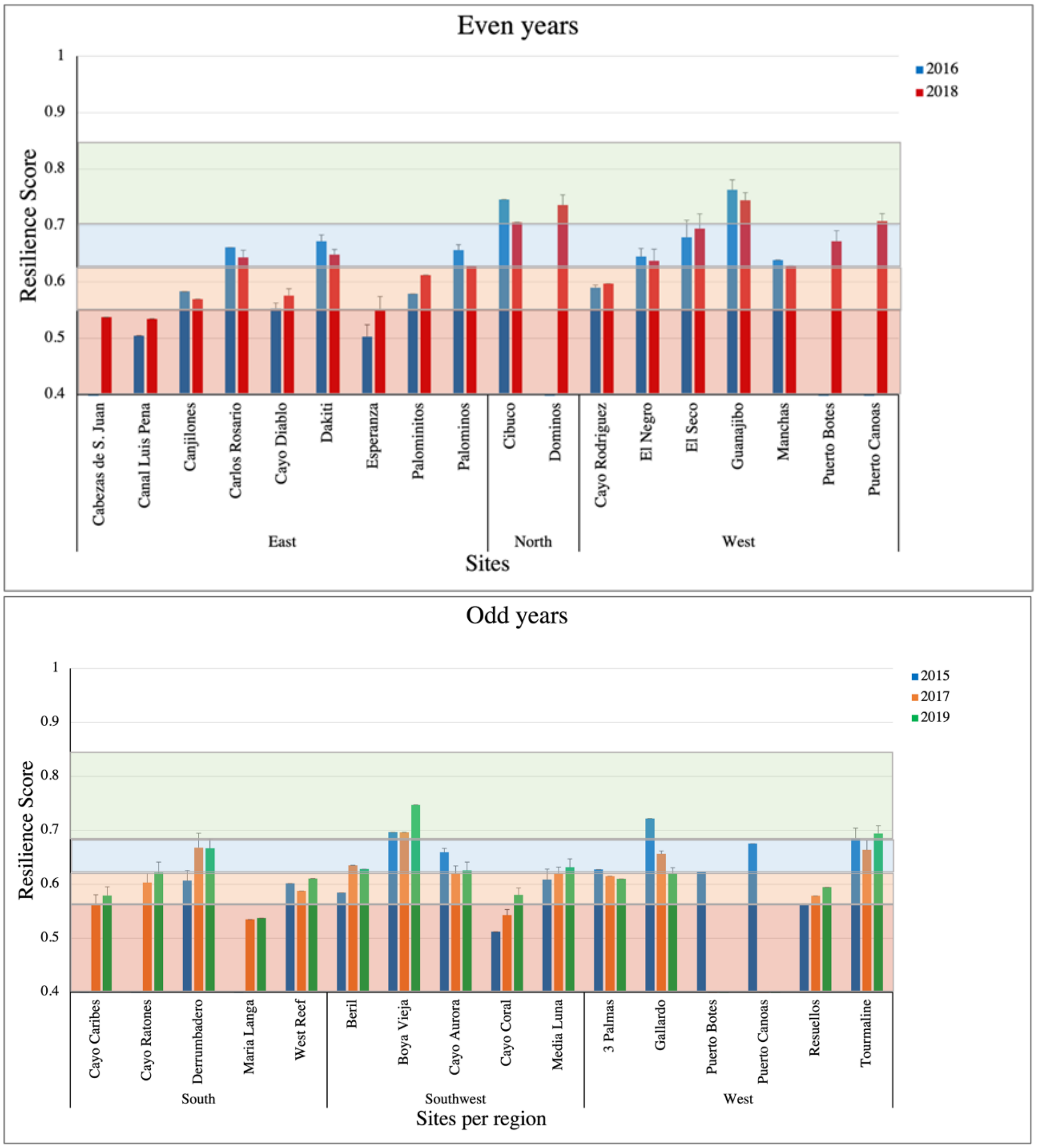


Figure 16. Average (+/- S.E.) resilience scores at different reef sites around Puerto Rico sampled during even and odd years. Color band represent resilience categories. Green = High, Blue = Medium High, Orange = Medium Low, Red = Low.

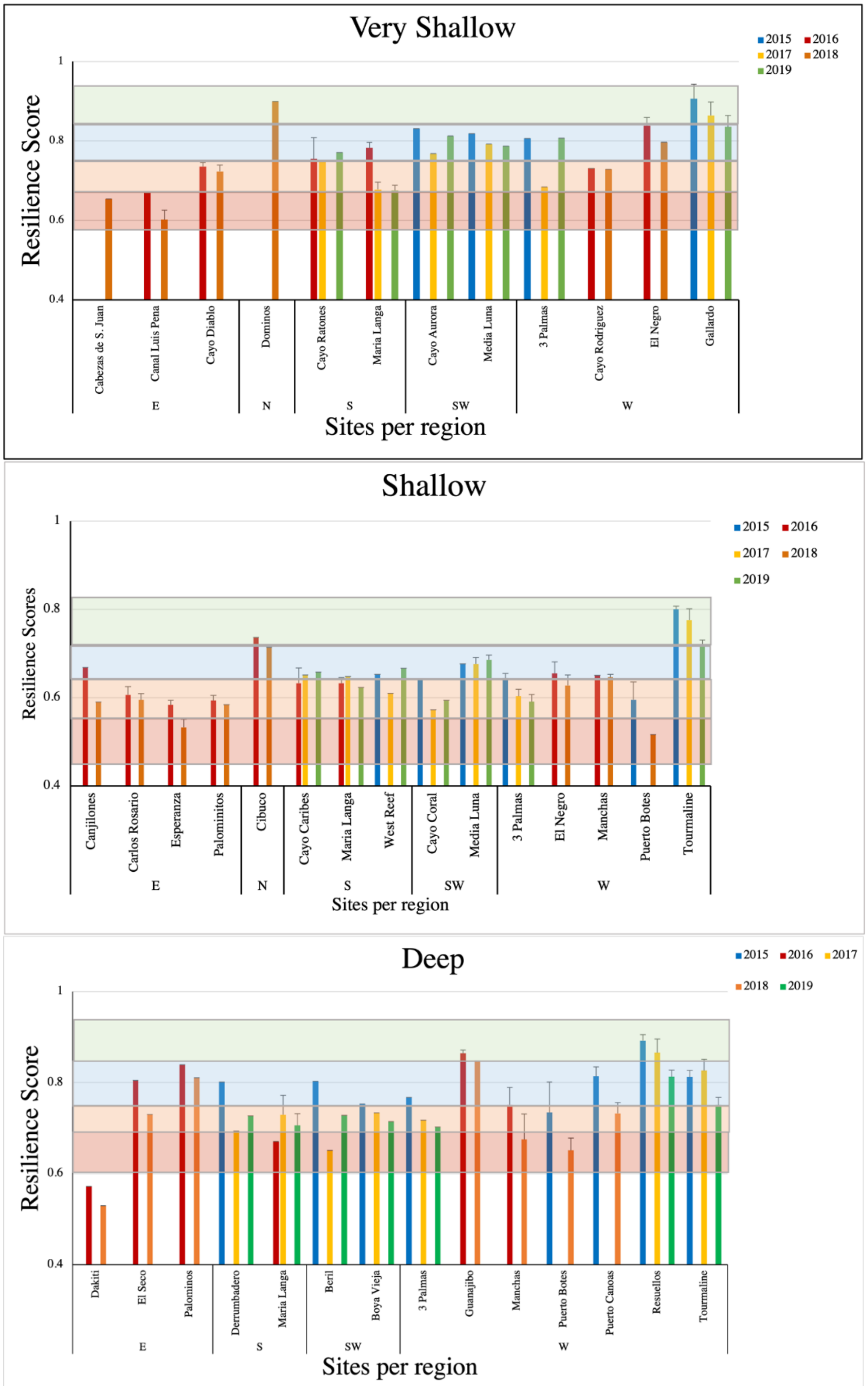


Figure 17. Average (+/- S.E.) resilience scores at different reef sites around Puerto Rico discriminated by depth strata. Color band represent resilience categories: Green = High, Blue = Medium High, Orange = Medium Low, Red = Low.

- *Multivariate (Indicators):*

PERMANOVA analyses indicated that despite significant variation among sites and years (*Pseudo F* = 8,93; $p < 0,001$; *d.f.* = 74, 437); there were also significant differences between groups of resilience categories (*Pseudo F* = 4,48; $p < 0,001$; *d.f.* = 3, 74). Multivariate ordinations (CAP) on the centroids of sampling sites and year, using the resilience score as discriminating factors; clearly showed these differences (Figure 18). This Figure also showed that the indicators that contributed the most (> 50%) to that discrimination were: Total percentage cover of corals, % cover of CCA, % cover of *Peyssonneliaceae*, and % cover of *Lobophora* (Figure 18). It can be noted that differences between "High" resilience sites and "Low" resilience sites occurred over a clear continuum (represented in Figure 18 over the first axis from left to right). Those differences were associated with "High" resilience sites having higher percentage cover of CCA and percentage cover of total coral, but lower percentage cover of *Peyssonneliaceae* and *Lobophora* sp than "Low" resilience sites (Figure 18).

When stratified by depth, additional indicators were important in discriminating between resilience categories, and those indicators slightly varied between the three depths considered in this study (Figure 19). For "very shallow" sites (< 5m), there were significant differences between resilience categories, but *a posteriori* comparison showed, however, that the only significant different group was the "low" resilience sites (i.e., there were not significant differences between the other three groups). Nevertheless, percentages of total cover and Peyssonneliaceae were important in discriminating among resilience categories (Figure 19 a). In this "shallow" strata, density of *D. antillarum* and the percentage of coral species resistant to bleaching were also important (Figure 19 a). The last indicator (% coral species resistant to bleaching), however, explained differences along the second axis of the ordination, indicating that this indicator is important to explain differences between sites within each resilience category; but not between resilience categories. In the case of "shallow" (6 – 15 m) sites, there were also significant differences between resilience categories, but in this case, sites with high resilience were different from the rest, but no statistical differences were found between Medium-high, Medium-Low, and Low. As before, total % coral cover was important in discriminating among resilience categories. However, those indicators related to % cover of *Lobophora* and Peyssonneliaceae were not important in this case (Figure 19 b). In addition, the following indicators were also important to discriminate between resilience categories: Simpson's species diversity index for corals, percentage cover of coral species resistant to diseases and percentage cover of coral species resistant to sedimentation. The indicator "relative abundance of parrotfishes was also important (> 50% correlation). However, it was related to the second axis of ordination, suggesting that this indicator is important to explain variations between sites within the resilience categories and not between categories (Figure 19 b). Finally, for the "deep" stratum (> 16m), differences across resilience categories were related to Simpson's diversity index for corals, percentage cover of *Lobophora* and macroalgae; but not the total cover of corals as observed in all other cases before (Figure 19 c). In this case, temperature variability also appeared as an important indicator related to differences observed for the low resilience category (Figure 19 c).

Overall, main indicators related to differences between resilience categories were related to benthic categories rather than to fish assemblages.

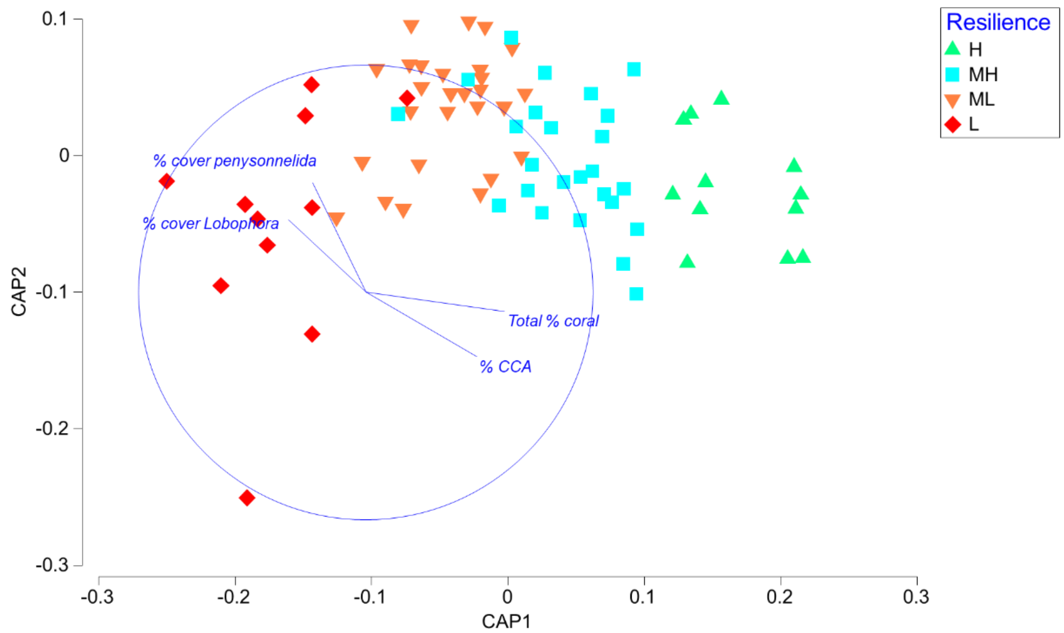


Figure 18. Canonical Analysis of Principal Coordinates (CAP) of centroids per site and year, discriminated on the basis of the resilience score. Vectors indicate correlation of original normalized scores with the first two axis of the ordination. Only indicators with > 70% correlation are shown.

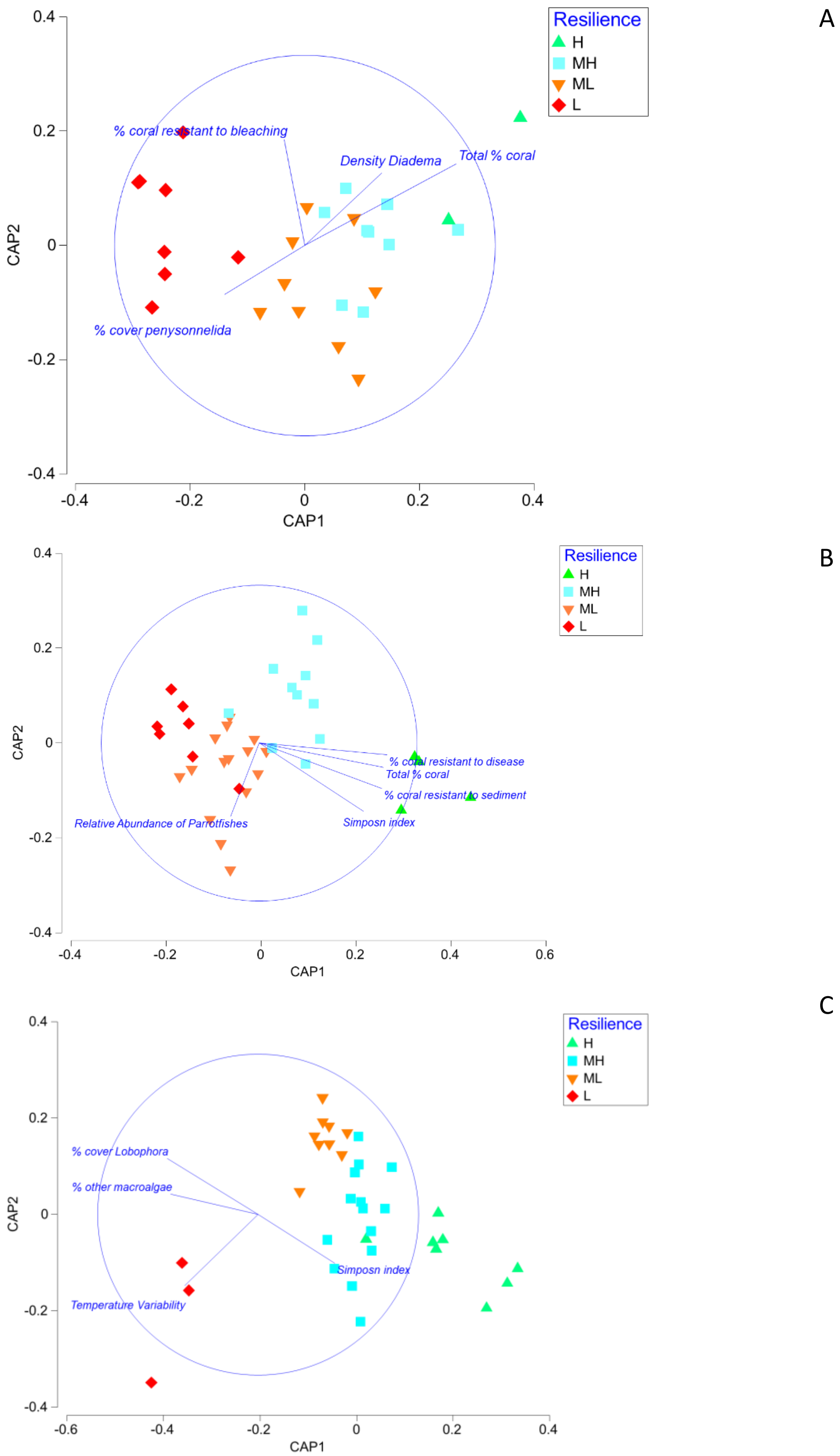


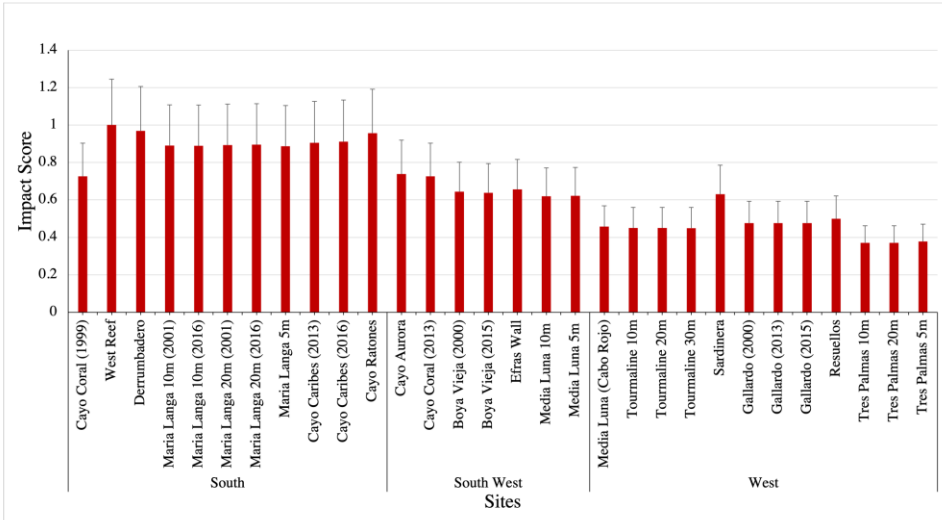
Figure 19. Canonical Analysis of Principal Coordinates (CAP) of centroids per site and year, discriminated based on the resilience score. A = Very Shallow sites, B = Shallow sites and C = Deep sites. Vectors indicate correlation of original normalized scores with the first two axis of the ordination. Only indicators with > 70% correlation are shown.

- Stressors:

Despite significant variation among sites, stressor scores per site showed very distinct patterns across regions (Figure 20). Overall, sites located in the West region had the lowest stressors impact, whereas those located in the North and South region had the highest stressor's scores. At the site level, the sites with the lowest stressor's score were those located in Tres Palmas and Desecheo (Puerto Botes y Puerto Canoas), whereas those with the highest stressor's score were those located in Ponce (West Reef and Derrumbadero) and Carolina (Dominos, Metropolitan Area of San Juan).

Correlations of stressors with discriminant analyses based on resilience showed that the stressors that best correlated with the discrimination among resilience categories were: DHW and Productivity (Figure 21). These two stressors were higher in sites identified as having low resilience than in sites having high resilience. The standard deviation around those two stressors were also highly correlated (>0.7). However, they were correlated with the second axis of the ordination, indicating that those variables explained variation among sites within the same resilience category (Figure 21). Finally, another important variable in this discriminant analysis was distance and area of nursery habitats (see appendix 4 for complete connectivity standardized variables per site), which was a variable that correlated with high resilience sites (Figure 21).

(A)



(B)

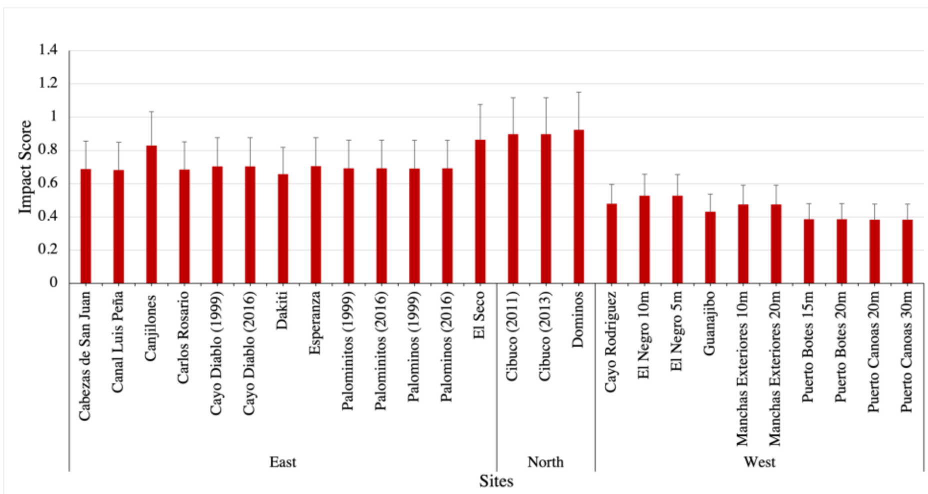


Figure 20. Average (+/- S.E.) stressor scores for different reef sites around Puerto Rico. Sites were discriminated between those sampled during even (A) and odd (B) years as per indicators.

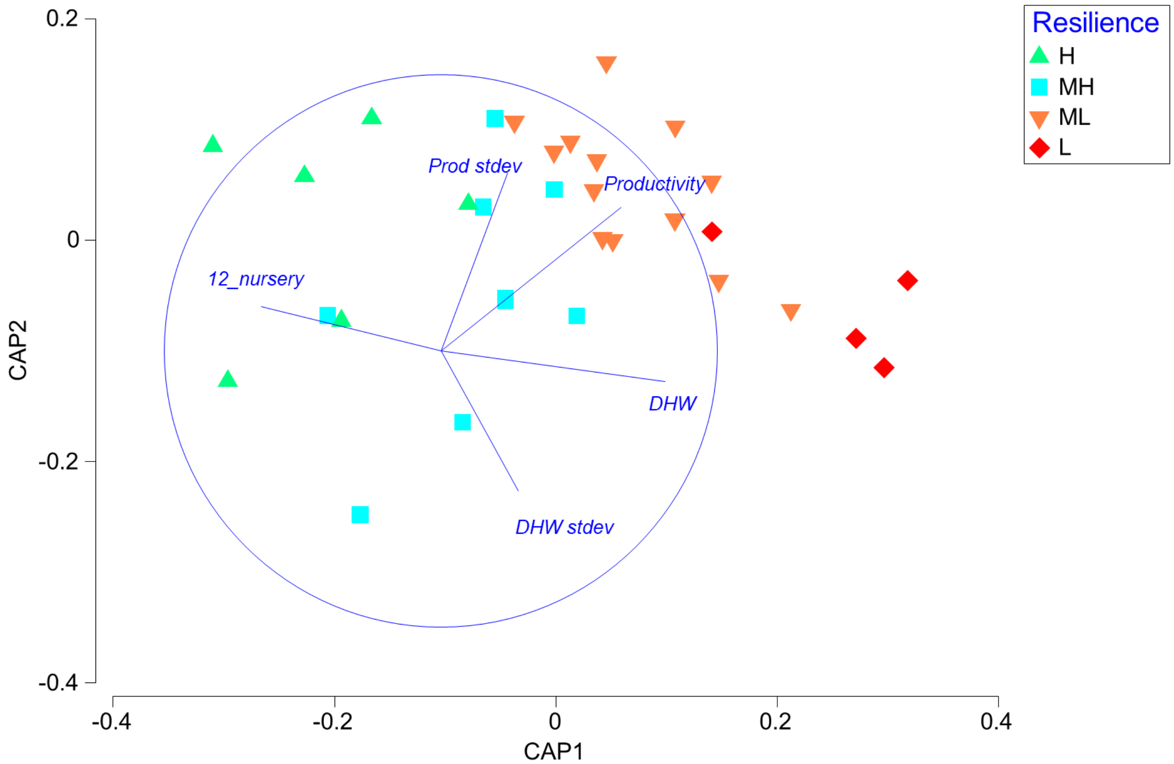


Figure 21. Canonical Analysis of Principal Coordinates (CAP) of centroids per site and year, discriminated based on the resilience score. Vectors indicate correlation of original normalized stressors with the first two axes of the ordination. Only stressors with > 70% correlation are shown.

CONCLUSIONS

Resilience Analysis

- Most reef sites that were analyzed for historical trends (1999-2019), showed a significant decrease of resilience scores (from high to low). These trends were observed using uni and multivariate approaches. Resilience indicators related to this decrease varied between sites and locations, however, percentage of coral cover and percentage of Peyssonneliaceae consistently showed in all analyses.

- At the site scale, there was not a clear effect of Hurricane Maria on the resilience scores, as the comparison before and after Maria was highly variable between sites, locations and regions.

- When stratified by depth, however, decreases of resilience were evident for shallow and deep strata but not for the very shallow stratum, which was unexpected since effects of hurricane are more likely to affect shallow areas of the reef.

- Patterns of spatial and temporal variation were different across sites and locations. Similarly, and despite some commonalities, indicators associated with those changes also varied across locations and sites. Despite these differences, coral and macroalgae cover such as *Lobophora* and the nuisance encrusting algae Peyssonneliaceae were main resilience indicators across most sites.

- Resilience indicators related to benthic fauna and flora were more important than those related to fish assemblages. This supports the fact that habitat-building invertebrates are key to target in resilience-based management. However, fish species like parrotfishes and damselfishes were important indicators explaining differences in overall resilience for some sites in Guanica, Ponce, and Tourmaline. The role of predatory fish assemblages in driving resilience could be underestimated in this study due to lack of pre-2004 data, the current overfished status of stocks, and low detection probabilities during belt transect reef fish visual censuses.

- Stressors related observed spatial and temporal patterns of resilience scores were: DHW and Productivity. Both were related to sites classified as low and medium-low resilience sites.

- The only connectivity variable related to high resilience sites was distance to nursery (i.e., mangroves and seagrasses).

- This report contains a recent resilience classification of most PRCRMP sites (Table 10), which can be used by managers to make decisions about a wide array of management actions and or plans. Below some examples based on the original managers questions raised during the stake holders' workshops.

Managers questions:

Out of six questions raised by DNER's managers during the stakeholders' workshops, data provided in this study can answer five as detailed below.

I. Identify ideal reefs to be used as restoration sites.

- Reply: Table 10 can be used as a guide of sites with higher resilience, as those identified as having high resilience can be the target of restoration efforts. Even though all regions had sites with high or -medium-high resilience, it is also important to consider that lower values of stressors were identified in the west and southwest. Our results also suggest that selection of sites should take into consideration those with low productivity and historical DHW but close to nursery habitats (mangrove and seagrasses). Finally, the decision to restore sites should also include logistic considerations, like proximity to support facilities. In addition, the results of this study indicate that a resilience-based management at reef-site small spatial scales (<1km) should be applied because resilience patterns of spatial and temporal variation (and related indicators) are site-dependent. This supports the strategy of creating small delimitations within MPAs (ex. recovery zones and/or integral protection zones) were recreational uses and fishing are limited. These areas also should consider connectivity with broader nursery habitat areas as it was correlated to high resilience sites.

II. Evaluate the effectiveness of MPAs in maintaining or increasing resilience indicators. This evaluation could be done by comparing temporal trends of resilience indicators inside and outside MPAs.

- Reply: This question is difficult to evaluate since all sites (except one) with enough temporal data (11) are within MPAs. As described in the section of historical analysis, trends of resilience scores were variable among all sites and locations, limiting a general conclusion about the generalized effect of MPAs on resilience scores. An interesting case is the location of Ponce that had two sites: one within MPA (West Reef) and another (Derrumbadero) outside the MPA. In that case, resilience scores were very different (higher in Derrumbadero than West Reef) until 2005. After that date, patterns of temporal variation were similar in both sites, suggesting that those patterns were unrelated to the presence of an MPA or not. However, extreme care must be taken, if site comparisons for the MPA factor are not replicated (i.e., one site per MPA condition).

III. Identify places where new MPAs should be located. This could be achieved by identifying places of high resilience which are not currently located inside MPAs.

- Reply: As per question 1, that would be those sites identified in Table 10 as having High or Medium High resilient scores and that do not actually belong to an MPA (Table 3). Also, it is important to take into consideration stressors and connectivity values.

IV. Resolve the priority disparities that exist among different government and federal organizations in terms of their management and conservation efforts. This resilience assessment could be used as a quantitative tool to homogenize the priorities among different organizations.

- Reply: The reefs identified here as highly resilient could be used by state and federal agencies to define priorities.

V. Identify the percentage of high resilient reefs that are currently located within an MPA.

- Reply: This is the inverse of point 3 above and could be done in the same process. 3 out of 7 reefs identified as high resilient reefs are not inside an MPA. These are: El Seco, Guanajibo and Dominos. Out of those three, Guanajibo is the reef with the lowest impact score.

VI. Use patterns of spatial variation of resilience status within MPAs to develop zonation uses.

- Reply: This cannot be done within this exercise as it would require smaller-scale assessments within different MPAs.

Database and the PRCMP:

- As a direct consequence of the data compilation and curation performed during the execution of this project all PRCRMP is now readily and easily available through different web portals.

- Stressor data continues to be limited. Monitoring Programs such as the PRCRMP should continue to pursue the integration of water quality monitoring to identify the drivers of change and identify best management practices.

- Sampling frequencies of the PRCRMP should be consistent among sites to increase the ability to test for hypotheses of temporal changes related to specific disturbances (i.e., all sites visited during the same year, when possible). Recent efforts of the DNER Coral Program to conduct the monitoring cycle (all 42 stations) in one year should be supported.

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APPENDICES

Appendix 1. List of people invited to the resilience assessment workshops.

Name	**Organization**	**Position**
Edgardo L. Belardo Ayala	DNER	DNER MPA Manager
Edwin Avila Gonzalez	DNER	DNER MPA Manager
Eloy Martinez Rivera	DNER	DNER MPA Manager
Farel S. Velazquez Cancel	DNER	DNER MPA Manager
Gaspar Pons Cintron	DNER	DNER MPA Manager
Gerardo Hernandez Guzman	DNER	DNER MPA Manager
Hecsor A. Serrano Delgado	DNER	DNER MPA Manager
Herminio A. Díaz Serrano	DNER	DNER MPA Manager
Humberto Figueroa Carrasquillo	DNER	DNER MPA Manager
Ibrahim Sued Causade	DNER	DNER MPA Manager
Idelfonso Ruiz Valentin	DNER	DNER MPA Manager
Jorge Canabal Perez	DNER	DNER MPA Manager
Jose R. Roman Soto	DNER	DNER MPA Manager

Juan E. Casanova Morales	DNER	DNER MPA Manager
Manuel A. Corbet Nieves	DNER	DNER MPA Manager
Manuel A. Velez Velez	DNER	DNER MPA Manager
Marinelly Valentin Sivico	DNER	DNER MPA Manager
Miguel A. Nieves Soto	DNER	DNER MPA Manager
Ricardo J. Colón Rivera	DNER	DNER MPA Manager
WetsyI Cordero Nazario	DNER	DNER MPA Manager
Tania M. Metz Estrella	DNER	DNER Employee
Ernesto L. Diaz	DNER	DNER Employee
Ernesto M. Olivares Gomez	DNER	DNER Employee
Aitza E. Pabon Valentin	DNER	DNER Employee
Aitza E. Pabon Valentin	DNER	DNER Employee
Angel Dieppa Ayala	DNER	DNER Employee
Alberto Mercado Vargas	DNER	DNER Employee
Darien López Ocasio	DNER	DNER Employee

Jenny E. Vazquez Morales	DNER	DNER Employee
Pablo Meléndez Hernández	DNER	DNER Employee
Geovanni Andujar Acosta	DNER	DNER Employee
Jose A. Rivera Ocasio	DNER	DNER Employee
Jose E. Casanova Morales	DNER	DNER Employee
Maritza Cintron Acevedo	DNER	DNER Employee
Robert Matos Morales	DNER	DNER Employee
Luis A. Encarnacion Santiago	DNER	DNER Employee
Myrna Aponte Reyes	DNER	DNER Employee
Richard Pimentel Burgos	DNER	DNER Employee
Samarith Sanchez Rivera	DNER	DNER Employee
Felipe Cuevas Vergara	DNER	DNER Employee
Damarys Del Rio Santiago	DNER	DNER Employee
Edwin Rodriguez Sanchez	DNER	DNER Employee
Felipe Cuevas Vergara	DNER	DNER Employee

Jose A. Colon Morales	DNER	DNER Employee
Kelvin Serrano Rodriguez	DNER	DNER Employee
Luis Bauzo Feliciano	DNER	DNER Employee
Maria de L. Olmeda Marrero	DNER	DNER Employee
Maribel Rodriguez Cruz	DNER	DNER Employee
Oberto Ruiz Romero	DNER	DNER Employee
Ramon Del Moral Lebron	DNER	DNER Employee
Samuel Garcia Vazquez	DNER	DNER Employee
Vilmarie Roman Padro	DNER	DNER Employee
Nilda Peña Ortíz	DNER	DNER Employee
Nilda M. Jimenez Marrero	DNER	DNER Employee
Carlos E. Diez Gonzalez	DNER	DNER Employee
Damaris Delgado Lopez	DNER	DNER Employee
Osvaldo A. Quinones Martinez	DNER	DNER Employee
Coralys D. Ortiz Maldonado	DNER	DNER Employee

Jinnie L. Nieves Reyes	DNER	DNER Employee
Raul Santini Rivera	DNER	DNER Employee
Vanessa I. Marrero Santiago	DNER	DNER Employee
Dr.Ernesto Weil	Department of Marine Sciences UPRM	Scientist
Alfredo Montanez	Sociedad Ambiente Marino	Scientist
Edwin Hernandez-Delgado	Sociedad Ambiente Marino	Scientist
Eloy Martinez	Bosque de Guanica	Scientist
Roberto Viqueira	Portectores de Cuenca	Scientist
Wanda Crespo	Estudios Tecnicos	Scientist
Luis Villanueva-Cubero	Independent Scientist	Scientist
Alida Ortiz	Independent Scientist	Scientist
Reni Garcia	Reef Restauration	Scientist
Dr. Roy Armstrong	Department of Marine Sciences UPRM	Scientist
Yasmin Detres	Department of Marine Sciences UPRM	Scientist
William Hernandez	University of Puerto Rico	Scientist
Clark E Sherman	Department of Marine Sciences UPRM	Scientist
Rene Esteves	Sea Grant	Scientist
Miguel Garcia-Bermudez	Fish and Wildlife	Scientist
Orian Tzadik	PEW Trust	Scientist
Julio Morell	Department of Marine Sciences UPRM	Scientist
Graciela Garcia-Moliner	Sea Map	Scientist
Aida Rosario	Independent Scientist	Scientist

Veronica Seda	Independent Scientist	Scientist
Edgardo Ojeda	University of Puerto Rico	Scientist
Richard Appeldoorn	Department of Marine Sciences UPRM	Scientist
Karen Serrano	DNER	DNER Employee
Dr.Nikolaos Schizas	Department of Marine Sciences UPRM	Scientist
Dr.Govind Nadathur	Department of Marine Sciences UPRM	Scientist
Lisamarie Carrubba	NOAA	Scientist
Humberto Figueroa	Independent Scientist	Scientist
Aileen T. Velazco	DNER	DNER Employee
Damaris Torres Pulliza	Sinoptica	Scientist
Jeiger Medina Muñiz	Independent Scientist	Scientist
Mary Ann Lucking	Coralations	Scientist
Bernarnd Rosado	Independent Scientist	Scientist
Misael Feliciano	Independent Scientist	Scientist
Joselyn Polanco	Independent Scientist	Scientist
Sylvia V. Nieves	Independent Scientist	Scientist
Ana Roman	Fish and Wildlife	Scientist
Pedro de Leon	Independent Scientist	Scientist
Sorren Varney	Independent Scientist	Scientist
Lyliana Crespo	Independent Scientist	Scientist
Edwin Quiñones	Independent Scientist	Scientist
Leonor Alicea	Independent Scientist	Scientist
Jorge Coll	Independent Scientist	Scientist
Waleksa Llabres	Fideicomiso	Scientist
Arlyn Fuentes	Fideicomiso	Scientist

José A. Norat	University of Puerto Rico	Scientist
Samuel Caraballo	Independent Scientist	Scientist
Suhey Ortiz	Department of Marine Sciences UPRM	Scientist
Walter E. Soler	Ambienta	Scientist
Gloria Ortiz	Independent Scientist	Scientist
José Caballero	Independent Scientist	Scientist
Gloria N.Toro	Junta de Calidad Ambienta	Scientist
Patrick Reyes	Independent Scientist	Scientist
Antonio L. Ortiz	University of Puerto Rico	Scientist
Evelyn Cepeda Pérez	Independent Scientist	Scientist
Michael Nemeth	NOAA	Scientist
Ilse Sanders	Independent Scientist	Scientist
Plablo Méndez Lazco	University of Puerto Rico	Scientist
Emmanuel Irizarry	Independent Scientist	Scientist
Beverly Yoshioka	Fish and Wildlife	Scientist
Julia Nignucci Sánchez	Independent Scientist	Scientist
Lisamarie Carubba	NOAA	Scientist
Héctor C. Horta	Independent Scientist	Scientist
Efra Figueroa	Sea Grant	Scientist
Conrado M. Calzada	Universidad Catolica de Puerto Rico	Scientist
Melissa Meléndez	University of Puerto Rico	Scientist
Paul Sturm	Ridge to Reef	Scientist
José L. Orengo Gómez	Excursiones Bornquen	Scientist
Miguel Canals	Independent Scientist	Scientist
Rina Haupfeld	Independent Scientist	Scientist
Vivian Padilla Rosado	Independent Scientist	Scientist
Ernesto Otero	Department of Marine Sciences UPRM	Scientist
GeoAmbiente	GeoAmbiente	NGO

AECIMA- Asociación de Estudiantes de Ciencias Marinas	AECIMA- Asociación de Estudiantes de Ciencias Marinas	NGO
Arrecifes de la Isla Verde	Arrecifes de la Isla Verde	NGO
Conservación con Ciencia	Conservación con Ciencia	NGO
Coralations	Coralations	NGO
Estuario de la Bahía de San Juan	Estuario de la Bahía de San Juan	NGO
Grupo 7 Quillas-CRES	Grupo 7 Quillas-CRES	NGO
HJR Reefscaping	HJR Reefscaping	NGO
ISER	ISER	NGO
OPAS	OPAS	NGO
Para La Naturaleza	Para La Naturaleza	NGO
Protectores de Cuencas	Protectores de Cuencas	NGO
Proyecto Reverdece tu Comunidad	Proyecto Reverdece tu Comunidad	NGO
Reef Check	Reef Check	NGO
Sea Grant	Sea Grant	NGO
Sociedad Ambiente Marino (SAM)	Sociedad Ambiente Marino (SAM)	NGO
TNC	TNC	NGO
VIDAS	VIDAS	NGO
Amigos de Tras Palmas, Inc (A.C.)	Amigos de Tras Palmas, Inc (A.C.)	NGO
Surf Rider	Surf Rider	NGO
Fideicomiso de Conservación e Historia de Vieques (A.C.)	Fideicomiso de Conservación e Historia de Vieques (A.C.)	NGO
Coalición Pro Corredor Ecologico del Noreste.	Coalición Pro Corredor Ecologico del Noreste.	NGO
Isla Mar	Isla Mar	NGO
Sea Ventures Dive Center	Sea Ventures Dive Center	NGO

Appendix 2

List of indicators that did not have available data.

Recruitment	**No data available**
Abundance vulnerable	Might be correlated with Resistant Coral Species
Bacterial presence	No data available
Coral disease (Incidence)	No data available (new cases/per time/per area)
Commercially important species	List of commerciallly important species keep changing
Relative abundance of S. planifrons	Data no copnsitent through time
Fish recruits	No data available
Proportion of loose vs consolidated substrate	No data available

Appendix 3.1. Benthic organisms identified to species level

#	Species		Species		Species		Species
1	*Agelas citrina*	49	*Diploria labyrinthiformis*	97	*Mycale laxissima*	145	*Valonia ventricosa*
2	*Agelas clathrodes*	50	*Dragmacidon reticulatum*	98	*Neofibularia nolitangere*	146	*Verongula reiswigi*
3	*Agelas conifera*	51	*Dysidea etheria*	99	*Neopetrosia carbonaria*	147	*Verongula rigida*
4	*Agelas dispar*	52	*Dysidea janiae*	100	*Neopetrosia proxima*	148	*Wrangelia bicuspidata*
5	*Agelas sceptrum*	53	*Ectyoplasia ferox*	101	*Neopetrosia rosariensis*	149	*Xestospongia muta*
6	*Agelas sventres*	54	*Erythropodium caribaeorum*	102	*Niphates alba*		
7	*Agelas tubulata*	55	*Eunicea calyculata*	103	*Niphates caycedoi*		
8	*Aiolochroia crassa*	56	*Eunicea flexuosa*	104	*Niphates digitalis*		
9	*Amphimedon caribica*	57	*Eunicea mammosa*	105	*Niphates erecta*		
10	*Amphimedon compressa*	58	*Eunicea pallida*	106	*Oculina diffusa*		
11	*Amphimedon viridis*	59	*Eunicea succinea*	107	*Palythoa caribaeorum*		
12	*Antillogorgia acerosa*	60	*Eunicea tourneforti*	108	*Palythoa grandis*		
13	*Antillogorgia americana*	61	*Eusmilia fastigiata*	109	*Petrosia pellasarca*		
14	*Antillogorgia bipinnata*	62	*Geodia neptuni*	110	*Petrosia weinbergi*		
15	*Antillogorgia rigida*	63	*Gorgonia mariae*	111	*Phorbas amaranthus*		
16	*Aplysina archeri*	64	*Gorgonia ventalina*	112	*Phymanthus crucifer*		
17	*Aplysina cauliformis*	65	*Halimeda discoidea*	113	*Plakortis angulospiculatus*		
18	*Aplysina fistularis*	66	*Halimeda tuna*	114	*Plakortis halichondrioides*		
19	*Aplysina fulva*	67	*Halisarca caerulea*	115	*Plexaura homomalla*		
20	*Aplysina lacunosa*	68	*Helioseris cucullata*	116	*Plexaura kukenthali*		
21	*Asparagopsis taxiformis*	69	*Iotrochota arenosa*	117	*Plexaurella nutans*		
22	*Bartholomea annulata*	70	*Iotrochota birotulata*	118	*Prosuberites laughlini*		
23	*Biemna caribea*	71	*Ircinia campana*	119	*Pseudoplexaura flagellosa*		
24	*Briareum asbestinum*	72	*Ircinia felix*	120	*Pseudoplexaura wagenaari*		
25	*Callyspongia armigera*	73	*Ircinia strobilina*	121	*Pterogorgia guadalupensis*		
26	*Callyspongia fallax*	74	*Isophyllia rigida*	122	*Ptilocaulis walpersii*		
27	*Callyspongia plicifera*	75	*Isophyllia sinuosa*	123	*Ricordea florida*		
28	*Callyspongia tenerrima*	76	*Lebrunia neglecta*	124	*Sargassum hystrix*		
29	*Callyspongia vaginalis*	77	*Lobophora variegata*	125	*Sargassum natans*		
30	*Caulerpa racemosa*	78	*Madracis auretenra*	126	*Scolymia cubensis*		
31	*Chondrilla caribensis*	79	*Madracis carmabi*	127	*Scopalina ruetzleri*		
32	*Chondrosia collectrix*	80	*Madracis decactis*	128	*Siderastrea radians*		
33	*Cinachyrella apion*	81	*Madracis formosa*	129	*Siderastrea siderea*		
34	*Cinachyrella kuekenthali*	82	*Madracis pharensis*	130	*Smenospongia aurea*		
35	*Clathria venosa*	83	*Madracis senaria*	131	*Smenospongia conulosa*		
36	*Cliona aprica*	84	*Manicina areolata*	132	*Solenastrea bournoni*		
37	*Cliona caribbaea*	85	*Martensia pavonia*	133	*Spheciospongia vesparium*		
38	*Cliona delitrix*	86	*Millepora alcicornis*	134	*Spirastrella coccinea*		
39	*Cliona laticavicola*	87	*Millepora complanata*	135	*Spirastrella hartmani*		
40	*Cliona tenuis*	88	*Millepora squarrosa*	136	*Stephanocoenia intersepta*		
41	*Cliona varians*	89	*Monanchora arbuscula*	137	*Stylaster roseus*		
42	*Colpophyllia natans*	90	*Muricea atlantica*	138	*Stypopodium zonale*		
43	*Cribrochalina vasculum*	91	*Muricea elongata*	139	*Svenzea zeai*		
44	*Dendrogyra cylindrus*	92	*Muricea muricata*	140	*Tedania klausi*		
45	*Desmapsamma anchorata*	93	*Muricea pinnata*	141	*Thalassia testudinum*		
46	*Dichocoenia stokesii*	94	*Muriceopsis flavida*	142	*Timea micraster*		
47	*Dichotomaria marginata*	95	*Mussa angulosa*	143	*Topsentia ophiraphidites*		
48	*Dictyonella funicularis*	96	*Mycale laevis*	144	*Trididemnum solidum*		

Appendix 3.2 Benthic organisms identified to other taxonomic levels different to species.

#	Domain	Class	Subclass	Order	Family	Genus
1	Eukaryota	Demospongiae	Octocorallia	Scleractinia	Meandrinidae	*agelas*
2		Anthozoa				*amphiroa*
3		Ascidiacea				*anemone*
4						*aplysina*
5						*ascidian*
6						*biemna*
7						*callyspongia*
8						*caulerpa*
9						*clathria*
10						*cliona*
11						*condominium*
12						*desmapsamma*
13						*dictyonella*
14						*dictyota*
15						*diplastrella*
16						*eudistoma*
17						*eunicea*
18						*galaxaura*
19						*gracilaria*
20						*haliclona*
21						*halimeda*
22						*halisarca*
23						*ircinia*
24						*jania*
25						*lobophora*
26						*madracis*
27						*millepora*
28						*neopetrosia*
29						*niphates*
30						*padina*
31						*petrosia*
32						*peyssonnelia*
33						*plakortis*
34						*plexaura*
35						*plexaurella*
36						*pseudoplexaura*
37						*pterogorgia*
38						*ramicrusta*
39						*scolymia*
40						*stypopodium*
41						*suberea*
42						*topsentia*
43						*udotea*
44						*verongula*

Appendix 4.1 Fish organisms identified to species level

#	Species	#	Species	#	Species	#	Species
1	*Abudefduf saxatilis*	49	*Coryphopterus glaucofraenum*	97	*Holocentrus rufus*	145	*Priacanthus arenatus*
2	*Abudefduf taurus*	50	*Coryphopterus lipernes*	98	*Hypleurochilus bermudensis*	146	*Prognathodes aculeatus*
3	*Acanthemblemaria aspera*	51	*Coryphopterus personatus*	99	*Hypoplectrus aberrans*	147	*Prognathodes aya*
4	*Acanthemblemaria chaplini*	52	*Cryptotomus roseus*	100	*Hypoplectrus chlorurus*	148	*Pseudupeneus maculatus*
5	*Acanthemblemaria maria*	53	*Ctenogobius saepepallens*	101	*Hypoplectrus gummigutta*	149	*Pterois volitans*
6	*Acanthemblemaria spinosa*	54	*Decapterus macarellus*	102	*Hypoplectrus guttavarius*	150	*Rypticus saponaceus*
7	*Acanthostracion polygonius*	55	*Diodon holocanthus*	103	*Hypoplectrus indigo*	151	*Sargocentron coruscum*
8	*Acanthostracion quadricornis*	56	*Diodon hystrix*	104	*Hypoplectrus nigricans*	152	*Sargocentron vexillarium*
9	*Acanthurus chirurgus*	57	*Echeneis naucrates*	105	*Hypoplectrus puella*	153	*Scarus coelestinus*
10	*Acanthurus coeruleus*	58	*Elacatinus dilepis*	106	*Hypoplectrus unicolor*	154	*Scarus coeruleus*
11	*Acanthurus tractus (bahianus)*	59	*Elacatinus evelynae*	107	*Kyphosus sectatrix*	155	*Scarus guacamaia*
12	*Aetobatus narinari*	60	*Elacatinus horsti*	108	*Lachnolaimus maximus*	156	*Scarus iseri*
13	*Aluterus scriptus*	61	*Elacatinus saucrus*	109	*Lactophrys bicaudalis*	157	*Scarus taeniopterus*
14	*Amblycirrhitus pinos*	62	*Epinephelus adscensionis*	110	*Lactophrys trigonus*	158	*Scarus vetula*
15	*Anisotremus surinamensis*	63	*Epinephelus guttatus*	111	*Lactophrys triqueter*	159	*Scomberomorus cavalla*
16	*Anisotremus virginicus*	64	*Epinephelus striatus*	112	*Liopropoma rubre*	160	*Scomberomorus regalis*
17	*Apogon maculatus*	65	*Equetus lanceolatus*	113	*Lutjanus analis*	161	*Scorpaena plumieri*
18	*Apogon townsendi*	66	*Equetus punctatus*	114	*Lutjanus apodus*	162	*Serranus baldwini*
19	*Aulostomus maculatus*	67	*Gerres cinereus*	115	*Lutjanus cyanopterus*	163	*Serranus tabacarius*
20	*Balistes vetula*	68	*Ginglymostoma cirratum*	116	*Lutjanus griseus*	164	*Serranus tigrinus*
21	*Bodianus rufus*	69	*Gnatholepis thompsoni*	117	*Lutjanus jocu*	165	*Sparisoma atomarium*
22	*Bothus lunatus*	70	*Gramma loreto*	118	*Lutjanus mahogoni*	166	*Sparisoma aurofrenatum*
23	*Calamus calamus*	71	*Gymnothorax funebris*	119	*Lutjanus synagris*	167	*Sparisoma chrysopterum*
24	*Calamus pennatula*	72	*Gymnothorax miliaris*	120	*Malacanthus plumieri*	168	*Sparisoma radians*
25	*Cantherhines macrocerus*	73	*Gymnothorax moringa*	121	*Malacoctenus gilli*	169	*Sparisoma rubripinne*
26	*Cantherhines pullus*	74	*Haemulon album*	122	*Malacoctenus triangulatus*	170	*Sparisoma viride*
27	*Canthidermis sufflamen*	75	*Haemulon aurolineatum*	123	*Melichthys niger*	171	*Sphoeroides greeleyi*
28	*Canthigaster rostrata*	76	*Haemulon carbonarium*	124	*Microspathodon chrysurus*	172	*Sphoeroides testudineus*
29	*Carangoides bartholomaei*	77	*Haemulon chrysargyreum*	125	*Monacanthus tuckeri*	173	*Sphyraena barracuda*
30	*Caranx crysos*	78	*Haemulon flavolineatum*	126	*Mulloidichthys martinicus*	174	*Stegastes adustus*
31	*Caranx hippos*	79	*Haemulon macrostomum*	127	*Muraena robusta*	175	*Stegastes fuscus*
32	*Caranx latus*	80	*Haemulon melanurum*	128	*Mycteroperca interstitialis*	176	*Stegastes leucostictus*
33	*Caranx lugubris*	81	*Haemulon parra*	129	*Mycteroperca tigris*	177	*Stegastes partitus*
34	*Caranx ruber*	82	*Haemulon plumierii*	130	*Mycteroperca venenosa*	178	*Stegastes planifrons*
35	*Carcharhinus perezii*	83	*Haemulon sciurus*	131	*Myrichthys breviceps*	179	*Stegastes variabilis*
36	*Centropyge argi*	84	*Haemulon squamipinna*	132	*Myrichthys ocellatus*	180	*Stephanolepis hispidus*
37	*Cephalopholis cruentata*	85	*Haemulon vittatum*	133	*Myripristis jacobus*	181	*Stephanolepis setifer*
38	*Cephalopholis fulva*	86	*Halichoeres bivittatus*	134	*Neoniphon marianus*	182	*Synodus intermedius*
39	*Chaenopsis ocellata*	87	*Halichoeres cyanocephalus*	135	*Ocyurus chrysurus*	183	*Synodus saurus*
40	*Chaetodipterus faber*	88	*Halichoeres garnoti*	136	*Odontoscion dentex*	184	*Thalassoma bifasciatum*
41	*Chaetodon capistratus*	89	*Halichoeres maculipinna*	137	*Ophioblennius atlanticus*	185	*Urobatis jamaicensis*
42	*Chaetodon ocellatus*	90	*Halichoeres poeyi*	138	*Ophioblennius macclurei*	186	*Xanthichthys ringens*
43	*Chaetodon sedentarius*	91	*Halichoeres radiatus*	139	*Paralabrax dewegeri*		
44	*Chaetodon striatus*	92	*Hemiramphus brasiliensis*	140	*Paranthias furcifer*		
45	*Chromis cyanea*	93	*Heteropriacanthus cruentatus*	141	*Pareques acuminatus*		
46	*Chromis insolata*	94	*Holacanthus ciliaris*	142	*Pempheris schomburgkii*		
47	*Chromis multilineata*	95	*Holacanthus tricolor*	143	*Pomacanthus arcuatus*		
48	*Clepticus parrae*	96	*Holocentrus adscensionis*	144	*Pomacanthus paru*		

Appendix 4.2 Fish organisms identified to other taxonomic levels different to species.

#	Family	Genus	Unknown
1	Blenniidae	*aluterus*	Unidentified spp.(fish)
2		*apogon*	
3		*calamus*	
4		*chromis*	
5		*coryphopterus*	
6		*epinephelus*	
7		*gobiosoma*	
8		*gymnothorax*	
9		*haemulon*	
10		*halichoeres*	
11		*hypoplectrus*	
12		*kyphosus*	
13		*malacoctenus*	
14		*monacanthus*	
15		*muraena*	
16		*mycteroperca*	
17		*priacanthus*	
18		*scarus*	
19		*serranus*	
20		*sphoeroides*	
21		*syngnathus*	
22		*liopropoma*	
23		*pempheris*	
24		*sparisoma*	

Appendix 5.1. Connectivity variables estimated for sites sampled during odd years. Reef area (A), heterogeneity type (B), distance to nursery (C), lobster connectivity (D), and yellowtail snapper connectivity (E).

Appendix 5.2 Connectivity variables estimated for sites sampled during even years. Reef area (A), heterogeneity type (B), distance to nursery (C), lobster connectivity (D), and yellowtail snapper connectivity (E).