Final Report

Puerto Rico Coral Reef Monitoring Program: Isla de Mona Survey 2020

CRCP State and Territorial Coral Reef Conservation Cooperative Agreement
NA17NOS4820037: Programmatic Activity 6 – Coral Reef Monitoring Program

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DNER's Coral Reef Conservation and Management Program has been an ongoing effort to conserve, manage, and protect coral reef ecosystems. The Program has monitored Puerto Rico's coral reefs since 1999, in order to collect important data that can be used to support management of coral reefs and associated ecosystems.

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I. Clarifications and changes from previous PRCRMP surveys

Corals

- Since the beginning of the PRCRMP in 1999, data on percent reef substrate cover by boulder star coral, *Montastrea annularis* and its two-sibling species, *M. faveolata* and *M. franksi* (Weil & Knowlton 1994) were reported as *Montastrea annularis* complex. The taxonomic classification of these species has changed, and are now under genus *Orbicella* (Huang et al., 2014). A decision was been made, (since 2018), to report the data on reef substrate cover by the three separate species. The three species are reported as *Orbicella annularis, O. faveolata* and *O. franksi* (Ellis & Solander, 1786).
- Nomenclature changes have been adopted for the symmetrical and knobby brain corals, previously reported as *Diploria strigosa* and *D. clivosa* now under the accepted binomial name *Pseudodiploria strigosa* and *P. clivosa* (Dana, 1846), and for *Madracis auretenra* (Locke, Weil & Coates, 2007) previously reported under the synonym *M. mirabilis* (sensu Wells, 1973).
- In several reports (1999, 2001a, 2009, 2016) the fire corals, *Millepora spp* were included under a "Hydrocorals" benthic category. In all other reports, the data on percent cover by *Millepora spp*. was included as part of the "hard corals" category. Readers should be advised of this when comparing the live coral cover between annual monitoring surveys.

Fish

Since the 2018 report, taxonomic updates on fish species names have been applied to the five-band surgeonfish, *Acanthurus bahianus*, now reported as *A. tractus*, and the striped parrotfish, *Scarus iserti* now reported as *S. iseri*. *Acanthurus tractus* was revalidated based on genetic and morphological data (Bernal and Rocha, 2011). *Acanthurus bahianus* is now considered to be endemic to Brazil. *Scarus iserti* is now considered a synonym of *S. iseri* (Rocha et al., 2012). Previous reports of the coney (*Cephalopholis fulva*, Linnaeus, 1758), graysby (*Cephalopholis cruentatus*, Lacepede, 1802) and sharknose goby, *Elacatinus evelynae* (Bohlke and Robins, 1968) under their synonyms *Epinephelus fulva*, *E. cruentatus* and *Gobiosoma evelynae*, respectively have been reverted to their presently accepted names *C. fulva* (Linnaeus, 1758), *C. cruentata* (Lacepede, 1802) and *E. evelynae* (Bohlke and Robins, 1968; in Froese and Pauly, 2018).

Invertebrates

In the 2018 PRCRMP Final Report (Garcia-Sais et al., 2018) density data for motile megabenthic invertebrates were reported from 20x3m belt-transects. In all previous reports, including this Isla de Mona Survey 2020 (this volume) motile megabenthic invertebrates were reported from the 10x3m belt-transects. 20x3m belt-transects only survey commercially important fishes.

Data Availability

Data collected since 1999 as part of the PRCRMP has been compiled and is now publicly available for download. Downloadable files include a data dictionary, all benthic and fish data (including biomass estimations derived from fish size-frequency data), and a Site Classification Database including various PRCRMP metadata. These data are available through the File Transfer Protocol (FTP) at the following link: ftp://ftp.nodc.noaa.gov/nodc/archive/arc0147/0204647/

II. Executive Summary

This work represents the fourth monitoring survey of coral reef communities from Isla de Mona 20 years after the original baseline survey in 2000 and one decade after the previous survey in 2010. Monitoring surveys were performed on existing sets of permanent transects at Playa Mujeres (MUJE20) and Las Carmelitas (CARM10) applying the standard PRCRMP protocol. A new baseline survey was produced off Playa Sardinera (SARD30). Mean substrate cover by hard corals was highest at SARD30 (12.52%) and lowest at MUJE20 (11.07%). Live hard coral cover increased 24.8% at CARM10 and decreased 5.7% at MUJE20. Differences of coral cover measured at these reef stations were not statistically significant and suggest that the percent cover by hard corals appear to have remained stable during the past decade after their large-scale degradation associated with the 2005 regional coral bleaching event. Benthic algae, a mixed assemblage comprised by turf, red crustose calcareous, red coralline, fleshy brown, and green calcareous macroalgae was the dominant benthic category covering reef substrate at the three reef stations surveyed. Temporal variations in the taxonomic composition of the main algal components relative to the previous 2010 monitoring survey included a marked reduction of cover by cyanobacteria and sharp increments of cover by fleshy macroalgae (*Dictyota sp*.), red coralline algae (mixed assemblage) and crustose calcareous macrolgae, mostly *Ramicrusta sp*. at both stations.

A total of 66 fish species and one motile-megabenthic invertebrate (*Panulirus argus*) were identified within belt-transects from the three reef stations surveyed in Isla de Mona during 2020. The highest fish densities and species richness were observed from MUJE20 with means of 98.0 Ind/30m^2 and 21.6 Spp/30m^2, respectively. The trophic structure of the fish community was dominated by zooplanktivores in terms of mean densities, but opportunistic carnivores were represented by a more specious assemblage at all three stations. The hervibore fish assemblage was present from all reef stations but in relatively lower densities. Large demersal and pelagic predators were observed in low densities within belt-transects. These included nurse sharks (*Ginglymostoma cirratum*), yellowfin grouper (*Mycteroperca venenosa*), great barracuda (*Sphyraena barracuda*), and black jack (*Caranx lugubris*). Adult spiny lobsters (*P. argus*) were observed in and out of belt-transects at the three reef stations surveyed.

Temporal variations of fish densities and species richness were statistically signifficant at MUJE20 and CARM10. Differences were influenced by the lowest values (for both parameters) recorded during the 2020 survey, since their 2000 baseline survey at both stations. Fish density variations between monitoring surveys were largely driven by the sharp density decline of numerically dominant species, particularly masked goby (*Coryphopterus personatus*) and other small species with aggregated distributions (e.g. *Chromis cyanea, Thalassoma bifsciatum*) relative to previous surveys, particularly the 2010 survey when peak density and species richness were recorded at MUJE20 and CARM10. Sharp density reductions or absence of small schooling fishes, particularly *C. personatus* were documented (2017-19) for the majority of shallow reef systems included in the PRCRMP and appear to be related with displacement and/or mortality caused by surge and abrasion effects forced by recent hurricanes (e.g. Irma, Maria – 2017) and/or exceptionally strong winter storm events (e.g. Riley - 2018). Temporal variations of fish species richness were directly affected by the loss of small schooling species and perhaps indirectly regulated by potential trophic cascading effects. The effects of habitat degradation associated with the drastic reductions of live coral cover upon fish density and species richness for Isla de Mona reefs is still uncertain, since the present 2020 data are not statistically different from the 2000 baseline survey when live hard coral cover was at its record peak values.

III. Resúmen Ejecutivo

Este trabajo representa el cuarto evento de monitoreo de las comunidades arrecifales de Isla de Mona, 20 años luego de sus respectivas caracterizaciones de línea base en el 2000 y una década después del evento previo de monitoreo en el 2010. Trabajos rutinarios de monitoreo siguiendo el protocolo estandarizado del PRCRMP fueron aplicados en las estaciones de Playa Mujeres (MUJE20) y Las Carmelitas (CARM10). Una nueva caracterización de línea base se produjo en una estación al oeste de Playa Sardinera (SARD30). El porcentaje promedio de cobertura por corales pétreos fue más alto en SARD30 (12.52%) y más bajo en MUJE20 (11.07%). El promedio de cobertura de corales pétreos aumentó 24.8% para CARM10 y se redujo 5.7% en MUJE20. Ninguna de estas diferencias en cobertura de corales pétreos fue estadísticamente significativa y sugiere que los corales de Isla de Mona (para las estaciones estudiadas) han permanecido relativamente estables durante la pasada década luego de su degradación a gran escala asociada con el evento de blanqueamiento regional de corales en el 2005. Las algas bénticas, integradas por un conjunto mixto de algas de alfombra, algas rojas coralinas y calcáreas crustosas, algas pårdas carnosas, y algas verdes calcåreas fueron la categoría béntica dominante en términos de cobertura de sustrato arrecifal en las tres estaciones estudiadas. Se evidenciaron variaciones temporales marcadas en la composición taxonómica relativa de los componentes principales de algas bénticas en el monitoreo del 2020, relativos al monitoreo previo del 2010. Las variaciones incluyen una reducción marcada de la cobertura por cianobacterias acompañada por aumentos proporcionales en cobertura de algas párdas (*Dictyota sp*.), algas rojas coralinas, y algas crustosas calcáreas, mayormente *Ramicrusta sp*. en ambas estaciones.

Un total de 66 especies de peces y un invertebrado mótil-megabéntico (*Panulirus argus*) fueron identificados dentro de los transectos de correa realizados en las estaciones de Isla de Mona en el evento de monitoreo 2020. Las densidades y riqueza de especies más altas fueron observadas en MUJE20 con promedios de 98.0 Ind/30m^2 y 21.6 Spp/30m^2, respectivamente. La estructura trófica de la comunidad de peces estuvo dominada en términos de densidad en transectos de correa por zooplanctívoros, pero el grupo con más especies fue el de oportunistas carnívoros en todas las estaciones. El grupo de peces herbívoros estuvo presente en todas las estaciones pero en una densidad relativamente más baja. Depredadores demersales y pelágicos de gran tamaño fueron observados en baja densidad en los transectos estudiados. Estos incluyeron el tiburón gata (*Ginglymostoma cirratum*), mero guajíl (*Mycteroperca venenosa*), barracuda (*Sphyraena barracuda*) y jurél negro (*Caranx lugubris*). Langostas espinosas adultas (*P. argus*) fueron observadas dentro y/o fuera de los transectos de correa en las tres estaciones estudiadas.

Variaciones temporales en la densidad y riqueza de especies de peces resultaron estadísticamente significativas para MUJE20 y CARM10. Las diferencias fueron influenciadas por los valores mínimos (para ambos parámetros) obtenidos durante el evento de montoreo del 2020 relativo a todos los eventos previos en ambas estaciones. Las fluctuaciones de densidad estuvieron mayormente relacionadas a especies pequeñas numericamente dominantes, particularmente *Coryphopterus personatus*, *Chromis cyanea y Thalassoma bifasciatum*. Las diferencias para ambos parámetros en el 2020 resultaron significativas en relación a monitoreos previos, particularmente el del 2010 cuando los máximos de densidad y riqueza de especies fueron documentados para MUJE20 y CARM10. Estas reducciones en densidad de especies de peces pequeños han sido documentados durante los años recientes (2017-19) en el PRCRMP y aparentan estar relacionados a desplazamientos y/o mortalidad causados por los efectos de resaca y abrasión forzados por los huracanes recientes (Irma y María – 2017) y por tormentas de invierno con oleaje excepcional (e.g. Riley – 2018). Las variaciones temporales en riqueza de

especies de peces estuvieron directamente afectadas por la reducción en densidad de las especies pequeñas y quizá indirectamente por potenciales efectos tróficos de cascada. Los efectos de la degradación del hábitat béntico asociados a la pérdida de cobertura por corales pétreos vivos en relación a los patrones observados de densidad y riqueza de especies de peces es aún incierto. Esto se debe a que los datos actuales del monitoreo 2020 para ambos parámetros no son estadísticamente diferentes a los valores obtenidos en la caracterización de línea base del 2000 cuando la cobertura de corales pétreos estuvo en su máximo valor medido en estas estaciones.

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IV. Introduction

The coral reefs of Isla de Mona were included as part of the PRCRMP in 2000 with quantitative baseline surveys of reef stations at Playa Pájaros 10m, Playa Mujeres 20m, and Las Carmelitas 10m (Garcia-Sais et al., 2001). Subsequent monitoring surveys of Playa Mujeres and Las Carmelitas were performed in 2008, 2009 and 2010 (Garcia-Sais et al., 2008, 2009, 2010a). Major degradation of the coral reef communities at these stations were documented during the first decade of monitoring surveys. Total live hard coral cover declined 67.9% at Playa Mujeres and 63.4% at Las Carmelitas, along with corresponding increments of benthic algae and sponges. Marked shifts of coral species dominance were noted, driven by the acute mortality of the main structural reef building coral, the *Orbicella spp*. complex and the relatively higher resilience of other coral species to the causal factors of coral mortality. Reductions of coral cover by the *Orbicella spp*. complex were measured as 93.5% from Playa Mujeres and 83.6% from Las Carmelitas (Garcia-Sais et al., 2008). Given the magnitude of the live coral loss and species affected, such changes appeared to be related to the late 2005 regional coral bleaching event (Garcia-Sais et al., 2006, 2008; 2010b; Hernández-Delgado 2006, 2014; Hernández-Pacheco et al., 2011). Bruckner and Hill (2009) reported outbreaks of yellow-band (YBD) and white plague (WP) diseases from Isla de Mona corals immediately following the 2005 bleaching event, resulting in losses of 24 – 36% of the *Orbicella spp*. colonies and tissue losses higher than 50% in most of the remaining (*Orbicella spp*) colonies.

Similar scenarios of statistically significant reductions of live coral cover and/or phase shifts of coral species dominance were also documented from reef stations at Isla Desecheo (Botes 20m, Botes 15m, Canoas 30m), Ponce (Derrumbadero 20m), Mayaguez (Tourmaline 10m) (Garcia-Sais et al., 2006), La Parguera (Weil et al., 2009), and neritic reefs from Isla de Vieques (Esperanza 10m, Canjilones 20m) (Garcia-Sais et al., 2013). A common denominator that these reef stations share with Isla de Mona coral reefs is that they are located far from shore, and/or up current from major rivers and characterized by clear oligotrophic waters with minor influences of coastal development, sedimentation, and/or eutrophication. Garcia-Sais et al. (2017) reported that coral mortality associated with the 2005 regional bleaching event decreased with depth and water turbidity. They suggested that the measured losses of coral cover were influenced by the synergistic effects of higher than normal sea surface temperatures and UV radiation. To date, a pattern of live coral cover recuperation has emerged from a total of eight reef stations under the PRCRMP (Garcia-Sais et al., 2019), with coastal reefs influenced by estuarine conditions showing the higher recuperation rates.

This is the fourth monitoring survey of reefs stations from Isla de Mona, Playa Mujeres 20m (MUJE20) and Las Carmelitas 10m (CARM10), approximately 20 years after the baseline surveys were performed at these stations and includes a new baseline characterization of a reef station off Playa Sardinera 30m (SARD30).

V. Research Background

Qualitative inferences of the geographic distribution, types of reef formations, and general condition of coral reef systems from Isla de Mona were initially contributed by Cintrón and Thurston (1975). Canals et al. (1981) produced the first quantitative work on the coral reefs of Isla de Mona as part of an initiative by the PRDNER to develop an inventory of the Puertorrican coral reefs (Goenaga and Cintrón, 1979). Reef sites along the south and west sections of the island, including Playa de Pájaros, Uvero, Veríl de Carabinero, Playa Sardinera, Las Carmelitas and Monito were included in the study by Canals et al. (1981). Quantitative determinations of percent coral cover were produced from 1m^2 quadrat samplings within the 1 - 28m depth range in most reef locations. Marked variations of coral cover, both in terms of species composition, percent cover, and diversity were noted between reefs and between reef zones, or depths. The highest cover by live corals were reported from elkhorn (*Acropora palmata*) and finger coral (*Porites porites*) biotopes at the backreef of Playa de Pájaros (cover: 80%) and Playa Sardinera (up to 100%). Also, prominent zones of high coral cover were reported from the backreef of Las Carmelitas (36.8%), and the spur and groove reef zones at Playa Sardinera (34.2%) and Playa de Pájaros (29.5%). The exact geographic positions of these quantitative baseline assessments of the coral reef communities from Isla de Mona are unavailable.

As part of the initial stages of the PRCRMP, Garcia-Sais et al. (2001) produced the first georeferenced quantitative baseline characterizations of Isla de Mona coral reefs based on sets of permanent transects at Playa de Pájaros, Playa Mujeres (MUJE20) and Las Carmelitas (CARM10). The two latter reef stations are still being monitored as part of the PRCRMP (Garcia-Sais et al. (this volume). In 2001, mean substrate cover by live hard corals was highest at MUJE20 (mean: 36.4%), with a total of 14 scleractinian coral species and one hydrocoral (*Millepora alcicornis*) intercepted by transects. Boulder star coral (*Montastraea annularis* complex) was the dominant coral in terms of reef substrate cover with a mean of 21.5%, representative of 59.1% of the total cover by hard corals and the main reef building species. Live coral cover at CARM10 averaged 25.4%, with substrate cover from *M. annularis* complex accounting for 67.6% of the total.

Drastic reductions of live coral cover were measured from MUJE20 (67.9%) and CARM10 (59.9%) during the first coral monitoring survey (Garcia-Sais et al., 2008). Live coral losses measured at Isla de Mona stations were the highest in the PRCRMP and appeared to be related to the late 2005 regional coral bleaching event (Garcia-Sais et al. 2006, 2008; Bruckner and Hill, 2009; Hernández-Delgado et al., 2006; Hernández-Delgado, 2014). Full or partial bleaching was reported in 58% of all coral colonies examined by Hernández-Delgado from Isla de Mona coral reefs in December 2005 (Garcia-Sais et al., 2010).

Disease outbreaks of yellow-band (YBD) and white plague (WP) were noted for Isla de Mona corals between 1998 – 2001, being the *M. annularis* species complex (now *Orbicella spp*) the more affected taxa with prevalence of 40 – 60% (Bruckner and Hill, 2009). Prevalence of YBD and WP increased immediately after the 2005 coral bleaching event with 24 - 32% losses of entire *M. annularis* complex colonies and partial tissue losses on most of the remaining colonies from corals examined at Las Carmelitas, Playa Mujeres and Playa de Pájaros (Bruckner and Hill, 2009). An evaluation of the coral recovery potential of Isla de Mona reefs, based on coral recruitment patterns was produced by Hernández-Delgado (2014). The conclusion from this latter study was that coral recruitment was generally low and largely associated with short-lived brooder species, whereas recruitment of the reef building coral species was very limited. The results from these studies were consistent with the findings of the PRCRMP in that coral recuperation after the 2005 bleaching event from reef stations in Isla de Mona had not occurred (Garcia-Sais et al., 2008, 2009, 2010).

A total of 128 fish species have been identified from PRCRMP monitoring surveys (including species observed out of transects) in Isla de Mona at reef stations SARD30, MUJE20, and CARM10 (Garcia-Sais et al., 2001, 2008, 2009, 2010a). Mean density of reef fishes within belt-transects have shown variations from a minimum of 85.6 Ind/30m^2 at CARM10 in 2000 to a maximum of 394.6 Ind/30m^2 at MUJE20 in 2010. Statistically significant fish density differences have been associated with abundance fluctuations of numerically dominant species with highly aggregated distributions, such as the masked goby (*Coryphopterus personatus*), bluehead wrasse (*Thalassoma bifasciatum*) and creole wrasse (*Clepticus parrae*). These are not commercially important species and their temporal variability dynamics in coral reef systems have not been comprehensively studied.

From the PRCRMP fish metadata, Esteves-Amador (2013) suggested that the interannual density variability of these species was density-independent and appeared to be related with aspects of their recruitment dynamics and vulnerability to physical forcing factors, such as wave action and associated surge and abrasion effects. The sharp density declines of several small fish populations, documented in other stations around Puerto Rico, particularly *C. personatus* after the pass of hurricanes Mathew in 2016 (Garcia-Sais et al., 2017), Irma and Maria in 2017, and/or winter storm Riley in 2018 (Garcia-Sais et al., 2018, 2019) appear to support the physical forcing hypothesis in relation to the observed temporal variability dynamics, at least for *C. personatus*. After 2016, populations of *C. personatus* have not been replenished to their previous mean densities in most reef stations surveyed. Given its high density and small size, *C. personatus* may be an important forage species in Puerto Rico's reefs and a key trophic link transferring energy from a plankton-based food sources to the piscivore and top predators of the reef system. In such case, its demise from coral reef systems may have implications for the population dynamics of other reef fish species, affecting the system community structure and biodiversity (species richness) due to potential cascading effects.

Previous to its No Take Zone (NTZ) designation by the DNER in 2004, Isla de Mona was the focus of an intense fishing effort for sea turtles and large commercially important groupers during their seasonal spawning aggregations (Scharer-Umpierre et al., 2014). The original designation of 1 nautical mile around the island was expanded in 2007 to include spawning aggregation sites of at least 22 coral reef fish species, including threatened red hind, tiger and yellowfin groupers (*Epinephelus guttatus, Mycteroperca tigris, M. venenosa*) that fell outside of the original NTZ boundaries (Scharer 2010). Based on diver surveys and Geographic Position System (GPS) tracking instruments, Nemeth et al. (2007) determined the spawning times and identified locations with highest densities of red hinds (*E. guttatus*) and yellowfin groupers (M. *venenosa*) during their spawning aggregations in Isla de Mona. Red hind aggregated at a depth of 20m on a low-relief colonized pavement habitat whereas yellowfin groupers were found at depths of 25 – 30m on the high relief shelf-edge (Nemeth et al., 2007). The reproductive behavior and sound production of yellowfin grouper was studied at a spawning aggregation site off Mona Island by Scharer (2010). The highest abundance was detected in March and April, five to nine days after the full moon.

Yellowfin grouper individuals in the size range of 30 – 89 cm were observed in these spawning aggregations (Nemeth et al., 2007).

Olson et al., (2019) evaluated the response of snapper (Lutjanidae) and grouper (Serranidae) populations from Isla de Mona 14 years after its initial 2004 NTZ designation by the DNER. Despite indications of fishing activity within the NTZ, a reserve-effect was evidenced from increasing mean sizes and densities of smaller growing species and mean total fish density 36% higher than 2005. However, the large demersal predators remained in low densities, preventing meaningful analyses of population trends. Recent follow-ups on grouper population stocks from visual and passive acoustic monitoring surveys during spawning aggregations in Isla de Mona support the conclusions by Olson et al. (2019) in that populations of red hind (*Epinephelus guttatus*), yellowfin grouper (*Mycteroperca venenosa*) and black grouper (*Mycteroperca bonaci*) were comprised by very low number of individuals. The maximum number of individuals observed per survey were of 67 for *M. venenosa*, 6 for *M. bonaci* and 14 for *E. guttatus*. Also, a decreasing density trend for *M. venenosa*, an increasing trend for *M. bonaci* and no change of mean density for *E. guttatus* between 2016 and 2017 visual surveys was reported by Ruiz et al. (2018).

VI. Methods

Three reef stations were included in this 2020 survey of Isla de Mona coral reefs under the PRCRMP. Recurrent monitoring surveys were performed at MUJE20 and CARM10. Permanent transects established at Playa Sardinera 30m station in 2008 could not be found and a new baseline survey was produced at this reef station, now coded as SARD30. The survey was performed during February 5 and 23, 2020. The location of the stations surveyed are shown in Figure 1 and the geographic positions, station name codes and mean depths are listed in Table 1. The transects geographic coordinates were obtained with a time-synchronized GPS placed inside a zip-lock bag and installed on a floater. Coordinates are from the starting rebar of each transect.

Table 1. Geographic coordinates and mean depths of reef survey stations included in the Isla de Mona 2020 survey – PRCRMP. Station coordinates are for Transect 3 and MUJE20 Transect 4.

Site	Reef Stations	Station Code	Survey Date	Mean Depth (m)	Latitude (degrees N)	Longitude (degrees W)
Isla de Mona	Sardinera 30	SARD 30	2/5/20	29.45	18.098323	67.95077
	Playa Mujeres 20 (T1-3)	MUJE20	2/5/20	18.69	18.07169	67.93698
	Playa Mujeres 20 (T4-5)	MUJE20	2/23/20	16.83	18.34732	67.26997
	Las Carmelitas 10	CARM10	2/5/20	6.85	18.09887	67.93818

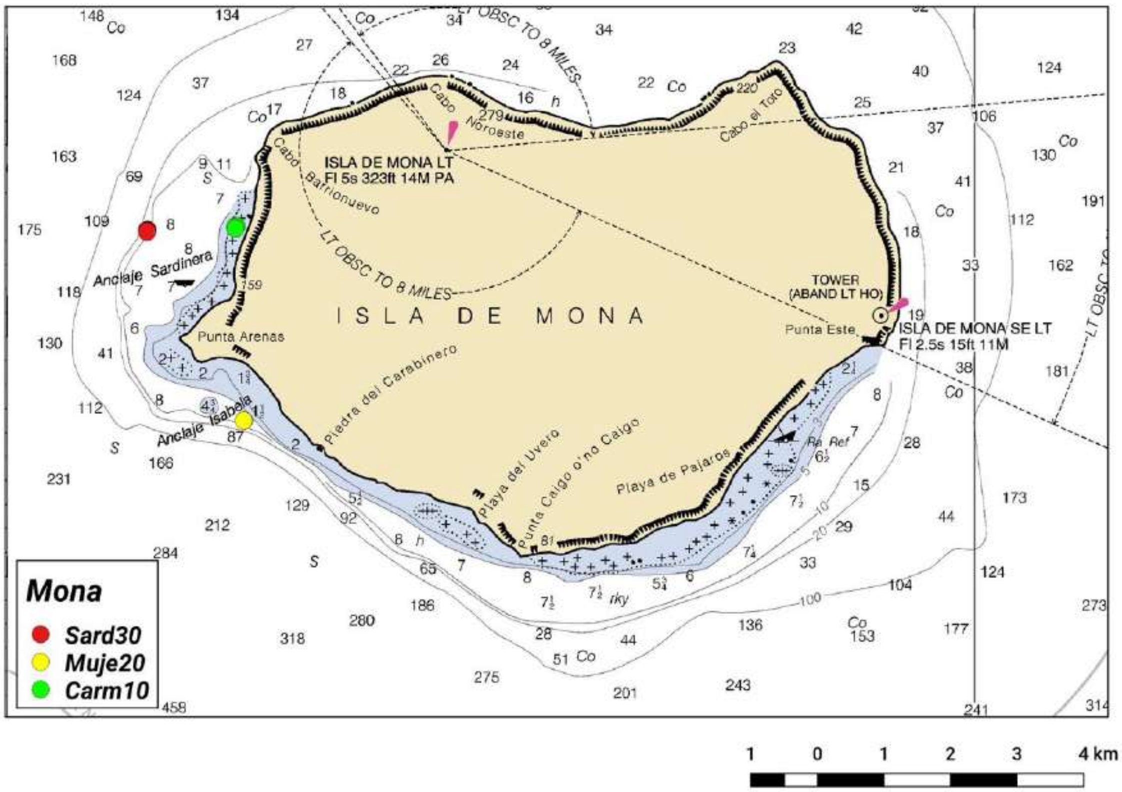


Figure 1. Location of reef stations surveyed at Isla de Mona, PRCRMP 2020.

A. Sessile-benthic Reef Communities

Sets of five 10m long permanent transects previously installed during baseline surveys (Garcia-Sais et al., 2001) were surveyed from MUJE20 and CARM10. A new set of five permanent transects were established at SARD30 at depths between 27.88m and 30.91m during this 2020 survey. Transects were positioned non-randomly in areas visually considered to be of optimal coral growth within similar depths (+/- 3m) and reef physiographic zones. Transect mean depths were determined from the five depth measurements taken at the start of each rebar marker, but depths may vary along transect paths. All transects were permanently marked with steel rebars set on naturally occurring crevices or holes in abiotic sections of the reef substrate at both ends. Wherever possible, the starting point of the transect was marked with a rebar on a reef structure of high topographic relief to facilitate visual recognition during future surveys. A thin white reference line was tied between the two end-markers to identify the transect paths during reef monitoring activities and removed upon survey completion.

Sessile-benthic reef communities were characterized by the continuous intercept chain-link method (as modified from Porter, 1972), following the CARICOMP (1994) protocol. The chain has 1.42 cm long links, marked every 10 links for facilitating underwater counting. The exact position of the chain is guided by a series of steel nails set into available hard (abiotic) substrates along transects. There are 704 chain links over a perfectly flat reef surface. Link counts above 704 are produced by substrate (topographic) relief along transects. The total links above 704 were multiplied by the link length (1.42cm) to provide estimates of substrate rugosity for each transect. Individual measurements of substrate categories, as recorded from the number of chain links were sorted, added and divided by the total distance (in chain links) on each transect to calculate the cumulative percent linear cover by each substrate category.

Soft corals, with the exception of encrusting forms (e.g. *Erythropodium caribaeorum, Briareum asbestinum*) were counted as number of colonies intercepted per transect (Colonies/Transect), whenever any of their branches crossed the transect reference line. Hard live coral colonies under the transect line were counted and examined visually for prevalence of apparent infectious diseases. Colonies of similar coral species growing close together and sharing attachment surfaces were counted as individual colonies if separated by distance of 15 cm or more. Diseased colonies on each transect were identified and counted. Preliminary field identifications of potential diseases were made whenever possible following the photographic guidelines by Raymundo et al. (2008). The percent coral disease prevalence was reported from the total number of diseased colonies divided by the total number of colonies intercepted by the five transects at each station.

Temporal variations (between surveys) of the percent reef substrate cover by hard corals were tested by Factorial Analysis of Variance (ANOVA) procedures on real values (un-transformed data). ANOVA p-values of < 0.05 were used to establish significant differences between surveys. The mean square error of the One-way ANOVAs was used to determine the 95% confidence intervals (CI) to allow pair-way comparisons between annual surveys. The percent changes of substrate categories between surveys were calculated as Percent Change= (y2 – y1/y1) *100, where Y2 is the most recent value. Reports of percent cover to second decimal units are for format uniformity and do not imply precision of measurements to such units.

B. Reef Fishes and Motile Megabenthic Invertebrates

Demersal, diurnal non-cryptic reef fishes and motile megabenthic invertebrates (lobsters, queen conch, large crabs, cleaner shrimps, urchins) were surveyed by sets of five 10m-long by 3m wide

($30m^2$) belt-transects centered along the reference line of transects used for sessile-benthic characterizations at each reef station. Detailed description of the belt-transect survey protocol is available in Garcia-Sais et al. (2019). The 10 x 3m belt transect was expanded to 20 x 3m ($60m^2$) to provide additional information on density and size distributions of fishes of commercial value (snappers, groupers, hogfishes, barracuda, jacks, mackerels, sharks) and/or fish species considered to be important reef herbivores (parrotfishes, doctorfishes).

The cephalothorax length, also known as carapace length (CL) in centimeters (cm) was used to report the size of lobsters (*Panulirus spp., Scyllarides sp*) within 10 x 3m belt-transects. Queen conch (*Lobotes gigas*) length was reported as the total (diagonal) shell length in cm. Fork length (cm) was used to report fish sizes. That is, C1 for fish 0 to 5cm; C2 for 6 to 10cm; C3 for 11 to 15cm, C4 for 16to 20cm and so on. Life history designations, such as recruit, juvenile, adult, and terminal phase male (TPM) were included for parrotfishes (Scaridae) based on the available information on length at maturity (Froese and Pauly, 2019). The recruitment juvenile designation was assigned to the smallest detectable fish size in the 1-5cm range (C1). Trophic classifications (zooplanktivores, herbivores, opportunistic carnivores, spongivores, corallivores, piscivores) applied to fish species within 10 x 3m belt-transects follow feeding habits information from Randall (1967) and/or Froese and Pauly (2019). Reference information on length at maturity, maximum length and feeding habits for fish species identified within belt-transects are available from Garcia-Sais et al. (2019).

Temporal variations (between surveys at each reef) of fish density and species richness were tested by One-way Factorial Analysis of Variance (ANOVA) procedures on real values (un-transformed data) for each reef station. Temporal variations of fish density and species richness were evaluated using only the data from 3m x 10m belt-transects. Pairwise comparisons of annual values were based on 95% confidence Interval (CI) calculated from the mean square error of the ANOVA tests.

VII. Results and Discussion

1. Sardinera 30m (SARD30)

1.1 Physical Description

Playa Sardinera is located on the west coast of Isla de Mona. At a distance of approximately 1.8 nautical miles off Playa Sardinera the insular shelf drops off into a series of narrow terraces with moderate slopes before finally dropping abruptly down to an almost vertical wall to the base of the slope at a depth of approximately 230m (Figure 1). Our survey was performed in one of these sloping terraces at depths between 27 – 31m. Permanent transects were oriented east – west following the main coral bioherms available for monitoring. The prevailing benthic habitat was a hard bottom or pavement colonized by large coral heads and erect sponges with interspersed coralline sand patches. Panoramic views of the reef community at SARD30 is presented as Photo Album 1.

1.2 Sessile-benthic Reef Community

The percent cover by sessile-benthic categories surveyed from SARD30 are presented in Table 2. Benthic algae, comprised by an assemblage of brown encrusting (*Lobophora sp*) and fleshy macroalgae (mostly *Dictyota sp*), turf, red coralline (CCA) and crustose calcareous algae (*Ramicrusta sp., Peyssonnelia spp*) were the dominant sessile-benthic category in terms of reef substrate cover with a combined mean of 59.19% (range: 51.97 – 70.12%) (Figure 2). The encrusting fan-leaf alga (*Lobophora sp*) was the main component of the benthic algae assemblage with a mean cover of 32.57%, representative of 55.03% of the total. Turf algae (mixed assemblage) and the y-twig alga were also prominent at SARD30 with means of 20.01% and 5.47%, respectively. Small patches of cyanobacteria were intercepted by all five transects with a mean cover of 1.39% (Table 2).

A total of 11 hard coral species were intercepted by transects at SARD30 with a mean substrate cover of 12.52% (range: 4.74 – 22.10%) and a mean density of 6.0 colonies/transect. The mountainous star coral (*Orbicella faveolata*) was the main component of the hard-coral assemblage with colonies intercepted by all five transects and a mean cover of 5.95%, representative of 47.52% of the total cover by hard corals (Figure 3). Leaf coral (*Agaricia agaricites*), and great star coral (*Montastraea cavernosa*) were present in three and four transects, respectively with a cumulative cover of 3.67%. Healthy colonies of maze coral (*Meandrina* *meandrites*), one of the most vulnerable coral species to the stony coral tissue loss disease (SCTLD) were intercepted by four of the five transects with a mean cover of 0.71%. In fact, all 30 hard coral colonies intercepted by transects were observed in healthy condition, resulting in a coral disease prevalence of 0. Large colonies of hard corals, particularly mountainous star coral (*O. faveolata*), greater starlet coral (*SIderastrea siderea*), and boulder brain coral (*Colpophyllia natans*) growing in close association with sponges produced biogenic reef outcrops, or bioherms that were the main contributors to the reef topographic relief and habitat complexity at SARD30.

Soft corals were represented by a mean of 8.0 erect colonies/transect. Some of the most common species included the common sea fan (*Gorgonia ventalina*), sea plumes (*Antillogorgia sp.*) and sea rods (*Eunicea spp, Plexaura sp.*). Horizontally projected (encrusting) soft corals were not intercepted by transects and none of the erect soft coral attachment surfaces were intercepted by transects either, resulting in 0% reef substrate cover. Nevertheless, soft corals were present in most if not all of the coral outcrops that characterized the main reef formation at SARD30 and contributed substantially to the reef structural complexity. Wire and bushy black corals (*Stichopathes lutkeni, Antipathes caribbeana*) were observed out of transects.

Sponges were represented by 17 species intercepted by transects with a combined mean substrate cover of 9.90 % (range: 5.75 – 14.76%). *Agelas citrina, Svenzea zeai, A. conifera* and *A. dispar* comprised the main assemblage in terms of reef substrate cover with a combined mean of 5.86% (Table 2). Branching tube sponges (*Agelas conifera, A. clathrodes, A. sventres, A. dispar*) were observed growing in close proximity to live coral heads producing large coral/sponge bioherms. Several giant basket sponges (*Xestospongia mut*a) were present (mostly outside transects) and contributed significantly to the reef topographic relief and habitat complexity at SARD30.

Abiotic categories presented a combined mean substrate cover of 17.00%. Reef overhangs produced by the vertical projections of coral growth were the main contributors to abiotic cover at SARD30 with mean of 8.49%. Reef overhangs create ledges below coral structures that serve as important protective habitats for fishes and spiny lobsters. Coralline sand patches with a mean substrate cover of 6.22% was found surrounding coral outcrops (Table 2). Reef rugosity averaged 2.38m and was largely produced by the coral heads, sponges and outcrop bioherm structures that contributed topography anomalies in an otherwise flat hard bottom.

Table 2. Percent reef substrate cover by sessile-benthic categories at SARD30, Isla de Mona.

Survey Date: February 5, 2020	**Transects**					
	1	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	**30**	**30.6**	**30.91**	**27.88**	**27.88**	**29.45**
Rugosity (m)	2.71	2.71	2.42	1.37	2.67	**2.38**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	3.96	11.56	6.43	5.05	15.47	**8.49**
Sand	9.47	6.61	3.72	9.98	1.33	**6.22**
Rubble	5.51	1.10	1.69	2.46	0.66	**2.29**
Total Abiotic	**18.94**	**19.27**	**11.84**	**17.49**	**17.46**	**17.00**
Benthic Algae						
Lobophora spp.	34.80	48.02	34.16	24.01	21.88	**32.57**
Turf (mixed) with sediment	13.55	3.52	31.57	18.97	17.68	**17.06**
Dictyota spp.	12.78		4.17	2.22	8.18	**5.47**
Turf (mixed)		4.41		5.17	5.19	**2.95**
CCA (total)		2.20	0.23	1.60		**0.81**
Ramicrusta spp.		1.10				**0.22**
Peyssonnelia spp.		0.55				**0.11**
Total Benthic Algae	**61.12**	**59.80**	**70.12**	**51.97**	**52.93**	**59.19**
Cyanobacteria	**0.44**	**0.99**	**4.28**	**1.23**	**0.00**	**1.39**
Hard Coral						
Orbicella faveolata	0.88	1.65	3.95	5.79	17.46	**5.95**
Agaricia agaricites	0.77	3.85		5.42		**2.01**
Montastraea cavernosa	3.08		3.38	0.74	1.10	**1.66**
Colpophyllia natans				3.57		**0.71**
Meandrina meandrites		0.66	0.45	1.35	1.10	**0.71**
Siderastrea siderea		1.98				**0.40**
Agaricia grahamae		1.87				**0.37**
Madracis decactis			0.23		0.77	**0.20**
Pseudodiploria strigosa					0.88	**0.18**
Stephanocoenia intersepta				0.86		**0.17**
Porites astreoides					0.77	**0.15**
Total Hard Coral	**4.74**	**10.02**	**8.00**	**17.73**	**22.10**	**12.52**
# Hard coral colonies/transect	**5**	7	**8**	**3**	**7**	**6.0**
# Diseased hard coral colonies/transect	**0**	**0**	**0**	**0**	**0**	**0.00**
Soft Corals	**0**	**0**	**0**	**0**	**0**	**0.00**
# Soft Coral Colonies/Transect	**10**	**9**	**9**	**5**	**7**	**8.0**
Sponges						
Agelas citrina	4.07	2.20		1.60	2.65	**2.11**
Svenzea zeai	4.41	4.19				**1.72**
Agelas conifera	3.19	1.32	1.58	0.25		**1.27**
Agelas dispar	2.09			1.72		**0.76**
Neofibularia nolitangere				3.08		**0.62**
Neopetrosia spp. smooth				2.59	0.44	**0.61**
Ircinia felix				0.49	2.43	**0.58**
Agelas clathrodes			2.25	0.62		**0.57**
Prosuberites laughlini		1.43	0.45		0.33	**0.44**
Xestospongia muta				1.23		**0.25**
Agelas sventres	0.66		0.34		0.22	**0.24**
Aiolochroia crassa					1.10	**0.22**
Plakortis spp.		0.44	0.45			**0.18**
Clathria spp.		0.33	0.45			**0.16**

Table 2. Percent reef substrate cover by sessile-benthic categories at SARD30, Isla de Mona.

Survey Date: February 5, 2020

	Transects					
	1	**2**	**3**	**4**	**5**	**Mean**
Aplysina fistularis					0.33	**0.07**
Niphates caribica	0.33					**0.07**
Suberea spp.			0.23			**0.05**
Total Sponges	**14.76**	**9.91**	**5.75**	**11.58**	**7.51**	**9.90**

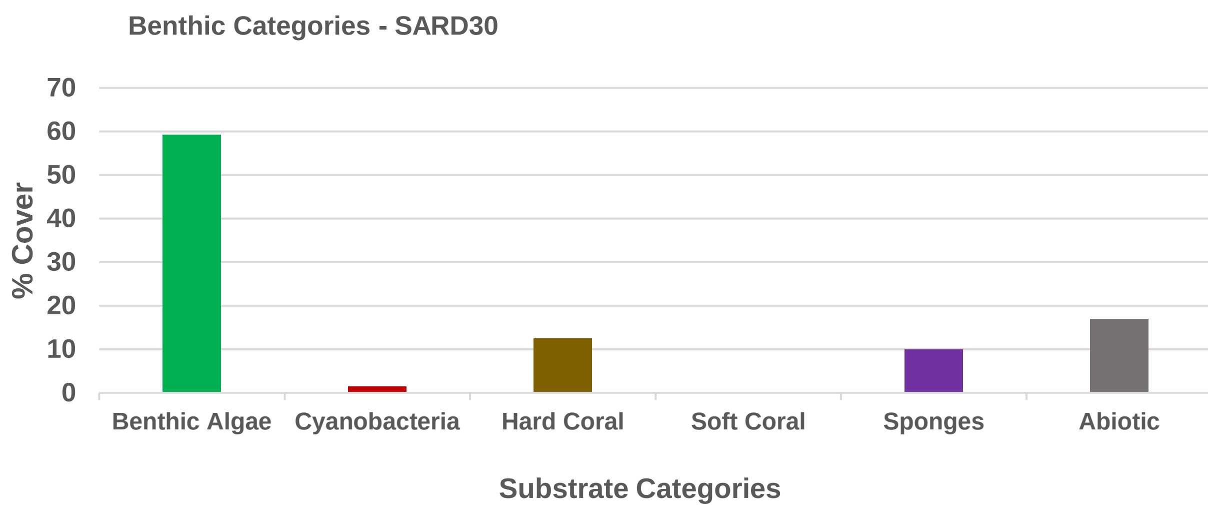


Figure 2. Mean percent cover by substrate categories at SARD30, Isla de Mona, 2020 Survey

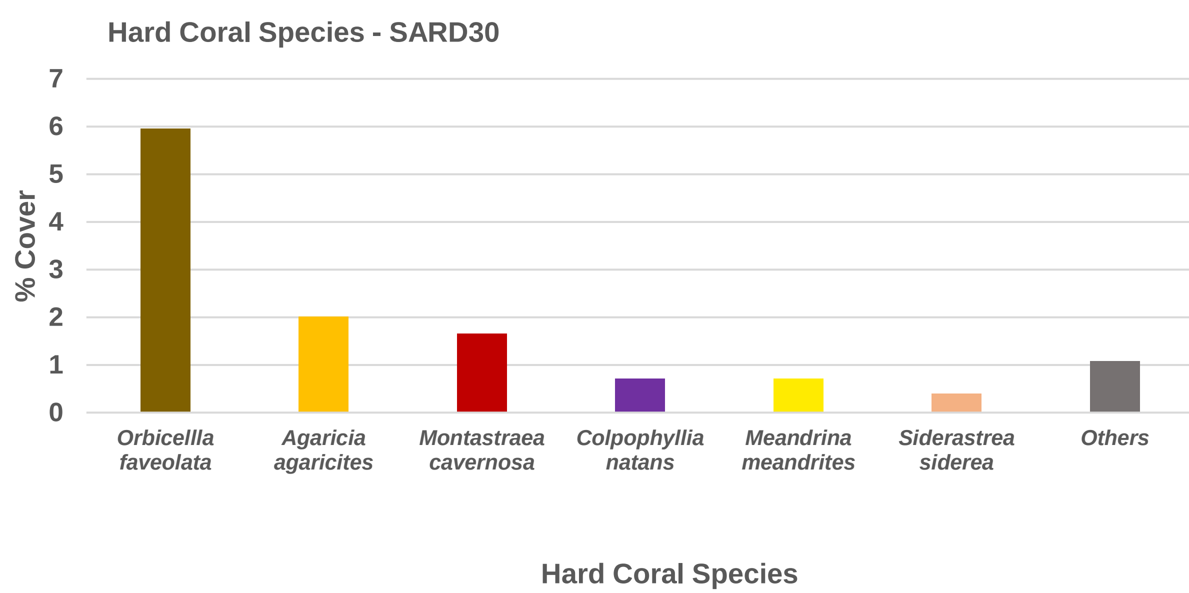


Figure 3. Mean percent cover by hard coral species at SARD30, Isla de Mona, 2020 Survey

1.3 Fishes and Motile Megabenthic Invertebrates

A total of 42 fish species and one motile megabenthic invertebrate (*Panulirus argus*) were identified within belt-transects with a mean density of 73.2 Ind/30m^2 and a mean species richness of 18.6 Spp/30m^2 (Table 3). The blue chromis (*Chromis cyanea*), creole wrasse (*Clepticus parrae*) and bicolor damselfish (*Stegastes partitus*) were the dominant species assemblage with a combined density of 40.6 Ind/30m^2, representative of 55.5% of the total fish density. Another seven species were observed from at least four transects, these included the fairy basslet (*Gramma loreto*), yellowhead wrasse (*Halichoeres garnoti*), french grunt (*Haemulon flavolineatum*), sharknose goby (*Elacatinus evelynae*), black-bar soldierfish (*Myripristis jacobus*), longjaw squirrelfish (*Neoniphon marianus*) and redband parrotfish (*Sparisoma aurofrenatum*). Guilds of adult and juvenile blue chromis (*C. cyanea*) were common over coral heads and also associated with branching sponges. Streaming schools of adult and juvenile creole wrasse (*C. parrae*) were observed in transit over the reef. Bicolor damselfishes (*S. partitus*) were observed occupying benthic territories over hard bottom. Motile megabenthic invertebrates were represented by two individuals of the spiny lobster (*P. argus*) within belt-transects.

The trophic structure of the fish community at SARD30 was dominated by pelagic and demersal zooplanktivores represented by four of the top five ranked species in terms of density within belt-transects. The combined density of the zooplanktivore assemblage (46.4 Ind/30m^2) represented 63.4% of the total fish density. The assemblage included two damselfishes (*Chromis cyanea, Stegastes partitus*), one wrasse (*Clepticus parrae*) and one basslet (*Gramma loreto*). Opportunistic carnivores, which mostly feed on small benthic invertebrates were represented by at least 20 species with a combined density of 19.4 Ind/30m^2, representative of 26.5% of the total fish density. The assemblage included wrasses (Labridae), gobies (Gobiidae), squirrelfishes (Holocentridae), grunts (Haemulidae), trumpetfishes (Aulostomidae), goatfishes (Mullidae), trunkfishes (Ostraciidae), drums (Sciaenidae) and small groupers (Serranidae). Herbivores were represented by nine species, including four parrotfishes (Scaridae), three doctorfishes (Acanthuridae), and two damselfishes (Pomacentridae). Small piscivores included the red hind (*Epinephelus guttatus*), schoolmaster and mahogani snappers (*Lutjanus apodus, L. mahogani*) and bar-jack (*Caranx ruber*). Spongivores (*Holacanthus tricolor*) and corallivores (*Chaetodon capistratus., Prognathodes aculeatus*) were also present in low abundance. Scavengers were represented by two spiny lobsters (*Panulirus argus*) within belt-transects. Top demersal predators, such as the yellowfin grouper (*Mycteroperca venenosa*) and the nurse shark (*Ginglymostoma cirratum*) were also present at SARD30.

Table 3. Taxonomic composition and density of fishes and motile megabenthic invertebrates at SARD30, Isla de Mona

Survey Date: 2-5-20	Belt-Transects (# Individuals/30m^2)					
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Chromis cyanea	12	12	7	25	27	**16.60**
Clepticus parrae	17	28	18	3	0	**13.20**
Stegastes partitus	20	7	12	9	8	**11.20**
Gramma loreto	4	4	3	1	8	**4.00**
Thalassoma bifasciatum	9	4	0	3	0	**3.20**
Halichoeres garnoti	6	1	4	1	3	**3.00**
Haemulon flavolineatum	1	4	4	5	1	**3.00**
Elacatinus evelynae	6	1	2	2	1	**2.40**
Myripristis jacobus	1	3	1	1	3	**1.80**
Neoniphon marianus	1	3	2	0	1	**1.40**
Chromis multilineata	0	1	6	0	0	**1.40**
Scarus iseri	0	0	0	6	0	**1.20**
Scarus taeniopterus	1	0	1	1	2	**1.00**
Sparisoma aurofrenatum	1	1	1	0	1	**0.80**
Coryphopterus lipernes	3	0	0	1	0	**0.80**
Stegastes leucostictus	0	1	1	0	2	**0.80**
Holacanthus tricolor	0	0	0	1	3	**0.80**
Holocentrus rufus	1	0	1	1	0	**0.60**
Cephalopholis cruentata	0	1	1	1	0	**0.60**
Acanthurus chirurgus	2	0	0	0	0	**0.40**
Chaetodon capistratus	0	1	1	0	0	**0.40**
Hypoplectrus nigricans	0	2	0	0	0	**0.40**
Acanthurus coeruleus	0	0	1	1	0	**0.40**
Epinephelus guttatus	1	0	0	0	0	**0.20**
Melichthys niger	1	0	0	0	0	**0.20**
Equetus punctatus	0	1	0	0	0	**0.20**
Prognathodes aculeatus	0	1	0	0	0	**0.20**
Acanthurus tractus	0	1	0	0	0	**0.20**
Coryphopterus glaucofraenum	0	1	0	0	0	**0.20**
Caranx ruber	0	1	0	0	0	**0.20**
Aulostomus maculatus	0	1	0	0	0	**0.20**
Cephalopholis fulva	0	1	0	0	0	**0.20**
Microspathodon chrysurus	0	1	0	0	0	**0.20**
Lutjanus apodus	0	0	1	0	0	**0.20**
Lutjanus mahogoni	0	0	1	0	0	**0.20**
Pseudupeneus maculatus	0	0	1	0	0	**0.20**
Anisotremus virginicus	0	0	0	1	0	**0.20**
Haemulon plumieri	0	0	0	1	0	**0.20**
Canthigaster rostrata	0	0	0	1	0	**0.20**
Sparisoma viride	0	0	0	1	0	**0.20**
Lactophrys triqueter	0	0	0	0	1	**0.20**
Acanthostracion polygonius	0	0	0	0	1	**0.20**
Total Individuals	**88**	**84**	**72**	**70**	**67**	**73.2**
Total Species	**17**	**24**	**19**	**19**	**14**	**18.6**
Invertebrates						
Panulirus argus	0	0	0	2	0	**0.40**
Totals	0	0	0	2	0	**0.40**

The size distribution of commercially important fishes observed within 20m x 3m belt-transects was largely represented by adult size classes of snappers (Lutjanidae), groupers (Serranidae), parrotfishes (Scaridae), doctorfishes (Acanthuridae), jacks (Carangidae) and scorpionfishes (Scorpaenidae) (Table 4). One terminal phase male (TPM) of stoplight parrotfish (*Sparisoma viride*) was observed within transects. Juveniles of redband and princess parrotfishes (*Sparisoma aurofrenatum, Scarus taeniopterus*), and one recruitment juvenile of blue tang (*Acanthurus coeruleus*) were observed from SARD30.

Table 4. Size distributions of commercially important fishes observed within 20 x 3m belt-transects at SARD30, Isla de Mona, 2020 Survey

Survey Date: 2-5-20			Belt-Transects						
		Observed	**(Ind/60m^2)**						**Life**
Species	**Family**	**Sizes (cm)**	**1**	**2**	**3**	**4**	**5**	**Mean**	**Stage**
Acanthurus chirurgus c3	Acanthuridae	13, 15	2					**0.40**	Adult
Acanthurus coeruleus c1	Acanthuridae	3				1		**0.20**	Juvenile
Acanthurus coeruleus c3	Acanthuridae	15, 17, 18			1	1	1	**0.60**	Adult
Acanthurus tractus c3	Acanthuridae	14	1					**0.20**	Juvenile
Acanthurus tractus c4	Acanthuridae	18, 19, 16		1		1	1	**0.60**	Adult
Caranx ruber c5	Carangidae	25		1				**0.20**	Adult
Cephalopholis cruentata c4	Serranidae	19		1				**0.20**	Adult
Cephalopholis cruentata c6	Serranidae	26, 24, 25		1	1	1		**0.60**	Adult
Cephalopholis fulva c4	Serranidae	20					1	**0.20**	Adult
Cephalopholis fulva c5	Serranidae	25	1					**0.20**	Adult
Cephalopholis fulva c6	Serranidae	27, 30		1	1			**0.40**	Adult
Epinephelus guttatus c7	Lutjanidae	34	1					**0.20**	Adult
Lutjanus apodus c5	Lutjanidae	23			1			**0.20**	Adult
Lutjanus apodus c6	Lutjanidae	30, 31			1		1	**0.40**	Adult
Lutjanus apodus c7	Lutjanidae	34, 35			1		1	**0.40**	Adult
Lutjanus mahogoni c4	Lutjanidae	20			1			**0.20**	Juvenile
Mycteroperca venenosa c14	Serranidae	70			1			**0.20**	Adult
Pterois spp. c6	Scorpaenidae	27					1	**0.20**	Adult
Scarus taeniopterus c2	Scaridae	9, 8, 8, 6, 6	1	2			2	**1.00**	Juvenile
Scarus taeniopterus c4	Scaridae	16				1		**0.20**	Adult
Scarus taeniopterus c5	Scaridae	23			1			**0.20**	Adult
Sparisoma aurofrenatum c2	Scaridae	7, 10			1		1	**0.40**	Juvenile
Sparisoma aurofrenatum c3	Scaridae	12, 12, 15	2	1				**0.60**	Juvenile
Sparisoma aurofrenatum c5	Scaridae	23			1			**0.20**	Adult
Sparisoma viride c7	Scaridae	32				1		**0.20**	Adult/TPM

Photo Album 1. SARD30

2. Playa Mujeres 20m (MUJE20)

2.1 Physical Description

Playa Mujeres is located on the southwest corner of Isla de Mona, between Piedra del Carabinero and Punta Arenas (Figure 1). The shelf is narrow (about 0.3 nautical miles) and consists of a series of hard ground terraces with abundant sand patches and interspersed coral outcrops and basket sponges. Our coral reef community survey of MUJE20 was performed at two separate (although adjacent) sections of the shelf where coral reef patches were found close to the shelf-edge at depths of 16.67 – 19.09m. The baseline survey of MUJE20 was performed during June 2000 (Garcia-Sais et al., 2001). Photo images of the coral reef community at the time of this monitoring are included as Photo Album 2.

2.2 Sessile-Benthic Reef Community

The data on percent reef substrate cover by benthic categories in transects surveyed from MUJE20 are presented in Table 5. Benthic algae, comprised by an assemblage of brown fleshy macroalgae (*Lobophora sp., Dictyota sp., Stypopodium sp.*), turf algae (mixed), red crustose calcareous algae (*Ramicrusta, Peyssonnelia spp.*), coralline algae (mixed) and green calcareous macroalgae (*Halimeda spp.*) were the dominant sessile-benthic category at MUJE20 with a combined mean reef substrate cover of 68.58 % (Figure 5). The encrusting fan alga (*Lobophora* sp.) was the main component of the benthic algae with a mean cover of 28.60%, representing 41.7% of the total benthic algae (Figure 6). *Lobophora sp*. was found overlying dead coral sections and growing intermixed with other low relief algae in all five transects, forming an algal mat over reef sections not colonized by stony corals or sponges. The fleshy brown Y-twig alga (*Dictyota* sp.) ranked second in terms of cover by benthic algae with a mean of 20.18%, it was observed growing in small bundles attached to the reef hard ground. Turf algae were observed colonizing hard substrates, sometimes intermixed with *Lobophora sp*. It was intercepted by all transects with a mean cover of 10.57%. Red crustose calcareous algae, including *Ramicrusta sp*. and *Peyssonnelia sp*. were intercepted by three transects each, with a combined mean cover of 4.30% and 0.55%, respectively. Red coralline algae (CCA) were intercepted by four transects with a combined mean cover of 2.81%. Small patches of cyanobacteria were observed in two transects with a mean substrate cover of 0.8% (Table 5).

Table 5. Percent substrate cover by sessile-benthic categories at MUJE20, Isla de Mona

Survey Dates: 2/5/20 (T1-3)	Transects					
2/23/20 (T4-5)	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	18.18	19.09	18.79	16.97	16.67	**17.94**
Rugosity (m)	2.56	2.04	2.25	1.51	3.20	**2.31**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	6.47	1.16	4.91	2.80	7.74	**4.62**
Sand	0.67	0.70	2.51	7.18	0.00	**2.21**
Rubble	1.11					**0.22**
Total Abiotic	**8.25**	**1.86**	**7.43**	**9.98**	**7.74**	**7.05**
Benthic Algae						
Lobophora spp.	23.08	49.07	40.46	16.06	14.32	**28.60**
Dictyota spp.	9.36	11.28	22.51	37.47	20.25	**20.18**
Turf (mixed)	14.16	2.09	6.63	1.70	4.24	**5.76**
Turf (mixed) with sediment		6.05	1.49	7.91	8.59	**4.81**
Ramicrusta spp.	11.93			3.53	6.04	**4.30**
CCA (total)	8.70		1.71	0.36	3.29	**2.81**
Stypopodium spp.		0.47	0.91	0.85	2.65	**0.98**
Peyssonnelia spp.	1.11			1.34	0.32	**0.55**
Halimeda spp.	1.45	0.81				**0.45**
Macroalgae spp.		0.70				**0.14**
Total Benthic Algae	**69.79**	**70.47**	**73.71**	**69.22**	**59.70**	**68.58**
Cyanobacteria	**0.00**	**1.16**	**2.86**	**0.00**	**0.00**	**0.80**
Hard Coral						
Colpophyllia natans	2.56			3.04	6.79	**2.48**
Porites astreoides	2.01	3.37	3.20	2.19	0.74	**2.30**
Agaricia agaricites	4.91	2.79	0.91	2.19		**2.16**
Orbicella faveolata	2.79	2.21			1.06	**1.21**
Eusmilia fastigiata			0.69		3.39	**0.82**
Siderastrea siderea		2.79				**0.56**
Meandrina meandrites	0.33		0.69	0.36	0.95	**0.47**
Diploria labyrinthiformis	1.45					**0.29**
Pseudodiploria strigosa	1.34					**0.27**
Millepora alcicornis	0.22	0.35			0.64	**0.24**
Madracis decactis	0.56	0.58				**0.23**
Dendrogyra cylindrus	0.22					**0.04**
Total Hard Coral	**16.39**	**12.09**	**5.49**	**7.79**	**13.57**	**11.07**
# Hard coral colonies/Transect	7.0	9.0	8.0	9.0	3.0	**7.20**
# Diseased hard coral colonies/Transect	0	0	0	0	0	0
Soft Corals						
Antillogorgia acerosa	0.33	0.00	0.00	0.00	0.00	**0.00**
Total Soft Corals	**0.33**	**0.00**	**0.00**	**0.00**	**0.00**	**0.07**
# Soft coral colonies/Transect	1	6	5	2	2	**3.20**

Table 5. Percent substrate cover by sessile-benthic categories at MUJE20, Isla de Mona

Survey Dates: 2/5/20 (T1-3)			Transects			
2/23/20 (T4-5)	**1**	**2**	**3**	**4**	**5**	**Mean**
Sponges						
Cliona caribbaea	1.00	5.58	9.26	10.83	6.47	**6.63**
Xestospongia muta		1.16	0.46	0.00	10.39	**2.40**
Agelas clathrodes		3.72			1.17	**0.98**
Agelas conifera	2.12	0.47	0.46			**0.61**
Spirastrella hartmani		1.86				**0.37**
Agelas citrina	0.33		0.34	0.85		**0.31**
Svenzea zeai		1.28				**0.26**
Agelas sp.				0.85	0.42	**0.26**
Unknown sponge				0.49	0.53	**0.20**
Amphimedon compressa	0.56					**0.11**
Aplysina fulva		0.35				**0.07**
Total Sponges	**4.01**	**14.42**	**10.51**	**13.02**	**18.98**	**12.19**

A total of 11 scleractinian corals and one hydrocoral (*Millepora alcicornis*) were intercepted by transects with a combined mean substrate cover of 11.07% and a mean density of 7.2 hard coral colonies/transect (Table 5). Boulder brain coral (*Colpophyllia natans*), mustard-hill coral (*Porites astreoides*), and lettuce coral (*Agaricia agaricites*) were the dominant species of the coral assemblage with a combined mean cover of 6.94%, representative of 62.7% of the total cover by hard corals (Figure 7). Small live coral fragments within mostly dead colonies of *Orbicella faveolata* were intercepted by three transects with a mean cover of 1.21%. Many dead colonies of *Orbicella spp*. and other massive corals (e.g. *Colpophyllia natans, Siderastrea siderea, Diploria spp*.) now colonized by benthic algae and sponges were observed, indicative of a major deterioration of the coral community at MUJE20. Several colonies of maze coral (*Meandrina meandrites*), one of the coral species highly vulnerable to the SCTLD disease were observed in healthy condition. None of the 16 hard coral colonies intercepted by transects at MUJE20 were observed infected by some type of disease, resulting in a coral disease prevalence of 0%.

Soft corals were not prominent at MUJE20 and only represented by erect forms along transects with a mean density of 3.20 colonies/transect. Given their vertical projection, these corals do not contribute to the percent reef substrate cover in proportion to their size but are important components to the reef benthic habitat complexity. Sea fans (*Gorgonia ventalina*), sea rods (*Eunicea spp*) and sea plumes (*Antillogorgia spp*) were observed in the vicinity of transects at MUJE20 during the 2020 survey.

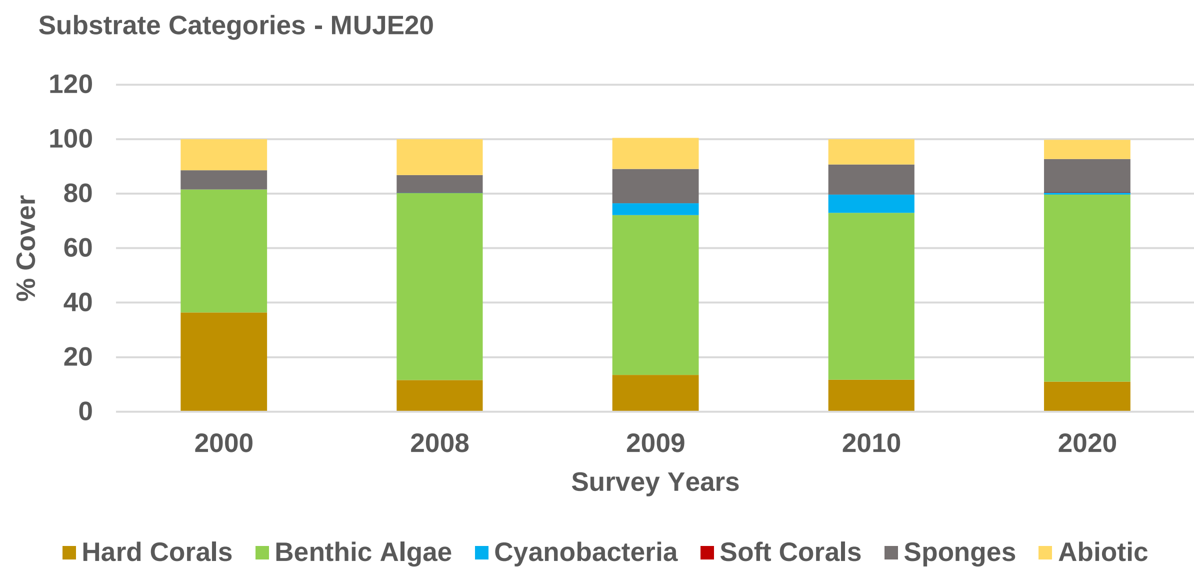


Figure 5. Variations of mean percent cover by substrate categories at MUJE20, Isla de Mona

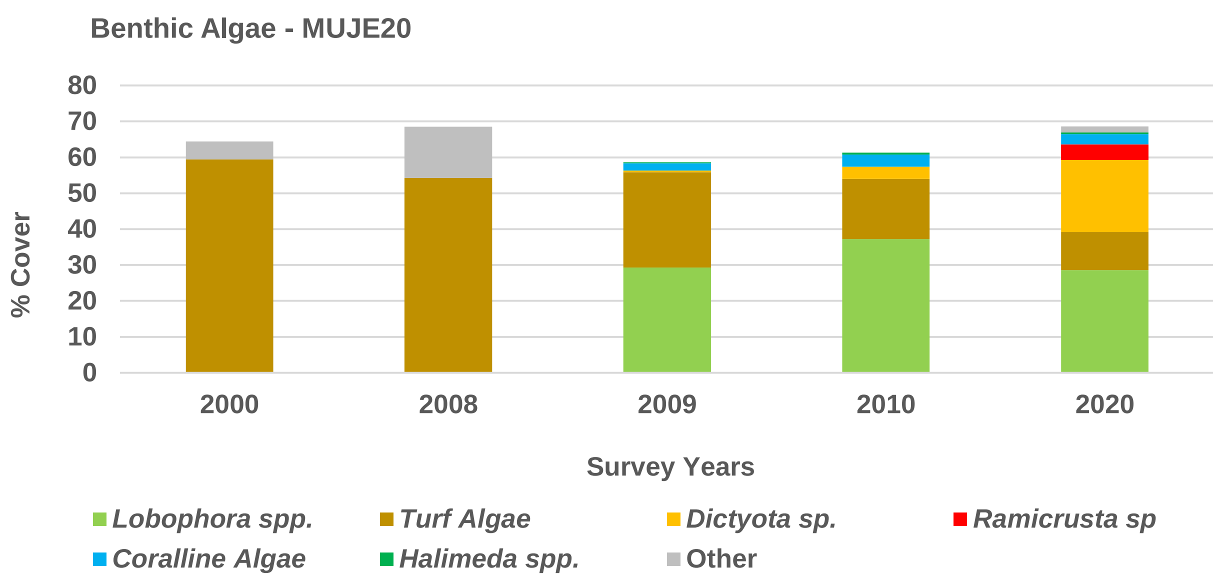


Figure 6. Variations of the mean percent cover by benthic algae taxa at MUJE20, Isla de Mona (2000 - 2020)

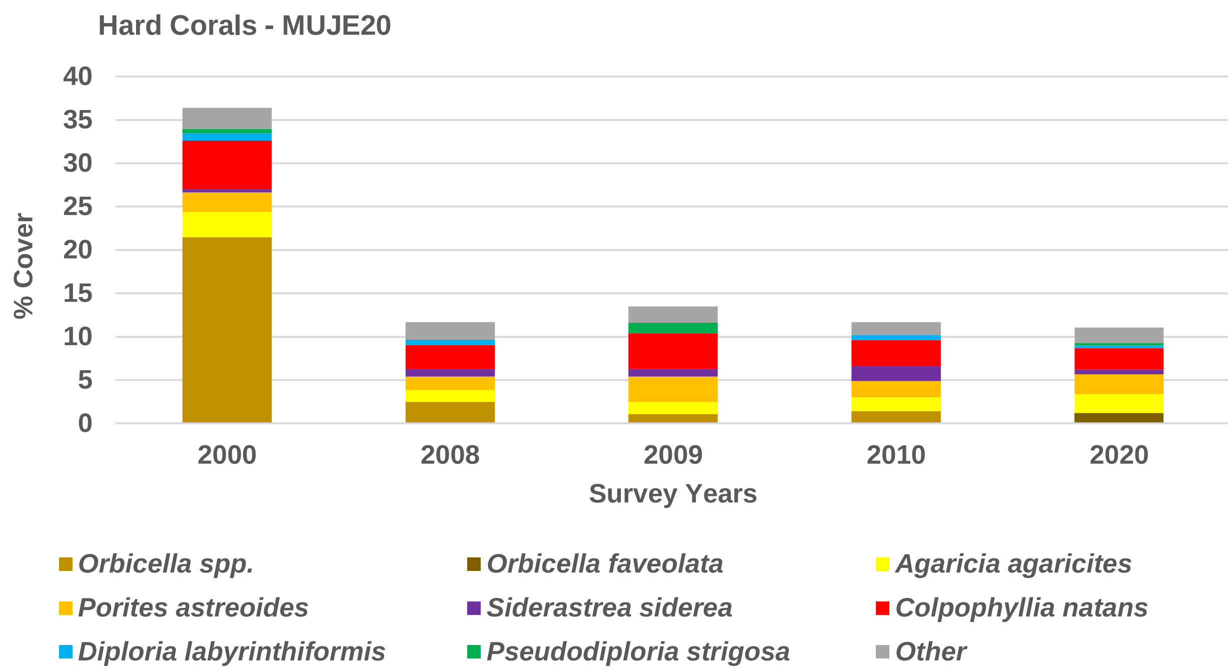


Figure 7. Variations of the mean percent cover by hard corals at MUJE20, Isla de Mona (2000 – 2020)

Sponges were represented by 11 species intercepted by transects with a combined mean cover of 12.19%. *Cliona caribbaea* was the dominant a species of the sponge assemblage with a mean cover of 6.63%, representative of 54.4% of the total cover by sponges (Table 5). This is an excavating species that typically colonizes dead coral colonies with negligible contributions to the reef topographic relief. Branching tube sponges (*Agelas spp*), represented by four species were prominent with a combined cover of 2.16% and along with the giant barrel sponge (*Xestospongia muta*) contributed substantially to the overall reef habitat complexity at MUJE20. Total abiotic cover averaged 7.05% and was mostly contributed by reef overhangs from still standing dead coral structures and sand patches. Reef rugosity averaged 2.31m.

Variations of the percent cover by sessile-benthic categories between the baseline survey in 2000 and the monitoring surveys of 2008, 2009, 2010 and 2020 are presented in Figure 5. Statistically significant differences of live hard coral cover were found between surveys (ANOVA; $p < 0.0001$) Differences were associated with the higher percent cover measured during the 2000 baseline survey relative to all other monitoring surveys. Live hard coral cover declined 67.8% between 2000 and 2008, from a mean of 36.4% in 2000 to 11.7% in 2008, indicative of an acute degradation of the coral community. In 2000, boulder star coral (*Montastraea annularis* complex) was the dominant coral species (complex) with a mean cover of 21.5%, representing 53.6% of the total cover by hard corals. In the 2008 survey, *M. annularis* presented a mean substrate cover of 2.5%, a reduction of 88.4% over the eight-year span. The collapse of live coral cover is consistent with the pattern observed for other coral reef systems in Puerto Rico associated with the regional bleaching event of 2005 (Garcia-Sais et al., 2008, 2009, 2010 a, b; Hernández-Delgado 2014, Weil et al., 2009). The reduction of cover by *M. annularis* from MUJE20 continued during 2009 down to a mean cover of 1.1%. The declining trend appeared to have ended in 2010, with a mean cover of 1.4%, which is similar to the mean cover of 1.21% measured in this 2020 monitoring survey. During the present 2020 survey, the total substrate cover by hard corals declined 5.7%, from 11.70% in 2010 to 11.07% in 2020 (Figure 7), but such variation was statistically insignificant.

Marked variations in the community structure of the benthic algae assemblage at MUJE20 were detected during the 2020 survey relative to the previous 2010 survey. Y-twig alga (*Dictyota sp*.) increased almost five-fold over this period (4.93X) and *Ramicrusta sp*. was recorded for the first time with a mean cover of 4.3%. Increments of these algae components were matched by corresponding reductions of cover by cyanobacteria and *Lobophora sp*. (Figures 5 - 6).

2.3 Fish and Motile Megabenthic Invertebrates

A total of 45 fish species were identified within belt-transects at MUJE20 with a mean density of 98.0 Ind/30m^2 and a mean species richness of 21.6 Spp/30m^2 (Table 6). The numerically dominant assemblage was comprised by blue chromis (*Chromis cyanea*), bluehead wrasse (*Thalassoma bifasciatum*) and bicolor damselfish (*Stegastes partitus*). The combined mean density of these three species (54.8 Ind/30m^2) represented 55.9% of the total fish density. In addition to the aforementioned species another eight were present in at least four out of the five transects. These included the redband, bucktooth and princess parrotfishes (*Sparisoma aurofrenatum, S. radians, Scarus taeniopterus*), fairy basslet (*Gramma loreto*), yellowhead wrasse (*Halichoeres garnoti*), beaugregory (*Stegastes leucostictus*), bermuda chub (*Kyphosus sp*.), graysbe (*Cephalopholis cruentata*) and sharknose goby (*Elacatinus evelynae*). Schools of creole wrasse (*Clepticus parrae*), black durgon (*Melichthys niger*), and bermuda chubs (*Kyphosus sp*.) were transient in mid-water over belt-transect areas. Sand tilefish (*Malacanthus plumieri*) and southern stingrays (*Dasyatis americana*) were observed over sandy areas outside transects. Motile megabenthic invertebrates were not observed within belt-transect areas. Two large spiny lobsters (*Panulirus argus*) were observed outside transects.

Table 6. Taxonomic composition and density of fishes and motile megabenthic invertebrates at MUJE20, Isla de Mona

Survey Date: 2-5-20

	Belt-Transects (# Individuals/30m^2)					
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Chromis cyanea	8	12	38	18	36	**22.4**
Thalassoma bifasciatum	12	16	13	36	14	**18.2**
Stegastes partitus	4	11	25	15	16	**14.2**
Clepticus parrae	14	15	3	0	0	**6.4**
Chromis multilineata	0	8	14	4	3	**5.8**
Gramma loreto	8	2	1	3	4	**3.6**
Scarus taeniopterus	6	5	1	2	3	**3.4**
Halichoeres garnoti	3	4	1	3	3	**2.8**
Sparisoma radians	2	2	0	2	3	**1.8**
Stegastes leucostictus	4	3	1	0	0	**1.6**
Elacatinus evelynae	3	0	1	2	1	**1.4**
Sparisoma aurofrenatum	2	2	0	1	2	**1.4**
Coryphopterus glaucofraenum	0	1	0	2	4	**1.4**
Halichoeres maculipinna	0	2	0	1	3	**1.2**
Melichthys niger	0	0	1	3	1	**1.0**
Kyphosus spp.	1	2	0	0	1	**0.8**
Cephalopholis cruentata	1	1	0	1	1	**0.8**
Scarus iseri	0	0	0	3	1	**0.8**
Chaetodon capistratus	0	0	1	2	0	**0.6**
Holacanthus tricolor	0	0	2	0	1	**0.6**
Haemulon flavolineatum	0	0	1	1	1	**0.6**
Microspathodon chrysurus	1	0	0	1	1	**0.6**
Stegastes planifrons	3	0	0	0	0	**0.6**
Prognathodes aculeatus	1	0	1	0	0	**0.4**
Sparisoma viride	1	0	1	0	0	**0.4**
Acanthurus chirurgus	0	1	1	0	0	**0.4**
Sparisoma atomarium	0	2	0	0	0	**0.4**
Holocentrus rufus	1	0	0	1	0	**0.4**
Cephalopholis fulva	0	0	0	1	1	**0.4**
Lactophrys triqueter	0	0	0	2	0	**0.4**
Sargocentron coruscum	0	0	0	2	0	**0.4**
Holacanthus ciliaris	0	0	0	2	0	**0.4**
Scorpaena plumieri	0	0	1	0	0	**0.2**
Bodianus rufus	0	1	0	0	0	**0.2**
Mulloidichthys martinicus	1	0	0	0	0	**0.2**
Acanthurus tractus	0	0	0	1	0	**0.2**
Acanthurus coeruleus	0	0	0	1	0	**0.2**

Table 6. Taxonomic composition and density of fishes and motile megabenthic invertebrates at MUJE20, Isla de Mona

Survey Date: 2-5-20	Belt-Transects (# Individuals/30m^2)					
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Serranus tigrinus	0	0	0	1	0	**0.2**
Neoniphon marianus	0	0	0	0	1	**0.2**
Abudefduf saxatilis	0	0	0	0	1	**0.2**
Lutjanus mahogoni	0	0	0	0	1	**0.2**
Aulostomus maculatus	0	0	0	0	1	**0.2**
Pseudupeneus maculatus	0	0	0	0	1	**0.2**
Balistes vetula	0	0	0	0	1	**0.2**
Total Individuals	**76**	**90**	**107**	**111**	**106**	**98.0**
Total Species	**19**	**18**	**18**	**26**	**26**	**21.40**
Invertebrates						
none	0	0	0	0	0	**0.00**

The fish trophic structure at MUJE20 was strongly dominated by zooplanktivores, represented by a total of eight species with a cumulative mean density of 54.4 Ind/30m^2, or 55.5% of the total fish density within belt-transects. The assemblage included the blue and brown chromis (*Chromis cyanea, C. multilineata*), creole wrasse (*Clepticus parrae*), bicolor damselfish (*Stegastes partitus*), fairy basslet (*Gramma loreto*), bermuda chub (*Kyphosus sp*), sergeant major (*Abudefduf saxatilis*) and black durgon (*Melichthys niger*). Opportunistic carnivores, which feed on benthic invertebrates and small fishes were represented by 19 species, with a cumulative density of 28.2 Ind/30m^2 or 28.8% of the total. These included four species of wrasses (Labridae), two gobies (Gobiidae), three squirrelfishes (Holocentridae), two goatfishes (Mullidae), one grunt (Haemulidae), three small groupers (Serranidae), one scorpionfish (Scorpaenidae), one triggerfish (Balistidae), one trunkfish (Ostraciidae), and one trumpetfish (Aulostomidae). Herbivorous taxa were represented by five parrotfishes (Scaridae) and one doctorfish (Acanthuridae) with a combined density of 12.7 Ind/30m^2, or 14.0% of the total density. Spongivores (*Holacanthus tricolor*) and corallivores (*Prognathodes aculeatus, Chaetodon capistratus*) were also present within belt-transects. Medium-sized demersal piscivores were represented by the mahogany snapper (*Lutjanus mahogoni*). Pelagic piscivores included one cero mackerel (*Scomberomorus regalis*) and black jacks (*Caranx lugubris*). Large demersal predators were not observed at MUJE20.

The size distribution of commercially important fishes, including the main reef herbivores is indicative that MUJE20 mostly serves as the residential and/or foraging habitat for late juvenile and adult fishes. Early juveniles, including recruitment size stages (C1:1-5cm) were only observed for the bucktooth, redband and princess parrotfishes (*Sparisoma radians, S. aurofrenatum, Scarus taeniopterus*) (Table 7). Juvenile and adult parrotfishes (Scaridae) were the most prominent assemblage within the 3m x 20m belt-transects with five species present and a cumulative mean density of 8.2 Ind/60m^2. One terminal phase male (TPM) of stoplight parrotfish (*S. viride*) was observed. Doctorfishes (Acanthuridae) were mostly represented by adult individuals with a cumulative density of 2.6 Ind/60m^2. Small groupers were represented by adult coneys (*Cephalopholis fulva*) and juveniles and adult graysbes (*C. cruentata*). Small adult schoolmasters (*Lutjanus apodus*) and one juvenile mahogany snapper (*L. mahogoni*) were present. Large grouper and/or snapper species were not observed at MUJE20. The largest fishes observed within belt-transects included a pair of adult black jacks (*Caranx lugubris*) and one cero mackerel (*Scomberomorus regalis*).

Monitoring data on fish density and species richness within belt-transects is shown in Figure 8. Density differences between monitoring surveys were statistically significant (ANOVA; $p < 0.0001$) related to higher fish densities during the 2010 survey relative to all other surveys. The density difference was largely influenced by the peak density (186.0 Ind/30m^2) of masked goby (*Coryphopterus personatus*) in the 2010 monitoring survey. Lower densities of other numerically prominent species, such as bluehead wrasse (*Thalassoma bifasciatum*), bicolor damselfish (*Stegastes partitus*) and blue chromis (*Chromis cyanea*) were also observed during the 2020 survey, relative to the previous 2010 survey. These are all small schooling species whose populations may have been adversely impacted by the pass of hurricanes and other extreme climatological/oceanographic events during 2017 and 2018 (Garcia-Sais 2018, 2019). Fish species richness has remained relatively stable since the 2000 baseline survey and differences were statistically insignificant (ANOVA; $p = 0.646$).

Table 7. Size distributions of commercially important fishes observed within 20 x 3m belt-transects at MUJE20, Isla de Mona, 2020 Survey. [*Observed sizes: dash separates the number of individuals seen with the same estimated FL (#individuals – estimated FL)]*

Survey Date: 2-5-20			**Belt-Transects**						
		Observed	**(Ind/60m^2)**						**Life**
Species	**Family**	**Sizes (cm)**	**1**	**2**	**3**	**4**	**5**	**Mean**	**Stage**
Acanthurus chirurgus c3	Acanthuridae	15, 15	1		1			**0.40**	Juvenile
Acanthurus chirurgus c4	Acanthuridae	18, 16, 18	1	2				**0.60**	Adult
Acanthurus coeruleus c3	Acanthuridae	15, 12				1	1	**0.40**	Adult
Acanthurus coeruleus c4	Acanthuridae	17				1		**0.20**	Adult
Acanthurus tractus c3	Acanthuridae	2-13, 2-14, 15		1	1	2	1	**1.00**	Juvenile
Balistes vetula c8	Balistidae	36					1	**0.20**	Adult
Caranx lugubris c10	Carangidae	50			1			**0.20**	Adult
Caranx lugubris c12	Carangidae	60			1			**0.20**	Adult
Cephalopholis cruentata c2	Serranidae	10					1	**0.20**	Juvenile
Cephalopholis cruentata c3	Serranidae	15	1					**0.20**	Juvenile
Cephalopholis cruentata c4	Serranidae	18				1		**0.20**	Adult
Cephalopholis cruentata c5	Serranidae	23		1				**0.20**	Adult
Cephalopholis fulva c4	Serranidae	20					1	**0.20**	Adult
Cephalopholis fulva c5	Serranidae	23, 25				1	1	**0.40**	Adult
Lutjanus apodus c6	Lutjanidae	28, 30				2		**0.40**	Adult
Lutjanus mahogoni c3	Lutjanidae	15					1	**0.20**	Juvenile
Scarus iseri c2	Scaridae	6, 6				2		**0.40**	Juvenile
Scarus iseri c3	Scaridae	15, 15, 18		1		1	1	**0.60**	Juvenile
Scarus iseri c4	Scaridae	22					1	**0.20**	Adult
Scarus taeniopterus c1	Scaridae	5, 5, 4		2		1		**0.60**	Recruit
Scarus taeniopterus c2	Scaridae	3-8, 3-10, 4-7, 8	6	3			2	**2.20**	Juvenile
Scarus taeniopterus c3	Scaridae	15, 16			1		1	**0.40**	Juvenile
Scarus taeniopterus c4	Scaridae	19, 4-20	2			2		**0.80**	Adult
Scomberomorus regalis c9	Scombridae	40					1	**0.20**	Adult
Sparisoma aurofrenatum c1	Scaridae	5					1	**0.20**	Recruit
Sparisoma aurofrenatum c2	Scaridae	9, 8, 8, 6	1	2			1	**0.80**	Juvenile
Sparisoma aurofrenatum c3	Scaridae	16				1		**0.20**	Adult
Sparisoma aurofrenatum c4	Scaridae	17	1					**0.20**	Adult
Sparisoma radians c1	Scaridae	3, 3, 2, 2, 2				2	3	**1.00**	Recruit
Sparisoma viride c6	Scaridae	30			1			**0.20**	Adult
Sparisoma viride c7	Scaridae	35, 32	1			1		**0.40**	Adult

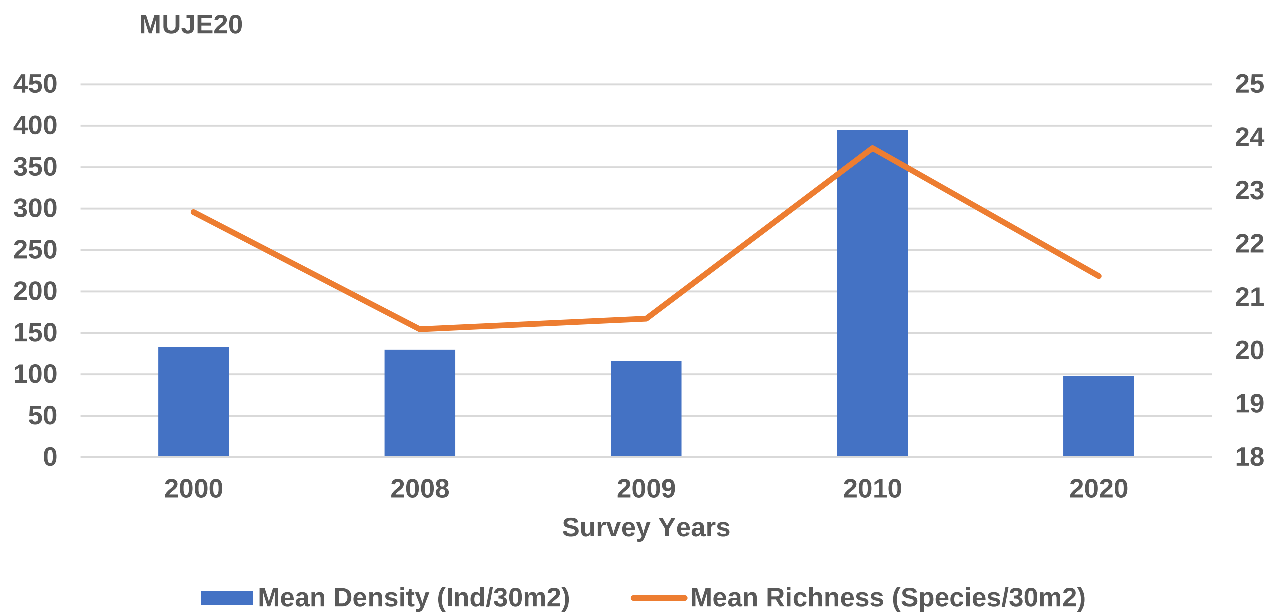


Figure 8. Monitoring trends (2000 – 2020) of fish species richness and abundance at MUJE20, Isla de Mona

Photo Album 2. MUJE20






3. Las Carmelitas (CARM10)

3.1 Physical Description

Las Carmelitas Reef is located due north of Playa Sardinera along the west coast of Isla de Mona (Figure 1). The reef extends from the shoreline to a depth of approximately 20m. From the shoreline, a sandy shallow backreef lagoon with scattered coral heads is protected from wave action by a fringe of emergent rocks, or reef crest. Live colonies of elkhorn coral (*Acropora palmata*), star corals (*Orbicella spp*.), and other stony corals and hydrocorals (*Millepora spp*.) were found along the margin of the backreef lagoon close to the reef crest. Below a depth of approximately 8m, the reef slope takes a diffuse spur-and-groove pattern as wide and deep sand channels separate the gently sloping hard bottom spurs. Permanent transects were installed along the edges of reef spurs at a depth of 7.5 – 9.1m during the baseline survey in June 2000 (Garcia-Sais et al., 2001). Images of the reef community from the time of this monitoring at CARM10 are shown as Photo Album 3.

3.2 Sessile-benthic Reef Community

Benthic algae were the dominant sessile-benthic category in terms of reef substrate cover at CARM10 with a mean of 69.12% (range: 59.46 – 83.48%). The benthic algae assemblage was comprised by turf algae, fleshy brown macroalgae (*Dictyota sp., Lobophora sp., Stypopodium sp*.), red coralline (CCA mixed) and crustose calcareous algae (*Ramicrusta sp., Peyssonnelia sp*.), and green calcareous algae (*Halimeda sp*.) (Table 8). Turf algae were the main component of the assemblage with a mean substrate cover of 32.09%, representative of 46.4% of the total cover by benthic algae. In addition to turf algae, the y-twig alga (*Dictyota sp*.), crustose calcareous alga (*Ramicrusta sp*.), encrusting fan alga (*Lobophora sp*.) and coralline algae (CCA) were intercepted by all five transects. Small patches of cyanobacteria were observed outside transects.

A total of 13 hard coral species were intercepted by transects at CARM10 with a mean substrate cover of 12.38% and a mean density of 6.4 colonies/transect (Table 8). The dominant coral assemblage in terms of reef substrate cover included the lettuce coral (*Agaricia agaricites*), mustard-hill coral (*Porites astreoides*), lobbed star coral (*Orbicella annularis*) and greater starlet coral (*Siderastrea siderea*) with a combined mean cover of 8.86%, representative of 71.6% of the total cover by hard corals. Dead standing large coral colonies colonized by sponges, turf and crustose calcareous algae were abundant at CARM10. One *S. siderea* out of the 32 colonies intercepted by transects showed signs of disease for a coral disease prevalence of 3.1%.

Table 8. Percent cover by sessile-benthic categories at CARM10, Isla de Mona, 2020

		Transects					
Survey Date: February 5, 2020		**1**	**2**	**3**	**4**	**5**	**Mean**
	Depth (m)	9.09	7.88	9.09	8.48	7.58	**8.42**
	Rugosity (m)	4.38	1.98	2.26	1.44	1.76	**2.36**
BENTHIC CATEGORIES							
Abiotic							
	Reef overhang	15.29	6.78	6.28	3.67	3.57	**7.12**
	Sand			1.14			**0.23**
	Rubble		0.23				**0.05**
	Total Abiotic	**15.29**	**7.01**	**7.42**	**3.67**	**3.57**	**7.39**
Benthic Algae							
	Turf (mixed)	25.12	28.04	17.24	9.18	27.98	**21.51**
	Dictyota spp.	10.32	15.19	3.65	32.93	30.71	**18.56**
	Turf (mixed) with sediment	5.16	0.82	16.89	27.29	2.74	**10.58**
	CCA (total)	8.86	9.70	13.13	5.14	2.38	**7.84**
	Ramicrusta spp.	10.81	2.34	6.74	1.96	4.05	**5.18**
	Lobophora spp.	2.34	1.40	2.28	4.04	2.38	**2.49**
	Stypopodium spp.	2.63	1.99		0.73	3.33	**1.74**
	Peyssonnelia spp.	1.75		1.03	0.86		**0.73**
	Halimeda spp.			1.14	1.35		**0.50**
	Total Benthic Algae	**66.99**	**59.46**	**62.10**	**83.48**	**73.57**	**69.12**
Hard Coral							
	Agaricia agaricites	3.80	2.45	5.48	2.69	2.26	**3.34**
	Porites astreoides	2.43	5.84	1.83	3.30	1.43	**2.97**
	Orbicella annularis	2.04	1.17			3.57	**1.36**
	Siderastrea siderea	0.19			1.84	3.93	**1.19**
	Pseudodiploria strigosa	0.29		0.23	1.35	1.79	**0.73**
	Orbicella faveolata	2.63			0.73		**0.67**
	Meandrina jacksoni					3.10	**0.62**
	Montastraea cavernosa	1.17		1.48			**0.53**
	Porites porites	0.19			1.59		**0.36**
	Diploria labyrinthiformis			1.71			**0.34**
	Porites furcata					0.83	**0.17**
	Dendrogyra cylindrus			0.34			**0.07**
	Stephanocoenia intersepta	0.19					**0.04**
	Total Hard Coral	**12.95**	**9.46**	**11.07**	**11.51**	**16.90**	**12.38**
	# Hard coral colonies /transect	**10**	**4**	**6**	**6**	**6**	**6.4**
	# Diseased hard coral colonies/transect	**0**	**0**	**0**	**0**	**1**	**0.2**
Soft Corals	*Briareum asbestinum*			0.23			**0.05**
	Total Soft Corals			**0.23**			**0.05**
	# Soft coral colonies/transect	**4**	**4**	**7**	**9**	**10**	**6.8**
Sponges							
	Cliona caribbaea	3.41	23.36	16.89		4.76	**9.69**
	Cliona aprica			2.28			**0.46**
	Neopetrosia spp. smooth				1.35		**0.27**
	Neopetrosia proxima					1.19	**0.24**
	Agelas dispar		0.47				**0.09**
	Aiolochroia crassa		0.23				**0.05**
	Total Sponges	**3.41**	**24.07**	**19.18**	**1.35**	**5.95**	**10.79**

Soft corals were not prominent at CARM10. The encrusting corky sea finger (*Briareum asbestinum*) was intercepted by one transect with a mean substrate cover of 0.05%. Erect forms were observed in all five transects with a mean density of 6.8 colonies/30m^2. Six sponge species were intercepted by transects with a mean substrate cover of 10.79%. The most prominent species was the coral excavating sponge *Cliona caribbaea*[1] with a mean cover of 9.69%, representative of 90.7% of the total cover by sponges. *Cliona* was observed colonizing entire massive (dead) coral colonies in four out of the five transects surveyed at CARM10. Abiotic categories presented a mean substrate cover of 7.39%, largely contributed by reef overhangs associated with both live and dead coral structures. Reef rugosity averaged 2.36m.

Monitoring trends of substrate cover by benthic categories at CARM10 are shown in Figure 9. Statistically significant differences of the percent cover by hard corals were found between monitoring surveys (ANOVA; $p < 0.0001$). Differences were associated with a 50.8% decline of cover between the 2000 baseline survey (mean cover: 25.4%) and the 2008 monitoring survey (mean cover: 12.5%). The marked reduction of coral cover was largely related to the mortality of the dominant species, *Montastraea annularis* (complex) which declined 85.7%, from a mean cover of 21.5% in 2000 to a mean cover of 2.5% in 2008 (Figure 10). Given the magnitude of coral cover loss and species affected such differences were associated with the regional coral bleaching event of 2005 (García-Sais et al. 2006, 2008). Corresponding increments of cover by benthic algae were measured in 2008, and by cyanobacteria from 2008 through its peak cover in 2010. Encrusting sponges, particularly the excavating sponge, *Cliona caribbaea* also increased in cover markedly after 2008 colonizing some of the larger dead coral heads.

During the present 2020 monitoring survey, reef substrate cover by hard corals increased 24.8% from the previous 2010 survey (Garcia-Sais et al., 2010). While such variation was within 95% CI, the trend is consistent with a pattern of increasing coral cover documented for nine additional reefs with baseline characterizations previous to 2005 (including MUJE20), at least until 2017, when minor reductions associated with hurricanes and other storm effects were measured in some of these reefs (Garcia-Sais et al., 2017, 2018, 2019). The increase of the total cover by hard corals was contributed by an increment of cover by lettuce coral (*Agaricia agaricites*) and the addition of colonies from five new species intercepted by the five transect matrix at CARM10.

[1] Previously reported as *Anthosigmella varians.*

These included *Meandrina jacksoni, Porites porites, Diploria labyrinthiformis, Dendrogyra cilindrus* and *Stephanocoenia intercepta* (Figure 10).

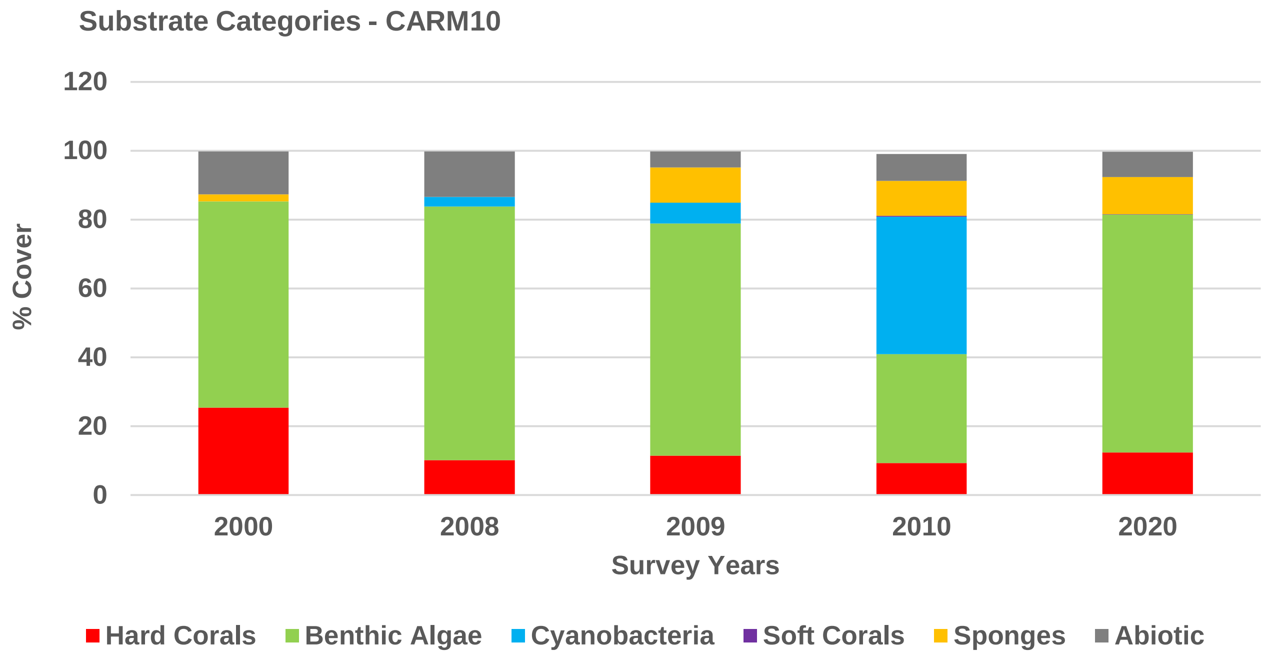


Figure 9. Mean percent cover by reef substrate categories at CARM10, Isla de Mona. (2000 – 2020)

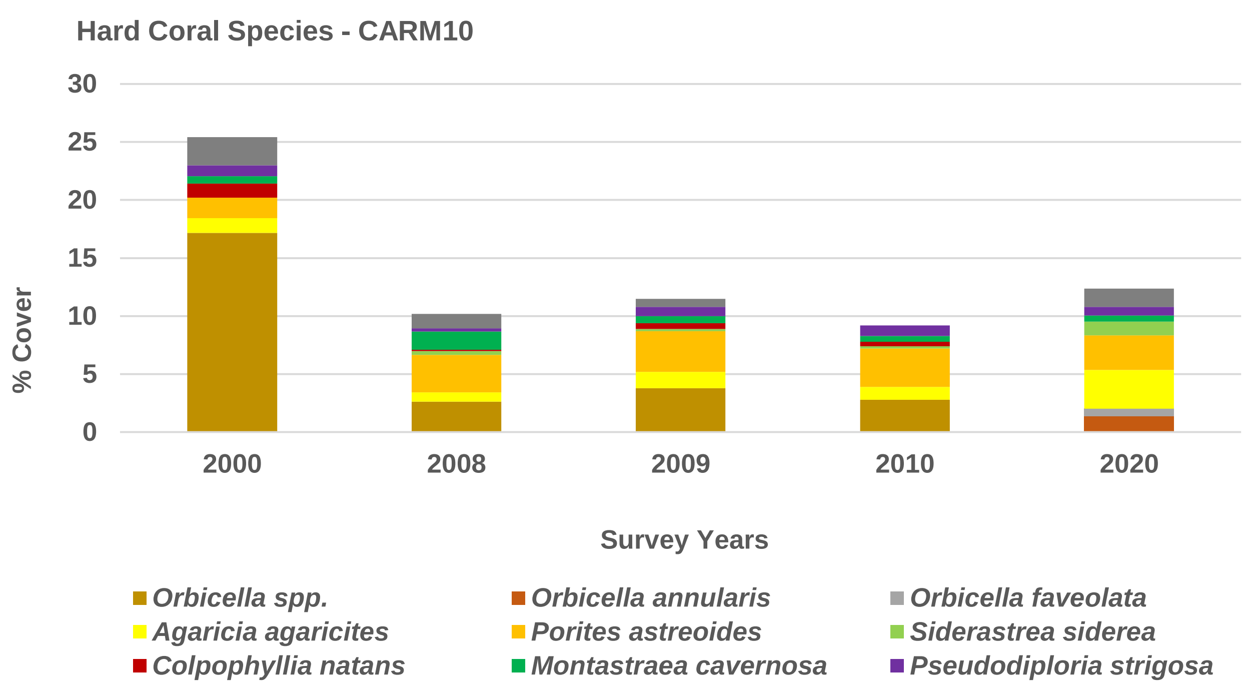


Figure 10. Mean percent cover by hard coral species at CARM10, Isla de Mona, (2000 – 2020)

Variations in the community structure of benthic algae at CARM10 between the present 2020 and previous surveys included marked increments of substrate cover by brown fleshy algae (*Dictyota sp*.) and red crustose calcareous algae, including *Ramicrusta sp*. and *Peyssonnelia sp*. (Figure 11). *Ramicrusta sp.* was detected for the first time from CARM10 in 2020 with a mean cover of 5.18%. A sharp decline of reef substrate cover by cyanobacteria from the previous 2010 survey was also measured (Figure 9).

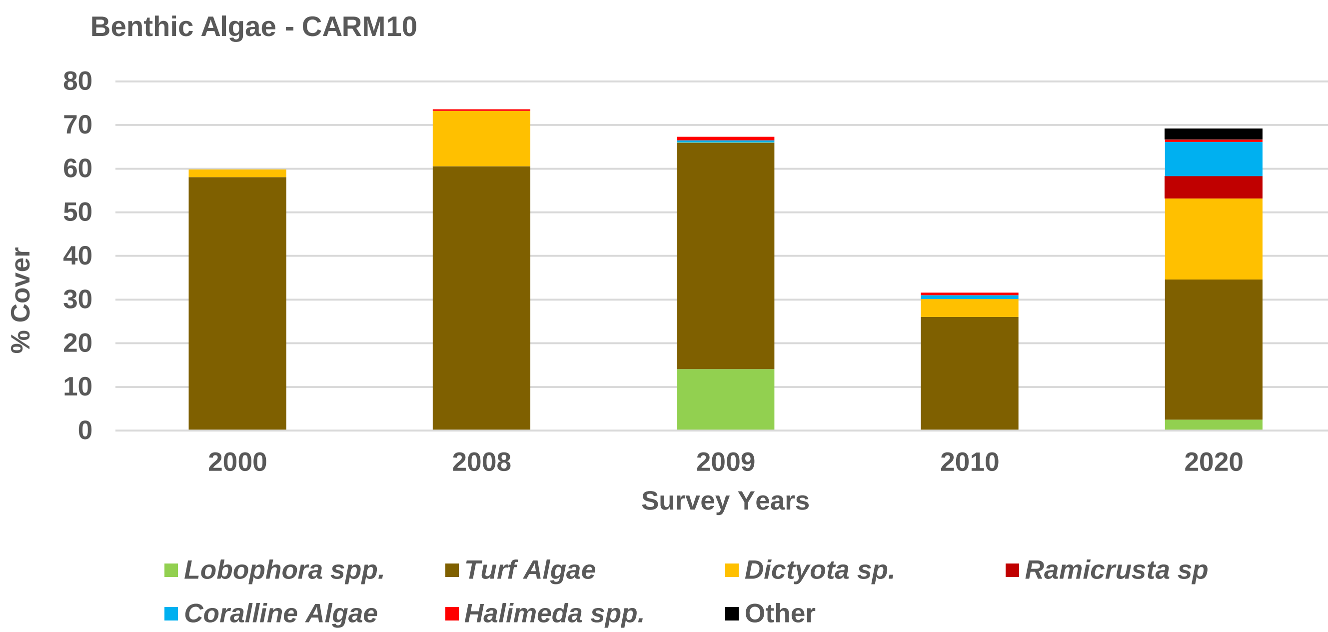


Figure 11. Mean percent cover by benthic algal taxa at CARM10, Isla de Mona, (2000 – 2020)

3.3 Fishes and Motile Megabenthic Invertebrates

A total of 37 fish species were identified within belt-transects at CARM10 during the 2020 survey with a mean density of 60.6 Ind/30m^2 and a mean species richness of 17.8 Spp./30m^2 (Table 9). The combined density of seven species represented 70.0% of the total fish density within belt-transects. The main assemblage included the blue chromis (*Chromis cyanea*), bluehead and yellowhead wrasses (*Thalassoma bifasciatum, Halichoeres garnoti*), fairy basslet (*Gramma loreto*), dusky and bicolor damselfishes (*Stegastes adustus, S. leucostictus*), and stripped grunt (*Haemulon chrysargyreum*). Blue chromis and bluehead wrasse were the most abundant with mean densities of 13.0 Ind/30m^2 and 10.6 Ind/30m^2, respectively. Both species were observed in schooling aggregations over coral promontories and soft coral colonies in the reef. Fairy basslets

(*G. loreto*) and small aggregations of striped and french grunts (*H. chrysargyreum, H. flavolineatum*) were observed under coral ledges at the walls of the reef spurs. Dusky, bicolor, and beaugregory damselfishes (*S. adustus, S. partitus, S. leucostictus*) occupied demersal territories within the reef top. Streaming schools of bermuda chubs (*Kyphosus sp*.) and black durgons (*Melichthys niger*) were transient over the reef in and out of belt-transect areas. Motile megabenthic invertebrates were not observed within belt-transect areas at CARM10. One adult spiny lobster (*Panulirus argus*) was present outside transects.

The fish trophic community structure at CARM10 was characterized by a well-balanced assemblage of zooplanktivores and opportunistic carnivores. Zooplanktivores were represented by six species, including three damselfishes (*Chromis spp., Stegastes sp*), basslets (*Gramma loreto*), bermuda chubs (*Kyphosus sp*.) and black durgons (*Melichthys niger*) with a cumulative density of 23.8 Ind/30m^2, representative of 39.3% of the total fish density within belt-transects. Opportunistic carnivores were represented by 19 species with a cumulative density of 23.6 Ind/30m^2, or 38.9% of the total density. The assemblage included wrasses (*Thalassoma sp., Halichoeres spp*., *Bodianus sp*.), grunts (*Haemulon spp*.), small groupers (*Cephalopholis spp*.), squirrelfishes (*Holocentrus spp., Neoniphon sp., Myripristis sp*.), big eyes (*Priacanthus sp*.), gobies (*Elacatinus sp., Coryphopterus sp*.), blennies (*Ophioblennius sp*.), and goatfishes (*Pseudupeneus sp*.). Herbivorous fishes were represented by 10 species, including five damselfishes (*Stegastes spp., Abudefduf sp., Microspathodon sp*.), three doctorfishes (*Acanthurus spp*.) and two doctorfishes (*Scarus sp., Sparisoma sp*.). Pelagic piscivores were represented within belt-transects by great barracuda (*Sphyraena barracuda*) and yellow jacks (*Caranx bartholomaei*).

The size distribution of fishes of commercial value at CARM10 is presented in Table 10. Doctorfishes (*Acanthurus spp*.) and parrotfishes (Scaridae) were present both as juvenile and adults, including recruitment juvenile stages of *A. chirurgus*, *A. coeruleus, Sparisoma viride* and *Scarus taeniopterus.* One adult terminal phase male (TPM) of *S. viride* was also observed. Small to mid-sized demersal piscivores, such as the graysbe (*Cephalopholis cruentata*), coney (*C. fulva*) and schoolmaster snapper (*Lutjanus apodus*) were present mostly as adults. Likewise, top demersal and pelagic predators, including the blackjack (*Caranx lugubris*), great barracuda (*Sphyraena barracuda*), and nurse shark (*Ginglymostoma cirratum*) were present as adults. Previous reports of demersal predators from CARM10 include juvenile tiger grouper (*Mycteroperca tigris*), dog snapper (*Lutjanus jocu*) and an adult red hind (*Epinephelus guttatus*) (Garcia-Sais et al., 2010).

Table 9. Taxonomic composition and density of fishes and motile megabenthic invertebrates identified within belt-transects at CARM10, Isla de Mona, 2020

Survey Date: 2-5-20			Belt-Transects (# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Chromis cyanea	8	15	5	30	7	**13.00**
Thalassoma bifasciatum	14	9	15	7	8	**10.60**
Gramma loreto	4	5	3	10	6	**5.60**
Stegastes adustus	2	4	6	3	6	**4.20**
Halichoeres garnoti	3	5	2	5	4	**3.80**
Haemulon chrysargyreum	12	0	3	0	0	**3.00**
Stegastes partitus	0	3	0	8	0	**2.20**
Stegastes leucostictus	1	2	3	1	2	**1.80**
Kyphosus spp.	5	2	0	0	1	**1.60**
Scarus taeniopterus	3	0	0	5	0	**1.60**
Microspathodon chrysurus	1	1	5	0	0	**1.40**
Acanthurus coeruleus	1	1	1	1	2	**1.20**
Haemulon flavolineatum	3	2	1	0	0	**1.20**
Priacanthus arenatus	1	0	1	2	0	**0.80**
Melichthys niger	1	1	1	0	1	**0.80**
Halichoeres maculipinna	2	0	0	2	0	**0.80**
Abudefduf saxatilis	0	0	3	0	1	**0.80**
Chromis multilineata	3	0	0	0	0	**0.60**
Acanthurus tractus	0	1	0	1	1	**0.60**
Acanthurus chirurgus	1	1	0	0	0	**0.40**
Myripristis jacobus	1	0	0	0	1	**0.40**
Elacatinus evelynae	1	0	1	0	0	**0.40**
Stegastes variabilis	0	1	0	0	1	**0.40**
Ophioblennius atlanticus	0	1	0	1	0	**0.40**
Carangoides bartholomaei	0	0	2	0	0	**0.40**
Malacoctenus triangulatus	0	0	0	1	1	**0.40**
Haemulon plumieri	1	0	0	0	0	**0.20**
Sparisoma viride	1	0	0	0	0	**0.20**
Cephalopholis cruentata	0	1	0	0	0	**0.20**
Haemulon carbonarium	0	0	1	0	0	**0.20**
Cephalopholis fulva	0	0	0	1	0	**0.20**
Coryphopterus glaucofraenum	0	0	0	1	0	**0.20**
Pseudupeneus maculatus	0	0	0	1	0	**0.20**
Bodianus rufus	0	0	0	0	1	**0.20**
Halichoeres radiatus	0	0	0	0	1	**0.20**
Neoniphon marianus	0	0	0	0	1	**0.20**
Sphyraena barracuda	0	0	0	0	1	**0.20**
Total Individuals	**70**	**57**	**56**	**84**	**51**	**60.6**
Total Species	**21**	**17**	**16**	**17**	**18**	**17.8**
Invertebrates						
none	0	0	0	0	0	**0.00**
Totals	0	0	0	0	0	**0.00**

Temporal variations of fish density and species richness within belt-transects is shown in Figure 12. Statistically significant differences between surveys were found for fish density (ANOVA; $p < 0.001$). Differences between surveys were largely associated with fluctuations of masked goby (*Coryphopterus personatus*), a small schooling species with highly aggregated distributions. The natural seasonal and/or interannual variability of this fish population in Puertorrican reefs has not been studied and deserves special attention because of its high numerical abundance and food quality for demersal piscivores.

Marked island-wide population density declines by *C. personatus* were reported by Garcia-Sais et al., (2018, 2019) and associated with events of extreme wave action, such as those caused by Hurricanes Irma and/or Maria in 2017 and/or winter storm Riley in 2018. Effects upon small fish populations appear to be exacerbated in shallow reefs (< 20m) where the advective effects of wave induced surge and abrasion are magnified. In the previous 2010 monitoring survey, *C. personatus* was the numerically dominant fish species at CARM10 with a mean density of 51.0 Ind/30m^2, representative of 28.2% of the total fish density. In contrast, during the 2020 survey, individuals of *C. personatus* were not observed within belt-transects. Statistically significant reductions of other numerically prominent species such as fairy basslet (*Gramma loreto*) and bluehead wrasse (*Thalassoma bifasciatum*) between the 2010 and the present 2020 survey were also found (ANOVA; $p < 0.001$). The decline of these species may have both direct and indirect effects upon fish species richness because of potential food web implications of these forage species. Also, the benthic habitat at CARM10 has changed markedly over the last two decades. Particularly, the drastic decline of live coral cover cannot be underestimated as a potential driver of the reef fish community structure degradation.

Table 10. Size distributions of commercially important fishes observed within 20 x 3m belt-transects at CARM10, Isla de Mona, 2020 Survey. [*Observed sizes: dash separates the number of individuals seen with the same estimated FL (#individuals – estimated FL)]*

Survey Date: 2-5-20			Belt-Transects						
		Observed	(Ind/60m^2)						Life
Species	**Family**	**Sizes (cm)**	**1**	**2**	**3**	**4**	**5**	**Mean**	**Stage**
Acanthurus chirurgus c1	Acanthuridae	4, 3	1	1				**0.40**	Recruit
Acanthurus coeruleus c1	Acanthuridae	3, 3	1		1			**0.40**	Recruit
Acanthurus coeruleus c3	Acanthuridae	15, 13, 15		1			2	**0.60**	Adult
Acanthurus coeruleus c4	Acanthuridae	16, 18				1	1	**0.40**	Adult
Acanthurus tractus c4	Acanthuridae	16, 3-17	1	1		1	1	**0.80**	Adult
Acanthurus tractus c3	Acanthuridae	3-12, 2-14, 15		1	2	1	2	**1.20**	Juvenile
Caranx lugubris c12	Carangidae	60		1				**0.20**	Adult
Caranx ruber c3	Carangidae	11					1	**0.20**	Juvenile
Caranx ruber c5	Carangidae	21			1			**0.20**	Juvenile
Caranx ruber c8	Carangidae	36, 36				2		**0.40**	Adult
Cephalopholis cruentata c5	Serranidae	22		1				**0.20**	Adult
Cephalopholis fulva c2	Serranidae	10		1				**0.20**	Juvenile
Cephalopholis fulva c5	Serranidae	25			1			**0.20**	Adult
Cephalopholis fulva c6	Serranidae	27				1		**0.20**	Adult
Ginglymostoma cirratum c14	Rhinocodontidae	70					1	**0.20**	Adult
Lutjanus apodus c8	Lutjanidae	36		2				**0.40**	Adult
Scarus iseri c4	Scaridae	20				1		**0.20**	Adult
Scarus taeniopterus c1	Scaridae	3, 4, 4	3					**0.60**	Recruit
Scarus taeniopterus c1	Scaridae	4, 4				2		**0.40**	Recruit
Scarus taeniopterus c2	Scaridae	7, 7, 7				3		**0.60**	Juvenile
Sparisoma aurofrenatum c4	Scaridae	17, 20				2		**0.40**	Adult
Sparisoma viride c1	Scaridae	3	1					**0.20**	Recruit
Sparisoma viride c5	Scaridae	25, 23	1	1				**0.40**	Adult
Sparisoma viride c6	Scaridae	28		1				**0.20**	Adult
Sparisoma viride c7	Scaridae	33		1				**0.20**	Adult/TPM
Sphyraena barracuda c10	Sphyraenidae	50					1	**0.20**	Adult

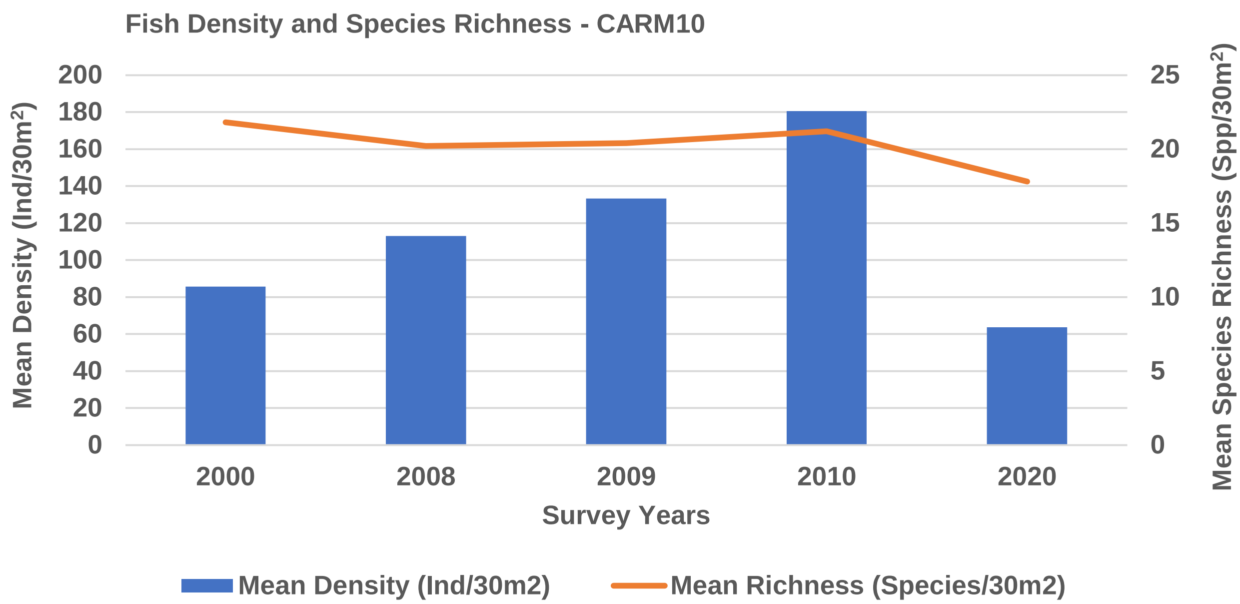
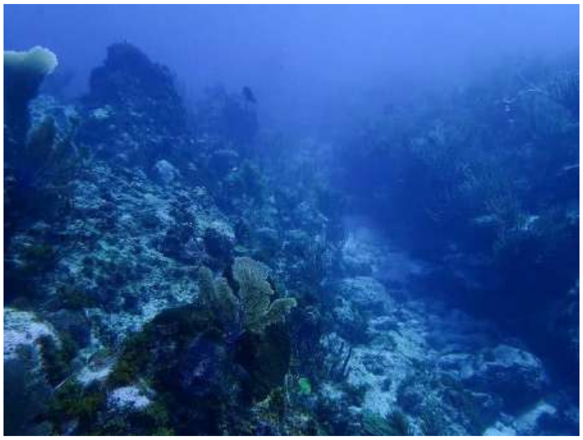
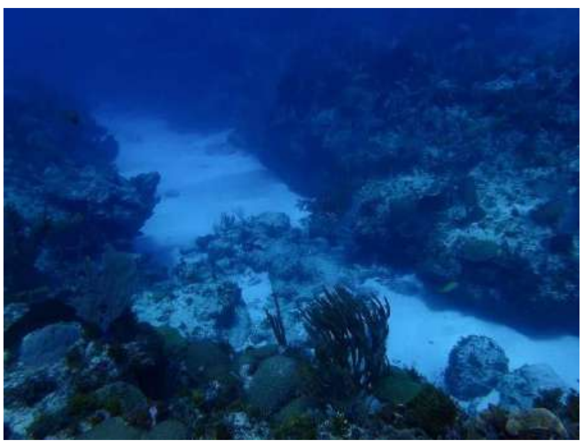


Figure 12. Monitoring trends (2000 – 2020) of fish species richness and abundance at CARM10, Isla de Mona

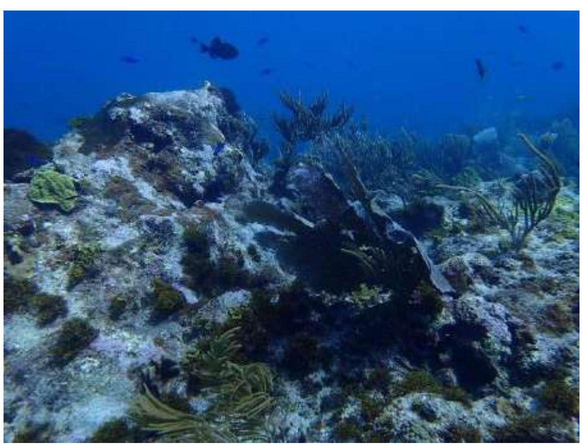
Photo Album 3. CARM10





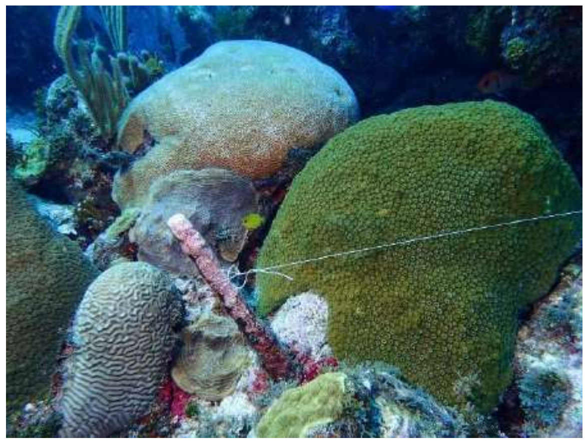










VIII. Conclusions

1- Live hard coral cover at Isla de Mona reef stations MUJE20 and CARM10 remained without statistically significant variations since the previous 2010 survey. Nevertheless, a 24.8% increase of live coral cover measured at CARM10 represents a positive trend of recuperation that includes extension in cover of habitat-forming species, such as *Agaricia agaricites, Dendrogyra cilindrus* and *Diploria labyrinthiformis*, in addition to the apparent recent recruitment by fast-growing species, such as *Porites porites, Meandrina jacksoni* and *Stephanocoenia intersepta*.

2- Several large dead coral colonies were colonized by the excavating sponge, *Cliona caribbaea* at MUJE20 and CARM10. Colonization by this sponge may be limiting the recruitment potential of coral planulae into the available reef hard bottom at these reef stations.

3- Only one (*Siderastrea siderea*) out of the 98 coral colonies intercepted by transects from the three reef stations surveyed was observed to be infected by coral disease, resulting in a coral disease prevalence of only 1.02%. This suggests that previous outbreaks of yellow band and white plague disease outbreaks associated with the collapse of *Orbicella spp*. and other coral species from Isla de Mona has receded and does not represent a major threat at present.

4- Contrary to the collapse of cover by live *Orbicella spp*. at MUJE20 and CARM10, large healthy colonies of *O. faveolata* were present at all five transects in SARD30, where it was the dominant species intercepted by transects representing 47.5% of the total cover by hard corals. This may be an indication of increased resilience or protection with increased depth from factors that contributed to the widespread mortality of this species in shallower areas of Isla de Mona.

5- The community structure of benthic algae exhibited marked variations in the 2020 survey relative to all previous surveys in Isla de Mona reefs. Reef substrate cover by brown fleshy macroalgae (*Dictyota sp*.) exhibited its maximum cover in the 2020 survey, and red crustose calcareous algae, mostly *Ramicrusta sp*. were prominent at MUJE20 and CARM10. Corresponding declines of cover by cyanobacteria were measured in 2020.

6- The fish community evidenced statistically significant reductions of density within belt-transects at both MUJE20 and CARM10 between the 2010 and 2020 surveys. As was the case in many reef stations included in the PRCRMP, the main driver of such density declines was associated with drastic reductions of density of small schooling fish species, particularly the masked goby (*Coryphopterus personatus*), but also included bluehead wrasse (*Thalassoma bifasciatum*), bicolor damselfish (*Stegastes partitus*) and blue chromis (*Chromis cyanea*). It is possible that such declines were influenced by displacements and/or mortality of the fish populations associated to extreme events of wave action forced by hurricanes (Irma and Maria) in 2017 and/or winter storm Riley in 2018.

7- The potential impact of the collapse of hard coral cover in Isla de Mona reefs over the last 20 years on the fish community structure remains inconclusive at this point because neither fish densities nor fish richness were statistically different in the 2020 survey compared to the 2000 baseline surveys at MUJE20 and CARM10, when live coral cover was at its historical highest measured.

8- Large demersal fish predators were observed in low density at reef stations surveyed, but our database for these species is not robust enough to reach any significant conclusions regarding the status of these populations.

9- Adult spiny lobsters (*Panulirus argus*), including some very large individuals were observed at all three stations surveyed from Isla de Mona reefs and represent perhaps the most noticeable positive response indicator of the reef community to the NTZ management strategy established since 2004 by the DNER.

IX. Research Priorities and Management Recommendations

1- The NTZ regulation encompassing most of the insular shelf of Isla de Mona allows for an interesting set of potential management options leading to the replenishment of the fish and shellfish populations, including the re-establishment of the large demersal predator populations. Seeding the Isla de Mona reefs with large growing groupers (*Mycteroperca app., Epinephelus spp*) raised in artificial cultures may be the best option to replenish these populations, since recent investigations showed that after 16 years of permanent fishing closure regulations these populations are still depauperate and may be naturally disappearing instead of recuperating.

2- Enforcement of the NTZ regulation needs to be perfect or almost perfect to have any chance for the recuperation of the large demersal predators because as documented from the most recent visual and acoustic surveys - it is evident that these populations are at the edge of total collapse. The specific recommendation is upgrade the surveillance capability of DNER officers in the island with technologically advanced equipment, such as drones.

3- Given the recent coral disease outbreaks in the Caribbean region (including SCTLD) and the arrival of the red crustose calcareous alga, *Ramicrusta sp*. in Isla de Mona reefs it is recommended to provide a more active coral reef monitoring schedule for this site.

4- Basic research directed to characterize the taxonomic composition and distribution of reef fish and shellfish larvae (lobsters, queen conch) around Isla de Mona is needed to evaluate the larval self-recruitment potential, as well as to have a better understanding of the dispersal and recruitment patterns for the desired species.

X. Literature Cited

Aguilar-Perera, A., M.T. Schärer, and M. Valdés-Pizzini. 2006. Marine Protected Areas in Puerto Rico: Historical and Current Management Approaches. Ocean and Coastal Management 49:961-975.

Bruckner, A. W. and R. L. Hill. 2009. Ten years of change to coral communities off Mona and Desecheo Islands, Puerto Rico, from disease and bleaching. Diseases of Aquatic Organisms, 87: 19-31

Canals, M., H. Ferrer and H. Ferrer. 1981. Los arrecifes de coral de Isla de Mona. Proceedings of the 8th Symposium of the Department of Natural Resources. Puerto Rico Commonwealth. San Juan, p 1-16.

Cintrón, G. and J. Thurston. 1975. Características de la plataforma insular de Isla de Mona. 2nd Symposium of the Department of Natural Resources. Puerto Rico Commonwealth. San Juan, p 1-16.

Esteves-Amador, 2013. Short-term changes to the coral reef community structure following the regional coral bleaching event of 2005. Ph. D. Dissertation, U. Puerto Rico, Mayaguez, 90p.

Froese, R. and D. Pauly (Editors). 2019. FishBase. World Wide Web electronic publication. Version 02/2019, available online at http://www.fishbase.org [details]

Goenaga, C. and G. Cintrón. 1979. Inventory of Puertorrican Coral Reefs. Internal Report of the Department of Natural and Environmental Resources (DNER). San Juan, P. R. 190 p.

García-Sais, J. R., R. Castro, J. Sabater and M. Carlo. 2001b. Coral reef communities from Natural Reserves in Puerto Rico: a baseline quantitative assessment for prospective monitoring programs. Vol. 2 - La Parguera, Boquerón, Isla de Mona, Isla Desecheo. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 193 pp

García-Sais, J. R., R. Castro, J. Sabater Clavell, R. Esteves and M. Carlo. 2006. Monitoring of coral reef communities at Isla Desecheo, Rincón, Mayaguez Bay, Guánica, Ponce and Isla Caja de Muerto, Puerto Rico, 2006. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 145 p

García-Sais, J. R., R. Castro, J. Sabater Clavell, M. Carlo, R. Esteves and, S. Williams. 2008a. Monitoring of coral reef communities at Isla Desecheo Isla de Mona, Rincón, Guánica, Ponce, Caja de Muerto, and Mayaguez. 2009-10. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 212 p

García-Sais, J. R., R. Castro, J. Sabater Clavell, M. Carlo, R. Esteves and, S. Williams. 2010a. Monitoring of coral reef communities at Isla Desecheo Isla de Mona, Rincón, Ponce, Isla Caja de Muerto, Guánica, and Mayaguez. 2007-08. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 221 p

García-Sais JR, Appeldoorn R, Batista T, Bauer L, Bruckner A, Caldow C, Carrubba, Corredor J, Díaz E Lilyestrom C, García-Moliner G, Hernández-Delgado E, Menza E, Morell J, Pait A, Sabater-Clavell J, Weil, E., Williams, E. (2010b). The State of Coral Reef Ecosystems of the Commonwealth of Puerto Rico. pp. 75-116. In Waddell J, Clarke AM (eds.) The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NOS/NCCOS. Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 569 p

García-Sais, J. R., R. Castro, J. Sabater Clavell, R. Esteves, S. Williams and M. Carlo. 2009. Monitoring of coral reef communities from Natural Reserves in Puerto Rico: Isla Desecheo, Isla de Mona, Rincón, Guánica, Ponce, Caja de Muerto and Mayaguez. 2008-09. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 228 p

García-Sais, J. R., R. Castro, J. Sabater Clavell, M. Carlo, R. Esteves and, S. Williams. 2010. Monitoring of coral reef communities from Natural Reserves in Puerto Rico: Isla Desecheo, Isla de Mona, Rincón, Guánica, Ponce, Caja de Muerto and Mayaguez. 2009-10. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 221 p

García-Sais, J. R. 2010. Reef habitats and associated sessile-benthic and fish assemblages across an euphotic-mesophotic depth gradient in Isla Desecheo, Puerto Rico. Coral Reefs, 29, 277-288

García-Sais, J. R., R. Esteves, S. Williams J. Sabater Clavell and M. Carlo. 2016. Monitoring of coral reef communities from Natural Reserves in Puerto Rico 2016. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 241 p

Garcia-Sais JR, Williams SM, Amirrezvani A. (2017) Mortality, recovery, and community shifts of scleractinian corals in Puerto Rico one decade after the 2005 regional bleaching event. PeerJ 5:e3611 https://doi.org/10.7717/peerj.3611

García-Sais, J. R., S. Williams, J. Sabater Clavell and M. Carlo. 2017. Monitoring of coral reef communities from Natural Reserves in Puerto Rico: 2017. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 311p

Hernández-Delgado E. A., C. Toledo, H. J. Claudio, J. Lassus, M. A. Lucking, J. Fonseca, K. Hall, S. J. Rafols, H. Horta, and A. M. Sabat. 2006. Spatial and taxonomic patterns of coral bleaching and mortality in Puerto Rico during year 2005. In: NOAA-NESDIS-CRWP. NOAA. U. S. Virgin Islands, St. Croix, USA.

Hernández-Delgado E. A., C. M. González-Ramos and P. J. Alejandro-Camis. 2014. Large-scale coral recruitment patterns on Mona Island, Puerto Rico: evidence of a transitional community trajectory after massive coral bleaching and mortality. Revista de Biología Tropical. On-line version ISSN 0034-7744. 13p.

Olson, J. C., R.S. Appeldoorn, M. T. Scharer-Umpierre, J. J. Cruz-Mota. 2019. Recovery when you are on your own: Slow population responses in an isolated marine reserve. PLOS ONE. Doi.org/10.1371/journal.pone.0223102.

Randall, J. E. 1967. Food habits of reef fishes of the West Indies. U. Miami. 183p.

Ruiz, H., M Scharer, R. Nemeth and E. Tuohy. 2018. Sustainability and recovery of groupers in Puerto Rico and the U. S. Virgin Islands. Final report submitted to NOAA/NMFS NA15NMF427034. 28p.

Scharer, M. 2012. Sound production and reproductive behavior of yellowfin grouper, *Mycteroperca venenosa* (Serranidae) at a spawning aggregation. Copeia. Doi: 10.1643/ce-10-151

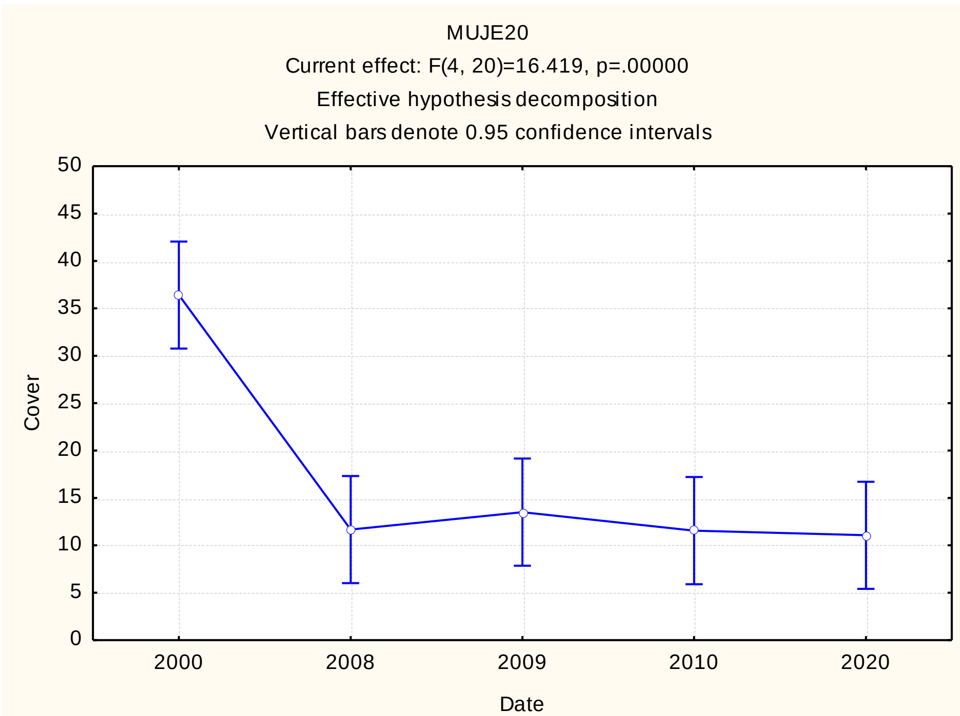
Scharer, M. T., M. Nemeth and R. S. Appeldoorn. 2010. Protecting a multispecies spawning aggregation at Mona Island, Puerto Rico. Proceedings of the 62th Gulf and Caribbean Fisheries Institute. Cumana, Venezuela. November 2-6, 2009.

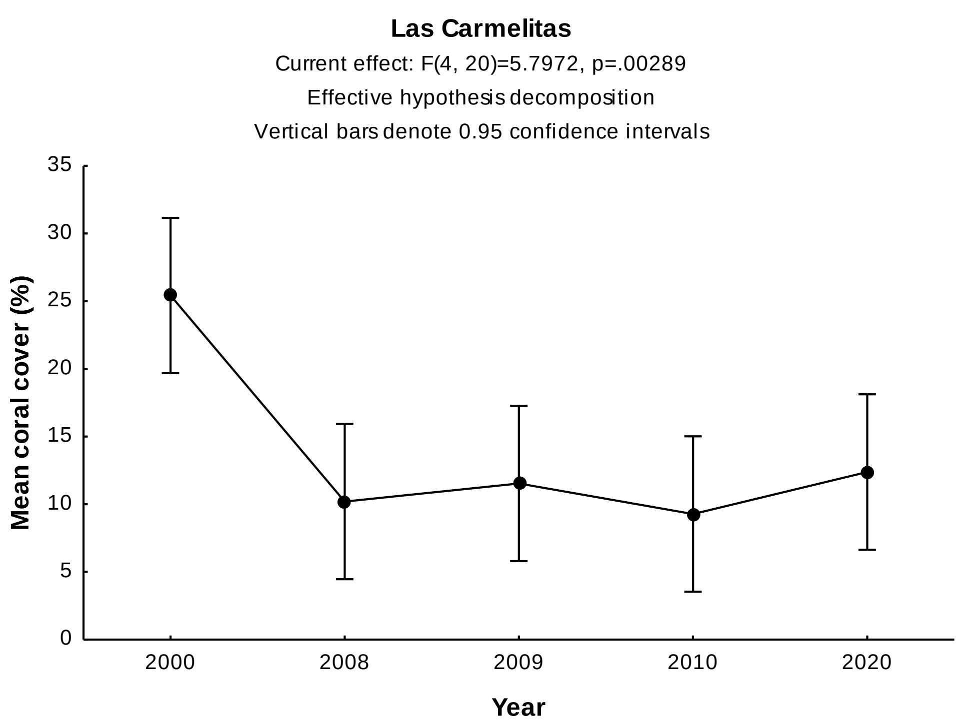
Scharer-Umpierre, M. T., Daniel Matos-Molina, R. Appeldoorn, I. Bejarano, E. A. Hernández-Delgado, R. S. Nemeth. M. I. Nemeth, M. Valdéz-Pizzini and T. B. Smith. 2014. Advances in Marine Biology, 69: 130 – 149

Weil, E.A. Croquer and I. Urreiztieta. 2009. Temporal variability and impact of coral diseases and bleaching in La Parguera, Puerto Rico from 2003 – 2007. Caribbean Journal of Science, 45:221-246.

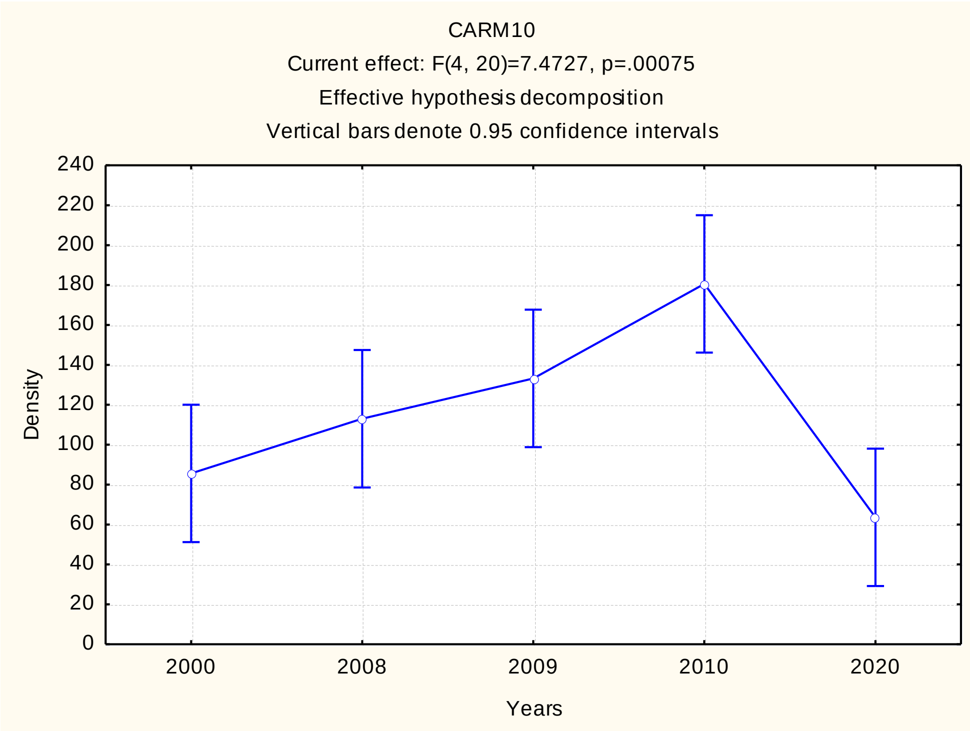
XI. Appendices

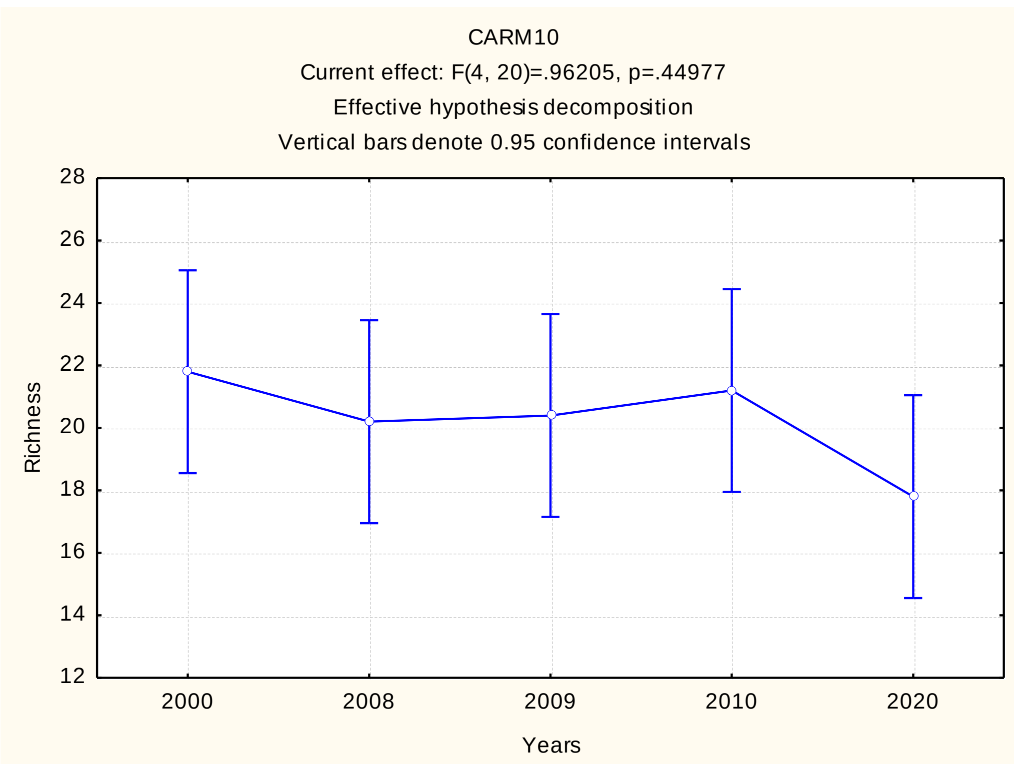
Appendix 1. One-way ANOVA testing for differences of percent hard coral cover between monitoring surveys

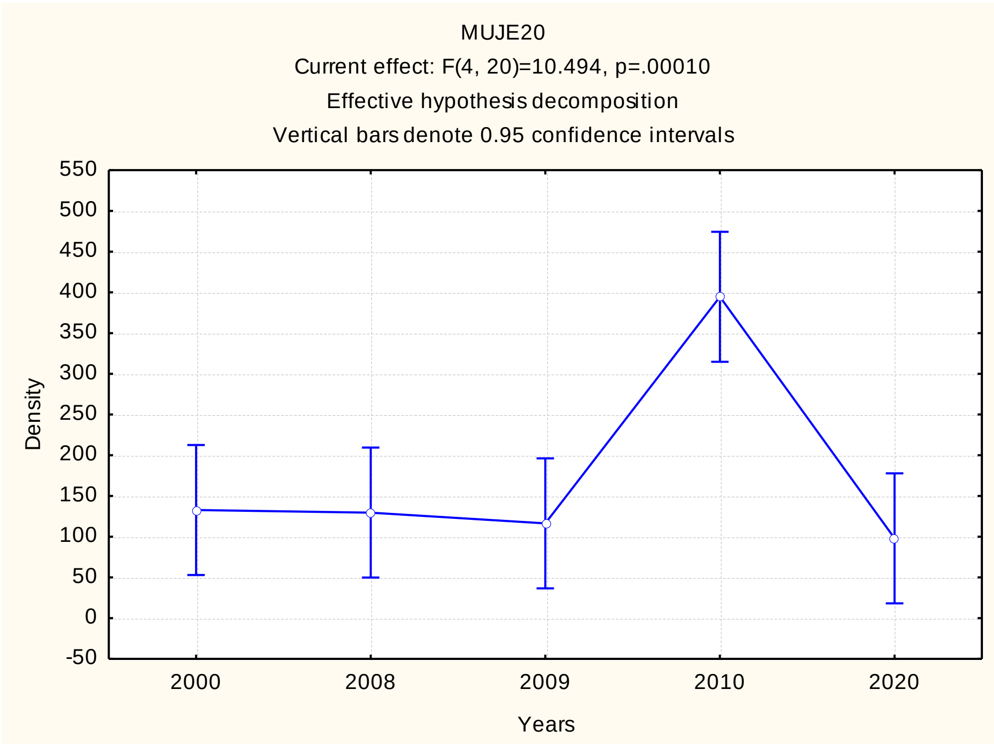


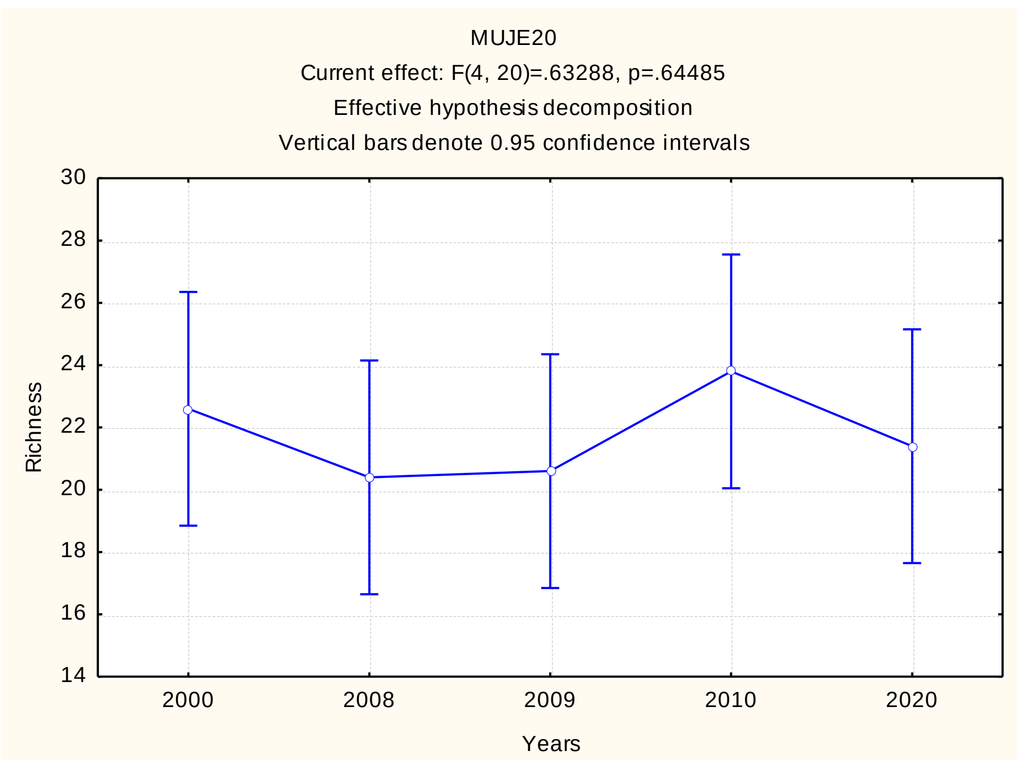


Appendix 2. One-way ANOVA testing for differences of fish density and species richness between monitoring surveys






MUJE20
Current effect: F(4, 20)=10.494, p=.00010
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Density
550
500
450
400
350
300
250
200
150
100
50
0
-50
2000
2008
2009
2010
2020
Years


MUJE20
Current effect: F(4, 20)=.63288, p=.64485
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Richness
30
28
26
24
22
20
18
16
14
2000
2008
2009
2010
2020
Years

XII. Definitions

Black corals – sessile-benthic marine animals in the Class Anthozoa, Order Antipatharia that grow as flexible vertically projected colonies of a jet-black or dark brown color

Calcareous algae – green algae in the Phylum Chlorophyta that secrete calcium-carbonate skeletons

Crustose coralline algae or CCA – refers to unidentifiable or mixed assemblage of crustose coralline algae. Red algae in the Order Corallinales that secrete Mg-calcite skeletons

Cyanobacteria – microscopic free-living marine autotrophic (photosynthetic/oxygenic) bacteria in the Phylum Cyanophyta that grow together forming reddish mats or patches over reef surfaces. Also known as "blue-green algae

Demersal – associated with the bottom, living at the bottom or near the bottom

Fleshy algae – refers to soft, fleshy algae. Includes algae within several phylogenetic groups

Gap – narrow open reef space between two other substrate categories. These gaps are typically narrow and deep enough such that the substrate below the chain is unrecognizable

Hard corals – sessile-benthic marine animals in the Phylum Cnidaria, Order Scleractinia that form a rigid calcium-carbonate skeleton. Also known as "stony corals"

Hydrocorals – colonial marine animals in the Phylum Cnidaria, Class Hydrozoa that secrete hard calcareous skeletons resembling hard corals. Also known as "fire corals" and/or "lace corals"

Motile megabenthic invertebrates – invertebrate animals (> 2 cm) with locomotion, capable of free movement over the reef substrate (e.g. lobsters, crabs, shrimps, conch)

No Take Zone (NTZ) – marine area closed to all fishing activities

Pelagic – organisms that live in the water column, not attached to the bottom

Rugosity – measurement of the reef substrate relief resulting from the excess in chain links above the 704 links that correspond to a completely flat 10m long transect. 1 chain-link = 1.4 cm

Reef overhang – reef space where the chain drops freely to the bottom without being in contact with any recognizable substrate category. Overhangs typically occur below a coral ledge, branch, or rock outcrop

Sessile-benthic – permanently attached to the substrate without any locomotive ability (e.g. hard corals, soft corals, black corals, sponges)

Soft corals – sessile-benthic colonial animals in the Phylum Cnidaria, sub-class Octocorallia that form flexible skeletons attached by a holdfast to the bottom. Also known as "gorgonians"

Sponges – sessile-benthic primitive organisms that belong to the Phylum Porifera that form dense skeletons

Turf algae – mixed assemblage of short algae (< 2cm) growing as a rug over reef hard bottom

XIII. Abbreviations and Acronyms

ANOVA – Analysis of variance

CARICOMP – Caribbean Coastal Marine Productivity

CCA – crustose coralline algae

CI – Confidence Interval

cm- centimeters

CRCP – Coral Reef Conservation Program

DNER- Puerto Rico Department of Natural and Environmental Resources

FL- Fork length

GPS – Geographic Positioning System

NOAA – National Oceanic and Atmospheric Administration

NTZ – No take zone

PRCRMP – Puerto Rico Coral Reef Monitoring Program

PRDNER – Puerto Rico Department of Natural and Environmental Resources

SCTLD – Stony Coral Tissue Loss Disease

Sp. – Species