Final Report

Puerto Rico Coral Reef Monitoring Program: 2019 Survey

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

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The Puerto Rico Department of Natural and Environmental Resources (DNER) 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 hve 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 2019 PRCRMP Final Report (this volume) motile megabenthic invertebrates

were reported from the 10x3m belt-transects. In the present report, 20x3m belt-transects only survey commercially important fishes.

Sampling Station Names and Codes

The monitoring station at Guánica's shelf-edge, previously refered to both as Guánica's Shelf-edge Reef (Garcia-Sais et al., 2015) and Efra's Wall Reef (Garcia-Sais et al. 2017) has been (since this 2019 report) named as Beril with the code BERI20.

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

A total of 21 reef stations were surveyed as part of the 2019 PRCRMP event, to complete the 2018-2019 monitoring cycle of 42 coral reef stations. Recurrent monitoring surveys were performed at TRES20, TRES10 and TRES05 in Rincon; TOUR30, TOUR20 and TOUR10 in Mayaguez; GALL05 and RESU10 in Cabo Rojo; BOYA20, MLUN10 and MLUN05 in La Parguera; BERI20, CORA10 and AURO05 in Guánica; MLAN20, MLAN10 and MLAN05 in Guayanilla; DERR20 and WEST10 in Ponce; and CARI10 and RATO05 in Salinas. Geographic coordinates and depth measurements were obtained for all individual transects. Determinations of the percent substrate cover by reef substrate (benthic) categories were produced from sets of five replicate 10m-long permanent transects per reef station based on a continuous (chain-link) intercept technique. Visual inspections of hard coral colonies intercepted by transects were performed to provide estimates of prevalence by infectious diseases. Reef fishes and motile megabenthic invertebrates (lobster, queen conch and sea urchins) were surveyed from 10 x 3m (30 m^2) belt-transects centered on the same array of five 10m-long transects used for benthic characterizations. Belt-transects were expanded to 20 x 3m (60 m^2) for density and size-frequency determinations of commercially important fishes, including parrotfishes and doctorfishes.

Reef substrate cover by live hard corals ranged from a maximum of 41.66% at TOUR10 to a minimum of 4.01% at MLAN05. Reductions of the mean reef substrate cover by hard corals were documented in 15 out of the 21 reefs surveyed, but none of these reductions of cover by hard corals between the previous 2017 and the 2019 monitoring survey were statistically significant (pairwise comparisons within 95% CI). The mean hard coral cover loss on the 15-reef stations with loss measurements was -9.73%. Overall, the net change of hard coral cover between the previous 2017 and the present 2019 monitoring survey for the 21-reef matrix was - 4.09%. The largest differences of hard coral cover were measured in GALL05 (-25.20%) and MLAN05 (-20.44%). Both of these shallow reefs appeared to be severely impacted by wave action, perhaps related to the pass of Hurricane Maria in September 2017 and/or by the winter storm Riley in March 2018. Aside from these important exceptions, our data showed that the overall impact of hurricanes and winter storm events on the hard-coral communities of reef stations included in the 2018-19 monitoring survey were minimal. Perhaps the most relevant impact of reef benthic community structure that appears to be linked to extreme wave and surge action event(s) was the loss of erect soft coral colonies. Statistically significant reductions of soft coral densities were measured from 13 reef stations (ANOVA, $p < 0.05$). The largest density reductions were

measured from TRES05 (-46.15%), MLUN05 (-30.95%), BERI20 (-24.63%), TRES20 (-23.08%), and DERR20 (-22.62%).

On the 21-reef station matrix in 2019, a total of 1,112 live hard coral colonies were intercepted by 105 transects surveyed for a mean density of 10.6 hard coral Col/Transect. Apparent infectious diseases were observed on 54 hard coral colonies for a mean coral disease prevalence of 4.86%. Massive starlet coral (*Siderastrea siderea*), with 20 infected colonies by what appeared to be the "Dark Spot Disease", was the most affected coral species accounting for 37.0% of all diseased coral colonies. Prospective monitoring surveys will be needed in order to evaluate the ecological implications of this disease (outbreak) on *S. siderea* colonies. Partially bleached hard coral colonies were observed from MLAN20 (4), MLAN10 (6), and DERR20 (2).

Benthic algae, a mixed assemblage comprised by turf, fleshy, crustose coralline and calcareous macroalgae, was the dominant reef substrate category in 20 of the 21 reef stations surveyed, ranging in mean cover from a maximum of 75.04% at MLAN05 to a minimum of 32.10% at MLUN10. Turf algae, in most cases packed with fine sediments, was the main component of the benthic algae assemblage on most reef stations. The red crustose coralline alga, *Ramicrusta sp*., was intercepted by transects in 15 reef stations with an overall mean substrate cover of 1.95%. Order of magnitude increments of cover by *Ramicrusta sp*. relative to the previous 2017 survey were measured at TRES05, TOUR20, TOUR10, and MLUN05.

Fish density ranged from 159.2 Ind/30m^2 at WEST10 to 20.8 Ind/30m^2 at RESU10. The mean fish species richness ranged from 21.0 Spp/30m^2 at WEST10 to 8.8 Spp/30m^2 at TRES05. The highest density of invertebrates was observed from MLUN05 (13.2 Ind/30m^2), mostly contributed by adult long-spined urchin, *Diadema antillarum*. Temporal variations of fish density between monitoring surveys were statistically significant at 11 reef stations (ANOVA, $p < 0.05$). Differences were mostly related to density fluctuations of numerically dominant fishes with highly aggregated distributions, such as the masked goby (*Coryphopterus personatus*), which presented generally low densities or absence from most reef stations during the 2019 survey. Such marked island-wide population declines may be related to meso-scale oceanographic phenomena, such as the physical disturbance caused by the pass of Hurricane Maria and/or winter storm Riley in March 2018. Statistically significant differences of fish species richness were measured from 13 reef stations, eight of which also exhibited fish density reductions.

Pelagic and demersal zooplanktivorous fish assemblages dominated the fish trophic structure of several outer shelf and shelf-edge reefs, such as WEST10 (61.1%), TOUR30 (42.2%), TOUR20 (38.1%) and DERR20 (30.0%) based on the relative density of species within belt-transects. The herbivore fish assemblage was the most prominent at coastal reefs, such as GALL05 (58.2%), CARI10 (53.4%), RESU10 (46.7%) and MLUN05 (41.7%). Small opportunistic carnivores presented higher relative densities at MLAN20 (66.4%), TRES10 (61.0%), TRES05 (57.3%), RATO05 (53.5%), BOYA20 (46.3%), TOUR10 (45.4%), TRES20 (44.4%), MLAN05 (48.6%) and MLAN10 (38.7%). Mid-sized piscivores, such as yellowtail and schoolmaster snappers (*Ocyurus chrysurus, Lutjanus apodus*), hogfish (*Lachnolaimus maximus*) and red hind (*Epinephelus guttatus*) were observed as juvenile and/or adults in many of the reefs surveyed without any evident pattern associated with depth and/or distance from shore. Large demersal predators were generally absent from belt- transect areas of the reefs surveyed with the exception of two adult Nassau groupers (*Epinephelus striatus*) observed at CORA10 and at TOUR20. Large pelagic predators included the crevalle jack (*Caranx latus*). Cero Mackerels (*Scomberomorus regalis*) and great barracudas (*Sphyraena barracuda*) were observed out of transects at several reef stations.

The fish size-frequency distribution data showed that most of the reefs surveyed function as recruitment, nursery and residential habitats for a wide variety of the larger reef fish herbivores, such as doctorfishes (*Acanthurus spp*) and parrotfishes (*Scarus spp, Sparisoma spp*). Recruitment size classes (1-5cm) of parrotfishes and doctorfishes were most abundant at CARI10 (19.2 Ind/60m^2), WEST10 (9.2 Ind/60m^2) and RATO05 (8.4 Ind/60m^2).

III. Resumen Ejecutivo

Un total de 21 estaciones arrecifales fueron estudiadas entre mayo y septiembre, 2019 para completar el evento de monitoreo de 42 comunidades de arrecifes de coral de Puerto Rico 2018-19 (PRCRMP). Monitoreos recurrentes fueron realizados en TRES 20, TRES10 y TRES05 en Rincón; TOUR30, TOUR20 y TOUR10 en Mayagüez; GALL05 y RESU10 en Cabo Rojo; BOYA20, MLUN10 y MLUN05 en La Parguera; BERI20, CORA10 y AURO05 en Guánica; MLAN20, MLAN10 y MLAN05 en Guayanilla; DERR20 y WEST10 en Ponce; y CARI10 y RATO05 en Salinas. Se registraron coordenadas geográficas y medidas de profundidad para todos los transectos individuales. Las determinaciones de porciento de cobertura por categorías bénticas en sustratos arrecifales se produjeron mediante la técnica de intercepto contínuo con cadena en grupos de cinco transectos permanentes replicados de 10m de largo por estación. Todas las colonias de corales pétreos interceptadas fueron visualmente inspeccionadas para determinar presencia de enfermedades infecciosas y su tasa de prevalencia (%) por estación. Determinaciones de la composición taxonómica, densidad y riqueza de especies de peces e invertebrados megabénticos mótiles (langostas, carruchos, erizos) se basaron en censos visuales de cinco transectos de correa de 10m de largo x 3m de ancho centralizados en los mismos transectos utilizados para caracterizaciones bénticas. Se extendieron estos transectos de correa a 20m de largo x 3m de ancho para incluir especies de peces de importancia comercial (peces cotorros y médicos incluidos) y sus respectivos tamaños.

Los promedios de cobertura de sustratos arrecifales por corales pétreos variaron entre 41.66% en TOUR10 y 4.01% en MLAN05. Reducciones en los porcientos de cobertura de corales pétreos fueron medidas en 15 de las 21 estaciones arrecifales estudiadas en el 2019, comparados a las medidas del censo anterior (2017). Sin embargo, ninguna de estas diferencias entre censos fue estadísticamente significativas (comparación entre pares dentro del 95% IC). La reducción promedio en las 15 estaciones en las cuales se midieron reducciones fue 9.73%. El cambio neto en porciento de cobertura promedio por corales pétreos para las 21 estaciones fue de -4.09%. Las mayores diferencias fueron medidas en GALL05 (-25.20%) y en MLAN05 (-20.44%). En ambos casos, estos arrecifes someros sufrieron daños estructurales severos aparentemente causados por oleaje extremo posiblemente asociado al paso del Huracán María en septiembre, 2017 y/o a la tormenta invernal Riley en marzo, 2018. Con excepción de estos dos importantes casos, los datos evidencian que en términos generales el impacto de huracanes y tormentas invernales sobre las comunidades de corales pétreos estudiadas en el censo de 2019 fueron de menor grado. Posiblemente el impacto más importante sobre las comunidades bénticas asociado a eventos extremos de oleaje y resaca fue la reducción en densidad de colonias de corales blandos (gorgonáceos). Diferencias estadísticamente

significativas (ANOVA, $p < 0.05$) se registraron para 13 estaciones arrecifales. Las mayores reducciones fueron medidas en TRES05 (-46.15%), MLUN05 (-30.95%), BERI20 (-24.63%), TRES20 (-23.08%), y DERR20 (-22.62%).

Un total de 1,112 colonias de corales pétreos fueron interceptadas por 105 transectos en las 21 estaciones arrecifales estudiadas para una densidad promedio de 10.6 Col/Transecto. Enfermedades aparentes en corales pétreos asociadas a infecciones fueron observados en 54 colonias para un promedio general de prevalencia de enfermedades de 4.86%. El coral masivo estrellado (*Siderastrea siderea*) afectados aparentemente por la enfermedad de manchas negras (Dark Spot Disease) fue la especie más afectada con 20 colonias infectadas, representativas del 37.0% del total en transectos. Las implicaciones ecológicas de estas infecciones deberán ser evaluadas a partir de monitoreos futuros en las comunidades afectadas. Colonias de corales pétreos parcialmente blanqueadas fueron observados en MLAN20 (4), MLAN10 (6), and DERR20 (2).

Las algas bénticas, integradas por alfombras de algas, algas carnosas, algas crustosas coralinas y algas calcáreas fueron la categoría béntica dominante en términos de porciento de cobertura en 20 de las 21 estaciones arrecifales, con promedios q fluctuaron entre 75.04% en MLAN05 y 32.10% en MLUN10. Las alfombras de algas (componente mixto), en muchos casos empacadas con sedimentos finos resultaron ser el componente principal de la categoría de algas bénticas en la mayoría de las estaciones estudiadas. El alga roja crustosa coralina, *Ramicrusta sp*. aumentó su porciento cobertura en al menos un órden de magnitud (10X) relativo al censo previo de 2017 en TRES05, TOUR20, TOUR10 y MLUN05.

Las densidades de peces variaron entre un promedio de 159.2 Ind/30m^2 en WEST10 y 20.8 Ind/30m^2 en RESU10. La riqueza de especies de peces varió entre 21.0 Spp/30m^2 en WEST10 y 8.8 Spp/30m^2 en TRES05. La densidad máxima de invertebrados mótiles megabénticos fue medida en MLUN05 (13.2 Ind/30m^2) mayormente asociada al erizo *Diadema antillarum*. Variaciones temporales en densidades de peces fueron estadísticamente significativas en 11 estaciones arrecifales (ANOVA, $p < 0.05$). Las diferencias entre censos estuvieron influenciadas en la mayoría de los casos por fluctuaciones en densidades de especies numéricamente dominantes con distribuciones agregadas, tales como el péz góbido, *Coryphopterus personatus* el cual presentó en el censo de 2019 densidades bajas en la mayoría de las estaciones comparado a censos anteriores. Tales reducciones a travéz de ámplias regiones costeras en PR pudieran relacionarse a procesos oceanográficos mesoescalares, tales como las marejadas causadas por el Huracán María en septiembre 2017 y/o la tormenta invernal Riley en marzo 2018. Diferencias en la riqueza de especies de peces fueron estadísticamente significativas en 13 estaciones arrecifales (ANOVA, $p < 0.05$), ocho de las cuales también exhibieron

reducciones en densidad asociadas a *C. personatus*. Es posible que las condiciones extremas de oleaje y resaca asociadas a huracanes y/o tormentas invernales hayan tenido implicaciones estresantes y/o mortalidad sobre un grupo ámplio de peces pequeños. A su vez, la ausencia o reducción en densidades de los peces pequeños pudiera influir negativamente en la densidad de depredadores potenciales, los cuales también contribuyen a la biodiversidad de las comunidades de peces (efecto cascada).

Basados en la densidad relativa de peces en transectos de correa los zooplanctívoros pelágicos y demersales fueron dominantes en la estructura trófica de varias estaciones arrecifales de la plataforma exterior y/o localizadas al borde de la plataforma tales como WEST10 (61.1%), TOUR30 (42.2%), TOUR20 (38.1%), y DERR20 (30.0%). El componente de peces herbívoros fue el más prominente en arrecifes costeros tales como GALL05 (58.2%), CARI10 (53.4%), RESU10 (46.7%) y MLUN05 (41.7%). Los carnívoros pequeños oportunistas fueron el grupo trófico dominante en MLAN20 (66.4%), TRES10 (61.0%), TRES05 (57.3%), RATO05 (53.5%), BOYA20 (46.3%), TOUR10 (45.4%), TRES20 (44.4%), MLAN05 (48.6%) y MLAN10 (38.7%). Peces piscívoros de tamaño mediano, tales como pargos (*Ocyurus chrysurus, Lutjanus apodus*), capitán (*Lachnolaimus maximus*), y mero cabrilla (*Epinephelus guttatus*) fueron observados en etapas juveniles y/o adultas en varios de los arrecifes estudiados sin mostrar patrones evidentes asociados a la profundidad y/o a la distancia de la costa. Peces piscívoros demersales grandes (meros, pargos, tiburones) fueron observados en muy bajas densidades o ausentes de las estaciones estudiadas. Solo dos meros cherna (*E. striatus*) adultos fueron observados en CORA10 y TOUR20. El jurel *Caranx latus* fue la única especie representativa de depredadores piscívoros pelágicos grandes en los transectos. Sierras (*Scomberomorus regalis*) y picúas (*Sphyraena barracuda*) fueron observados en varias estaciones fuera de los transectos.

Los datos sobre la distribución de tamaños de peces son indicativos de que la mayoría de los arrecifes estudiados sirven como hábitats de reclutamiento, criadero y residencia para una ámplia variedad de especies de peces arrecifales herbívoros tales como médicos (*Acanthurus spp*) y cotorros (*Scarus spp, Sparisoma spp*). Etapas de juveniles reclutas (1-5cm) de médicos y cotorros fueron más abundantes en CARI10 (19.2 Ind/60m^2), WEST10 (9.2 Ind/60m^2) y RATO05 (8.4 Ind/60m^2).

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IV. Introduction

This is the final report corresponding to the 2019 survey of the Puerto Rico Coral Reef Monitoring Program (PRCRMP) sponsored by NOAA/CRCP and administered by the PR Department of Natural and Environmental Resources (PRDNER). The program started in 1999 with baseline characterizations of reef substrate cover by sessile-benthic categories and determinations of fish and motile megabenthic invertebrate taxonomic composition and densities. Annual monitoring events were conducted on a total of 15 reefs between 2003 and 2015. In 2016, the PRCRMP was modified to expand the geographical range and number of reef monitoring sites to achieve a 42-reef station framework, with alternate year monitoring surveys at each reef station. The 2019 coral monitoring event includes an array of 21 reef stations surveyed between May 23 and September 6, 2019, all of which represent recurrent monitoring sites. Monitoring surveys were performed at reef stations in Rincon (TRES20, TRES10, TRES05), Mayaguez (TOUR30, TOUR20, TOUR10), Cabo Rojo (RESU10, GALL05), La Parguera (BOYA20, MLUN10, MLUN05), Guánica (AURO05, CORA19, BERI20), Guayanilla (MLAN05, MLAN10, MLAN20), Ponce (DERR20, WEST10) and Salinas (VARI10, RATO05).

During September 2017, two category 4-5 hurricanes (Irma and Maria) impacted the Puertorrican coastlines. Irma impacted the northeast coastline, including the islands of Vieques, Culebra and the smaller islands in the Cordillera de Fajardo. Maria affected essentially the entire coastline of Puerto Rico with hurricane strength winds. In March 2018, an event of exceptionally high waves associated with winter storm Riley impacted the north and west coasts of Puerto Rico with potentially harmful effects to shallow coral reef systems within the insular shelf.

An assessment of impact(s) upon coral communities potentially related to these extreme climatological events was included in the previous 2018 PRCRMP final report (Garcia et al., 2018). Statistically significant differences of total live hard coral cover between the 2015-16 baselines and the 2017-18 monitoring surveys were measured at reef stations of Isla de Vieques (ESPE10 and CANJ20), Isla de Culebra (LPEN05) and at reef stations of Isla Desecheo (BOTE15 and BOTE20). In all cases, differences were associated with a decline of coral cover in 2018 relative to previous surveys. Loss of total hard coral cover was measured in 17 of the 19 reef stations surveyed in 2018. The mean reduction of coral cover from the 17-reef station data set was 18.02%. Differences of octocoral densities between monitoring surveys were also statistically significant at four reef stations (LPEN05, DAKI20, PALN20, MEXT10), all of which resulted from declining densities measured in 2018. The general decline of hard coral cover (%) and octocoral

densities was associated to mechanical breakage and/or detachment and overturn of colonies due to extreme surge and/or abrasion effects that may have prevailed during the pass of hurricanes (Irma and/or Maria) and/or winter storm Riley.

This 2018-19 monitoring progress report aims to provide a complementary assessment of the potential impact(s) of hurricanes Irma and Maria and winter storm Riley on coral reef communities included in the PRCRMP since the previous 2018 report only examined 21 out of the 42-reef station matrix. Complete data sets for all reef sites can be found in previous PRCRMP annual monitoring reports (García-Sais et al., 2001a, 2001b, 2001c, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2012, 2014, 2015, 2016, 2017, 2018). Such information contributes to an existing network of U.S. coral reef monitoring sites sponsored by NOAA. A comprehensive database with all quantitative transect data on percent cover by benthic categories, and taxonomic composition, density, and size frequency distribution of fishes collected since 1999 has been prepared and is available in in Microsoft Access.

V. PR Coral Reef Monitoring Program - Research Synthesis (1999 - 2018)

Since the start of this monitoring program in 1999, coral reef systems in Puerto Rico have shown a variety of ecological health trends. Coastal shallow reefs of the south coast, such as CORA10 in Guánica and WEST10 in Isla Caja de Muerto in Ponce exhibited a moderate, yet statistically significant decline of live coral cover between their 1999-2001 baseline survey(s) and 2005. During a similar time-frame, reefs in the oceanic islands of Mona (CARM05, MUJE20) and Desecheo (CANO20, BOTE20, BOTE15), as well as shelf-edge reefs in Mayaguez (TOUR 30, TOUR20, TOUR10) and Ponce (DERR20, CDM10), and reefs all around Vieques (Garcia-Sais et al. 2000, 2001d, 2004) maintained stable live hard coral cover.

A sharp decline of live coral cover was measured from reefs in Ponce (DERR20), Isla Desecheo (CANO30, BOTE20, BOTE15) and Mayaguez (TOUR10) during the 2006 monitoring survey after a severe regional coral bleaching event affected reef systems in the northern Caribbean during late 2005 (Miller et al., 2006; Hernandez et al., 2006; García-Sais et al., 2008; Weil et al., 2009; Eakin et al., 2010). Posterior monitoring surveys in Isla de Mona (Garcia-Sais et al., 2010) and Vieques (Garcia-Sais et al., 2014) detected marked reductions of coral cover in the range (25 – 50%) previously noted for reefs in Desecheo and Ponce, suggesting that such declines of coral cover were associated with the 2005 coral bleaching event. Sibling species of Boulder Star Coral

(*Montastraea annularis* and *M. faveolata*; genus now changed to *Orbicella spp.*) were the most vulnerable to the bleaching event. Thus, reef systems strongly dominated in terms of substrate cover by these species, such as those in the oceanic islands of Mona and Desecheo, the shelf-edge reefs of Ponce (DERR20), TOUR10 in Mayaguez and those in Vieques were the most severely affected.

A pattern of lower coral mortality with increasing depth, from 20 to 30m was observed from Tourmaline Reef stations in Mayaguez (TOUR30, TOUR20, TOUR10), Puerto Canoas/Puerto Botes Reef stations in Isla Desecheo (CANO30, BOTE20, BOTE15), and the Canjilones (CANJ20) and Boya Esperanza (ESPE10) reefs in Vieques in 2006 after the bleaching event. The Tres Palmas Reef system in Rincon, dominated in terms of substrate cover by Elkhorn coral (*Acropora palmata*) at depths of 1-3m (TRES05), and by *M. cavernosa* at 10m (TRES10) did not show any statistically significant decline of live coral cover. Reefs located near the coastline and/or influenced by estuarine conditions (PALO05, RESU10) in the Cabo Rojo shelf exhibited low or negligible impacts to their mean coral cover after the 2005 bleaching event. A negative correlation between a satellite-derived light attenuation coefficient (Kd 490) and the percent live coral loss was found, suggesting that protection from incident light provided both from water turbidity and increasing depths contributed to the protection of corals from bleaching induced mortality (Garcia-Sais et al., 2017).

After two consecutive years of measuring what appeared to be lingering effects of the 2005 coral bleaching event, variable but consistent increments of live coral cover were measured from a subset of eight (8) PRCRMP stations considered as impacted reefs (Garcia-Sais et al., 2017, 2016 and references therein). These included CANO30, BOTE15, CORA10, DERR20, WEST10, TOUR30, TOUR20, and TOUR10. Increments of reef substrate cover by live corals, while not statistically significant for all reef stations, represent recuperation trends of corals after the bleaching event at these stations. A positive relationship was observed between coral cover increments at reefs impacted by bleaching and Kd 490, suggesting that in some instances, estuarine conditions influencing reefs near the coast could be providing more favorable conditions for coral recuperation of reef substrate cover. Since variations of chlorophyll-a concentrations (influenced by phytoplankton biomass) explained more than 90% of the spatial variability associated with light attenuation (turbidity) in the vicinity of our monitored reef stations (Garcia-Sais et al., 2017), it is possible that the higher increments of coral cover measured in estuarine influenced reefs may be related to the higher plankton food availability. It is important to note that

more than half (27 out of 42) of the currently monitored PRCRMP stations do not have [pre-2005] historical data to determine potential recovery trends.

During September 2017, two category 4-5 hurricanes (Irma and Maria) impacted the Puertorrican coastlines and during March 2018, an extreme event of exceptionally high waves associated with winter storm Riley impacted the north and west coast of Puerto Rico. Impacts of these extreme climatological events upon 21 of the 42 coral reef communities included in the PRCRMP were analyzed by Garcia-Sais et al. (2018). Statistically significant differences of total live coral cover were evidenced between the 2016 baseline and the 2018 monitoring survey at reef stations of Isla de Vieques (ESPE10 and CANJ20), Isla de Culebra (LPEN05), and between the previous 2015 and the 2018 monitoring survey at reef stations of Isla Desecheo (BOTE15 and BOTE20). In all cases, differences were associated with a decline of coral cover in 2018 relative to previous survey(s). Loss of total live coral cover was measured in 17 of the 19 reef stations surveyed in 2018 where previous assessments were available for comparison. The mean reduction of coral cover from the 17-reef station data set was 18.02%. The largest losses of live coral cover were measured at LPEN05 in Isla de Culebra (-51.7%), DIAB05 in Fajardo (-38.9%), and BOTE20 in Isla Desecheo (-33.7%). Finger coral (*Porites porites*) and lobed star coral (*Orbicella annularis*) were the main species associated with coral loss of substrate cover at reef stations, but several other species contributed to the decline of cover by hard corals.

Differences of octocoral densities between monitoring surveys were also statistically significant at four reef stations (e.g. LPEN05, DAKI20, PALN20, MEXT10), all of which resulted from declining densities measured in 2018. The general decline of coral cover (%) and octocoral densities appeared related to mechanical breakage and/or detachment and overturn of colonies due to extreme surge and/or abrasion effects that may have prevailed during the pass of hurricanes (Irma and/or Maria) in September 2017, and/or another extreme wave storm event impacting shallow reefs of the north and west coasts of PR in March 2018, prior to our reef monitoring survey. Coral disease prevalence for the 21-reef data set averaged 5.3% in 2018, resulting from 64 apparently diseased colonies out of a total of 1,210 colonies intercepted by transects. Although a comprehensive evaluation of coral disease infections was not part of the scope of work of this monitoring survey, the ubiquitous appearance of dark spots in coral colonies suggests high prevalence of the “dark spot syndrome” at reef stations surveyed in 2018, particularly on massive starlet coral (*Siderastrea siderea*).

Phase shifts in the taxonomic composition of reef substrate cover by live corals have been noted for TOUR10 (Mayaguez) and at BOTE20 and BOTE15 (Isla Desecheo). In both cases, mortality of boulder star coral (*Orbicella annularis* complex) has allowed branching corals to become the dominant coral taxa in terms of substrate cover. In the case of Tourmaline Reef, yellow pencil coral (*Madracis auretenra*) grew over dead coral sections of *O. annularis* and other reef hard ground to the point where total cover by live corals has increased from its original condition before the 2005 bleaching induced mortality. Dead coral sections have been largely overgrown by turf and red encrusting crustose algae (*Ramicrusta sp.*) in other reefs stations (Garcia-Sais et al. 2017, 2016 and references therein). Still, subtle recuperation trends of reef substrate cover by *Orbicella* appeared to be emerging from most reef sites until 2017.

Shifts in the relative contribution of taxonomic components to the reef substrate cover by benthic algae were evidenced from ESPE10, LPEN05 and CROS10. These included marked reductions of cover by the red crustose algae *Ramicrusta sp*., due to overgrowth by brown and red fleshy algae (ESPE10, LPEN05), and reductions of brown fleshy algae associated with corresponding increments of cyanobacteria (CROS10). It is unclear if such changes were influenced by mechanical forces or if they are part of a dynamic process involving benthic algae succession and competition for available reef hard bottom. Statistically significant changes in the relative composition of substrate cover by benthic algal assemblages involving displacement of the previously dominant turf algae by crustose Peyssonnelid red algae (mostly *Ramicrusta sp.*) were noted during the 2016 survey from reefs stations of Vieques (CANJ20, ESPE10). Despite the measured losses, red crustose Peyssonnelid algae prevailed as the dominant assemblage in terms of substrate cover at the Vieques reefs (CANJ20, ESPE10), and other east coast reef stations in Fajardo (PALT10, DIAB05) and Culebra (CROS10, LPEN05) during the 2018 survey. Conversely, west coast reefs at similar depths (MEXT20, MEXT10, RODR05, GUAN20, NEGR10, NEGR05, BOTE20, BOTE15) and mesophotic reefs (CANO30, SECO30) exhibited benthic algal assemblages strongly dominated by turf and/or brown fleshy algae, with only minor contributions of reef substrate cover by *Ramicrusta sp*.

A total of 210 species of diurnal, non-cryptic fish species have been identified by the PRCRMP during all survey years (1999 – 2018). In general, fish populations have presented a trend of fluctuating (statistically significant) differences of density and species richness within belt-transects (Esteves, 2013, García-Sais et al., 2016 and reference therein). Variations between surveys were mostly associated with fluctuations of density by numerically dominant populations

that exhibit highly aggregated distributions, such as the masked goby (*Coryphopterus personatus*), blue chromis (*Chromis cyanea*), blue-head wrasse (*Thalassoma bifasciatum*) and creole wrasse (*Clepticus parrae*). Such fluctuations appear to be related to density-independent factors influencing recruitment patterns of these short-lived populations (Garcia-Sais, 2010; Esteves, 2013). Variations also appear to be driven by physical forces, such as wave action affecting the reef during field surveys. This has been observed to be particularly relevant for shallow reefs (< 20 m) and more critically determinant for *Acropora* reefs, such as TRES05, GALL05, MLAN05, and AURO05. Statistically significant reductions of fish density and species richness also appear strongly related to hurricane and/or other extreme wave action events (Garcia-Sais et al., 2018). Depth, distance from shore, and substrate rugosity stand as the main factors explaining the variations of taxonomic composition and relative abundance of fish species at the reefs studied (Garcia-Sais, 2010; Esteves, 2013).

VI. Approach and Methodology

A. Sampling Design

The 2019 PRCRMP monitoring event included recurrent monitoring surveys at 21 reef stations located along the west (TRES 20, TRES10, TRES05; TOUR30, TOUR20 and TOUR10; GALL05 and RESU10), southwest (BOYA 20, MLUN10 and MLUN05; BERI20, CORA10 and AURO05) and south coast of Puerto Rico (MLAN20, MLAN10 and MLAN5; DERR20, CDMU10; CARI10 and RATO05). The locations of reef stations in the PRCRMP, highlighting those included for monitoring during the present 2018-19 cycle, are shown in Figure 1. Name codes and mean depths of reef stations surveyed are listed in Table 1.

The PRCRMP follows a depth, distance from shore and geographical (east-west; north-south) sampling design that includes some of the main oceanographic gradients that appear to drive the ecological health and community structure of neritic coral reefs in Puerto Rico. Neritic coral reef included in this monitoring program are all shallower than 40 m, and thus lie within the Caribbean Surface Mixed Layer water mass with pycnocline at depths between 45 – 70 m. Due to the permanent stratification forces acting on this water mass, oceanic waters around Puerto Rico remain highly oligotrophic, and the coastal estuarine influence of river discharge, watershed runoff, and resuspension/remineralization processes from the insular shelf produce marked inshore-offshore gradients of water turbidity associated with both dissolved and particulate organic and inorganic sources.

Coral reefs located to the east of the mainland, such as those in the Cordillera de Fajardo (PALO20, PALT10, DIAB05), and the islands of Vieques (CANJ20, ESPE10, and SECO30) and Culebra (DAKI20, CROS10, LPEN05) are at the head of the current and receive minor estuarine influence from land masses. Likewise, reefs located in the oceanic Isla Desecheo (CANO30, BOTE20, BOTE15) are also far from estuarine influences. Shelf-edge reefs (BOYA20, BERI20, TOUR30) associated with the mainland are intermediate across this inshore-offshore gradient and their estuarine influence is variable, being higher in the west and north coasts, and lower in the south coast due to the presence/absence of major rivers. The natural exponential decline of light penetration with increasing depth creates another relevant gradient for coral reef ecology that needs to be addressed in the understanding of potential causes of reef degradation and management options. Thus, the coral monitoring program includes vertically (depth) stratified sampling designs on several reef sites. Similar depth formats on the east, west and south coasts enable comparative analyses between depths and across natural turbidity gradients associated with riverine influences and island mass effects.

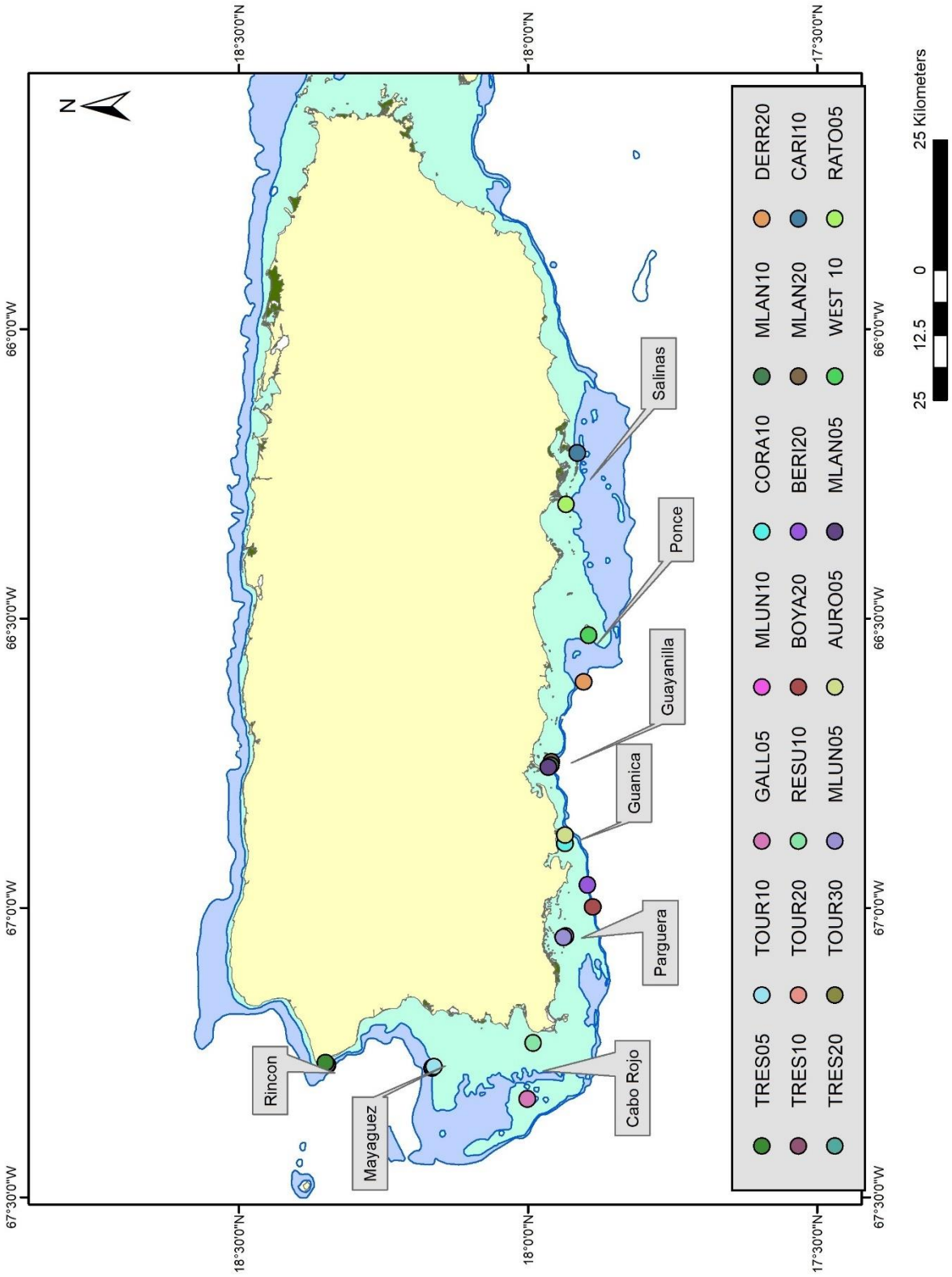


Figure 1. Map showing location of reef monitoring sampling stations. PRCRMP 2019 Survey

Table 1. Geographic coordinates and mean depths of reef survey stations included in the PRCRMP 2019 monitoring event. Station coordinates listed here are for Transect 3.

Site	Reef Stations	Station Code	Survey Date	Mean Depth (m)	Latitude (degrees N)	Longitude (degrees W)
Rincon						
	Tres Palmas 20	TRES20	5/23/19	17.46	18.34652	67.27118
	Tres Palmas 10	TRES10	5/23/19	9.39	18.34732	67.26997
	Tres Palmas 5	TRES05	5/23/19	1.64	18.35072	67.26688
Mayaguez						
	Tourmaline 30	TOUR30	5/27/19	27.94	18.16637	67.27632
	Tourmaline 20	TOUR20	6/7/19	18.73	18.16517	67.27524
	Tourmaline 10	TOUR10	5/27/19	10.97	18.16304	67.27367
Cabo Rojo						
	Gallardo	GALL05	6/7/19	6.00	18.00170	67.32990
	Resuellos	RESU10	6/7/19	7.86	17.99116	67.23322
La Parguera						
	Boya Vieja 20	BOYA20	6/14/19	18.12	17.88827	66.99780
	Media Luna 10	MLUN10	6/14/19	8.73	17.93472	67.04850
	Media Luna 5	MLUN05	6/14/19	3.09	17.93937	67.05067
Guánica						
	Beril de Guanica 20	BERI20	8/9/19	16.97	17.89758	66.95987
	Cayo Coral 10	CORA10	8/9/19	8.68	17.93622	66.88838
	Cayo Aurora 5	AURO05	8/9/19	4.14	17.93670	66.87390
Guayanilla						
	Maria Langa 20	MLAN20	8/10/19	15.08	17.95953	66.74698
	Maria Langa 10	MLAN10	8/10/19	8.76	17.96093	66.75292
	Maria Langa 5	MLAN05	8/10/19	3.54	17.96488	66.75647
Ponce						
	Derrumbadero	DERR20	9/5/19	16.42	17.90400	66.60860
	West Reef	WEST10	9/5/19	7.44	17.89502	66.52838
Salinas						
	Cayo Caribes	CARI10	9/6/19	9.18	17.91533	66.21407
	Cayo Ratones	RATO05	9/6/19	4.12	17.93458	66.30247

B. Sessile-benthic Reef Communities

A set of five 10m long permanent transects previously installed during baseline surveys were surveyed from each reef station. Transects were positioned non-randomly in areas visually considered to be of optimal coral growth within similar depths (+/- 3 m) and reef physiographic

zones. Transect mean depths were determined from the five depth measurements taken at the start 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. Individual geographic coordinates were obtained for all transects surveyed at each reef station in the monitoring program with a time-synchronized GPS placed inside a zip-lock bag and installed on a floater. Coordinates were taken from the starting rebar of each transect.

Sessile-benthic reef communities were characterized by the continuous intercept chain-link method (as modified from Porter, 1972), following the CARICOMP (1994) protocol. This method provides information on the percent linear cover by sessile-benthic biota and other substrate categories along transects. It allows construction of reef community profiles by assignment of metric units to each substrate transition, which serves as a high precision baseline for monitoring. 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 (Col/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.

During conditions of extreme wave and surge action, such as those occurring during hurricanes and/or exceptionally high North Atlantic swells, rebar transect markers may become detached from the reef structure. In such cases, rebars were re-installed in the same place without any alteration of the transect path. In cases where the reef structure supporting the rebar was physically displaced, overturned, or collapsed, the transect path was identified using the remaining marker and the sequence of existing nails and continued until a 10m linear path was reached. A new rebar marker was installed at the transect end point whenever the original rebar was lost in the sand or could not be found. In extreme cases where neither the transect rebars or the guide nails could be found, a set of new permanent transects were constructed within the same general vicinity of the reef station previously surveyed.

Temporal variations (between surveys) of the percent reef substrate cover by hard and soft 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. Reports of percent cover to second decimal units are for format uniformity and do not imply precision of measurements to such units.

C. Reef Fishes and Motile Megabenthic Invertebrates

Densities of demersal, diurnal non-cryptic reef fishes and motile megabenthic invertebrates (lobsters, queen conch, large crabs, cleaner shrimps, urchins) were estimated 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. 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). Species density data from 10 x 3m transects are compiled and analysed separately from size-frequency density data from the 20 x 3m transect.

Each transect was surveyed for 10 - 12 minutes depending on the complexity of the fish community on each transect. The initial minute was dedicated to detection of transitory species that may swim away from divers (e.g. snappers, jacks, mackerels, groupers, hogfish, large parrotfishes, etc.). During the next four minutes, the diver swam over both sides of the transect area counting fishes that form schooling aggregations over the reef (e.g. *Chromis spp., Clepticus parrae, Bodianus*, etc.) and other transitory species as they entered the survey area, including the wrasses (e.g. *Thalassoma, Halichoeres spp*.) which tend to be attracted to divers and thereby, may increase in density during the survey. A second run over both sides of transects was performed during the next two minutes in order to count demersal and territorial fishes (e.g. *Stegastes spp*, *Gramma loreto*, squirrelfishes, etc.) that remained within the transect area. Small gobies (e.g. *Coryphopterus spp*., *Elacatinus* spp.) associated with coral heads on both sides of transects were counted on the next two minutes. The last three minutes were dedicated to survey large commercially important fishes and/or larger reef fish herbivores.

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 (*Strombus gigas*) length was reported as the total (diagonal) shell length in cm. Fork length (FL) in centimeters (cm) was used to report fish sizes and assigned to size classes of 5cm intervals. That is, C1 for fish FL of 0 to 5cm; C2 for 6 to 10cm; C3 for 11 to 15cm, C4 for 16 to 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 in the PRCRMP 2019 survey is included as Appendix 1.

Temporal variations (between surveys at each reef) of percent cover by benthic categories, reef 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% CI calculated from the mean square error of the ANOVA tests.

VII. Results and Discussion - Monitoring of Coral Reef Communities 2019

1. Tres Palmas 20m – TRES20

1.1 Physical Description

A diffuse “spur-and-groove” coral reef formation is found associated with the shelf-edge off Tres Palmas within a depth range of 18 - 23m. Irregular, low relief spurs separated by narrow sand channels are oriented perpendicular to the shelf-edge. The shelf breaks in a series of irregular steps, forming narrow terraces at depths from 23 – 40m (Figure 2). The baseline survey of TRES20 was performed in 2004. Permanent transects were installed at depths between 16.97m and 17.88m in two sections of the reef separated by a sand patch. Panoramic views of the reef community are shown in Photo Album 1.

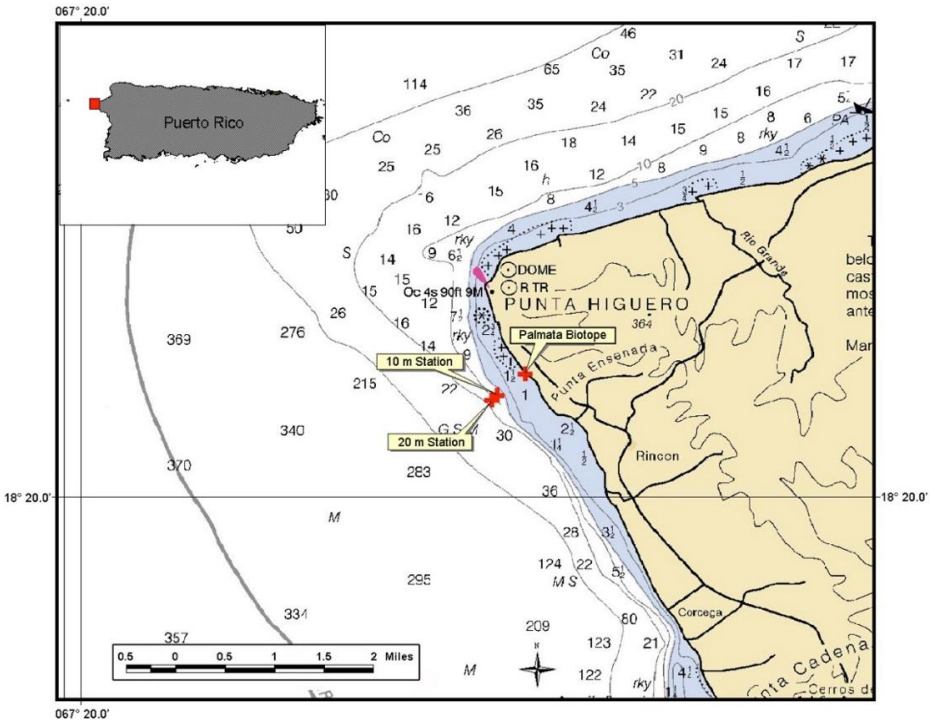


Figure 2. Location of coral reef monitoring stations off Tres Palmas, Rincón.

1.2 Sessile-benthic Reef Community

Turf algae were the dominant sessile-benthic component in terms of substrate cover with an average of 43.88%, representative of 68.8% of the total cover by benthic algae (Table 2). Turf algae were found overgrowing rocky substrates, as well as dead coral sections and other hard

ground. Crustose red (*Peyssonnelia sp*.) and fleshy brown macroalgae (*Dictyota sp*.) were present in all five transects with a combined mean substrate cover of 10.83%. The encrusting fan-leaf alga (*Lobophora variegata*) was observed in four transects growing intermixed with turf and fleshy macroalgae. Isolated tufts of tubular thicket alga (*Galaxaura sp*.) and other green calcareous algae (*Caulerpa sp*., *Halimeda spp*.) were also present with relatively lower cover at TRES20. The total reef substrate cover by benthic algae was 63.81%. Patches of cyanobacteria were observed in all five transects with a mean cover of 3.66%.

A total of 15 hard coral species were intercepted by line transects during the 2019 survey with a mean substrate cover of 21.96% and a mean density of colonies of 13.2 Col/Transect (Table 2). Hard corals occurred mostly as small to moderate size mound shaped and encrusting colonies. Mountainous star coral (*Orbicella faveolata*) was the dominant species in terms of substrate cover with a mean of 6.39%, representing 29.1% of the total cover by hard corals. The sibling species, *O. franksi* was intercepted by two transects with a mean cover of 1.30%. Lettuce coral (*Agaricia agaricites*), mustard-hill coral (*Porites astreoides*), great star coral (*Montastraea cavernosa*), and maze coral (*Meandrina meandrites*) were present in at least four transects with a combined cover of 9.04%. Three hard coral colonies (2-*Siderastrea siderea*; 1-*Stephanocoenia intersepta*) from the 66 total colonies intercepted by transects were observed to be apparently affected by infectious diseases (coral disease prevalence = 4.5%) (Appendix 2).

Soft corals were moderately abundant, with an average of 12.0 Col/transect. The main assemblage included sea plumes (*Allotogorgia acerosa, P. americana*), knobby sea rods, (*Eunicea spp*.), and the common sea fan (*Gorgonia ventalina*) (Table 2). The deep-water sea fan (*Iciligorgia schrammi*) was common at the shelf-edge, particularly at the edge of rock walls and crevices. The encrusting gorgonians, *Briareum asbestinum* and *Erythropodium caribaeorum,* were present in transects with a combined mean cover of 2.01%. Sponges were represented by at least 21 species intercepted by transects with a combined cover of 6.54%. Several branching (*Agelas spp, Aplysina spp, Iotrochota sp*) and barrel-type growth (*Xestospongia muta*) were present and contributed substantially to the reef topographic relief and habitat complexity, but small encrusting colonies prevailed within transects at TRES20.

Abiotic cover largely contributed by reef overhangs averaged 1.72% during the 2019 survey (Table 2). This implies that basically the entire reef substrate surveyed within transects at TRES20 was colonized by biological taxa with only very minor sections covered by sand (mean cover:

0.08%) and/or any other abiotic features. Reef substrate rugosity averaged 2.11m influenced mostly by the sedimentary features of the shelf with minor contributions by hard and soft corals and sponges. Large coral buildups contributing reef topographic relief were not observed.

Table 2. Percent reef substrate cover by sessile-benthic categories at TRES20, Rincon.

Survey Date: May 23, 2019	**Transects**					
TRES20	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	17.88	16.97	17.58	17.58	17.27	**17.46**
Rugosity (m)	2.00	1.26	1.49	3.66	2.12	**2.11**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	1.17	1.99	1.22	2.77	1.04	**1.64**
Sand				0.41		**0.08**
Total Abiotic	1.17	1.99	1.22	3.18	1.04	**1.72**
Benthic Algae						
Turf (mixed)	46.21	52.36	35.81	44.26	40.76	**43.88**
Dictyota spp.	5.48	2.86	5.72	7.48	9.82	**6.27**
Peyssonnelia spp.	5.60	8.33	3.29	1.54	4.04	**4.56**
Lobophora spp.	5.02		4.14	2.25	4.04	**3.09**
Gracilaria spp.	4.55	3.11		3.59	2.31	**2.71**
Turf (mixed) with sediment			6.09			**1.22**
Caulerpa spp.		4.35				**0.87**
Halimeda spp.			1.58	0.31	0.81	**0.54**
CCA (mixed)		0.62		1.02		**0.33**
Jania spp.				0.82		**0.16**
Sargassum histrix			0.49			**0.10**
Galaxaura spp.					0.35	**0.07**
Total Benthic Algae	66.86	71.64	57.13	61.27	62.13	**63.81**
Cyanobacteria	0.47	4.10	8.40	3.59	1.73	**3.66**
Hard Coral						
Orbicella faveolata	7.47	3.23	10.96	4.51	5.77	**6.39**
Agaricia agaricites	2.57	1.24		4.92	4.50	**2.65**
Porites astreoides	4.67	0.75		3.59	3.58	**2.52**
Montastraea cavernosa	1.87	2.24	2.44	1.02	3.81	**2.28**
Siderastrea siderea	3.15	3.48		1.74		**1.67**
Meandrina meandrites	1.75	0.50	3.53	2.15		**1.59**
Colpophyllia natans	1.75				5.77	**1.50**
Orbicella franksi			3.29		3.23	**1.30**
Pseudodiploria strigosa	1.17			1.84		**0.60**
Madracis decactis	0.35	0.25	0.24	3.09%.	0.81	**0.33**
Stephanocoenia intersepta		0.75	1.10			**0.37**
Meandrina jacksoni				1.74		**0.35**
Diploria labyrinthiformis	1.17					**0.23**
Millepora alcicornis	0.23				0.46	**0.14**
Mycetophyllia aliciae				0.20		**0.04**
Total Hard Coral	26.14	12.44	21.56	21.72	27.94	**21.96**
# Coral Colonies/Transect	9	13	13	17	14	**13.2**
#Diseased Hard Coral Colonies/Transect	1	1	1	0	0	**0.6**

Survey Date: May 23, 2019	Transects					
TRES20	**1**	**2**	**3**	**4**	**5**	**Mean**
Soft Corals						
Erythropodium caribaeorum		3.98	5.85			**1.97**
Gorgonia ventalina				0.20		**0.04**
Total Soft Corals	0.00	3.98	5.85	0.20	0.00	**2.01**
# Soft Coral Colonies/Transect	12	8	7	16	17	**12.0**
Sponges						
Agelas sceptrum		2.36	0.37	3.07	0.69	**1.30**
Xestospongia muta	1.63		1.22	1.74		**0.92**
Amphimedon compressa		0.87	0.37	2.25	0.58	**0.81**
Cliona tenuis	2.10			0.41		**0.50**
Iotrochota arenosa		1.24		0.20	0.58	**0.41**
Neopetrosia spp. smooth	0.47	0.25	0.61	0.61		**0.39**
Cliona caribbaea			0.73		1.15	**0.38**
Verongula reiswigi			1.46			**0.29**
Sponge spp.		0.62			0.81	**0.29**
Aiolochroia crassa				0.20	0.81	**0.20**
Aplysina cauliformis		0.25			0.69	**0.19**
Chondrilla caribensis	0.82					**0.16**
Ircinia strobilina			0.73			**0.15**
Agelas conifera			0.37	0.31		**0.13**
Agelas dispar					0.46	**0.09**
Niphates erecta		0.25			0.12	**0.07**
Cliona delitrix	0.35					**0.07**
Ectyoplasia ferox					0.35	**0.07**
Clathria spp.					0.23	**0.05**
Scopalina ruetzleri					0.23	**0.05**
Agelas sventres					0.12	**0.02**
Total Sponges	5.37	5.85	5.85	8.81	6.81	**6.54**
Other						
Trididemnum solidum	0.00	0.00	0.00	0.31	0.35	**0.13**

A mild, but consistent trend of declining mean hard coral cover between monitoring surveys was measured from 2005 and 2008 (Figure 3). Since then, small statistically insignificant fluctuations of coral cover have been measured until the present 2019 survey (ANOVA; $p = 0.867$, Appendix 3). The mean cover by live corals measured in 2019 represents a 14.22% decline from the total cover by live hard corals measured in the previous 2017 survey, but still within the range of mean cover previously measured at TRES20.

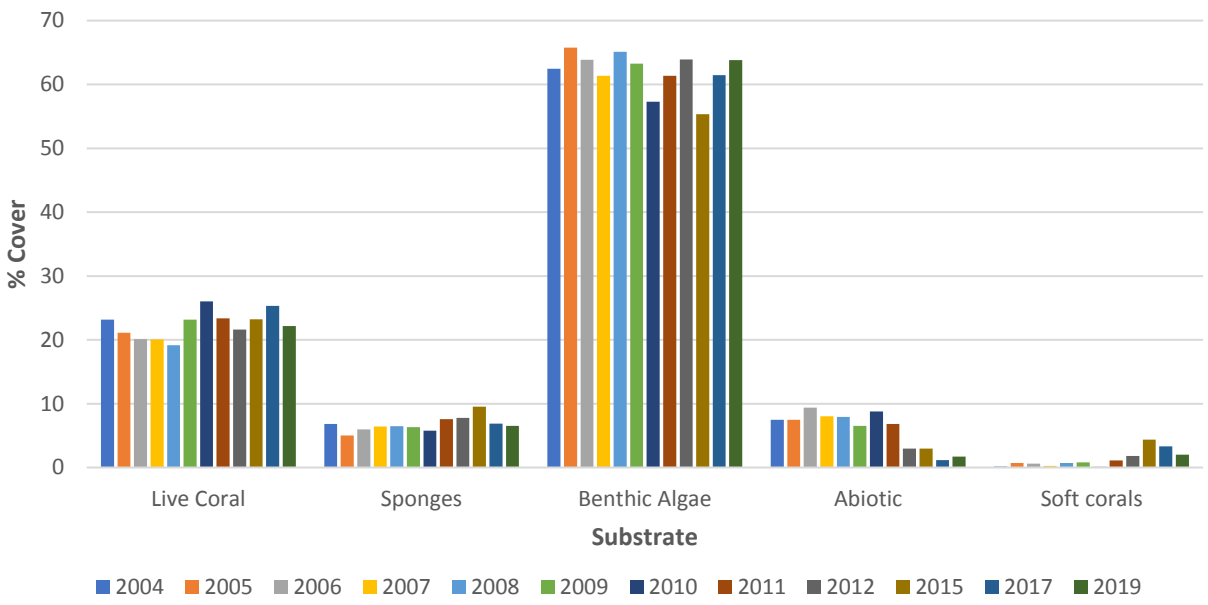


Figure 3. Monitoring trends (2004 – 2019) of mean substrate cover by sessile-benthic categories at TRES20, Rincon.

The largest variation of live hard coral cover was associated with a decline of cover by *Orbicella spp.* (Figure 4). The combined cover by *Orbicella spp* (complex) declined 42.14% between the previous 2017 (13.29%) and the 2019 (7.69%) surveys. Particular attention will be addressed to this matter during the prospective 2021 survey to evaluate if this decline of cover is real or an artifact of sampling variability.

Variations of soft coral densities between monitoring surveys at TRES20 were small and statistically insignificant (ANOVA, $p = 0.152$, Appendix 4). These data are indicative that soft corals at TRES20 were resilient to the physical forces (wave action surge and abrasion) associated with the pass of hurricanes during 2017 and winter storm Riley in March 2018.

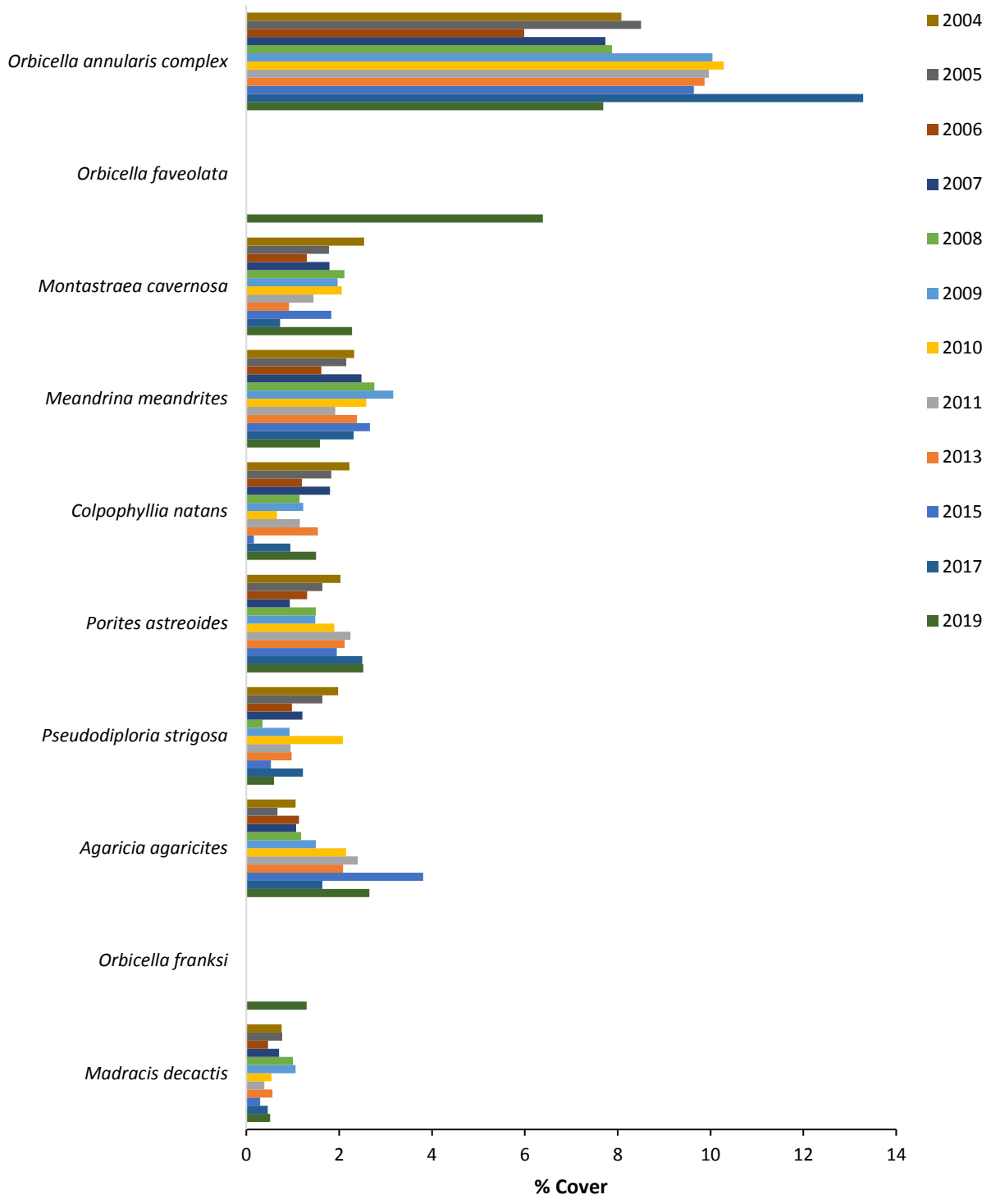


Figure 4. Monitoring trends (2004 – 2019) of mean substrate cover by hard coral species at TRES20, Rincon. Note that previous to 2019, all three *Orbicella* species were documented under" *Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

1.3 Fishes and Motile Megabenthic Invertebrates

A total of 41 fish species were identified within belt-transects from TRES20 during the 2019 with a mean density of 91.4 Ind/30m^2 (range: 73 – 112 Ind/30m^2) and a mean species richness of 17.8 Spp/30m^2 (Table 3). An assemblage of three (3) numerically dominant species, with a combined density of 48.4 Ind/30m^2 represented 53.0% of the total fish individuals within belt-transects. These included the bluehead wrasse (*Thalassoma bifasciatum*), bicolor damselfish (*Stegastes partitus*) and blue chromis (*Chromis cyanea*). In addition, the peppermint and sharknose gobies (*Coryphopterus lipernes, Elacatinus evelynae*), yellowhead wrasse (*Halichoeres garnoti*), and graysby (*Cephalopholis cruentata*) were present in at least four transects surveyed and appear to comprise numerically dominant small demersal resident fish assemblage at TRES20.

The fish community structure exhibited a species rich component of opportunistic carnivore species that included 17 species and a combined density of 40.6 Ind/30m^2, representative of 44.4% of the total fish density. These included wrasses (Labridae), gobies (Gobiidae), small groupers, hamlets and sea basses (Serranidae), grunts (Haemulidae), squirrelfishes (Holocentridae), puffers (Tetraodontidae), and goatfishes (Mullidae). Pelagic and demersal zooplanktivores were represented by a few numerically dominant species, including the bicolor damselfish (*Stegastes partitus*), blue and brown chromis (*Chromis cyanea, C. multilineata*), creole wrasse, (*Clepticus parrae*) and masked goby (*Coryphopterus personatus*). Their combined density represented 42.4% of the total. Large schools of creole wrasse and mackerel scad (*Decapterus macarellus*) were observed at mid-water over the reef. These are zooplanktivores that serve as prey for pelagic predators, such as cero mackerels, blue runners and great barracudas that have been previously reported to occur at this reef (Garcia-Sais et al., 2014). Parrotfishes (Scaridae), doctorfishes (Acanthuridae) and damselfishes (Pomacentridae) comprised the main herbivorous assemblage with 12 species and a combined density of 8.2 Ind/30m^2, or 9.0% of the total fish density. Larger invertebrate and small fish predators included the yellowtail and mahogany snappers (*Ocyurus chrysurus, Lutjanus mahogoni*) and coneys (*Cephalopholis fulva*). One flamingo tongue (*Cyphoma gibbosum*) was the only megabenthic invertebrate observed within belt-transects at TRES20 (Table 3).

TRES20 functions as a recruitment and residential habitat of several parrotfishes (Scaridae) including the stoplight, redband, bucktooth and princess (*Sparisoma viride, S. aurofrenatum, S. radians, Scarus taeniopterus*) as evidenced by the presence a wide range of size classes, including (1–5cm) recruitment stages (Table 4). Terminal phase male stages of *S. viride* and *S.*

taeniopterus were observed. Doctorfishes (Acanthuridae) were present as juveniles and adults. Adult stages of demersal predators, including the coney (*Cephalopholis fulva*), graysbe (*C. cruentata*), lionfish (*Pterois sp*), yellowtail and mahogany Snappers (*Ocyurus chrysurus, Lutjanus mahogoni*) were also observed. TRES20 is also an ideal habitat for adult reef fishes, as evidenced by the presence of adult lane and schoolmaster snappers, red hinds, great barracuda, cero mackerel and blue runners previously reported (Garcia-Sais et al., 2017).

Annual fluctuations of fish abundance and species richness from the baseline survey of 2004 to the present 2019 survey are presented in Figure 5. Statistically significant differences of both fish density species richness were found between monitoring surveys (ANOVA; $p < 0.0001$, Appendix 5-6). Mean fish density has shown a 5-fold fluctuation from a baseline maximum of 531.4 Ind/30m^2 in 2004 to a minimum of 82.6 Ind/30m^2 during the 2017 survey. The main species that has contributed to the variability of fish density between monitoring surveys is the masked goby (*Coryphopterus personatus*). This is a small carnivorous fish (< 4.0cm) that at certain times forms swarms of hundreds of individuals below coral ledges and near the sand-coral interface of the spur and groove reef formation, thus it has highly aggregated or patchy distributions in the reef. The temporal abundance dynamics for this species has not been studied. Thus, the factors that influence its abundance fluctuations between annual surveys remain unclear.

Both the mean fish density and species richness measured in the present 2019 survey fall within the lower range of previous observations at TRES20, and slightly higher than during the previous 2017 survey (Figure 5). Consistent with the 2017 survey, a sharp decline of *C. personatus* population was noted. It is possible that the decline of densities by *C. personatus* and other small fish species was influenced by the strong wave action associated with the pass of hurricane and/or winter storm Riley previous to the 2019 survey. If substantial mortality of the adult (reproductively active) populations occurred during the disturbance events the population replenishment rates may be impaired due to a reduction of spawning stock biomass and the likelihood that the replenishment dynamics of this population depends largely on self-recruitment processes (Leis and Miller 1976; Leis, 1982; Ramírez and García, 2003).

Table 3. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at TRES20, Rincon. Survey date: 5-23-19.

			Belt-Transects			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	16	13	3	42	18	**18.4**
Stegastes partitus	16	8	14	25	13	**15.2**
Chromis cyanea	15	13	23	12	11	**14.8**
Coryphopterus lipernes	9	4	15	8	7	**8.6**
Halichoeres garnoti	5	11	1	5	3	**5.0**
Coryphopterus personatus	0	0	23	0	0	**4.6**
Clepticus parrae	9	6	0	0	0	**3.0**
Elacatinus evelynae	0	2	3	3	4	**2.4**
Stegastes leucostictus	3	2	3	0	0	**1.6**
Scarus taeniopterus	4	0	0	3	0	**1.4**
Halichoeres maculipinna	0	1	0	5	1	**1.4**
Cephalopholis cruentata	1	1	1	1	2	**1.2**
Chromis multilineata	0	0	6	0	0	**1.2**
Sparisoma aurofrenatum	1	3	0	1	0	**1.0**
Cephalopholis fulva	0	4	0	0	1	**1.0**
Scarus iseri	0	0	0	1	4	**1.0**
Acanthurus tractus	1	1	0	1	1	**0.8**
Mulloidichthys martinicus	1	0	3	0	0	**0.8**
Sparisoma radians	0	2	0	0	2	**0.8**
Holocentrus rufus	0	1	0	1	2	**0.8**
Myripristis jacobus	0	0	4	0	0	**0.8**
Haemulon flavolineatum	2	1	0	0	0	**0.6**
Holacanthus tricolor	1	0	1	0	0	**0.4**
Lutjanus mahogoni	2	0	0	0	0	**0.4**
Stegastes variabilis	2	0	0	0	0	**0.4**
Canthigaster rostrata	1	0	0	0	1	**0.4**
Serranus tigrinus	1	1	0	0	0	**0.4**
Sparisoma viride	0	0	0	2	0	**0.4**
Sparisoma rubripinne	0	0	0	0	1	**0.2**
Melichthys niger	1	0	0	0	0	**0.2**
Acanthurus coeruleus	1	0	0	0	0	**0.2**
Neoniphon marianus	1	0	0	0	0	**0.2**
Bodianus rufus	1	0	0	0	0	**0.2**
Chaetodon capistratus	1	0	0	0	0	**0.2**
Pterois volitans	1	0	0	0	0	**0.2**
Microspathodon chrysurus	0	0	1	0	0	**0.2**
Acanthurus chirurgus	0	0	1	0	0	**0.2**
Hypoplectrus unicolor	0	0	0	1	0	**0.2**
Myrichthys breviceps	0	0	0	1	0	**0.2**
Pseudupeneus maculatus	0	0	0	0	1	**0.2**
Chaetodon striatus	0	0	0	0	1	**0.2**
Total Individuals	96	74	102	112	73	**91.4**
Total Species	24	17	15	16	17	**17.8**
Invertebrates						
Ciphoma gibbosum	0	0	0	0	1	**0.2**
Totals	0	0	0	0	1	**0.2**

Table 4. Size-frequency distributions of commercially important fishes observed within 20 x 3m belt-transects at TRES20, Rincon. Survey date: 5-23-19.

					TRANSECTS (Ind/60m^2)				
Species	**Family**	**Size Range (cm)**		**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c4	Acanthuridae	16-20	Adult	1	0	1	0	1	**0.6**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	1	0	1	0	1	**0.6**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	1	0	1	0	0	**0.4**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	0	1	0	4	0	**1.0**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	0	0	1	0	1	**0.4**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	1	0	0	0	0	**0.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	0	0	1	0	1	**0.4**
Cephalopholis cruentata c5	Serranidae	21-25	Adult	0	1	0	0	1	**0.4**
Cephalopholis cruentata c6	Serranidae	26-30	Adult	0	0	0	1	1	**0.4**
Cephalopholis fulva c4	Serranidae	16-20	Adult	0	0	0	0	1	**0.2**
Cephalopholis fulva c5	Serranidae	21-25	Adult	0	4	0	0	0	**0.8**
Lutjanus mahogoni c3	Lutjanidae	11-15	n/d	1	0	0	0	0	**0.2**
Lutjanus mahogoni c4	Lutjanidae	16-20	n/d	1	0	0	0	0	**0.2**
Ocyurus chrysurus c7	Lutjanidae	31-35	Adult	1	0	0	0	0	**0.2**
Pterois spp. c2	Scorpaenidae	6-10	Juvenile	0	0	0	1	0	**0.2**
Pterois spp. c6	Scorpaenidae	26-30	Adult	1	0	1	0	0	**0.4**
Pterois spp. c7	Scorpaenidae	31-35	Adult	1	0	0	0	0	**0.2**
Scarus iseri c1	Scaridae	1-5	Recruit	0	0	0	1	2	**0.6**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	0	0	0	2	**0.4**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	0	0	0	3	0	**0.6**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	1	0	0	0	0	**0.2**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	2	3	0	0	0	**1.0**
Scarus taeniopterus c4	Scaridae	16-20	Adult	0	0	0	0	0	**0.0**
Scarus taeniopterus c5	Scaridae	21-25	Adult	0	0	1	1	0	**0.4**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	0	1	0	0	0	**0.2**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	2	0	0	0	0	**0.4**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	2	0	2	1	**1.0**
Sparisoma radians c1	Scaridae	1-5	Recruit	0	2	0	0	4	**1.2**
Sparisoma viride c1	Scaridae	1-5	Recruit	0	0	0	2	0	**0.4**
Sparisoma viride c4	Scaridae	16-20	Adult	0	1	0	0	0	**0.2**
Sparisoma viride c6	Scaridae	26-30	Adult	0	1	0	0	0	**0.2**
Sparisoma viride c7	Scaridae	31-35	Adult	0	0	0	0	1	**0.2**
Totals				14	16	7	15	17	**13.8**

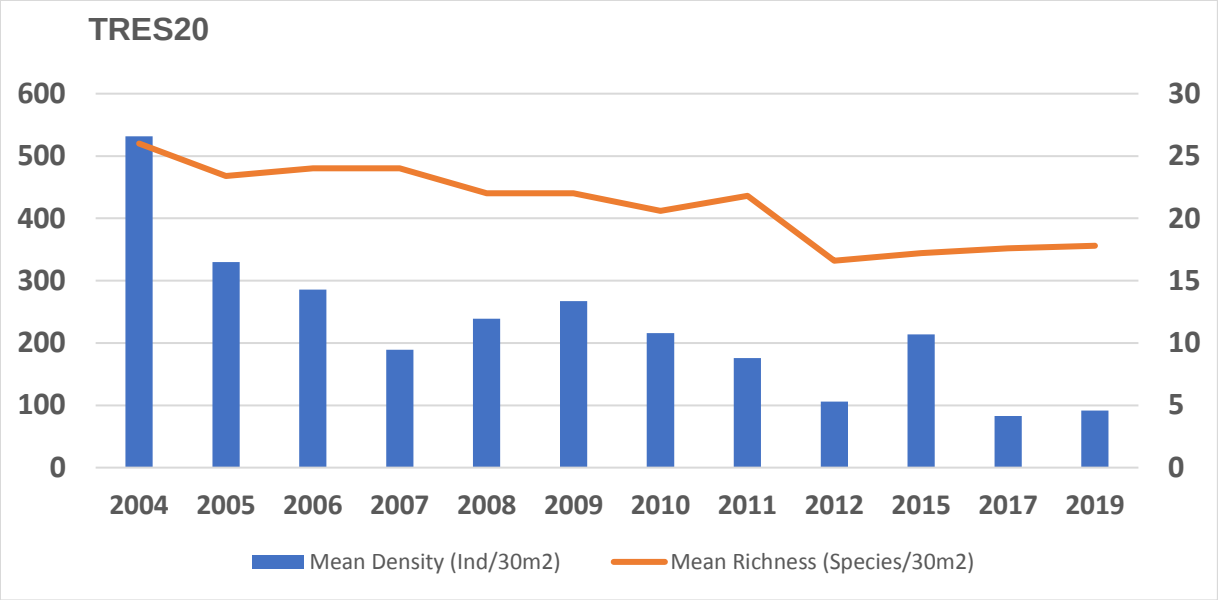


Figure 5. Monitoring trends (2004 – 2019) of mean fish density and species richness within 3x10 m belt-transects at TRES20, Rincon.

1.4 Photo Album 1 TRES20

2. Tres Palmas Reef 10m (TRES10)

2.1 Physical Description

A series of submerged patch reefs are located in the Tres Palmas outer shelf, at about 0.5 kilometers east from the shelf-edge. Patch reefs are associated with an irregular and discontinuous line of hard ground promontories that rise from a sandy bottom at depths of 12 - 15m. Our permanent transects were installed during the baseline survey in 2004 within one of these patch reef promontories at a depth of 9.09 – 9.70m running parallel to each other east to west over the reef top. The reef rises from the bottom as a vertical wall on the eastern end, forming a sloping terrace toward the west. The east wall is about 5m high and exhibits deep crevices and overhangs. At the top, the reef platform is mostly flat, with some depressions, but without any prominent pattern of spurs and/or grooves. Large sand channels separate the reef promontories. Panoramic views of the outer shelf patch reefs are presented as Photo Album 2.

2.2 Sessile-benthic Community

Benthic algae, comprised by a mixed assemblage of turf, fleshy brown fleshy (mostly *Dictyota sp*), red coralline (*Galaxaura sp*., *Gracilaria sp.*) and crustose (*Ramicrusta sp, Peyssonnelia sp*), and green calcareous macroalgae (*Halimeda spp*) presented the highest percent of reef substrate cover by sessile-benthic categories with a combined mean of 70.39% (range: 56.95 – 79.58%). Turf algae (mixed assemblage), *Dictyota sp*. and *Galaxaura sp*. were intercepted by all transects surveyed and were the main components of the algal assemblage at TRES10. Cyanobacteria were observed growing over sandy patches with a mean substrate cover of 1.25% (Table 5).

A dense and diverse assemblage of vertically projected soft corals was the most prominent feature of the sessile-benthic reef community at TRES10. Soft corals were present at all transects surveyed with a mean density of 21.8 Col/Transect (range: 16 – 28 Col/Transect) and largely contributed to the reef habitat structural and biological complexity (Table 5). The most abundant taxa included sea rods (*Eunicea spp*, *Pseudoplexaura flagellosa*, *Plexaura sp*.) and the common sea fan (*Gorgonia ventalina*) among others. The encrusting (soft coral) species, *Erythropodium caribaeorum* was present in one transect with low substrate cover (<1%).

Hard corals, represented by 13 scleractinians and one hydrocoral (*Millepora alcicornis*) were abundant at TRES10, with a total of 60 colonies distributed in the five (replicate) transect array for a mean density of 12.0 Col/Transect (Table 5). Hard corals occurred mostly as isolated encrusting colonies of typically small size and low vertical relief, although several large colonies

of grooved brain coral (*Pseudodiploria labyrinthiformis*), boulder brain coral (*Colpophyllia natans*) and pillar coral (*Dendrogyra cylindrus*) were observed with significant contributions to the reef topographic relief. A total of 17 species of stony corals have been identified from the patch reef community at TRES10, including 14 species intercepted by transects during the 2019 monitoring survey. Reef substrate cover by live hard corals averaged 19.89% (range: 11.12 – 30.12%). Great star coral (*M. cavernosa*) and mustard-hill coral (*Porites astreoides*) were intercepted by all five transects and were the dominant species in terms of reef substrate cover with means of 4.26% and 2.79%, respectively. In addition to the aforementioned species, another three hard coral species that included *Pseudodiploria strigosa, Agaricia agaricites* and *M. alcicornis* were present in at least four transects. Coral diseases were observed affecting four colonies out of the 60 colonies intercepted by transects (disease prevalence = 6.7%). These included 1-*Pseudodiploria strigosa*, 1- *Montastraea cavernosa*, 1- *Siderastrea siderea* and 1- *Stephanocoenia intersepta* (see Appendix 2).

Sponges represented by at least 18 species within transects presented a mean substrate cover of 6.20% (range: 3.11 – 9.78%). The giant barrel sponge (*Xestospongia muta*) was present in three transects with a mean reef substrate cover of 1.84 % and was the most prominent species with several large colonies providing substantial topographic relief at TRES10. In general, sponges were represented by small encrusting species with relatively low substrate cover. The encrusting zoanthid (*Palythoa sp.*) was observed in two transects. Total abiotic cover averaged 1.32%, a marked decline from the 16.8% reported in 2013. Such variations of sand cover are typical of this reef and are largely associated with sand transport driven by strong wave action as winter swells reach the western coastline of PR.

The sessile-benthic community at the patch reef surveyed is typical of high wave energy environments, dominated by turf algae, encrusting stony corals and sponges. The high abundance of small coral colonies may be an indication of active recruitment. Mortality of coral colonies induced by mechanical detachment during heavy wave action is most likely to be a prevailing process in this reef which has probably led to the high coral species richness evidenced during the monitoring program. The reef hard ground was mostly colonized by turf and fleshy brown macroalgae, which is the dominant assemblage and a quasi-permanent feature of high energy reefs in the north coast of Puerto Rico (García-Sais et al., 2003).

Table 5. Percent reef substrate cover by sessile-benthic categories at TRES10, Rincon

TRES10			**Transects**			
Survey Date: May 23, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	9.7	9.7	9.09	9.39	9.09	**9.39**
Rugosity (m)	1.45	1.31	1.27	1.48	1.24	**1.35**
BENTHIC CATEGORIES						
Abiotic						
Sand	2.81	0.25	0.87	1.34		**1.05**
Reef overhang				0.85	0.50	**0.27**
Total Abiotic	2.81	0.25	0.87	2.20	0.50	**1.32**
Benthic Algae						
Turf (mixed) with sediment	50.73	42.70	46.34	35.61	49.81	**45.04**
Dictyota spp.	10.02	14.36	11.43	11.34	23.41	**14.11**
Galaxaura spp.	7.21	3.96	5.22	6.22	3.86	**5.29**
Turf (mixed)	1.83	6.81	3.11	1.10	2.49	**3.07**
Ramicrusta spp.	0.73	1.98	1.61	0.24		**0.91**
Halimeda spp.	2.08		1.86	0.24		**0.84**
CCA (mixed)			1.74	0.98		**0.54**
Peyssonnelia spp.	1.22					**0.24**
Caulerpa spp.				1.22		**0.24**
Gracilaria spp.			0.50			**0.10**
Total Benthic Algae	73.84	69.81	71.80	56.95	79.58	**70.39**
Cyanobacteria	1.96	1.36	0.50	1.59	0.87	**1.25**
Hard Coral						
Montastraea cavernosa	0.24	7.43	6.58	3.41	3.61	**4.26**
Porites astreoides	0.98	4.46	1.61	2.68	4.23	**2.79**
Colpophyllia natans				11.71		**2.34**
Pseudodiploria strigosa		3.47	3.35	1.83	1.99	**2.13**
Orbicella faveolata	5.62				2.12	**1.55**
Diploria labyrinthiformis	0.00		5.71		1.99	**1.54**
Agaricia agaricites	1.59	0.62	2.61	1.10	1.37	**1.46**
Millepora alcicornis	0.24	2.48	0.87	1.59		**1.03**
Siderastrea siderea			1.74	3.17		**0.98**
Dendrogyra cylindrus				4.63		**0.93**
Madracis decactis	1.10		0.25			**0.27**
Stephanocoenia intersepta	1.34					**0.27**
Porites divaricata		1.24				**0.25**
Meandrina meandrites		0.50				**0.10**
Total Hard Coral	11.12	20.17	22.73	30.12	15.32	**19.89**
# Coral Colonies/Transect	6	14	12	13	15	**12.0**
# Diseased Coral Colonies/Transect	1	2	0	1	0	**0.8**
Soft Corals						
Pseudoplexaura flagellosa			0.25	0.98		**0.24**
Antillogorgia americana			0.25	0.24		**0.10**
Gorgonia ventalina			0.25	0.24		**0.10**
Eunicea flexuosa	0.49					**0.10**
Eunicea spp.			0.25			**0.05**
Erythropodium caribaeorum				0.24		**0.05**
Plexaura kukenthali				0.12		**0.02**
Total Soft Corals	0.49	0.00	0.99	1.83	0.00	**0.66**
# Soft Corals/Transect	28	25	21	16	19	**21.8**
Zoanthids						

TRES10			**Transects**			
Survey Date: May 23, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Palythoa caribaeorum	0.00	0.00	0.00	0.98	0.37	**0.27**
Sponges						
Xestospongia muta	4.52	2.23		2.44		**1.84**
Neopetrosia spp. smooth	0.24	3.22	0.62	0.24	0.87	**1.04**
Amphimedon compressa		1.11		1.95	0.75	**0.76**
Neofibularia nolitangere					1.74	**0.35**
Agelas conifera			1.74			**0.35**
Aplysina cauliformis	1.22			0.49		**0.34**
Sponge spp.	1.10			0.37		**0.29**
Mycale laevis		0.87		0.24		**0.22**
Callyspongia plicifera	1.10					**0.22**
Prosuberites laughlini	0.61					**0.12**
Scopalina ruetzleri			0.50			**0.10**
Desmapsamma anchorata		0.50				**0.10**
Agelas dispar	0.24		0.25			**0.10**
Petrosia pellasarca	0.49					**0.10**
Monanchora arbuscula	0.24			0.24		**0.10**
Cliona delitrix				0.37		**0.07**
Agelas sventres		0.25				**0.05**
Niphates erecta		0.25				**0.05**
Total Sponges	9.78	8.42	3.11	6.34	3.36	**6.20**

Variations of reef substrate cover by sessile-benthic categories between monitoring surveys at TRES10 are shown in Figure 6. Fluctuations of the mean reef substrate cover by hard corals between monitoring surveys were not statistically significant (ANOVA; p= 0.869; Appendix 3). The mean coral cover measured during the 2019 survey (19.89%) was 13.9% lower than that measured in 2017, but still within the upper range of measurements at TRES10.

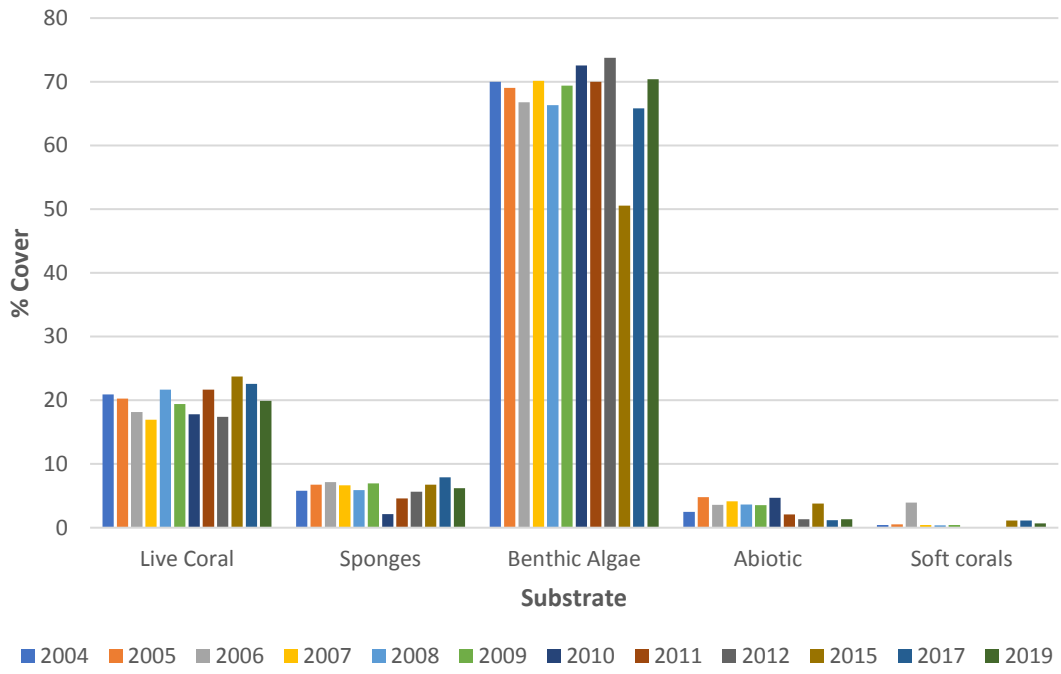


Figure 6. Monitoring trends (2004 – 2019) of mean substrate cover by sessile-benthic categories at TRES10, Rincon.

Fluctuations of coral cover have been relatively small and mostly influenced by an increasing trend of cover by mustard-hill coral (*Porites astreoides*) since the 2011 monitoring survey (Figure 7). The most relevant change of community structure at TRES10 has been a statistically significant variation of density by erect soft corals (ANOVA, p= 0.010; Appendix 4). A 36.6% decline of density was measured in 2017 (15.6 Col/Transect) relative to the previous density of 24.6 Col/Transect measured in 2015. The sharp reduction may have been related to mechanical detachment by exceptionally high wave and surge action and associated with the pass of Hurricane Matthew close to the south coast of PR during October 2016. Partial recuperation of the soft coral density was measured at TRES10 in 2019 (21.8 Col/Transect), suggesting that between 2017 – 2019 physical disturbances (including hurricanes) had negligible effects upon the benthic community at TRES10.

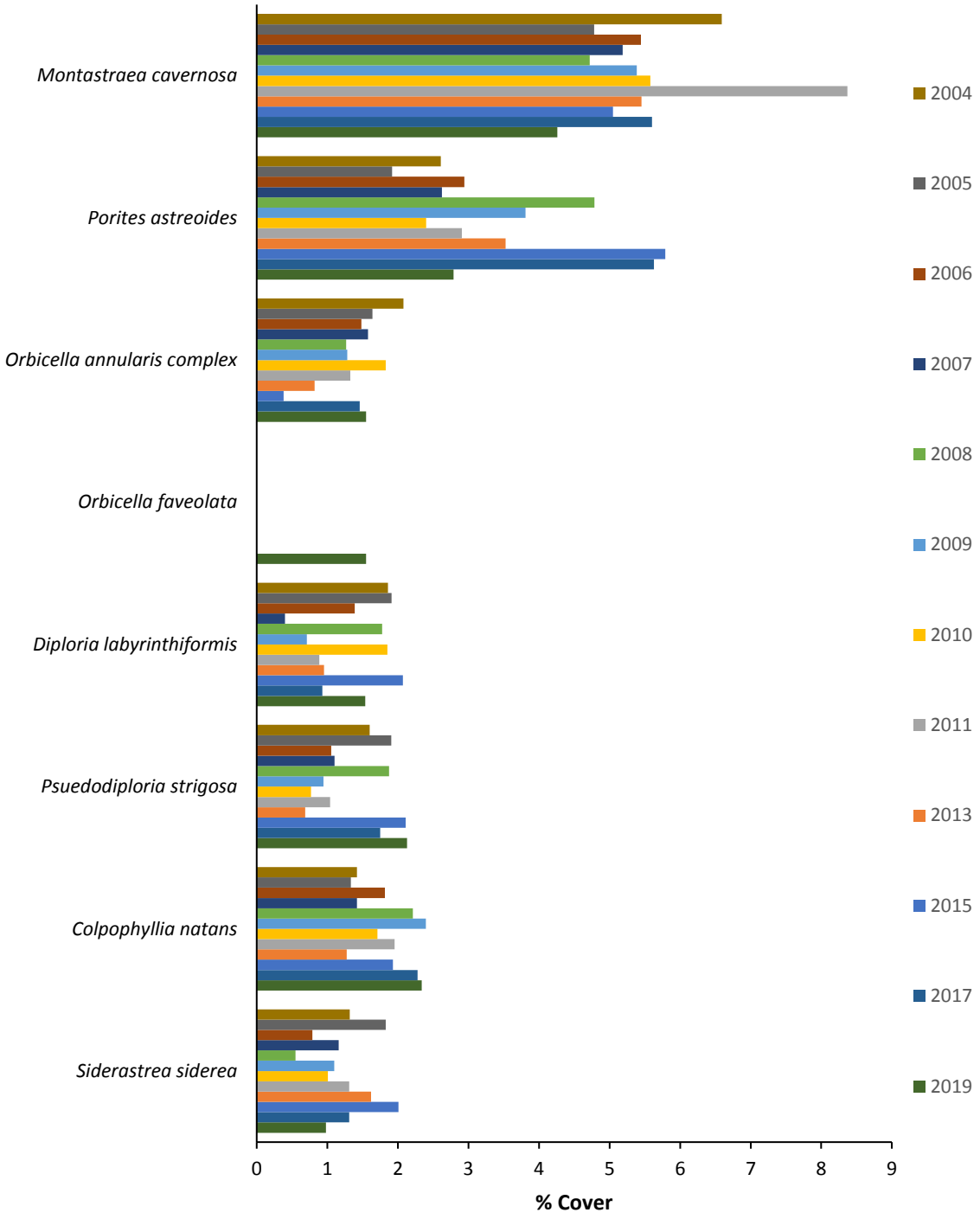


Figure 7. Monitoring trends (2004 – 2019) of mean substrate cover by hard coral species at TRES10, Rincon. Note that previous to 2019, all three *Orbicella* species were documented under" *Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

2.3 Fishes and Motile Megabenthic Invertebrates

A total of 24 fish species were identified from TRES10 during the 2019 survey with a mean density of 57.4 Ind/30 m^2 (range: 37 - 89 Ind/30 m^2) and a mean species richness of 13.8 (range: 13 – 16 Spp/30m^2). The bluehead wrasse (*Thalassoma bifasciatum*) and the bicolor damselfish (*Stegastes partitus*) were (as in previous surveys) numerically dominant within belt-transects with mean abundances of 21.4 and 11.4 Ind/30 m^2, respectively (Table 6). The combined abundance of these two-species represented 57.1% of the total fish abundance within belt-transects. In addition to the two-aforementioned species, *Chromis cyanea, Cephalopholis fulva, Sparisoma aurofrenatum, Serranus tigrinus* and *Holocentrus rufus* were observed in at least four of the five transects surveyed. Given their prevalence in previous surveys they appear to represent a resident fish assemblage on this reef.

Motile megabenthic invertebrates were represented within belt-transects by cleaner shrimps (*Periclimenes pedersoni*) and a hermit crab (*Pagurus sp*). Spiny lobsters (*Panulirus argus*), urchins (*Eucidaris tribuloides*), shrimps (*Stenopus hispidus*), and arrow crabs (*Stenorhynchus seticornis*) have been previously reported from this reef (Garcia-Sais et al., 2014).

The high energy environment at the reef top of TRES10 is an appropriate habitat for opportunistic carnivores, such as wrasses (*Thalassoma bifasciatum, Halichoeres garnoti, H. maculipinna*) which feed on small benthic invertebrates that become exposed upon disturbances of the substrate due to wave action. The small carnivore assemblage included at least 13 species and a combined density of 35.0 Ind/30 m^2, or 61.0% of the total fish density within belt-transects (Table 6). Herbivores, including parrotfishes (Scaridae), doctorfishes (Acanthuridae) and damselfishes (Pomacentridae) were represented by seven species within belt-transects with a combined mean density of 6.8 Ind/30 m^2, or 11.8% of the total. Zooplanktivores were represented by three species (*Stegastes partitus, Chromis cyanea, C. multilineata*) with a combined density of 15.2 Ind/30 m^2, or 26.5% of the total fish density at TRES10. Mid-size predators include an abundant assemblage of snappers, coneys and squirrelfishes, among others (Garcia-Sais et al., 2014). The abundance of coneys (*Cephalopholis cruentatus*) is of particular interest because it is one of the highest among the reefs surveyed. Pelagic piscivores, such as barracudas (*Sphyraena barracuda*), mackerels (*Scomberomorus regalis*) and jacks (*Caranx crysos, C. ruber*) have been previously reported (García-Sais et al., 2015 and references therein) and are the top predators of this reef.

Table 6. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 10m x 3m belt- transects at TRES10, Rincon.

Survey Date: 5-23-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	9	23	12	14	49	**21.4**
Stegastes partitus	10	11	7	13	16	**11.4**
Halichoeres garnoti	4	8	3	3	3	**4.2**
Elacatinus evelynae	5	2	3	4	1	**3.0**
Chromis cyanea	3	5	0	2	4	**2.8**
Scarus iseri	1	4	0	5	0	**2.0**
Cephalopholis fulva	2	2	2	0	2	**1.6**
Sparisoma aurofrenatum	2	2	1	2	1	**1.6**
Acanthurus tractus	3	0	1	0	2	**1.2**
Canthigaster rostrata	1	1	1	1	2	**1.2**
Serranus tigrinus	1	1	1	0	2	**1.0**
Holocentrus rufus	1	0	2	1	1	**1.0**
Chromis multilineata	0	0	1	3	1	**1.0**
Sparisoma radians	0	0	2	3	0	**1.0**
Amblycirrhitus pinos	0	1	0	2	0	**0.6**
Chaetodon capistratus	0	2	0	0	0	**0.4**
Acanthurus coeruleus	0	0	0	1	1	**0.4**
Acanthurus chirurgus	0	0	0	0	2	**0.4**
Serranus baldwini	1	0	0	0	0	**0.2**
Hypoplectrus puella	1	0	0	0	0	**0.2**
Halichoeres radiatus	0	1	0	0	0	**0.2**
Halichoeres maculipinna	0	0	1	0	0	**0.2**
Coryphopterus spp.	0	0	0	0	1	**0.2**
Microspathodon chrysurus	0	0	0	0	1	**0.2**
Total Individuals	44	63	37	54	89	**57.4**
Total Species	14	13	13	13	16	**13.8**
Invertebrates						
Periclimenes pedersoni	0	0	0	1	0	**0.2**
Pagurus spp. (unidentified)	0	1	0	0	0	**0.2**
Totals	0	1	0	1	0	**0.4**

Fish size distributions are indicative that TRES10 is an important residential habitat for a number of commercially important reef fishes, including coneys, red hind, lane, yellowtail and mahogoni snappers as both juveniles and adults were observed during the 2019 (Table 7) and/or previous surveys (Garcia-Sais et al., 2015 and references therein). TRES10 is also a recruitment and residential habitat for several species of doctorfishes (*Acanthurus coeruleus* and *A. tractus*) and

parrotfishes (*Scarus iseri, S. taeniopterus, Sparisoma aurofrenatum, S, rubripinne, S. radians*). Recruitment juvenile stages of stripped and bucktooth parrotfishes (*Scarus iseri, Sparisoma radians*) were observed during the 2019 survey (Table 7).

Fish density and species richness have shown wide fluctuations at this reef with a period of higher richness and mean density between 2004 – 2007, and a period of both lower richness and density between 2008 - 2019 surveys (Figure 8). The temporal variations of both fish density and species richness between surveys were statistically significant (ANOVA, $p < 0.0001$, see Appendices 5-6). This reef is frequently exposed to very high wave energy and the surge conditions that prevail during high wave action events appears to have an effect of forcing fish individuals to seek deeper areas within the Rincon narrow shelf. Differences observed during the monitoring program are in the 2-fold range for species richness and in the 3-fold range for mean density. The 2019 mean fish density (57.4 Ind/30 m^2) and species richness (13.8 Spp/30m^2) fell within 1 standard deviation of the historical means for both parameters (Appendix 5-6). Interannual variations of fish density have been associated with fluctuations by numerically dominant species and such differences are believed to be regulated by density-independent and physical forcing factors (Esteves, 2013).

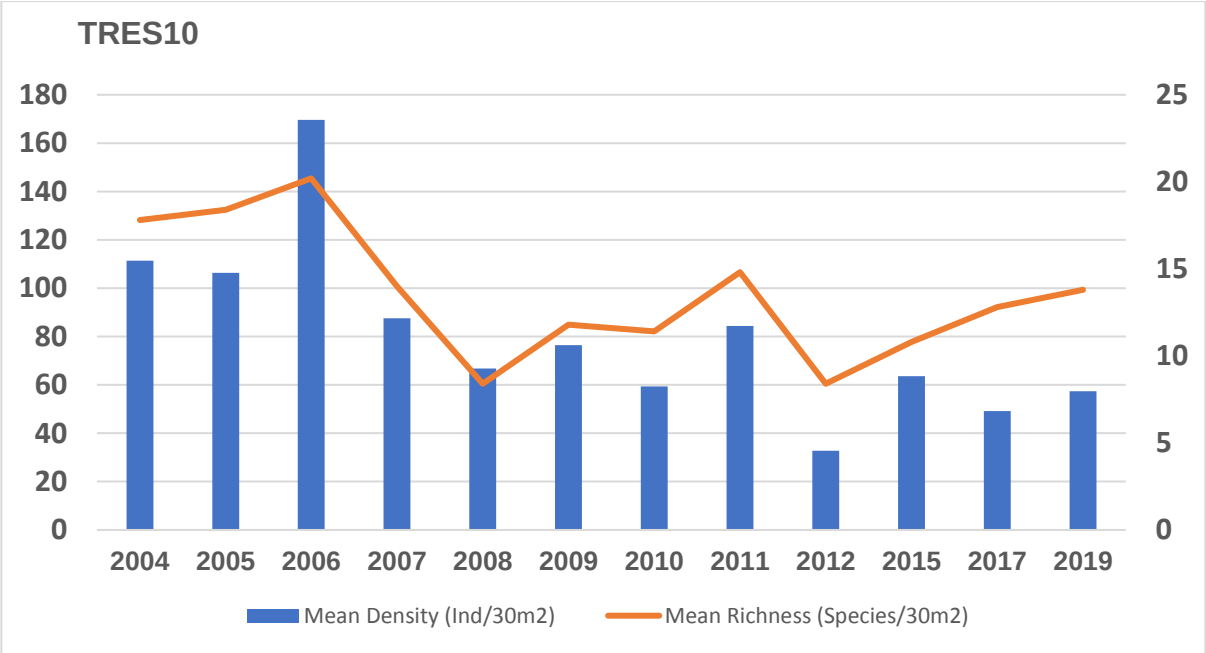
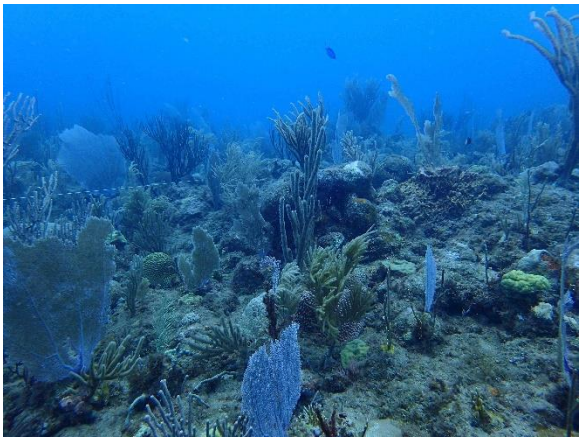


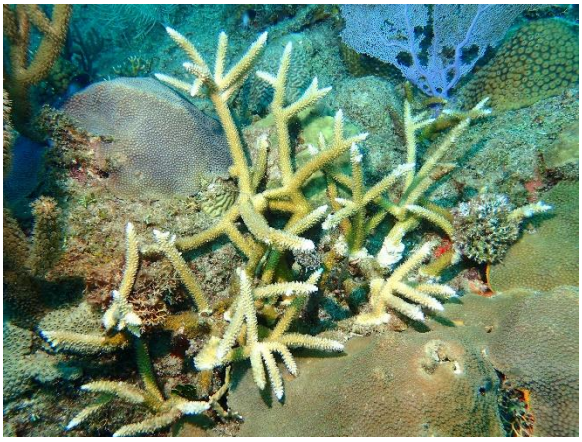
Figure 8. Monitoring trends (2004 – 2019) of mean fish density and species richness within 3x10 m belt-transects at TRES10, Rincon.

Table 7. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at TRES10, Rincon. Survey date: 5-23-19.

					TRANSECTS				
		Size			(Ind/60m^2)				
Species	**Family**	**Range (cm)**		**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	0	0	0	0	1	**0.2**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	0	0	1	0	**0.2**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	1	0	0	0	0	**0.2**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	2	2	2	0	2	**1.6**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	0	0	0	1	1	**0.4**
Cephalopholis fulva c3	Serranidae	11-15	Juvenile	1	0	0	1	0	**0.4**
Cephalopholis fulva c4	Serranidae	16-20	Adult	0	1	1	0	2	**0.8**
Cephalopholis fulva c5	Serranidae	21-25	Adult	1	1	1	0	2	**1.0**
Lutjanus mahogoni c4	Lutjanidae	16-20	n/d	0	0	1	0	0	**0.2**
Lutjanus synagris c3	Lutjanidae	11-15	Juvenile	1	0	0	0	0	**0.2**
Scarus iseri c1	Scaridae	1-5	Recruit	0	4	0	5	0	**1.8**
Scarus iseri c3	Scaridae	11-15	Juvenile	1	0	0	0	0	**0.2**
Scarus iseri c4	Scaridae	16-20	Adult	0	1	0	0	0	**0.2**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	0	1	0	0	0	**0.2**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	1	0	0	1	0	**0.4**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	1	0	1	1	1	**0.8**
Sparisoma radians c1	Scaridae	1-5	Recruit	1	0	2	3	0	**1.2**
Sparisoma rubripinne c4	Scaridae	16-20	Adult	0	0	0	0	1	**0.2**
Totals				10	10	8	13	10	**10.2**

2.4 Photo Album 2 TRES10





3. Tres Palmas Reef 5m (TRES05)

3.1 Physical Description

The rocky shoreline of the Tres Palmas Marine Reserve leads to a narrow backreef lagoon with coarse sandy sediments. The lagoon is a semi-protected environment associated with an extensive elkhorn coral (*Acropora palmata*) reef system that has developed along a hard ground platform fringing the shoreline. The top of the reef platform is found at depths between 1 - 4m. The branching elkhorn coral colonies are large, rising more than one meter from the hard ground platform almost to the surface and wide, extending more than two meters horizontally in many cases. Where the hard ground platform is continuous, coral colonies grow close together forming a dense and intertwined elkhorn coral biotope. Sand pools and channels separate the reef where the hard ground platform breaks up. Interspersed within the *A. palmata* biotope are abundant colonies of encrusting corals, mostly *Pseudodiploria clivosa, P. strigosa* and *Porites astreoides*. A set of five permanent transects were installed during the 2015 baseline survey at depths between 1.5 – 1.8m.

3.2 Sessile Benthic Reef Community

Benthic algae, comprised of a mixed assemblage of turf, fleshy, red coralline and red crustose algae, was the dominant category covering the reef substrate with a mean cover of 45.65% (Table 8). Turf algae was the main component of this assemblage, with a mean cover of 38.80%, representing 84.6% of the total cover by benthic algae. *Ramicrusta sp*. was present in all transects surveyed with a mean cover of 3.93%, which represents a 20-fold increment relative to the 2017 survey. The fleshy y-twig alga (*Dictyota sp*.) and the red coralline alga (*Galaxaura sp*.) were intercepted by four transects but with low cover (<1.5%), as well as other CCA and *Peyssonnelia sp*., which were present in very low cover.

Live hard coral cover averaged 34.40% (range: 17.66 – 49.02%) with a mean of 4.8 Col/Transect (rough estimate due to intertwined colonies). Elkhorn coral (*Acropora palmata*) was the dominant species documented, with a mean substrate cover of 29.19% (range: 8.12 – 43.94%), representing 84.8% of the total cover by hard corals (Table 8). Four additional coral species (*Pseudodiploria strigosa, P. clivosa*, *Porites astreoides*, *Agaricia agaricites*) were also documented in this survey. Of 24 colonies below transect lines, one *A. palmata* and one *Pseudodiploria strigosa* colony were observed with coral disease infections, for a disease prevalence of 8.3% (Appendix 2). Our preliminary assessment of the infectious disease affecting *A. palmata* is “patchy necrosis”.

Table 8. Percent reef substrate cover by sessile-benthic categories at TRES05, Rincon

Survey Date: May 23, 2019	Transects					
	1	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	1.82	1.82	1.52	1.52	1.52	**1.64**
Rugosity (m)	2.14	3.79	3.24	3.30	5.67	**3.63**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	8.42	2.74	15.86	16.84	28.33	**14.44**
Gaps/Holes				0.84		**0.17**
Total Abiotic	8.42	2.74	15.86	17.68	28.33	**14.61**
Benthic Algae						
Turf (mixed) with sediment	13.38	29.14	13.42	22.84	29.13	**21.58**
Turf (mixed)	17.42	20.51	24.84	17.37	5.99	**17.22**
Ramicrusta spp.	1.96	6.60	4.65	0.53	5.90	**3.93**
Dictyota spp.		2.94	1.06	1.68	0.36	**1.21**
CCA (mixed)	1.73	3.65		0.42		**1.16**
Galaxaura spp.	0.92	0.20		0.32	0.45	**0.38**
Peyssonnelia spp.			0.85			**0.17**
Total Benthic Algae	35.41	63.05	44.82	43.16	41.82	**45.65**
Cyanobacteria	0	0	0	0	0	**0.00**
Hard Coral						
Acropora palmata	43.94	8.12	31.50	36.11	26.27	**29.19**
Pseudodiploria strigosa	3.92	5.08	4.33	1.37	1.97	**3.33**
Porites astreoides	0.92	2.44	1.69		0.71	**1.15**
Pseudodiploria clivosa		2.03		1.05		**0.62**
Agaricia agaricites	0.23			0.32		**0.11**
Total Hard Coral	49.02	17.66	37.53	38.84	28.95	**34.40**
# Coral Colonies/Transect	4	7	4	4	5	**4.8**
# Diseased Coral Colonies/Transect	0	0	1	0	1	**0.4**
Zoanthids						
Palythoa caribaeorum	7.15	15.43	0.53			**4.62**
Total Zoanthids	7.15	15.43	0.53	0.00	0.00	**4.62**
Soft Corals						
Eunicea flexuosa		0.71				**0.14**
Antillogorgia americana		0.41				**0.08**
Total Soft Corals	0.00	1.12	0.00	0.00	0.00	**0.22**
# Soft Coral Colonies/Transect	1	3	1	1	1	**1.40**
Sponges						
Ircinia strobilina			1.06			**0.21**
Desmapsamma anchorata					0.80	**0.16**
Niphates erecta				0.32		**0.06**
Ircinia spp. brown			0.21			**0.04**
Cliona caribbaea					0.09	**0.02**
Total Sponges	0.00	0.00	1.27	0.32	0.89	**0.50**

Soft corals were observed in low densities (mean: 1.4 Col/Transect) contributing to a reef substrate cover of 0.22%. Sponges, represented by five species, were present as small encrusting colonies with very low combined substrate cover (< 1%). The encrusting zoanthid, (*Palythoa caribaeorum)* was present in three transects with a mean cover of 4.62%. Abiotic categories, largely associated with reef overhangs produced by growth of elkhorn coral, averaged a substrate cover of 14.61% and strongly contributed to a mean rugosity of 3.63m (Table 8).

Figures 9 and 10 present monitoring trends of the sessile-benthic community and of hard coral species, respectively. Mean live coral cover declined 23.72% in 2017 relative to the baseline survey of 2015, largely driven by the loss of reef substrate cover by *A. palmata*. Differences between monitoring surveys were associated to coral breakage and mortality due to the exceptionally high waves produced by hurricane Matthew in October 2016. During the 2019 survey, hard coral substrate cover averaged 34.40%, which represents an increase of 18.95% over the previous survey. The temporal variations of hard coral cover between monitoring surveys were not statistically significant (ANOVA, p= 0.319; Appendix 3), indicative that the TRES05 coral community was resilient to extreme physical disturbances previous to 2019 survey.

A statistically significant difference of soft coral densities between monitoring surveys was found (ANOVA, p = 0.017; Appendix 4). The main difference was related to a marked decline (-46.15%) between the 2017 survey (2.6 Col/Transect) and the present 2019 survey (1.4 Col/ Transect). This appears to be the main loss of biological complexity at TRES05 that may be linked to extreme wave energy associated with the pass of hurricanes in 2017 and/or winter storm Riley in 2018. In addition, the sharp increment of cover by *Ramicrusta sp*. may have been influenced by an increase of available (uncolonized) hard substrates that may have been exposed after the physical disturbances.

3.3 Reef Fishes and Motile Megabenthic Invertebrates

During the 2019 survey, 22 fish species were observed within belt-transects with a mean density of 45.0 Ind/30m^2 and a mean density of 8.8 Spp/30m^2 (Table 9). The numerically dominant species was the bluehead wrasse (*Thalassoma bifasciatum* - mean density: 16.2 Ind/30m^2), followed by the dusky damselfish (*Stegastes adustus* – mean density: 8.4 Ind/30m^2). These were the only species present in all transects and their combined abundance represented 54.7% of the total fish density. Schooling striped grunts (*Haemulon chrysargyreum*) were observed below large elkhorn coral arms in one transect. Fish observed in at least three transects were the yellowtail

damselfish (*Microspathodon chrysurus*), clown wrasse (*Halichoeres maculipinna*), slippery dick (*Halichoeres bivittatus*) and french grunt (*H. flavolineatum*). The aforementioned species have been consistently observed at this reef, along with doctorfishes (*Acanthurus coeruleus, A, tractus, A. chirurgus*), redlip blenny (*Ophioblennius atlanticus*), bermuda chub (*Kyphosus bermudensis*), sweepers (Pempheridae), sergeant major (*Abudefduf saxatilis*) and the yellowtail parrotfish (*Sparisoma rubripinne*) appear to comprise the main residential fish assemblage at TRES05. Motile megabenthic invertebrates were not observed within belt-transects during the 2019 survey (Table 9). Adult spiny lobsters (*Panulirus argus*), rock lobsters (*P. guttatus*) and sea urchins (*Diadema antillarum, Eucidaris tribuloides, Echinometra lucunter*) have been previously reported from this reef (García-Sais et al., 2017).

Large mixed schools of adult doctorfishes (*Acanthurus spp*.) and parrotfishes (mostly *Sparisoma rubripinne*) were observed in transit over the reef, occasionally grazing on the benthic algae. Recruitment juveniles and adult ocean surgeons (*A. tractus*) and blue tangs (*A. coeruleus*) were identified within 20 x 3m belt transects (Table 10). Juvenile stages of striped and queen parrotfishes (*Scarus iseri, S. vetula*), and adults of stoplight and yellowtail parrotfishes (*Sparisoma viride, S. rubripinne*) were also present. Juvenile stages of demersal fish predators observed within belt-transect included the mutton, schoolmaster and mahogany snappers (*Lutjanus analis, L. apodus, L. mahogany*).

The shallow, high energy environment at TRES05 is an ideal habitat for opportunistic carnivores, such as wrasses (Labridae), blennies (Blenniidae) and juvenile grunts (Haemulidae), which feed on small benthic (infaunal) invertebrates that become exposed upon disturbances of the substrate due to wave action. The opportunistic carnivore assemblage included 10 species with a combined density of 25.8 Ind/30m^2, representative of 57.3% of the total fish density within belt-transects. The herbivorous fish assemblage, comprised by damselfishes (Pomacentridae), parrotfishes (Scaridae) and doctorfishes (Acanthuridae) were also prominent with seven species and a combined density of 13.8 Ind/30m^2, representative of 30.7% of the total fish density within belt-transects. Piscivores (Lutjanidae) and spongivores (Pomacanthidae) were represented by one species each within belt-transects at TRES05.

Large pelagic piscivores, such as cero mackerels (*Scomberomorus regalis*), bar jacks (*Caranx ruber*) and blue runners (*C. crysos*) have been observed feeding upon dense aggregations of zooplanktivorous anchovies and sardines (*Anchoa spp., Harengula spp*.) near the surface.

Juvenile stages of snappers (*Lutjanus analis, L. apodus, L. synagris*) have been observed during previous surveys (García-Sais et al., 2015) suggesting that this shallow reef system functions as a nursery area for these commercially important species.

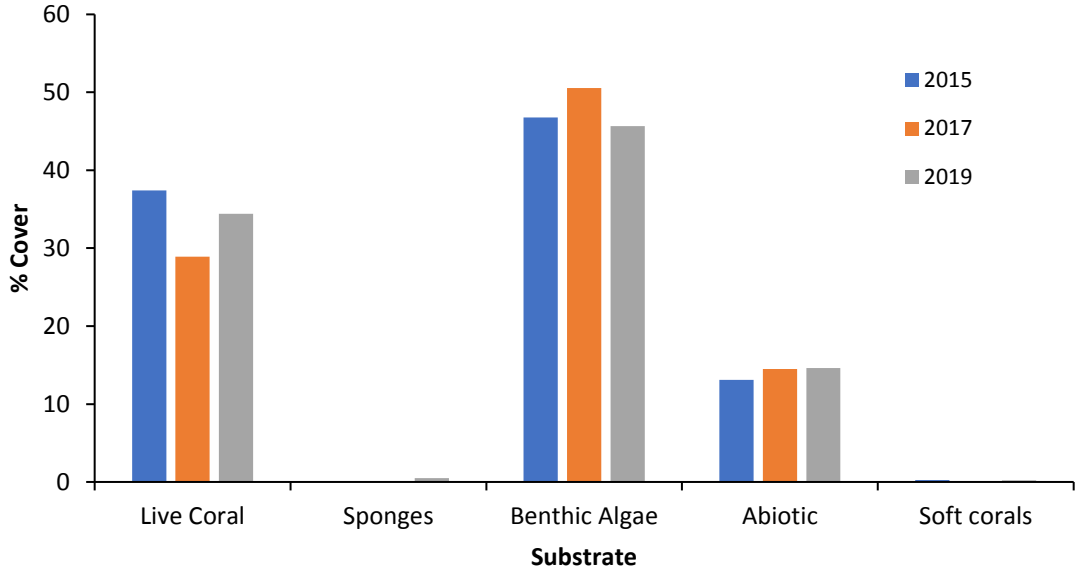


Figure 9. Monitoring trends (2015 – 2019) of mean substrate cover by sessile-benthic categories at TRES05, Rincon.

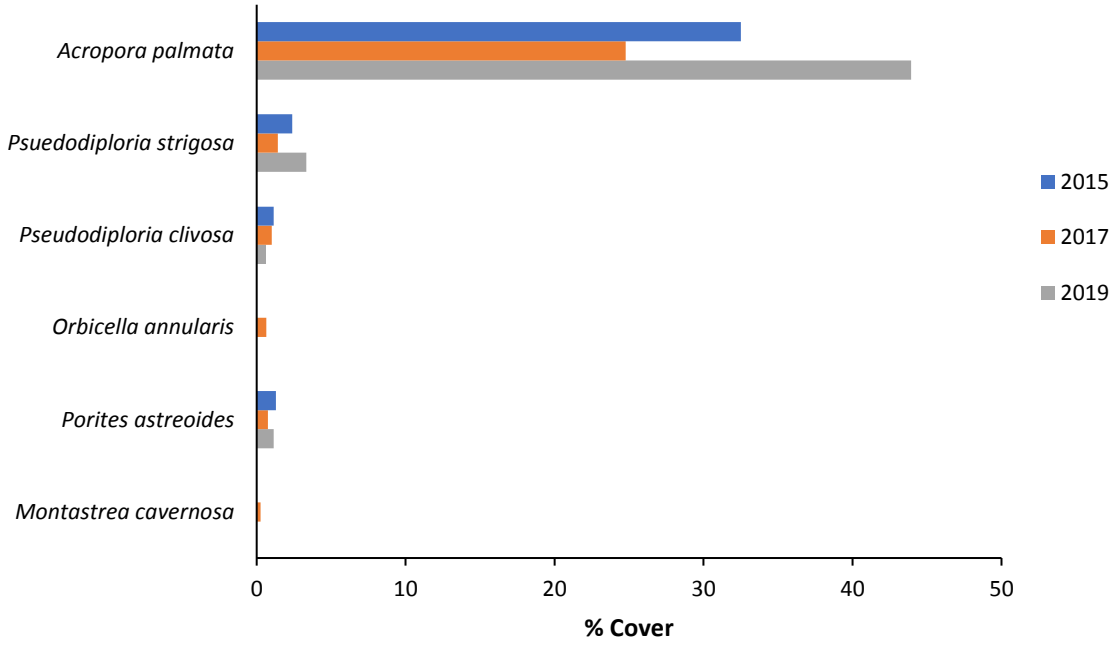


Figure 10. Monitoring trends (2015 – 2019) of mean substrate cover by hard coral species at TRES05, Rincon.

Monitoring trends of mean fish density and species richness are shown in Figure 11. Fish density means have fluctuated between 34.4 – 74.0 Ind/30m^2 and species richness have fluctuated between 8.8 – 10.0 Spp/30m^2. Differences of both fish density and species richness between monitoring surveys were statistically insignificant (see Appendix 5-6). Density fluctuations of bluehead wrasse (*Thalassoma bifasciatum*), the numerically dominant species with aggregated distributions at TRES05 explained most of the density variability between surveys.

Table 9. Taxonomic composition and density of fishes and motile megabentic invertebrates surveyed within 3x10m belt- transects at TRES05, Rincon.

Survey Date: 5-23-19			**Belt-Transects**			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	15	9	10	6	41	**16.2**
Stegastes adustus	7	9	11	8	7	**8.4**
Haemulon chrysargyreum	0	0	22	2	0	**4.8**
Abudefduf saxatilis	8	0	0	0	0	**1.6**
Halichoeres maculipinna	2	3	0	0	3	**1.6**
Microspathodon chrysurus	3	0	2	0	2	**1.4**
Halichoeres bivittatus	0	2	1	1	2	**1.2**
Acanthurus tractus	3	0	1	0	0	**0.8**
Acanthurus coeruleus	0	4	0	0	0	**0.8**
Scarus iseri	0	4	0	0	0	**0.8**
Haemulon flavolineatum	0	0	1	1	2	**0.8**
Sparisoma rubripinne	0	0	3	1	0	**0.8**
Bodianus rufus	0	1	0	1	0	**0.4**
Sparisoma viride	0	0	1	1	0	**0.4**
Scarus vetula	0	0	0	2	0	**0.4**
Anisotremus virginicus	0	0	0	0	2	**0.4**
Ophioblennius atlanticus	1	0	0	0	0	**0.2**
Lutjanus apodus	0	1	0	0	0	**0.2**
Holacanthus ciliaris	0	1	0	0	0	**0.2**
Haemulon plumierii	0	1	0	0	0	**0.2**
Holocentrus adscensionis	0	0	0	0	1	**0.2**
Halichoeres radiatus	0	0	0	0	1	**0.2**
Total Individuals	40	37	55	27	66	**45.0**
Total Species	7	10	9	9	9	**8.8**
Invertebrates						
none observed						
Totals	0	0	0	0	0	**0.0**

Table 10. Size-frequency distributions of commercially important fishes observed within 20 x 3m belt-transects at TRES05, Rincon. Survey date: 5-23-19.

					Belt-Transects (Ind/60m^2)				
Species	**Family**	**Size Range (cm)**	**Life Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Fishes									
Acanthurus chirurgus c4	Acanthuridae	16-20	Adult	1	0	0	0	0	**0.2**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	1	0	0	0	0	**0.2**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	1	0	1	0	0	**0.4**
Acanthurus coeruleus c4	Acanthuridae	16-20	Adult	0	0	0	1	0	**0.2**
Acanthurus tractus c1	Acanthuridae	1-5	Recruit	2	0	0	0	0	**0.4**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	3	2	1	0	0	**1.2**
Lutjanus analis c3	Lutjanidae	11-15	Juvenile	0	3	0	0	2	**1.0**
Lutjanus analis c4	Lutjanidae	16-20	Juvenile	0	0	0	0	3	**0.6**
Lutjanus apodus c4	Lutjanidae	16-20	Juvenile	0	1	0	0	0	**0.2**
Lutjanus mahogoni c4	Lutjanidae	16-20	n/d	0	0	1	0	0	**0.2**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	4	0	0	0	**0.8**
Scarus vetula c2	Scaridae	6-10	n/d	0	0	0	2	0	**0.4**
Sparisoma rubripinne c5	Scaridae	21-25	Adult	0	0	3	2	0	**1.0**
Sparisoma rubripinne c6	Scaridae	26-30	Adult	0	0	0	1	1	**0.4**
Sparisoma viride c5	Scaridae	21-25	Adult	0	0	1	1	0	**0.4**
Sparisoma viride c6	Scaridae	26-30	Adult	0	0	0	1	0	**0.2**
Totals				8	10	7	8	6	**7.8**

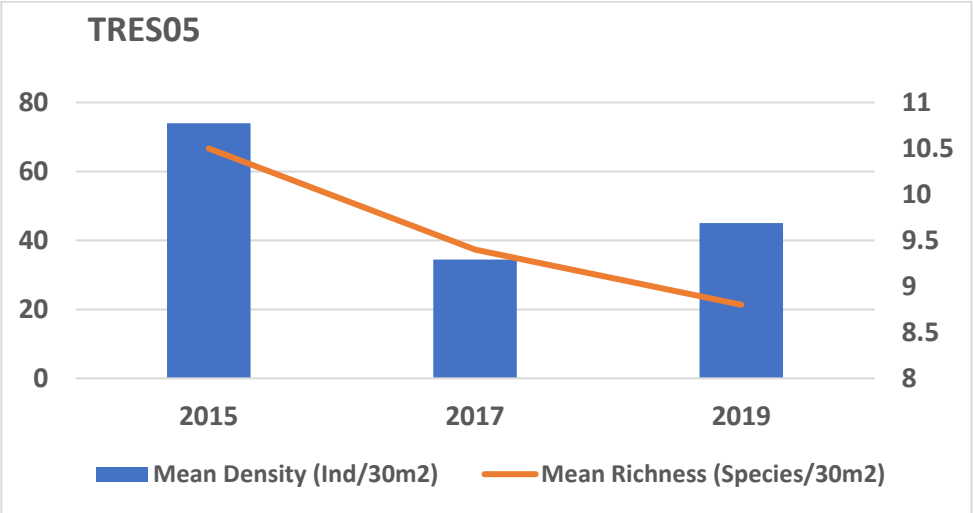
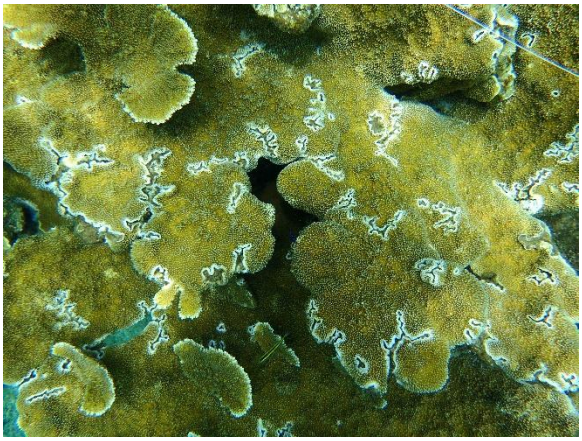


Figure 11. Monitoring trends (2015 – 2019) of mean fish density and species richness within 3x10m belt-transects at TRES05, Rincon

3.4 Photo Album 3 TRES05



4. Tourmaline 30m (TOUR30)

4.1 Physical Description

Tourmaline Reef located due west of Bahía Bramadero; Cabo Rojo was designated as a Natural Reserve in 1996 in recognition of its ecological value as the most important coral reef system of the west coast of Puerto Rico. The reef sits at the northern section of the Cabo Rojo platform, approximately five miles away from the coastline (Figure 12).

Tourmaline is a submerged coral reef system comprised by a series of narrow hard ground terraces or steps fringing the edge of the Mayaguez Bay shelf along a depth range of 10 - 32 m. The reef starts at a depth of 10m with a well-defined" spur-and-groove" formation that follows a gentle slope towards the north. A more irregular spur-and-groove reef formation of massive coral buildup is found at a depth of 17m, extending due north to a depth of 21m. The third and last hard ground terrace is narrow, breaking abruptly from 22m down to 32m along an irregular slope with high topographic relief given by large massive corals. Permanent transects were oriented south - north, perpendicular to the shelf-edge and on top of the spurs at a depth of 28 - 30m at TOUR30. Panoramic views of TOUR30 are presented in Photo Album 4.

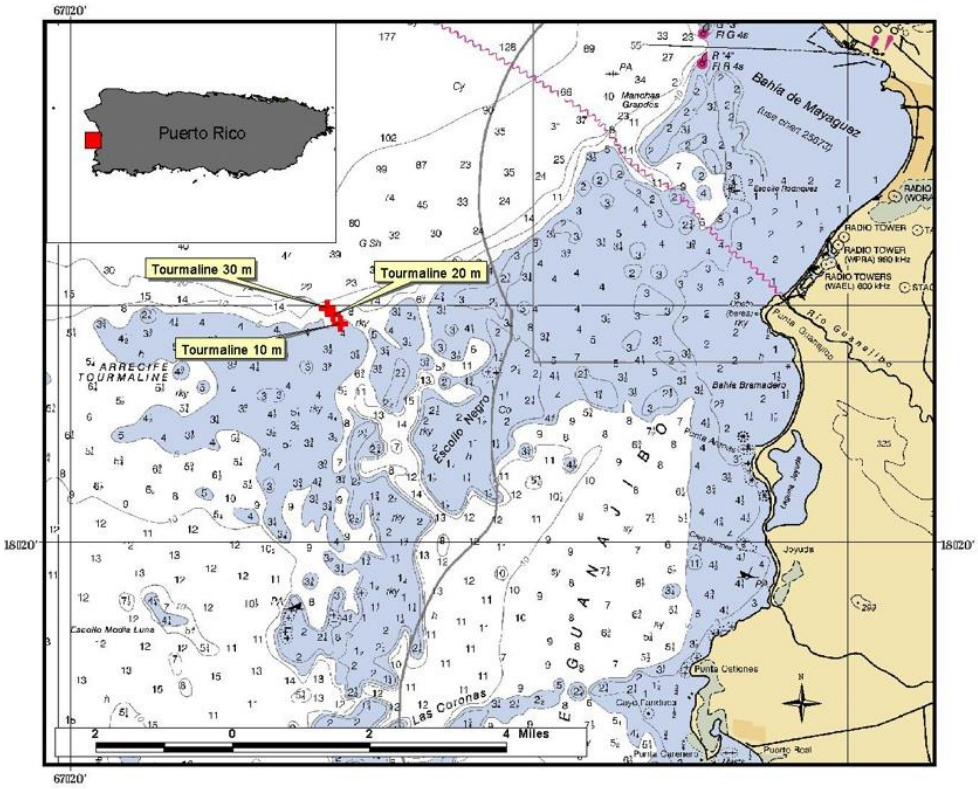


Figure 12. Location of coral reef survey stations at Tourmaline Reef, Mayaguez.

4.2 Sessile-Benthic Reef Community

Benthic algae comprised by an assemblage of turf (mixed), fleshy brown (*Dictyota sp., Lobophora variegata*), crustose red (*Peyssonnelia sp., Ramicrusta sp*.) and green calcareous macroalgae (*Halimeda spp*) were the dominant sessile-benthic category in terms of reef substrate cover at TOUR30 with a combined mean cover of 47.04% (range: 38.05 – 54.67%). Turf algae, a mixed assemblage of short red and brown algae was the dominant component with a mean cover of 24.00%, representative of 51.0% of the total cover by benthic algae (Table 11). Small scattered patches of benthic cyanobacteria were intercepted by two transects with a mean cover of 0.31%.

A total of 21 hard corals and two black coral species have been identified from TOUR30, including 13 species intercepted by transects during the 2019 survey (Table 11). Reef substrate cover by hard corals averaged 21.48% (range: 14.99 – 27.49%) with an average of 13.4 Col/Transect. Mountainous star coral (*Orbicella faveolata*) and grahame sheet coral (*Agaricia grahamae*) were the dominant species in terms of reef substrate cover with means of 5.78% and 5.72%, respectively. Lettuce (*Agaricia spp*) corals were represented by four species with a combined cover of 11.46%, or 53.4% of the total cover by hard corals at TOUR30 (Table 11). Colonies of mustard-hill coral (*Porites astreoides*) and great star coral (*Montastraea cavernosa*) were present in at least four transects with a combined cover of 2.14% and along with the aforementioned species comprised the main hard coral species assemblage at TOUR30. Coral diseases were observed in one colony (1-*Orbicella faveolata*) out of the 74 colonies intercepted by transects for a coral disease prevalence of 1.4% (Appendix 2).

Erect soft corals were present in all transects with an average of 10.0 Col/Transect (Table 11). Encrusting species, such as the corky sea-finger (*Briareum asbestinum)* and the encrusting gorgonian (*Erythropodium caribaeorum)* contributed a combined substrate cover of 5.20%. Colonies of bushy black coral (*Antipathes caribbeana*) and wire coral (*Stichopathes lutkeni*) were present outside transects at a depth of 32m. Encrusting and erect sponges were represented by 11 species along transects surveyed with an average substrate cover of 2.89%. *Plakortis sp*. was the most prevalent species along transects. Reef overhangs were the main contribution to abiotic cover with a mean of 18.46%, representative of 80.0% of the total abiotic cover. These were associated with both substrate irregularities and coral growth and strongly influenced the mean reef rugosity of 3.61m.

Table 11. Percent reef substrate cover by sessile-benthic categories at TOUR30, Mayaguez.

Survey Date: May 27, 2019			**Transects**			
	1	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	28.48	28.48	28.18	27.27	27.27	**27.94**
Rugosity (m)	1.26	4.64	6.00	1.40	4.77	**3.61**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	18.91	23.04	19.77	10.32	20.28	**18.46**
Sand		5.74	1.49	6.14		**2.67**
Gaps/Holes	1.37	2.49	1.84	3.44	0.57	**1.94**
Total Abiotic	20.27	31.26	23.10	19.90	20.85	**23.08**
Benthic Algae						
Turf (mixed) with sediment	43.53	17.88	11.20	21.25	12.61	**21.29**
Dictyota spp.		12.14	25.02	21.99	25.50	**16.93**
Peyssonnelia spp.		5.07	5.42	4.30	6.73	**4.30**
Turf (mixed)		2.10	3.41	4.05	3.98	**2.71**
Ramicrusta spp.			0.61		2.27	**0.58**
CCA (mixed)		0.86	1.57			**0.49**
Lobophora spp.				2.09		**0.42**
Halimeda spp.			0.44	0.98	0.19	**0.32**
Total Benthic Algae	43.53	38.05	47.68	54.67	51.28	**47.04**
Cyanobacteria	0.00	1.15	0.00	0.00	0.38	**0.31**
Hard Coral						
Orbicella faveolata	5.47	6.60	3.24	3.93	9.67	**5.78**
Agaricia grahamae	15.55	5.16	5.60		2.27	**5.72**
Agaricia agaricites		1.91	2.80	4.42	7.01	**3.23**
Agaricia lamarcki	3.36	1.91	3.59	1.60	0.95	**2.28**
Porites astreoides	1.74	0.86	1.92	0.49	0.57	**1.12**
Montastraea cavernosa	1.37	0.57	0.79		2.37	**1.02**
Madracis carmabi		3.35				**0.67**
Orbicella franksi				2.95		**0.59**
Siderastrea siderea			1.05	1.23		**0.46**
Agaricia fragilis		1.15				**0.23**
Madracis decactis		0.38	0.26		0.47	**0.22**
Stephanocoenia intersepta		0.19	0.26			**0.09**
Meandrina meandrites				0.37		**0.07**
Total Hard Coral	27.49	22.08	19.51	14.99	23.32	**21.48**
# Coral Colonies /Transect	16	14	11	13	13	**13.4**
# Diseased Coral Colonies/Transect	0	0	0	0	1	**0.20**
Soft Corals						
Briareum asbestinum		3.73	7.87	9.34	0.47	**4.28**
Erythropodium caribaeorum	4.60					**0.92**
Total Soft Corals	4.60	3.73	7.87	9.34	0.47	**5.20**
# Soft Coral Colonies/Transect	10	10	12	7	11	**10.0**
Sponges						
Sponge spp.	4.10	0.48	0.87			**1.09**
Plakortis spp.		1.43	0.44	0.49		**0.47**
Agelas conifera					1.71	**0.34**
Svenzea zeai		1.53				**0.31**
Callyspongia fallax					1.04	**0.21**
Iotrochota arenosa				0.00	0.76	**0.15**
Agelas dispar				0.61		**0.12**
Monanchora arbuscula		0.29				**0.06**
Niphates erecta			0.26			**0.05**
Prosuberites laughlini			0.26			**0.05**
Aplysina cauliformis					0.19	**0.04**
Total Sponges	4.10	3.73	1.84	1.11	3.70	**2.89**

Temporal variations of mean percent cover by sessile-benthic categories at TOUR30 are presented in Figure 13. Differences of hard coral cover between monitoring surveys were statistically significant, (ANOVA; p = 0.016, Appendix 3). The mean percent cover by hard corals remained stable during the period between the baseline survey in 2004 and 2010. Since then, a consistent increment of live coral cover was measured until the previous 2017 survey. Substrate cover accretion by live hard coral reached 75.11%, from 13.54% during the baseline survey to 23.71% in 2017. The accretion of live coral was associated with increments by the two dominant corals, the *Agaricia spp* assemblage, of which *A. grahamae* was the main component, and *Orbicella faveolata* (Figure 14).

Since our baseline survey in 2004, many large colonies of *Orbicella spp.* were already dead and overgrown by turf algae, indicative of a major stress acting over this coral species (complex) some time before our baseline survey. Hard coral has re-colonized (previously) dead coral sections by displacing turf algae, which have shown a corresponding declining trend of reef substrate cover over time. The mean cover of 21.48% measured during the present 2019 survey represents a decline of 9.40% from the previous 2017 survey. This difference was statistically insignificant (see Appendix 3).

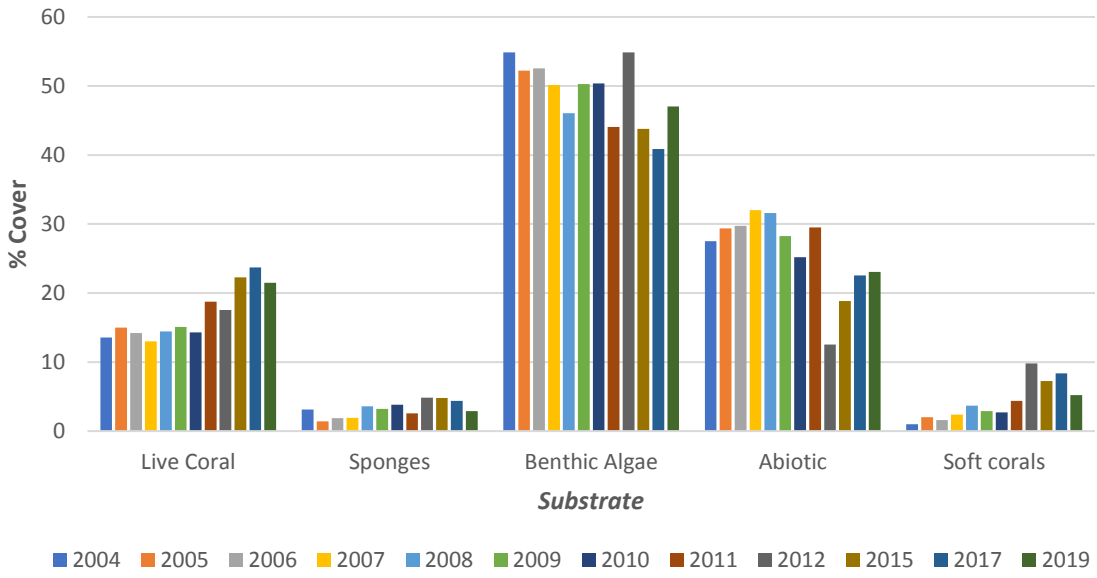


Figure 13. Monitoring trends (2004 – 2019) of mean substrate cover by sessile-benthic categories at TOUR30, Mayaguez.

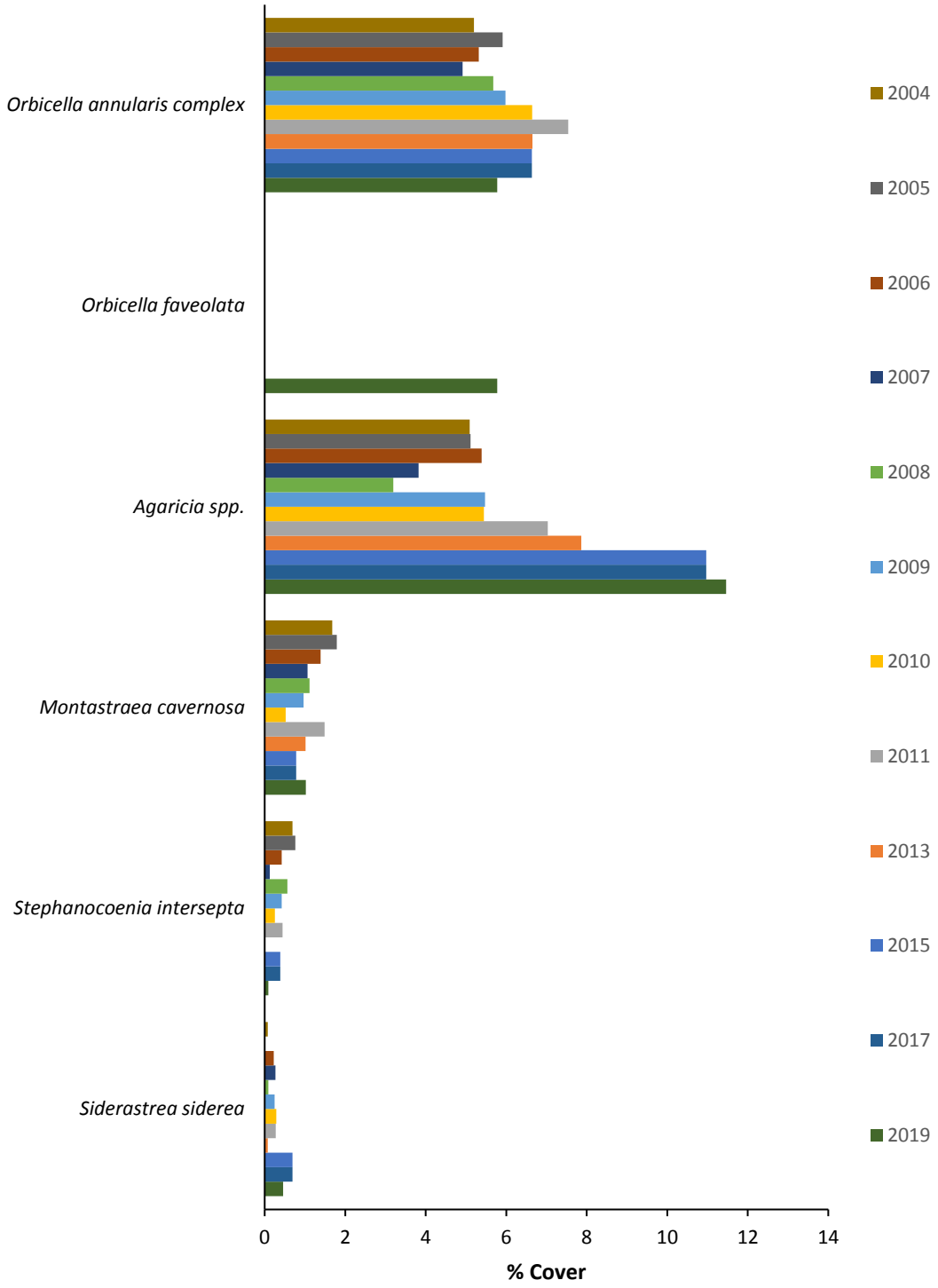


Figure 14. Monitoring trends (2004 – 2019) of mean substrate cover by hard coral species at TOUR30, Mayaguez. Note that previous to 2019, all three *Orbicella* species were documented under" *Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

4.3 Fishes and Motile Megabenthic Invertebrates

A total of 34 fish species were observed within belt-transects during the 2019 monitoring survey at TOUR30 with a mean density 71.6 Ind/30m^2 (range: 55 - 100 Ind/30m^2) and a mean species richness of 17.6 Spp/30m^2 (Table 12). The masked goby (*Coryphopterus personatus)* and the blue chromis (*Chromis cyanea*) were the numerically dominant species with mean densities of 16.0 Ind/30m^2 and 11.0 Ind/30m^2, respectively. The combined abundance of eight species represented 75.7% of the total individuals observed within belt-transects. In addition to the aforementioned species, the main assemblage included the tomtate (*Haemulon aurolineatum*), peppermint goby (*C. lipernes*), fairy basslet (*Gramma loreto*), bicolor damselfish (*Stegastes partitus*), black bar soldierfish (*Myripristis jacobus*), and princess parrotfish (*Scarus taeniopterus*). One spiny lobster (*Panulirus argus*) was the only motile megabenthic invertebrate observed within belt-transects (Table 12).

Demersal zooplanktivores, comprised by three of the top six numerically dominant species (*Coryphopterus personatus*, *Chromis cyanea* and *Stegastes partitus*) were the main trophic component within belt-transects with a combined abundance of 30.2 Ind/30m^2, representing 42.2% of the total individuals at TOUR30. Schools of mackerel scad (*Decapterus macarellus*) have been observed at mid-water (Garcia-Sais et al., 2017) and along with other zooplanktivore species serve as forage for pelagic predators such as jacks (Carangidae), mackerels (Scombridae) and barracudas (Sphyraenidae). A large variety of small invertebrate feeders, such as wrasses (Labridae), gobies (Gobiidae), hamlets and small groupers (Serranidae), basslets (Grammatidae), squirrelfishes (Holocentridae), grunts (Haemulidae) and puffers (Tetraodontidae) represented another prominent fish assemblage in this reef with 17 species and a combined abundance of 28.0 Ind/30m^2, or 39.1% of the total fish density. Herbivores were represented by parrotfishes (Scaridae), doctorfishes (Acanthuridae) and damselfishes (Pomacentridae) with eight species and a combined abundance of 6.0 Ind/30m^2, or 8.4% of the total. Mid-size carnivores included the red hind (*Epinephelus guttatus*) and lane snapper (*Lutjanus synagris*).

Table 12. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at TOUR30, Mayaguez.

Tourmaline 30m (TOUR30)						
Survey Date: 5-27-19			**Belt-Transects**			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Coryphopterus personatus	35	1	25	7	12	**16.0**
Chromis cyanea	10	30	0	12	3	**11.0**
Haemulon aurolineatum	10	16	3	3	1	**6.6**
Coryphopterus lipernes	2	1	4	9	12	**5.6**
Gramma loreto	1	5	10	7	2	**5.0**
Stegastes partitus	4	7	8	1	1	**4.2**
Myripristis jacobus	3	8	3	1	1	**3.2**
Scarus taeniopterus	0	3	2	4	5	**2.8**
Elacatinus evelynae	0	1	1	2	5	**1.8**
Chromis multilineata	0	8	0	0	0	**1.6**
Stegastes leucostictus	1	2	2	1	2	**1.6**
Sparisoma aurofrenatum	0	2	2	0	2	**1.2**
Acanthurus tractus	0	0	0	0	5	**1.0**
Holocentrus rufus	1	2	1	1	0	**1.0**
Thalassoma bifasciatum	2	0	3	0	0	**1.0**
Scarus iseri	0	3	0	1	0	**0.8**
Chromis insolata	0	0	3	0	0	**0.6**
Lutjanus synagris	1	1	1	0	0	**0.6**
Neoniphon marianus	0	1	1	0	1	**0.6**
Stegastes planifrons	0	0	0	0	3	**0.6**
Acanthurus chirurgus	0	1	0	0	1	**0.4**
Anisotremus virginicus	1	0	0	1	0	**0.4**
Canthigaster rostrata	0	1	0	0	1	**0.4**
Chaetodon aculeatus	0	0	1	1	0	**0.4**
Chaetodon capistratus	0	0	0	2	0	**0.4**
Halichoeres maculipinna	0	2	0	0	0	**0.4**
Holacanthus tricolor	0	1	0	0	1	**0.4**
Hypoplectrus puella	0	0	1	1	0	**0.4**
Mulloidichthys martinicus	0	2	0	0	0	**0.4**
Sparisoma radians	0	2	0	0	0	**0.4**
Cephalopholis cruentata	1	0	0	0	0	**0.2**
Epinephelus guttatus	0	0	0	0	1	**0.2**
Hypoplectrus chlorurus	0	0	0	0	1	**0.2**
Liopropoma rubre	0	0	0	1	0	**0.2**
Total Individuals	72	100	71	55	60	**71.6**
Total Species	13	22	17	17	19	**17.6**
Invertebrates						
Panulirus argus	1	0	0	0	0	**0.2**
Totals	1	0	0	0	0	**0.2**

Juvenile and adult parrotfishes (*Sparisoma spp, Scarus sp*) and doctorfishes (*Acanthurus spp*.) comprised the most abundant commercially important taxa at TOUR30 (Table 13). Recruitment juvenile stages (1–5 cm) of *Scarus taeniopterus* and *S, iseri*) and one terminal phase male of *S. taeniopterus* were observed. Full adult stages of top demersal and pelagic predators, such as snappers, groupers, hogfish, mackerels and barracudas have been observed at the shelf-edge reef, but in low abundance (Garcia-Sais et al., 2017 and references therein).

Table 13. Size-frequency distributions of commercially important fishes observed within 20 x 3m belt-transects at TOUR30, Mayaguez. Survey date: 5-27-19.

					TRANSECTS				
		Size	Life		(Ind/60m^2)				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c2	Acanthuridae	6-10	Juvenile	0	0	0	0	1	**0.2**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	0	1	0	0	0	**0.2**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	0	1	0	0	0	**0.2**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	0	0	0	0	1	**0.2**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	0	0	0	0	1	**0.2**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	1	0	0	0	0	**0.2**
Epinephelus guttatus c7	Serranidae	31-35	Adult	0	0	0	0	1	**0.2**
Lutjanus apodus c7	Lutjanidae	31-35	Adult	0	1	0	0	0	**0.2**
Lutjanus mahogoni c5	Lutjanidae	21-25	Adult	1	0	0	0	0	**0.2**
Lutjanus synagris c3	Lutjanidae	11-15	Juvenile	0	1	0	0	0	**0.2**
Lutjanus synagris c5	Lutjanidae	21-25	Adult	3	0	2	0	0	**1.0**
Lutjanus synagris c6	Lutjanidae	26-30	Adult	0	0	1	0	0	**0.2**
Scarus iseri c1	Scaridae	1-5	Recruit	0	3	0	0	0	**0.6**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	0	0	1	0	**0.2**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	0	7	0	0	0	**1.4**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	0	3	1	2	0	**1.2**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	0	0	1	1	3	**1.0**
Scarus taeniopterus c4	Scaridae	16-20	Adult	0	0	0	1	0	**0.2**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	0	0	0	0	2	**0.4**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	2	0	0	0	**0.4**
Totals				5	19	5	5	9	**8.6**

Annual fluctuations of fish species richness and density at TOUR30 are shown in Figure 15. Differences of fish density and species richness between annual surveys were statistically significant (ANOVA; $p < 0.0001$, Appendix 5-6). Density differences between monitoring surveys were mostly driven by the fluctuations of masked goby (*Coryphopterus personatus*), which is a schooling species with highly aggregated or patchy distributions and numerically dominant within belt-transects. Such aggregated distributions introduce high sampling variability and many

observations are needed within any given reef system to detect temporal density patterns. Consistent with the previous 2017 survey, density of masked goby was low again in 2019, influencing the difference of total fish density relative to previous surveys. Annual fluctuations of species richness did not show any consistent pattern through time and may be related to variable physical conditions at the time of surveys.

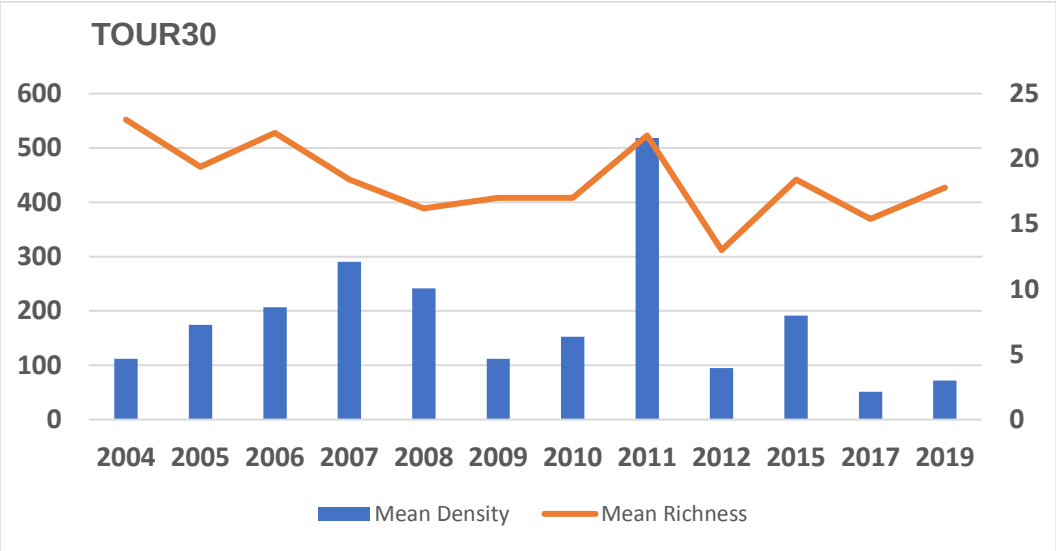
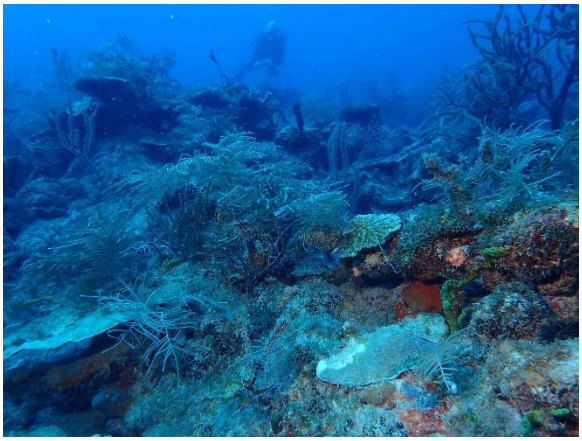


Figure 15. Monitoring trends (2004 – 2019) of mean fish density and species richness within 3x10 m belt-transects at TOUR30, Mayaguez.

4.4 Photo Album 4. TOUR30



5. Tourmaline 20m (TOUR20)

5.1 Physical Description

Tourmaline outer shelf reef is separated from the shelf-edge by an irregular fringe of sandy-silt bottom. Submerged at a depth of 16m, the reef extends down a narrow and abrupt slope to a depth of 21m. A rugged and diffuse “spur-and-groove” formation of massive coral buildup is the main structural feature of the reef. The spurs are rather narrow (< 2 m) and rise from the sandy channels or grooves about 2 – 3m. At the deeper edge of the reef massive coral colonies have grown close together forming large coral promontories that partially mask the spur and groove pattern. Permanent transects were installed on top of consecutive spurs at depth between 18.5 – 18.8m. Panoramic views of TOUR20 are presented in Photo Album 5.

5.2 Sessile-benthic Reef Community

Benthic algae, comprised by fleshy brown (*Lobophora variegata, Dictyota sp*.), turf (mixed), and red crustose (*Peyssonnelia sp., Ramicrusta sp*., CCA) algae were the dominant sessile-benthic component in terms of substrate cover at TOUR20 with an average of 45.97% (range: 42.25 – 51.92%). The encrusting fan alga (*L. variegata*) and turf algae were the main component of the benthic algal assemblage with a combined cover of 33.97%, representative of 73.9% of the total cover by benthic algae (Table 14). Small patches of cyanobacteria were intercepted by two transects with a mean cover of 0.47%.

A total of 13 hard coral species were intercepted by line transects during the 2019 survey (Table 14) with a combined substrate cover of 27.59% (range: 22.27 – 32.85%). Hard corals occurred as massive (*Orbicella faveolata, O. franksi*, *Siderastrea siderea*, *Colpophyllia natans, Pseudodiploria labyrinthiformis*), branching (*Madracis spp., Porites porites*), encrusting (*Mycetophyllia spp.*) and mound shaped colonies (*P. astreoides, M. cavernosa*). Mountainous star coral (*O. faveolata*) was the dominant species with a mean of 17.46%, representing 63.3% of the total cover. Colonies of *O. faveolata* and its sibling species *O. franksi* were intercepted by all five transects with a combined cover of 22.04%. A total of 63 hard coral colonies were intercepted by transects, six of which appeared to be affected by coral diseases resulting in a coral disease prevalence of 9.5%. Diseased coral species included *Orbicella faveolata* (2), *O. franksi* (1), *Siderastrea siderea* (1), and *Montastraea cavernosa* (2) (see Appendix 2).

Table 14. Percent reef substrate cover by sessile-benthic categories at TOUR20, Mayaguez

Survey Date: June 7, 2019			**Transects**			
	1	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	18.48	18.79	18.79	18.79	18.79	**18.73**
Rugosity (m)	2.66	3.86	3.83	6.16	5.27	**4.36**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	15.60	14.24	15.59	18.98	20.44	**16.97**
Rubble	2.99	0.71	3.14	1.82	2.47	**2.23**
Sand				2.60		**0.52**
Gaps/Holes				1.47	0.46	**0.39**
Total Abiotic	18.58	14.95	18.72	24.87	23.37	**20.10**
Benthic Algae						
Lobophora spp.	18.14	21.31	26.42	12.05	14.94	**18.57**
Turf (mixed)	16.48	12.32	12.75	21.06	14.39	**15.40**
Peyssonnelia spp.	2.99	6.26	5.47	4.77	7.61	**5.42**
Dictyota spp.	2.99	5.86	4.05	4.68	2.57	**4.03**
Ramicrusta spp.	2.43	0.20	0.30	2.17	2.75	**1.57**
CCA (mixed)	1.66	0.30	2.53			**0.90**
Macroalgae spp.			0.40			**0.08**
Total Benthic Algae	44.69	46.26	51.92	44.71	42.25	**45.97**
Cyanobacteria	0.00	0.00	0.00	0.78	1.56	**0.47**
Hard Coral						
Orbicella faveolata	22.12	19.70	11.84	17.16	16.50	**17.46**
Orbicella franksi	3.76	5.35	5.77	5.89	2.11	**4.58**
Porites astreoides		1.31	1.01	1.13	2.02	**1.09**
Siderastrea siderea	0.33		2.63	1.65	0.82	**1.09**
Montastraea cavernosa	2.99	0.40	1.21		0.46	**1.01**
Colpophyllia natans		3.23				**0.65**
Millepora alcicornis	0.66		1.21	0.26		**0.43**
Madracis decactis		0.51		1.13	0.37	**0.40**
Agaricia agaricites	1.44	0.20				**0.33**
Stephanocoenia intersepta	1.22					**0.24**
Diploria labyrinthiformis			1.01			**0.20**
Madracis carmabi	0.33					**0.07**
Eusmilia fastigiata		0.20				**0.04**
Total Hard Coral	32.85	30.91	24.70	27.21	22.27	**27.59**
# Coral Colonies /Transect	12	14	12	15	10	**12.6**
# Diseased Coral Colonies/Transect	2	0	3	0	1	**1.20**
Soft Corals						
Briareum asbestinum	2.32	6.46	4.45	1.73	8.80	**4.75**
Erythropodium caribaeorum	1.33	1.41				**0.55**
Total Soft Corals	3.65	7.88	4.45	1.73	8.80	**5.30**
# Soft Corals/Transect	18	11	10	4	8	**10.20**
Sponges						
Agelas conifera					1.47	**0.29**
Topsentia ophiraphidites				0.69		**0.14**
Clathria spp.					0.27	**0.05**
Niphates erecta			0.20			**0.04**
Total Sponges	0.00	0.00	0.20	0.69	1.74	**0.53**
Other						
Trididemnum solidum	0.22	0.00	0.00	0.00	0.00	**0.04**

Vertically projected soft corals were moderately abundant at TOUR20 with an average of 10.2 Col/Transect. Some of the most common taxa included sea fans (*Gorgonia ventalina*) and sea plumes (*Antillogorgia sp*.). Encrusting species, such as *Briareum asbestinum* and *Erythropodium caribaeorum* combined for a mean substrate cover of 5.30% (Table 18). Colonies of bushy black coral (*Antipathes caribbeana*) and wire coral (*Stichopathes lutkeni*) were present at the reef base and associated with reef crevices and overhangs. Encrusting sponges were represented by four species along transects with a mean cover of 0.53 %. Reef overhangs associated with ledges of massive corals averaged a substrate cover of 16.97% and contributed markedly to the reef rugosity of 4.36m. Total abiotic cover averaged 20.10% (Table 14).

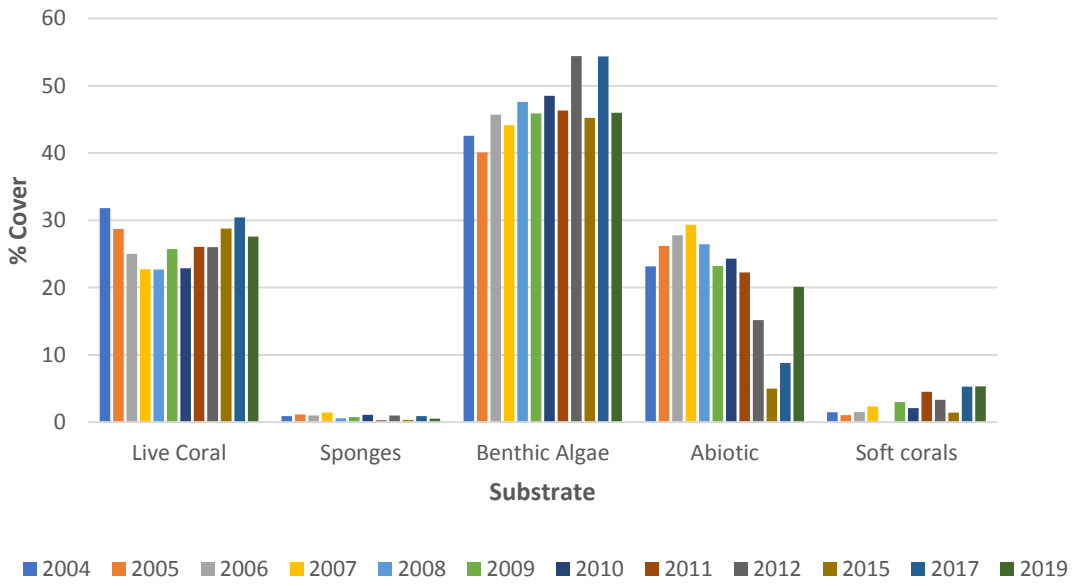


Figure 16. Monitoring trends (2004 – 2019) of mean substrate cover by sessile-benthic categories at TOUR20, Mayaguez.

Figure 16 presents the variations of mean percent substrate cover by sessile-benthic categories from TOUR20. Reef substrate cover by hard corals showed a gradual decline from a baseline mean of 31.79 % in 2004 to a minimum of 22.80% in 2007. Such decline was probably associated with coral bleaching-induced mortalities after the regional event of late August 2005, with lingering effects down to 2008. After 2010 live coral cover maintained an increasing trend until the previous 2017 survey, evidencing a recuperation of 34.45 % from its lowest cover in 2010 and approaching its baseline cover at 31.79%. Differences associated with this recuperation trend were statistically significant (ANOVA, p = 0.028, Appendix 3). During the 2019 survey mean substrate cover by

hard corals registered a 10.4% decline from the previous survey of 2017, but such differences were statistically insignificant. Additional monitoring observations are needed to evaluate if the decline of hard coral cover measured at TOUR20 during 2019 are real or an artifact of sampling variability.

The combined reef substrate cover by *Orbicella spp*, previously described as the *O. annularis* complex was the main driver of the declining trend of live coral between 2004 and 2007 and also of its recent recuperation trend because they are the dominant coral species complex at TOUR20 (Figure 17). During the 2019 survey the combined cover by *Orbicella spp*. (22.04%) declined 7.89% from the mean cover in 2017 (23.78%). From the reef stations monitored so far, TOUR20 exhibited the highest coral disease prevalence (9.5%, Appendix 2) and several colonies of *O. faveolata* were observed to be suffering from infectious diseases.

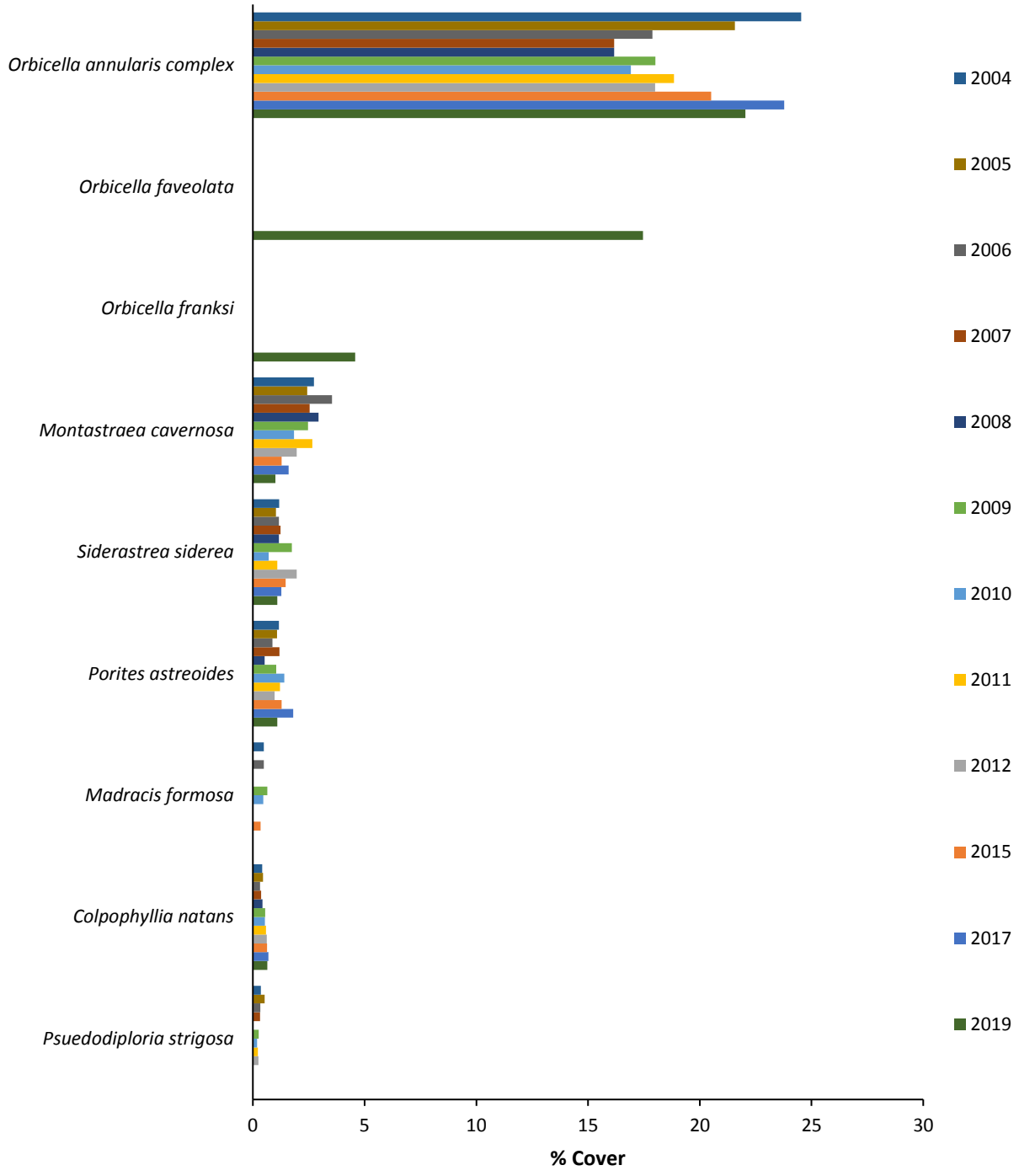


Figure 17. Monitoring trends (2004 – 2019) of mean substrate cover by hard coral species* at TOUR20, Mayaguez. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

5.3 Fishes and Motile Megabenthic Invertebrates

A total of 33 fish species were identified within belt-transects from TOUR20 during 2019 with a mean abundance of 67.2 Ind/30m^2 (range: 59 - 72 Ind/30m^2) and a mean species richness of 17.6 Spp/30m^2 (Table 15). An assemblage of 10 species were present in at least four transects with a combined density of 51.8 Ind/30m^2 representative of 77.1% of the total individuals observed within belt-transects. This group included the bluehead and creole wrasses (*Thalassoma bifasciatum, Clepticus parrae*), masked and peppermint gobies (*Coryphopterus personatus, C. lipernes*), blue chromis (*Chromis cyanea*), bicolor and beaugregory damselfishes (*Stegastes partitus, S. leucostictus*), fairy basslet (*Gramma loreto*), redband and princess parrotfishes (*Sparisoma aurofrenatum, Scarus taeniopterus*) (Table 15). Motile-megabenthic invertebrates were not observed within belt-transects during the 2019 survey at TOUR20.

The fish trophic structure at TOUR20 presented a well-balanced assemblage. Demersal zooplanktivore species included five numerically dominant species (*C. personatus*, *Clepticus parrae, Chromis cyanea*, *Gramma loreto*, *Stegastes partitus*) with a combined density of 25.6 Ind/30m^2, representative of 38.1% of the total fish density. Small invertebrate opportunistic carnivores were represented by 13 species with a combined density of 22.4 Ind/30m^2, or 33.3% of the total fishes within belt-transects. The assemblage included wrasses (Labridae), gobies (Gobiidae), small groupers and hamlets (Serranidae), puffers (Tetraodontidae), grunts (Haemulidae) and squirrelfishes (Holocentridae). Parrotfishes (*Scarus spp., Sparisoma spp*.), doctorfishes (*Acanthurus spp*.) and damselfishes (*Stegastes spp*.), comprised the main herbivorous fish assemblage, with a combined abundance of 11.6 Ind/30m^2, or 17.3% of the total individuals within belt-transects. Corallivores (*Chaetodon spp*) and spongivores (*Pomacanthus spp*) were also present in low densities at TOUR20.

Large invertebrate and fish predators were observed within the 20 x 3m transects (Table 16). These included groupers (*Cephalopholis spp., Epinephelus guttatus, E. striatus, Mycteroperca interstitialis*), snappers (*Lutjanus apodus, Ocyurus chrysurus*) and the green moray (*Gymnothorax funebris*). Cubera and dog snappers (*L. cyanopterus, L. jocu*), Great barracuda (*Sphyraena barracuda*) and cero mackerels (*Scomberomorus regalis*) have been previously reported to occur in this reef (García-Sais et al, 2015 and references therein).

Table 15. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at TOUR20, Mayaguez.

Tourmaline 20m (TOUR20)						
Survey Date: 6-7-19			**Belt-Transects**			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	4	22	11	10	8	**11.0**
Coryphopterus personatus	0	15	5	17	3	**8.0**
Clepticus parrae	9	0	6	10	13	**7.6**
Chromis cyanea	10	6	3	3	8	**6.0**
Coryphopterus lipernes	3	7	4	5	8	**5.4**
Stegastes partitus	12	2	5	4	2	**5.0**
Gramma loreto	10	4	2	3	1	**4.0**
Scarus iseri	4	0	7	0	4	**3.0**
Stegastes leucostictus	2	3	4	1	1	**2.2**
Sparisoma aurofrenatum	3	1	3	2	1	**2.0**
Scarus taeniopterus	1	0	1	1	5	**1.6**
Acanthurus tractus	3	0	2	0	1	**1.2**
Halichoeres garnoti	3	0	0	2	1	**1.2**
Myripristis jacobus	0	0	0	1	5	**1.2**
Haemulon flavolineatum	1	2	0	0	2	**1.0**
Acanthurus coeruleus	1	1	0	2	0	**0.8**
Canthigaster rostrata	0	2	0	0	1	**0.6**
Chaetodon capistratus	0	1	0	2	0	**0.6**
Elacatinus evelynae	0	2	0	1	0	**0.6**
Acanthurus chirurgus	0	0	1	0	1	**0.4**
Anisotremus virginicus	1	0	0	0	1	**0.4**
Chaetodon ocellatus	0	0	0	2	0	**0.4**
Hypoplectrus puella	0	1	1	0	0	**0.4**
Pomacanthus arcuatus	2	0	0	0	0	**0.4**
Pomacanthus paru	0	1	1	0	0	**0.4**
Sparisoma viride	0	0	2	0	0	**0.4**
Aulostomus maculatus	1	0	0	0	0	**0.2**
Cephalopholis cruentata	1	0	0	0	0	**0.2**
Chaetodon aculeatus	0	0	1	0	0	**0.2**
Gymnothorax funebris	0	0	0	0	1	**0.2**
Holacanthus tricolor	1	0	0	0	0	**0.2**
Holocentrus rufus	0	1	0	0	0	**0.2**
Ocyurus chrysurus	0	0	0	0	1	**0.2**
Total Individuals	72	71	59	66	68	**67.2**
Total Species	19	16	17	16	20	**17.6**
Invertebrates						
none observed						
Totals	0	0	0	0	0	**0.0**

Parrotfishes (*Scarus taeniopterus, S. iseri, Sparisoma aurofrenatum, S. viride*) and doctorfishes (*Acanthurus spp*) were the most abundant commercially important fish species present at TOUR20 (Table 16). The size distribution data shows that TOUR20 functions both as a recruitment and residential habitat for important herbivore fish taxa. Recruitment juveniles (1–5 cm) of *A. coeruleus*, *S. iseri*, *S. taeniopterus*, and *S. aurofrenatum* were observed in the 2019 survey. Three terminal phase male (TPM) individuals of *S. viride* were present within belt-transects. Juveniles of yellowtail and schoolmaster snappers (*Ocyurus chrysurus*, *Lutjanus apodus*) and yellowmouth grouper (*Mycteroperca interstitialis)* were also present (Table 16). One adult Nassau grouper (*Epinephelus striatus*) was observed within belt-transects. Tourmaline Reef, including the section of TOUR20 has been identified as a red hind (*Epinephelus guttatus*) spawning aggregation site and seasonally closed to fishing (December – February) since 1996 (CFMC, 1996).

Differences of fish density and species richness between monitoring surveys at TOUR20 were statistically significant (ANOVA; $p < 0.0001$, Appendix 5-6). Density variations were associated with density peaks in 2005, 2006, 2008, 2011 and 2015 relative to other monitoring surveys (Figure 18). Such density peaks were driven by high densities of masked goby (*Coryphopterus personatus*). A sharp consistent decline of species richness was observed after the coral bleaching event of late 2005 with lingering effects until 2008. The bleaching event severely affected the amount of live coral and perhaps with corresponding implications to fish recruitment and residential habitats. The mean fish density measured during the 2019 survey (67.2 Ind/30m^2) fell within the low range of densities previously measured at TOUR20, influenced by a low density of *C. personatus* relative to other surveys. Mean species richness in 2019, however, increased 8.5% from the previous 2017 survey. Both the mean fish density and species richness were within one standard deviation of the mean during 2019 at TOUR20.

Table 16. Size-frequency distributions of commercially important fishes observed within 20 x 3m belt-transects at TOUR20, Mayaguez. Survey date: 6-7-19.

Tourmaline 20m (TOUR20)									
Survey Date: 5-27-19					**TRANSECTS**				
		Size	**Life**		**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c2	Acanthuridae	6-10	Juvenile	0	0	1	0	1	**0.4**
Acanthurus chirurgus c4	Acanthuridae	16-20	Adult	0	0	1	0	0	**0.2**
Acanthurus coeruleus c1	Acanthuridae	1-5	Recruit	1	0	0	1	0	**0.4**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	0	0	0	1	0	**0.2**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	2	2	0	1	1	**1.2**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	1	0	0	0	1	**0.4**
Acanthurus tractus c3	Acanthuridae	11-15	Adult	2	0	0	0	0	**0.4**
Acanthurus tractus c3	Acanthuridae	11-15	Adult	0	0	2	0	0	**0.4**
Cephalopholis cruentata c2	Serranidae	6-10	Juvenile	0	1	0	0	0	**0.2**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	0	0	0	0	1	**0.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	1	0	0	0	0	**0.2**
Epinephelus striatus c10	Serranidae	46-50	Adult	0	1	0	0	0	**0.2**
Gymnothorax moringa c15	Muraenidae	71-75	Adult	0	0	0	0	1	**0.2**
Lutjanus apodus c3	Lutjanidae	11-15	Juvenile	0	0	0	1	0	**0.2**
Mycteroperca interstitialis c6	Serranidae	26-30	Juvenile	0	0	0	0	1	**0.2**
Ocyurus chrysurus c2	Lutjanidae	6-10	Juvenile	0	0	0	0	1	**0.2**
Scarus iseri c1	Scaridae	1-5	Recruit	3	3	0	0	4	**2.0**
Scarus iseri c2	Scaridae	6-10	Juvenile	1	4	1	0	0	**1.2**
Scarus iseri c3	Scaridae	11-15	Juvenile	0	0	5	0	0	**1.0**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	0	0	0	0	4	**0.8**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	1	0	0	0	1	**0.4**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	1	0	0	2	0	**0.6**
Scarus taeniopterus c4	Scaridae	16-20	Adult	0	0	1	0	0	**0.2**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	0	0	1	0	0	**0.2**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	0	0	2	2	0	**0.8**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	3	1	0	0	0	**0.8**
Sparisoma viride c2	Scaridae	6-10	Juvenile	0	0	1	0	0	**0.2**
Sparisoma viride c7	Scaridae	31-35	Adult	1	0	1	1	0	**0.6**
			Totals	17	12	16	9	16	**14.0**

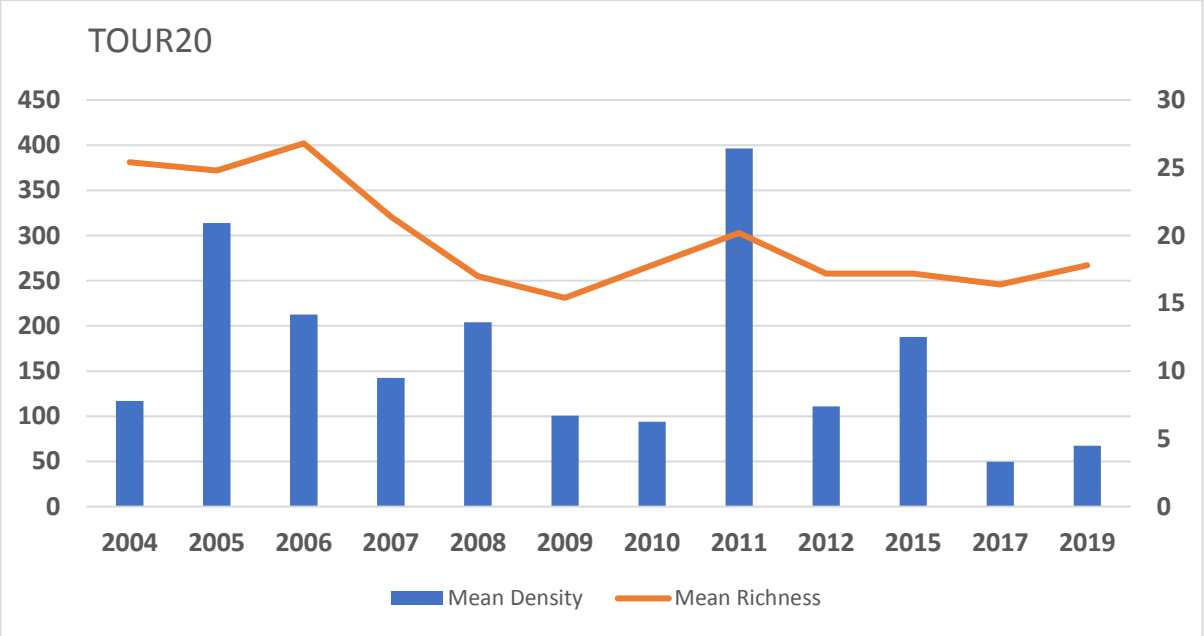
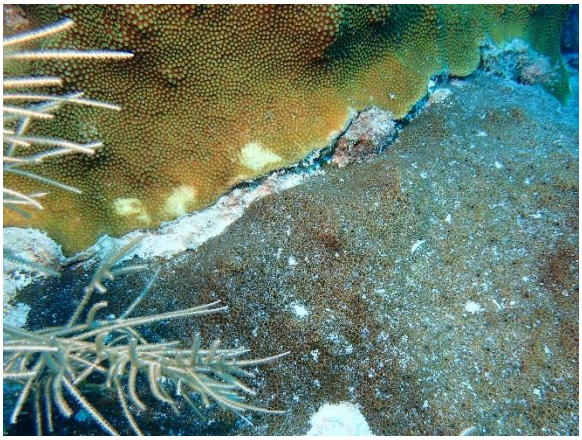
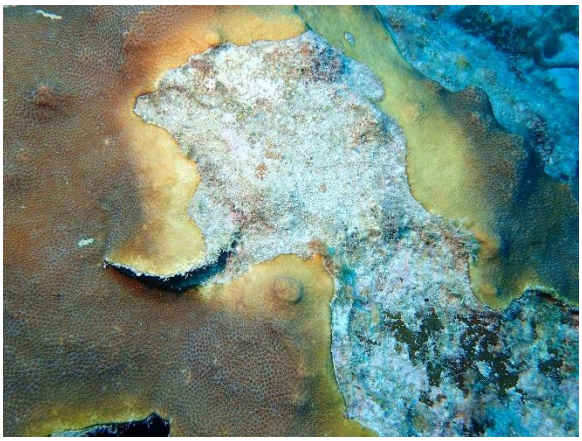


Figure 18. Monitoring trends (2004 – 2019) of mean fish density and species richness within 3x10m belt-transects at TOUR20, Mayaguez.

5.4 Photo Album 5. TOUR20





6. Tourmaline Reef 10m (TOUR10)

6.1 Physical Description

TOUR10 features a low to moderate relief and well defined “spur-and-groove” formation that runs perpendicular to the shelf-edge and ends in a sandy-silt basin at a depth of 14.0m. Spurs are about 1 - 3 m tall, separated by coralline sand and coral rubble deposited at the grooves. Stony corals grow on top of the spurs and along the walls in massive, branching and encrusting colonies. Soft corals are common and a visually prominent feature of the reef benthos. A set of five permanent transects were established on top of the spurs during the baseline characterization in 1999 by García-Sais et al. (2001). Panoramic views of TOUR10 are presented in Photo Album 6.

6.2 Sessile-benthic Reef Community

Turf algae, comprised by a mixed assemblage of short filamentous red and brown macroalgae was the dominant sessile-benthic category in terms of reef substrate cover at TOUR10 with an average cover of 27.10% (range: 18.64 – 34.62%), representing 59.4% of the total cover by benthic algae (Table 17). Turf algae was found overgrowing rocky substrates, as well as dead coral sections and other hard ground. The fleshy brown y-twig alga (*Dictyota sp*.) and the red encrusting alga (*Ramicrusta sp*.) were intercepted by all five transects with mean cover of 8.24% and 7.91%, respectively. Other components of the benthic algae assemblage at TOUR10 included the brown encrusting fan-leaf alga (*Lobophora variegata*), green calcareous (*Halimeda sp*) and fleshy red (*Galaxaura sp*.) and coralline algae (CCA mixed). Total cover by benthic algae averaged 45.60%. Cyanobacterial films were observed in four transects with a mean substrate cover of 1.15%.

A total of 19 hard coral species were identified from TOUR10 during the 2019 survey with a combined mean substrate cover of 41.66% (range: 30.46 – 59.84%) and an average of 19.2 Col/Transect (Table 17), the highest in the PRCRMP. Hard corals occurred as massive (*Orbicella annularis*, *Colpophyllia natans, Montastraea cavernosa, Dendrogyra cylindrus*, branching (*Madracis spp., Porites porites, Acropora cervicornis*), encrusting (*P. astreoides, M. cavernosa, Millepora sp.)* and mound shaped colonies (*P. astreoides, M. cavernosa*). Yellow pencil coral (*Madracis auretenra*) was the numerically dominant species in terms of mean coral cover (mean: 8.47%), representing 20.3% of the total live coral cover. An assemblage of four coral species were present in all five transects. These included lettuce coral (*Agaricia agaricites*), mustard-hill and finger corals (*Porites astreoides, P. porites*) and boulder star coral (*Orbicella franksi*). Mountainous and lobed star corals (*O. faveolata, O. annularis*) were also intercepted by transects at TOUR10 resulting in a mean combined cover of 10.63% for the *Orbicella spp*. complex (Table 17). Infectious diseases were not observed affecting coral colonies intercepted by transects at TOUR10.

Table 17. Percent reef substrate cover by sessile-benthic categories at TOUR10, Mayaguez

TOUR10	Transects					
Survey Date: May 27, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	10.91	10.91	10.91	10.91	11.21	**10.97**
Rugosity (m)	2.91	0.74	2.18	3.99	3.79	**2.72**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	3.25	0.91			0.51	**0.93**
Gaps/Holes			0.57			**0.11**
Total Abiotic	3.25	0.91	0.57	0.00	0.51	**1.05**
Benthic Algae						
Turf (mixed)	27.55	18.64	31.15	23.52	34.62	**27.10**
Dictyota spp.	9.22	8.08	4.60	7.01	12.28	**8.24**
Ramicrusta spp.	4.56	3.00	21.61	5.71	4.67	**7.91**
Lobophora spp.	4.88				1.52	**1.28**
CCA (mixed)				1.90	0.71	**0.52**
Halimeda spp.	0.33		0.34	0.70	0.30	**0.34**
Galaxaura spp.				0.70		**0.14**
Macroalgae spp.				0.40		**0.08**
Total Benthic Algae	46.53	29.73	57.70	39.94	54.11	**45.60**
Cyanobacteria	0.76	2.35	1.95	0.70	0.00	**1.15**
Hard Coral						
Madracis auretenra		42.37				**8.47**
Agaricia agaricites	5.31	0.78	3.33	12.51	7.51	**5.89**
Porites astreoides	7.27	2.48	7.82	1.70	8.02	**5.46**
Porites porites	8.24	0.26	3.22	4.80	3.55	**4.02**
Orbicella franksi	3.04	2.35	3.33	4.30	5.08	**3.62**
Orbicella faveolata	4.88		7.36	4.90	0.51	**3.53**
Orbicella annularis		11.60	1.38	4.40		**3.48**
Dendrogyra cylindrus	7.70			7.61		**3.06**
Colpophyllia natans			4.02			**0.80**
Meandrina meandrites			1.61	1.40	0.30	**0.66**
Millepora alcicornis	0.65			1.40	0.91	**0.59**
Montastraea cavernosa	0.43		1.38		0.91	**0.55**
Helioseris cucullata	2.49					**0.50**
Diploria labyrinthiformis					1.93	**0.39**
Madracis decactis			0.46		0.81	**0.25**
Pseudodiploria strigosa					0.91	**0.18**
Acropora cervicornis			0.57			**0.11**
Siderastrea siderea			0.23			**0.05**

TOUR10	Transects					
Survey Date: May 27, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Porites divaricata				0.20		**0.04**
Total Hard Coral	40.02	59.84	34.71	43.24	30.46	**41.66**
# Coral Colonies /Transect	24	12	19	22	19	**19.2**
# Diseased Coral Colonies/Transect	0	0	0	0	0	**0.0**
Zoanthids						
Palythoa caribaeorum	0.98			2.80	0.91	**0.94**
Soft Corals						
Briareum asbestinum	6.62	3.00	2.30	10.11	9.24	**6.25**
Erythropodium caribaeorum	0.87			1.00	0.20	**0.41**
Plexaura kukenthali	0.22					**0.04**
Plexaura homomalla				0.20		**0.04**
Total Soft Corals	7.70	3.00	2.30	11.31	9.44	**6.75**
# Soft Coral Colonies/Transect	12	7	11	18	20	**13.6**
Sponges						
Neopetrosia spp.			1.95		1.73	**0.74**
Mycale laevis	0.11	2.22	0.57	0.40		**0.66**
Niphates erecta		0.26			2.23	**0.50**
Monanchora arbuscula		1.17		0.90		**0.41**
Scopalina ruetzleri	0.22				0.41	**0.12**
Sponge spp.	0.22	0.26				**0.10**
Aplysina fulva		0.26				**0.05**
Amphimedon compressa			0.23			**0.05**
Callyspongia fallax					0.20	**0.04**
Agelas conifera				0.20		**0.04**
Clathria spp.				0.20		**0.04**
Total Sponges	0.54	4.17	2.76	1.70	4.57	**2.75**
Other						
Eudistoma spp.				0.30		**0.06**
Ascidian spp. (unidentified)	0.22					**0.04**

Erect soft corals were highly abundant with an average of 13.6 Col/Transect and along with hard corals were the most visually prominent assemblage of the reef benthos. Encrusting soft corals were represented by the corky sea-finger (*Briareum asbestinum*) and the encrusting gorgonian (*Erythropodium caribaeorum*) with a combined reef substrate cover of 6.66%. Sponges were represented by at least 11 species and a combined mean cover of 2.75%. Small encrusting colonies prevailed with minor contributions to the reef topographic relief and habitat complexity.

Abiotic cover was minimal at TOUR10 with a mean cover of 1.05% largely contributed by reef overhangs. The mean reef rugosity averaged 2.72m largely influenced by massive coral growth. Figure 19 shows the monitoring trends of reef substrate cover by sessile-benthic categories from TOUR10, including the baseline survey of 1999 and 12 annual monitoring surveys (2004-19). Overall, differences of substrate cover by live corals were not statistically significant (ANOVA; p = 0.994, Appendix 3). During the 2006 monitoring survey, mean live coral cover declined 22.43%, from 44.14% in 2005 to 34.24%. This decline was measured after the regional coral bleaching event that affected most of the northern Caribbean Sea (Garcia-Sais et al, 2008). At the community level, the variation of total coral cover was not statistically significant, perhaps due to the high variability associated with the magnitude (not direction) of the variations within transects.

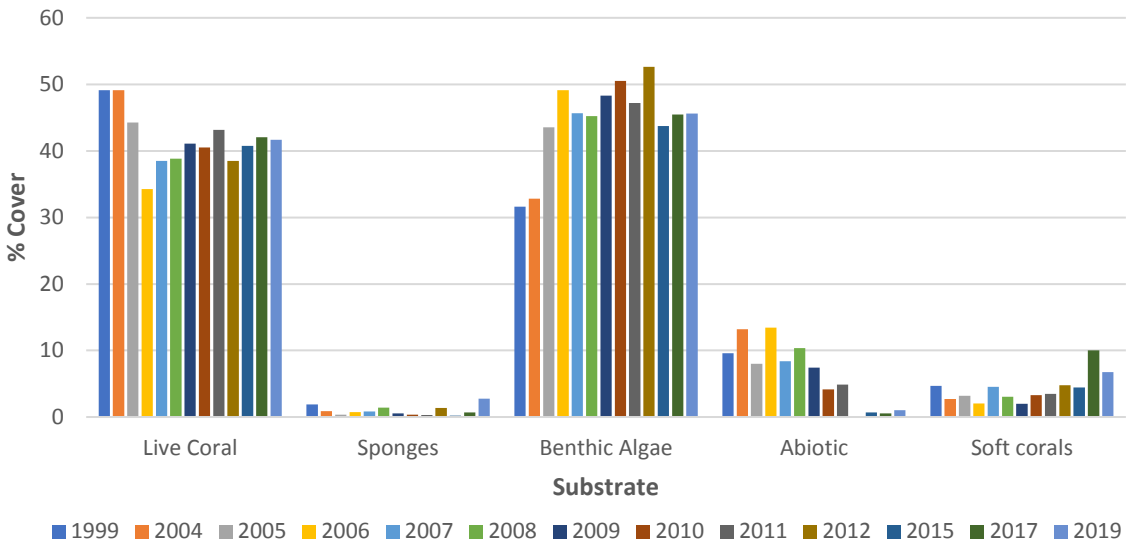


Figure 19. Monitoring trends (1999 – 2019) of mean substrate cover by sessile-benthic categories at TOUR10, Mayaguez.

At the population level, a statistically significant decline of live coral cover was found for *Orbicella annularis* (complex) (ANOVA; p= 0.028), the dominant coral species in terms of reef substrate cover at TOUR10 (García-Sais et al., 2006). Reef substrate cover by *O. annularis* declined 46.0% between 2005 and 2006 and was the main driver of the overall decline of live coral from TOUR20. After 2009, the *O. annularis* species complex presented a consistent pattern of increasing reef substrate cover until the 2015 survey. During the 2017 survey, the *O. annularis* complex exhibited a mild reduction of reef substrate cover, but the variation was statistically insignificant. During the present 2019 survey the mean cover by the *Orbicella* species complex (10.63%) showed a value

similar to that of 2015 (Figure 20), suggesting that the small decline measured in the previous 2017 survey was probably an artifact of sampling variability.

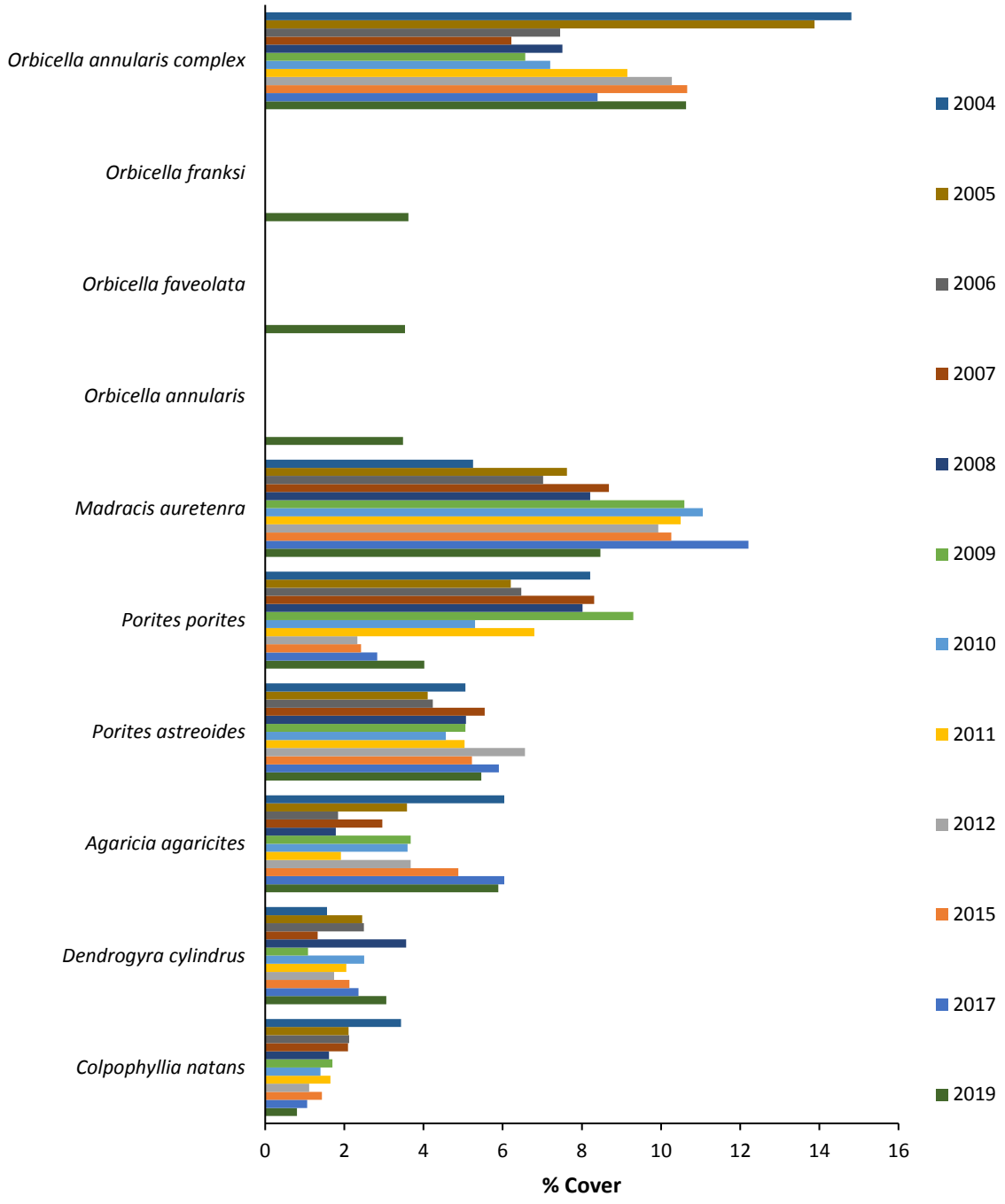


Figure 20. Monitoring trends (1999 – 2019) of mean substrate cover by hard coral species at TOUR10, Mayaguez. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

6.3 Fishes and Motile Megabenthic Invertebrates

A total of 33 fish species were identified within belt-transects from TOUR10 in the 2019 survey with a mean density of 67.8 Ind/30 m^2 (range: 32 – 91 Ind/30 m^2) and a mean species richness of 16.2 Spp/Transect (Table 18). The bluehead wrasse (*Thalassoma bifasciatum*) was the numerically dominant species with a mean density of 21.2 Ind/30m^2, representing 31.3% of the total within belt-transects. Five other species were present in at least four transects with a combined density of 27.6 Ind/30m^2. These included the bicolor damselfish (*Stegastes partitus*), blue chromis (*Chromis cyanea*), princess parrotfish (*Scarus taeniopterus),* french grunt (*Haemulon flavolineatum*) and beaugregory (*Stegastes leucostictus*). Motile megabenthic invertebrates were not observed within belt-transects at TOUR10 during the 2019 survey.

The trophic structure of the fish community at TOUR10 was dominated by small, opportunistic carnivores that included 16 species with a combined density of 30.8 Ind/30m2, representative of 45.4% of the total fish density within belt-transects (Table 18). The assemblage was comprised by wrasses (Labridae), grunts (Haemulidae), gobies (Gobiidae), small groupers and hamlets (Serranidae), squirrelfishes (Holocentridae), puffers (Tetraodontidae), and hawkfishes (Cirrhitidae). Demersal and pelagic zooplanktivores, including the bicolor damselfish (*S. partitus*), blue chromis (*C. cyanea*), creole wrasse (*C. parrae*) and masked goby (*C. personatus*) presented a combined density of 17.8 Ind/30m^2, or 26.2% of the total fish density. Herbivores were represented within belt-transects by six species of parrotfishes (Scaridae), three doctorfishes (Acanthuridae) and three damselfishes (Pomacentridae), with a combined abundance of 17.4 Ind/30 m^2 or 25.7% of the total individuals. Corallivores (Chaetodontidae) and spongivores (Pomacanthidae) were present in low densities (< 2%).

Among large invertebrate and small demersal fish predators, groupers such as red hind (*E. guttatus*), coneys (*C. fulva*) and graysbe (*C. cruentata*) were observed within belt-transects (Table 19). Adult and juvenile, Nassau (*E. striatus*) and yellowfin grouper (*M. venenosa*), schoolmaster, mahogany and yellowtail snappers (*Lutjanus apodus, L. mahogoni, O. chrysurus*) represent top demersal predators observed during previous surveys at this reef (Garcia-Sais et al., 2017 and references therein). Schools of mackerel scad (*Decapterus macarellus*) and ballyhoo, (*Hemiramphus ballyhoo*) serve as forage for pelagic predators, such as cero mackerels (*Scomberomorus regalis*), great barracuda (*Sphyraena barracuda*) and blue runners (*Caranx crysos*) previously reported at TOUR10 (Garcia-Sais et al., 2017 and references therein).

Table 18. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at TOUR10, Mayaguez.

Tourmaline 10m (TOUR10)						
Survey Date: 5-27-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	32	29	6	27	12	**21.2**
Stegastes partitus	8	11	6	4	9	**7.6**
Chromis cyanea	7	8	2	15	2	**6.8**
Scarus taeniopterus	6	2	0	8	5	**4.2**
Haemulon flavolineatum	1	5	1	11	1	**3.8**
Clepticus parrae	0	15	0	1	0	**3.2**
Stegastes leucostictus	5	3	0	2	6	**3.2**
Elacatinus evelynae	0	3	0	7	0	**2.0**
Sparisoma aurofrenatum	2	2	0	0	5	**1.8**
Acanthurus tractus	1	2	1	0	4	**1.6**
Scarus iseri	4	3	0	1	0	**1.6**
Stegastes planifrons	0	0	8	0	0	**1.6**
Acanthurus coeruleus	2	1	0	1	2	**1.2**
Sparisoma radians	0	1	0	0	4	**1.0**
Chaetodon capistratus	2	1	0	1	0	**0.8**
Halichoeres garnoti	0	2	0	0	2	**0.8**
Acanthurus chirurgus	0	1	0	1	1	**0.6**
Amblycirrhitus pinos	0	1	0	0	1	**0.4**
Canthigaster rostrata	1	0	1	0	0	**0.4**
Cephalopholis cruentata	1	0	0	0	1	**0.4**
Cephalopholis fulva	0	0	1	0	1	**0.4**
Holocentrus rufus	0	1	0	1	0	**0.4**
Hypoplectrus unicolor	1	0	0	1	0	**0.4**
Serranus tigrinus	1	0	1	0	0	**0.4**
Sparisoma viride	1	0	1	0	0	**0.4**
Chaetodipterus faber	0	0	1	0	0	**0.2**
Coryphopterus lipernes	0	0	0	1	0	**0.2**
Coryphopterus personatus	0	0	1	0	0	**0.2**
Haemulon sciurus	0	0	0	1	0	**0.2**
Holacanthus tricolor	0	0	0	0	1	**0.2**
Pomacanthus arcuatus	0	0	1	0	0	**0.2**
Scomberomorus regalis	0	0	1	0	0	**0.2**
Stegastes variabilis	0	0	0	1	0	**0.2**
Total Individuals	75	91	32	84	57	**67.8**
Total Species	16	18	14	17	16	**16.2**
Invertebrates						
none observed						
Totals	0	0	0	0	0	**0.0**

Parrotfishes (*Scarus taeniopterus, S. iseri, Sparisoma viride, S. aurofrenatum, S. varians*) and doctorfishes (*Acanthurus spp*) were the numerically dominant assemblage of commercially important fish species observed within belt-transects at TOUR10 (Table 19). Size distributions were in general indicative that TOUR10 functions as a recruitment and residential habitat for both parrotfishes and doctorfishes. Recruitment juveniles (1–5cm) of *S. viride*, *S. radians, S aurofrenatum* and *S. iseri* were observed, as well as terminal phase male individuals of *S. viride*, and *S. taeniopterus*. Adult individuals of red hind (*E. guttatus*), coneys (*C. fulva*) and graysbe (*C. cruentata*) were observed within belt-transects. One recruitment juvenile of *C. fulva* was observed, indicative that TOUR10 also serves as a recruitment habitat or this species. Juvenile Nassau (*E. striatus*) and yellowfin groupers (*Mycteroperca venenosa*) were previously reported from TOUR10 (Garcia-Sais et al., 2017).

Annual monitoring trends of fish density and species richness are presented in Figure 21. Minimum mean values of fish density and species richness were observed during 2008, when mean density declined 31.4 % relative to the baseline survey. Density differences between annual surveys were statistically significant (ANOVA; $p < 0.0001$, Appendix 5). Variations of fish density at TOUR10 are influenced by schooling zooplanktivores with highly aggregated distributions, such as the blue chromis (*Chromis cyanea*), masked goby (*Coryphopterus personatus*), and creole wrasse (*Clepticus parrae*). Inter-annual fluctuations of these species appear to be related to density-independent factors and physical conditions at the time of survey. Differences of fish species richness between surveys were statistically significant (ANOVA; $p < 0.0001$, Appendix 6), driven by a sharp decline of species during 2008 and 2017 relative to all other surveys. Such declines coincided with low densities of *C. personatus* and/or *C. parrae*. It is possible that density fluctuations of these forage species affect the presence of predators and thus influence fish species richness at the community level. An alternate hypothesis may be that physical conditions associated with wave action impact an assemblage of small fishes that cannot withstand the surge and abrasion effects associated with strong wave action and are displaced from the shallow reef. During the 2019 survey both mean fish density and species richness increased relative to the previous 2017 survey, but still fell within the lower range of the historic means for both parameters (see Appendix 5-6).

Table 19. Size-frequency distributions of commercially important fishes observed within 20 x 3m belt-transects at TOUR10, Mayaguez. Survey date: 5-27-19.

					TRANSECTS				
		Size			(Ind/60m^2)				
Species	**Family**	**Range (cm)**		**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c2	Acanthuridae	6-10	Juvenile	0	1	0	0	0	**0.2**
Acanthurus chirurgus c3	Acanthuridae	11-15	Adult	0	0	0	0	1	**0.2**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	1	0	0	0	2	**0.6**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	1	0	1	1	**0.6**
Acanthurus coeruleus c4	Acanthuridae	16-20	Adult	1	0	0	0	0	**0.2**
Acanthurus tractus c3	Acanthuridae	11-15	Adult	3	3	2	1	5	**2.8**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	1	0	0	0	0	**0.2**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	0	0	0	1	0	**0.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	0	0	0	0	1	**0.2**
Cephalopholis cruentata c6	Serranidae	26-30	Adult	1	0	0	0	0	**0.2**
Cephalopholis fulva c1	Serranidae	1-5	Recruit	0	0	0	0	1	**0.2**
Cephalopholis fulva c6	Serranidae	26-30	Adult	0	0	1	1	1	**0.6**
Epinephelus guttatus c7	Serranidae	31-35	Adult	0	1	0	0	1	**0.4**
Scarus iseri c1	Scaridae	1-5	Recruit	4	2	0	0	1	**1.4**
Scarus iseri c2	Scaridae	6-10	Juvenile	1	0	0	2	0	**0.6**
Scarus iseri c3	Scaridae	11-15	Juvenile	1	0	0	0	0	**0.2**
Scarus iseri c4	Scaridae	16-20	Adult	0	1	0	0	0	**0.2**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	4	0	0	8	2	**2.8**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	3	2	0	0	0	**1.0**
Scarus taeniopterus c4	Scaridae	16-20	Adult	0	0	1	0	0	**0.2**
Scarus taeniopterus c6	Scaridae	26-30	Adult	0	1	0	0	0	**0.2**
Scarus vetula c8	Scaridae	36-40	Adult	0	1	0	0	0	**0.2**
Scomberomorus regalis c12	Scaridae	56-60	Adult	0	0	1	0	0	**0.2**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	1	2	0	0	2	**1.0**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	0	0	3	0	2	**1.0**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	1	0	0	0	2	**0.6**
Sparisoma aurofrenatum c5	Scaridae	21-25	Adult	0	0	0	0	1	**0.2**
Sparisoma radians c1	Scaridae	1-5	Recruit	0	0	1	0	4	**1.0**
Sparisoma viride c1	Scaridae	1-5	Recruit	1	0	1	0	0	**0.4**
Sparisoma viride c6	Scaridae	26-30	Adult	1	0	0	0	0	**0.2**
Sparisoma viride c7	Scaridae	31-35	Adult	0	1	0	0	0	**0.2**
Totals				24	16	10	14	27	**18.2**

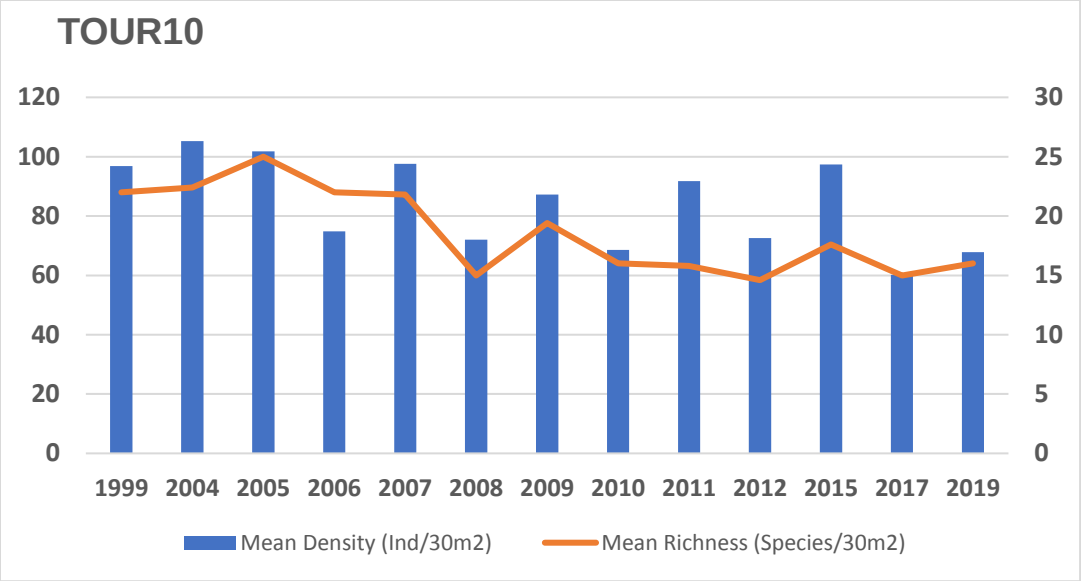
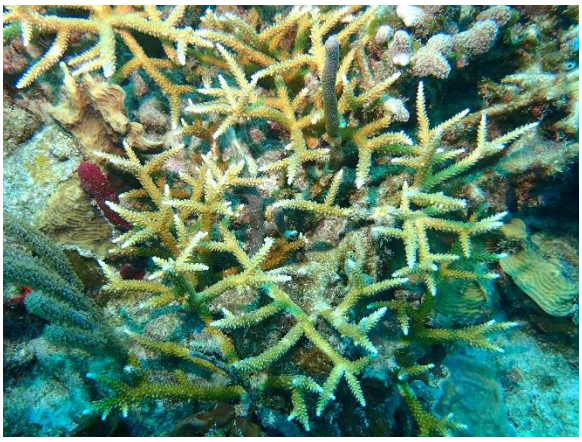
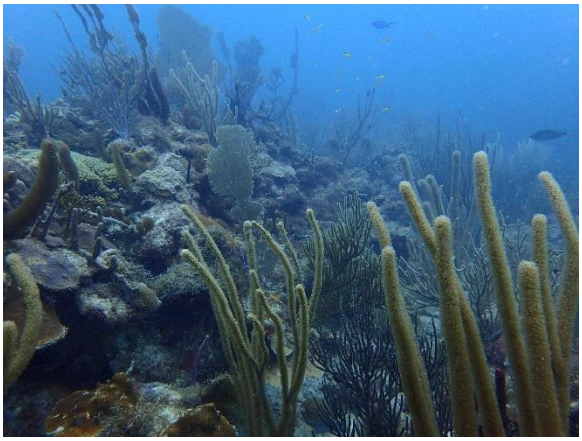


Figure 21. TOUR10. Monitoring trends (1999 – 2019) of mean fish density and species richness within 3x10 m belt-transects at TOUR10, Mayaguez.

6.4 Photo Album 6. TOUR10





7. Gallardo Reef (GALL05)

7.1 Physical Description

Bajo Gallardo is one of the more distant reefs from the southwest shoreline, located at approximately seven nautical miles due west off Pta. Melones, Cabo Rojo (Figure 22). The reef is a cluster of submerged promontories sitting in an irregular hard-ground platform at a depth of about 13m. The shallower reef sections rise to less than two meters from the surface and are elkhorn coral (*Acropora palmata*) reef zones. This reef is subject to intense seasonal wave action associated with North Atlantic swells. Our 2015 baseline survey was performed at a depth of four meters within the *A. palmata* biotope. During the 2019 survey all of the transect rebar markers at GALL05 were buried under a massive deposit of coral debris that resulted from a large-scale mechanical destruction of the shallow reef associated with extreme wave action. We installed new rebar markers setting-up five new permanent transects within the same reef station over the few standing *A. palmata* thickets at depths between 5–7 m. Panoramic views of GALL05 are shown in Photo Album 7.

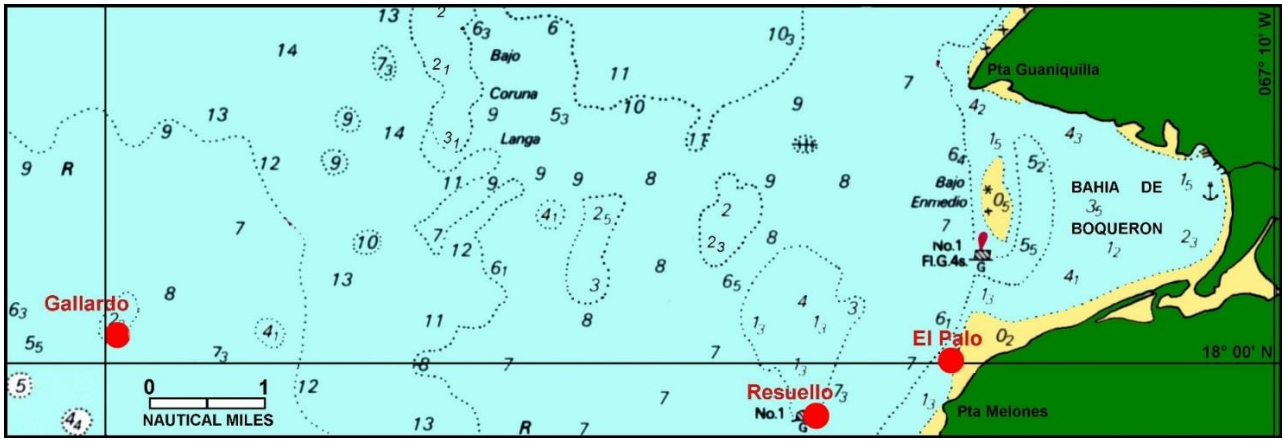


Figure 22. Location of reefs surveyed within the Boqueron (Cabo Rojo) Natural Reserve

7.2 Sessile-Benthic Reef Community

Patchy growth of elkhorn coral (*Acropora palmata*) was the most prominent feature of GALL05 at depths between 5–7m. Elkhorn coral was observed growing as thickets of variable dimensions surrounded by a deposit of mostly of dead, relict elkhorn coral fragments. Evidently, a large-scale mechanical destruction of the elkhorn coral took place before our survey, probably related to the

pass of Hurricanes Irma and/or Maria in September 2017, and/or by the impact of winter storm Riley later in March 2018, or both. Live elkhorn coral colonies were present in all transects surveyed with a mean substrate cover of 40.69% (range: 33.37 – 51.30%), representing 99.6% of the total cover by corals along transects (Table 20). A total of 46 coral colonies were intercepted by transects none of which were observed to be infected by coral diseases (Appendix 2).

Red crustose coralline algae, mostly *Ramicrusta sp*. and *Peyssonnelia sp*. were observed overgrowing dead *Acropora palmata* fragments with a combined cover of 22.36%, representative of 51.3% of the total cover by benthic algae. Turf algae, growing mostly intermixed with tufts of fleshy brown macroalgae (*Dictyota sp*) was present in all transects with a mean cover of 13.06%. Reef overhangs produced by growth of *A. palmata* were the main component of the abiotic category with a mean substrate cover of 8.51%, representative of 86.8% of the total abiotic cover.

Hard coral cover remained stable both in terms of substrate cover and taxonomic composition at GALL05 between the 2015 baseline and the 2017 monitoring surveys (Garcia-Sais et al., 2017). The loss of permanent transects in 2019 constrains the quantitative assessment of changes in the sessile-benthic reef community structure between the 2019 and previous surveys. Nevertheless, the new transects were set in the same vicinity of the previous permanent transects and some major differences were noted. Even though transects were constructed on sections of optimal coral growth, a 25.20% reduction of live hard coral cover was measured relative to the previous 2017 survey (Figure 23), largely associated with a decline of cover by *A. palmata* (Figure 24). This is an underestimate of the real loss of live hard coral at GALL05 influenced by the fact that live *A. palmata* fragments lying on the seafloor were included in our live hard coral measurements. Our visual estimate of hard coral loss at GALL05 during the 2019 survey is closer to 50%. Patches of the encrusting gorgonian (*Erythropodium caribaeorum*) were present with a mean cover of 4.24%. Erect soft corals were present in very low density (0.2 Col/Transect).

Table 20. Percent reef substrate cover by sessile-benthic categories at GALLA05, Cabo Rojo.

Survey Date: 6-7-19			**Transects**			
	1	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	5.45	5.76	6.06	6.36	6.36	**6.00**
Rugosity (m)	4.74	3.38	3.59	3.68	4.52	**3.98**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	5.32	9.83	6.69	5.94	14.75	**8.51**
Rubble	3.42					**0.68**
Gaps/Holes			0.72	1.64	0.68	**0.61**
Total Abiotic	8.74	9.83	7.42	7.57	15.43	**9.80**
Benthic Algae						
Ramicrusta spp.	26.97	28.45	10.30	19.34	9.26	**18.86**
Turf (mixed)	10.07	8.79	22.86	14.33	9.26	**13.06**
CCA (mixed)	3.51	4.81	3.50	4.71	2.03	**3.71**
Peyssonnelia spp.	5.60	1.99	7.52	1.13	1.25	**3.50**
Dictyota spp.	1.80	1.88	5.05	2.87		**2.32**
Jania spp.	0.28	2.51	2.27		0.29	**1.07**
Halimeda spp.			0.62	2.05	0.48	**0.63**
Macroalgae (mixed)	0.76	0.94				**0.34**
Lobophora spp.				0.61		**0.12**
Total Benthic Algae	49.00	49.37	52.11	45.04	22.57	**43.62**
Cyanobacteria	0.47	0.52	0.41	1.43	0.00	**0.57**
Hard Coral						
Acropora palmata	41.79	38.81	38.21	33.37	51.30	**40.69**
Agaricia agaricites			0.41		0.48	**0.18**
Total Hard Coral	41.79	38.81	38.62	33.37	51.78	**40.87**
# CoralColonies /Transect	8	8	11	7	12	**9.2**
# Diseased Coral Colonies/Transect	0	0	0	0	0	**0.0**
Zoanthids						
Palythoa caribaeorum	0.00	0.00	0.00	1.43	0.29	**0.34**
Soft Corals						
Erythropodium caribaeorum			1.44	11.16	8.58	**4.24**
Total Soft Corals			1.44	11.16	8.58	**4.24**
# Soft Coral Colonies/Transect		1				**0.2**
Sponges						
Cliona caribbaea		1.46			1.35	**0.56**
Total Sponges	0.00	1.46	0.00	0.00	1.35	**0.56**

The large-scale destruction of hard coral associated with what appears to have been event(s) of extreme wave action produced (presumably) by either hurricanes Irma and/or Maria in September 2017 and/or winter storm Riley in March 2018 was facilitated by the fact that a large fraction of the coral in that shallow reef section is growing up from relict broken coral fragments and not anchored on solid reef hard ground. Such extreme wave action events have evidently occurred in the past with similar implications at GALL05 and the reef keeps on growing over a massive deposit of relict coral fragments that are turned over and destroyed during extreme wave action events.

Aside from the major changes of hard coral composition, the high exposure and availability of new hard uncolonized substrate appears to have facilitated colonization by opportunistic encrusting taxa, such as red crustose algae (*Ramicrusta sp*.), zoanthids (*Palythoa sp.*) and encrusting gorgonian (*Erythropodium sp*) which exhibited major increments of reef substrate cover relative to previous surveys at GALL05.

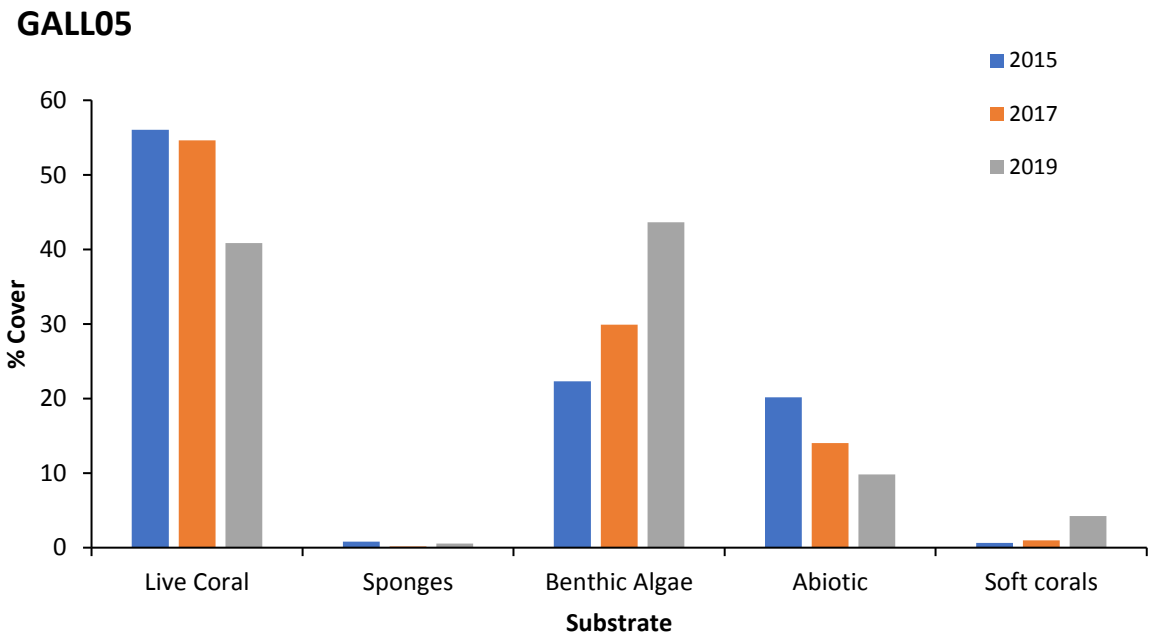


Figure 23. Monitoring trends (2015 – 2019) of mean substrate cover by sessile-benthic categories at GALL05, Cabo Rojo.

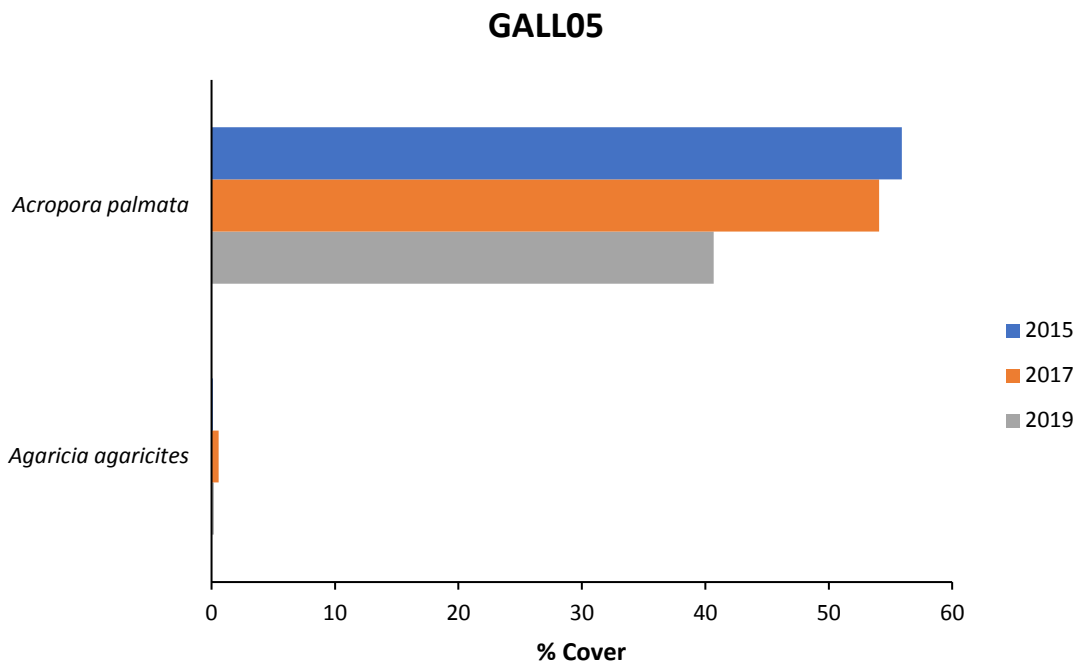


Figure 24. Monitoring trends (2015 – 2019) of mean substrate cover by hard coral species at GALL05, Cabo Rojo.

7.3 Fishes and Motile megabenthic Invertebrates

A total of 23 fish species were identified within belt-transects from GALL05 during the 2019 monitoring survey with a mean density of 51.2 Ind/30m^2 (range: 43 – 63 Ind/30m^2) and a mean species richness of 11.6SPP/30m^2 (Table 21). The bluehead wrasse (*Thalassoma bifasciatum*) was the most abundant species within belt-transects (13.8 Ind/30m^2) and along with stoplight parrotfish (*Sparisoma viride*), yellowtail damselfish (*Microspathodon chrysurus*), dusky damselfish (*Stegastes adustus*), striped parrotfish (*Scarus iseri*) and redlip blenny (*Ophioblennius atlanticus*) comprised the numerically dominant assemblage at GALL05 with a combined density of 42.2%, or 82.4% of the total fish density within belt-transects. Schools of blue chromis (*Chromis cyanea*) were observed over elkhorn coral colonies. Black durgon (*Melichthys niger*) and bermuda chubs (*Kyphosus bermudensis*) were common in mid-water and observed in several transects at GALL05. Two long-spined urchins (*Diadema antillarum*) were observed within belt-transects (Table 21).

The trophic structure of the fish community at GALL05 was dominated by herbivores with nine species and a combined density of 29.8 Ind/30 m^2, or 58.2% of the total individuals within belt-

transects (Table 21). The herbivore assemblage included six species of parrotfishes (Scaridae), two doctorfishes (Acanthuridae), and two “farmer damselfishes” (e.g. *Stegastes adustus, M. chrysurus* - Pomacentridae). Opportunistic carnivores which feed on small benthic invertebrates were represented by 10 species with a combined density of 18.2 Ind/30 m^2, or 35.5% of the total fish density. These included numerically dominant species, such as the bluehead wrasse (*T. bifasciatum*), blennies (*Ophioblennius atlanticus*), wrasses (*Halichoeres spp*), hawkfishes (Cirrhitidae), lizardfishes (Synodontidae), trumpetfishes (Aulostomidae) and small groupers and hamlets (Serranidae). Zooplanktivorous fishes were only represented within belt-transects by the blue chromis (*Chromis cyanea*) with a mean density of 1.4 Ind/30m^2. Schools of mackerel scad (*Decapterus macarellus*) have been previously reported to occur at GALL05 (Garcia-Sais et al., 2017 and references therein). These zooplanktivores serve as important forage species for larger predators, such barracudas (Sphyraenidae), jacks (Carangidae) and mackerels (Scombridae).

Table 21. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt- transects at GALL05, Cabo Rojo.

Survey Date: 6-7-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	18	15	12	8	16	**13.8**
Sparisoma viride	6	7	10	13	5	**8.2**
Microspathodon chrysurus	6	8	9	9	9	**8.2**
Stegastes adustus	8	7	5	7	3	**6.0**
Scarus iseri	0	15	0	5	0	**4.0**
Ophioblennius atlanticus	2	2	4	1	1	**2.0**
Chromis cyanea	0	2	0	1	4	**1.4**
Chaetodon capistratus	0	2	0	1	3	**1.2**
Scarus vetula	0	3	2	1	0	**1.2**
Acanthurus coeruleus	0	1	2	1	1	**1.0**
Amblycirrhitus pinos	1	0	1	0	1	**0.6**
Cephalopholis cruentata	0	0	1	0	2	**0.6**
Chaetodon striatus	1	0	0	1	0	**0.4**
Sparisoma aurofrenatum	0	1	0	0	1	**0.4**
Scarus taeniopterus	0	0	0	2	0	**0.4**
Sparisoma radians	0	0	0	2	0	**0.4**
Halichoeres radiatus	1	0	0	0	0	**0.2**
Pseudupeneus maculatus	0	0	1	0	0	**0.2**
Halichoeres garnoti	0	0	0	1	0	**0.2**
Aulostomus maculatus	0	0	0	0	1	**0.2**
Synodus intermedius	0	0	0	0	1	**0.2**
Hypoplectrus puella	0	0	0	0	1	**0.2**
Pomacanthus arcuatus	0	0	0	0	1	**0.2**
Total Individuals	43	63	47	53	50	**51.2**
Total Species	8	11	10	14	15	**11.6**
Invertebrates						
Diadema antillarum	1	0	1	0	0	**0.4**
Totals	1	0	1	0	0	**0.4**

Size distributions of commercially important fishes surveyed within 3 x 20m belt-transects are presented in Table 22. Recruitment stages of stoplight parrotfish (*Sparisoma viride*) were highly abundant indicative that GALL05 functions as an important recruitment habitat for this reef fish herbivore. Recruitment stage individuals of bucktooth parrotfish (*Sparisoma radians*) and blue tang (*Acanthurus coeruleus*) were also present. Both juvenile and adult parrotfishes and doctorfishes were present, including terminal phase males of *S. viride, Sparisoma rubripinne* and *Scarus vetula* indicative that this reef is also a residential habitat for these fishes. Adults of cero mackerel (*Scomberomorus regalis*) and yellowtail snapper (*Ocyurus chrysurus*) were observed within transects.

Table 22. Size-frequency distributions of commercially important fishes observed within 20 x 3m belt-transects at GALL05, Cabo Rojo. Survey date: 5-27-19.

					TRANSECTS				
		Size	Life		(Ind/60m^2)				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus coeruleus c1	Acanthuridae	1-5	Recruit	0	0	0	0	1	**0.2**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	0	0	2	0	3	**1.0**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	3	0	2	1	**1.2**
Cephalopholis cruentata c2	Serranidae	6-10	Juvenile	0	0	0	0	1	**0.2**
Cephalopholis cruentata c5	Serranidae	21-25	Adult	0	0	1	0	1	**0.4**
Ocyurus chrysurus c7	Lutjanidae	31-35	Adult	0	0	1	0	0	**0.2**
Scarus iseri c2	Scaridae	6-10	Juvenile	5	5	0	2	0	**2.4**
Scarus iseri c3	Scaridae	11-15	Juvenile	0	9	0	3	0	**2.4**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	6	0	0	4	0	**2.0**
Scarus taeniopterus c4	Scaridae	16-20	Adult	0	0	1	0	0	**0.2**
Scarus vetula c2	Scaridae	6-10	Juvenile	0	0	1	0	2	**0.6**
Scarus vetula c3	Scaridae	11-15	Juvenile	0	0	1	2	1	**0.8**
Scarus vetula c4	Scaridae	16-20	Adult	0	2	0	0	1	**0.6**
Scarus vetula c5	Scaridae	21-25	Adult	0	1	0	0	1	**0.4**
Scarus vetula c6	Scaridae	26-30	Adult	1	0	0	0	0	**0.2**
Scarus vetula c7	Scaridae	31-35	Adult	1	0	0	0	0	**0.2**
Scomberomorus regalis c10	Scaridae	46-50	Adult	0	0	0	0	1	**0.2**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	0	1	0	0	1	**0.4**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	0	1	0	0	**0.2**
Sparisoma radians c1	Scaridae	1-5	Recruit	0	0	2	2	0	**0.8**
Sparisoma rubripinne c7	Scaridae	31-35	Adult	0	0	0	1	0	**0.2**
Sparisoma viride c1	Scaridae	1-5	Recruit	3	5	6	9	4	**5.4**
Sparisoma viride c2	Scaridae	6-10	Juvenile	0	0	0	3	0	**0.6**
Sparisoma viride c3	Scaridae	11-15	Juvenile	2	1	0	1	0	**0.8**
Sparisoma viride c4	Scaridae	16-20	Adult	0		2	0	0	**0.4**
Sparisoma viride c6	Scaridae	26-30	Adult	2	1	1	0	0	**0.8**
Sparisoma viride c7	Scaridae	31-35	Adult	0	1	0	0	1	**0.4**
Totals				20	29	19	29	19	**23.2**

Statistically significant differences of fish density between monitoring surveys were found at GALL05 (ANOVA, $p < 0.0001$, Appendix 5). Differences were associated with the higher fish density measured in 2015 relative to other surveys. Higher densities of schooling zooplanktivorous fishes, such as brown and blue chromis (*Chromis multilineata, C. cyanea*), creole wrasse (*Clepticus parrae*), schooling bar jacks (*Carangoides ruber*), and bluehead wrasse (*Thalassoma bifasciatum*) were present in 2015 compared to other surveys. Differences of zooplankton biomass may be influencing the recruitment and replenishment of zooplanktivore fish

populations that have short generation times and that their abundances have been shown to vary independently from live coral cover and other benthic community attributes except depth, distance from shore and substrate rugosity (Esteves, 2013). Differences of fish species richness between monitoring surveys were not statistically significant (ANOVA; p = 0.556, Appendix 6). Fish density and species richness during 2019 fell within one standard deviation of the mean for both parameters. Additional surveys are needed to elucidate temporal patterns of fish abundance and species richness at this reef.

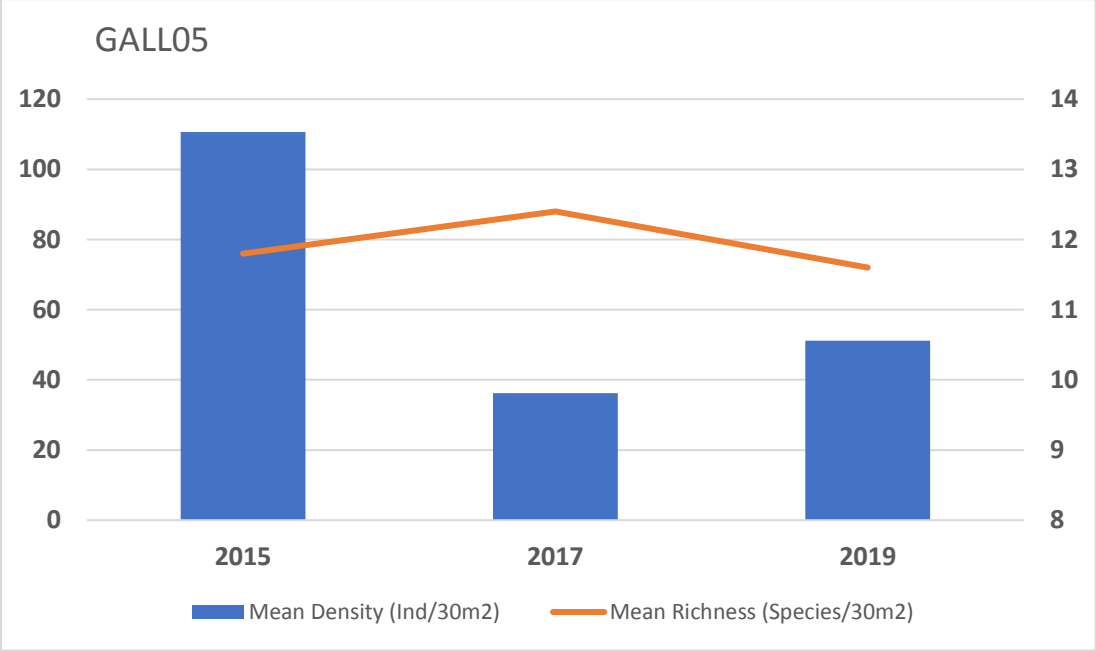
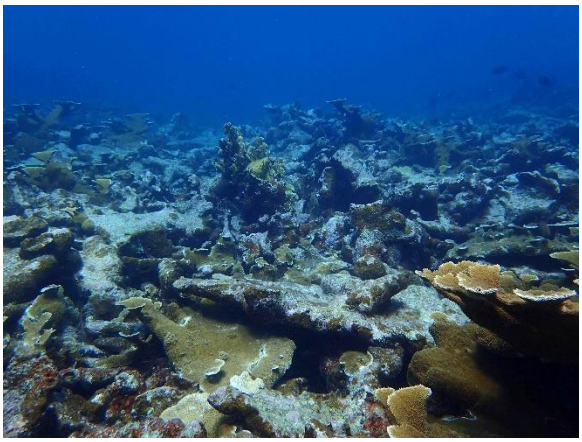
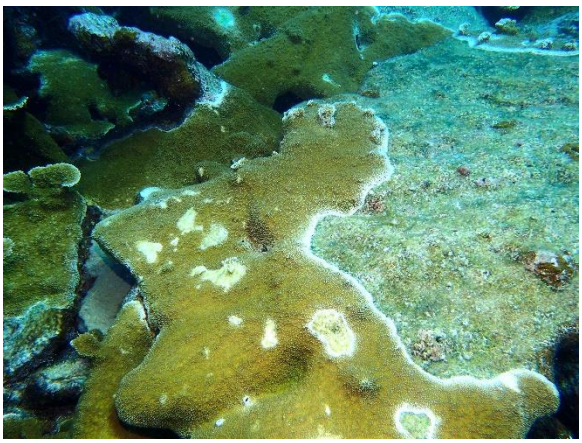
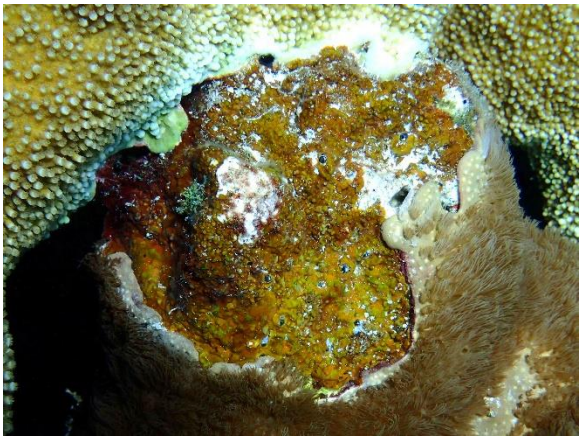


Figure 25. Monitoring trends (2013 – 2019) of mean fish density and species richness within 3x10m belt-transects at GALL05, Cabo Rojo.

7.4 Photo Album 7. GALL05







8. Resuellos Reef (RESU10)

8.1 Physical Description

Resuellos Reef (RESU10) is a hard-ground promontory located at about one nautical mile due west from Pta. Melones, Cabo Rojo (Figure 22). The reef emerges from a mostly flat platform covered by sandy-silt sediments at a depth of 12.0m to about 2.0m from the surface, where breakers form during events of heavy wave action. Hard and soft corals provide substantial topographic relief to the reef, particularly on the slopes. The top section of the reef is a hard-ground platform with scattered coral colonies and dense growth of soft corals. Very large colonies of elkhorn coral (*Acropora palmata*) were observed within this upper reef section in an advanced stage of degradation (e.g. mostly overgrown by turf algae). Some were still standing, while others were overturned and rested broken on the reef bottom. Our baseline survey was performed on the reef slope, close to the base of the reef during May 2000 (Garcia-Sais et al., 2001). Transects were installed following the 7-9m depth contour along the fore-reef slope. Panoramic views of RESU10 are presented in Photo Album 8.

8.2 Sessile-Benthic Reef Community

Soft corals were the most prominent feature of the sessile-benthic community at RESU10 with a mean of 19.6 erect Col/Transect and a reef substrate cover of 23.59% (Table 23). Some of the most abundant vertically projected species included *Antillogorgia acerosa* and *Eunicea spp*. The encrusting soft corals (*Briareum asbestinum* and *Erythropodium caribaeorum*) were present in five and four transects, respectively with a combined mean substrate cover of 23.45%. The encrusting colonial zoanthid (*Palythoa caribaeorum*) was intercepted by two transects with a mean cover off 0.67%.

Hard corals including 14 species intercepted by transects contributed a mean linear cover of 19.82% (range: 11.63 – 26.03%), with a mean density of 10.8 Col/Transect. Mountainous star coral (*Orbicella faveolata*) was the dominant coral species with a mean cover of 6.10%, representing 30.8% of the total cover by hard corals. Its sibling species, *O. franksi* was present in two transects with a mean cover of 2.27%, for a combined cover by the *Orbicella spp*. complex of 8.37% (Table 23). Blushing star coral (*Stephanocoenia intersepta*) and mustard-hill coral (*Porites astreoides*) were present in all five transects with a combined cover of 6.02%. A total of 54 hard coral colonies were intercepted by transects at RESU10. Two (2) *Siderastrea siderea* were observed to be apparently diseased at RESU10 (disease prevalence = 3.7%; Appendix 2).

Table 23. Percent reef substrate cover by sessile-benthic categories at RESU10, Cabo Rojo

RESU10	Transects					
Survey Date: June 7, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	6.97	7.48	8.48	7.88	8.48	**7.86**
Rugosity (m)	2.53	2.74	4.08	4.83	4.91	**3.82**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	8.72	11.10	12.82	6.61	10.33	**9.92**
Sand					2.25	**0.45**
Gaps/Holes		1.76				**0.35**
Total Abiotic	8.72	12.86	12.82	6.61	12.58	**10.72**
Benthic Algae						
Turf (mixed) with sediment	28.72	40.44	38.87	35.32	28.08	**34.28**
Dictyota spp.		3.85	1.49	0.94		**1.26**
Turf (mixed)	0.11			2.36		**0.49**
CCA (mixed)			0.80			**0.16**
Gracilaria spp.	0.67					**0.13**
Peyssonnelia spp.			0.10	0.47		**0.11**
Total Benthic Algae	29.50	44.29	41.25	39.09	28.08	**36.44**
Cyanobacteria	0.67	0.00	0.00	0.00	0.00	**0.13**
Hard Coral						
Orbicella faveolata	10.39	6.37		2.27	11.46	**6.10**
Stephanocoenia intersepta	1.34	6.04	7.26	0.28	3.47	**3.68**
Porites astreoides	2.23	2.75	2.19	2.27	2.25	**2.34**
Orbicella franksi	7.60			3.78		**2.27**
Colpophyllia natans		2.64		5.67	2.82	**2.22**
Montastraea cavernosa	2.23		1.19		0.56	**0.80**
Meandrina meandrites			0.99		2.82	**0.76**
Mycetophyllia ferox		3.19				**0.64**
Pseudodiploria strigosa					1.50	**0.30**
Millepora alcicornis	1.01					**0.20**
Agaricia agaricites		0.99				**0.20**
Siderastrea siderea	0.89					**0.18**
Diploria labyrinthiformis	0.34					**0.07**
Porites porites		0.33				**0.07**
Total Hard Coral	26.03	22.31	11.63	14.26	24.88	**19.82**
# Coral Colonies/Transect	8	15	11	5	15	**10.8**
# Diseased Coral Colonies/Transect	0	0	1	0	1	**0.40**
Zoanthids						
Palythoa caribaeorum	2.01	1.32				**0.67**
Soft Corals						
Briareum asbestinum	20.45	5.16	18.99	29.65	19.53	**18.76**
Erythropodium caribaeorum	5.47	7.03	9.05	1.89		**4.69**

RESU10	Transects					
Survey Date: June 7, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Antillogorgia acerosa				0.38		**0.08**
Eunicea spp. (unidentified)					0.38	**0.08**
Total Soft Corals	25.92	12.20	28.03	31.92	19.91	**23.59**
# Soft Coral Colonies/Transect	21	14	26	16	21	**19.6**
Sponges						
Niphates erecta	1.56	0.44	1.49	1.32	1.97	**1.36**
Mycale laevis	1.01	2.20	0.99	0.57	1.22	**1.20**
Aplysina cauliformis		0.55	1.19		4.04	**1.16**
Monanchora arbuscula	0.78	0.55	0.70	1.32	2.16	**1.10**
Chondrilla caribensis	3.24		0.40		1.50	**1.03**
Aplysina fistularis		0.66		2.55	0.75	**0.79**
Plakortis spp.	0.34	1.10	0.30	0.28	0.19	**0.44**
Agelas citrina		1.10			0.66	**0.35**
Ircinia felix			0.80		0.66	**0.29**
Dysidea etheria	0.22	0.22			0.38	**0.16**
Ircinia strobilina			0.20		0.38	**0.11**
Neopetrosia spp. smooth				0.47		**0.09**
Amphimedon compressa					0.38	**0.08**
Aplysina fulva				0.28		**0.06**
Sponge spp.					0.28	**0.06**
Iotrochota arenosa		0.22				**0.04**
Clathria spp. (unidentified)			0.20			**0.04**
Ircinia spp. brown				0.19		**0.04**
Total Sponges	7.15	7.03	6.26	6.99	14.55	**8.40**
Others						
Lebrunia neglecta				0.94		**0.19**
Ascidian spp.				0.19		**0.04**

Sponges were also prominent components of the sessile-benthic community at RESU10 with at least 18 species intercepted by transects and a mean linear cover of 8.40%. Small erect, branching and encrusting colonies were the prevailing growth types observed. *Niphates erecta*, *Mycaele laevis, Aplysina cauliformis, Monachora arbuscula* and *Chondrilla caribensis,* comprised the main taxonomic assemblage with a combined cover of 5.85%, representative of 69.6% of the total cover by sponges at RESU10. Reef overhangs largely associated with massive and laminar coral growth were the main contributor of abiotic cover with a mean of 9.92% and also contributed to a mean reef rugosity of 3.82m (Table 23).

Turf algae packed with fine sediments was the main component of the benthic algae assemblage with a mean substrate cover of 34.28% at RESU10, representative of 94.1% of the total cover by benthic algae. Fleshy brown macroalgae (*Dictyota sp*) were intercepted by three transects with a mean cover of 1.26%. Crustose red (*Peyssonnelia sp*), fleshy red (*Gracilaria sp*) and coralline (CCA mixed) algae were present in low cover (< 1%) at RESU10.

Variations of the mean substrate cover by reef sessile-benthic categories of RESU10 during the baseline survey in 2001 and subsequent monitoring surveys are shown in Figure 26. The first monitoring survey of this reef was performed more than a decade after the baseline survey (Garcia-Sais et al., 2001). A mild reduction of live coral cover was measured in 2013, but such difference was not statistically significant (Garcia-Sais et al., 2014). Most of the difference was associated with the loss of reef substrate cover by boulder brain coral (*Colpophyllia natans*) from an initial cover of 5.86% down to 0% (Figure 27). Boulder star coral (*Orbicella annularis* complex), which suffered the most acute mortality during and after the 2005 regional coral bleaching event in many reefs included in the PRCRMP did not show any statistically significant loss of live coral cover between dates. An increasing trend of hard coral cover was observed at RESU10 until the 2017 monitoring survey. During the 2019 survey a small (statistically insignificant) reduction (-7.6%) of cover by hard corals was measured.

Because of the relatively shallow depth, strong prevailing wind energy and soft sediments at its base, RESU10 is typically impacted by inorganic turbidity caused by suspended sediments. It is possible that such turbid conditions may have been instrumental in protecting corals from the bleaching effects of the 2005 event, which appears to have been triggered not only by the increased sea surface temperatures, but by the synergistic effects of UV radiation, as suggested by the most acute effects exhibited by corals from reefs in clear waters (Garcia-Sais et al, 2017). The most relevant change in reef benthic community structure was a statistically significant decline in the number of erect soft corals (gorgonians) intercepted by transects, from a mean of 44.6 Col/Transect in 2015 to 24.2 Col/Transect during 2017 (ANOVA, $p < 0.0001$, Appendix 4). Such drastic decline may be related to mechanical detachment and mortality associated with extreme surge conditions prevailing during the pass of Hurricane Matthew close to the south coast of PR during October 2016. Likewise, strong wave action associated with the pass of hurricanes Irma and/or Maria in September 2017 and/or winter storm Riley in March 2018 may be have influenced the 19.0% decline of soft coral colonies from the previous density measured in the 2017 survey at RESU10.

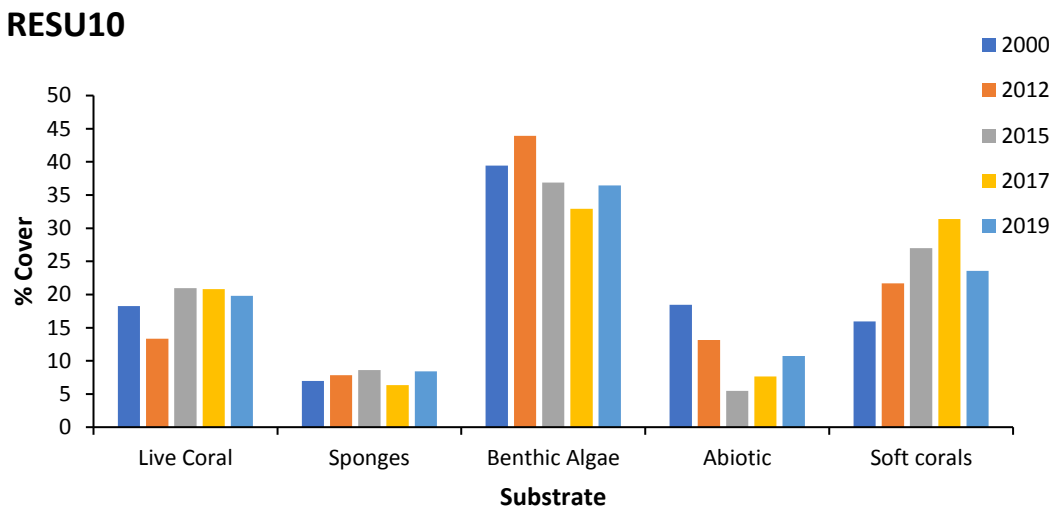


Figure 26. Monitoring trends (2000 – 2019) of mean substrate cover by sessile-benthic categories at RESU10, Cabo Rojo.

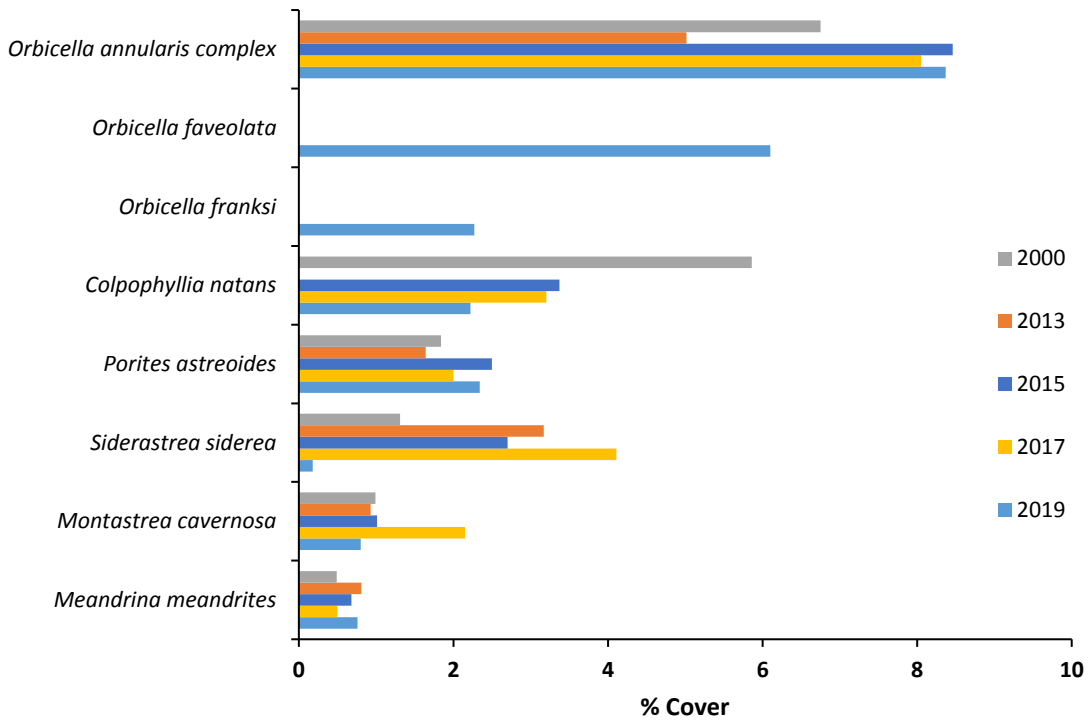


Figure 27. Monitoring trends (2000 – 2019) of mean substrate cover by hard coral species at RESU10, Cabo Rojo. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

8.3 Fishes and Motile Megabenthic Invertebrates

A total of 27 fish species and one megabenthic invertebrate were present within belt-transect at RESU10 during the 2019 survey with a mean density of 20.8 Ind/30m^2 (range: 16 - 32 Ind/30 m^2) and a mean species richness of 12.2 SPP/30m^2 (Table 24). The numerically dominant fish assemblage included the striped, redband and stoplight parrotfishes (*Scarus iseri, Sparisoma aurofrenatum, S. viride*), sharknose goby (*Elacatinus sp*), squirrelfish (*Holocentrus rufus*), beaugregory (*Stegastes leucostictus*) and bluehead wrasse (*Thalassoma bifasciatum*).

Small opportunistic carnivores and herbivore fishes prevailed within belt-transects at RESU10 during the 2019 survey. Herbivores included parrotfishes (Scaridae - 5 species), doctorfishes (Acanthuridae – 2 species) and “farmer damselfishes” (Pomacentridae – 2 species). The combined herbivorous assemblage represented approximately 46.7% of the total individuals within belt-transects. Opportunistic carnivores which feed on small benthic invertebrates and fishes were represented within belt-transects by 13 species with a combined density of 8.6 Ind/30m^2 representative of 40.9% of the total fish density. The assemblage included wrasses (Labridae), hamlets and small groupers (Serranidae), gobies (Gobiidae), squirrelfishes (Holocentridae), and one trumpetfish (Aulostomidae). Zooplanktivores were represented by two species (*Coryphopterus personatus, Gramma loreto*) with a combined density of 0.6 Ind/30m^2 representative of 2.8% of the total fish density. Spongivores (Pomacanthidae) and corallivores (Chaetodontidae) were represented by three species, representative of 6.7% of the total fish density at RESU10. Red hinds (*Epinephelus guttatus*), hogfish (*Lachnolaimus maximus*), yellowtail, schoolmaster and dog Snappers (*Ocyurus chrysurus, Lutjanus apodus, L. jocu*) represented the main demersal top predator component observed in the 2019 survey. Mutton and cubera snappers, cero mackerel and great barracudas are also top predators that have been previously reported at RESU10 (Garcia-Sais et al., 2017).

Parrotfishes (Scaridae) were present in their full-size range, including recruitment juvenile stages of *Scarus iseri* and *Sparisoma viride* and terminal phase male stages of *Scarus taeniopterus*. Recruitment and juvenile stages of doctorfishes were also observed within belt-transects at RESU10 during 2019. Snappers (*Ocyurus chrysurus, Lutjanus spp*), red hind (*Epinephelus guttatus*), and hogfish (*Lachnolaimus maximus*) were only present as adults (Table 25). Temporal variations of fish abundance and species richness between monitoring surveys (Figure 28) have been relatively small and statistically insignificant (ANOVA $p > 0.05$; Appendix 5-6).

Table 24. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at RESU10, Cabo Rojo.

Survey Date: 6-7-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Scarus iseri	5	4	0	5	0	**2.8**
Elacatinus evelynae	1	2	3	3	2	**2.2**
Holocentrus rufus	2	2	1	2	2	**1.8**
Sparisoma aurofrenatum	2	0	2	3	1	**1.6**
Stegastes leucostictus	1	2	1	3	1	**1.6**
Thalassoma bifasciatum	0	1	0	5	2	**1.6**
Sparisoma viride	1	0	0	3	2	**1.2**
Stegastes planifrons	3	0	1	0	0	**0.8**
Chaetodon capistratus	1	1	2	0	0	**0.8**
Acanthurus chirurgus	0	1	0	3	0	**0.8**
Ocyurus chrysurus	1	1	1	0	0	**0.6**
Scarus taeniopterus	0	1	0	2	0	**0.6**
Hypoplectrus unicolor	0	0	2	0	1	**0.6**
Hypoplectrus chlorurus	0	0	1	1	1	**0.6**
Aulostomus maculatus	1	0	0	1	0	**0.4**
Pomacanthus arcuatus	0	1	0	1	0	**0.4**
Coryphopterus personatus	0	0	0	0	2	**0.4**
Myripristis jacobus	1	0	0	0	0	**0.2**
Acanthurus tractus	0	1	0	0	0	**0.2**
Haemulon aurolineatum	0	1	0	0	0	**0.2**
Halichoeres garnoti	0	1	0	0	0	**0.2**
Sparisoma rubripinne	0	0	1	0	0	**0.2**
Odontoscion dentex	0	0	1	0	0	**0.2**
Holacanthus ciliaris	0	0	0	0	1	**0.2**
Diodon hystrix	0	0	0	0	1	**0.2**
Gramma loreto	0	0	0	0	1	**0.2**
Cephalopholis cruentata	0	0	0	0	1	**0.2**
Total Individuals	19	19	16	32	18	**20.8**
Total Species	11	13	11	13	13	**12.2**
Invertebrates						
Mithrax spinosissimus	0	0	0	1	0	**0.2**
Totals	0	0	0	1	0	**0.2**

Table 25. Size-frequency distributions of commercially important fishes observed within 20 x 3m belt-transects at RESU10, Survey date: 6-7-19.

					TRANSECTS				
		Size			(Ind/60m^2)				
Species	**Family**	**Range (cm)**		**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c1	Acanthuridae	1-5	Recruit	0	1	0	1	0	**0.4**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	0	0	0	1	1	**0.4**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	0	1	0	0	**0.2**
Acanthurus tractus c1	Acanthuridae	1-5	Recruit	0	1	0	0	0	**0.2**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	0	2	0	0	0	**0.4**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	0	0	1	0	0	**0.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	0	0	0	0	1	**0.2**
Cephalopholis cruentata c5	Serranidae	21-25	Adult	0	0	0	1	0	**0.2**
Epinephelus guttatus c7	Serranidae	31-35	Adult	0	0	0	0	1	**0.2**
Lachnolaimus maximus c10	Labridae	46-50	Adult	0	0	0	1	0	**0.2**
Lutjanus apodus c6	Lutjanidae	26-30	Adult	1	0	0	0	0	**0.2**
Lutjanus jocu c6	Lutjanidae	26-30	Adult	0	0	0	0	1	**0.2**
Lutjanus jocu c8	Lutjanidae	36-40	Adult	0	0	0	0	1	**0.2**
Ocyurus chrysurus c2	Lutjanidae	6-10	Juvenile	0	1	1	0	0	**0.4**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	0	1	0	0	0	**0.2**
Ocyurus chrysurus c5	Lutjanidae	21-25	Adult	1	0	0	1	0	**0.4**
Scarus iseri c1	Scaridae	1-5	Recruit	0	0	0	5	0	**1.0**
Scarus iseri c2	Scaridae	6-10	Juvenile	5	4	0	0	0	**1.8**
Scarus iseri c3	Scaridae	11-15	Juvenile	1	0	0	0	0	**0.2**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	0	0	0	1	0	**0.2**
Scarus taeniopterus c5	Scaridae	21-25	Adult	0	1	0	0	0	**0.2**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	2	0	0	0	0	**0.4**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	0	0	1	1	0	**0.4**
Sparisoma aurofrenatum c5	Scaridae	21-25	Adult	0	0	2	0	1	**0.6**
Sparisoma aurofrenatum c6	Scaridae	26-30	Adult	0	0	0	1	0	**0.2**
Sparisoma rubripinne c6	Scaridae	26-30	Adult	0	0	1	0	0	**0.2**
Sparisoma viride c1	Scaridae	1-5	Recruit	0	0	0	1	2	**0.6**
Sparisoma viride c3	Scaridae	11-15	Juvenile	1	1	0	0	0	**0.4**
Sparisoma viride c5	Scaridae	21-25	Adult	0	1	0	1	0	**0.4**
Sparisoma viride c6	Scaridae	26-30	Adult	0	0	0	1	0	**0.2**
Totals				11	13	7	16	8	**11.0**

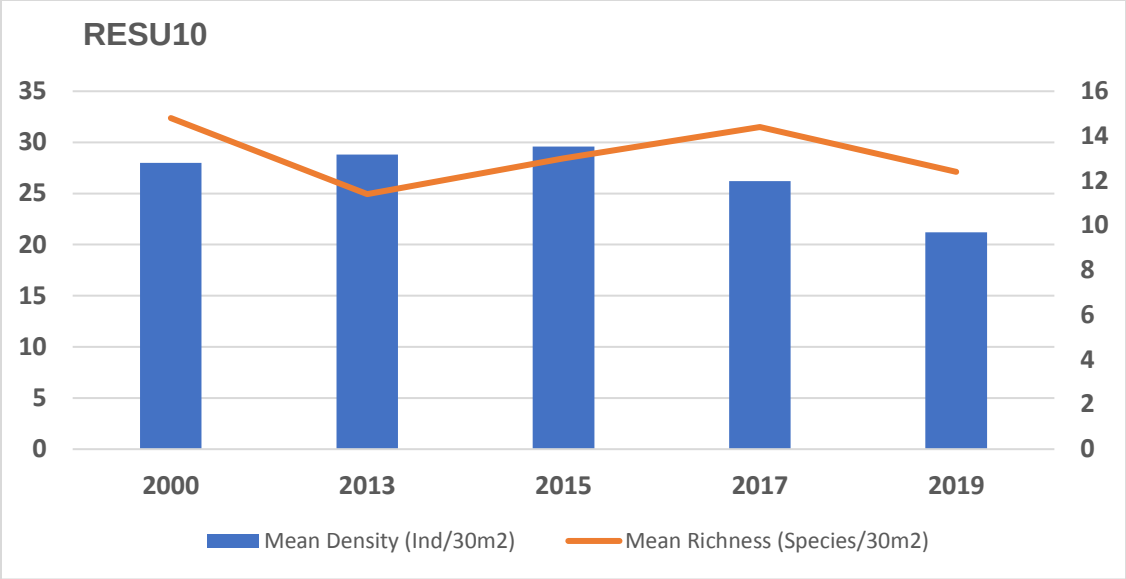
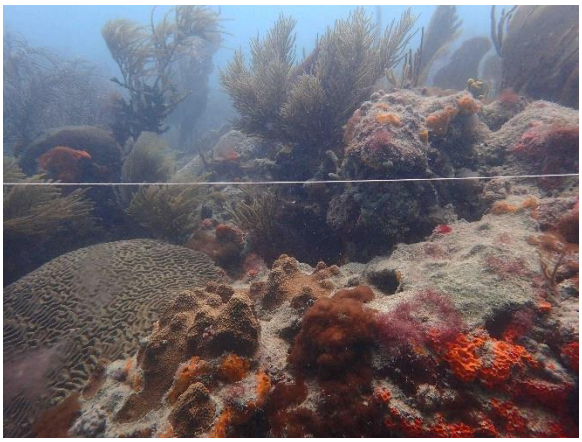
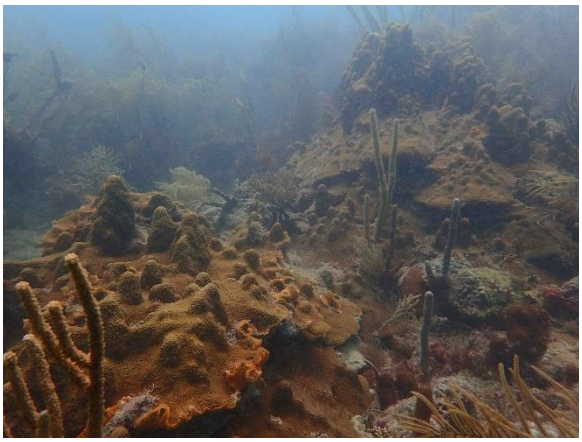
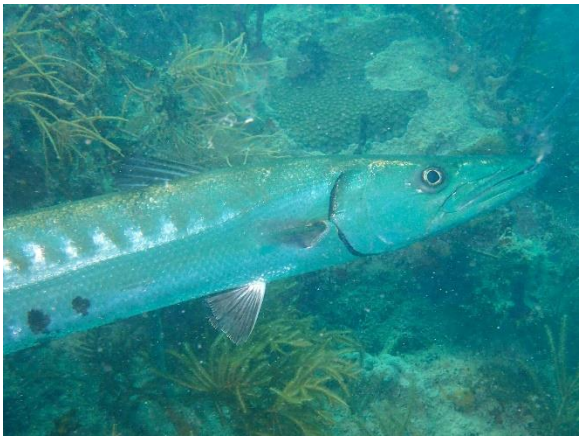


Figure 28. Monitoring trends (2000 – 2019) of mean fish density and species richness within 3x10m belt-transects at RESU10, Cabo Rojo.

8.4 Photo Album 8. RESU10







9. Boya Vieja 20m (BOYA20)

9.1 Physical Description

La Parguera Natural Reserve was designated in 1979 and amended in 1998 to expand its marine boundaries. Its total surface area includes 12,638 acres (DRNA, 1999). It is located due east of Cabo Rojo on the southwest coast. The insular shelf is one of the broadest in Puerto Rico extending up to 6 nautical miles offshore. There is an extensive coral reef system bordering the shelf-edge, a chain of emergent reefs near mid-shelf that run parallel to the coastline, and an interior set of fringing reefs. Mixed seagrass beds are typically associated with the backreef zones of the main emergent coral reefs (Garcia-Sais and Sabater-Clavell, 2004).

BOYA20 is a section of the extensive coral reef system fringing the shelf-edge off La Parguera, submerged at depths of 17 – 22m (Figure 29). The coral reef is largely a spur and groove formation with spurs that reach 3 – 4m in height separated by coralline sand channels of variable width dimensions. The shelf -edge exhibits an abrupt slope with coral development along the edge and down the upper insular slope. The initial baseline characterization at BOYA20 was performed in 2000 by Garcia Sais et al. (2001b), but no further monitoring observations were made at this reef station. A new baseline characterization of BOYA20 was produced in 2015 (Garcia-Sais et al., 2015). Our set of five transects were set at depths between 17.9 – 18.5m on top of spurs at both sides of the buoy block. A general photographic documentation of BOYA20 system is presented as Photo Album 9.

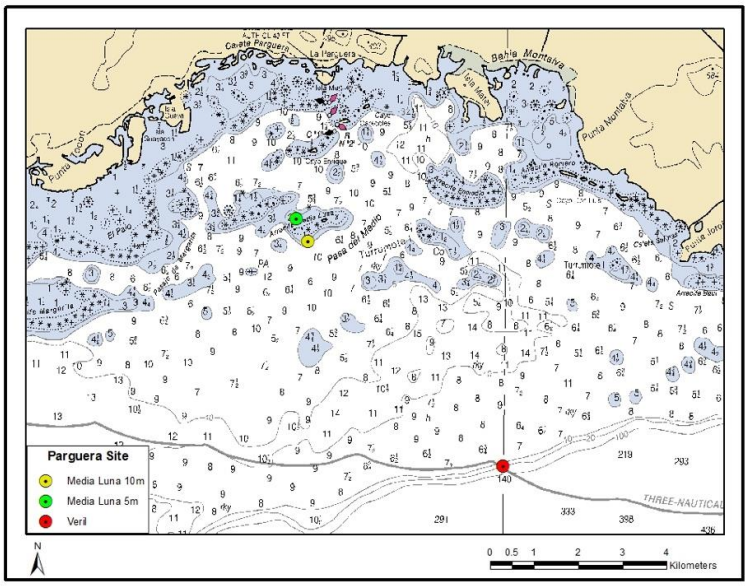


Figure 29. Location of reefs surveyed within the La Parguera Natural Reserve

9.2 Sessile-Benthic Reef Community

Benthic algae, comprised by a mixed assemblage of fleshy brown macroalgae, turf algae and crustose coralline algae were the dominant category in terms of reef substrate cover at BOYA20 with a combined mean of 61.77% (range: 52.88 – 68.06%). The encrusting fan-leaf alga (*Lobophora variegata*), turf algae (mixed assemblage), y-twig alga (*Dictyota sp*.) and red crustose coralline algae (CCA) were intercepted by all five transects overgrowing many dead massive coral sections of the reef (Table 26). Tufts of calcareous green algae (*Halimeda spp*.) were intercepted by three transects with a mean cover of 0.21%. Small cyanobacteria patches were present in all five transects with a mean substrate cover of 2.48%.

A total of 15 hard corals species were intersected by line transects from BOYA20 during 2019 with a mean substrate cover of 24.24% (range: 18.21 – 37.18%) and a mean density of 14.0 Col/Transect (Table 26). Hard corals occurred as massive, encrusting and mound shaped colonies. Mountainous star coral (*Orbicella faveolata*) was the dominant species in terms of substrate cover with a mean of 6.94% (range: 3.13 – 12.30%), representing 28.6% of the total cover by hard corals. Its sibling species, *O. franksi* and *O. annularis* were also intercepted by transects resulting in a combined cover by the *Orbicella spp.* complex of 13.6%, representative of 56.1% of the total cover by live hard corals. Mustard-hill coral (*Porites astreoides*) and lettuce coral (*Agaricia agaricites*) were present in all five transects and along with the *Orbicella spp* complex comprised the main hard coral assemblage at BOYA20 (Table 26). A total of 70 live hard coral colonies were intercepted by transects, including one diseased *Siderastrea siderea* colony for a coral disease prevalence of 1.4% at BOYA20 (Appendix 2).

Erect soft corals were a prominent component of the BOYA20 benthic community with a mean density of 8.8 Col/Transect and a mean reef substrate cover of 1.92% (Table 26). Erect soft corals were present in a variety of sizes, including large and lush colonies that contributed substantially to the overall reef topographic relief and habitat complexity. The main species in terms of reef substrate cover were the encrusting species, *Briareum asbestinum* and *Erythropodium caribaeorum*. Sea Fans (*Gorgonia ventalina*) and Sea Rods (*Eunicea spp.*) were the most common erect growth forms. Sponges represented in transects by 15 species contributed a mean reef substrate cover of 6.64%. *Cliona caribbaea, Xestospongia muta, Agelas dispar* and *A. conifera* comprised the main sponge assemblage in terms of reef substrate cover.

Table 26. Percent reef substrate cover by sessile-benthic categories at BOYA20. La Parguera

BOYA20	Transects					
Survey Date: June 14, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	17.88	17.88	18.18	18.18	18.48	**18.12**
Rugosity (m)	1.93	2.99	3.76	3.66	2.98	**3.07**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang		3.77	4.37	1.43	2.48	**2.41**
Sand		2.16				**0.43**
Total Abiotic	0.00	5.93	4.37	1.43	2.48	**2.84**
Benthic Algae						
Lobophora spp.	38.49	36.10	35.20	46.00	41.32	**39.42**
Turf (mixed)	9.47	14.55	19.63	10.86	15.53	**14.01**
Dictyota spp.	3.12	1.19	8.55	7.99	4.96	**5.16**
CCA (mixed)	1.20	2.16	3.05	0.82	2.05	**1.86**
Turf (mixed) with sediment		3.23				**0.65**
Peyssonnelia spp.			1.42			**0.28**
Halimeda spp.			0.20	0.20	0.65	**0.21**
Macroalgae spp. (mixed)	0.60				0.32	**0.18**
Total Benthic Algae	52.88	57.22	68.06	65.88	64.83	**61.77**
Cyanobacteria	2.40	1.29	1.53	2.87	4.31	**2.48**
Hard Coral						
Orbicella faveolata	10.19	3.13	4.98	4.10	12.30	**6.94**
Porites astreoides	8.99	0.32	2.34	8.40	4.42	**4.90**
Orbicella franksi	6.00	4.74	3.97	4.61	1.94	**4.25**
Orbicella annularis	5.16	5.06		1.84		**2.41**
Agaricia agaricites	0.60	1.83	1.02	2.15	1.29	**1.38**
Siderastrea siderea	1.32		3.46	1.02	0.43	**1.25**
Porites porites	1.20	0.86		2.97		**1.01**
Diploria labyrinthiformis	1.68	0.97				**0.53**
Madracis decactis	1.44			0.41		**0.37**
Montastraea cavernosa			0.92	0.72		**0.33**
Dendrogyra cylindrus			1.53			**0.31**
Agaricia lamarcki		1.40				**0.28**
Pseudodiploria strigosa		0.65				**0.13**
Millepora alcicornis	0.60					**0.12**
Porites furcata		0.22				**0.04**
Total Hard Coral	37.18	19.18	18.21	26.23	20.39	**24.24**
# Coral Colonies/Transect	22	8	10	16	14	**14.0**
# Diseased Coral Colonies/Transect	0	0	0	1	0	**0.2**
Soft Corals						
Briareum asbestinum	0.84	2.69	0.31	1.95	0.22	**1.20**
Erythropodium caribaeorum		0.65	1.32		1.08	**0.61**
Gorgonia ventalina	0.36					**0.07**
Eunicea spp.					0.22	**0.04**
Total Soft Corals	1.20	3.34	1.63	1.95	1.51	**1.92**
# Soft Coral Colonies/Transect	8	5	16	5	10	**8.8**
Sponges						
Cliona caribbaea		6.47	3.97		3.13	**2.71**
Xestospongia muta	5.16					**1.03**
Agelas dispar	1.20	0.54			2.05	**0.76**

BOYA20			Transects			
Survey Date: June 14, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Agelas conifera	0.60		1.63	0.20		**0.49**
Neopetrosia spp. smooth	0.36			1.23	0.65	**0.45**
Agelas citrina		1.40				**0.28**
Ircinia strobilina	1.08					**0.22**
Agelas clathrodes		0.75				**0.15**
Sponge spp.				0.20	0.43	**0.13**
Mycale laevis		0.54				**0.11**
Niphates erecta	0.24				0.22	**0.09**
Agelas sventres			0.41			**0.08**
Agelas spp.		0.32				**0.06**
Ectyoplasia ferox		0.22				**0.04**
Scopalina ruetzleri			0.20			**0.04**
Total Sponges	8.63	10.24	6.21	1.64	6.47	**6.64**
Others						
Trididemnum solidum		2.80				**0.56**

Major changes of reef benthic community structure are evident at BOYA20 since the original baseline survey of 2000, when a total of 18 species were intercepted by transects with a total live coral cover of 41.19% (Garcia-Sais et al, 2001b). During 2015, the new baseline survey performed in the same reef locality and depths yielded a live coral cover of 19.6% that represents a decline of 52.42% of reef substrate cover over a period of 15 years. Likewise, the reduction of coral species intercepted by transects from 18 to 11 is also indicative of a major deterioration of benthic community structure associated with loss of coral species richness. The magnitude of live coral loss at BOYA20 was similar to the pattern exhibited by other shelf-edge reefs in the south coast, such as DERR20, and of reefs at oceanic islands such as Mona (MUJE20) and Desecheo (CANO20) at similar depths after the 2005 regional coral bleaching event (Garcia-Sais et al., 2007, 2008, 2014, 2015 and references therein).

Since the 2015 baseline, reef substrate cover by hard corals has maintained a mild but consistent pattern of increase reaching now at 24.24%, an overall increment of 23.67% relative to the 2015 baseline. (Figure 30), a difference that although statistically insignificant, may be revealing a recuperation trend that has been measured in other reefs of the south and west coasts of Puerto Rico (Garcia-Sais et al., 2016; Garcia-Sais et al., 2017 and references therein). The increasing trend of live coral cover at BOYA20 was associated with an 16.14% increase of reef substrate cover by *Orbicella spp*. relative to the 2015 baseline (Figure 31).

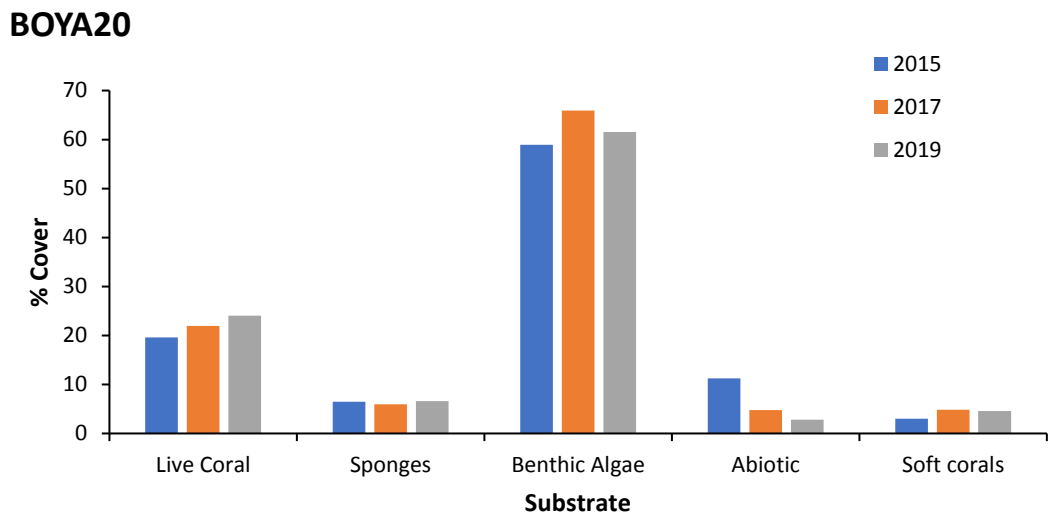


Figure 30. Monitoring trends (2015 – 2019) of mean substrate cover by sessile-benthic categories at BOYA20, La Parguera.

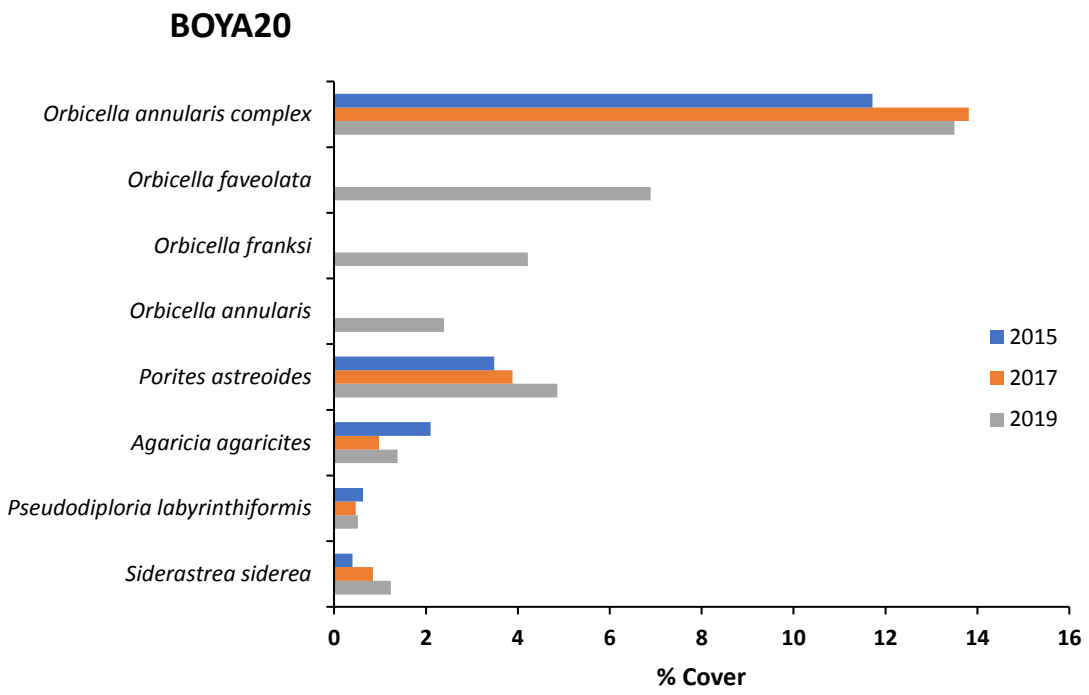


Figure 31. Monitoring trends (2015 – 2019) of mean substrate cover by hard coral species at BOYA20, La Parguera. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

9.3 Fishes and Motile Megabenthic Invertebrates

A total of 36 fish species were identified within belt-transects from BOYA20 during the 2019 monitoring survey with a mean density of 69.6 Ind/30m^2 (range: 65 – 76 Ind/30 m^2) and a mean species richness of 18.2 Spp/Transect (Table 27). The bluehead wrasse (*Thalassoma bifasciatum*) and the blue chromis (*Chromis cyanea*) were the numerically dominant species with a combined density of 25.0 Ind/30m^2, representative of 35.9% of the total individuals within belt-transects. Another seven species were present in at least four transects. These included the peppermint and sharknose gobies (*Coryphopterus lipernes, Elacatinus evelynae*), bicolor damselfish (*Stegastes partitus*), striped and redband parrotfishes (*Scarus iseri, Sparisoma aurofrenatum*) and the yellowhead wrasse (*Halichoeres garnoti*). Motile megabenthic invertebrates were not observed within belt-transects during the 2019 monitoring survey.

Small opportunistic carnivores were the most specious and abundant fish trophic assemblage at BOYA20 with a total of 14 species and a combined density of 32.2 Ind/30m^2, representative of 46.3% of the total individuals within belt-transects. The assemblage included wrasses (Labridae), gobies (Gobiidae), squirrelfishes (Holocentridae), grunts (Haemulidae), small groupers and hamlets (Serranidae), puffers (Tetraodontidae) and trumpetfish (Aulostomidae). Zooplanktivores were represented by six species, including damselfishes (*Chromis cyanea, C. multilineata, S. partitus, Abudefduf saxatilis*), gobies (*C. personatus*) and wrasses (*Clepticus parrae*) with a combined density of 22.4 Ind/30m^2, or 32.1% of the total density. Herbivores were represented by parrotfishes (Scaridae), doctorfishes (Acanthuridae) and damselfishes (Pomacentridae) with a combined density of 12.6 Ind/30m^2 or 18.1% of the total individuals. Corallivores (*Chaetodon spp*.) and spongivores (*Holacanthus ciliaris*) were also present within belt-transects in low densities. Larger invertebrate and fish predators (piscivores) included the red hind (*Epinephelus guttatus*) and the yellowtail snapper (*Ocyurus chrysurus*) observed in 20 x 3m belt-transects (Table 28). Hogfish (*Lachnolaimus maximus*), schoolmaster, cubera, and dog snappers, *(Lutjanus apodus, L. cyanopterus, L. jocu*) were observed outside transects and represent some of the larger demersal predators of the reef system. Pelagic predators are also important components of the BOYA20 reef community. Some of these include the great barracuda (*Sphyraena barracuda*), amberjacks (*Seriola spp*), mackerels (*Scomberomorus spp*), wahoo (*Acanthosybium solandri*), and dolphinfish (*Coryphaena spp*) (Garcia-Sais et al., 2017).wahoo (*Acanthosybium solandri*), and dolphinfish (*Coryphaena spp*).

Table 27. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt- transects at BOYA20, La Parguera.

Survey Date: 6-14-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	12	17	6	17	11	**12.6**
Chromis cyanea	14	15	14	5	14	**12.4**
Coryphopterus lipernes	16	3	8	11	2	**8.0**
Stegastes partitus	6	7	5	10	9	**7.4**
Elacatinus evelynae	6	2	5	3	7	**4.6**
Scarus iseri	6	0	2	7	1	**3.2**
Halichoeres garnoti	2	3	3	2	2	**2.4**
Sparisoma aurofrenatum	3	0	3	2	2	**2.0**
Scarus taeniopterus	1	2	3	1	2	**1.8**
Chromis multilineata	0	4	0	0	3	**1.4**
Melichthys niger	1	0	4	0	1	**1.2**
Sparisoma viride	0	3	2	1	0	**1.2**
Coryphopterus sp.	0	6	0	0	0	**1.2**
Clepticus parrae	0	0	6	0	0	**1.2**
Haemulon flavolineatum	1	2	0	1	1	**1.0**
Stegastes leucostictus	0	1	0	2	2	**1.0**
Cephalopholis cruentata	1	1	0	0	2	**0.8**
Sparisoma radians	0	1	1	2	0	**0.8**
Chaetodon ocellatus	2	0	1	0	0	**0.6**
Acanthurus tractus	1	0	0	1	1	**0.6**
Chaetodon capistratus	0	0	2	1	0	**0.6**
Acanthurus chirurgus	1	0	0	0	1	**0.4**
Canthigaster rostrata	0	1	0	0	1	**0.4**
Ocyurus chrysurus	0	0	1	1	0	**0.4**
Epinephelus guttatus	1	0	0	0	0	**0.2**
Sargocentron coruscum	1	0	0	0	0	**0.2**
Halichoeres maculipinna	1	0	0	0	0	**0.2**
Microspathodon chrysurus	0	1	0	0	0	**0.2**
Hypoplectrus puella	0	1	0	0	0	**0.2**
Acanthurus coeruleus	0	0	1	0	0	**0.2**
Cantherhines pullus	0	0	1	0	0	**0.2**
Neoniphon marianus	0	0	0	1	0	**0.2**
Aulostomus maculatus	0	0	0	1	0	**0.2**
Holacanthus ciliaris	0	0	0	0	1	**0.2**
Bodianus rufus	0	0	0	0	1	**0.2**
Abudefduf saxatilis	0	0	0	0	1	**0.2**
Total Individuals	76	70	68	69	65	**69.6**
Total Species	18	17	18	18	20	**18.2**
Invertebrates						
none observed						

The size frequency distribution of fishes of commercial value observed within belt-transects at BOYA20 is presented in Table 28. Parrotfishes (Scaridae) were represented by five species, mostly present as juvenile and/or adults, including recruitment juvenile stages of the stoplight and striped parrotfishes (*Sparisoma viride, Scarus iseri*). Terminal-phase males of *S. iseri, S. taeniopterus* and *S. viride* were present. Likewise, doctorfishes (Acanthuridae) were represented by the three known species in Puerto Rico as juveniles and/or adults, including the recruitment juvenile stages of *Acanthurus chirurgus* and *A. tractus* (Table 28). These data show that BOYA20 functions as a recruitment and residential habitat for a variety of species within these important fish herbivore families. Adult stages of mid-size demersal predators, such as the yellowtail snapper (*Ocyurus chrysurus*) and red hind (*E. guttatus*) were also observed within belt-transects.

Variations of mean fish density species richness between monitoring surveys are presented in Figure 32. Significant differences of fish density between surveys were evidenced between the 2015 baseline and the 2017 monitoring survey (ANOVA, $p = 0.006$, Appendix 5). Differences were largely related to the higher density of schooling zooplanktivore species (e.g. *Chromis cyanea, Clepticus parrae, Stegastes partitus*) during the baseline survey compared to the 2017 survey. Density fluctuations of these small zooplanktivore species have been shown to be mostly regulated by density-independent factors, including physical conditions at the time of survey (Estevez, 2013) and more observations are needed to determine if these variations are associated to changes of habitat quality and/or productivity. Differences of species richness were not statistically significant (ANOVA, $p = 0.707$, Appendix 6). The mean fish density and species richness measured during the 2019 survey at BOYA20 fell well within one standard deviation of the historical mean at BOYA20 for both parameters.

Table 28. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at BOYA20, La Parguera. Survey date: 6-14-19.

					TRANSECTS (Ind/60m^2)				
Species	**Family**	**Size Range (cm)**		**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c2	Acanthuridae	6-10	Juvenile	2	0	0	0	0	**0.4**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	0	0	0	0	2	**0.4**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	0	0	1	0	0	**0.2**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	1	0	0	0	**0.2**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	1	0	3	1	1	**1.2**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	1	0	1	1	2	**1.0**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	1	2	0	1	2	**1.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	0	0	0	0	1	**0.2**
Epinephelus guttatus c6	Serranidae	26-30	Adult	1	0	0	0	0	**0.2**
Lutjanus mahogoni c4	Lutjanidae	16-20	Adult	0	0	1	0	0	**0.2**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	0	0	1	0	0	**0.2**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	0	0	0	1	0	**0.2**
Ocyurus chrysurus c5	Lutjanidae	21-25	Adult	0	1	1	1	0	**0.6**
Scarus iseri c2	Scaridae	6-10	Juvenile	5	0	0	7	0	**2.4**
Scarus iseri c3	Scaridae	11-15	Juvenile	0	0	2	0	0	**0.4**
Scarus iseri c4	Scaridae	16-20	Adult	0	0	1	0	1	**0.4**
Scarus iseri c5	Scaridae	21-25	Adult	1	0	1	0	0	**0.4**
Scarus iseri c6	Scaridae	26-30	Adult	1	0	0	0	0	**0.2**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	0	2	0	0	0	**0.4**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	4	3	1	0	0	**1.6**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	0	0	1	0	2	**0.6**
Scarus taeniopterus c4	Scaridae	16-20	Adult	0	0	0	1	0	**0.2**
Scarus taeniopterus c6	Scaridae	26-30	Adult	0	0	1	0	0	**0.2**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	1	0	0	1	1	**0.6**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	3	0	1	0	1	**1.0**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	0	2	1	1	**0.8**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	0	0	1	0	1	**0.4**
Sparisoma radians c1	Scaridae	1-5	Recruit	0	1	1	2	0	**0.8**
Sparisoma viride c1	Scaridae	1-5	Recruit	0	3	2	1	0	**1.2**
Sparisoma viride c2	Scaridae	6-10	Juvenile	0	0	0	1	0	**0.2**
Sparisoma viride c3	Scaridae	11-15	Juvenile	0	0	0	1	0	**0.2**
Sparisoma viride c4	Scaridae	16-20	Adult	0	0	1	0	0	**0.2**
Sparisoma viride c5	Scaridae	21-25	Adult	0	1	0	0	0	**0.2**
Sparisoma viride c6	Scaridae	26-30	Adult	0	1	1	0	0	**0.4**
Totals				21	15	24	20	15	**19.0**

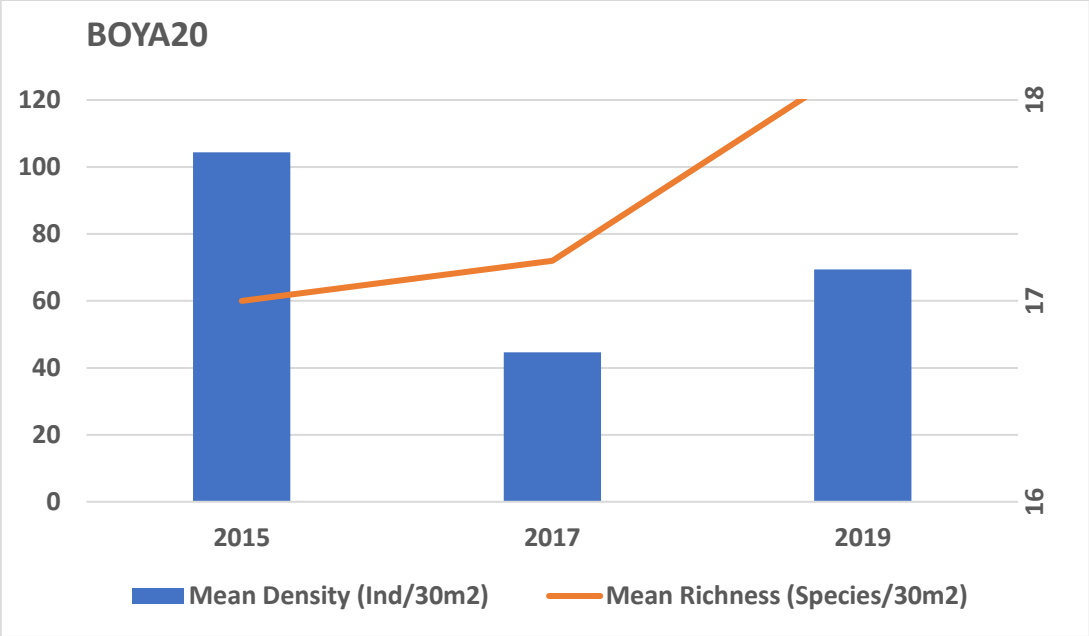
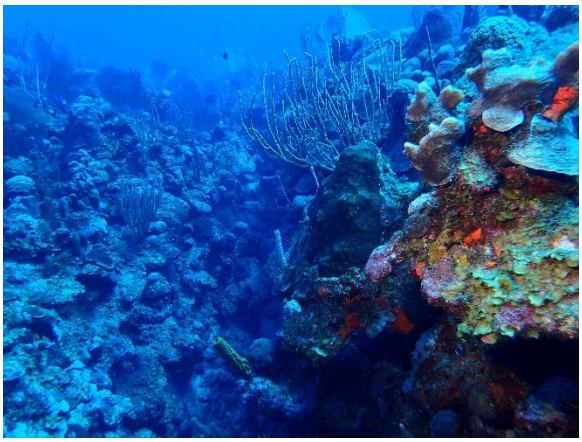


Figure 32. Monitoring trends (2015 – 2019) of mean fish density and species richness within 3 x10 m belt-transects at BOYA20, La Parguera

9.4 Photo Album 9. BOYA20



10. Media Luna 10m (MLUN10)

10.1 Physical Description

With a longitudinal extension of approximately 1.2 km, Media Luna is one of the largest emergent reefs of the La Parguera Marine Reserve. It is located due south of the town of La Parguera at a distance of about 3.5 km from the shoreline. There are two main emergent sections of low relief and devoid of mangrove development. The reef is highly exposed to wave action and there is substantial accumulation of broken coral fragments on its relatively narrow littoral zone. The fore-reef has a well-developed reef crest with some growth of elkhorn coral, but mostly colonized by colonial zoanthids, fire corals, encrusting corals and turf algae (Garcia-Sais and Sabater-Clavell, 2004). The fore-reef slope is moderately abrupt and heavily colonized by massive, branching and encrusting hard and soft corals. The base of the reef is a sandy-silt basin at a depth of approximately 20m. Five permanent transects were set along the mid-section of the fore-reef at a depth of approximately 10m in the same general location where the original CARICOMP baseline characterization of Media Luna Reef was performed in 1994 (Ogden et al.,1997). Panoramic views of MLUN10 are shown in Photo Album 10.

10.2 Sessile-Benthic Reef Community

Soft corals were the most prominent sessile-benthic component of the reef community at MLUN10 with a mean density of 31.4 Col/Transect (range: 29 - 34 Col/Transect) and a mean substrate cover of 15.83% (Table 29). The encrusting species, *Briareum asbestinum* and *Erythropodium caribaeorum* combined for a mean substrate cover of 15.34%. Given their vertical projection, erect soft coral colonies presented relatively low substrate cover (combined 0.48%) but contributed highly to the overall reef habitat structural complexity due to their high density and large colony sizes. Some of the main species included *E. flexuosa, P. flagellosa* and *A. acerosa* (Table 29).

A total 10 hard coral species with a combined mean substrate cover of 30.94% and a density of 12.2 Col/Transect were intercepted by transects during the 2019 monitoring survey of MLUN10 (Table 29). Mountainous Star Coral (*Orbicella faveolata*) was the dominant species in terms of reef substrate cover a mean of 16.51%, representative of 53.36% of the total cover by hard corals. Mustard-Hill Coral (*Porites astreoides*) and Lettuce Coral (*Agaricia agaricites*) were present in all five transects with mean substrate cover of 5.75% and 3.84%, respectively. One colony of *P. astreoides* out of the 61 hard coral colonies intercepted by transects at MLUN10 was observed to be apparently affected by coral disease, resulting in a coral disease prevalence of 1.6% (see Appendix 2).

Table 29. Percent cover by sessile-benthic categories at MLUN10, La Parguera

MLUN10	Transects					
Survey Date: June 14, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	8.79	8.48	9.09	8.79	8.48	**8.73**
Rugosity (m)	3.22	4.48	2.57	3.29	4.78	**3.67**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	12.61	6.77	5.57	5.80	3.68	**6.88**
Sand	1.06	0.48	3.23			**0.95**
Rubble		1.55				**0.31**
Gaps/Holes		0.97	0.56			**0.30**
Total Abiotic	13.67	9.77	9.35	5.80	3.68	**8.45**
Benthic Algae						
Turf (mixed)	30.51	31.72	19.38	22.87	41.75	**29.25**
Turf (mixed) with sediment		4.35	3.90	2.21		**2.09**
CCA (mixed)			1.22		0.85	**0.41**
Dictyota spp.				0.53	0.76	**0.26**
Macroalgae spp.			0.45			**0.09**
Total Benthic Algae	30.51	36.07	24.94	25.61	43.36	**32.10**
Cyanobacteria	0.00	0.00	0.00	0.00	0.00	**0.00**
Hard Coral						
Orbicella faveolata	18.01	16.25	24.61	17.28	6.41	**16.51**
Porites astreoides	6.14	2.03	6.24	9.06	5.28	**5.75**
Agaricia agaricites	1.38	0.39	7.80	4.53	5.09	**3.84**
Pseudodiploria strigosa	2.12		3.01	3.79		**1.78**
Montastraea cavernosa	0.53	4.35	1.45	0.53		**1.37**
Porites porites	0.64	0.48	1.67	2.21	0.85	**1.17**
Millepora alcicornis	1.06	0.10				**0.23**
Porites divaricata					0.85	**0.17**
Porites furcata					0.38	**0.08**
Siderastrea siderea		0.19				**0.04**
Total Hard Coral	29.87	23.79	44.77	37.41	18.85	**30.94**
# Coral Colonies /Transect	8	10	11	18	14	**12.2**
# Diseased Coral Colonies/Transect	1	0	0	0	0	**0.2**
Soft Corals						
Briareum asbestinum	19.81	4.93	6.12	16.12	5.59	**10.52**
Erythropodium caribaeorum		17.99		3.48	2.64	**4.82**
Eunicea flexuosa	0.53				0.57	**0.22**
Pseudoplexaura flagellosa		0.29		0.32		**0.12**
Antillogorgia acerosa				0.32		**0.06**
Plexaura kukenthali			0.22			**0.04**
Plexaurella spp.	0.21					**0.04**
Total Soft Corals	20.55	23.21	6.35	20.23	8.79	**15.83**
# Soft Coral Colonies/Transect	31	29	31	34	32	**31.4**
Zoanthids						
Palythoa caribaeorum	2.75		9.80	2.00	11.22	**5.15**
Sponges						
Chondrilla caribensis	1.06	5.90	0.00	3.90	4.24	**3.02**
Cliona caribbaea	0.42	0.19	3.45	2.74	7.92	**2.95**
Amphimedon compressa	0.21			1.37		**0.32**

MLUN10 Survey Date: June 14, 2019	Transects 1	2	3	4	5	Mean
Ircinia spp. brown					0.94	**0.19**
Ircinia felix	0.74					**0.15**
Mycale laevis		0.19	0.22	0.32		**0.15**
Agelas conifera		0.58				**0.12**
Sponge spp.		0.29	0.22			**0.10**
Niphates erecta	0.21			0.21		**0.08**
Ircinia strobilina				0.42		**0.08**
Total Sponges	2.65	7.16	3.90	8.96	13.10	**7.15**
Others						
Ricordea florida			0.67		0.57	**0.25**
Lebrunia neglecta			0.22			**0.04**

Turf algae, a mixed assemblage of short articulated red and brown macroalgae was the main component of the benthic algae with a mean cover of 31.34%, representative of 97.63% of the total benthic algae. Small patches of crustose coralline algae (CCA) and fleshy brown macroalgae (*Dictyota sp*.) were also present in transects with low substrate cover (< 1.0%). The encrusting zoanthid, *Palythoa caribaeorum* was intercepted by four transects with a mean cover of 5.15%. Sponges were represented by at least 10 species along transects with a mean substrate cover of 7.15%. The dominant species in terms of reef substrate cover were *Chondrilla caribensis* and *Cliona caribbaea* with a combined cover of 5.97%, representative of 83.5% of the total cover by sponges at MLUN10 (Table 29).

Reef overhangs produced both by growth of massive coral colonies and the irregular sedimentary features of the fore-reef slope were the main component of the abiotic category in terms of substrate cover with a mean of 6.88% and strongly contributed to the substrate mean rugosity of 3.67m. Small pockets of sand and rubble were also observed in transects (Table 29).

Temporal variations of reef substrate cover by sessile-benthic categories at MLUN10 during the 2015 baseline survey and the 2017 and 2019 monitoring surveys are shown in Figure 33. Differences of substrate cover by hard corals between surveys were not statistically different (ANOVA, $p = 0.162$; Appendix 3). The lower mean cover by hard corals measured during the 2015 baseline relative to the 2017 and 2019 surveys appear to be a sampling error due to the proliferation of rebar markers at MLUN10. Reef substrate cover by hard corals during the 2019 survey varied only by -1.6% relative to the previous 2017 survey, which tends to confirm that the low cover of 21.9% measured during 2015 was a sampling error. Variations of hard coral cover at MLUN10 were strongly driven by variations of cover by the dominant *Orbicella spp*. complex (Figure 34).

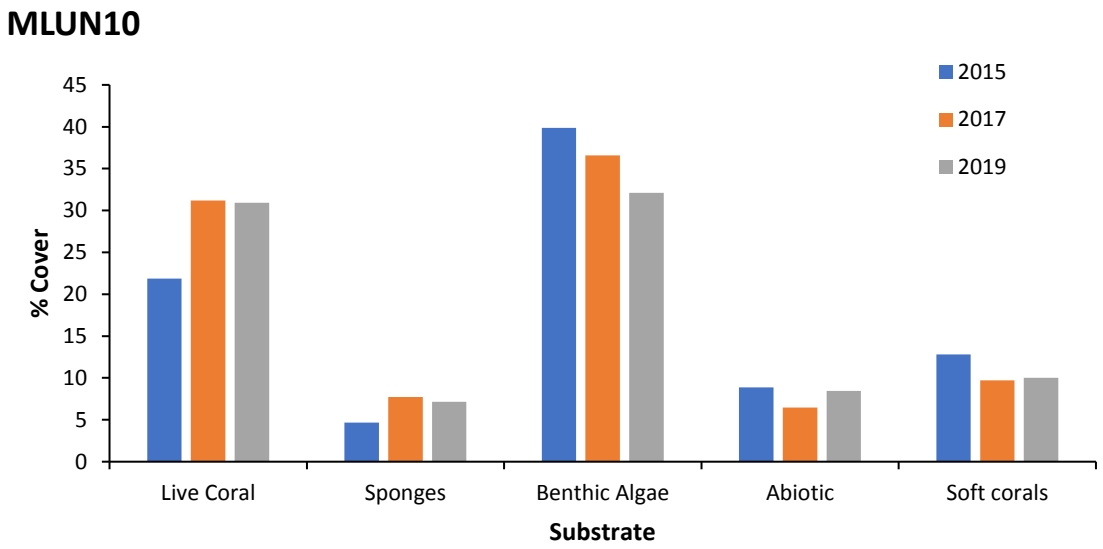


Figure 33. Monitoring trends (2015 – 2019) of mean substrate cover by sessile-benthic categories at MLUN10, La Parguera.

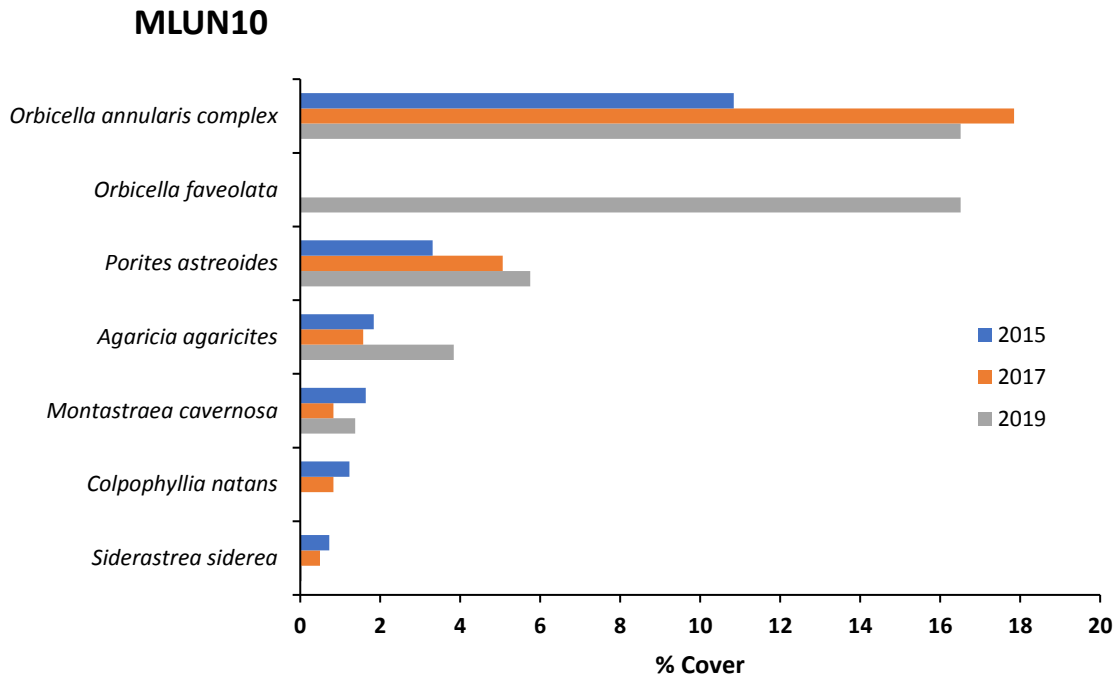


Figure 34. Monitoring trends (2015 – 2019) of mean substrate cover by hard coral species at MLUN10, La Parguera. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

10.3 Fishes and Motile Megabenthic Invertebrates

A total of 31 fish species and one motile megabenthic invertebrate species were identified within belt-transects at MLUN10 during the 2019 monitoring survey (Table 30). Mean fish density within belt-transects was 34.4 Ind/30m^2 (range: 28 – 45 Ind/30 m^2). Fish species richness averaged 14.8 Species/30m^2 (range: 13 – 17 Species/30m^2). An assemblage of six fish species accounted for 65.7% of the total fish density within belt-transects. These included the bluehead wrasse (*Thalassoma bifasciatum*), bicolor and dusky damselfishes (*Stegastes partitus, S. adustus*), stoplight parrotfish (*Sparisoma viride*) and blue and brown chromis (*Chromis cyanea, C. multilineata*). Motile megabenthic invertebrates were represented by the longspine urchin (*Diadema antillarum*) with a mean density of 6.0 Ind/30m^2 (range: 3 – 8 Ind/30m^2).

Fish community structure at MLUN10 was strongly influenced by opportunistic carnivores. An assemblage of 11 species combined for a cumulative density of 15.6 Ind/30m^2, or 45.9% of the total fish density within belt-transects (Table 30). These included wrasses (Labridae), grunts (Haemulidae), hamlets (Serranidae), goby (Gobiidae), squirrelfish (Holocentridae), puffer (Tetraodontidae) and trumpetfish (Aulostomidae). Herbivores were represented by seven species with a combined density of 8.4 Ind/30m^2, or 24.4% of the total fish density. These included parrotfishes (Scaridae), damselfishes (Pomacentridae) and doctorfishes (Acanthuridae). Longspine urchin (*Diadema antillarum*) also contributed to the herbivore trophic assemblage at MLUN10. The zooplanktivore assemblage was comprised by three of the top five numerically dominant species (*Stegastes partitus*, *Chromis spp*) with a combined density of 8.4 Ind/30m^2 representative of 24.4% of the total individuals. Spongivores (Pomacanthidae) and corallivores (Chaetodontidae) were also present. Piscivores and larger invertebrate predators included small groupers (*Epinephelus guttatus*) and snappers (*Lutjanus apodus*).

The taxonomic composition and size-frequency distributions of commercially important fishes and the main reef herbivores observed within 20 x 3m belt-transects at MLUN10 are shown in Table 31. The parrotfish assemblage was comprised by five species that included both juvenile and adult individuals. Recruitment juvenile stages (1-5cm) of stoplight, redband, bucktooth, princess and stripped parrotfishes (*Sparisoma viride, S. aurofrenatum, S. radians, Scarus taeniopterus, S. iseri*) were present, evidencing the role of this reef as a recruitment habitat for these species. Schoolmaster and yellowtail snappers (*Lutjanus apodus, Ocyurus chrysurus*) were present as small adults. One adult red hind (*Epinephelus guttatus*) was also observed.

Table 30. Taxonomic composition and density of fishes surveyed within 3x10m belt-transects at MLUN10, La Parguera.

Survey Date: 6-14-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	10	18	9	5	8	**10.0**
Stegastes partitus	1	8	5	2	4	**4.0**
Stegastes adustus	3	3	2	2	4	**2.8**
Chromis cyanea	0	0	2	6	6	**2.8**
Chromis multilineata	3	0	0	3	2	**1.6**
Sparisoma viride	1	3	1	1	1	**1.4**
Elacatinus evelynae	1	1	3	0	1	**1.2**
Microspathodon chrysurus	2	1	1	1	1	**1.2**
Halichoeres garnoti	2	0	2	0	2	**1.2**
Sparisoma aurofrenatum	0	1	1	2	1	**1.0**
Holocentrus rufus	1	0	1	0	3	**1.0**
Scarus iseri	0	0	1	2	1	**0.8**
Scarus taeniopterus	0	1	0	0	2	**0.6**
Haemulon flavolineatum	0	1	1	0	1	**0.6**
Acanthurus coeruleus	1	1	0	0	1	**0.6**
Canthigaster rostrata	0	1	0	1	0	**0.4**
Anisotremus virginicus	1	0	0	1	0	**0.4**
Holacanthus ciliaris	0	1	0	0	0	**0.2**
Halichoeres maculipinna	0	1	0	0	0	**0.2**
Pomacanthus paru	0	1	0	0	0	**0.2**
Chaetodon capistratus	0	1	0	0	0	**0.2**
Chaetodon striatus	0	1	0	0	0	**0.2**
Cantherhines pullus	0	1	0	0	0	**0.2**
Hypoplectrus unicolor	1	0	0	0	0	**0.2**
Hypoplectrus chlorurus	1	0	0	0	0	**0.2**
Holacanthus tricolor	1	0	0	0	0	**0.2**
Aulostomus maculatus	0	0	1	0	0	**0.2**
Caranx ruber	0	0	1	0	0	**0.2**
Epinephelus guttatus	0	0	0	1	0	**0.2**
Lutjanus apodus	0	0	0	1	0	**0.2**
Pomacanthus arcuatus	0	0	0	0	1	**0.2**
Total Individuals	29	45	31	28	39	**34.4**
Total Species	14	17	14	13	16	**14.8**
Invertebrates						
Diadema antillarum	4	7	8	3	8	**6.0**

Table 31. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at MLUN10, La Parguera. Survey date: 6-14-19.

				TRANSECTS				
				(Ind/60m^2)				
Species	**Family**	**Size Range (cm)**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus coeruleus c1	Acanthuridae	1-5	0	0	1	0	0	**0.2**
Acanthurus coeruleus c2	Acanthuridae	6-10	0	0	0	0	1	**0.2**
Acanthurus coeruleus c3	Acanthuridae	11-15	1	1	0	0	2	**0.8**
Acanthurus tractus c3	Acanthuridae	11-15	1	0	0	0	0	**0.2**
Caranx ruber c8	Carangidae	36-40	0	0	1	0	0	**0.2**
Epinephelus guttatus c6	Serranidae	26-30	0	0	0	1	0	**0.2**
Lutjanus apodus c4	Lutjanidae	16-20	0	0	0	1	0	**0.2**
Ocyurus chrysurus c3	Lutjanidae	11-15	0	1	0	0	0	**0.2**
Scarus iseri c1	Scaridae	1-5	0	4	0	1	1	**1.2**
Scarus iseri c2	Scaridae	6-10	0	0	0	1	0	**0.2**
Scarus iseri c3	Scaridae	11-15	1	0	0	0	0	**0.2**
Scarus iseri c5	Scaridae	21-25	0	0	1	0	0	**0.2**
Scarus taeniopterus c1	Scaridae	1-5	0	0	0	0	2	**0.4**
Scarus taeniopterus c4	Scaridae	16-20	0	1	0	0	0	**0.2**
Sparisoma aurofrenatum c1	Scaridae	1-5	0	0	0	2	0	**0.4**
Sparisoma aurofrenatum c2	Scaridae	6-10	0	0	1	0	0	**0.2**
Sparisoma aurofrenatum c3	Scaridae	11-15	1	0	0	0	1	**0.4**
Sparisoma aurofrenatum c4	Scaridae	16-20	0	1	1	1	0	**0.6**
Sparisoma radians c1	Scaridae	1-5	0	0	0	1	0	**0.2**
Sparisoma viride c1	Scaridae	1-5	0	2	0	0	0	**0.4**
Sparisoma viride c2	Scaridae	6-10	0	0	0	1	1	**0.4**
Sparisoma viride c3	Scaridae	11-15	1	1	1	0	1	**0.8**
Sparisoma viride c5	Scaridae	21-25	0	0	0	1	0	**0.2**
Sparisoma viride c6	Scaridae	26-30	0	0	1	0	0	**0.2**
Totals			5	11	7	10	9	**8.4**
Invertebrates			5	10	6	8	9	**7.6**
Diadema antillarum (adult)			6	10	12	4	10	**8.4**

Temporal variations of mean fish density and species richness between monitoring surveys are presented in Figure 35. Both fish density and species richness increased during the 2019 survey relative to previous surveys, but differences were not statistically significant (ANOVA, $p > 0.05$, Appendix 5-6). MLUN10 is a forereef slope environment exposed to strong wave and surge action. These physical factors appear to be relevant in the regulation of both fish species richness and density at the times of visual monitoring surveys.

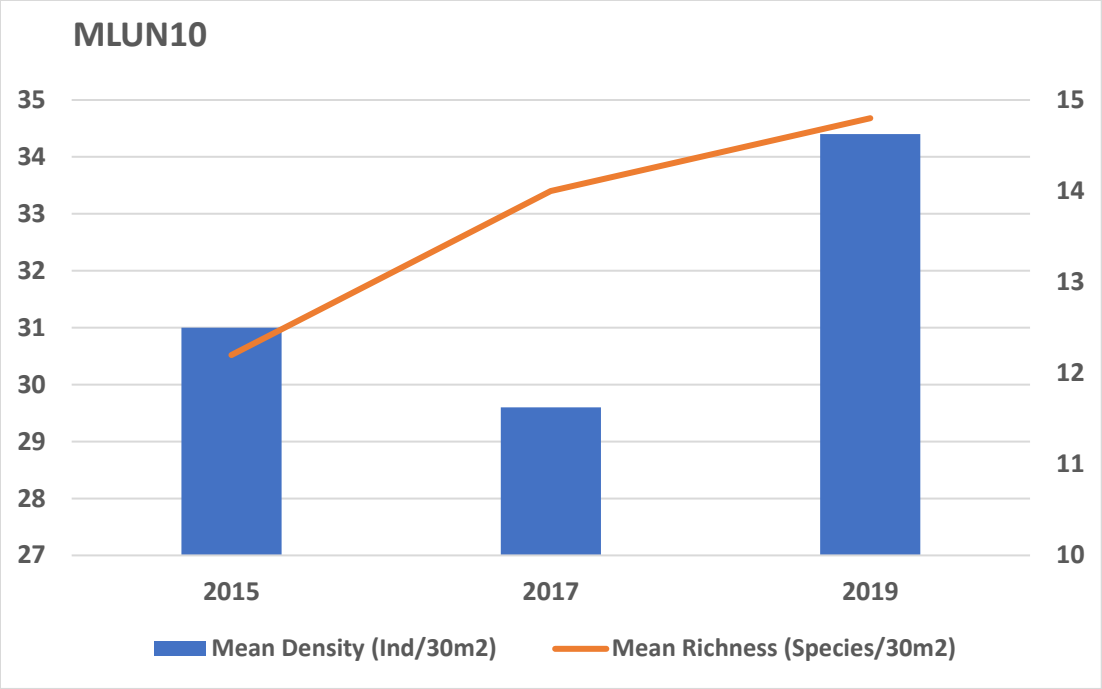
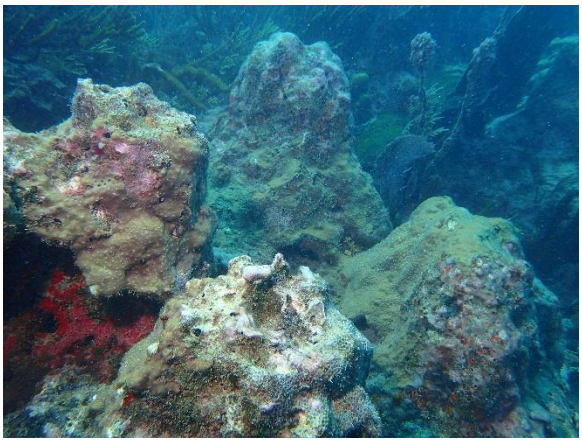
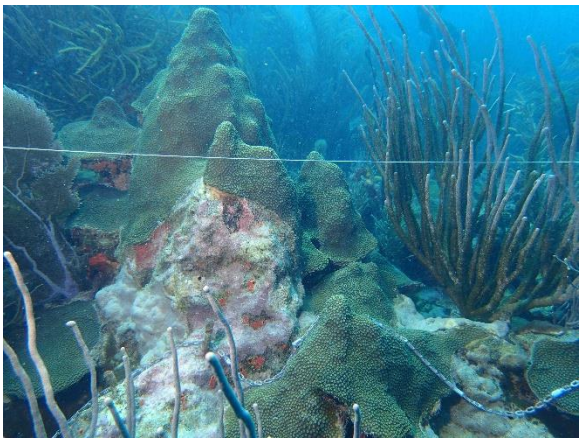


Figure 35. Monitoring trends (2015 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at MLUN10, La Parguera

10.4 Photo Album 10. MLUN10





11. Media Luna 5m (MLUN05)

11.1 Physical Description

A series of patch reefs are found in the mid-section of the Media Luna back-reef at depths of 1 – 5m. The reef promontories are coral formations, mostly of lobed and mountainous star coral (*Orbicella annularis, O. faveolata)* that rise from the base of the reef to variable heights, some almost reaching the surface. Patch reefs are irregular formations separated by sandy-silt sediments. The backreef slopes down gradually to a depth of about 6m and then drops down more abruptly to a backreef basin reaching a sill depth of approximately 20m. Our permanent transects were established in three patch reefs at depths of 2 – 4m. The baseline characterization of MLUN05 was produced in 2015 (Garcia-Sais et al., 2015). Panoramic documentation of the MLUN05 reef community is shown in Photo Album 11.

11.2 Sessile-Benthic Reef Community

Benthic algae comprised by turf (mixed assemblage), fleshy brown (*Dictyota sp*), green calcareous (*Halimeda sp., Udotea sp*.), red crustose (*Ramicrusta sp*) and coralline macroalgae (CCA) was the main category in terms of reef substrate cover at MLUN05 with a mean of 46.77% (range: 33.23 – 56.65%). Turf algae, including sections packed with fine sediments was the dominant component in terms of substrate cover with a combined mean of 37.27%, representative of 79.7% of the total cover by benthic algae (Table 32). Small patches of cyanobacteria, or blue-green algal films were observed in all five transects with a mean substrate cover of 2.05%.

Six hard coral species with a combined mean substrate cover of 12.16% and a mean density of 4.8 Col/Transect were intercepted by line transects at MLUN05 during the 2019 monitoring survey (Table 32). Lobed star coral (*Orbicella annularis*) was the dominant species in terms of reef substrate cover with a mean of 7.32%, representing 60.2% of the total cover by hard corals. It's sibling species, *O. faveolata* ranked second in substrate cover with a mean of 3.50% for a combined cover by the *Orbicella* species complex of 10.82%, equivalent to 89.0% of the total cover by hard corals. Large massive colonies of lobed star coral were observed growing from the base of the reef and reaching almost to the surface. Colonies of pillar coral (*Dendrogyra cilindrus*), greater starlet coral (*Siderastrea siderea*), lettuce coral (*Agaricia agaricites)*, and blushing star coral (*Stephanocoenia intersepta*) were also intercepted by transects but represented minor components of the reef sessile benthos. One colony of *S. siderea* out of the 24 total hard coral colonies intercepted by transects was observed to be apparently infected by coral disease yielding a coral disease prevalence of 4.2% (Appendix 2).

Table 32. Percent reef substrate cover by sessile-benthic categories at MLUN05, La Parguera

MLUN05			**Transects**			
Survey Date: June 14, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	3.33	2.42	2.42	3.64	3.64	**3.09**
Rugosity (m)	3.47	4.80	7.23	6.53	4.98	**5.40**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	14.55	30.47	18.28	22.86	18.60	**20.95**
Sand	5.20	0.37	16.49	3.47		**5.11**
Rubble	0.21				5.61	**1.16**
Gaps/Holes					0.56	**0.11**
Total Abiotic	19.96	30.83	34.77	26.33	24.77	**27.33**
Benthic Algae						
Turf (mixed)	20.69	35.32	16.41	33.19	28.04	**26.73**
Turf (mixed) with sediment	21.52	5.22	9.67	7.87	8.41	**10.54**
Dictyota spp.	9.25	1.65	0.81	7.37	5.89	**4.99**
Halimeda spp.	5.20	0.55	3.66	3.39	5.42	**3.64**
Ramicrusta spp.			2.68			**0.54**
CCA (mixed)				1.02		**0.20**
Udotea spp.					0.65	**0.13**
Total Benthic Algae	56.65	42.73	33.23	52.84	48.41	**46.77**
Cyanobacteria	1.66	0.37	3.57	2.29	2.34	**2.05**
Hard Coral						
Orbicella annularis	12.47	3.20	2.27	6.01	12.62	**7.32**
Orbicella faveolata			16.65	0.85		**3.50**
Dendrogyra cylindrus			3.09			**0.62**
Agaricia agaricites		1.65		0.17		**0.36**
Siderastrea siderea	0.21	1.10	0.16			**0.29**
Stephanocoenia intersepta		0.37				**0.07**
Total Hard Coral	12.68	6.31	22.18	7.03	12.62	**12.16**
# Coral Colonies/Transect	5	4	6	4	5	**4.8**
# Diseased Coral Colonies/Transect	0	1	0	0	0	**0.20**
Soft Corals						
Briareum asbestinum	1.77	2.74	2.84	3.22	0.47	**2.21**
Erythropodium caribaeorum	0.83	2.20	2.60	1.10	2.06	**1.76**
Eunicea succinea	0.21					**0.04**
Eunicea tourneforti	0.21					**0.04**
Pseudoplexaura flagellosa	0.21					**0.04**
Total Soft Corals	3.22	4.94	5.44	4.32	2.52	**4.09**
# Soft Coral Colonies/Transect	12	12	13	13	8	**11.6**
Sponges						
Chondrilla caribensis	4.26	7.23	0.24	6.60	8.22	**5.31**
Cliona caribbaea		3.66				**0.73**
Cliona tenuis		0.64				**0.13**
Ircinia spp. brown				0.59		**0.12**
Mycale laevis	0.31		0.24			**0.11**
Niphates erecta			0.32			**0.06**
Total Sponges	4.57	11.53	0.81	7.20	8.22	**6.47**

MLUN05			**Transects**			
Survey Date: June 14, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Others						
Condominium spp.					0.75	**0.15**
Phymanthus crucifer	0.62					**0.12**
Ricordea florida	0.62					**0.12**
Bartholomea annulata					0.37	**0.07**

Soft corals were prominent at MLUN05 with a mean density of 11.6 Col/Transect and a mean reef substrate cover of 4.09% (Table 32). Encrusting colonies of *Briareum asbestinum* and *Erythropodium caribaeorum* were intercepted by all five transects with a combined mean cover of 3.97%, representative of 97.1% of the total cover by soft corals. The prominence of erect soft corals was under-represented by their reef substrate cover due to their vertical projection but their high density and large colony sizes at MLUN05 contributed substantially to the overall reef habitat structural and biological complexity. Some of the most abundant erect forms included sea rods (*Eunicea spp.*) and sea plumes (*Pseudoplexaura sp*). Sponges were present in all transects with a mean cover of 6.47%. A total of six species were intercepted by transects. *Chondrilla caribensis* was present in all transects and was the dominant species in terms of reef substrate cover with a mean of 5.31%, representative of 82.1% of the total cover by sponges at MLUN05.

Reef overhangs produced by growth of massive hard coral colonies were the main component of the abiotic substrate cover at MLUN05 with a mean of 20.95%, representative of 76.7% of the total abiotic cover (Table 32). Sand pockets were also intercepted by four transects with a mean cover of 5.11%. Reef substrate rugosity averaged 5.4m, indicative of the high topographic relief contributed by coral growth.

Variations of live hard coral cover between monitoring surveys are shown in Figure 36. Differences between the 2015 baseline (mean: 11.67%) and the present 2019 survey (mean: 12.16%) were below 5% and not statistically significant (ANOVA, $p = 0.897$; Appendix 3). Reef substrate cover by hard corals at MLUN05 is largely influenced by cover of the *Orbicella spp* complex and these have remained stable between monitoring surveys at MLUN05 (Figure 37). Still, the high relative composition of turf algae overgrowing standing dead coral sections, particularly of *Orbicella spp*. are indicative of a major reef degradation event or series of events that occurred prior to our baseline survey (perhaps the 2005 coral bleaching event).

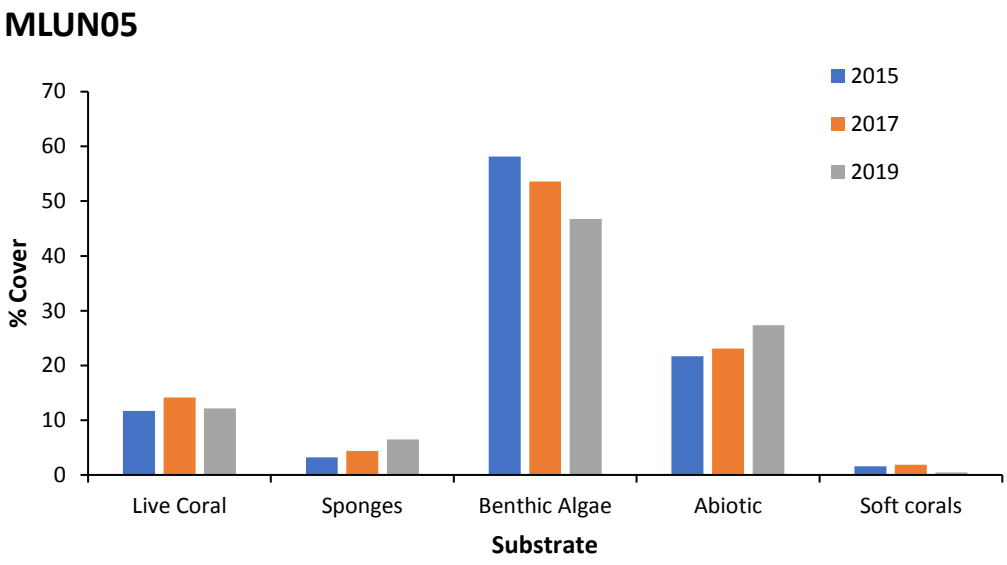


Figure 36. Monitoring trends (2015 – 2019) of mean substrate cover by sessile-benthic categories at MLUN05, La Parguera.

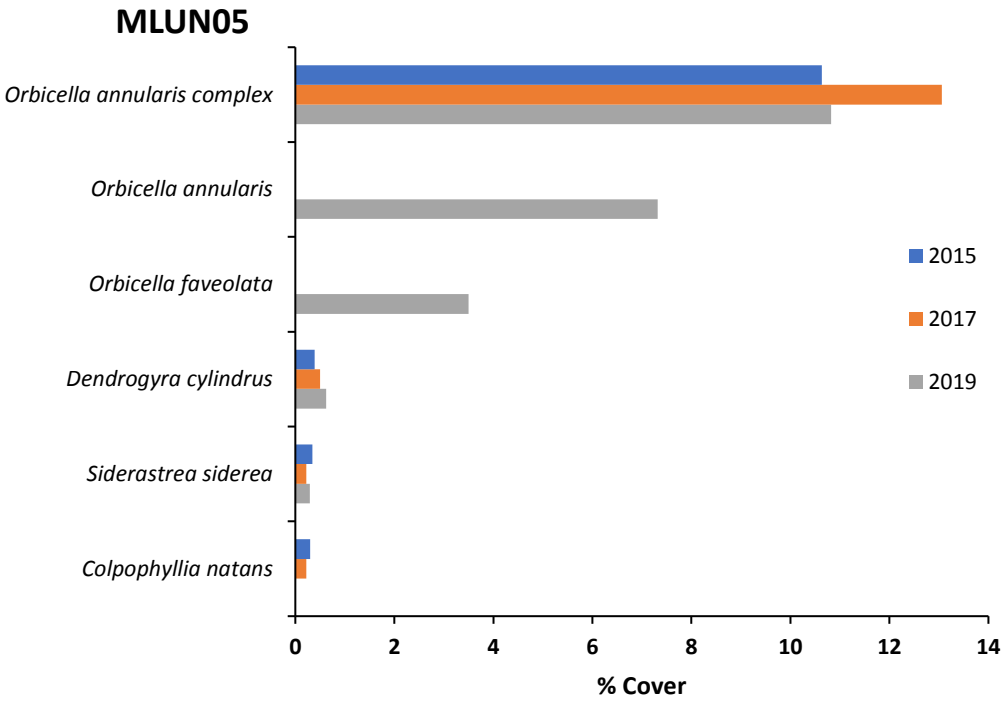


Figure 37. Monitoring trends (2015 – 2019) of mean substrate cover by hard coral species at MLUN05, La Parguera. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

Density of erect soft corals has shown a declining trend since the 2015 baseline survey when the mean density was reported as 22.0 Col/Transect. The mean density of 11.6 Col/Transect measured in the present 2019 survey represents reduction of 47.3% that was statistically significant (ANOVA, $p = 0.023$; Appendix 4). The declining trend of erect soft corals at MLUN05 may be related to events of extreme wave action associated with the pass of Hurricanes Mathew in 2016 and Maria in 2017 which have been shown to have had adverse effects on the benthic communities of shallow coral reef systems.

11.3 Fishes and Motile Megabenthic Invertebrates

A total of 26 fish species and two motile megabenthic invertebrate species were identified within belt-transects at MLUN05 during the 2019 monitoring survey with a mean density of 47.0 Ind/30m^2 (range: 34 – 71 Ind/30m^2) and a mean species richness of 12.6 Species/30m^2 (Table 33). An assemblage of six species with a combined density of 35.0 Ind/m^2 represented 74.5% of the total fish density within belt-transects. These included the bluehead wrasse (*Thalassoma bifasciatum*), brown chromis (*Chromis cyanea*), dusky and threespot damselfishes (*Stegastes adustus, S. planifrons*), and the stoplight and striped parrotfishes (*Sparisoma viride, Scarus iseri*). The yellowtail damselfish (*Microspathodon chrysurus*) and the sharpnose goby (*Elacatinus evelynae*) were present in all five transects and along with the numerically dominant aforementioned species comprised the main small demersal territorial fish assemblage of MLUN05.

The longspine urchin (*Diadema antillarum*) with a mean density of 13.0 Ind/30m^2 was the main motile megabenthic invertebrate present within belt-transects (Table 33). The density of long-spined urchins at MLUN05 is the highest recorded in the PRCRMP. This may have been influenced by a restoration initiative that involved the out-planting of 340 urchins in this general locality in an attempt to reduce the high algal overgrowth at this reef after the marked mortality of live coral cover presumably related with the 2005 coral bleaching event (Williams, 2017).

The herbivorous fish assemblage comprised by a total of 11 species and with a combined density of 19.6 Ind/30m^2 was the most prominent trophic group at MLUN05 representative of 41.7% of the total fish density within belt-transects. The assemblage included five damselfishes (Pomacentridae), four parrotfishes (Scaridae) and two doctorfishes (Acanthuridae). The longspine urchin (*D. antillarum*) was another important component of the herbivore group at MLUN05. Opportunistic carnivores, represented by the numerically dominant species, the bluehead wrasse (*Thalassoma bifasciatum*), two grunts (Haemulidae), one squirrelfish

(Holocentridae), two hamlets and one small grouper (Serranidae) presented a combined density of 15.0 Ind/30m^2, or 31.9% of the total individuals. Zooplanktivores were represented by two damselfishes (Pomacentridae) with a combined density of 9.4 Ind/30m^2, or 20.0% of the total fish density within belt-transects. Larger invertebrate and fish predators were represented by two snappers (Lutjanidae) and one jack (Carangidae). Spongivores (Pomacanthidae) and corallivores (Chaetodontidae) were also present in low density. The relative abundance of herbivorous fishes, particularly parrotfishes (Scaridae) has been shown to increase towards the coastline possibly associated with the higher connectivity of recruitment and nursery habitats and/or the higher availability of benthic algae. Conversely, the relative abundance and species richness of zooplanktivorous fishes exhibit an increasing offshore pattern (Esteves-Amador, 2013).

Fish species of commercial value observed within 20 x 3m belt-transects are listed in Table 34. Four parrotfish species (*Sparisoma spp., Scarus spp*.) comprised the main assemblage in terms of density and species richness. Striped, princess and stoplight parrotfishes (*Scarus iseri, S. taeniopterus, Sparisoma viride*) were present as both juvenile and adults, including early recruitment juvenile stages (1-5cm) and terminal phase male stages of *S. viride*. Likewise, doctorfishes (*Acanthurus spp*) were observed as recruitment juveniles, larger juveniles, and full adult stages. Snappers (*Lutjanus apodus*, *Ocyurus chrysurus)* and jacks (*Caranx ruber*) were present as juveniles and/or small adults. Size frequency distributions of commercially important fishes are indicative that MLUN05 functions as a recruitment and residential habitat for an assemblage of important reef fish herbivores, such as parrotfishes and doctorfishes and a residential and feeding grounds for small demersal predators.

Temporal variations of fish species richness and abundance during monitoring surveys are presented in Figure 38. Statistically significant differences were evidenced for species richness (ANOVA, $p = 0.010$, Appendix 6) associated with a decline during 2019 relative to previous surveys. The decline was possibly related to a physical disturbance caused by wave action during the time of survey, since differences were mostly associated to small residential species that have widespread distributions in shallow reefs. Physical disturbances at the time of surveys have been noted to be one of the main drivers of temporal variability in fish community structure in shallow reefs included in the PRCRMP. Density differences were statistically insignificant (ANOVA, $p = 0.060$; Appendix 5)

Table 33. Taxonomic composition and density of fishes surveyed within 3x10m belt-transects at MLUN05, La Parguera.

Survey Date: 6-14-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	9	11	16	10	12	**11.6**
Chromis multilineata	2	9	19	8	3	**8.2**
Stegastes adustus	6	7	12	2	4	**6.2**
Sparisoma viride	2	5	3	4	3	**3.4**
Scarus iseri	0	0	6	3	7	**3.2**
Stegastes planifrons	3	4	2	1	2	**2.4**
Scarus taeniopterus	0	5	0	0	2	**1.4**
Holocentrus rufus	0	2	1	3	1	**1.4**
Caranx ruber	7	0	0	0	0	**1.4**
Haemulon flavolineatum	1	0	4	0	1	**1.2**
Stegastes partitus	0	1	0	2	3	**1.2**
Microspathodon chrysurus	0	2	2	0	1	**1.0**
Sparisoma aurofrenatum	0	1	1	2	0	**0.8**
Acanthurus coeruleus	0	0	1	2	0	**0.6**
Chaetodon capistratus	1	0	2	0	0	**0.6**
Cephalopholis cruentata	1	0	0	0	1	**0.4**
Hypoplectrus chlorurus	1	0	0	0	0	**0.2**
Stegastes leucostictus	1	0	0	0	0	**0.2**
Chaetodon striatus	0	1	0	0	0	**0.2**
Stegastes variabilis	0	0	1	0	0	**0.2**
Holacanthus ciliaris	0	0	1	0	0	**0.2**
Pomacanthus arcuatus	0	0	0	1	0	**0.2**
Acanthurus tractus	0	0	0	0	1	**0.2**
Hypoplectrus unicolor	0	0	0	0	1	**0.2**
Lutjanus apodus	0	0	0	0	1	**0.2**
Ocyurus chrysurus	0	0	0	0	1	**0.2**
Total Individuals	34	48	71	38	44	**47.0**
Total Species	11	11	14	11	16	**12.6**
Invertebrates						
Diadema antillarum	13	23	4	14	11	**13.0**
Eucidaris tribuloides	0	0	1	0	0	**0.2**

Table 34. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at MLUN05, La Parguera.

MLUN05									
Survey Date: 6/14/2019					**TRANSECTS**				
		Size			**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**		**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus coeruleus c1	Acanthuridae	1-5	Recruit	0	0	1	0	0	**0.2**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	1	0	1	1	0	**0.6**
Acanthurus coeruleus c3	Acanthuridae	11-15	Juvenile	1	0	0	2	0	**0.6**
Acanthurus tractus c1	Acanthuridae	1-5	Recruit	0	0	0	0	1	**0.2**
Acanthurus tractus c3	Acanthuridae	11-15	Adult	0	0	0	1	0	**0.2**
Caranx ruber c3	Carangidae	11-15	Juvenile	1	0	0	0	0	**0.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	1	0	0	0	1	**0.4**
Lutjanus apodus c5	Lutjanidae	21-25	Adult	0	0	0	4	0	**0.8**
Ocyurus chrysurus c2	Lutjanidae	6-10	Juvenile	0	0	1	0	0	**0.2**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	0	0	1	0	0	**0.2**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	0	0	0	0	1	**0.2**
Scarus iseri c1	Scaridae	1-5	Recruit	3	0	0	9	6	**3.6**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	0	0	0	4	**0.8**
Scarus iseri c5	Scaridae	21-25	Adult	0	0	0	1	0	**0.2**
Scarus iseri c6	Scaridae	26-30	Adult	0	0	0	0	1	**0.2**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	2	3	2	0	0	**1.4**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	0	2	1	0	4	**1.4**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	0	2	1	1	0	**0.8**
Sparisoma aurofrenatum c5	Scaridae	21-25	Adult	0	1	0	2	0	**0.6**
Sparisoma viride c1	Scaridae	1-5	Recruit	1	2	3	3	4	**2.6**
Sparisoma viride c2	Scaridae	6-10	Juvenile	0	1	0	1	0	**0.4**
Sparisoma viride c3	Scaridae	11-15	Juvenile	0	1	0	0	0	**0.2**
Sparisoma viride c4	Scaridae	16-20	Adult	1	2	0	0	0	**0.6**
Sparisoma viride c5	Scaridae	21-25	Adult	0	0	1	0	0	**0.2**
Sparisoma viride c6	Scaridae	26-30	Adult	2	0	0	0	0	**0.4**
Sparisoma viride c8	Scaridae	36-40	Adult	0	1	0	0	0	**0.2**
Totals				13	15	12	25	22	**17.4**

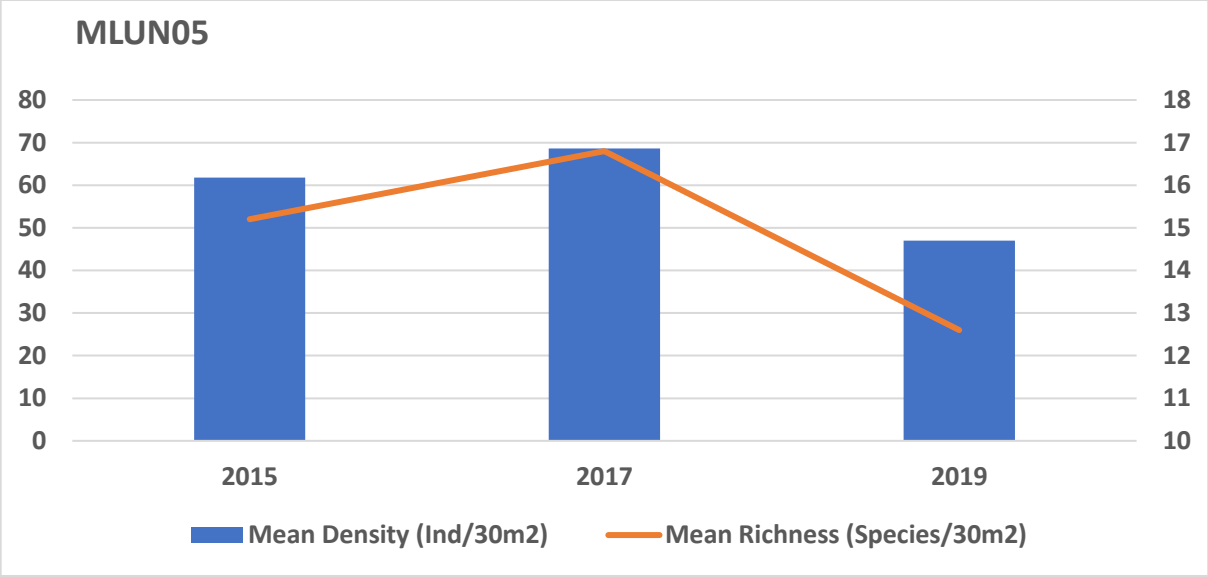
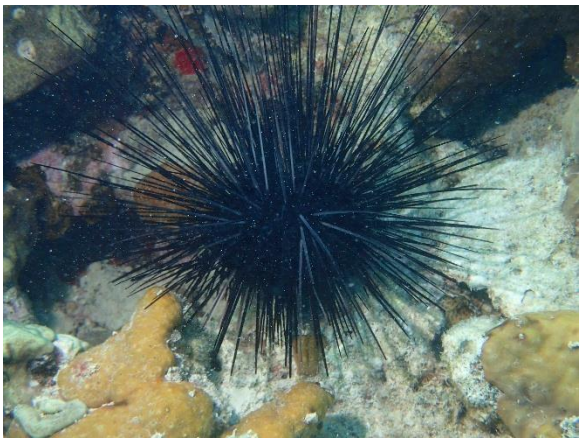


Figure 38. Monitoring trends (2015 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at MLUN05, La Parguera

11.4 Photo Album 11. MLUN05



12. Cayo Coral (CORA10)

12.1 Physical Description

Guánica is located on the southwest coast of Puerto Rico. The marine section of the Natural Reserve extends 8.9 kilometers along the coastline from the eastern corner of Guánica Bay in the West, almost to Punta Ventana in the East, and approximately 1.6 kilometers offshore from Punta Jacinto. There is a deep submarine canyon associated with Guánica Bay that cuts through the insular shelf and extends easterly towards the shelf-edge.

Cayo Coral is an emergent reef located to the west of Cayos de Caña Gorda, between Punta Ballena and the mouth of Guánica Bay (Figure 39). The reef is about two kilometers long and sits in the same platform as Caña Gorda Reef, at the northern edge of Guanica's submarine canyon. A series of submerged patch reefs are found to the north and east of Cayo Coral. Our baseline survey of CORA10 was performed in 1999 (Garcia-Sais et al., 2001a). Permanent transects were surveyed at depths of 7.9 – 9.7 m in the fore reef slope. Panoramic views of CORA10 are presented as Photo Album 12.

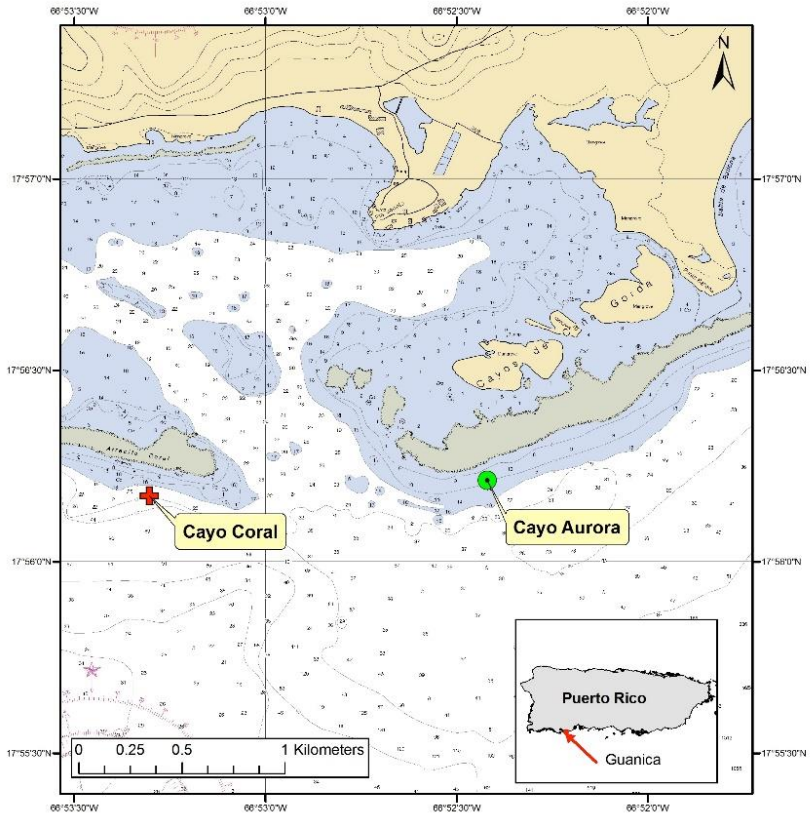


Figure 39. Location of coral reef survey stations at Cayo Coral and Cayo Aurora, Guánica.

12.2 Sessile-benthic Reef Community

Benthic algae, comprised by turf (mixed assemblage), fleshy brown (*Dictyota sp., Lobophora sp*.), green calcareous (*Halimeda sp., Caulerpa sp*.), crustose red (*Ramicrusta sp., Peyssonnelia sp.*) and fleshy red (*Galaxaura sp.*) macroalgae was the most prominent sessile-benthic category at CORA10 with a combined mean substrate cover of 50.89% (Table 35). Turf algae, a mixed assemblage of short articulated red and brown algae was the dominant component of the benthic algae with a mean cover of 35.70%, representative of 70.2% of the total. It was observed colonizing hard ground substrates, particularly dead coral colonies, packed with fine sediments in some sections. Tufts of y-twig alga (*Dictyota sp*.) were abundant at CORA10 with a mean cover of 10.32% and intercepted by all five transects. Cyanobacterial patches were also prominent colonizing hard substrates and sandy sections in all five transects with a mean cover of 8.02%. Abiotic substrates, contributed by reef overhangs, rubble and sand averaged 18.23% (Table 35).

A total of 15 hard coral species (including one hydrocoral) were intersected by line transects from CORA10 with a mean substrate cover of 13.75% (range: 3.68 – 15.04%) with a mean of 7.4 Col/Transect (Table 35). Hard corals occurred as massive, encrusting, mound shaped and branching colonies. Mountainous star coral (*Orbicella faveolata)* was the dominant species in terms of substrate cover with a mean of 4.31%, representing 31.3% of the total cover by hard corals and was present in all five transects. Mustard hill coral (*Porites astreoides*), lettuce coral (*Agaricia agaricites*) and great star coral (*Montastraea cavernosa*) were the only other hard coral species intercepted by at least three transects. Infectious diseases were observed in three (2-*Porites astreoides*, 1-*Siderastrea siderea*) out of 37 coral colonies intercepted by transects at CORA10 for a coral disease prevalence of 8.1% (Appendix 2).

Soft corals were moderately abundant with an average of 20.0 Col/Transect. At least 24 species of soft corals are known to occur within the 7 – 10 m depth range at CORA10 (García-Sais et al. 2007). Encrusting forms, such as *Erythropodium caribaeorum* and *Briareum asbestinum* were intercepted by all transects with a combined mean substrate cover of 2.92% (Table 35). Soft corals contributed substantial habitat complexity and substrate heterogeneity at CORA10, representing an important protective habitat for reef fishes and invertebrates. Sponges were represented by 17 species within transects with an average cover of 4.59%. *Neopetrosia sp*, and *Xestospongia muta* were the most prominent along transects with a combined cover of 2.64%, representative of 57.5% of the total cover by sponges.

Table 35. Percent reef substrate cover by sessile-benthic categories at CORA10, Guánica

CORA10	Transects					
Survey Date: August 9, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	9.7	9.4	7.9	7.9	8.5	**8.68**
Rugosity (m)	3.02	2.66	3.83	3.69	5.33	**3.71**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	4.62	9.18	3.74	16.26	9.41	**8.64**
Rubble	6.45	2.21	4.55	5.11	5.84	**4.84**
Sand	7.53	1.88	1.52	11.76	1.10	**4.76**
Total Abiotic	**18.60**	**13.27**	**9.82**	**33.13**	**16.35**	**18.23**
Benthic Algae						
Turf (mixed)	16.34	21.24	19.53	20.86	27.85	**21.17**
Turf (mixed) with sediment	9.35	26.55	13.16	14.72	8.86	**14.53**
Dictyota spp.	12.26	5.53	8.70	10.84	14.25	**10.32**
Halimeda spp.	0.86		3.44	2.35	4.38	**2.21**
Peyssonnelia spp.	1.51	0.33	1.32		0.82	**0.79**
Ramicrusta spp.	0.22	2.43		0.20	0.73	**0.72**
Caulerpa spp.	0.65		0.81	0.82	0.46	**0.55**
CCA (total)		0.44	0.20	1.02	0.27	**0.39**
Galaxaura spp.					0.82	**0.16**
Lobophora spp.	0.32					**0.06**
Total Benthic Algae	**41.51**	**56.53**	**47.17**	**50.82**	**58.45**	**50.89**
Cyanobacteria	**15.81**	**2.43**	**10.63**	**5.83**	**5.39**	**8.02**
Hard Coral						
Orbicella faveolata	3.33	4.20	4.25	1.74	8.04	**4.31**
Porites astreoides	2.26	2.21	1.01	1.33	2.65	**1.89**
Colpophyllia natans			9.31			**1.86**
Pseudodiploria strigosa	4.30		0.51			**0.96**
Siderastrea siderea	1.83	2.54				**0.87**
Orbicella franksi		4.31				**0.86**
Porites porites			3.74		0.46	**0.84**
Agaricia agaricites	1.40	1.11	0.51		1.10	**0.82**
Montastraea cavernosa			2.33	0.20	0.18	**0.54**
Meandrina meandrites			1.62			**0.32**
Eusmilia fastigiata		0.66				**0.13**
Madracis decactis	0.54					**0.11**
Porites furcata	0.43					**0.09**
Millepora alcicornis				0.41		**0.08**
Agaricia fragilis	0.22					**0.04**
Total Hard Coral	**14.30**	**15.04**	**23.28**	**3.68**	**12.42**	**13.75**
# Hard Coral Colonies/Transect	7	10	11	2	7	**7.4**
# Diseased Coral Colonies/Transect	1	1	1	0	0	**0.60**
Soft Corals						
Erythropodium caribaeorum	2.58	1.66	1.52	0.31	1.37	**1.49**
Briareum asbestinum	0.32	1.99	1.82	0.72	2.28	**1.43**
Pseudoplexaura flagellosa			0.51		1.19	**0.34**
Total Soft Corals	**2.90**	**3.65**	**3.85**	**1.02**	**4.84**	**3.25**

CORA10	Transects					
Survey Date: August 9, 2019	**1**	**2**	**3**	**4**	**5**	**Mean**
# Soft Coral Colonies/Transect	17	18	20	12	33	**20.0**
Sponges						
Neopetrosia proxima	1.08	4.54	2.94	0.72	1.64	**2.18**
Xestospongia muta	0.22	0.55		1.53		**0.46**
Monanchora arbuscula	0.22		0.40	0.72		**0.27**
Iotrochota birotulata	1.29					**0.26**
Ectyoplasia ferox	0.86	0.22			0.18	**0.25**
Mycale laevis	0.86					**0.17**
Agelas conifera	0.75					**0.15**
Neopetrosia spp. smooth	0.32			0.31		**0.13**
Iotrochota arenosa			0.20	0.41		**0.12**
Spirastrella hartmani				0.41		**0.08**
Cliona caribbaea			0.40			**0.08**
Spirastrella coccinea			0.30			**0.06**
Aplysina fistularis			0.30			**0.06**
Niphates erecta	0.22					**0.04**
Prosuberites laughlini					0.18	**0.04**
Amphimedon compressa			0.10			**0.02**
Cinachyrella kuekenthali	1.08					**0.22**
Total Sponges	**6.88**	**5.31**	**4.66**	**4.09**	**2.01**	**4.59**
Others						
Ricordea florida		2.32	0.40	1.43	0.55	**0.94**
Lebrunia neglecta		0.88				**0.18**
Palythoa caribaeorum		0.55				**0.11**
Phymanthus crucifer			0.20			**0.04**

Variations of mean percent cover by sessile-benthic categories from CORA10 are presented in Figure 40. Differences of reef substrate cover by live stony corals between surveys were statistically significant (ANOVA, p = 0.009, see Appendix 3). Differences were associated with a sharp decline of 41.3% between the baseline survey in 1999 and the first monitoring survey in 2005. The lack of monitoring data between 1999 and 2005 constrains analysis of coral cover change during that time, but massive coral bleaching was reported for the south coast of Puerto Rico in 1998 (Williams and Williams, 2000). Therefore, declines of coral cover measured during 2005 at CORA10 may be related to the lingering effects of the 1998 coral bleaching event. Other declines of live hard coral cover were measured at CORA10 in 2007 and 2008, mostly associated with mortality of the dominant coral species complex, *Orbicella annularis*. Such declines appear to be related to the late 2005 regional coral bleaching event, with lingering effects to 2008 (Garcia-Sais et al., 2007, 2008 and references therein). The declining trend of live coral cover stabilized during 2009, with several massive coral species showing a recuperation trend.

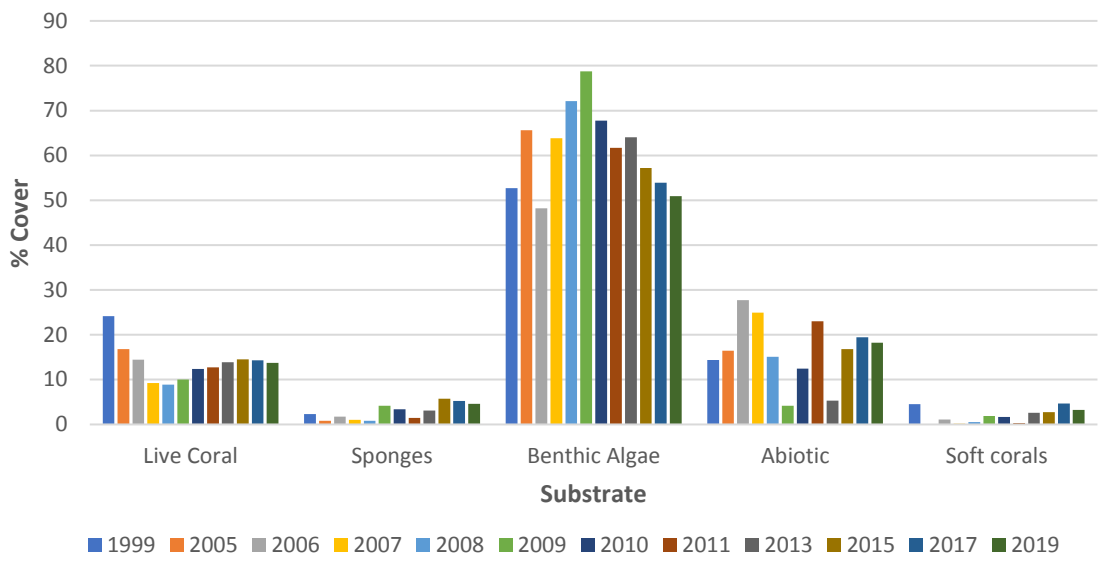


Figure 40. Monitoring trends (1999 – 2019) of mean substrate cover by sessile-benthic categories at CORA10, Guánica.

Since the 2010 monitoring survey, hard coral cover at CORA10 exhibited an increasing trend that continued until 2015 and has remained virtually stable until the present 2019 survey at an average reef substrate cover of 13.75%. The increasing trend since 2010 was mostly driven by recuperation of reef substrate cover by the *Orbicella spp complex* with minor contributions from *Colpophyllia natans*, *Porites astreoides* and *Siderastrea siderea* (Figure 41). These data are indicative that the pass of Hurricanes Irma and Maria in September 2017 had minimal effects on the coral community at CORA10. There was a 14.5% decline in density of soft corals (gorgonians) that may be related to strong wave action associated perhaps with Hurricane Maria, but temporal differences of soft coral densities at CORA10 were statistically insignificant (ANOVA, $p = 0.109$; Appendix 4).

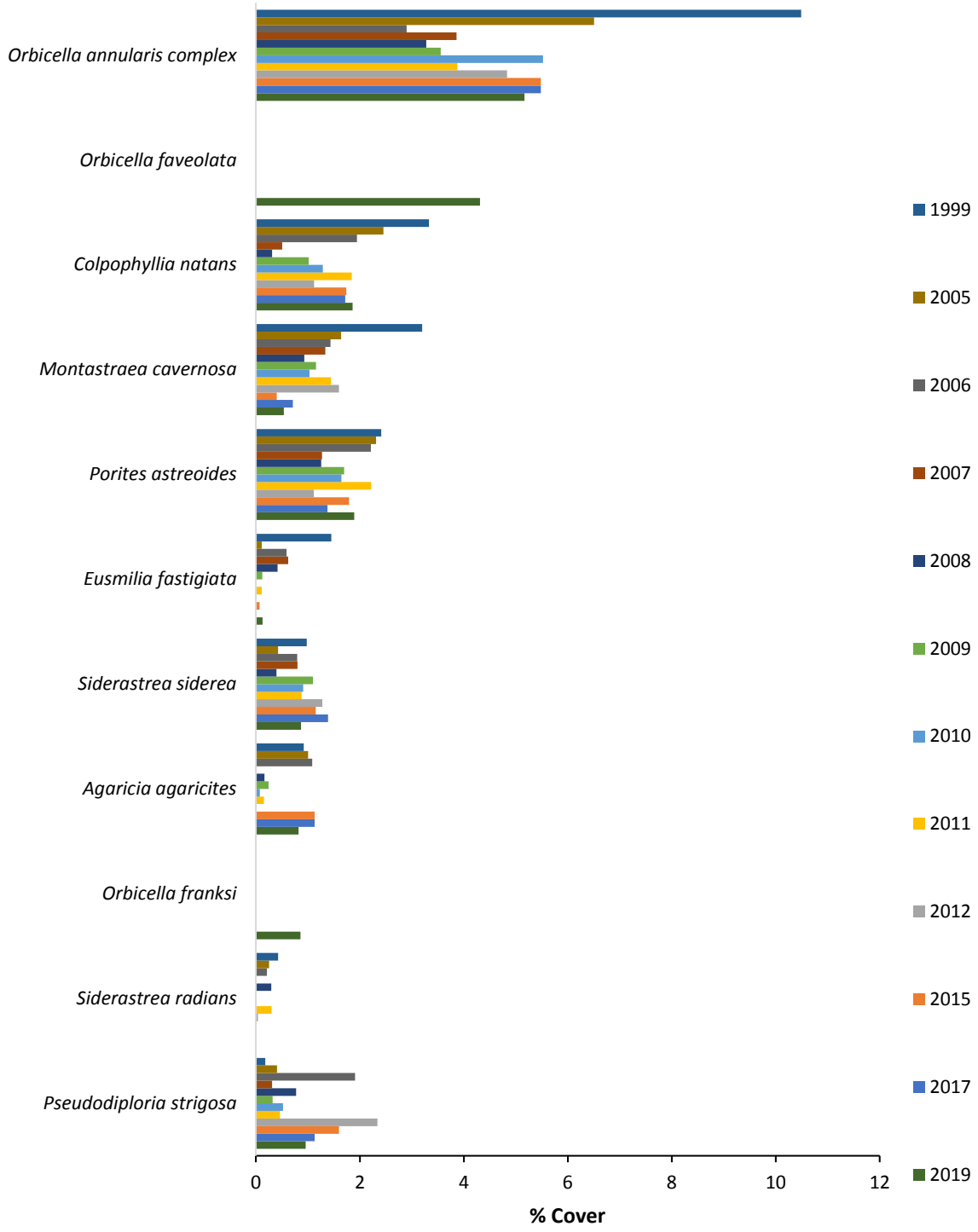


Figure 41. Monitoring trends (1999 – 2019) of mean substrate cover by hard coral species at CORA10, Guánica. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

12.3 Fishes and Motile Megabenthic Invertebrates

A total of 30 fish species were identified within belt-transects during the 2019 survey at CORA10 with a mean density of 42.8 Ind/30 m^2 (range: 28 - 55 Ind/30 m^2) and a mean species richness of 14.4 Spp/Transect (Table 36). Blue chromis (Chromis cyanea), bluehead wrasse (*Thalassoma bifasciatum*) and dusky damselfish (*Stegastes adustus)* were the numerically dominant species with a combined density of 24.2 Ind/30 m^2, representative of 56.5% of the total fish density. Yellowhead wrasse (*Halichoeres garnoti*), stoplight and redband parrotfishes (*Sparisoma viride, S. aurofrenatum*), yellowtail damselfish (*Microspathodon chrysurus*) and sharknose goby (*Elacatinus evelynae*) were present in at least 4 transects and were also part of the main small demersal fish assemblage at CORA10. The main pelagic fish assemblage was represented by streaming schools of creole wrasse (*Clepticus parrae*), some of which entered belt-transect areas and cero mackerels (*Scomberomorus regalis*) and great barracudas (*Sphyraena barracuda*) observed out of transects. Motile megabentic invertebrates were not observed within belt-transects (Table 36).

The fish community at CORA10 exhibited a well-balanced trophic structure, perhaps with the scarcity of large demersal predators. Small opportunistic carnivores, mainly invertebrate and small fish predators included 13 species and a combined density of 16.6 Ind/30m^2, representative of 38.8% of the total fish density within belt-transects. The assemblage included wrasses (*Thalassoma sp., Halichoeres sp.*), gobies (*Elacatinus, Coryphopterus spp*.), Squirrelfishes (*Holocentrus spp, Sargocentron sp*), grunts (*Haemulon spp*), lizardfish (*Synodus sp.*), trumpetfish (*Aulostomus sp*.), spotted drum (*Equetus sp*) and small groupers (*Cephalopholis sp*). Herbivores included 10 species with a combined density of 13.6 Ind/30m^2, or 31.3% of the total fish density. The herbivore assemblage included five species of parrotfishes (*Sparisoma spp., Scarus spp*.), two doctorfishes (*Acanthurus spp*), and three damselfishes (*Stegastes spp, Microspathodon sp*). Zooplanktivores included four species (*Chromis spp, Clepticus sp, Abudefduf sp, Stegastes partitus)* with a combined density of 11.6 Ind/30m^2, or 27.1% of the total fish density within belt-transects. Corallivores included two species of butterflyfishes (*Chaetodon spp*). The larger demersal predators included the red hind and Nassau groupers (*Epinephelus guttatus, E. striatus*), hogfish (*Lachnolaimus maximus*), and schoolmaster snapper (*Lutjanus apodus*) observed in the 20x3m belt-transects (Table 37). Pelagic predators included cero mackerels (*Scomberomorus regalis*) and great barracudas (*Sphyraena barracuda*) observed outside transects. Several bottlenose dolphins (*Turciops truncatus*), at the top of the pelagic food chain were reported from CORA10 during the 2010 survey (Garcia-Sais et al., 2012).

Table 36. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at CORA10, Guánica.

Cayo Coral (CORA10)						
Survey Date: 8-9-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Chromis cyanea	16	2	28	0	0	**9.2**
Thalassoma bifasciatum	8	1	0	18	18	**9.0**
Stegastes adustus	6	5	8	6	5	**6.0**
Halichoeres garnoti	1	2	1	2	8	**2.8**
Sparisoma aurofrenatum	1	2	2	1	2	**1.6**
Clepticus parrae	6	0	2	0	0	**1.6**
Elacatinus evelynae	1	2	3	2	0	**1.6**
Sparisoma viride	2	1	2	0	3	**1.6**
Acanthurus tractus	1	3	0	0	1	**1.0**
Microspathodon chrysurus	1	1	1	1	1	**1.0**
Haemulon flavolineatum	0	1	2	0	1	**0.8**
Chaetodon capistratus	0	2	1	0	0	**0.6**
Scarus iseri	0	3	0	0	0	**0.6**
Scarus taeniopterus	0	0	0	1	2	**0.6**
Stegastes leucostictus	2	0	0	1	0	**0.6**
Stegastes partitus	3	0	0	0	0	**0.6**
Aulostomus maculatus	1	1	0	0	0	**0.4**
Cephalopholis cruentata	1	0	0	1	0	**0.4**
Serranus tigrinus	1	0	0	0	1	**0.4**
Abudefduf saxatilis	0	0	1	0	0	**0.2**
Acanthurus coeruleus	0	0	1	0	0	**0.2**
Cantherhines pullus	1	0	0	0	0	**0.2**
Chaetodon ocellatus	0	0	1	0	0	**0.2**
Coryphopterus glaucofraenum	0	0	0	0	1	**0.2**
Coryphopterus lipernes	0	0	1	0	0	**0.2**
Equetus punctatus	0	0	1	0	0	**0.2**
Holocentrus rufus	0	0	0	0	1	**0.2**
Sargocentron coruscum	0	1	0	0	0	**0.2**
Stegastes variabilis	0	1	0	0	0	**0.2**
Synodus intermedius	1	0	0	0	0	**0.2**
Total Individuals	53	28	55	33	44	**42.6**
Total Species	17	15	16	11	13	**14.4**
Invertebrates						
none observed						

Variations of mean fish density and species richness between monitoring surveys are presented in Figure 42. Both fish density and species richness evidenced statistically significant differences between monitoring surveys (ANOVA; $p < 0.0001$, Appendix 5 - 6). The typically high variability of the fish community structure both in terms of density and species richness appears to be

regulated in part by the physical conditions at the time of survey because of the relatively shallow depth. Fishes tend to hide or swim to deeper water when conditions of surge and abrasion prevail at the reef. Another relevant factor seems to be the natural abundance fluctuations of numerically dominant fishes, such as masked goby (*Coryphopterus personatus*), creole wrasse (*Clepticus parrae*) and *Chromis spp*. The temporal fluctuations of abundance by these small, short generation schooling fishes appear to be strongly influenced by density independent factors, such as recruitment success (Esteves, 2013). During the 2019 monitoring survey, mean fish density (42.8 Ind/30m^2) and species richness (14.4 Spp/30m^2) were within one standard deviation of the historical mean for both parameters (see Appendix 5-6).

Table 37. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at CORA10, Guánica.

Survey Date: 8-9-19					**TRANSECTS**				
		Size	**Life**		**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus coeruleus c1	Acanthuridae	1-5	Recruit	0	0	1	0	0	**0.2**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	0	0	1	0	**0.2**
Acanthurus coeruleus c4	Acanthuridae	16-20	Adult	1	0	0	0	0	**0.2**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	1	5	3	1	2	**2.4**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	0	1	0	0	1	**0.4**
Caranx ruber c3	Carangidae	11-15	Juvenile	0	0	15	0	2	**3.4**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	2	0	0	1	0	**0.6**
Epinephelus guttatus c3	Serranidae	11-15	Juvenile	0	0	0	0	1	**0.2**
Epinephelus striatus c10	Serranidae	46-50	Adult	1	0	0	0	0	**0.2**
Lachnolaimus maximus c6	Labridae	26-30	Adult	0	0	0	0	1	**0.2**
Lutjanus apodus c5	Lutjanidae	21-25	Juvenile	0	1	0	0	0	**0.2**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	2	0	0	0	**0.4**
Scarus iseri c3	Scaridae	11-15	Juvenile	0	1	0	0	0	**0.2**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	0	0	0	0	2	**0.4**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	0	0	0	1		**0.25**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	1	0	0	1	0	**0.4**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	0	1	0	0	1	**0.4**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	1	1	1	1	**0.8**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	0	0	2	0	0	**0.4**
Sparisoma radians c1	Scaridae	1-5	Recruit	0	0	0	0	2	**0.4**
Sparisoma viride c1	Scaridae	1-5	Recruit	2	0	2	0	2	**1.2**
Sparisoma viride c4	Scaridae	16-20	Adult	0	0	0	0	1	**0.2**
Sparisoma viride c6	Scaridae	26-30	Adult	1	0	0	0	0	**0.2**
			Totals	**9**	**12**	**24**	**6**	**16**	**13.4**

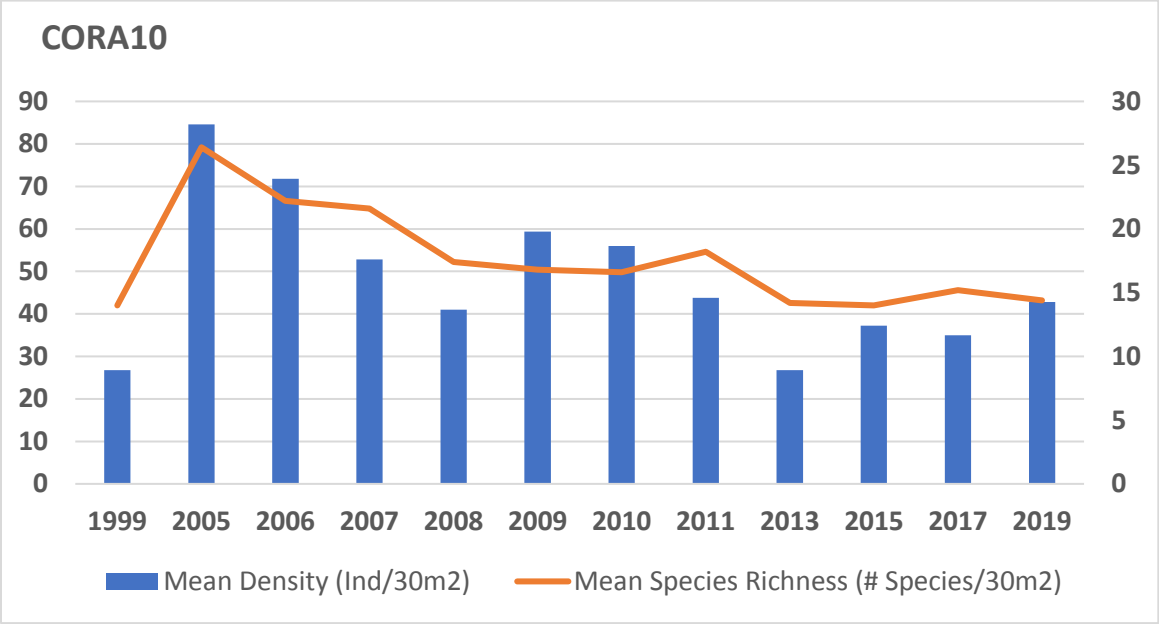
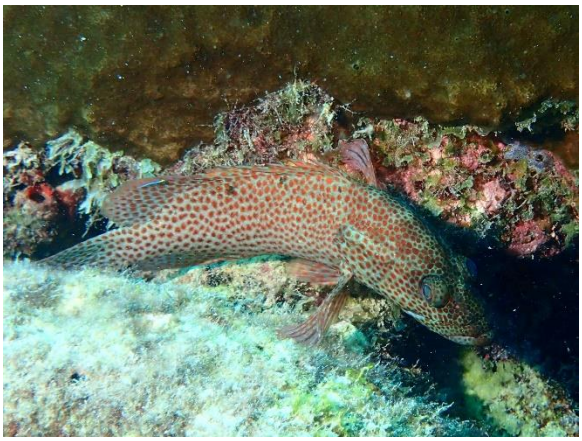


Figure 42. Monitoring trends (1999 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at CORA10, Guánica

12.4 Photo Album 12. CORA10



13. Cayo Aurora (AURO05)

13.1 Physical Description

Cayo Aurora, also known as "Gilligan Island," is an emergent section of Cayos de Caña Gorda, a fringing coral reef system that extends southwesterly from Punta Ballena in the east towards Punta Jacinto in the west. The reef is approximately 2.3 km long and at least 1 km wide. It is separated from Cayo Coral by a deep submarine canyon that cuts through the insular shelf and extends easterly towards the shelf-edge. A georeferenced map of benthic habitats and qualitative characterization of marine communities associated with the main benthic habitats at Cayo Aurora was prepared by Garcia-Sais et al. (2005). The fore-reef of Cayo Aurora is characterized by a gently sloping terrace where elkhorn coral (*Acropora palmata*) represents the main reef structural component, creating a biotope intermixed with massive and encrusting corals and gorgonians at depths between 2 – 5 m (Garcia-Sais et al, 2005). The baseline survey of AURO05 was performed during 2015 (Garcia-Sais et al., 2015). Transects were established at a depth of 4.0 – 4.6 m along the western section of Cayo Aurora 's fore-reef, at the deepest edge of a well-defined *A. palmata* zone (Figure 39). Panoramic views of AURO05 are shown in Photo Album 13.

13.2 Sessile-benthic Reef Community

A total of seven hard coral species were intersected by transects during the 2019 monitoring survey at AURO05 (Table 38). Substrate cover by hard corals averaged 38.46% (range: 24.56 – 47.19%), with a mean density of 11.4 Col/Transect. Elkhorn coral (*Acropora palmata*) was the main coral species in terms of substrate cover with a mean of 31.17% (range: 23.74 – 42.63%), representing 81.0% of the total cover by hard corals. Staghorn coral (*Acropora cervicornis*), fire coral (*Millepora complanata*), mustard hill coral (*Porites astreoides*), massive starlet coral (*Siderastrea siderea*) and symmetrical brain coral (*Pseudodiploria strigosa*) comprised the coral assemblage within transects. Elkhorn coral colonies were observed growing from a hard ground bottom covered by sand. During the baseline survey, elkhorn coral colonies were found in very good health condition and dead standing or large broken fragments were uncommon. During the 2017 survey, *A. palmata* fragments of variable dimensions, including many large branches were abundant over the reef bottom. Evidently, this reef was exposed to extreme wave action and the broken colonies appear to have resulted from mechanical damage associated with the pass of Hurricane Mathew along the south coast of Puerto Rico during October 2016. Four hard coral colonies out of the 57 intercepted by transects showed signs of apparent infectious disease for a coral disease prevalence of 7.0%. Diseased hard coral species included 1- *Porites astreoides*, 2- *Acropora cervicornis* and 1- *A. palmata* (Appendix 2).

Table 38. Percent reef substrate cover by sessile-benthic categories at AURO05, Guánica

AURO05 Survey Date: 8-9-19	Transects 1	2	3	4	5	Mean
Depth (m)	4.0	4.1	4.6	4.0	4.0	**4.14**
Rugosity (m)	2.22	4.10	2.70	3.57	4.25	**3.37**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	15.58	17.38	12.24	23.12	19.74	**17.61**
Gaps/Holes	1.37		1.10	0.83	4.22	**1.51**
Rubble		1.69				**0.34**
Sand				1.14	0.20	**0.27**
Total Abiotic	**16.95**	**19.07**	**13.34**	**25.08**	**24.17**	**19.72**
Benthic Algae						
Turf (mixed)	26.00	11.32	23.93	16.41	20.92	**19.72**
Turf (mixed) with sediment		9.83		13.52	1.47	**4.96**
CCA (total)	5.27	5.56	5.07	2.06	0.98	**3.79**
Ramicrusta spp.	1.26	4.47	3.31	3.72	3.44	**3.24**
Peyssonnelia spp.	4.01	0.70	2.54	0.62	0.20	**1.61**
Dictyota spp.		0.70	1.10	2.06		**0.77**
Total Benthic Algae	**36.54**	**32.57**	**35.94**	**38.39**	**27.01**	**34.09**
Cyanobacteria	**0.00**	**0.00**	**0.00**	**1.03**	**0.00**	**0.21**
Hard Coral						
Acropora palmata	25.66	29.10	34.73	23.74	42.63	**31.17**
Acropora cervicornis	3.55	5.36	10.92	0.83		**4.13**
Millepora alcicornis	6.07	1.49			0.98	**1.71**
Agaricia agaricites	0.57	0.70	0.99			**0.45**
Porites astreoides	1.03	0.40	0.55			**0.40**
Siderastrea siderea	1.83					**0.37**
Pseudodiploria strigosa		1.19				**0.24**
Total Hard Coral	**38.72**	**38.23**	**47.19**	**24.56**	**43.61**	**38.46**
# Coral Colonies /Transect	**11**	**12**	**10**	**11**	**13**	**11.4**
#Diseased Coral Colonies/Transect	**1**	**0**	**3**	**0**	0	**0.80**
Soft Corals						
Erythropodium caribaeorum	2.29		1.21	1.44	3.83	**1.76**
Total Soft Corals	**2.29**	**0**	**1.21**	**1.44**	**3.83**	**1.76**
# Soft Coral Colonies/Transect					5	**1.00**
Sponges						
Cliona caribbaea	0.57	3.08		2.58		**1.25**
Chondrilla caribensis		1.59	0.44	1.44		**0.69**
Desmapsamma spp.					0.98	**0.20**
Iotrochota birotulata					0.39	**0.08**
Scopalina ruetzleri				0.10		**0.02**
Total Sponges	**0.57**	**4.67**	**0.44**	**4.13**	**1.38**	**2.24**
Zoanthids						
Palythoa caribaeorum	4.93	5.46	1.87	4.54	0	**3.36**
Others *Ricordea florida*				0.83		**0.17**

Soft corals were represented within transects by the encrusting gorgonian (*Erythropodium caribaeorum*) with a mean substrate cover of 1.76%. Erect soft coral colonies were observed outside transects but in very low abundance. Small encrusting sponges were intercepted by all transects with a mean substrate cover of 2.24%. *Cliona caribbaea* and *Chondrilla caribensis* were the most prominent along transects with a combined mean cover of 1.94%, or 86.6% of the total cover by sponges. The encrusting zoanthid (*Palythoa caribaeorum*) was present in four transects with a mean cover of 3.36% (Table 38). Turf algae was the main component of the benthic algae assemblage with a mean cover of 24.68%, representative of 72.4% of the total cover by benthic algae. Crustose red coralline algae, including CCA (mixed assemblage), *Ramicrusta sp.* and *Peyssonnelia sp*. were present in all transects with a combined substrate cover of 8.64%. Abiotic cover, which averaged 19.72% was mostly associated with large overhangs created by elkhorn coral branches and gaps and contributed to a mean reef substrate rugosity of 3.37m (Table 38).

Figure 43 shows the mean cover by substrate categories at AURO05 during the monitoring surveys. Differences of hard coral cover between surveys were not statistically different (ANOVA, $p = 0.268$; Appendix 3). Elkhorn coral represented more than 80% of the total cover by corals in all surveys and although substantial breakage of branches was noted for the 2017 survey, most fell along the transects and were still alive during the monitoring survey and were quantified as live coral cover, with only small reductions to the overall live coral cover. During the 2019 survey substrate cover by hard corals increased 9.1% relative to the previous 2017 survey largely influenced by an increase of cover of staghorn coral (*Acropora cervicornis*) (Figure 44). These were mostly new colonies that have colonized the reef since the previous 2017 monitoring survey.

13.3 Fishes and Motile Megabenthic Invertebrates

A total of 27 fish species were identified within belt-transects from AURO05 during the 2019 survey with a mean density of 69.4 Ind/30 m^2 (range: 56 – 78 Ind/30 m^2) and a mean species richness of 14.0 Spp/Transect (Table 39). The bluehead wrasse (*Thalassoma bifasciatum*) was the absolute dominant species with a mean density of 32.2 Ind/30 m^2, representative of 46.4% of the total fish density within belt-transects. Another seven species were present in at least four out of the five transects and appear to be part of the small demersal resident fish assemblage at AURO05. These are the dusky, bicolor and yellowtail damselfishes (*Stegastes adustus. S. partitus, Microspathodon chrysurus*), redlip blenny (*Ophioblennius atlanticus*), clown wrasse (*Halichoeres maculipinna*), yellowtail snapper (*Ocyurus chrysurus*) and five-band surgeonfish (*Acanthurus tractus*). Motile megabenthic invertebrates were not observed within belt-transects.

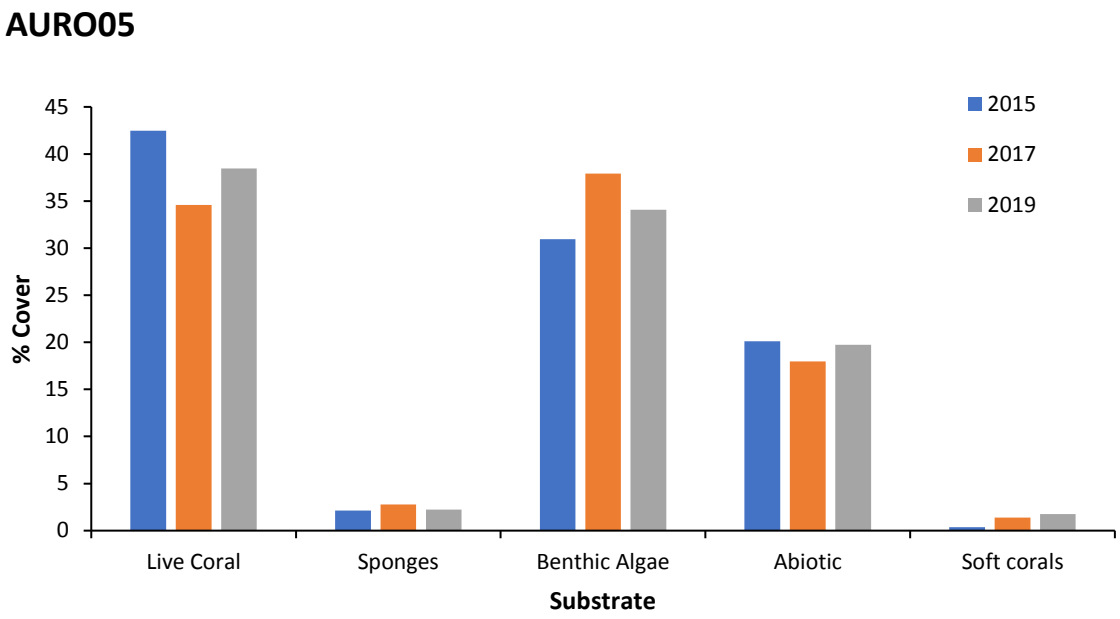


Figure 43. Monitoring trends (2015 – 2019) of mean substrate cover by sessile-benthic categories at AURO05, Guánica.

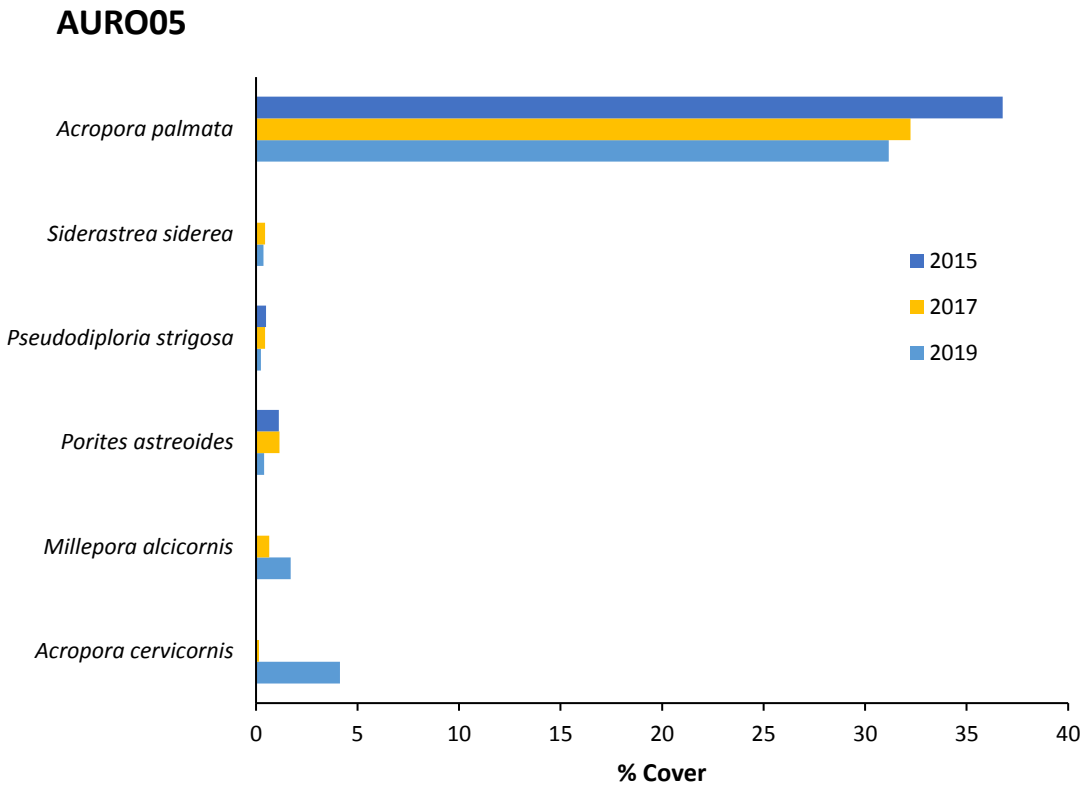


Figure 44. Monitoring trends (2015 – 2019) of mean substrate cover by hard coral species at AURO05, Guánica.

Table 39. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at AURO05, Guánica.

Cayo Aurora (AURO05)						
Survey Date: 8-9-19			**Belt-Transects**			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	24	35	32	22	48	**32.2**
Stegastes partitus	14	4	11	7	2	**7.6**
Stegastes adustus	9	7	7	8	6	**7.4**
Microspathodon chrysurus	5	3	7	3	3	**4.2**
Ophioblennius atlanticus	8	4	4	3	1	**4.0**
Caranx ruber	0	0	0	0	8	**1.6**
Halichoeres maculipinna	1	1	2	2	1	**1.4**
Halichoeres bivittatus	1	0	0	2	3	**1.2**
Ocyurus chrysurus	2	2	0	1	1	**1.2**
Sparisoma aurofrenatum	2	0	1	3	0	**1.2**
Acanthurus tractus	1	2	0	1	1	**1.0**
Haemulon flavolineatum	0	0	1	1	2	**0.8**
Halichoeres garnoti	0	1	3	0	0	**0.8**
Scarus iseri	0	4	0	0	0	**0.8**
Sargocentron coruscum	1	1	0	0	1	**0.6**
Acanthurus coeruleus	0	0	1	0	1	**0.4**
Chaetodon capistratus	0	0	2	0	0	**0.4**
Halichoeres radiatus	0	1	1	0	0	**0.4**
Malacoctenus triangulatus	1	0	0	1	0	**0.4**
Stegastes variabilis	0	1	1	0	0	**0.4**
Acanthurus chirurgus	1	0	0	0	0	**0.2**
Aulostomus maculatus	1	0	0	0	0	**0.2**
Cephalopholis cruentata	1	0	0	0	0	**0.2**
Chaetodon striatus	0	0	0	1	0	**0.2**
Melichthys niger	0	1	0	0	0	**0.2**
Sparisoma viride	0	0	0	1	0	**0.2**
Stegastes leucostictus	0	0	1	0	0	**0.2**
Total Individuals	72	67	74	56	78	**69.4**
Total Species	15	14	14	14	13	**14.0**
Invertebrates						
none observed						

The fish trophic structure of AURO05 was strongly dominated by an assemblage of opportunistic carnivore species, as is typical of high energy reef systems. These included 13 species with a cumulative density of 45.0 Ind/30 m^2, representative of 64.8% of the total fish density within belt-transects. The assemblage included wrasses (Labridae), blennies (Blenniidae), jacks (Carangidae), snappers (Lutjanidae), trumpetfish (Aulostomidae), squirrelfishes (Holocentridae), small groupers (Serranidae) and grunts (Haemulidae). Herbivores were represented by 11 species with a combined density of 16.1 Ind/30 m^2, or 23.2% of the total density. Parrotfishes (Scaridae), doctorfishes (Acanthuridae) and damselfishes (Pomacentridae) comprised the main herbivorous fish assemblage.

Zooplanktivores were represented by the bicolor damselfish with a mean abundance of 7.6 Ind/30 m^2, or 11.0% of the total individuals within belt-transects. Large demersal predators were not observed. Adult yellowtail snappers (*Ocyurus chrysurus*) and juvenile jacks (*Caranx spp*) comprised the main pelagic predators observed within 20 x 3m belt-belt-transects (Table 40).
The size distribution of commercially important fishes and the larger reef fish herbivores was characterized by juvenile stages of doctorfishes (Acanthuridae), parrotfishes (Scaridae), jacks (Carangidae) and yellowtail snappers (Lutjanidae). Recruitment juveniles (1-5cm) of the redband parrotfish (*Sparisoma aurofrenatum*) were observed (Table 40). Juvenile and adult schoolmaster snappers (*Lutjanus apodus*), adult coneys (*Cephalopholis fulva*) and juvenile yellowfin grouper (*Mycteroperca venenosa*) were previously reported from AURO05 (Garcia-Sais et al., 2017).

Temporal variations of the mean fish density and species richness within belt-transects at AURO05 are shown in Figure 45. Both fish density and species richness peaked during the present 2019 survey. Differences of fish density between monitoring surveys were statistically significant (ANOVA, $p = 0.001$; Appendix 5). The total fish density measured during 2019 was driven by the peak abundance of bluehead wrasse (*Thalassoma bifasciatum*) which increased in density more than 3-fold relative to previous surveys at AURO05. This may have been influenced by a successful recruitment event or by the relatively calm conditions prevailing during the 2019 survey that allow small water column fishes to remain in shallow reef areas. Temporal differences of fish species richness were statistically insignificant (ANOVA, $p = 0.259$; Appendix 6).

Table 40. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at AURO05, Guánica.

Cayo Aurora (AURO05)									
Survey Date: 8-9-19					**TRANSECTS**				
		Size	**Life**		**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	1	1	0	0	0	**0.4**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	1	0	1	0	2	**0.8**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	0	3	0	0	0	**0.6**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	1	0	1	1	1	**0.8**
Caranx crysos c2	Carangidae	6-10	Juvenile	0	10	0	0	0	**2.0**
Caranx ruber c2	Carangidae	6-10	Juvenile	0	0	0	0	14	**2.8**
Caranx ruber c3	Carangidae	11-15	Juvenile	0	0	0	0	1	**0.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	1	0	0	0	0	**0.2**
Ocyurus chrysurus c2	Lutjanidae	6-10	Juvenile	0	0	0	0	1	**0.2**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	2	0	0	1	0	**0.6**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	1	0	0	0	0	**0.2**
Ocyurus chrysurus c7	Lutjanidae	31-35	Adult	0	2	0	0	0	**0.4**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	4	0	10	0	**2.8**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	0	0	0	0	3	**0.6**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	1	0	0	2	0	**0.6**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	0	0	0	2	1	**0.6**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	1	1	1	0	0	**0.6**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	1	0	0	0	1	**0.4**
Sparisoma viride c2	Scaridae	6-10	Juvenile	0	0	1	0	0	**0.2**
Sparisoma viride c3	Scaridae	11-15	Juvenile	1	0	0	0	0	**0.2**
Sparisoma viride c4	Scaridae	16-20	Adult	0	0	0	1	0	**0.2**
			Totals	**11**	**21**	**4**	**17**	**24**	**15.4**

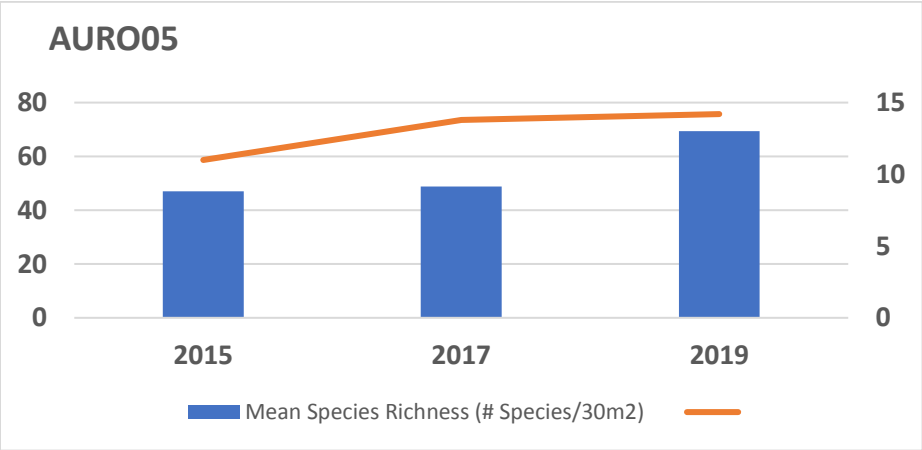
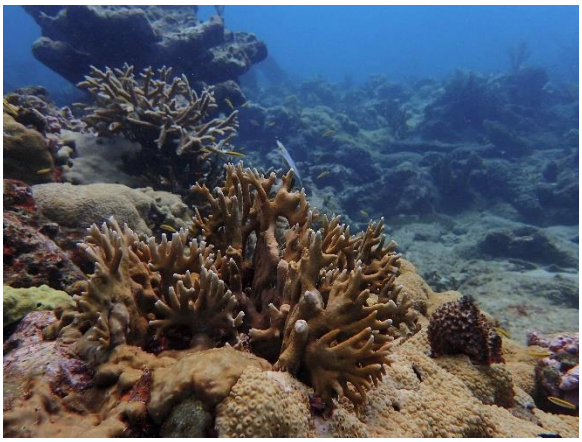


Figure 45. Monitoring trends (2015 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at AURO05, Guánica

13.4 Photo Album 13. AURO05



14. Beril de Guanica Reef (BERI20)

14.1 Physical Description

A spur and groove coral reef formation is found at depths between 17 – 23m along the shelf-edge from Guánica to La Parguera. Spurs run perpendicular to the shelf-edge and exhibit variable dimensions. Our reef monitoring station (BERI20) is located about 3.5 NM offshore between Guánica and La Parguera. Spurs were of relatively low relief (1 meter) increasing towards the edge and separated by sand channels. Five permanent transects were installed on top of the spurs about 50m from the shelf-edge at depths of 15.8 – 18.2 m. The baseline characterization was performed during 2015 (Garcia-Sais et al., 2015). Panoramic view of the Guánica shelf-edge reef is included here as Photo Album 14.

14.2 Sessile Benthic Community

Benthic algae were the dominant category in terms of reef substrate cover at BERI20 with a combined mean of 60.01% (range: 48.41 – 69.87%). Turf algae (mixed assemblage) was the dominant component with a mean cover of 26.41%, representing 44.01% of the total cover by benthic algae. Fleshy brown macroalgae (*Dictyota sp., Lobophora variegata*) were also highly prominent with a combined cover of 28.03%. Red crustose coralline algae (CCA) were present in al transects with a mean cover of 4.43%. *Ramicrusta sp* and *Peyssonnelia sp*. were present but with low substrate cover (<1%). Cyanobacterial patches were intercepted by all five transects with a mean reef substrate cover of 6.86%. Abiotic cover included reef overhangs, sand and coral rubble with a mean combined cover of 5.84% (Table 54). The mean rugosity was 2.85m influenced by low to moderate substrate topographic relief and vertical coral projection.

A total of 14 hard coral species were intercepted by transects during the 2019 survey with a mean substrate cover of 17.87% (range: 12.07 – 25.41%) and a mean density of 9.6 Col/Transect (Table 41). Mostly isolated encrusting, mound-shaped and branching colonies of small to moderate size and low topographic relief prevailed at BERI20. Mountainous star coral (*Orbicella faveolata*) and boulder star coral (*O. franksi*) were the dominant hard corals with a combined mean of 8.14%, representing 45.6% of the total cover by hard corals. Mustard hill coral (*Porites astreoides*), great star coral (*Montastrea cavernosa*), lettuce coral (*Agaricia agaricites*), and fire coral (*Millepora alcicornis*) were intercepted by four transects each with a combined cover of 5.59%. A total of three hard coral colonies (1-*Siderastrea siderea*, 1-*Porites astreoides*, 1-*Orbicella faveolata*), out of the 48 total colonies intercepted by transects showed signs of apparent disease infections resulting in a coral disease prevalence of 6.1% (Appendix 2).

Table 41. Percent reef substrate cover by sessile-benthic categories at BERI20, Guánica

BERI20	**Transects**					
Survey date: 8-9-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	15.8	17.0	15.8	18.2	18.2	**17.0**
Rugosity (m)	3.54	0.78	2.52	2.88	4.55	**2.85**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	6.20	1.04	2.24	5.33	6.16	**4.19**
Sand			3.02		1.25	**0.85**
Rubble				1.09	2.89	**0.79**
Total Abiotic	**6.20**	**1.04**	**5.26**	**6.41**	**10.30**	**5.84**
Benthic Algae						
Turf (mixed) with sediment	26.37	17.40	27.29	31.30	21.56	**24.79**
Dictyota spp.	11.58	15.97	17.00	13.70	19.54	**15.56**
Lobophora spp.	3.21	26.88	16.89	10.65	4.72	**12.47**
CCA (total)	8.38	7.01	1.23	4.67	0.87	**4.43**
Turf (mixed)	0.93	2.34	2.57	1.41	0.87	**1.62**
Halimeda spp.				2.07		**0.41**
Peyssonnelia spp.	1.34	0.26			0.29	**0.38**
Macroalgae spp.				0.76		**0.15**
Ramicrusta spp.	0.41					**0.08**
Caulerpa spp.					0.38	**0.08**
Jania spp.					0.19	**0.04**
Total Benthic Algae	**52.22**	**69.87**	**64.99**	**64.57**	**48.41**	**60.01**
Cyanobacteria	**5.17**	**9.61**	**6.94**	**5.00**	**7.60**	**6.86**
Hard Coral						
Orbicella faveolata	6.51	0.78	5.59	3.15	5.87	**4.38**
Orbicella franksi	4.34		5.37	2.07	7.03	**3.76**
Montastraea cavernosa	3.52	3.90		3.70	1.44	**2.51**
Porites astreoides	0.31	4.68	2.35	1.09		**1.68**
Porites porites					7.89	**1.58**
Siderastrea siderea	2.28	3.25			0.29	**1.16**
Millepora alcicornis	1.55	1.04	0.22		0.77	**0.72**
Agaricia agaricites	0.52	0.78	1.23	0.87		**0.68**
Pseudodiploria strigosa			1.01		2.12	**0.62**
Dichocoenia stokesii				0.98		**0.20**
Madracis decactis	0.72			0.22		**0.19**
Diploria labyrinthiformis			0.89			**0.18**
Meandrina meandrites	0.83					**0.17**
Stephanocoenia intersepta	0.21					**0.04**
Total Hard Coral	**20.79**	**14.42**	**16.67**	**12.07**	**25.41**	**17.87**
# Coral Colonies/Transect	**11**	**10**	**8**	**8**	**11**	**9.6**
#Diseased Coral Colonies/Transect	**1**	**1**	**0**	**1**	**0**	**0.60**
Soft Corals						
Erythropodium caribaeorum			0.22	1.96	0.48	**0.53**
Pseudoplexaura flagellosa	0.93				0.19	**0.22**
Briareum asbestinum			0.22	0.22	0.38	**0.17**
Antillogorgia americana				0.43		**0.09**
Eunicea tourneforti					0.29	**0.06**
Eunicea succinea			0.22			**0.04**
Plexaura homomalla	0.21					**0.04**

BERI20			**Transects**			
Survey date: 8-9-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Total Soft Corals	**1.14**		**0.67**	**2.61**	**1.35**	**1.15**
# Soft Coral Colonies/Transect	18	22	26	21	14	**20.2**
Sponges						
Xestospongia muta	6.83					**1.37**
Agelas conifera			1.12	3.37	1.44	**1.19**
Agelas dispar	0.72		2.01	1.74		**0.90**
Iotrochota birotulata	1.14	0.26	0.56	0.54	0.19	**0.54**
Verongula rigida			0.45	1.41	0.38	**0.45**
Ircinia strobilina	1.45				0.58	**0.41**
Neofibularia nolitangere		1.69				**0.34**
Ircinia felix	0.83	0.78				**0.32**
Amphimedon compressa			0.22	1.09	0.19	**0.30**
Agelas clathrodes	1.03		0.45			**0.30**
Neopetrosia spp. smooth	0.31	0.65	0.45			**0.28**
Monanchora arbuscula	0.62			0.43	0.29	**0.27**
Plakortis spp.		0.78			0.38	**0.23**
Aiolochroia crassa					0.96	**0.19**
Chondrilla caribensis					0.87	**0.17**
Ectyoplasia ferox					0.87	**0.17**
Neopetrosia proxima	0.52	0.26				**0.16**
Scopalina ruetzleri	0.21	0.26			0.19	**0.13**
Cliona caribbaea				0.65		**0.13**
Niphates erecta	0.62					**0.12**
Mycale laevis					0.58	**0.12**
Spheciospongia vesparium		0.26				**0.05**
Niphates caribica			0.22			**0.04**
Clathria spp.	0.21					**0.04**
Niphates digitalis		0.13				**0.03**
Agelas sventres				0.11		**0.02**
Total Sponges	**14.48**	**5.06**	**5.48**	**9.35**	**6.93**	**8.26**

Erect soft corals were prominent at BERI20 with a mean density of 20.2 Col/Transect. Some of the most abundant species included *Pseudoplexaura flagellosa*, *Eunicea spp*. and *Antillogorgia americana*. The encrusting types, *Erythropodium caribaeorum* and *Briareum asbestinum*, contributed a combined mean substrate cover of 0.70%. At least 26 sponge species were intercepted by transects with a combined reef substrate cover of 8.26%. *Xestospongia muta* and *Agelas spp* were the main taxonomic assemblage in terms of reef substrate cover (Table 54).

Temporal variations of reef substrate cover by sessile-benthic categories at BERI20 are presented in Figure 46. Hard coral cover increased 13.0% relative to the previous 2017 monitoring survey, but differences were statistically insignificant (ANOVA, p = 0.728; Appendix 3). Small variations of substrate cover were associated with fluctuations of cover by *Montastraea cavernosa, Agaricia agaricites* and *Porites porites* (Figure 47).

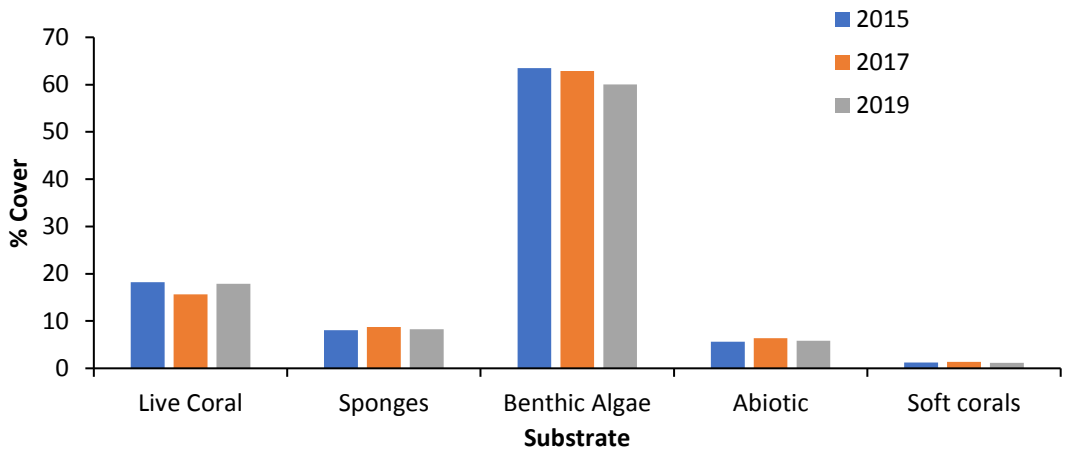


Figure 46. Monitoring trends (2015 – 2019) of mean substrate cover by sessile-benthic categories at BERI20, Guánica.

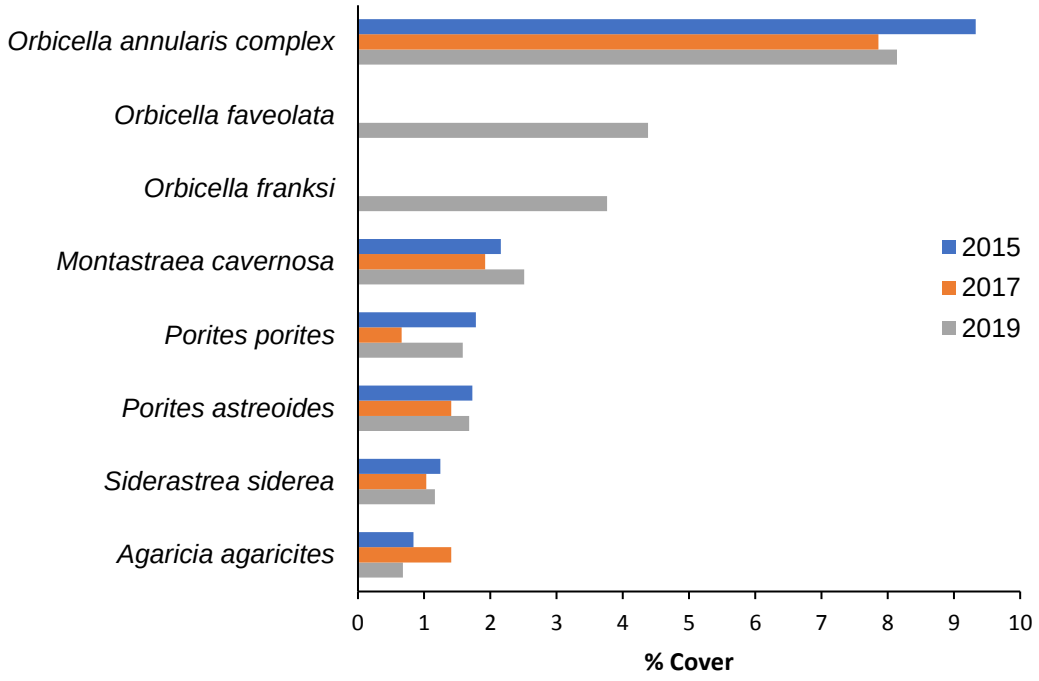


Figure 47. Monitoring trends (2015 – 2019) of mean substrate cover by hard coral species at BERI20, Guánica. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

14.3 Fishes and Motile Megabenthic Invertebrates

A total of 29 fish species were identified within belt-transects at BERI20 with a mean density of 43.4 Ind/30 m^2 (range: 23 – 61 Ind/30 m^2) and a mean species richness of 14.4 Spp/Transect. The bicolor damselfish (*Stegastes partitus*) and the bluehead wrasse *(Thalassoma bifasciatum*) were the numerically dominant fish species with a combined mean density of 21.2 Ind/30m^2, representative of 49.1% of the total fish density within belt-transects (Table 42). Blue chromis (*Chromis cyanea*), Yellowhead wrasse (*Halichoeres garnoti*), Striped parrotfish (*Scarus iseri*), sharknose goby (*Elacatinus evelynae*), longspine squirrelfish (*Holocentrus rufus*) and yellowtail snapper (*Ocyurus chrysurus*) were present in four transects each with a combined density of 8.8 Ind/30m^2. One large hermit crab (*Pagurus sp*) was the only motile megabenthic invertebrate observed within belt-transects (Table 42).

The trophic structure of the fish community at BERI20 was strongly represented by small opportunistic carnivores that typically feed upon small invertebrates and small fishes. The assemblage included 16 species with a combined density of 21.2 Ind/30m^2, representative of 48.8% of the total fish density within belt-transects. The assemblage included wrasses (*Thalassoma sp, Halichoeres spp*), gobies (*Elacatinus sp, Coryphopterus spp*.), squirrelfishes (*Holocentrus sp*), small groupers (*Cephalopholis sp*), grunts (*Haemulon spp*), puffers (*Canthigaster sp*), goatfishes (*Pseudupeneus sp*) and porgies (*Anisotremus sp*). Zooplanktivores were represented by three species, including two damselfishes (*Stegastes partitus, Chromis cyanea*) and one goby (*Coryphopterus sp*) with a combined density of 14.4 Ind/30m^2, representative of 33.2% of the total fish density. Herbivores were represented by six species of parrotfishes (*Sparisoma spp, Scarus spp*), and three doctorfishes (*Acanthurus spp*) with a combined density of 6.8 Ind/30m^2, or 15.7% of the total fish density. Large demersal predators were represented by one hogfish (*Lachnolaimus maximus*).

The size distribution of fish species of commercial value and the larger reef herbivores is presented in Table 43. Juvenile and adult parrotfishes (*Scarus spp, Sparisoma spp*) and doctorfishes (*Acanthurus spp*) were the most abundant commercially important fish assemblage. Terminal phase males of princess parrotfish (*S. taeniopterus*) and recruitment juveniles (1-5 cm) of redband and bucktooth parrotfishes (*S. aurofrenatum, S. radians*) were also observed. Juvenile and adult coneys (Cephalopholis fulva), yellowtail and lane snappers (*O. chrysurus, L. synagris*) and one adult hogfish (*L. maximus*) comprised the larger demersal predator assemblage. One adult great barracuda (*S. barracuda*) was observed out of transects.

Table 42. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at BERI20, Guánica.

Survey Date: 8-9-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Stegastes partitus	7	4	16	9	18	**10.8**
Thalassoma bifasciatum	12	0	21	0	19	**10.4**
Chromis cyanea	1	4	7	0	1	**2.6**
Halichoeres garnoti	3	1	2	0	4	**2.0**
Scarus iseri	0	5	2	1	3	**2.2**
Elacatinus evelynae	2	0	2	1	2	**1.4**
Holocentrus rufus	1	2	2	2	0	**1.4**
Cephalopholis fulva	2	2	1	0	0	**1.0**
Sparisoma radians	5	0	0	0	0	**1.0**
Sparisoma aurofrenatum	1	3	0	1	0	**1.0**
Coryphopterus sp.	0	2	0	3	0	**1.0**
Acanthurus tractus	1	0	1	2	0	**0.8**
Ocyurus chrysurus	1	1	1	1	0	**0.8**
Cephalopholis cruentata	1	0	0	2	1	**0.8**
Haemulon flavolineatum	1	0	1	0	1	**0.6**
Canthigaster rostrata	1	1	1	0	0	**0.6**
Scarus taeniopterus	1	0	0	0	2	**0.6**
Acanthurus coeruleus	0	1	1	1	0	**0.6**
Serranus tigrinus	0	1	1	0	1	**0.6**
Chaetodon capistratus	2	0	0	0	0	**0.4**
Canthigaster rostrata	0	1	1	0	0	**0.4**
Acanthurus chirurgus	0	1	1	0	0	**0.4**
Chaetodon striatus	0	2	0	0	0	**0.4**
Halichoeres maculipinna	0	0	0	0	2	**0.4**
Anisotremus virginicus	1	0	0	0	0	**0.2**
Haemulon sciurus	1	0	0	0	0	**0.2**
Sparisoma viride	1	0	0	0	0	**0.2**
Coryphopterus lipernes	0	1	0	0	0	**0.2**
Pseudupeneus maculatus	0	1	0	0	0	**0.2**
Lachnolaimus maximus	0	0	0	1	0	**0.2**
Total Individuals	45	33	61	24	54	**43.4**
Total Species	19	17	16	11	11	**14.8**
Invertebrates						
Pagurus spp.	1	0	0	0	0	**0.2**

Table 43. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at BERI20, Guánica.

Survey Date: 8-9-19					TRANSECTS				
		Size	Life		(Ind/60m^2)				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c2	Acanthuridae	6-10	Juvenile	0	2	1	0	0	**0.6**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	0	1	1	0	0	**0.4**
Acanthurus chirurgus c4	Acanthuridae	16-20	Adult	0	0	0	1	0	**0.2**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	0	1	1	1	1	**0.8**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	0	2	0	2	0	**0.8**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	1	0	2	1	1	**1.0**
Cephalopholis cruentata c2	Serranidae	6-10	Juvenile	0	0	0	0	1	**0.2**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	1	0	0	2	1	**0.8**
Cephalopholis fulva c2	Serranidae	6-10	Juvenile	1	2	0	0	0	**0.6**
Cephalopholis fulva c3	Serranidae	11-15	Juvenile	0	1	0	0	2	**0.6**
Cephalopholis fulva c4	Serranidae	16-20	Adult	1	0	1	0	0	**0.4**
Lachnolaimus maximus c4	Labridae	16-20	Adult	0	0	0	1	0	**0.2**
Lutjanus synagris c2	Lutjanidae	6-10	Juvenile	1	0	0	0	0	**0.2**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	1	2	0	1	0	**0.8**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	0	0	1	0	0	**0.2**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	4	0	3	0	**1.4**
Scarus iseri c3	Scaridae	11-15	Juvenile	0	1	2	0	0	**0.6**
Scarus iseri c4	Scaridae	16-20	Adult	0	1	0	0	0	**0.2**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	0	0	0	0	2	**0.4**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	1	0	0	0	0	**0.2**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	0	2	0	1	0	**0.6**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	1	0	0	0	0	**0.2**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	1	0	2	0	**0.6**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	1	0	0	0	0	**0.2**
Sparisoma chrysopterum c6	Scaridae	26-30	Adult	1	0	0	0	0	**0.2**
Sparisoma radians c1	Scaridae	1-5	Recruit	5	0	1	0	0	**1.2**
			Totals	**15**	**20**	**10**	**15**	**8**	**13.6**

Figure 48 shows the variations of mean fish density and species richness monitoring surveys. Statistically significant differences were evidenced for both fish density (ANOVA, p = 0.010, Appendix 5) and species richness (ANOVA, p = 0.015, Appendix 6). The difference is related to the lower density and richness measured during the 2017 compared to the 2015 baseline and the

most recent 2019 monitoring surveys. Density differences were driven by fluctuations in the density of mackerel scad (*Decapterus macarellus*) and bluehead wrasse (*Thalassoma bifasciatum*). The former was the numerically dominant species during the 2015 baseline survey, whereas the latter was a numerically dominant species in 2019. Both species were either absent or present in much lower densities in 2017. Mackerel scad is a schooling pelagic species that is not a reef resident, but rather an occasional transitory species not expected to be consistently included in fish monitoring surveys. Therefore, the higher density in 2015 was probably driven by an sporadic occurrence of this species in the reef. In the case of the bluehead wrasse, its density variations between monitoring surveys may be related to short-term fluctuations of recruitment success and/or to physical conditions at the time of survey.

Variations of species richness were also related to the lower measurements in 2017 compared to the 2015 baseline and the monitoring 2017 survey. Given the fact that both the fish density and species richness measured during 2015 and 2017 are similar it is suggested that the minimum values measured in 2017 were related to short-term events and not a real pattern of ecological significance at BERO20.

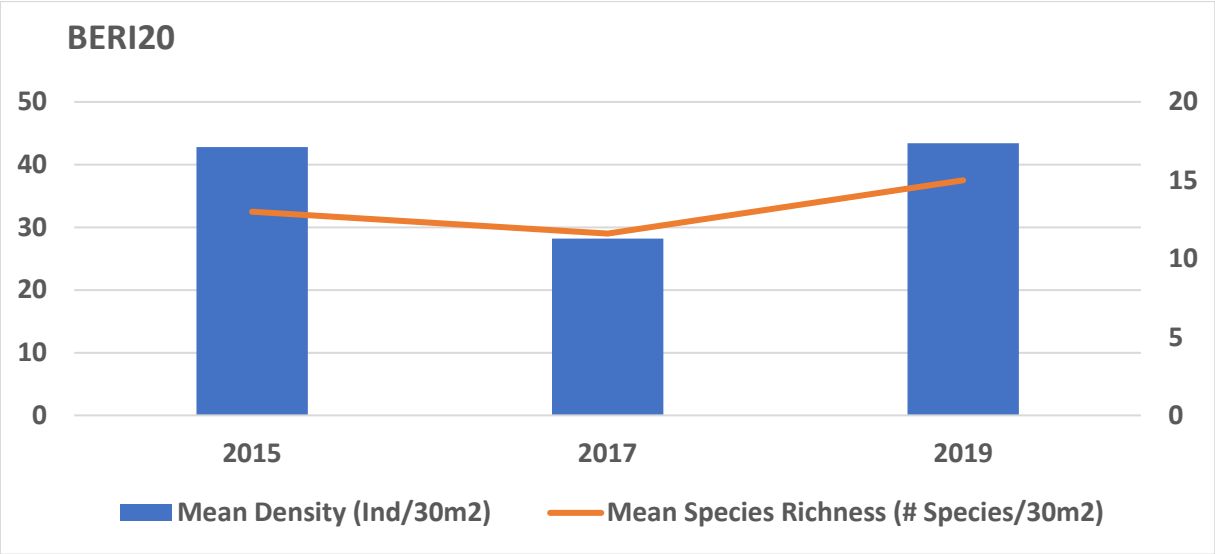
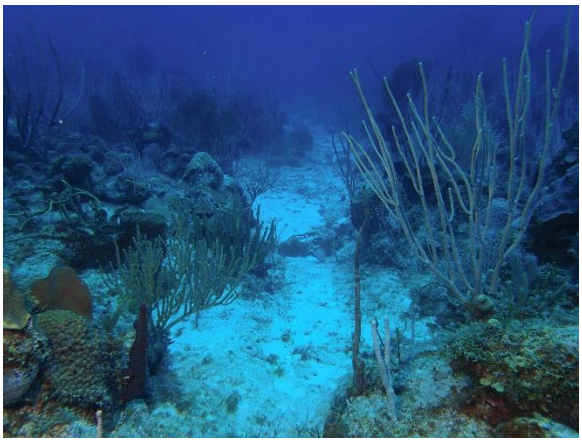
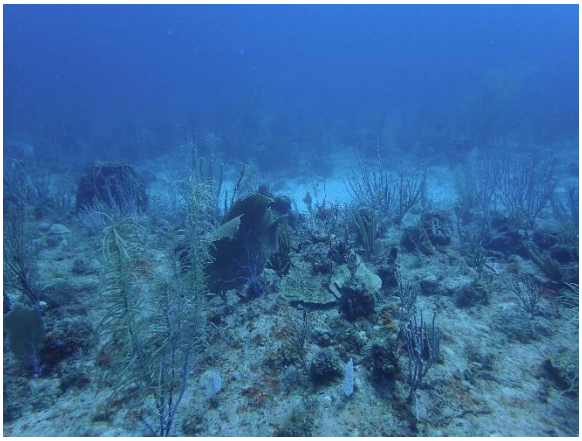


Figure 48. Monitoring trends (2015 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at BERI20, Guánica

14.4 Photo Album 14. BERI20





15. Maria Langa Reef 20 (MLAN20)

15.1 Physical Description

Maria Langa is a fringing reef system bordering the east section of the entrance channel of Guayanilla Bay (Figure 49). The reef sits at the edge of the Guayanilla submarine canyon and is thereby influenced by both estuarine and oceanic conditions. Our survey was performed along a relatively flat terrace at the base of the fore-reef within a depth contour of 14.6 – 16.2m. Panoramic views of the reef community at MLAN20 are shown as Photo Album 15.

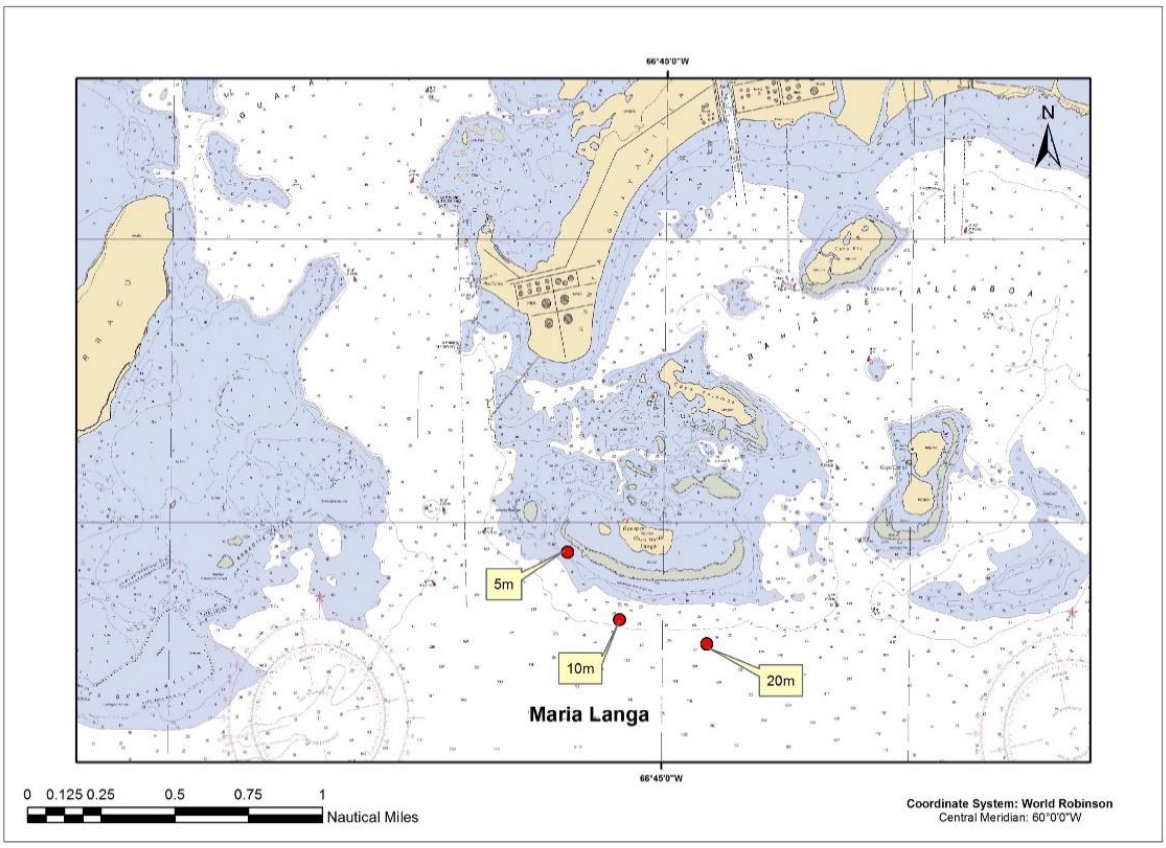


Figure 49. Map of Guayanilla Bay entrance channel showing location of reef monitoring stations

15.2 Sessile Benthic Reef Community

Benthic algae were the dominant sessile-benthic reef component in terms of substrate cover at MLAN20 with a mean of 53.19% (range: 40.26 – 64.40%). Turf algae, a mixed assemblage of short brown and red algae strongly dominated the benthic algal component with a mean substrate cover of 48.37 % (range: 41.4 – 64.9%), representing 90.9% of the total cover by benthic algae (Table 44). Most of the turf algae intercepted by transects was densely packed with fine

sediments. Red crustose coralline algae (*CCA*) were present in all five transects with a mean cover of 1.75%. Small patches of cyanobacteria were observed over consolidated sand sections and intermixed with the turf algae. Abiotic substrate categories averaged 26.00% mostly contributed by reef overhangs and sand. The reef substrate rugosity averaged 3.08m, largely influenced by the sedimentary features of the shelf, with minor contributions from hard corals and sponges.

Erect soft corals were the most prominent sessile-benthic invertebrate component at MLAN20 with a mean density of 27.4 Col/Transect. Because of their vertical projection they contributed poorly to the reef substrate cover but substantially to the benthic habitat complexity. Species identifications of erect soft corals were not produced, but sea plumes (*Antillogorgia spp*), sea rods (*Eunicea spp*) and sea fans (*Gorgonia spp*) were the most common. Encrusting soft corals, such as the corky sea-finger (*Briareum asbestinum*) and the encrusting gorgonian (*Erythropodium caribaeorum*) were present in five and four transects, respectively with a combined mean substrate cover of 4.43% (Table 44). Sponges were represented by 11 species intercepted by transects with a mean substrate cover of 1.42%. Small encrusting colonies prevailed with low contributions to the overall reef topographic relief and benthic habitat complexity. *Mycaele levis* was the dominant species with a mean cover of 0.49%. The encrusting zoanthid (*Palythoa caribaeorum*) was also present in two transects with a mean cover of 0.44%.

Hard corals were represented by 12 species intercepted by transects with a mean substrate cover of 13.85% (range: 9.66 – 16.17%) and a man density of 8.8 Col/Transect (Table 44). Lettuce coral (*Agaricia agaricites*) and mountainous star coral (*Orbicella faveolata*) were the most prominent in terms of reef substrate cover with means of 4.74% and 3.39%, respectively. Blushing star coral (*Stephanocoenia intercepta*) and massive starlet coral (*Siderastrea siderea*) were intercepted by all five transects and along with the aforementioned species comprised part of the main hard coral assemblage at MLAN20. Hard corals were mostly present as isolated mound-shaped and encrusting colonies providing low to moderate contributions to the reef topographic relief. A total of 44 hard coral colonies were intercepted at MLAN20, including six with apparent signs of infectious diseases, resulting in a coral disease prevalence of 13.6%. Apparently diseased colonies included 5-*Siderastrea siderea* and 1-*Orbicella faveolata* (Appendix 2). A total of four partially bleached hard coral colonies were also observed at MLAN20.

Table 44. Percent reef substrate cover by sessile-benthic categories at MLAN20, Guayanilla.

MLAN20	**Transects**					
Survey date: 8-10-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	14.8	16.2	14.6	15.0	14.8	**15.08**
Rugosity (m)	3.48	2.54	2.81	3.58	3.01	**3.08**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	13.29	4.02	10.49	11.86	25.19	**12.97**
Sand	15.06	3.01	20.11	3.20	13.24	**10.92**
Rubble	2.08	7.37				**1.89**
Gaps/Holes		0.56	0.55			**0.22**
Total Abiotic	**30.43**	**14.96**	**31.15**	**15.05**	**38.43**	**26.00**
Benthic Algae						
Turf (mixed) with sediment	48.70	61.83	39.78	54.85	32.29	**47.49**
Peyssonnelia spp.	0.21	1.56	2.19	4.23	7.21	**3.08**
CCA (total)	1.25	1.00	2.95	2.78	0.75	**1.75**
Turf (mixed)	4.05		0.33			**0.88**
Total Benthic Algae	**54.21**	**64.40**	**45.25**	**61.86**	**40.26**	**53.19**
Cyanobacteria	**0.00**	**1.12**	**1.09**	**0.00**	**0.00**	**0.44**
Hard Coral						
Agaricia agaricites	2.80	4.80	4.92	7.53	3.66	**4.74**
Orbicella faveolata	2.91		9.51	2.27	2.26	**3.39**
Stephanocoenia intersepta	0.31	1.67	0.33	1.65	3.98	**1.59**
Siderastrea siderea	1.04	3.68	0.33	1.13	0.22	**1.28**
Colpophyllia natans	2.18				3.98	**1.23**
Porites astreoides		1.90	0.22			**0.42**
Madracis decactis		0.56	0.66	0.72		**0.39**
Agaricia lamarcki		1.12				**0.22**
Montastraea cavernosa		0.67			0.43	**0.22**
Millepora alcicornis	0.42		0.22		0.22	**0.17**
Helioseris cucullata					0.65	**0.13**
Scolymia cubensis					0.32	**0.06**
Total Hard Coral	**9.66**	**14.40**	**16.17**	**13.30**	**15.72**	**13.85**
# Coral Colonies /Transect	**9**	**10**	**8**	**8**	**9**	**8.8**
#Diseased Coral Colonies/Transect	**1**	**2**	**1**	**2**	**0**	**1.20**
# Bleached Coral Colonies/Transect	**2**	**2**	**0**	**0**	**0**	**0.80**
Soft Corals						
Briareum asbestinum	3.63	1.56	5.03	6.19	1.72	**3.63**
Erythropodium caribaeorum	0.83	0.45		1.96	0.75	**0.80**
Antillogorgia americana			0.44			**0.09**
Antillogorgia acerosa	0.21					**0.04**
Total Soft Corals	**4.67**	**2.01**	**5.46**	**8.14**	**2.48**	**4.55**
# Soft Coral Colonies/Transect	**32**	**25**	**25**	**26**	**29**	**27.4**
Sponges						
Mycale laevis	0.42	0.56	0.66	0.52	0.32	**0.49**
Prosuberites laughlini		0.33			0.54	**0.17**

MLAN20			**Transects**			
Survey date: 8-10-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Amphimedon compressa	0.21				0.65	**0.17**
Scopalina ruetzleri			0.22		0.43	**0.13**
Niphates erecta		0.33	0.00	0.21		**0.11**
Niphates caribica		0.45				**0.09**
Iotrochota arenosa				0.41		**0.08**
Plakortis spp.		0.33				**0.07**
Niphates spp.	0.21					**0.04**
Monanchora arbuscula				0.21		**0.04**
Agelas conifera					0.11	**0.02**
Total Sponges	**0.83**	**2.01**	**0.87**	**1.34**	**2.05**	**1.42**
Others						
Palythoa caribaeorum		1.12			1.08	**0.44**
Ricordea florida	0.21					**0.04**

Variations of reef substrate cover by sessile-benthic categories during monitoring surveys are shown in Figure 50. The main difference was related to an increase of cover by abiotic categories, along with a corresponding decline of benthic algae possibly influenced by an increase of sand deposition during events of high wave and surge energy. The mean substrate cover by hard corals declined 8.4% in 2019 relative to the 2017 mean, but differences between monitoring surveys were statistically insignificant (ANOVA, p=0.658; Appendix 3). Mountainous star coral (*Orbicella faveolata*) and lettuce coral (*Agaricia agaricites*) remained as the dominant corals in terms of reef substrate cover without any major differences in cover at MLAN20 during 2019 (Figure 51). Variations of density by erect soft coral colonies between monitoring surveys were also minor and statistically insignificant (ANOVA, p = 0.127; Appendix 4). These data are indicative that the pass of hurricanes Mathew in 2016 and Irma and Maria in 2017 did not have any significant ecological implications to the benthic community of MLAN20.

15.3 Fishes and Motile Megabenthic Invertebrates

A total of 34 fish species were identified within belt-transects from MLAN20 with a mean density of 21.4 Ind/30m^2 (range: 11– 29 Ind/30m^2) and a mean species richness of 11.6 Spp/Transect (Table 45). The bluehead wrasse (*Thalassoma bifasciatum*), bar-jack (*Caranx ruber*), bicolor and beaugregory damselfishes (*Stegastes partitus, S. leucostictus*), sharknose and peppermint gobies (*Elacatinus evelynae, Coryphopterus lipernes*) were the numerically dominant species with a combined abundance of 13.2 Ind/30m^2, representing 61.7% of the total fish density. Motile megabenthic invertebrates were not observed within belt-transects at MLAN20 in 2019 (Table 45).

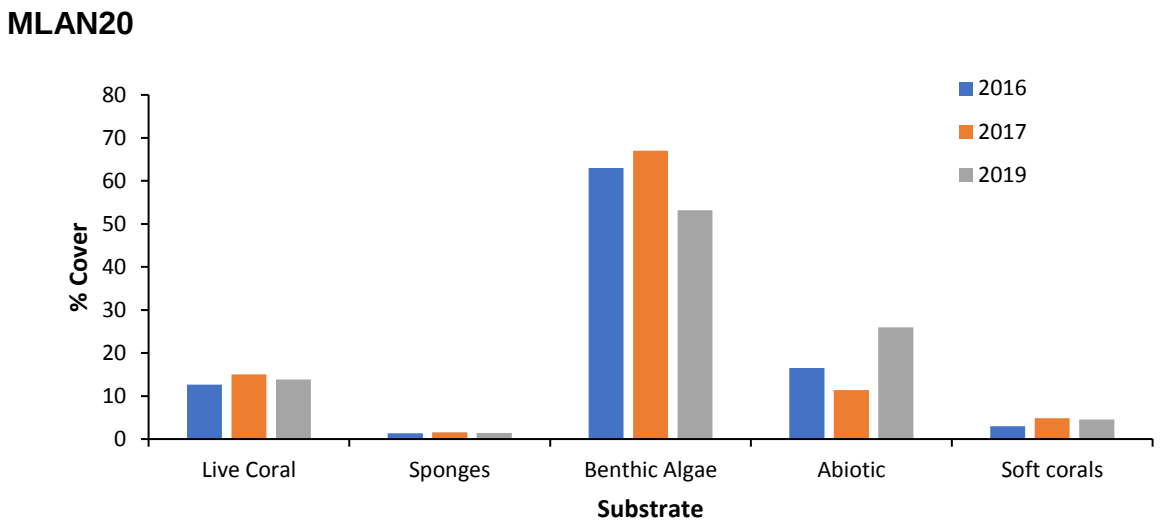


Figure 50. Monitoring trends (2015 – 2019) of mean substrate cover by sessile-benthic categories at MLAN20, Guayanilla.

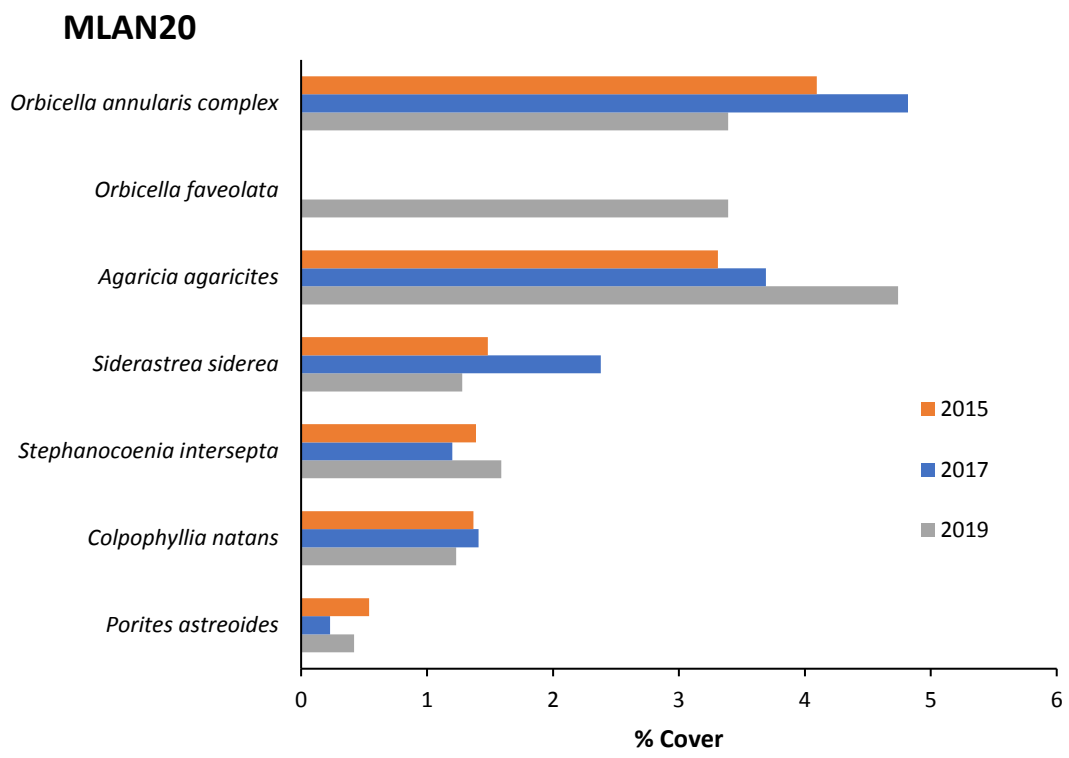


Figure 51. Monitoring trends (2015 – 2019) of mean substrate cover by hard coral species at MLAN20, Guayanilla. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

Table 45. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at MLAN20, Guayanilla.

Maria Langa 20m (MLAN20)						
Survey Date: 8-10-19			**Belt-Transects**			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	4	8	5	1	0	**3.6**
Caranx ruber	0	0	0	0	15	**3.0**
Stegastes partitus	5	4	1	2	1	**2.6**
Elacatinus evelynae	7	1	1	0	0	**1.8**
Coryphopterus lipernes	2	0	2	1	1	**1.2**
Stegastes leucostictus	2	1	0	1	1	**1.0**
Ocyurus chrysurus	1	2	0	0	0	**0.6**
Chaetodon capistratus	1	0	1	0	0	**0.4**
Sparisoma aurofrenatum	1	0	1	0	1	**0.6**
Haemulon flavolineatum	0	0	1	1	0	**0.4**
Scarus iseri	0	1	0	1	1	**0.6**
Halichoeres maculipinna	0	0	2	0	0	**0.4**
Pomacanthus paru	0	0	0	2	0	**0.4**
Anisotremus virginicus	0	0	1	0	1	**0.4**
Holocentrus rufus	0	0	0	1	1	**0.4**
Chaetodon ocellatus	0	0	0	0	2	**0.4**
Neoniphon marianus	1	0	0	0	0	**0.2**
Coryphopterus sp.	1	0	0	0	0	**0.2**
Acanthurus chirurgus	1	0	0	0	0	**0.2**
Canthigaster rostrata	1	0	0	0	0	**0.2**
Acanthurus tractus	0	0	1	0	0	**0.2**
Hypoplectrus puella	0	1	0	0	0	**0.2**
Serranus baldwini	0	1	0	0	0	**0.2**
Bodianus rufus	0	1	0	0	0	**0.2**
Cephalopholis cruentata	0	0	1	0	0	**0.2**
Sparisoma radians	0	0	1	0	0	**0.2**
Scarus taeniopterus	0	0	1	0	0	**0.2**
Myripristis jacobus	0	0	1	0	0	**0.2**
Amblycirrhitus pinos	0	0	0	1	0	**0.2**
Cephalopholis fulva	0	0	0	0	1	**0.2**
Lactophrys triqueter	0	0	0	0	1	**0.2**
Aulostomus maculatus	0	0	0	0	1	**0.2**
Hypoplectrus chlorurus	0	0	0	0	1	**0.2**
Holacanthus tricolor	0	0	0	0	1	**0.2**
Total Individuals	27	20	20	11	29	**21.4**
Total Species	12	9	14	9	14	**11.6**
Invertebrates						
none observed						

The trophic structure of the fish community at MLAN20 was strongly comprised by a species rich assemblage of small opportunistic carnivores that included 21 species with a combined density of 14.2 Ind/30m^2, or 66.4% of the total fish density within belt-transects. The assemblage included wrasses (Labridae), jacks (Carangidae), gobies (Gobiidae), grunts (Haemulidae), squirrelfishes (Holocentridae), puffers (Tetraodontidae), boxfishes (Ostraciidae), hawkfish (Cirrhitidae) and small groupers and sea basses (Serranidae). Herbivores were represented by eight species with a combined density of 3.0 Ind/30m^2, or 14.0% of the total individuals. Parrotfishes (Scaridae), damselfishes (Pomacentridae) and doctorfishes (Acanthuridae) comprised the main herbivorous fish assemblage. Zooplanktivorous fishes were represented by only two species (*Stegastes partitus, Coryphopterus sp*) with a combined density of 2.8 Ind/30m^2, or 13.8% of the total fish density. Medium-sized demersal predators included the red hind (*Epinephelus guttatus*), and the schoolmaster and yellowtail snappers (*Lutjanus apodus, Ocyurus chrysurus*) (Table 46). One jewfish (*Epinephelus itajara*) was observed from MLAN20 during the 2017 survey (Garcia-Sais et al., 2017). Pelagic predators included one cero mackerel (*Scomberomorus regalis*) and one great barracuda (*Sphyraena barracuda*) observed out of transects.

The size-frequency distribution of fishes within 20 x 3m belt-transects suggests that the reef serves largely as the residential habitat for an assemblage of juvenile and adult doctorfishes (*Acanthurus spp*), parrotfishes (*Scarus spp., Sparisoma spp*), groupers (*Cephalopholis spp., Epinephelus spp*) and yellowtail snappers (*Ocyurus chrysurus*) (Table 46). Terminal phase males of redband, stoplight, princess, and striped parrotfishes (*Sparisoma aurofrenatum, S. viride, Scarus taeniopterus, S. iseri*) were also present.

Temporal variations of fish density and species richness are shown in Figure 52. Differences of density and species richness between monitoring surveys were small and statistically insignificant (ANOVA, $p > 0.05$; Appendix 5 - 6). Density variations have been influenced by the presence of blue runners (*Caranx crysos*), a transitory schooling pelagic species that penetrated transect areas during the 2016 baseline survey, but that are not part of the resident fish community at MLAN20. The mean fish density and species richness measured in 2019 were within one standard deviation of the study-period means at MLAN20 (see Appendix 5-6).

Table 46. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at MLAN20, Guayanilla.

MLAN20									
Survey Date: 8-10-19					**TRANSECTS**				
		Size	**Life**		**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	1	0	0	0	0	**0.2**
Acanthurus chirurgus c4	Acanthuridae	16-20	Adult	1	0	0	0	1	**0.4**
Acanthurus coeruleus c4	Acanthuridae	16-20	Adult	0	1	1	0	0	**0.4**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	0	0	1	1	0	**0.4**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	1	2	0	0	0	**0.6**
Caranx ruber c3	Carangidae	11-15	Juvenile	0	0	0	7	1	**1.6**
Cephalopholis cruentata c2	Serranidae	6-10	Juvenile	0	0	1	0	0	**0.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	0	1	0	0	0	**0.2**
Cephalopholis fulva c4	Serranidae	16-20	Adult	0	0	0	0	1	**0.2**
Epinephelus guttatus c5	Serranidae	21-25	Juvenile	0	0	1	0	0	**0.2**
Epinephelus guttatus c7	Serranidae	31-35	Adult	0	0	0	0	1	**0.2**
Lutjanus apodus c4	Lutjanidae	16-20	Juvenile	0	1	0	0	0	**0.2**
Ocyurus chrysurus c2	Lutjanidae	6-10	Juvenile	2	0	0	0	0	**0.4**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	2	0	0	0	0	**0.4**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	1	0	0	0	0	**0.2**
Ocyurus chrysurus c5	Lutjanidae	21-25	Adult	0	1	0	2	0	**0.6**
Ocyurus chrysurus c6	Lutjanidae	26-30	Adult	0	0	0	1	0	**0.2**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	0	0	1	1	**0.4**
Scarus iseri c4	Scaridae	16-20	Adult	0	1	0	0	0	**0.2**
Scarus taeniopterus c4	Scaridae	16-20	Adult	0	0	1	0	0	**0.2**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	1	1	2	1	1	**1.2**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	2	0	1	0	1	**0.8**
Sparisoma radians c2	Scaridae	6-10	n/d	0	0	1	0	0	**0.2**
Sparisoma viride c6	Scaridae	26-30	Adult	0	0	1	1	0	**0.4**
			Totals	**11**	**8**	**10**	**14**	**7**	**10.0**

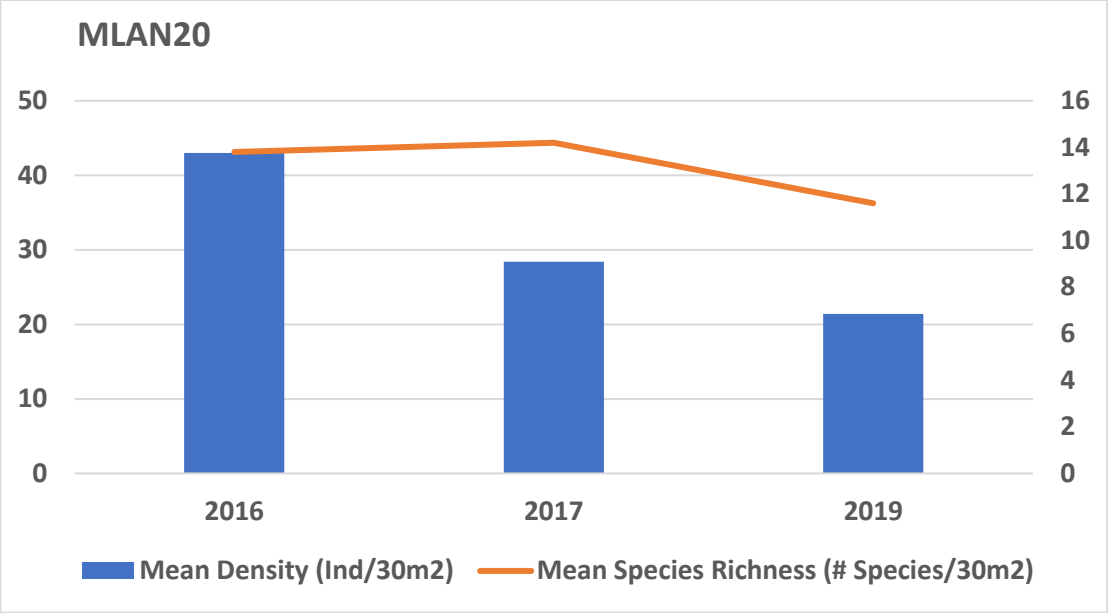
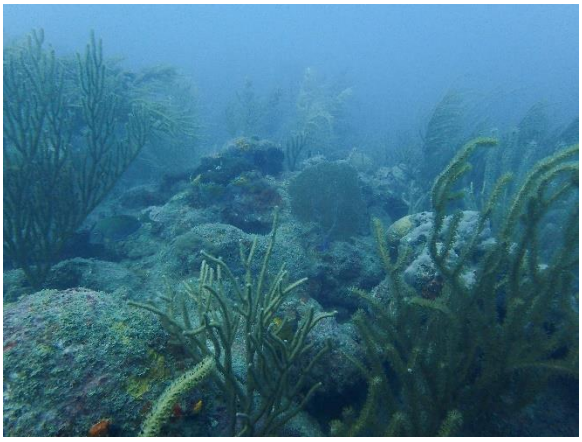
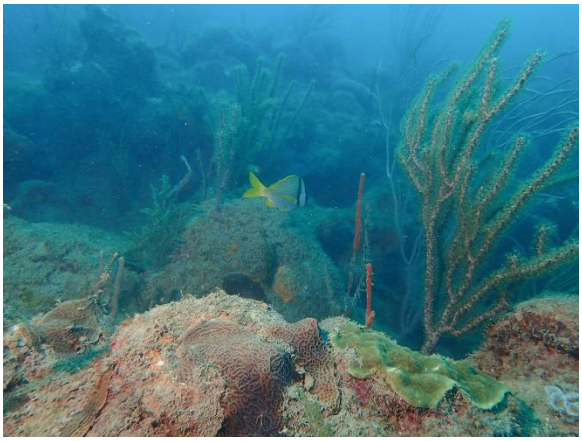


Figure 52. Monitoring trends (2016 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at MLAN20, Guayanilla

15.4 Photo Album 15. MLAN20





16. Maria Langa Reef 10m (MLAN10)

16.1 Physical Description

The reef at MLAN10 corresponds to a mid-slope section of the Maria Langa fore-reef at depths between 8.4 – 9.1m (Figure 49). Transects were established within a relatively wide terrace with a gentle slope during the baseline survey in 2016 (Garcia-Sais et al., 2016). Panoramic views of the reef community at MLAN10 are included as Photo Album 16.

16.2 Sessile Benthic Reef Community

Benthic algae were the dominant biotic category covering reef substrate at MLAN10 with a combined mean cover of 54.47% (Table 47). Turf algae, a mixed assemblage of short filamentous brown and red algae was the main component of the benthic algae, with a mean cover of 43.12%, or 79.2% of the total cover by benthic algae. Fleshy brown macroalgae, mostly *Dictyota sp*. were present in all transects with a mean cover of 9.81%. Crustose encrusting red algae, including CCA (mixed assemblage), *Peyssonnelia sp*. and *Ramicrusta sp* were intercepted by three transects with a combined mean cover of 1.45%. Small cyanobacterial patches were intercepted by three transects with a mean substrate cover of 0.63%.

Sponges were represented by 15 species along transects with a combined mean substrate cover of 4.63%. *Amphimedon compressa, Chondrilla caribensis* and *Niphates erecta* were the most prominent species with a combined cover of 2.52%, or 54.4% of the total cover by sponges. Small encrusting sponges with low vertical projection prevailed at MLUN10. The encrusting zoanthid, *Palythoa caribaeorum* was intercepted by four transects with a mean substrate cover of 2.00%. Abiotic substrate categories presented a mean substrate cover of 7.09% associated with reef overhangs and sand patches (Table 47). Reef rugosity averaged 2.3m influenced by a mostly flat and homogeneous substrate with low to moderate contributions of coral buildup.

Erect soft corals were the most prominent sessile-benthic component at MLAN10 with a mean density of 43.2 Col/Transect, the highest in the PRCRMP, and because of their large size, high density and vertical projection contributed highly to the overall benthic habitat complexity. Sea rods (*Eunicea sp, Plexaura spp, Pseudoplexaura sp),* sea plumes (*Antillogorgia spp*) and sea fans (*Gorgonia ventalina*) were common. Encrusting soft coral species, *Briareum asbestinum* and *Erythropodium caribaeorum* were present in five and four transects, respectively with a combined mean substrate cover of 9.41% (Table 47).

Table 47. Percent reef substrate cover by sessile-benthic categories at MLAN10, Guayanilla.

MLAN10	**Transects**					
Survey date: 8-10-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	8.8	9.1	8.6	8.9	8.4	**8.76**
Rugosity (m)	2.40	2.38	1.91	2.42	2.38	**2.30**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	3.84	5.77	2.12	1.01	5.09	**3.57**
Sand	2.48		3.41	9.36		**3.05**
Rubble			2.35			**0.47**
Total Abiotic	**6.32**	**5.77**	**7.87**	**10.37**	**5.09**	**7.09**
Benthic Algae						
Turf (mixed) with sediment	33.63	39.59	41.60	40.92	39.59	**39.07**
Dictyota spp.	4.51	7.01	8.70	12.97	15.84	**9.81**
Turf (mixed)	5.53	5.66	3.17	1.01	4.86	**4.05**
Peyssonnelia spp.	2.26	1.58	1.18	0.23	0.23	**1.09**
CCA (total)	1.02	0.45				**0.29**
Macroalgae spp.				0.45		**0.09**
Ramicrusta spp.				0.34		**0.07**
Total Benthic Algae	**46.95**	**54.30**	**54.64**	**55.92**	**60.52**	**54.47**
Cyanobacteria	**0.00**	**0.90**	**0.00**	**1.47**	**0.79**	**0.63**
Hard Coral						
Orbicella faveolata	6.43	9.16			10.52	**5.22**
Pseudodiploria strigosa	8.35	2.38	0.71	6.20	5.54	**4.64**
Siderastrea siderea	0.79	7.81	6.93	5.30		**4.17**
Montastraea cavernosa	3.95	1.36	7.17	3.95		**3.28**
Porites astreoides	1.13	0.79	1.18	4.51	0.23	**1.57**
Dendrogyra cylindrus	3.95					**0.79**
Diploria labyrinthiformis				2.48		**0.50**
Millepora alcicornis	0.34	0.23	0.47	0.45	0.23	**0.34**
Stephanocoenia intersepta				1.24		**0.25**
Agaricia agaricites					0.68	**0.14**
Colpophyllia natans		0.34				**0.07**
Total Hard Coral	**24.94**	**22.06**	**16.45**	**24.13**	**17.19**	**20.95**
# Coral Colonies/Transect	**10**	**9**	**9**	**10**	**9**	**9.4**
#Diseased Coral Colonies/Transect	1	1	0	3	1	**1.2**
Soft Corals						
Briareum asbestinum	11.40	5.20	2.70	2.71	5.20	**5.44**
Erythropodium caribaeorum	3.61	4.64	7.76		3.85	**3.97**
Eunicea flexuosa					0.79	**0.16**
Antillogorgia acerosa	0.79					**0.16**
Plexaura homomalla	0.23	0.23				**0.09**
Antillogorgia americana		0.34				**0.07**
Eunicea tourneforti			0.24			**0.05**
Pseudoplexaura flagellosa			0.24			**0.05**
Plexaura kukenthali		0.23				**0.05**
Total Soft Corals	**16.03**	**10.63**	**10.93**	**2.71**	**9.84**	**10.03**
# Soft Coral Colonies/Transect	**36**	**37**	**49**	**48**	**46**	**43.2**
Sponges						
Amphimedon compressa	0.68	0.23	0.47	1.69	1.92	**1.00**
Chondrilla caribensis	0.90		2.82		0.11	**0.77**
Niphates erecta		0.79	1.06	0.45	1.47	**0.75**
Scopalina ruetzleri		1.02	0.47	0.68	0.23	**0.48**

MLAN10			**Transects**			
Survey date: 8-10-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Iotrochota birotulata	1.24		0.24	0.68	0.23	**0.48**
Callyspongia fallax	1.92					**0.38**
Sponge spp.	0.23	0.23		0.45		**0.18**
Cinachyrella kuekenthali	0.79					**0.16**
Aplysina cauliformis		0.11			0.57	**0.14**
Plakortis spp.			0.35			**0.07**
Ptilocaulis walpersii					0.34	**0.07**
Mycale laevis			0.24			**0.05**
Clathria spp.		0.11			0.11	**0.05**
Ircinia spp. brown				0.23		**0.05**
Monanchora arbuscula					0.11	**0.02**
Total Sponges	**5.76**	**2.49**	**5.64**	**4.17**	**5.09**	**4.63**
Others						
Palythoa caribaeorum		3.85	4.47	1.24	0.45	**2.00**
Lebrunia neglecta					0.57	**0.11**
Ascidian spp.					0.23	**0.05**
Ricordea florida					0.23	**0.05**

Hard corals corals were represented by 11 species with a combined mean substrate cover of 20.95% (range: 16.45 – 24.94 %) and a mean of 9.4 Col/Transect. An assemblage of four species with a combined cover of 17.31% represented 82.6% of the total hard coral cover at MLAN10 (Table 62). These included the mountainous star coral (*Orbicella faveolata*), symmetrical brain coral (*Pseudodiploria strigosa*), massive starlet coral (*Siderastrea siderea*), and great star coral (*Montastrea cavernosa*). Mound-shaped, encrusting and laminar colonies of small to moderate size prevailed at MLAN10, although some large laminar colonies of *O. faveolata* and *Dendrogyra cylindrus* were present. Infectious diseases were observed on six hard coral colonies (1-*P. strigosa*, 1-*S. siderea*, 1-*D. labyrinthiformis*, 1-*P. astreoides*, 1-*S. intercepta* and 1-*M. cavernosa*) of the 47-total intercepted by transects for a coral disease prevalence of 12.8%. (Appendix 2).

Differences of hard coral cover between monitoring surveys included an 18.4% increase between the 2016 baseline and the 2017 monitoring survey and a 3.4% reduction of cover between the 2017 and the most recent 2019 survey (Figure 53). These differences were statistically insignificant (ANOVA, p = 0.239; Appendix 3). The main hard coral species assemblage and their relative contributions to the total substrate cover by hard corals remained consistent between monitoring surveys (Figure 54). Differences in the density of soft corals were small and statistically insignificant (ANOVA, p= 0.704; Appendix 4). In general, the main components of the reef sessile benthos exhibited a mostly stable and resilient condition despite strong wave action associated with the pass of hurricanes Mathew near the south coast of PR in October 2016 and Hurricane Maria in September 2017.

MLAN10

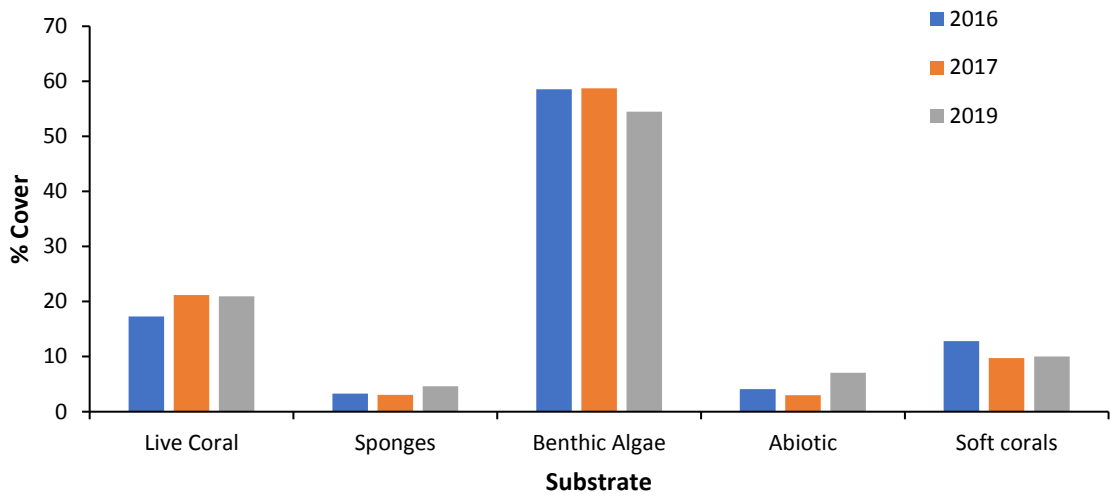


Figure 54. Monitoring trends (2016 – 2019) of mean substrate cover by sessile-benthic categories at MLAN10, Guayanilla.

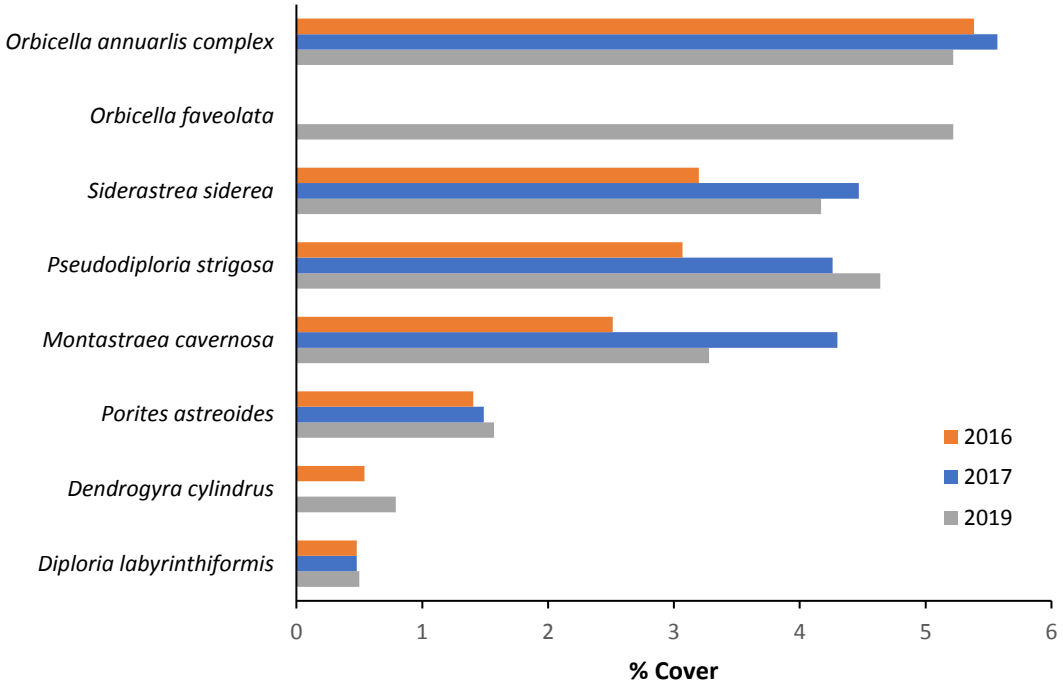


Figure 55. Monitoring trends (2016 – 2019) of mean substrate cover by hard coral species at MLAN10, Guayanilla. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

16.3 Fishes and Motile Megabenthic Invertebrates

A total of 27 fish species were identified within belt-transects from MLAN10 with a mean density of 21.2 Ind/30m^2 (range: 16 – 31 Ind/30m^2) and a mean species richness of 13.0 Spp/30m^2 (Table 48). An assemblage of three species with a combined density of 8.6 Ind/30m^2, represented 40.5% of the total fishes within belt-transects. These included the bicolor damselfish (*Stegastes partitus*), the bluehead wrasse (*Thalassoma bifasciatum*) and the redband parrotfish (*Sparisoma aurofrenatum*). The yellowtail snapper (*Ocyurus chrysurus*) and yellowhead wrasse (*Halichoeres garnoti*) were present in four transects each with a combined density of 2.0 Ind/30m^2. Motile megabenthic invertebrates observed within belt-transects included one spotted spiny lobster (*Panulirus guttatus*) (Table 48).

Small opportunistic carnivores dominated the fish trophic structure at MLAN10 with a total of 13 species and a cumulative density of 8.2 Ind/30m^2, representative of 38.7% of the total fish density within belt-transects. The assemblage included three species of wrasses (Labridae), two squirrelfishes (Holocentridae), two grunts (Haemulidae), one puffer (Tetraodontidae), one goby (Gobiidae), one goatfish (Mullidae) and three small groupers and sea basses (Serranidae). Herbivores were represented by four species of parrotfishes (Scaridae), two doctorfishes (Acanthuridae) and two damselfishes (Pomacentridae) with a combined density of 5.6 Ind/30m^2 representing 26.4% of the total fish individuals. Zooplanktivorous fishes were only represented by the bicolor damselfish (*Stegastes partitus* – Pomacentridae), with a mean density of 4.0 Ind/30m^2, or 10.3% of the total individuals. Corallivores (Chaetodontidae) and spongivores (Pomacanthidae) were represented by two and one species, respectively. Medium sized piscivores included the yellowtail and schoolmaster snappers (*Ocyurus chrysurus, Lutjanus apodus*) and the crevalle jack (*Caranx latus*).

The size-frequency distribution of commercially important fishes and the main reef herbivores are presented in Table 49. The prevalence of juvenile and adult stages of doctorfishes (Acanthuridae), parrotfishes (Scaridae), small groupers (Serranidae) and snappers (Lutjanidae) observed within transects identify MLAN10 as a residential habitat for several species within these families and a recruitment habitat for stoplight and redband parrotfishes (*Sparisoma viride*, *S. aurofrenatum*). Recruitment juvenile stages (1-5cm) of striped and bucktooth parrotfishes (*S. iseri, S. radians*) were previously reported (Garcia-Sais et al., 2016).

Table 48. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at MLAN10, Guayanilla.

Maria Langa 10m (MLAN10)						
Survey Date: 8-10-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Stegastes partitus	6	5	5	3	1	**4.0**
Thalassoma bifasciatum	6	2	0	5	2	**3.0**
Sparisoma aurofrenatum	2	1	2	2	1	**1.6**
Acanthurus tractus	4	1	0	0	0	**1.0**
Chaetodon capistratus	2	1	0	0	2	**1.0**
Haemulon flavolineatum	2	0	2	1	0	**1.0**
Halichoeres garnoti	1	1	1	2	0	**1.0**
Ocyurus chrysurus	0	1	2	1	1	**1.0**
Acanthurus chirurgus	1	0	1	0	1	**0.6**
Myripristis jacobus	1	1	0	0	1	**0.6**
Sparisoma radians	1	0	0	0	2	**0.6**
Stegastes leucostictus	1	0	1	0	1	**0.6**
Anisotremus virginicus	1	0	0	0	1	**0.4**
Cephalopholis cruentata	1	1	0	0	0	**0.4**
Cephalopholis fulva	1	0	0	1	0	**0.4**
Chaetodon striatus	0	1	1	0	0	**0.4**
Elacatinus evelynae	1	0	0	1	0	**0.4**
Halichoeres maculipinna	0	0	0	2	0	**0.4**
Microspathodon chrysurus	0	1	0	0	1	**0.4**
Pomacanthus arcuatus	0	1	0	1	0	**0.4**
Scarus iseri	0	0	0	1	1	**0.4**
Scarus taeniopterus	0	0	2	0	0	**0.4**
Serranus tigrinus	0	1	1	0	0	**0.4**
Cantherhines pullus	0	0	0	1	0	**0.2**
Canthigaster rostrata	0	0	1	0	0	**0.2**
Holocentrus rufus	0	0	1	0	0	**0.2**
Pseudupeneus maculatus	0	0	0	0	1	**0.2**
Total Individuals	31	18	20	21	16	**21.2**
Total Species	15	13	12	12	13	**13.0**
Invertebrates						
Panulirus guttatus	0	1	0	0	0	**0.2**

Temporal variations of fish density and species richness between monitoring survey are shown in Figure 55. Fish density was slightly higher during the 2016 baseline survey relative to the 2017 and 2019 monitoring surveys, but differences were not statistically significant (ANOVA, p = 0.062; Appendix 5). The peak density in 2016 was influenced by high density of bar jacks (*Caranx ruber*), a transitory schooling pelagic species that is not part of the resident fish community of MLAN10. Differences of species richness between surveys were statistically significant (ANOVA, p = 0.022; Appendix 6) driven by higher species richness during the recent 2019 survey, relative to the 2016

baseline survey. Differences may be related to the physical conditions at the time of survey since MLAN10 is a high energy reef system subject to sudden changes in surge and water transparency due to wave action. Additional monitoring observations are needed to establish if such temporal variations between monitoring surveys are real patterns or sampling variability artifacts.

Table 49. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at MLAN10, Guayanilla.

Survey Date: 8-10-19					**TRANSECTS**				
		Size	**Life**		**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	1	0	1	0	1	**0.6**
Acanthurus chirurgus c4	Acanthuridae	16-20	Adult	1	0	0	0	0	**0.2**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	0	0	2	0	**0.4**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	5	0	0	0	0	**1.0**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	1	0	0	0	0	**0.2**
Caranx latus c10	Carangidae	46-50	Adult	0	0	0	1	0	**0.2**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	1	0	0	0	0	**0.2**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	0	1	0	0	0	**0.2**
Cephalopholis fulva c3	Serranidae	11-15	Juvenile	1	0	0	0	0	**0.2**
Cephalopholis fulva c4	Serranidae	16-20	Adult	0	1	0	1	1	**0.6**
Lutjanus apodus c3	Lutjanidae	11-15	Juvenile	2	0	0	0	0	**0.4**
Ocyurus chrysurus c2	Lutjanidae	6-10	Juvenile	0	0	0	0	1	**0.2**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	0	1	0	0	0	**0.2**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	0	1	1	1	4	**1.4**
Ocyurus chrysurus c5	Lutjanidae	21-25	Adult	1	0	0	0	0	**0.2**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	0	3	1	0	**0.8**
Scarus iseri c3	Scaridae	11-15	Juvenile	0	1	0	0	0	**0.2**
Scarus iseri c4	Scaridae	16-20	Adult	0	0	0	0	1	**0.2**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	0	0	4	2	0	**1.2**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	0	0	0	1	0	**0.2**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	1	0	1	0	1	**0.6**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	1	1	0	2	0	**0.8**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	0	0	2	0	1	**0.6**
Sparisoma radians c2	Scaridae	6-10	n/d	0	0	0	0	2	**0.4**
Sparisoma viride c1	Scaridae	1-5	Recruit	1	0	0	0	0	**0.2**
Sparisoma viride c2	Scaridae	6-10	Juvenile	0	0	0	0	2	**0.4**
			Totals	**16**	**6**	**12**	**11**	**14**	**11.8**

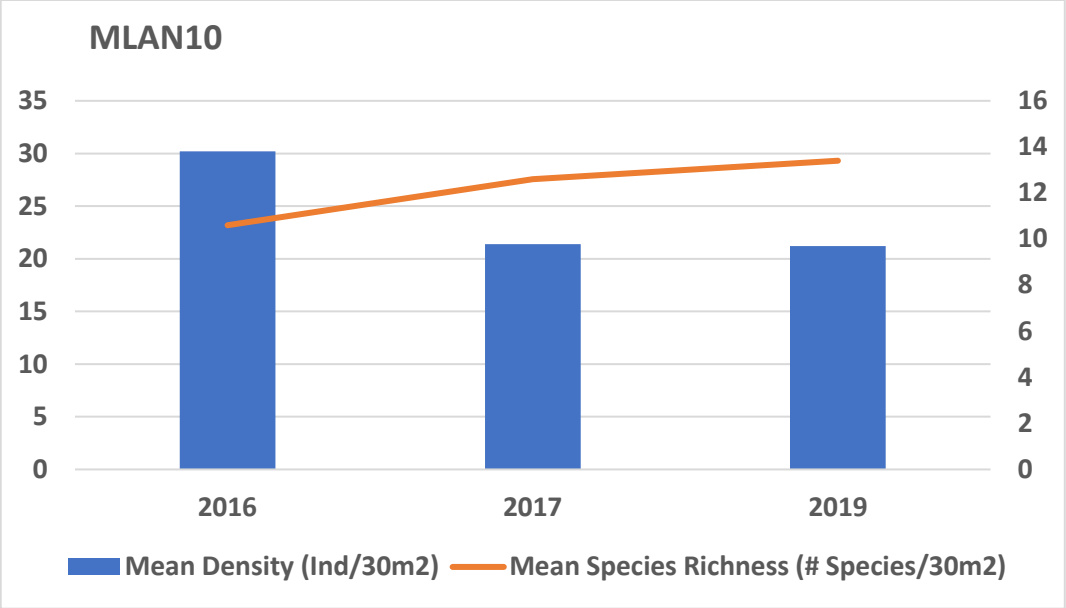
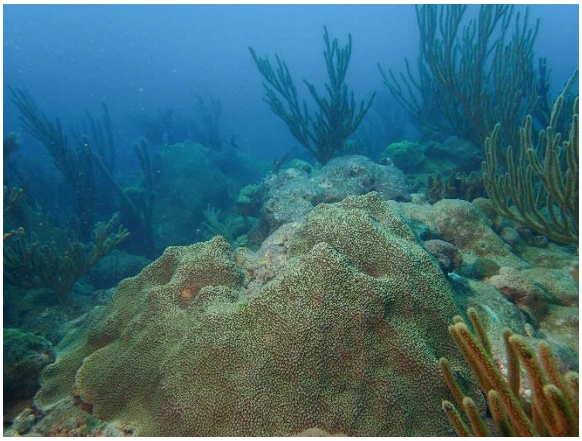
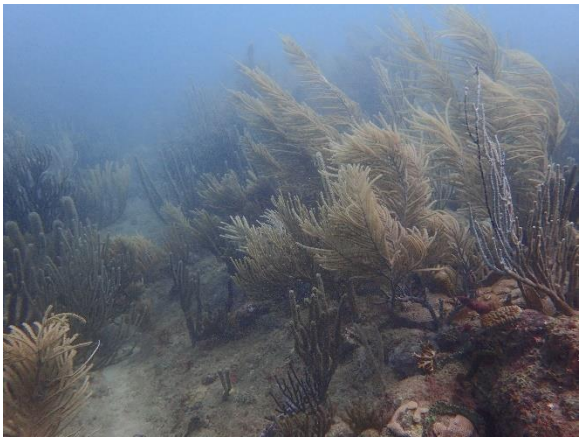


Figure 55. Monitoring trends (2016 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at MLAN10, Guayanilla.

16.4 Photo Album 16. MLAN10





17. Maria Langa Reef 5m (MLAN05)

17.1 Physical Description

MLAN05 is at the reef crest of Maria Langa Reef (Figure 49). The reef crest is relatively broad and characterized by a gentle slope forming a shallow terrace where wave breakers mark the reef. This is a zone of strong wave and surge action. Transects were installed roughly parallel to the reef face on a hard ground platform during the baseline characterization in 2016 (Garcia-Sais et al., 2016). Panoramic views of MLAN05 reef community are included as Photo Album 17.

17.2 Sessile Benthic Reef Community

Turf algae, a mixed assemblage of short filamentous brown and red algae was the main component of the benthic algae substrate at MLAN05, with a mean cover of 68.20%, representing 90.88% of the total cover by benthic algae (Table 50). Most of the turf algae was observed packed with fine sediments and sand colonizing most of the reef hard ground. Red crustose coralline algae, including CCA (mixed assemblage) and *Ramicrusta sp*. were also present with a combined mean substrate cover of 6.84%.

Hard corals were represented by seven species intercepted by transects with a combined mean substrate cover of 4.01% (range: 2.88 – 7.24 %), and a mean density of 3.8 Col/Transect. Mustard-hill coral (*Porites astreoides*) was the dominant coral species intercepted by transects with a mean cover of 1.45%, representing 36.2% of the total hard coral cover (Table 50). Lettuce coral (*Agaricia agaricites*) was the only other coral species intercepted by more than two transects. Hard corals occurred mostly as small isolated encrusting and mound-shaped colonies that contributed poorly to the reef topographic relief and structural complexity. None of the 19 hard coral colonies intercepted by transects were observed to be diseased at MLUN05.

Vertically projected soft corals were present but not prominent at MLAN05 with a mean density of 1.8 Col/Transect. Small colonies of sea fans (*Gorgonia ventalina*) were the most common.
Encrusting soft coral species, *Erythropodium caribaeorum* and *Briareum asbestinum* were present with a combined mean cover of 0.49%. Sponges represented by four species in transects had a combined mean cover of 14.42%. The encrusting species, *Cliona caribbea* was prominent in all transects with a mean cover of 13.78%, representing 95.6% of the total cover by sponges. The encrusting zoanthid, *Palythoa caribaeorum* was also present in four transects with a combined mean cover of 0.82% (Table 50).

Table 50. Percent reef substrate cover by sessile-benthic categories at MLAN05, Guayanilla.

MLAN05			**Transects**			
Survey date: 8-10-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	3.9	3.5	3.4	3.4	3.5	**3.54**
Rugosity (m)	1.80	2.12	0.71	1.83	0.37	**1.37**
BENTHIC CATEGORIES						
Abiotic						
Sand			2.35	12.78	0.94	**3.22**
Rubble	1.54	0.81	2.61	1.18		**1.23**
Reef overhang		1.85		1.78		**0.72**
Total Abiotic	**1.54**	**2.66**	**4.97**	**15.74**	**0.94**	**5.17**
Benthic Algae						
Turf (mixed) with sediment	47.69	54.39	54.51	54.08	55.33	**53.20**
Turf (mixed)	16.37	16.28	18.43	5.44	18.49	**15.00**
CCA (total)	7.47	3.70	7.45	0.71	8.37	**5.54**
Ramicrusta spp.	2.97		1.05	0.71	1.75	**1.30**
Total Benthic Algae	**74.50**	**74.36**	**81.44**	**60.95**	**83.94**	**75.04**
Hard Coral						
Porites astreoides	1.54	0.92	0.92	2.25	1.62	**1.45**
Siderastrea siderea	2.49				2.29	**0.96**
Acropora cervicornis	2.73		1.31			**0.81**
Millepora alcicornis		1.96	0.26			**0.44**
Agaricia agaricites	0.47		0.39	0.24		**0.22**
Siderastrea radians					0.40	**0.08**
Pseudodiploria strigosa				0.24		**0.05**
Total Hard Coral	**7.24**	**2.89**	**2.88**	**2.72**	**4.32**	**4.01**
# Coral Colonies/Transect	**9**	**3**	**1**	**3**	**3**	**3.8**
#Diseased CoralColonies/Transect	**0**	**0**	**0**	**0**	**0**	**0.00**
Soft Corals						
Erythropodium caribaeorum		0.23	1.31			**0.31**
Briareum asbestinum		0.92				**0.18**
Total Soft Corals		**1.15**	**1.31**			**0.49**
# Soft Coral Colonies/Transect	**2**	**2**	**1**	**2**	**2**	**1.80**
Sponges						
Cliona caribbaea	13.05	17.78	8.89	19.05	10.12	**13.78**
Chondrilla caribensis	0.71	0.69		0.71		**0.42**
Neopetrosia proxima				0.83		**0.17**
Spheciospongia vesparium			0.26			**0.05**
Total Sponges	**13.76**	**18.48**	**9.15**	**20.59**	**10.12**	**14.42**
Others						
Palythoa caribaeorum	2.97	0.46	0.26		0.40	**0.82**
Ricordea florida					0.27	**0.05**

Abiotic substrates at MLAN05 presented a mean cover of 5.17%, largely associated with sand and coral rubble patches. Reef rugosity averaged 1.37m, indicative of a mostly flat topography with relatively low contributions by sedimentary shelf features and/or coral structures to the reef underwater relief.

Variations of reef substrate cover by sessile-benthic categories between monitoring surveys are shown in Figure 56. Differences of reef substrate cover by hard corals were statistically significant (ANOVA, p = 0.0048; Appendix 3) and related to a sharp decline (62.4%) measured in 2017 relative to the 2016 baseline cover. Such reduction of hard coral cover was influenced by the disappearance of staghorn coral (*Acropora cervicornis*) from permanent transects (Figure 57). Staghorn coral was the dominant coral in terms of reef substrate cover with a mean of 9.4% in 2016 and the main coral species contributing structural complexity at MLAN05. Such marked decline was driven by the rupture, detachment and mortality of colonies exposed to conditions of extreme wave and surge action during the pass of Hurricane Matthew across the northern Caribbean close to the south coast of PR during October 2016 (Garcia-Sais et al., 2017). During the 2019 monitoring survey hard coral cover declined 20.4%, from 5.04% in 2017 to 4.01% in 2019, but differences between the 2017 and 2019 surveys were statistically insignificant (see Appendix 3). The reduction of hard coral cover measured in 2019 was probably associated to another event of extreme wave action associated with Hurricane Maria in September 2017. Reef substrate cover by encrusting soft corals and sponges also declined in 2019 relative to the 2017 surveys. Corresponding increments of cover by benthic algae and abiotic categories were measured in 2019.

17.3 Fishes and Motile Megabenthic Invertebrates

A total of 21 fish species were identified within belt-transects at MLAN05 with a mean density of 51.0 Ind/30m^2 (range: 36 – 63 Ind/30m^2) and a mean species richness of 12.0 Spp/30m^2 (Table 51). The bluehead wrasse (*Thalassoma bifasciatum*), dusky and bicolor damselfishes (*Stegastes adustus, S. partitus)* were the numerically dominant species with a combined density of 33.2 Ind/30m^2, representing 65.1% of the total fish density. The slippery dick, (*Halichoeres bivittatus*), redlip blenny (*Ophioblennius macclurei*), doctorfish (*Acanthurus chirurgus*) and clown wrasse (*Halichoeres maculipinna*) were present in all transects and along with the numerically dominant aforementioned species comprised the main small demersal resident fish assemblage at MLAN05 (Table 51). One juvenile spiny lobster (*Panulirus argus*) and one rock-boring urchin (*Echinometra lucunter*) were the motile-megabenthic invertebrates observed within belt-transect.

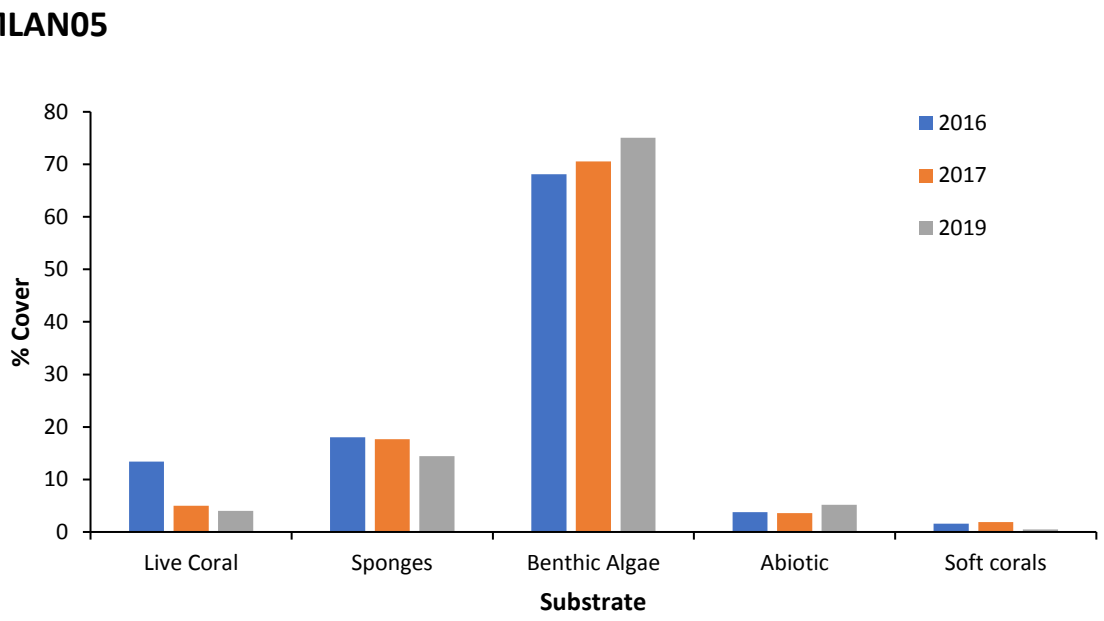


Figure 56. Monitoring trends (2016 – 2019) of mean substrate cover by sessile-benthic categories at MLAN05, Guayanilla.

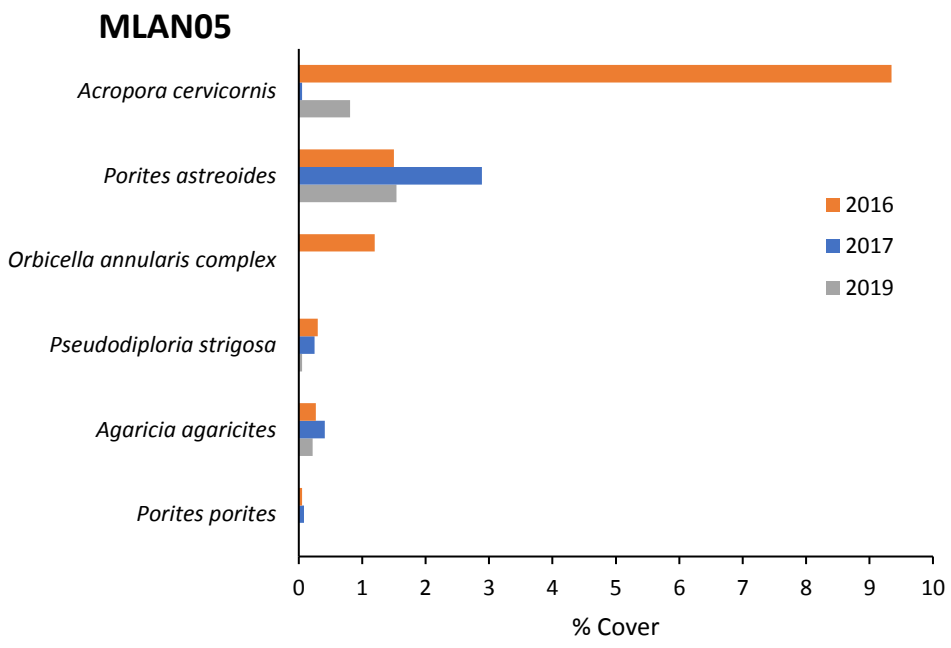


Figure 57. Monitoring trends (2016 – 2019) of mean substrate cover by hard coral species at MLAN05, Guayanilla. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex".

Table 51. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at MLAN05, Guayanilla.

Maria Langa 5m (MLAN05)						
Survey Date: 8-10-19			**Belt-Transects**			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	21	11	19	11	14	**15.2**
Stegastes adustus	21	12	8	6	7	**10.8**
Stegastes partitus	9	3	12	4	8	**7.2**
Ophioblennius atlanticus	3	1	4	3	3	**2.8**
Halichoeres bivittatus	1	1	5	3	1	**2.2**
Halichoeres maculipinna	2	3	3	0	2	**2.0**
Acanthurus chirurgus	1	2	3	2	2	**2.0**
Halichoeres poeyi	0	0	2	3	3	**1.6**
Stegastes variabilis	0	1	1	0	4	**1.2**
Caranx latus	0	0	0	5	0	**1.0**
Acanthurus tractus	0	0	2	0	2	**0.8**
Scarus iseri	0	0	0	4	0	**0.8**
Sparisoma aurofrenatum	0	0	1	1	1	**0.6**
Microspathodon chrysurus	1	0	1	1	0	**0.6**
Sargocentron coruscum	1	0	0	1	0	**0.4**
Amblycirrhitus pinos	0	1	0	0	1	**0.4**
Chaetodon capistratus	0	0	0	2	0	**0.4**
Sparisoma rubripinne	0	0	1	1	0	**0.4**
Chaetodon striatus	0	1	0	0	0	**0.2**
Acanthurus coeruleus	0	0	1	0	0	**0.2**
Malacoctenus triangulatus	0	0	0	0	1	**0.2**
Total Individuals	60	36	63	47	49	**51.0**
Total Species	9	10	14	14	13	**12.0**
Invertebrates						
Echinometra lucunter	1	0	0	1	0	**0.4**
Panulirus argus	0	1	0	1	0	**0.4**

The fish trophic structure at MLAN05 was characterized by a fairly well-balanced composition of small opportunistic carnivores and herbivores, with relatively lower abundance of zooplanktivores and large demersal predators within belt-transects. Small opportunistic carnivores included four wrasses (Labridae), one squirrelfish (Holocentridae), two blennies (Blenniidae), and one hawkfish (Cirrhitidae) with a combined density of 24.8 Ind/30m^2, representative of 48.6% of the total fish density. Herbivores included three damselfishes (Pomacentridae), three doctorfishes (Acanthuridae) and three parrotfishes (Scaridae) with a combined abundance of 17.4 Ind/30m^2,

or 34.1% of the total individuals. Demersal zooplanktivores were represented by the bicolor damselfish, with a mean density of 7.2 Ind/30m^2, or 14.1 of the total fish individuals within transects. Medium and large-sized piscivores included the yellowtail snapper (*Ocyurus chrysurus*) and crevalle jacks (*Caranx latus*) (Table 52). One great barracuda (*Sphyraena barracuda*) was observed out of transects.

The size-frequency distribution of commercially important fishes observed from MLAN05 are presented in Table 52. Most parrotfishes (*Scarus spp, Sparisoma spp*), doctorfishes (*Acanthurus spp*), yellowtail snappers (*Ocyurus chrysurus*), and coneys (*Cephalopholis fulva*) were observed as juvenile and/or adult stages. Recruitment juvenile stages of the doctorfish (*A. chirurgus*) were present. Pelagic predators (*Caranx latus, Sphyraena barracuda*) were present as large adults.

Variations of fish density and species richness between monitoring surveys are presented in Figure 58. Mean fish density varied from a minimum of 42.2 Ind/30m^2 in the 2016 baseline survey to a maximum of 51.2 Ind/30m^2 during the present 2019 monitoring survey. The small density differences were not statistically significant (ANOVA, $p = 0.257$; Appendix 5). Fish species richness in the 2019 survey was 40.9% higher than that of 2016 and such difference was statistically significant (ANOVA, $p = 0.046$; Appendix 6). This is an interesting result in the sense that despite such a marked reduction of live coral cover after the 2016 baseline survey the fish community structure did not respond with a proportional decline of either fish density nor species richness, but rather appeared to vary independently from the variation in coral cover or increase in the case of species richness. This data suggests that the fish population of MLAN05 is using alternate microhabitats to replace the previously available branching coral habitat contributed by staghorn coral (*A. cervicornis*). Also, the fish community at MLAN05 is largely comprised by juvenile and adult wrasses (Labridae), doctorfishes (Acanthuridae) and parrotfishes (Scaridae) which do not typically shelter in coral microhabitats, but rather display a transitory lifestyle across the shallow reef.

Table 52. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at MLAN05, Guayanilla.

Survey Date: 8-10-19					TRANSECTS				
		Size	Life		(Ind/60m^2)				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c1	Acanthuridae	1-5	Recruit	1	0	0	2	0	**0.6**
Acanthurus chirurgus c2	Acanthuridae	6-10	Juvenile	0	0	0	0	1	**0.2**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	1	1	3	0	1	**1.2**
Acanthurus chirurgus c4	Acanthuridae	16-20	Adult	0	1	1	0	0	**0.4**
Acanthurus coeruleus c4	Acanthuridae	21-25	Adult	0	1	1	0	0	**0.4**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	0	1	0	0	0	**0.2**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	0	1	2	0	2	**1.0**
Caranx latus c10	Carangidae	46-50	Adult	0	0	0	5	0	**1.0**
Cephalopholis fulva c5	Serranidae	21-25	Adult	0	0	1	0	0	**0.2**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	1	0	0	0	0	**0.2**
Scarus iseri c2	Scaridae	6-10	Juvenile	1	0	1	3	0	**1.0**
Scarus taeniopterus c4	Scaridae	16-20	Adult	1	0	0	0	1	**0.4**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	2	1	0	0	**0.6**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	1	0	3	3	3	**2.0**
Sparisoma rubripinne c3	Scaridae	11-15	Juvenile	0	0	1	2	0	**0.6**
Sparisoma rubripinne c5	Scaridae	21-25	Adult	0	1	0	0	0	**0.2**
Sparisoma rubripinne c6	Scaridae	26-30	Adult	0	0	0	1	0	**0.2**
Sparisoma viride c5	Scaridae	16-20	Adult	0	0	0	0	1	**0.2**
Sparisoma viride c6	Scaridae	26-30	Adult	0	0	0	0	1	**0.2**
			Totals	**6**	**8**	**14**	**16**	**9**	**10.6**

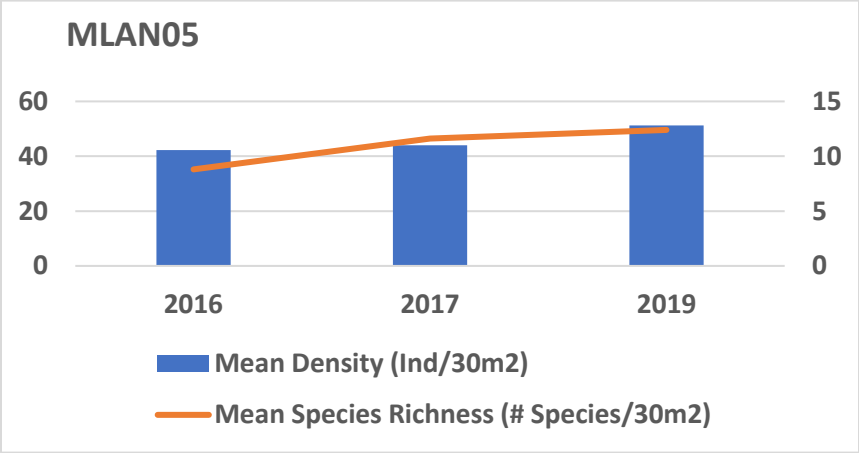
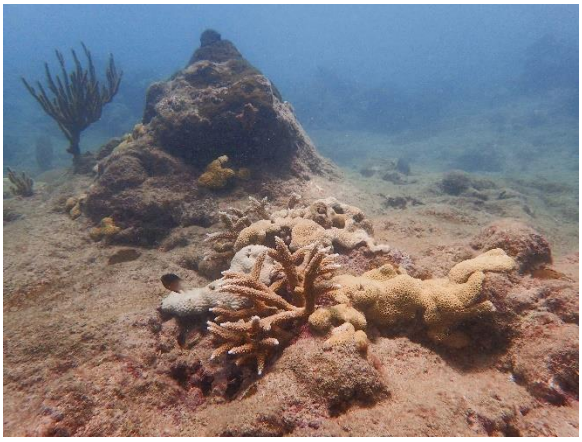
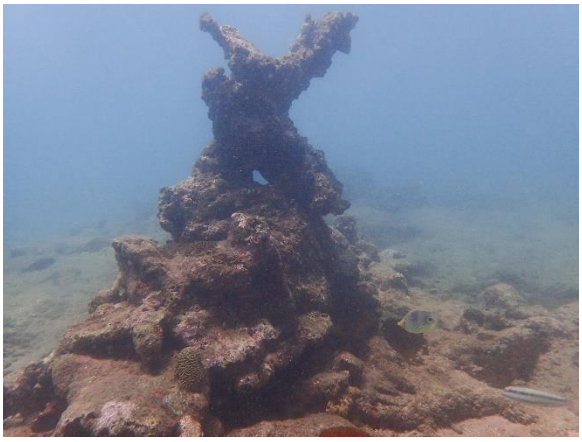
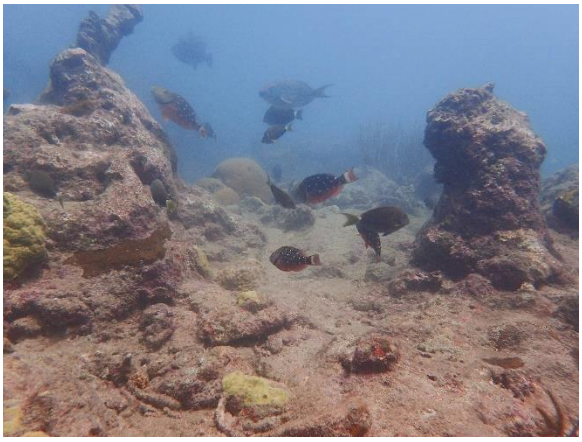


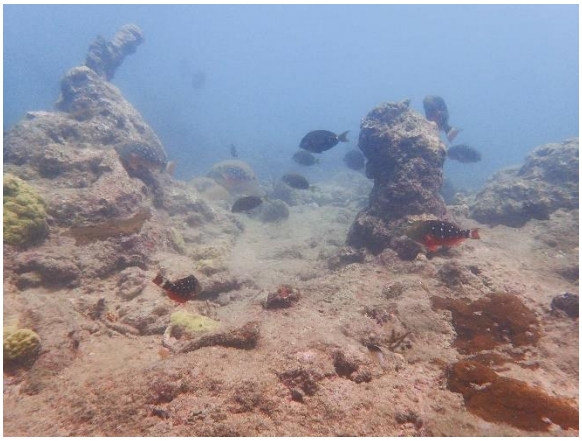
Figure 58. Monitoring trends (2016 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at MLAN05, Guayanilla.

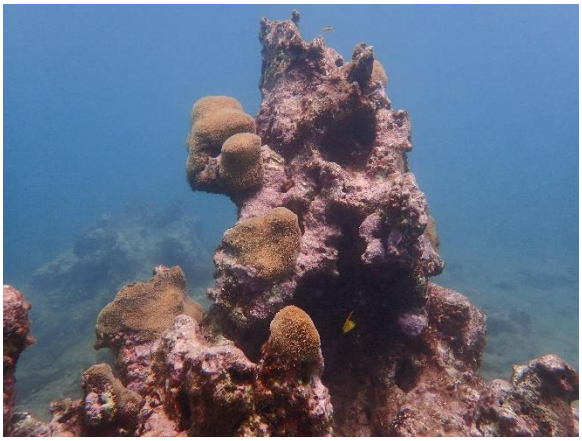
17.4 Photo Album. MLAN05











18. West Reef (WEST10)

18.1 Physical Description

Caja de Muerto is an island within the insular shelf located approximately 8.5 km off the south coast of Puerto Rico, between Ponce and Santa Isabel. It is the largest emergent reef system of the south coast. The main reef platform includes Cayo Berbería, 5.5 km to the northeast and Isla Morrillitos, adjacent to the main island, Caja de Muerto. The total surface area of the natural reserve is approximately 188.36 square kilometers (Villamil et al., 1980).

West Reef (WEST10) is located on the northwest coast of Isla Caja de Muerto (Figure 59). It is a submerged patch coral reef formation that runs essentially parallel to the coastline. The base of the reef is a sandy-silt bottom at a depth of approximately 15m. The reef rises to a depth of five meters from the surface. It consists of a shallow platform at the reef top and a drop-off wall with deep channels that run perpendicular to the wall facing down to the base of the reef. Most of the coral development occurs along the wall, with substantial hard coral and soft coral growth into the channels. Goenaga and Cintrón (1979) described the geomorphology of this reef and provided the first taxonomic description of the benthic communities. The baseline survey pf WEST10 was performed in May 1999 (Garcia-Sais et al., 2001a). Transects were set roughly parallel to the coastline depths of 6.7 – 7.8 m on the fore reef slope. Panoramic views of WEST10 are presented in Photo Album 18.

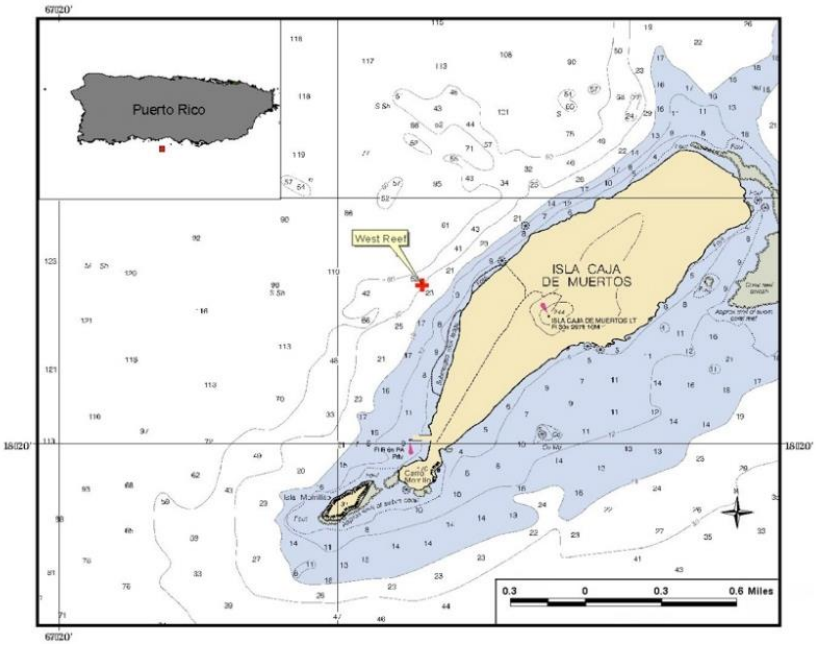


Figure 59. Location of coral reef monitoring stations at WEST10, Isla Caja de Muerto, Ponce.

18.2 Sessile-benthic Reef Communities

A dense algal turf packed with fine sediments was the dominant component of benthic algae at WEST10. Turf algae, a mixed assemblage of short red and brown algae was observed colonizing most of the available hard ground at WEST10 with a combined (with and without sediments) mean substrate cover of 44.33%, representative of 94.6% of the total cover by benthic algae (Table 53). Crustose red algae (*Ramicrusta, CCA, Peyssonnelia sp*) were present in all transects with a combined cover of 1.44%. Fleshy brown macroalgae was comprised by the y-twig alga (*Dictyota sp.)* and the encrusting fan alga (*Lobophora variegata*) with a combined mean substrate cover of 1.07%. Cyanobacterial patches were observed growing intermixed with the algal turf and also overlying sediment pockets in the reef with a mean cover of 9.55%. Abiotic categories, comprised by reef overhangs, coral rubble and sand presented a combined mean substrate cover of 24.94%. Large coral heads (mostly dead *Orbicella spp*) contributed to a high topographic relief and a mean rugosity of 5.67m.

A total of 13 hard coral species were intersected by transects at WEST10 with a mean reef substrate cover of 15.22% (range: 10.31 – 25.35%) and a mean density of 10.2 Col/Transect (Table 53). Boulder star coral (*Orbicella franksi*) was the dominant coral species with a mean substrate cover of 5.90% (range: 0.54 – 14.84%), representative of 38.8% of the total substrate cover by live hard corals. Great star coral (*Montastrea cavernosa*), mustard-hill coral (*Porites astreoides*), massive starlet coral (*Siderastrea siderea*) and lettuce coral (*Agaricia agaricites*) were present in at least three transects with a combined cover of 6.67% and along with boulder star coral comprised the main coral assemblage at WEST10. Apparent infectious diseases were observed in three (1-*O. faveolata*, 1-*P. astreoides*, 1-*M. cavernosa*) out of the 51 coral colonies intercepted by transects during 2019, for a mean prevalence of 5.9% (Appendix 2).

Erect soft corals were moderately abundant at WEST10 with a mean density of 13.0 Col/Transect. Although a species survey of erect soft corals was not performed, some of the most common taxa included sea fans (*Gorgonia ventalina*), sea plumes (*Allotogorgia spp),* and sea rods (*Plexaura spp*, *Eunicea spp*). Encrusting species, such as *Erythropodium caribaeorum* was present in four transects with a mean cover of 0.60%. Sponges were represented by at least 19 species intercepted by transects with a mean substrate cover of 3.41%. The giant barrel sponge (*Xestospongia muta*) was the dominant species in terms of reef substrate cover with a mean of 0.91% and due to its vertical projection and size contributed to the reef rugosity and habitat complexity.

Table 53. Percent reef substrate cover by sessile-benthic categories at WEST10, Caja de Muertos, Ponce.

WEST10 Survey Date: 9-5-19	Transects					
	1	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	7.7	7.6	7.8	6.7	7.4	**7.44**
Rugosity (m)	4.53	5.19	6.90	6.07	5.64	**5.67**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	13.29	11.52	21.79	19.08	18.35	**16.81**
Rubble	13.29	1.66	2.49		3.58	**4.20**
Sand	8.57	5.81	0.83	0.39	4.03	**3.92**
Total Abiotic	**35.16**	**18.99**	**25.10**	**19.46**	**25.96**	**24.94**
Benthic Algae						
Turf (mixed) with sediment	42.10	34.47	30.90	44.08	39.93	**38.30**
Turf (mixed)		8.66	9.11	12.36		**6.03**
Ramicrusta spp.	0.77	0.83	2.07	0.29	1.16	**1.02**
Dictyota spp.		0.83	2.24	1.25	0.63	**0.99**
CCA (total)		0.37		0.87	0.54	**0.35**
Lobophora spp.			0.41			**0.08**
Peyssonnelia spp.					0.36	**0.07**
Total Benthic Algae	**42.87**	**45.16**	**44.74**	**58.84**	**42.61**	**46.85**
Cyanobacteria	**8.57**	**7.47**	**10.11**	**5.12**	**16.47**	**9.55**
Hard Coral						
Orbicella franksi	6.26	14.84	4.89	2.99	0.54	**5.90**
Montastraea cavernosa	0.19	3.78	1.08	5.79	4.74	**3.12**
Porites astreoides	2.70	0.46	1.33	0.58	4.48	**1.91**
Siderastrea siderea	1.16	2.67	0.75		0.27	**0.97**
Orbicella faveolata		3.59				**0.72**
Agaricia agaricites			0.66	0.19	2.51	**0.67**
Dendrogyra cylindrus			2.07			**0.41**
Pseudodiploria strigosa			1.91			**0.38**
Meandrina meandrites				1.74		**0.35**
Millepora alcicornis			0.66	1.06		**0.34**
Stephanocoenia intersepta			0.33	1.16		**0.30**
Porites furcata				0.19	0.36	**0.11**
Porites porites			0.17			**0.03**
Total Hard Coral	**10.31**	**25.35**	**13.84**	**13.71**	**12.89**	**15.22**
# Coral Colonies/Transect	**7**	**12**	**8**	**13**	**11**	**10.2**
# Diseased Coral Colonies/Transect	**0**	**2**	**0**	**0**	**1**	**0.6**
Soft Corals						
Erythropodium caribaeorum	0.19		0.33	1.93	0.54	**0.60**
Gorgonia ventalina		0.46				**0.09**
Total Soft Corals	**0.19**	**0.46**	**0.33**	**1.93**	**0.54**	**0.69**
# Soft Coral Colonies/Transect	**16**	**9**	**15**	**8**	**17**	**13.0**
Sponges						
Xestospongia muta	1.16		3.40			**0.91**
Ircinia strobilina				1.74		**0.35**
Aplysina fistularis		0.65		0.39	0.27	**0.26**

WEST10
Survey Date: 9-5-19

	Transects					
	1	**2**	**3**	**4**	**5**	**Mean**
Niphates erecta	0.39	0.37		0.19		**0.19**
Cliona delitrix		0.83				**0.17**
Ircinia felix				0.77		**0.15**
Aiolochroia crassa	0.77					**0.15**
Chondrilla caribensis		0.18	0.58			**0.15**
Sponge spp.	0.19		0.17	0.19	0.18	**0.15**
Amphimedon compressa				0.68		**0.14**
Ectyoplasia ferox			0.66			**0.13**
Ircinia spp. brown		0.28			0.36	**0.13**
Monanchora arbuscula			0.50			**0.10**
Mycale laevis		0.18		0.19	0.09	**0.09**
Cliona varians					0.45	**0.09**
Aplysina cauliformis		0.09	0.33			**0.08**
Verongula rigida	0.39					**0.08**
Cliona tenuis				0.29		**0.06**
Plakortis spp.					0.18	**0.04**
Total Sponges	**2.89**	**2.58**	**5.63**	**4.44**	**1.52**	**3.41**
Others						
Lebrunia neglecta				0.48		**0.10**
Bartholomea annulata			0.25			**0.05**

Temporal variations of reef substrate cover by the main sessile-benthic categories of WEST10 are shown in Figure 60. Differences of substrate cover by hard corals between monitoring surveys were statistically significant (ANOVA; p = 0.0007, Appendix 3). Differences were associated with a marked decline of cover after the 1999 baseline survey. Live hard coral cover declined 40.9% between the 2005 (19.32%) and 2006 (11.42%) monitoring surveys. Sharp reductions of live coral were measured in all transects surveyed. During 2007 live coral declined again, but the 6.3% decline was relatively small compared to previous records and statistically similar to the 2006 condition. Recently dead coral accounted for a total of 7.7% during 2007, associated with mortality of massive corals, such as *Orbicella annularis* (complex) and *Colpophyllia natans* after the late 2005 coral bleaching event (Figure 61). Hard coral cover stabilized since the 2008 monitoring survey and has shown a recuperation trend during the last three surveys, mostly driven by a sharp increment of cover by *Orbicella spp.* (Figure 61). During the 2019 survey hard coral cover at WEST10 declined -4.88% relative to the previous 2017 survey, but such difference was statistically insignificant (see Appendix 3).

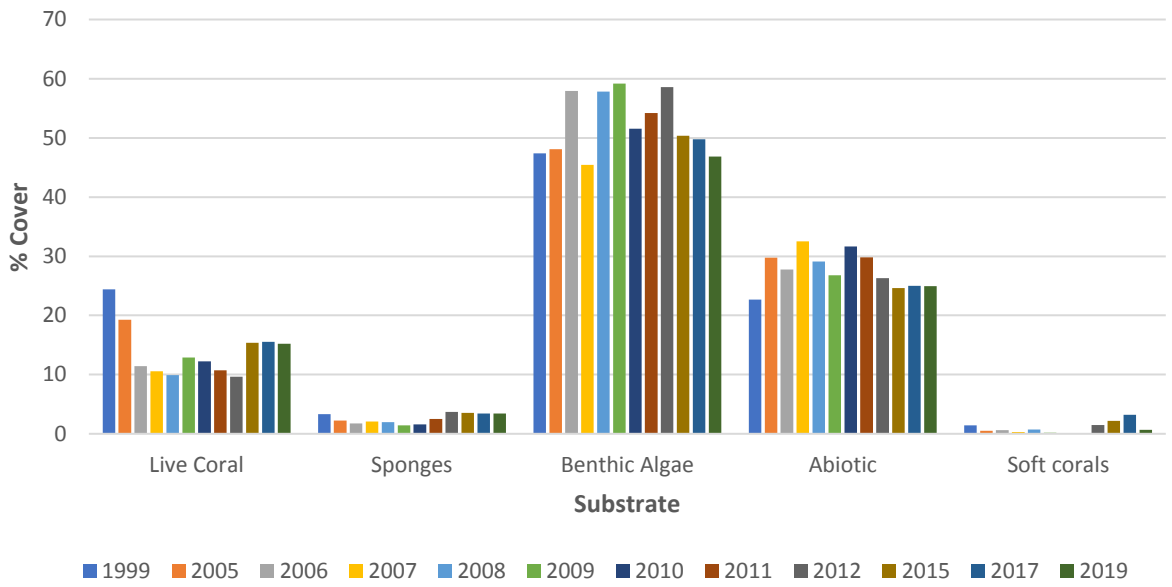


Figure 60. Monitoring trends (1999 – 2019) of mean substrate cover by sessile-benthic categories at WEST10, Ponce.

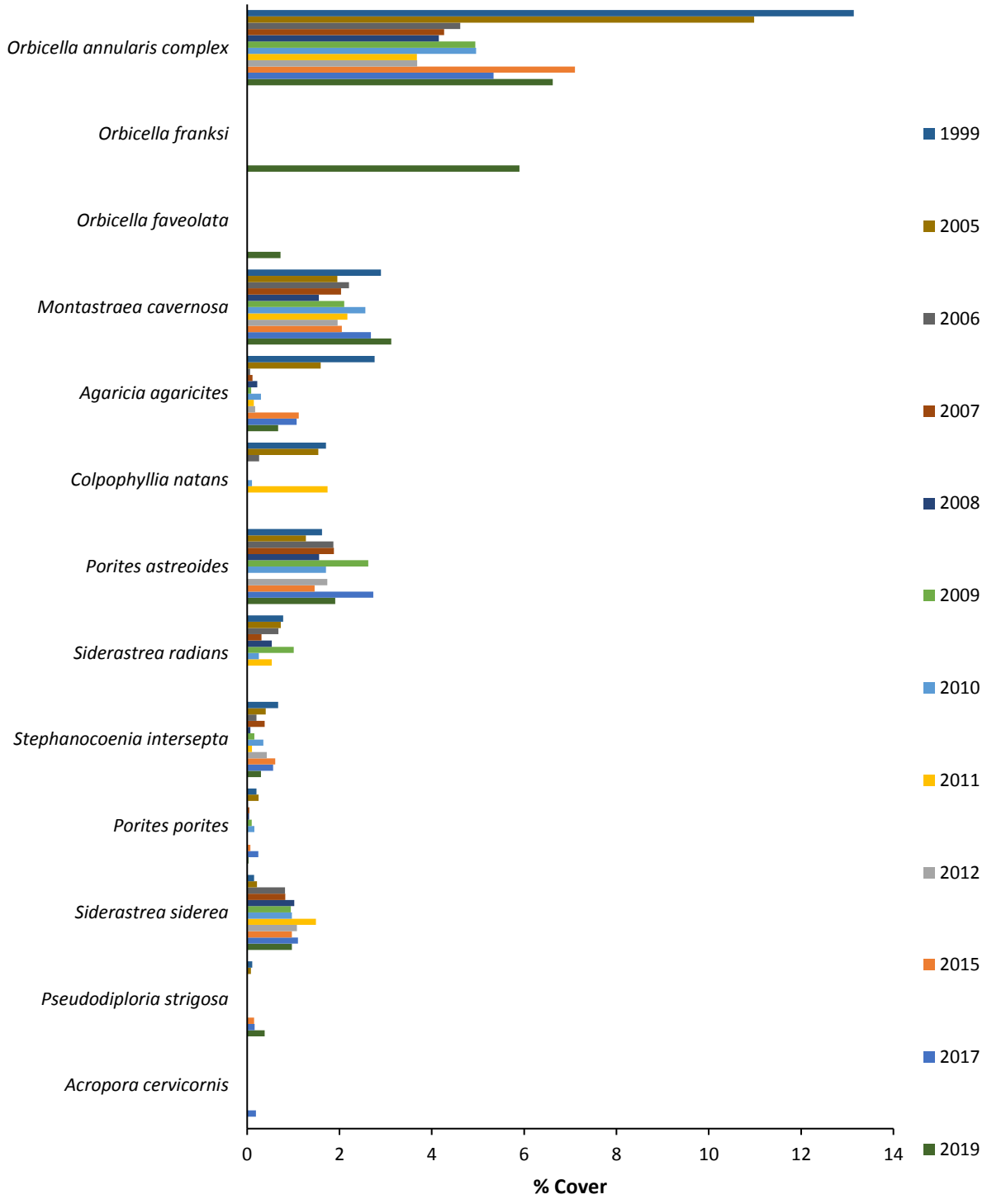


Figure 61. Monitoring trends (1999 – 2019) of mean substrate cover hard coral species at WEST10, Ponce. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

18.3 Fishes and Motile Megabenthic Invertebrates

A total of 40 fish species were identified within belt-transects at WEST10 during the 2019 survey with a mean density of 159.2 Ind/30 m^2 (range: 134 - 185 Ind/30m^2) and a mean species richness of 21.0 Ind/30m^2 (Table 54). The masked goby (*Coryphopterus personatus*) was the numerically dominant species with a combined density of 89.6 Ind/30m^2, or 56.3% of the total individuals within belt-transects. The masked goby was observed in swarms of 15 – 60 individuals close to the reef substrate, below ledges, in front of crevices and other protective microhabitats of the reef. Six other species were present in all five transects, including the bluehead wrasse (*Thalassoma bifasciatum*), bicolor and dusky damselfishes (*Stegastes partitus, S. adustus*), bridled goby (*Coryphopterus glaucofraenum*), and striped and redband parrotfishes (*Scarus iseri, Sparisoma aurofrenatum*) with a combined density of 41.6 Ind/30m^2, or 26.1% of the total fish density within belt-transects. Motile megabenthic invertebrates were not observed within belt-transects at WEST10 in the 2019 survey. Five adult spiny lobsters (*Panulirus argus*) were observed outside transect areas.

Demersal zooplanktivore fishes comprised by the numerically dominant species, *Coryphopterus personatus* and to a lesser extent by *S. partitus* and *C. multilineata* were the most abundant fish trophic assemblage at WEST10 with a combined density of 97.4 Ind/30m^2, representative of 61.1% of the total fish density within belt-transects (Table 54). Streaming schools of creole wrasse (*Clepticus parrae*) and mackerel scad (*Decapterus macarellus*) were observed out of transects. Many zooplanktivorous fish species serve as forage for a diverse assemblage of top pelagic and demersal predators at WEST10, including barracudas, jacks, and large groupers and snappers observed during this and previous surveys (Garcia-Sais et al., 2017 and references therein). Small opportunistic carnivores included 17 species with a combined density of 33.6 Ind/30m^2, representative of 21.1% of the total fish density within belt-transects. The assemblage included two species of wrasses (Labridae), one goby (Gobiidae), one puffer (Tetraodontidae), two grunts (Haemulidae), one trumpetfish (Aulostomidae), one squirrelfish (Holocentridae), one hawkfish (Cirrhitidae), one goatfish (Mullidae) and seven small groupers, hamlets and sea basses (Serranidae). Herbivores were represented by 13 species with a combined density of 20.6 Ind/30m^2, or 12.9% of the total fish density. The assemblage was comprised by six parrotfishes (Scaridae), four damselfishes (Pomacentridae) and three doctorfishes (Acanthuridae). Spongivores (Pomacanthidae) and corallivores (Chaetodontidae) were also present in smaller densities. Piscivores were represented by the dog, schoolmaster and yellowtail snappers (*Lutjanus jocu, L. apodus, Ocyurus chrysurus*) and jacks (*Caranx crysos, C. ruber*) (Table 54).

Table 54. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at WEST10, Ponce.

West Reef (WEST10)						
Survey Date: 9-5-19			**Belt-Transects**			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Coryphopterus personatus	90	130	60	58	110	**89.6**
Thalassoma bifasciatum	13	11	16	36	22	**19.6**
Stegastes partitus	8	9	3	5	7	**6.4**
Stegastes adustus	3	5	9	6	3	**5.2**
Coryphopterus glaucofraenum	9	1	5	4	3	**4.4**
Caranx ruber	12	0	0	0	9	**4.2**
Scarus iseri	1	5	4	3	2	**3.0**
Sparisoma viride	1	4	4	3	3	**3.0**
Haemulon aurolineatum	2	1	5	1	5	**2.8**
Sparisoma aurofrenatum	2	0	6	3	1	**2.4**
Scarus taeniopterus	2	1	0	6	2	**2.2**
Caranx crysos	9	0	0	0	0	**1.8**
Chromis multilineata	0	0	6	1	0	**1.4**
Stegastes leucostictus	1	0	2	1	3	**1.4**
Stegastes variabilis	2	0	0	3	1	**1.2**
Acanthurus tractus	1	1	0	1	2	**1.0**
Canthigaster rostrata	0	1	1	2	1	**1.0**
Cephalopholis cruentata	1	0	1	1	2	**1.0**
Halichoeres garnoti	0	0	2	0	3	**1.0**
Chaetodon capistratus	2	1	0	0	1	**0.8**
Aulostomus maculatus	0	1	2	0	0	**0.6**
Serranus tigrinus	1	0	0	0	2	**0.6**
Acanthurus coeruleus	0	0	2	0	0	**0.4**
Holocentrus rufus	0	1	0	0	1	**0.4**
Hypoplectrus chlorurus	0	1	1	0	0	**0.4**
Hypoplectrus unicolor	1	0	0	1	0	**0.4**
Microspathodon chrysurus	0	1	1	0	0	**0.4**
Acanthurus chirurgus	0	0	0	0	1	**0.2**
Amblycirrhitus pinos	0	1	0	0	0	**0.2**
Chaetodon striatus	0	0	0	1	0	**0.2**
Haemulon sciurus	0	1	0	0	0	**0.2**
Holacanthus ciliaris	0	0	1	0	0	**0.2**
Holacanthus tricolor	0	0	1	0	0	**0.2**
Hypoplectrus niger	0	0	0	0	1	**0.2**
Hypoplectrus puella	0	0	0	1	0	**0.2**
Hypoplectrus spp.	0	0	1	0	0	**0.2**
Pomacanthus arcuatus	1	0	0	0	0	**0.2**
Pseudupeneus maculatus	1	0	0	0	0	**0.2**
Sparisoma chrysopterum	0	1	0	0	0	**0.2**
Sparisoma radians	0	0	1	0	0	**0.2**
Total Individuals	163	177	134	137	185	**159.2**
Total Species	21	19	23	19	23	**21.0**
Invertebrates						
none observed						

The size-frequency distribution of commercially important fishes, including the main reef herbivores is presented in Table 55. Six species of parrotfishes (Scaridae) were present as juvenile and/or adults, including terminal phase males (TPM) of stoplight, redband, princess and striped parrotfish (*Sparisoma viride, S, aurofrenatum, Scarus taeniopterus, S. iseri).* Recruitment juveniles (1-5cm) of *S. viride, S. iseri, S. taeniopterus* and *S. aurofrenatum* were also present (Table 55). Doctorfishes (*Acanthurus spp*) were observed as juveniles and full adult individuals in the 6–20 cm range. Although both stages were not observed within belt-transects, juvenile and adult graysbies (*Cephalopholis cruentata*) and yellowtail and schoolmaster snappers (*Ocyurus chrysurus*, *Lutjanus apodus*) were common at WEST10. One large adult dog snapper (*L. jocu*) was also present. Yellowtail snappers concentrate at the face of the fore-reef slope (wall), with small juveniles (< 5 cm) using the dense soft coral "forest" as protective habitat. Juvenile and young adult mutton snappers (*L. analis*) have been observed foraging along with an adult lane snapper (*L. synagris*) aggregation during previous surveys (García-Sais et al., 2006, 2014). Hogfish (*Lachnolaimus maximus*), red hind (*Epinephelus guttatus*) and a juvenile yellowfin grouper (*Mycteroperca venenosa*) have been reported during previous surveys (Garcia-Sais et al., 2005, Garcia-Sais et al., 2015 and references therein). These data are indicative that WEST10 functions as an important recruitment habitat for several species of parrotfishes and is a residential habitat for a variety of commercially important species that include hogfish (*L. maximus*), snappers (*Lutjanus spp, O. chrysurus*), and groupers (*E. guttatus, M. venenosa*).

Figure 62 shows the annual trends of mean fish density and species richness during monitoring surveys at WEST10. Statistically significant differences of fish density and species richness were found for both parameters (ANOVA; $p < 0.0001$, Appendix 5 -6). Density differences were largely driven by abundance fluctuations of the masked goby (*Coryphopterus personatus*), a numerically dominant species that forms large schooling aggregations of 100's of individuals within belt transects. Densities of *C. personatus* were relatively lower during the 1999 baseline survey and then again in the period of 2006-08 and 2017 relative to the period of 2009-2011 and the most recent 2019 survey. Differences of fish species richness within belt-transects were also detected (ANOVA; $p < 0.0001$; Appendix 6). The main pattern was a decline of the number of species during the 2007, 2008 and during the 2013 relative to other surveys. The absence or low densities of *C. personatus* could have influenced the presence of small piscivores and thus reduce the complexity of the food web, resulting in lower fish species richness. Physical conditions at the time of survey are also a relevant factor for species richness at WEST10, as small fishes tend to hide and/or migrate to deeper water during periods of strong wave and surge action.

Table 55. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at WEST10, Ponce.

Survey Date: 9-5-19					TRANSECTS				
		Size	Life		(Ind/60m^2)				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	0	3	1	1	**1.0**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	0	0	0	1	0	**0.2**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	1	1	1	2	1	**1.2**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	0	2	0	0	0	**0.4**
Caranx crysos c3	Carangidae	11-15	Juvenile	9	0	0	0	0	**1.8**
Caranx ruber c2	Carangidae	6-10	Juvenile	12	0	0	0	9	**4.2**
Cephalopholis cruentata c2	Serranidae	6-10	Juvenile	0	0	1	0	2	**0.6**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	0	1	0	0	2	**0.6**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	0	0	0	1	0	**0.2**
Cephalopholis cruentata c5	Serranidae	21-25	Adult	1	0	0	0	0	**0.2**
Lutjanus apodus c3	Lutjanidae	11-15	Juvenile	0	0	0	1	0	**0.2**
Lutjanus apodus c4	Lutjanidae	16-20	Juvenile	0	0	0	0	1	**0.2**
Lutjanus jocu c11	Lutjanidae	51-60	Adult	0	0	0	1	0	**0.2**
Ocyurus chrysurus c4	Lutjanidae	16-20	Adult	1	0	0	0	0	**0.2**
Scarus iseri c1	Scaridae	1-5	Recruit	5	18	3	3	0	**5.8**
Scarus iseri c2	Scaridae	6-10	Juvenile	1	1	2	3	2	**1.8**
Scarus iseri c3	Scaridae	11-15	Juvenile	0	0	0	1	0	**0.2**
Scarus iseri c4	Scaridae	16-20	TPM	0	0	1	2	2	**1.0**
Scarus iseri c5	Scaridae	21-25	TPM	1	0	0	0	0	**0.2**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	0	0	0	6	0	**1.2**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	2	0	0	0	0	**0.4**
Scarus taeniopterus c4	Scaridae	16-20	TPM	0	1	1	0	0	**0.4**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	0	0	4	0	0	**0.8**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	0	0	1	0	1	**0.4**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	1	0	1	1	2	**1.0**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	1	1	0	0	0	**0.4**
Sparisoma aurofrenatum c4	Scaridae	16-20	TPM	1	0	0	2	0	**0.6**
Sparisoma aurofrenatum c5	Scaridae	21-25	Adult	1	0	0	0	0	**0.2**
Sparisoma chrysopterum c5	Scaridae	21-25	Adult	0	0	0	1	0	**0.2**
Sparisoma radians c2	Scaridae	6-10	Juvenile	0	0	1	0	0	**0.2**
Sparisoma viride c1	Scaridae	1-5	Recruit	1	0	3	0	3	**1.4**
Sparisoma viride c4	Scaridae	16-20	Adult	0	0	1	0	0	**0.2**
Sparisoma viride c6	Scaridae	21-25	Adult	1	2	0	0	0	**0.6**
Sparisoma viride c6	Scaridae	26-30	TPM	0	0	1	0	0	**0.2**
			Totals	**39**	**27**	**24**	**26**	**26**	**28.4**

TPM = Terminal phase males

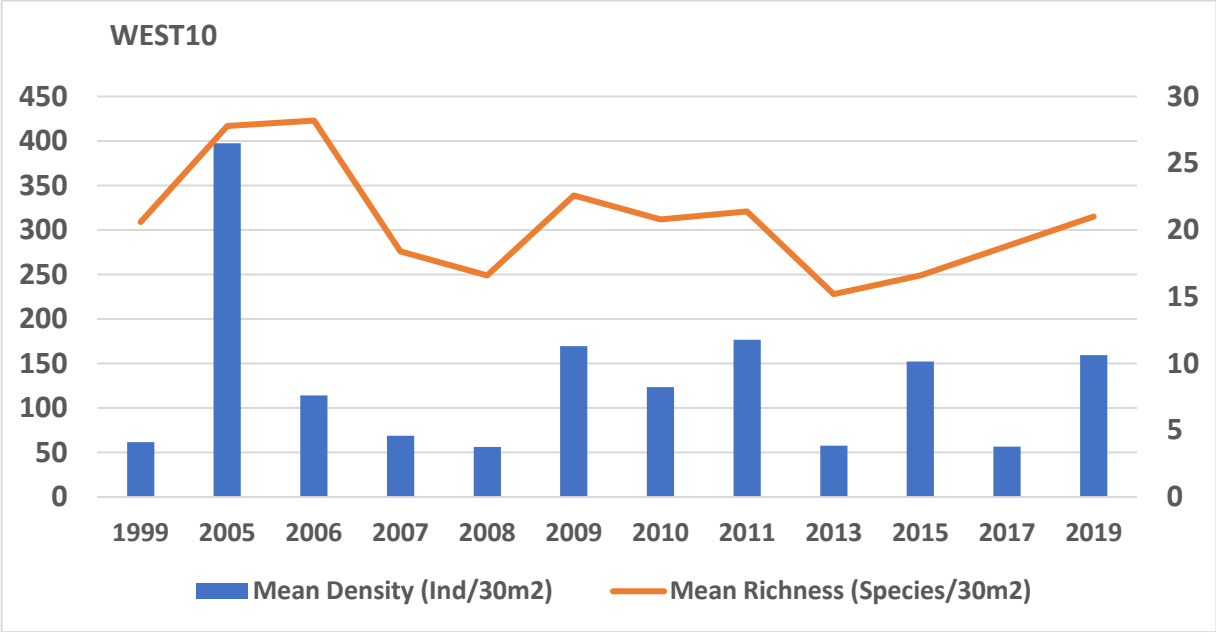
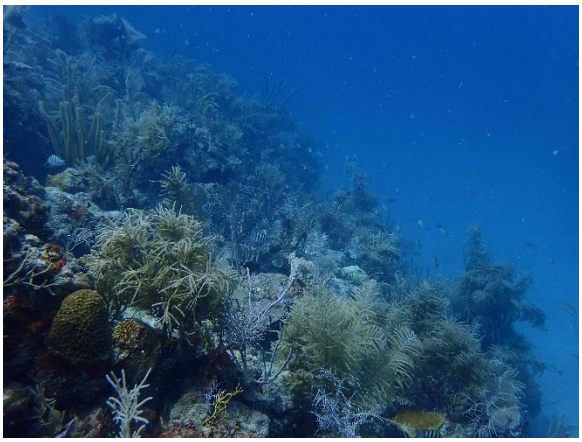


Figure 62. Monitoring trends (1999 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at WEST10, Ponce.

18.4 Photo Album 18. WEST10



19. Derrumbadero Reef (DERR20)

19.1 Physical Description

Derrumbadero (DERR20) is a submerged promontory fringing the shelf-edge located 2.2 NM southeast off from the mouth of Ponce Bay (Figure 63). The promontory rises from the outer shelf at a depth of about 25 -30 m to a reef top at 15m, and then drops down the insular slope along the south and west margins. The reef top platform has an irregular spherical shape. It measures approximately 2 kilometers from east to west and about 0.7 kilometers from north to south. Permanent transects were established at the southern edge of the reef, close to the shelf-edge drop-off wall during the baseline survey in August 2001 (Garcia-Sais et al., 2001c).

DERR20 exhibits an impressive spur-and groove coral reef formation that resembles the shelf-edge reef systems of La Parguera and Guánica. Coralline sand channels cut through the reef down to the shelf-edge, separating spurs of approximately five metes high. Massive, branching and encrusting hard corals and soft corals colonize the spurs and grow towards the channels, creating a highly complex habitat of large coral mounds, ledges and overhangs. Panoramic views of DERR20 ref community are presented as Photo Album 19.

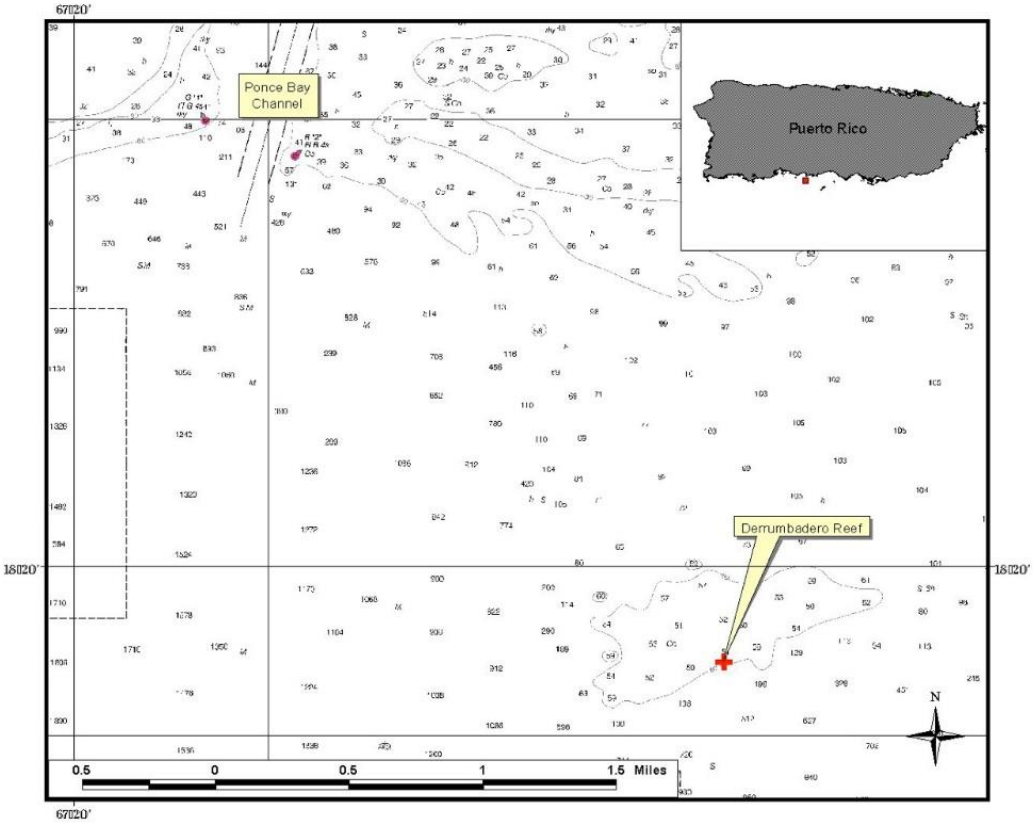


Figure 63. Location of the coral reef monitoring station at Derrumbadero Reef, Ponce.

19.2 Sessile-Benthic Reef Community

Benthic algae comprised by an assemblage of fleshy brown (*Lobophora sp*., *Dictyota sp*), turf (mixed), green calcareous (*Halimeda spp*) and red crustose algae (CCA, *Ramicrusta sp, Peyssonnelia sp*.) were the most prominent sessile-benthic category in terms of substrate cover at DERR20 with a combined mean of 59.27% (range: 49.37 – 67.93%). The y-twig alga (*Dictyota sp*) and turf algae (mixed assemblage) were the dominant components of the benthic algae with mean substrate cover of 22.44% and 20.28%, respectively. The encrusting fan-alga (*Lobophora sp*) and crustose coralline algae (CCA) were present in all five transects with mean cover of 13.35% and 2.01%, respectively. *Ramicrusta sp*. and *Peyssonnelia sp*. were intercepted by transects at DERR20 but with relatively low cover (<1%) (Table 56). Cyanobacterial patches were present in three transects with a mean substrate cover of 2.12%. Abiotic categories were present mostly as reef overhangs largely produced by mounds and ledges of mountainous and boulder star coral (*Orbicella faveolata, O. franksi*) contributing to a mean reef substrate rugosity of 2.77m.

A total of 16 hard coral species were intersected by line transects during 2019 at DERR20 with a mean substrate cover of 20.06% (range: 9.97 – 27.76%) and a mean density of 13.8 Col/Transect (Table 56). Hard corals occurred as massive, encrusting, branching and mound shaped colonies. Mountainous star coral (*Orbicella faveolata*) and mustard-hill coral (*Porites astreoides*) were the dominant species in terms of substrate cover with means of 6.68% and 5.16%, respectively. The sibling species *O. franksi* and *O. annularis* were also intercepted by transects with a combined reef substrate cover by the *Orbicella spp* complex of 9.81%, representative of 48.9% of the total cover by hard corals at DERR20. Lettuce coral (*Agaricia agaricites*) was present in all five transects with a mean substrate cover of 1.58% (Table 56). Three out of 69 hard coral colonies intercepted by transects were observed to be apparently affected by an infectious disease for a coral disease prevalence of 4.3%. Diseased coral colonies included 1-*O. faveolata*, 1-*O. franksi*, and 1-*S. siderea* (Appendix 2).

Black corals (Antipatharia) were observed off the shelf-edge at depths of 25–30 m. These included the wire black coral (*Stichopathes lutkeni*), and the bushy black coral (*Antipathes caribbeana*). Erect soft corals were abundant at DERR20 (mean: 26.0 Col/Transect) and because of their vertical projection and large sizes, contributed substantially to the structural complexity of the reef. Sea plumes (*Antillogorgia acerosa, A. americana*), sea fans (*Gorgonia ventalina*) and sea rods (*Pseudoplexaura sp*, *Eunicea spp*.) were the most common.

Table 56. Percent reef substrate cover by sessile-benthic categories at DERR20, Ponce.

Survey Date: 9-5-19	**Transects**					
	1	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	16.8	16.6	16.1	16.3	16.3	**16.42**
Rugosity (m)	2.56	2.53	1.70	2.64	4.41	**2.77**
BENTHIC CATEGORIES						
Abiotic						
Reef overhang	0.45	8.04	1.79	5.98	6.71	**4.59**
Rubble				0.66		**0.13**
Total Abiotic	**0.45**	**8.04**	**1.79**	**6.64**	**6.71**	**4.73**
Benthic Algae						
Dictyota spp.	17.50	24.36	21.17	26.02	23.13	**22.44**
Turf (mixed)	20.40	29.16	25.72	14.95	11.18	**20.28**
Lobophora spp.	16.61	11.17	13.28	14.62	11.08	**13.35**
CCA (total)	1.78	2.23	1.67	2.10	2.24	**2.01**
Peyssonnelia spp.		0.56	0.72	1.22	0.97	**0.69**
Halimeda spp.			0.84	0.44		**0.26**
Ramicrusta spp.		0.45			0.78	**0.24**
Total Benthic Algae	**56.30**	**67.93**	**63.40**	**59.36**	**49.37**	**59.27**
Cyanobacteria	**2.90**	**0.00**	**3.71**	**0**	**3.98**	**2.12**
Hard Coral						
Orbicella faveolata	12.93	4.58	5.14	2.66	8.07	**6.68**
Porites astreoides	4.79	3.69	7.06	4.43	5.83	**5.16**
Orbicella franksi	3.23	1.56	2.99	2.10	5.44	**3.07**
Agaricia agaricites	1.90	1.56	3.11	0.44	0.87	**1.58**
Montastraea cavernosa	2.12	0.00	4.31			**1.28**
Colpophyllia natans	0.00	3.69				**0.74**
Meandrina meandrites	2.12					**0.42**
Pseudodiploria strigosa		1.12				**0.22**
Stephanocoenia intersepta		0.00			1.07	**0.21**
Siderastrea siderea		0.11	0.60	0.22		**0.19**
Helioseris cucullata		0.67				**0.13**
Agaricia lamarcki	0.67					**0.13**
Millepora alcicornis					0.58	**0.12**
Orbicella annularis					0.29	**0.06**
Scolymia cubensis			0.24			**0.05**
Madracis decactis				0.11		**0.02**
Total Hard Coral	**27.76**	**16.98**	**23.44**	**9.97**	**22.16**	**20.06**
# Coral Colonies /Transect	**11**	**12**	**14**	**14**	**18**	**13.8**
# Diseased Coral Colonies/Transect	**0**	**1**	**2**	**0**	**0**	**0.60**
# Bleached Coral Colonies/Transect	**0**	**0**	**1**	**0**	**1**	**0.40**
Soft Corals						
Briareum asbestinum	2.68		0.36	12.96	0.87	**3.37**
Erythropodium caribaeorum	1.67		4.07	0.66	1.94	**1.67**
Gorgonia ventalina	0.33	0.56		1.66	0.49	**0.61**

Survey Date: 9-5-19			**Transects**			
	1	**2**	**3**	**4**	**5**	**Mean**
Pseudoplexaura flagellosa	0.56		0.24	0.55		**0.27**
Antillogorgia acerosa		0.22	0.72			**0.19**
Eunicea spp.				0.44		**0.09**
Antillogorgia americana					0.39	**0.08**
Eunicea succinea			0.24			**0.05**
Eunicea flexuosa		0.22				**0.04**
Total Soft Corals	**5.24**	**1.01**	**5.62**	**16.28**	**3.69**	**6.37**
# Soft Coral Colonies/Transect	**19**	**24**	**34**	**26**	**27**	**26.0**
Sponges						
Agelas sventres	0.45	1.01		2.88	2.53	**1.37**
Agelas conifera	1.78				3.69	**1.10**
Agelas citrina	2.23	1.01			0.87	**0.82**
Agelas dispar	0.89	1.01	0.48	0.66	0.68	**0.74**
Petrosia pellasarca					2.04	**0.41**
Niphates digitalis			0.72		1.26	**0.40**
Monanchora arbuscula	1.00				0.68	**0.34**
Amphimedon compressa		0.22	0.24	0.44	0.78	**0.34**
Ircinia strobilina		0.78			0.19	**0.20**
Mycale laevis		0.22		0.11	0.49	**0.16**
Cliona caribbaea		0.78				**0.16**
Agelas clathrodes	0.78					**0.16**
Neopetrosia proxima				0.78		**0.16**
Verongula rigida					0.68	**0.14**
Aplysina fistularis				0.66		**0.13**
Niphates spp.		0.56				**0.11**
Clathria spp.			0.24	0.11	0.19	**0.11**
Niphates caribica		0.22		0.22		**0.09**
Iotrochota arenosa				0.44		**0.09**
Agelas sceptrum			0.36			**0.07**
Scopalina ruetzleri		0.22				**0.04**
Sponge spp.	0.22					**0.04**
Chondrilla caribensis				0.22		**0.04**
Ectyoplasia ferox				0.22		**0.04**
Neopetrosia spp. smooth				0.22		**0.04**
Niphates erecta				0.22		**0.04**
Total Sponges	**7.36**	**6.03**	**2.03**	**7.20**	**14.09**	**7.34**
Others						
Trididemnum solidum				0.33		**0.07**
Anemone spp.				0.22		**0.04**

Encrusting species, such as the corky sea finger (*Briareum asbestinum*) and the encrusting gorgonian (*Erythropodium caribaeorum*) were present in four transects each with a combined mean cover of 5.04% (Table 56). At least 26 sponge species were intercepted by transects with a combined mean substrate cover of 7.34%. *Agelas spp*. were the most prominent in terms of reef substrate cover with a combined mean cover of 4.10%, representative of 55.8% of the total cover by sponges at DERR20.

Temporal variations of mean percent cover by sessile-benthic categories during monitoring surveys at DERR20 are presented in Figure 64. Differences of mean reef substrate cover by hard corals between monitoring surveys were statistically significant (ANOVA; $p < 0.0001$; Appendix 3). Differences were mostly related to a sharp decline of hard coral cover after the 2005 survey. Total live coral declined 59.1%, from 34.7% in 2005 to 14.2% in 2006. A proportional increment of cover by benthic algae was measured. Such drastic, short-term collapse of the DERR20 coral reef system was associated with the massive regional coral bleaching event that affected Puerto Rico and the USVI during late September through October 2005 (García-Sais et al., 2006, 2007, 2008). Another decline of 24% from the mean cover in 2007 was measured during the 2008 survey. Since 2012, a mild but consistent trend of increasing live hard coral cover was measured until the 2017 survey (Figure 64), reaching a recuperation of 62% from the pre-bleaching live coral cover of 2005.

During the present 2019 survey hard coral cover averaged 20.06%, a decline of 7.3%. Such difference was not statistically different from the previous 2017 survey. Monitoring trends of mean substrate cover by coral species at DERR20 are shown in Figure 65. During the baseline survey in 2001, the *Orbicella spp* complex was the dominant coral taxa in terms of reef substrate cover at DERR20, representing 58.3% of the total cover by live hard corals. *Orbicella spp* complex declined 64.2% between the 2001 baseline (24.31%) and the 2006 monitoring survey (8.7%). Marked reductions of mean substrate cover by live corals were also measured for *Montastraea cavernosa*, *Agaricia agaricites, Diploria labyrinthiformis*, and *Acropora cervicorni*s. Since 2012, a mild but consistent increase of reef substrate cover by *Orbicella spp* has been measured until the present survey and represents an important contribution to the overall recuperation of the coral community at DERR20 (Figure 65).

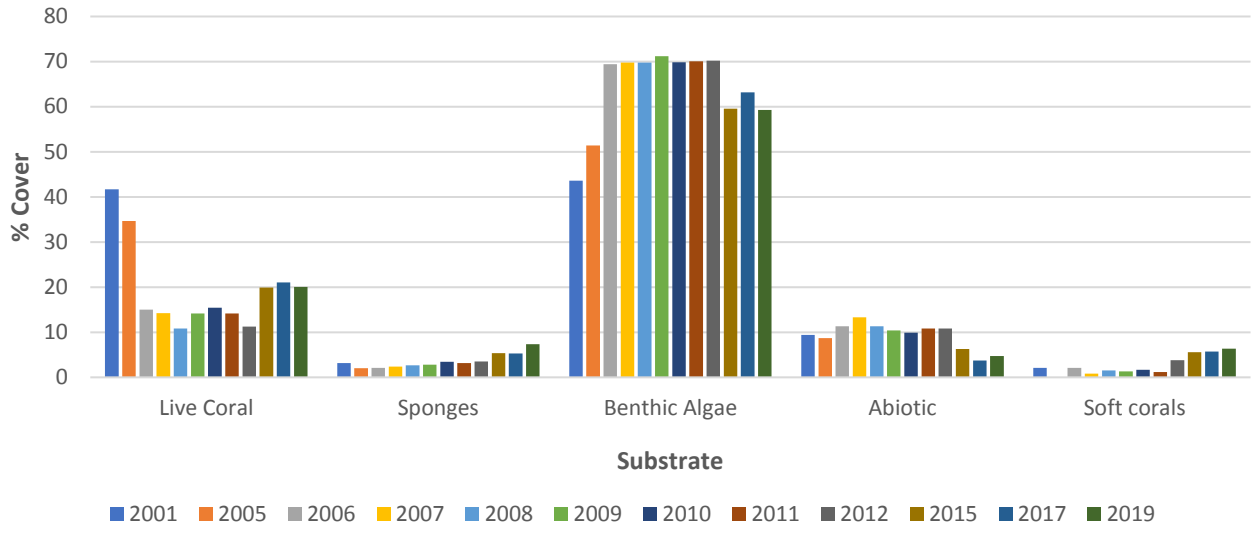


Figure 64. Monitoring trends (2001 – 2019) of mean substrate cover by sessile-benthic categories at DERR20, Ponce.

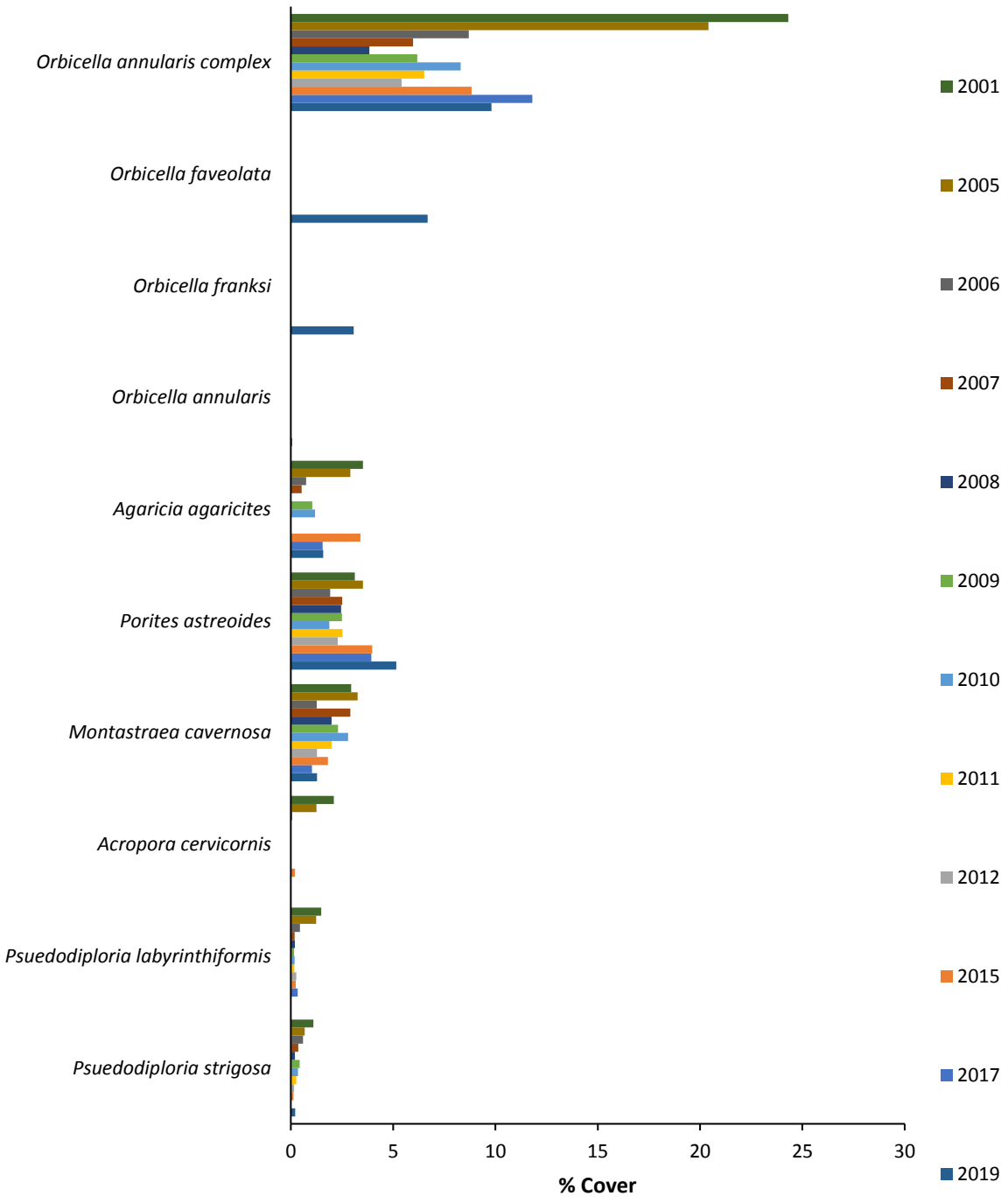


Figure 65. Monitoring trends (2001 – 2019) of mean substrate cover by hard coral species at DERR20, Ponce. Note that previous to 2019, all three *Orbicella* species were documented under "*Orbicella annularis* complex". In 2019, *Orbicella* complex were divided by species, which can be seen in this graph.

19.3 Fishes and Motile Megabenthic Invertebrates

A total 37 fish species were identified within belt transects at DERR20 during the 2019 survey with a mean density of within belt-transects of 78.6 Ind/30m^2 (range: 55 - 116 Ind/30m^2) and a mean species richness of 18.2 Spp/Transect (Table 57). The creole wrasse (*Clepticus parrae*) and the blue chromis (*Chromis cyanea*) were the numerically dominant species within belt-transects with a combined mean density of 24.4 Ind/30m^2, representative of 31.0% of the total fish density. The bicolor damselfish (*Stegastes partitus*), peppermint goby (*Coryphopterus lipernes*), striped and redband parrotfishes (*Scarus iseri, Sparisoma aurofrenatum*), and beaugregory (*S. leucostictus*) were present in all five transects with a combined density of 21.0 Ind/30m^2, representative of another 26.7% of the total fishes within belt-transects. One school of 26 bar jacks (*Caranx ruber*) were observed in one transect and another school of 23 bluehead wrasse (*Thalassoma bifasciatum*) were present within transects contributing with a combined density of 11.6 Ind/30m^2. In addition to the aforementioned species, the princess parrotfish (*S. taeniopterus*), four-eye butterflyfish (*Chaetodon capistratus*), and french grunt (*Haemulon flavolineatum*) were present in at least three of the five transects surveyed and were also part of the resident demersal fish community at DERR20. Motile megabenthic invertebrates were not observed within belt-transects.

Zooplanktivores, represented within belt-transects by the three most abundant species (*Clepticus parrae, Chromis cyanea and Stegastes partitus*) were the main fish trophic group at DERR20 with a mean density of 31.2 Ind/30m^2, or 39.7% of the total fish density (Table 57). Small opportunistic carnivores included a total of 16 species with a combined density of 21.6 Ind/30m^2, representative of 27.5% of the total individuals. The assemblage included two gobies (Gobiidae), three wrasses (Labridae), three squirrelfishes (Holocentridae), two grunts (Haemulidae), one puffer (Tetraodontidae), two hamlets and one small grouper (Serranidae). Herbivores were represented by 10 species, including five parrotfishes (Scaridae), three doctorfishes (Acanthuridae) and two damselfishes (Pomacentridae) with a combined density of 14.2 Ind/30m^2, or 18.1% of the total individuals. Mid-size piscivores included the red hind (*Epinephelus guttatus*) and the lionfish (*Pterois sp*). Spongivores (Pomacanthidae) and corallivores (Chaetodontidae) were also present in low density (< 3%) (Table 57).

Table 57. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at DERR20, Ponce.

Derrumbadero (DERR20)						
Survey Date: 9-5-19			**Belt-Transects**			
		(# Individuals/30m^2)				
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Clepticus parrae	15	7	0	41	0	**12.6**
Chromis cyanea	25	3	10	2	19	**11.8**
Stegastes partitus	12	7	6	5	4	**6.8**
Coryphopterus lipernes	5	2	5	12	8	**6.4**
Caranx ruber	29	0	0	0	0	**5.8**
Thalassoma bifasciatum	1	0	5	0	23	**5.8**
Scarus iseri	12	4	6	1	1	**4.8**
Sparisoma aurofrenatum	3	3	3	3	3	**3.0**
Elacatinus evelynae	0	0	2	8	3	**2.6**
Coryphopterus personatus	0	12	0	0	0	**2.4**
Stegastes leucostictus	2	2	1	3	3	**2.2**
Scarus taeniopterus	0	2	2	2	2	**1.6**
Holocentrus rufus	1	2	2	1	0	**1.2**
Chaetodon capistratus	1	2	0	2	0	**1.0**
Haemulon flavolineatum	2	1	1	0	1	**1.0**
Halichoeres garnoti	1	3	0	1	0	**1.0**
Myripristis jacobus	0	0	4	0	1	**1.0**
Acanthurus coeruleus	1	0	0	2	1	**0.8**
Cephalopholis cruentata	0	2	0	1	0	**0.6**
Chaetodon striatus	0	0	1	2	0	**0.6**
Halichoeres maculipinna	0	0	0	3	0	**0.6**
Lutjanus apodus	2	0	0	0	1	**0.6**
Sparisoma viride	0	0	1	0	2	**0.6**
Acanthurus chirurgus	0	0	1	1	0	**0.4**
Acanthurus tractus	1	1	0	0	0	**0.4**
Bodianus rufus	0	0	1	1	0	**0.4**
Epinephelus guttatus	1	0	1	0	0	**0.4**
Holacanthus tricolor	0	0	0	0	2	**0.4**
Canthigaster rostrata	0	0	1	0	0	**0.2**
Haemulon sciurus	0	1	0	0	0	**0.2**
Holacanthus ciliaris	0	0	1	0	0	**0.2**
Hypoplectrus niger	0	0	1	0	0	**0.2**
Hypoplectrus puella	1	0	0	0	0	**0.2**
Microspathodon chrysurus	0	0	0	0	1	**0.2**
Neoniphon marianus	0	1	0	0	0	**0.2**
Pterois volitans	0	0	0	0	1	**0.2**
Sparisoma radians	1	0	0	0	0	**0.2**
Total Individuals	116	55	55	91	76	**78.6**
Total Species	19	17	20	18	17	**18.2**
Invertebrates						
none observed						

The size distributions of commercially important fishes observed within 20 x 3m belt-transects at DERR20 during the 2019 monitoring survey are presented in Table 58. The larger reef herbivores represented by parrotfishes (Scaridae) and doctorfishes (Acanthuridae) were mostly present as juveniles and adults. Terminal phase male (TPM) stages of the stoplight (*Sparisoma viride*), redband (*S. aurofrenatum*), princess (*Scarus taeniopterus*) and striped (*S. iseri*) parrotfishes were present. Recruitment juvenile stages (1–5cm) of *S. aurofrenatum* were also observed within belt-transects. Garcia-Sais et al (2017) also reported recruitment juvenile stages of *S. viride* and *S. radians* at DERR20. Mid-size demersal piscivores (*L. apodus, E. guttatus*) were represented within belt-transects by juvenile and large adults. Top pelagic predators, including cero mackerel (*Scomberomorus regalis*) and great barracuda (*Sphyraena barracuda*) were observed out of transects. Hogfish (*L. maximus*), almaco jack (*Seriola sp*.), cubera snappers (*L. cyanopterus*) yellowfin and Nassau groupers (*M. venenosa, E. striatus*) and other large demersal and pelagic predators have been previously reported for DERR20 (Garcia-Sais et al. 2017 and references therein). The species composition and size distribution data are indicative that DERR20 functions largely as an important residential and recruitment habitat for several parrotfish and doctorfish species and a prime residential and foraging ground for top demersal and pelagic predators of commercial value. The presence in high densities of schooling pelagic and demersal zooplanktivores contribute to the value of DERR20 as a foraging ground for large reef fish predators as they serve as forage for these piscivore populations.

Temporal variations of fish density and species richness between monitoring surveys at DERR20 were statistically significant (ANOVA; $p < 0.0001$; Appendix 5 - 6). Higher fish densities were observed during the 2001, 2005 and 2011 surveys compared to the 2006 – 10, 2013, 2017 and 2019 surveys (Figure 66). Differences have been largely driven by the abundance fluctuations of masked goby (*Coryphopterus personatus*) a species that was numerically dominant during the baseline (2001) and also in the 2005, 2011, 2015 and 2019 monitoring surveys. This is a small zooplanktivorous fish species that forms dense swarms of 100’ of individuals below coral ledges. Its mean abundance within belt-transects has varied more than 10-fold between monitoring surveys. Such marked fluctuations of abundance by masked goby are unaccounted for and beyond the scope of this monitoring work but appear to be related to density-independent factors, such as its recruitment dynamics and vulnerability to wave and surge action in shallow reef systems (Esteves, 2013).

Table 58. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at DERR20, Ponce.

Derrumbadero (DERR20)									
Survey Date: 9-5-19					**TRANSECTS**				
		Size	**Life**		**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c3	Acanthuridae	11-15	Juvenile	2	0	2	1	0	**1.0**
Acanthurus chirurgus c4	Acanthuridae	16-20	Adult	0	0	0	1	0	**0.2**
Acanthurus coeruleus c3	Acanthuridae	11-15	Adult	0	0	1	2	0	**0.6**
Acanthurus coeruleus c4	Acanthuridae	16-20	Adult	1	1	0	1	1	**0.8**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	0	1	0	0	0	**0.2**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	1	1	1	0	2	**1.0**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	0	0	0	1	0	**0.2**
Caranx ruber c2	Carangidae	6-10	Juvenile	0	3	0	0	0	**0.6**
Caranx ruber c3	Carangidae	11-15	Juvenile	29	5	0	0	0	**6.8**
Caranx ruber c3	Carangidae	11-15	Juvenile	0	5	0	0	0	**1.0**
Cephalopholis cruentata c3	Serranidae	11-15	Juvenile	0	3	0	0	0	**0.6**
Cephalopholis cruentata c4	Serranidae	16-20	Adult	0	0	0	1	0	**0.2**
Epinephelus guttatus c5	Serranidae	21-25	Juvenile	0	0	0	0	1	**0.2**
Epinephelus guttatus c6	Serranidae	26-30	Adult	1	0	0	0	0	**0.2**
Epinephelus guttatus c7	Serranidae	31-35	Adult	0	0	1	0	0	**0.2**
Lutjanus apodus c4	Lutjanidae	16-20	Juvenile	1	0	0	0	0	**0.2**
Lutjanus apodus c5	Lutjanidae	21-25	Juvenile	1	1	0	0	0	**0.4**
Lutjanus apodus c5	Lutjanidae	21-25	Juvenile	0	1	0	0	0	**0.2**
Lutjanus apodus c7	Lutjanidae	31-35	Adult	0	0	0	0	1	**0.2**
Lutjanus apodus c7	Lutjanidae	31-35	Adult	0	0	0	0	1	**0.2**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	0	0	3	0	0	**0.6**
Pterois spp. c6	Scorpaenidae	26-30	Adult	0	0	0	0	1	**0.2**
Scarus iseri c2	Scaridae	6-10	Juvenile	6	3	6	0	0	**3.0**
Scarus iseri c3	Scaridae	11-15	Juvenile	0	1	0	1	0	**0.4**
Scarus iseri c4	Scaridae	16-20	Adult	1	0	0	0	0	**0.2**
Scarus iseri c4	Scaridae	16-20	TPM	0	0	0	0	1	**0.2**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	0	2	4	0	0	**1.2**
Scarus taeniopterus c3	Scaridae	11-15	Juvenile	0	0	0	2	2	**0.8**
Scarus taeniopterus c4	Scaridae	16-20	TPM	1	0	0	0	0	**0.2**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	1	0	0	1	1	**0.6**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	1	1	2	1	0	**1.0**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	1	1	2	1	3	**1.6**
Sparisoma aurofrenatum c4	Scaridae	16-20	TPM	2	1	0	1	1	**1.0**
Sparisoma radians c2	Scaridae	6-10	Juvenile	1	0	1	0	0	**0.4**
Sparisoma viride c4	Scaridae	16-20	Adult	0	0	1	0	1	**0.4**
Sparisoma viride c5	Scaridae	21-25	Adult	0	0	0	0	1	**0.2**
Sparisoma viride c6	Scaridae	26-30	Adult	1	0	0	0	0	**0.2**
Sparisoma viride c6	Scaridae	26-30	TPM	0	1	0	1	0	**0.4**
			Totals	**51**	**31**	**24**	**15**	**17**	**27.6**

TPM = Terminal phase males

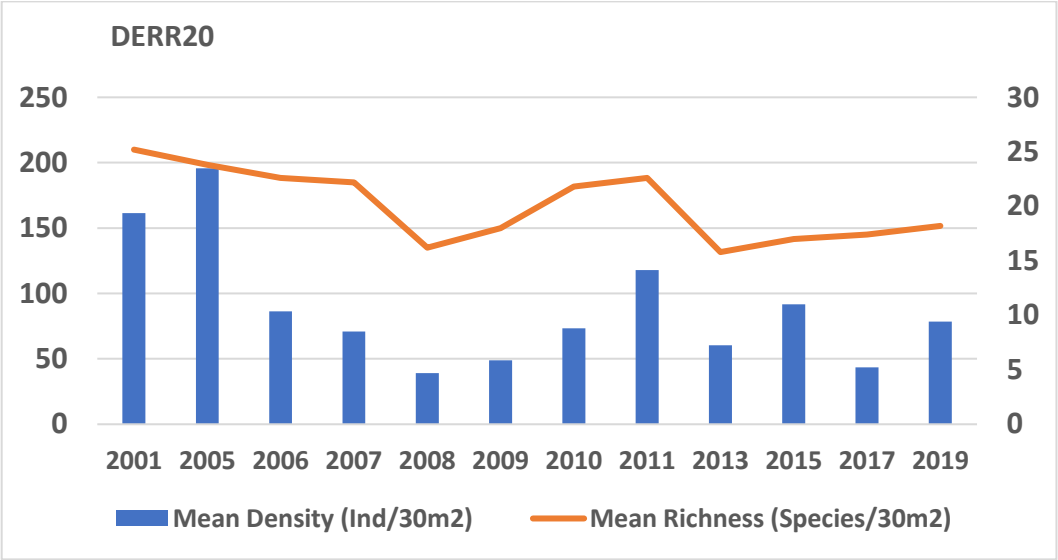


Figure 66. Monitoring trends (2001 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at DERR20, Ponce

19.4 Photo Album 19. DERR20

20. Cayo Caribes 10m (CARI10)

20.1 Physical Description

Cayo Caribes is an emergent fringing reef located approximately 1.5 NM off the Guayama/Salinas coastline. It is at the eastern margin of Boca del Infierno, the entrance channel to Jobos Bay (Figure 67). The reef sits in what appears to be a fairly extensive hard ground insular shelf at depths of 60 – 70 m and rises to the surface along a series of narrow steps or terraces producing a moderately steep fore-reef slope. Permanent transects were established at depths between 6.7 – 7.8m during the baseline survey in 2016 (Garcia-Sais et al., 2016). Photographic characterization of CARI10 and its representative reef community is included as Photo Album 20.

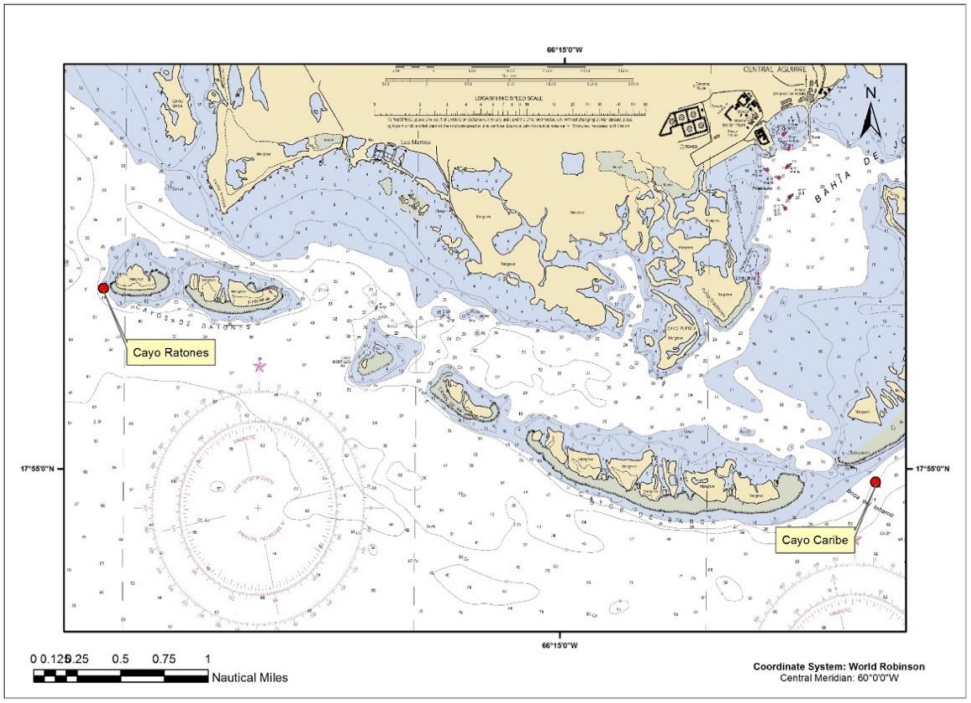


Figure 67. Location of CARI10 and RATO05 reef sampling stations off Jobos Bay, Salinas

20.2 Sessile-benthic Reef Community

Turf algae were the dominant biotic category in terms of substrate cover at CARI10 with a combined mean cover of 36.89%, representative of 80.0% of the total cover by benthic algae (Table 59). Fleshy brown macroalgae (*Dictyota sp*) were prominent in all transects with a mean cover of 7.38%. Red crustose coralline algae (CCA, *Ramicrusta sp., Peyssonnelia sp.*) and fleshy red macroalgae were also present with low substrate cover (< 2%). Cyanobacterial patches were observed intermixed with the turf algae with a mean substrate cover of 9.55%.

Table 59. Percent reef substrate cover by sessile-benthic categories at CARI10, Salinas.

CARI10			**Transects**			
Survey date: 9-6-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	9.5	9.2	9.1	9.1	9.0	**9.2**
Rugosity (m)	2.50	1.76	1.87	2.17	1.86	**2.03**
BENTHIC CATEGORIES						
Abiotic						
Reef overhangs	2.35	1.07	1.65	0.69	1.30	**1.41**
Sand	0.34	1.55	1.89	0.92	2.13	**1.36**
Rubble	1.90					**0.38**
Total Abiotic	**4.59**	**2.62**	**3.54**	**1.61**	**3.42**	**3.16**
Benthic Algae						
Turf (mixed) with sediment	41.21	44.64	36.20	38.55	22.79	**36.68**
Dictyota spp.	6.05	3.45	10.14	3.91	13.34	**7.38**
CCA (total)	2.58	1.31	0.35	1.38	0.59	**1.24**
Peyssonnelia spp.	0.45	0.24		1.15		**0.37**
Turf (mixed)	0.34	0.71				**0.21**
Gracilaria spp.				0.92		**0.18**
Ramicrusta spp.		0.24				**0.05**
Total Benthic Algae	**50.62**	**50.60**	**46.70**	**45.91**	**36.72**	**46.11**
Cyanobacteria	**0.78**	**2.86**	**3.54**	**3**	**7.56**	**3.59**
Hard Coral						
Montastraea cavernosa	4.37	7.26	6.49	3.57	13.93	**7.12**
Orbicella faveolata	7.61				5.43	**2.61**
Porites astreoides	4.37	1.79		4.83	0.35	**2.27**
Siderastrea siderea	4.82	0.83		2.53	2.48	**2.13**
Pseudodiploria strigosa	2.58	0.95		2.19		**1.14**
Millepora alcicornis		1.79	0.35	1.27		**0.68**
Porites divaricata	1.12	1.55				**0.53**
Agaricia agaricites	0.56			0.46		**0.20**
Pseudodiploria clivosa			0.71			**0.14**
Madracis decactis	0.45					**0.09**
Stephanocoenia intersepta	0.22					**0.04**
Total Hard Coral	**26.09**	**14.17**	**7.55**	**14.84**	**22.20**	**16.97**
# Coral Colonies/Transect	**16**	**10**	**6**	**10**	**9**	**10.2**
# Diseased Coral Colonies/Transect	**1**	**0**	**0**	**0**	**0**	**0.20**
Soft Corals						
Briareum asbestinum	3.25	0.00	10.26	11.97	11.45	**7.39**
Erythropodium caribaeorum	3.02	11.90	7.43	2.53	0.71	**5.12**
Muriceopsis flavida					0.35	**0.07**
Total Soft Corals	**6.27**	**11.90**	**17.69**	**14.50**	**12.51**	**12.58**
# Soft Coral Colonies/Transect	**13**	**20**	**15**	**16**	**24**	**17.60**
Sponges						
Ircinia spp. brown	2.35	3.45	3.30	5.52	2.83	**3.49**
Iotrochota birotulata	1.01	1.19	1.53	3.57	4.37	**2.33**
Niphates erecta	2.24	2.74	0.94	2.42	2.01	**2.07**
Neopetrosia spp. smooth	0.22	0.71	8.02			**1.79**
Xestospongia muta		4.76		0.81		**1.11**
Cinachyrella kuekenthali	0.90	1.19	1.06		0.94	**0.82**
Amphimedon compressa	0.90	0.83	0.71	0.69	0.24	**0.67**
Niphates digitalis		0.83	1.65		0.83	**0.66**

CARI10			**Transects**			
Survey date: 9-6-19	**1**	**2**	**3**	**4**	**5**	**Mean**
Mycale laevis	0.22	1.55	0.83		0.59	**0.64**
Desmapsamma anchorata	1.01			1.04	0.94	**0.60**
Sponge spp.	0.78		0.35	0.35	1.06	**0.51**
Ircinia strobilina			0.71		1.18	**0.38**
Scopalina ruetzleri		0.24	0.47	0.35		**0.21**
Smenospongia aurea					0.94	**0.19**
Smenospongia conulosa	0.45			0.23	0.24	**0.18**
Ircinia felix				0.81		**0.16**
Chondrilla caribensis			0.24	0.46		**0.14**
Spirastrella coccinea					0.59	**0.12**
Topsentia ophiraphidites	0.45					**0.09**
Verongula rigida		0.36				**0.07**
Niphates caribica			0.35			**0.07**
Monanchora arbuscula				0.35		**0.07**
Niphates spp.				0.23		**0.05**
Iotrochota arenosa	0.11					**0.02**
Total Sponges	**10.64**	**17.86**	**20.17**	**16.80**	**16.77**	**16.45**
Others						
Palythoa caribaeorum			0.83	3.11		**0.79**
Lebrunia neglecta	1.01				0.47	**0.30**
Anemone spp.					0.35	**0.07**

Hard corals were represented by 11 species intercepted by transects with a combined mean substrate cover of 16.97% (range: 7.55 – 26.09%) and a mean of 10.2 Col/Transect (Table 59). Great star coral (*Montastrea cavernosa*) was the dominant coral in terms of reef substrate cover with a mean of 7.12%, representing 42.0% of the total cover by hard corals. Mountainous star coral (*Orbicella faveolata*), mustard-hill coral (*Porites astreoides*), massive starlet coral (*Siderastrea siderea*) and symmetrical brain coral (*Pseudodiploria strigosa*) represented (along with *M. cavernosa*) the main hard coral assemblage in terms of reef substrate cover. Small to moderate-sized laminar and encrusting colonies prevailed at CARI10, possibly as an adaptation to strong wave action and poor light penetration. Infectious diseases were observed in one (*S. siderea*) of the 51 coral colonies intercepted by transects at CARI10 for a coral disease prevalence of 2.0% (Appendix 2).

Erect soft corals were moderately abundant at CARI10 with a mean density of 17.6 Col/Transect (Table 59). Because of their vertical projection their contribution to the reef substrate cover was disproportionally low, but their contribution to the overall benthic complexity was highly relevant. The encrusting gorgonian species, *Erythropodium caribaeorum* and *Briareum asbestinum* combined for a mean substrate cover of 12.51%.

Sponges were represented by at least 24 species intercepted by transects at CARI10 with a combined mean substrate cover of 16.45%. *Ircinia sp, Iotrochota birotulata*, *Niphates erecta* and *Neopetrosia sp*. comprised the dominant assemblage with a combined cover of 9.69%, representative of 58.8% of the total cover by sponges. Sponges were present in variable sizes and growth forms, including large erect colonies of giant basket sponge (*Xestospongia muta*) and contributed significantly to the reef biodiversity and benthic habitat complexity. Abiotic substrate categories at CARI10 presented a mean substrate cover of 3.16%, largely associated reef overhangs and sand. Reef rugosity averaged 2.03m, indicative of a mostly regular topography with relatively low contributions from vertical coral buildup or sedimentary features of the shelf.

Variations of reef substrate cover by sessile-benthic categories between the 2016 baseline and subsequent monitoring surveys are presented in Figure 68. Differences of live coral cover were very small and statistically insignificant (ANOVA, $p = 0.995$; Appendix 3). Reef substrate cover by hard corals remained stable between surveys with *Montastraea cavernosa* as the dominant species (Table 69). Variations of soft coral density between monitoring surveys were also statistically insignificant (ANOVA, $p = 0.095$; Appendix 4). These data are indicative that the sessile-benthic reef community at CARI10 was resilient to the mechanical forces associated with the pass of hurricanes and other events of extreme physical disturbances previous to the 2019 monitoring survey.

20.3 Fishes and Motile Megabenthic Invertebrates

A total of 29 fish species were identified within belt-transects at CARI10 with a mean density of 53.2 Ind/30m^2 (range: 44 – 66 Ind/30m^2) and a mean species richness of 16.6 Spp/30m^2 (Table 60). The bluehead wrasses (*Thalassoma bifasciatum)*, princess parrotfish (*Scarus taeniopterus*) and the dusky and bicolor damselfishes (*Stegastes adustus, S. partitus*) were the numerically dominant species with a combined mean density of 27.8 Ind/30m^2, representative of 52.2% of the total fish density within belt-transects. Another eight species were present in at least four transects. These included the beau gregory (*Stegastes leucostictus*), clown and black-ear wrasses *(Halichoeres maculipinna, H. poeyi*), stoplight parrotfish (*Sparisoma viride*), red-spotted hawkfish (*Amblycirrhitus pinos*), harlequin bass (*Serranus tigrinus*) and five-band surgeonfish (*Acanthurus tractus*). Motile megabenthic invertebrates were not observed within belt-transects.

CARI10

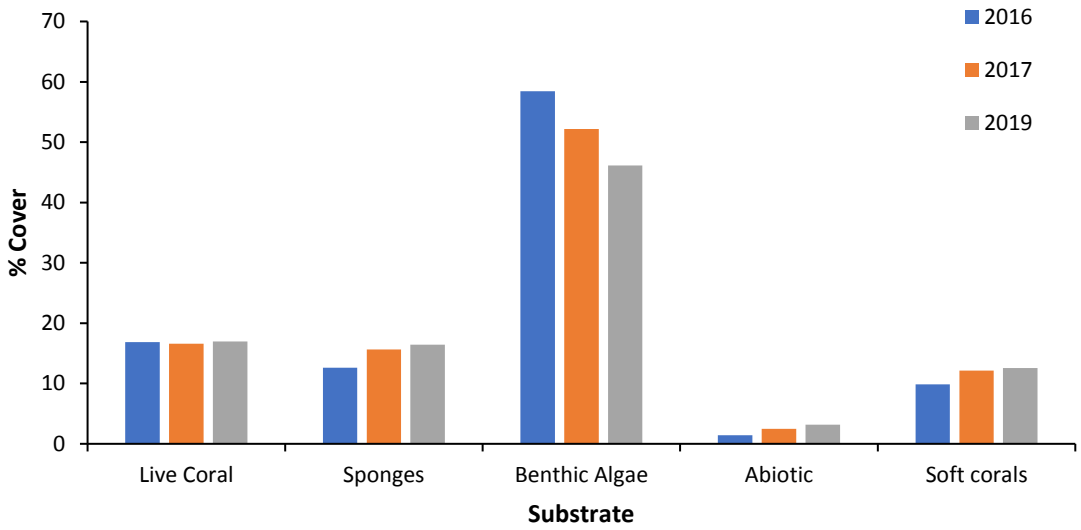


Figure 68. Monitoring trends (2016 – 2019) of mean substrate cover by sessile-benthic categories at CARI10, Salinas.

CARI10

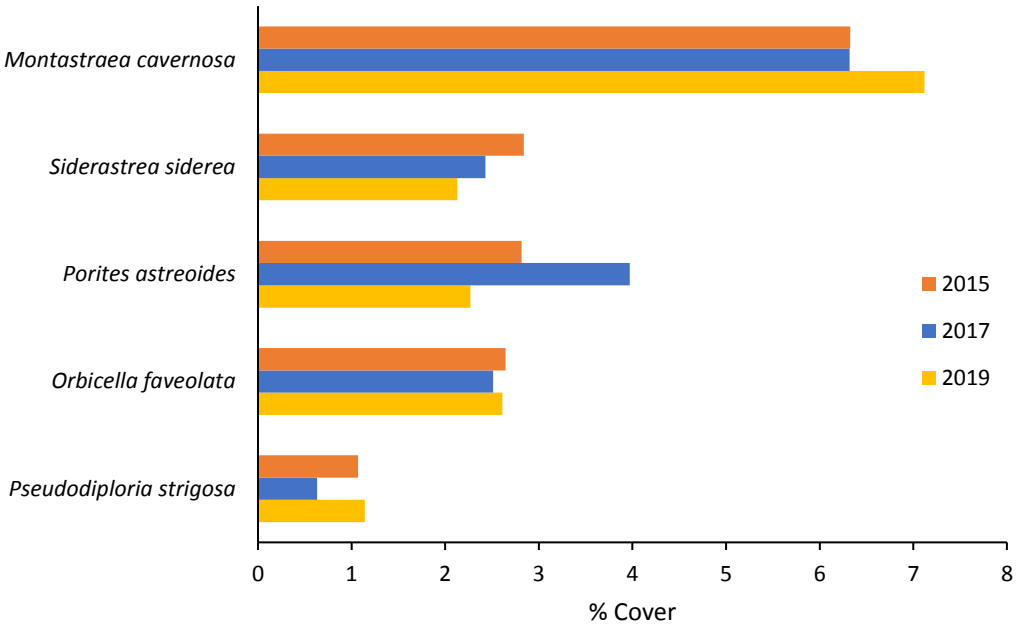


Figure 69. Monitoring trends (2016 – 2019) of mean substrate cover by hard coral species at CARI10, Salinas.

The trophic structure of the fish community at CARI10 was strongly dominated by herbivores with 11 species and a combined density of 28.4 Ind/30m^2, representative of 53.4% of the total individuals within belt-transects. Herbivores were represented by six species of parrotfishes (Scaridae), three damselfishes (Pomacentridae) and two doctorfishes (Acanthuridae). Small opportunistic carnivores, including the wrasses (Labridae), gobies (Gobiidae), squirrelfishes (Holocentridae), hawkfish (Cirrhitidae), grunts (Haemulidae), blennies (Blenniidae), hamlets, small groupers and sea basses (Serranidae) combined for 39.1% of the total fish density. Zooplanktivorous fishes were only represented within belt-transects by the bicolor damselfish (*Stegastes partitus*) with a mean density of 3.2 Ind/30m^2, or 6.0% of the total individuals. Spongivores (Pomacanthidae) were present in low density (< 1%). Medium sized predators included the yellowtail snapper (*Ocyurus chrysurus*), red hind (*Epinephelus guttatus*) and the hogfish (*Lachnolaimus maximus*) (Table 61). Larger demersal piscivores, such as the Nassau and yellowfin grouper (*E. striatus, Mycteroperca venenosa*) and the nurse shark (*Ginglymostoma cirratum*) were previously reported for CARI10 (Garcia-Sais et al., 2017).

Recruitment juvenile stages (1-5cm) of seven species were observed within belt-transects at CARI10 (Table 61). These included the doctorfish and five-band surgeonfish (*A. chirurgus, A. tractus*), yellowtail snapper (*Ocyurus chrysurus*), and the striped, princess, bucktooth and stoplight parrotfishes (*Scarus iseri, S. taeniopterus, Sparisoma radians, S. viride*). These data are indicative that CARI10 functions as an important recruitment and nursery habitat for a number of important reef herbivores, particularly parrotfishes and doctorfishes, but also for some groupers and snappers.

Variations of fish density and species richness between monitoring surveys are presented in Figure 70. Density was highest during the 2019 survey, but differences were statistically insignificant (ANOVA, $p= 0.212$; Appendix 5). Lower fish species richness was measured in the baseline survey relative to the 2017 and 2019 surveys (ANOVA, $p < 0.0001$). More observations are needed to consider any real trend as physical conditions of wave, currents and underwater visibility markedly influence determinations of fish density and species richness in shallow reefs such as CARI10.

Table 60. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at CARI10, Salinas.

Cayo Caribes (CARI10)						
Survey Date: 9-6-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	13	18	10	12	4	**11.4**
Scarus taeniopterus	7	17	5	4	2	**7.0**
Stegastes adustus	4	8	5	8	6	**6.2**
Stegastes partitus	2	2	4	3	5	**3.2**
Scarus iseri	3	0	0	0	11	**2.8**
Acanthurus tractus	2	0	4	2	3	**2.2**
Stegastes leucostictus	1	4	4	1	1	**2.2**
Scarus spp.	0	0	2	8	0	**2.0**
Acanthurus chirurgus	3	3	0	2	0	**1.6**
Stegastes variabilis	2	2	3	0	1	**1.6**
Amblycirrhitus pinos	1	2	2	1	1	**1.4**
Halichoeres poeyi	0	2	1	2	2	**1.4**
Sparisoma radians	0	2	0	5	0	**1.4**
Halichoeres maculipinna	2	0	1	2	1	**1.2**
Serranus tigrinus	1	0	1	2	2	**1.2**
Sparisoma viride	0	1	1	2	2	**1.2**
Holocentrus rufus	2	2	0	0	0	**0.8**
Canthigaster rostrata	1	0	0	1	1	**0.6**
Coryphopterus spp.	0	0	1	2	0	**0.6**
Elacatinus evelynae	0	1	2	0	0	**0.6**
Malacoctenus triangulatus	1	0	2	0	0	**0.6**
Holacanthus tricolor	2	0	0	0	0	**0.4**
Ocyurus chrysurus	1	0	0	0	1	**0.4**
Haemulon flavolineatum	0	0	0	1	0	**0.2**
Halichoeres garnoti	0	0	1	0	0	**0.2**
Hypoplectrus indigo	0	1	0	0	0	**0.2**
Hypoplectrus puella	1	0	0	0	0	**0.2**
Pomacanthus arcuatus	0	1	0	0	0	**0.2**
Sparisoma aurofrenatum	0	0	0	0	1	**0.2**
Total Individuals	49	66	49	58	44	**53.2**
Total Species	18	15	17	17	16	**16.6**
Invertebrates						
none observed						

Table 61. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at CARI10, Salinas.

Cayo Caribes (CARI10)									
Survey Date: 9-6-19					**TRANSECTS**				
		Size	**Life**		**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c1	Acanthuridae	1-5	Recruit	1	2	0	6	0	**1.8**
Acanthurus chirurgus c2	Acanthuridae	6-10	Juvenile	0	0	1	0	0	**0.2**
Acanthurus coeruleus c2	Acanthuridae	6-10	Juvenile	0	0	0	0	2	**0.4**
Acanthurus coeruleus c4	Acanthuridae	16-20	Adult	0	0	0	2	0	**0.4**
Acanthurus tractus c1	Acanthuridae	1-5	Recruit	2	2	1	2	3	**2.0**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	5	0	0	1	0	**1.2**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	0	0	0	0	1	**0.2**
Epinephelus guttatus c5	Serranidae	21-25	Juvenile	0	0	0	0	1	**0.2**
Lachnolaimus maximus c5	Labridae	21-25	Adult	1	0	0	0	0	**0.2**
Lutjanus apodus c3	Lutjanidae	11-15	Juvenile	0	0	0	0	1	**0.2**
Ocyurus chrysurus c1	Lutjanidae	1-5	Recruit	0	0	1	0	0	**0.2**
Ocyurus chrysurus c2	Lutjanidae	6-10	Juvenile	0	1	0	0	1	**0.4**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	1	0	0	0	2	**0.6**
Scarus iseri c1	Scaridae	1-5	Recruit	0	0	6	3	11	**4.0**
Scarus iseri c2	Scaridae	6-10	Juvenile	0	0	0	0	0	**0.0**
Scarus spp. C1	Scaridae	1-5	Recruit	0	0	2	8	0	**2.0**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	11	17	5	4	2	**7.8**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	1	1	1	1	0	**0.8**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	1	0	0	1	**0.4**
Sparisoma radians c1	Scaridae	1-5	Recruit	0	2	0	1	0	**0.6**
Sparisoma radians c2	Scaridae	6-10	Juvenile	1	0	0	0	0	**0.2**
Sparisoma viride c1	Scaridae	1-5	Recruit	0	0	1	2	1	**0.8**
Sparisoma viride c2	Scaridae	6-10	Juvenile	0	1	0	1	1	**0.6**
Sparisoma viride c7	Scaridae	31-35	TPM	0	1	0	0	0	**0.2**
			Totals	**23**	**28**	**18**	**31**	**27**	**25.4**

TPM=Terminal phase male

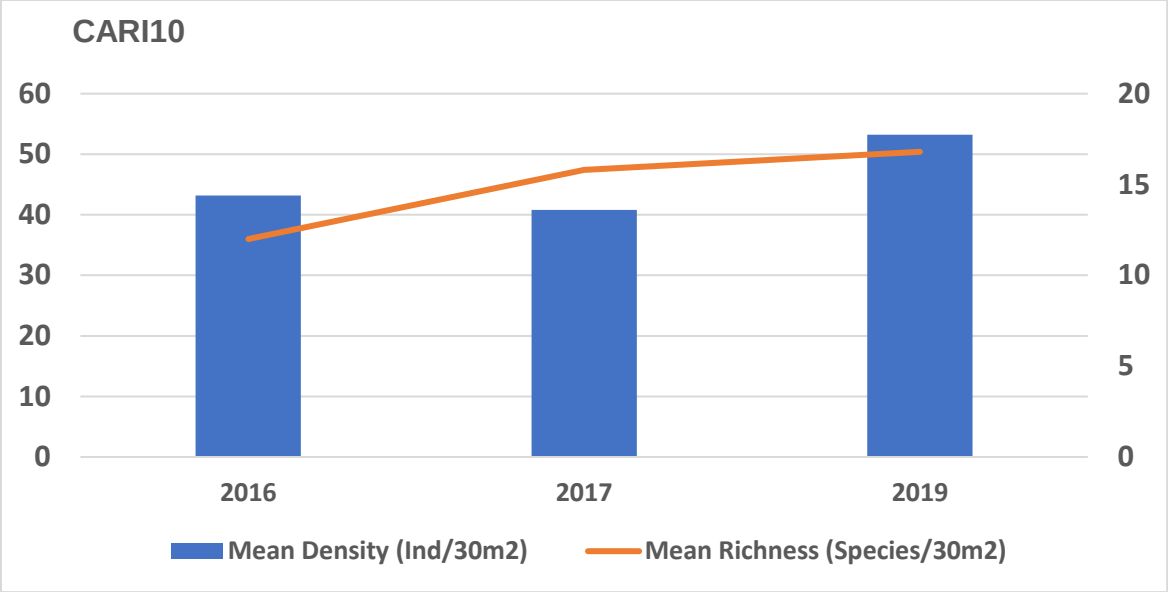
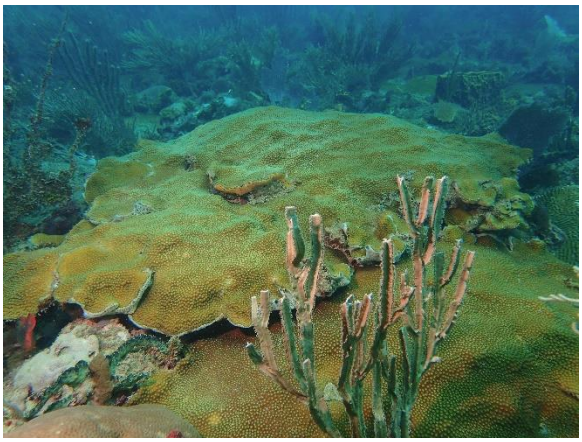


Figure 70. Monitoring trends (2016 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at CARI10, Salinas.

20.4 Photo Album 20. CARI10



21. Cayo Ratones 5m (RATO05)

21.1 Physical Description

Cayo Ratones is one of the emergent islets or keys that run parallel to the shoreline off the Guayama/Salinas coast. It is located about 0.6 NM off Punta Arenas (Figure 67). Our baseline survey was performed in 2016. Permanent transects were placed on adjacent coral promontories within a depth range of 3.7 – 4.7m on the western side of the fore reef, an area where the reef breaks into a series of small patch reef promontories surrounded by coralline sand. Panoramic views of RATO05 coral reef community are included in Photo Album 21.

21.2 Sessile Benthic Reef Community

Benthic algae, with a combined mean substrate cover of 55.25% were the dominant sessile-benthic category covering reef substrate at RATO05. Turf algae, a mixed assemblage of short filamentous brown and red algae was the main component of the benthic algae, with a mean cover of 24.79%, representing 44.9% of the total cover by benthic algae (Table 62). Green calcareous (*Halimeda sp*) and fleshy brown macroalgae (*Dictyota sp*) were present in all transects with mean cover of 16.21% and 8.60%, respectively. Small patches of red coralline algae, *Jania sp*. and *Galaxaura sp*. were present in five and three transects, respectively with a combined cover of 3.34%. Cyanobacterial patches were observed in three transects overlying sand pockets with a mean cover of 2.46% (Table 62).

Hard corals were represented by 12 species intercepted by linear transects with a combined mean substrate cover of 18.79% (range: 13.83 – 27.13%), and a mean of 10.0 Col/Transect (Table 62). Massive starlet coral (*Siderastrea siderea*) was the dominant hard coral species in terms of reef substrate cover with a mean cover of 15.13%, representing 80.52% of the total cover by hard corals. Very large colonies of *S. siderea* separated by sand patches were common at RATO05. Great star coral (*Montastrea cavernosa*) and lettuce coral (*Agaricia agaricites*) were present in three transects with a combined cover of 1.69%. The three *Orbicella* sibling species were intercepted by transects with a combined cover of 1.07% for the species complex. Four hard coral colonies out of the 50 total colonies intercepted by transects were apparently diseased, for a coral disease prevalence of 8.0% (Appendix 2). The presence of multiple whitish dots on massive starlet coral (*S. siderea*) suggests infections by what appeared to be “Dark Spot Disease” (DSD).

Table 62. Percent reef substrate cover by sessile-benthic categories at RATO05, Salinas.

RATO05 **Survey date: 9-6-19**	**Transects**					
	1	**2**	**3**	**4**	**5**	**Mean**
Depth (m)	4.7	4.3	4.1	3.7	3.8	**4.12**
Rugosity (m)	3.47	1.86	3.30	2.35	4.28	**3.05**
BENTHIC CATEGORIES						
Abiotic						
Sand	4.68	6.02	14.11	14.06	20.10	**11.79**
Reef overhang	3.74	1.18	6.84	7.94	5.88	**5.12**
Total Abiotic	**8.42**	**7.20**	**20.95**	**22.00**	**25.98**	**16.91**
Benthic Algae						
Turf (mixed) with sediment	26.92	24.44	36.21	19.73	12.55	**23.97**
Halimeda spp.	9.56	28.45	13.16	11.34	18.53	**16.21**
Dictyota spp.	10.08	3.31	5.89	13.04	10.69	**8.60**
Jania spp.	1.35	2.36	0.42	4.99	1.37	**2.10**
Galaxaura spp.	4.47	0.59		1.13		**1.24**
CCA (mixed)	1.04	2.01	1.37		1.57	**1.20**
Caulerpa spp.	1.46		0.42	2.49	1.18	**1.11**
Turf (mixed)				0.68	3.43	**0.82**
Total Benthic Algae	**54.89**	**61.16**	**57.47**	**53.40**	**49.31**	**55.25**
Cyanobacteria	**0.00**	**6.26**	**1.16**	**4.88**	**0.00**	**2.46**
Hard Coral						
Siderastrea siderea	21.83	16.29	12.21	10.20	15.10	**15.13**
Montastraea cavernosa			1.79	2.27	2.45	**1.30**
Orbicella faveolata	3.22				0.39	**0.72**
Agaricia agaricites	0.42		0.95		0.59	**0.39**
Orbicella annularis				1.36		**0.27**
Porites astreoides		1.30				**0.26**
Siderastrea radians	1.04	0.12				**0.23**
Porites porites		0.35	0.32			**0.13**
Pseudodiploria strigosa			0.63			**0.13**
Stephanocoenia intersepta					0.49	**0.10**
Orbicella franksi	0.42					**0.08**
Millepora alcicornis	0.21					**0.04**
Total Hard Coral	**27.13**	**18.06**	**15.89**	**13.83**	**19.02**	**18.79**
# Coral Colonies/Transect	**20**	**6**	**10**	**5**	**9**	**10.0**
# Diseased Coral Colonies/Transect	**2**	**0**	**0**	**2**	**0**	**0.8**
Soft Corals						
Briareum asbestinum	4.47	2.48	1.68	2.72	4.31	**3.13**
Erythropodium caribaeorum	2.18	0.94		2.04		**1.03**
Plexaura homomalla					0.29	**0.06**
Gorgonia ventalina				0.23		**0.05**
Eunicea spp.	0.21					**0.04**
Pseudoplexaura flagellosa					0.20	**0.04**
Total Soft Corals	**6.86**	**3.42**	**1.68**	**4.99**	**4.80**	**4.35**

RATO05

Survey date: 9-6-19

	Transects					
	1	**2**	**3**	**4**	**5**	**Mean**
# Soft Coral Colonies/Transect	**12**	**7**	**12**	**11**	**9**	**10.2**
Sponges						
Chondrilla caribensis	1.46	1.65	1.05	0.45		**0.92**
Ircinia spp. brown		2.24				**0.45**
Cliona caribbaea			1.37			**0.27**
Aplysina fistularis	1.25					**0.25**
Cinachyrella kuekenthali			0.42	0.45		**0.17**
Total Sponges	**2.70**	**3.90**	**2.84**	**0.91**	**0.00**	**2.07**
Others						
Anemone spp.					0.88	**0.18**

Vertically projected soft corals were present in all five transects at RATO05 with a mean density of 10.2 Col/Transect. Sea rods (*Plexaura sp, Pseudoplexaura sp, Eunicea spp*) and sea fans (*Gorgonia ventalina*) were the most common erect forms. The encrusting gorgonian species, *Briareum asbestinum* and *Erythropodium caribaeorum* were present in five and three transects, respectively with a combined mean substrate cover of 4.16% (Table 62). Sponges were represented by five species with a combined mean substrate cover of 2.07%. *Chondrilla caribensis* was the most important species in terms of reef substrate cover and the only one observed in more than two transects. In general, sponges were mostly represented by small encrusting individuals growing intermixed with algal turf and another encrusting biota. Abiotic substrate categories presented a mean substrate cover of 16.91% (range: 7.2 – 25.98%). Coralline sand was the main component the abiotic category with a mean cover of 11.79%, representative of 69.7% of the total cover by abiotic categories (Table 62). Reef rugosity averaged 3.05m, influenced by large coral mounds of massive starlet coral (*Siderastrea siderea*).

Temporal variations of reef substrate cover by sessile-benthic categories between monitoring surveys are presented in Figure 71. Differences of hard coral cover between surveys were small and statistically insignificant (ANOVA, p = 0.686, Appendix 3). The taxonomic composition of the main hard coral species remained stable between monitoring surveys and differences of mean substrate cover by coral species were small and within sampling variability error (Figure 72). Variations in the density of erect soft corals between surveys were also statistically insignificant (ANOVA, p= 0.647; Appendix 4). These data are indicative that the sessile-benthic reef community at RATO05 was resilient to the physical disturbances associated with the pass of hurricanes and other extreme climatological events previous to the 2019 monitoring survey.

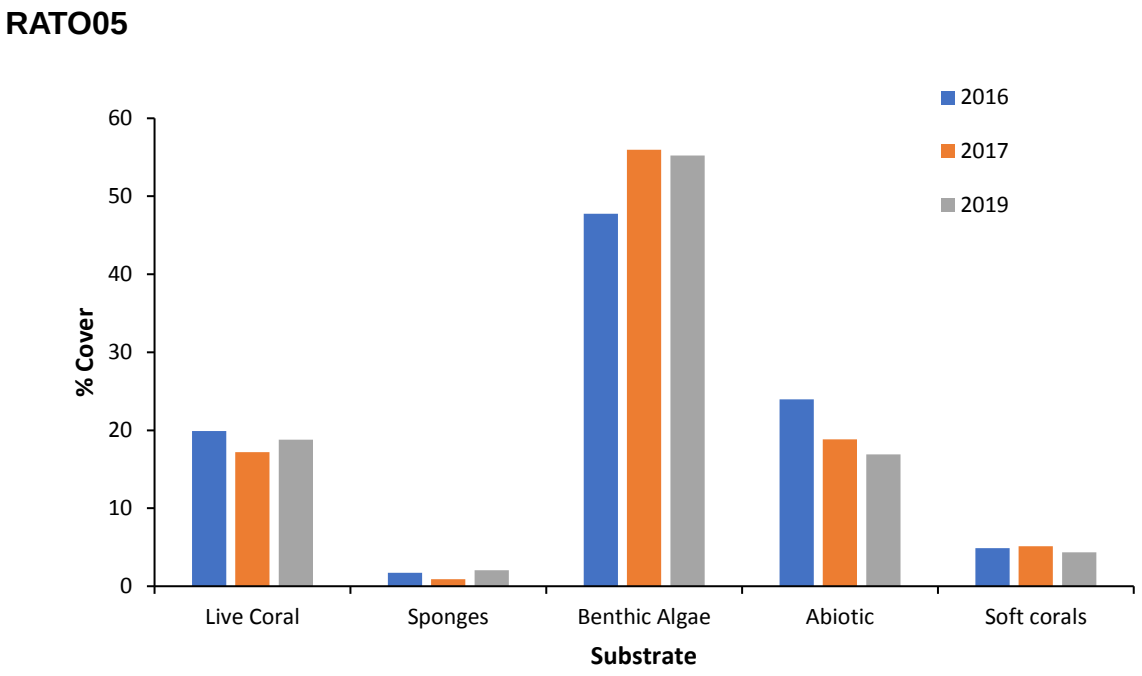


Figure 71. Monitoring trends (2016 – 2019) of mean substrate cover by sessile-benthic categories at RATO05, Salinas.

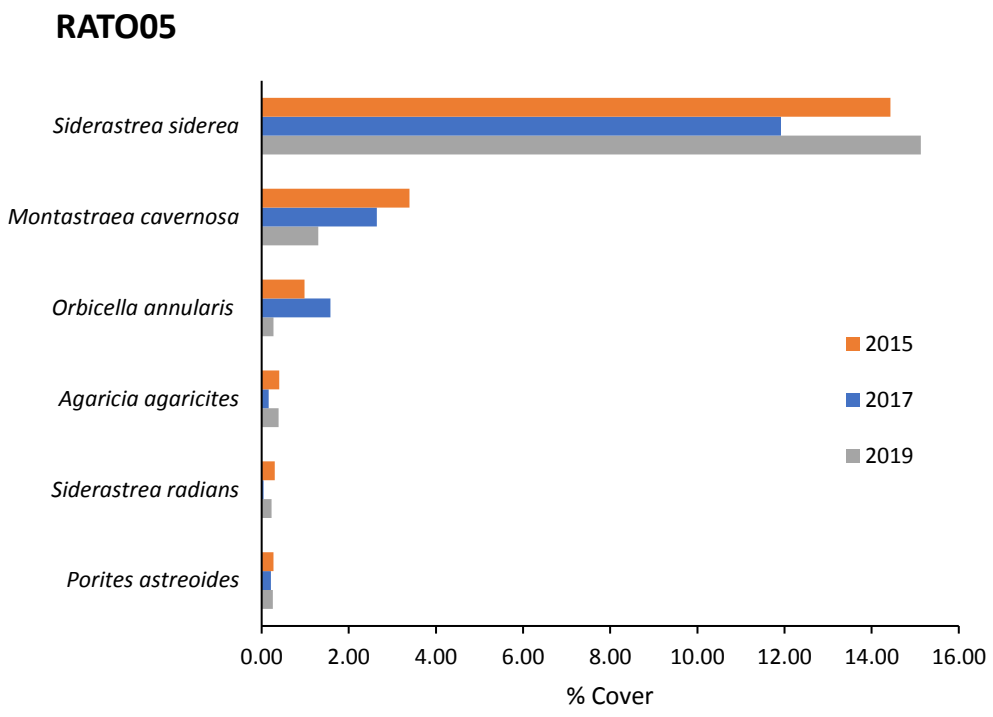


Figure 72. Monitoring trends (2016 – 2019) of mean substrate cover by hard coral species at RATO05, Salinas.

21.3 Fishes and Motile Megabenthic Invertebrates

A total of 29 fish species were identified within belt-transects from RATO05 during the 2019 monitoring survey with a mean density of 31.4 Ind/30m^2 (range: 23 – 45 Ind/30m^2) and a mean species richness of 12.6 Spp/Transect (Table 63). The bluehead wrasses (*Thalassoma bifasciatum*) was the dominant species with a mean density of 7.8 Ind/30m^2, representative of 24.8% of the total fish density. The princess and stoplight parrotfishes (*Scarus taeniopterus, Sparisoma viride*), dusky damselfish (*Stegastes adustus*), doctorfish (*Acanthurus chirurgus*) and the clown and black-ear wrasses (*Halichoeres maculipinna, H. poeyi*) were observed in at least four transects with a combined density of 13.0 Ind/30m^2, representative of 41.4% of the total individuals. Motile megabenthic invertebrates were not observed within belt-transects (Table 63).

The trophic structure of RATO05 was strongly dominated by small opportunistic carnivores represented within belt-transects by five species of wrasses (Labridae), one hamlet (Serranidae), one grunt (*Haemulidae*), one squirrelfish (Holocentridae), two gobies (Gobiidae) one lizardfish (Synodontidae), one goatfish (Mullidae) and one blenny (Blenniidae) with a combined density of 16.8 Ind/30m^2, or 53.5% of the total fish density. Herbivores, represented by four species of parrotfishes (Scaridae), four damselfishes (Pomacentridae) and three doctorfishes (Acanthuridae) were also prominent with a cumulative density of 12.6 Ind/30m^2, representing 40.1% of the total density. Zooplanktivorous fishes were only represented within belt-transects by two damselfishes with combined densities <3% of the total. Medium sized piscivores included the Yellowtail and Schoolmaster Snappers (*Ocyurus chrysurus*, *Lutjanus apodus*).

Table 64 presents the size-frequency distribution of commercially important fishes, including the larger reef fish herbivores observed within 20 x 3m belt-transects at RATO 05. Recruitment juvenile (1-5 cm) stages of seven species were present, including three doctorfishes (*Acanthurus coeruleus, A. chirurgus, A. tractus*) and four parrotfishes (*Sparisoma spp, Scarus spp*). Juveniles and adult stages of doctorfishes and parrotfishes were also present, including one terminal phase male of *S. viride*. Yellowtail and schoolmaster snappers (*Ocyurus chrysurus, Lutjanus apodus*) were observed as juveniles and adults. These data suggest that RATO05 serves as an important recruitment, nursery and residential habitat for a diverse assemblage of important reef herbivores such as parrotfishes and doctorfishes and a foraging and residential habitat for medium sized piscivores such as yellowtail and schoolmaster snappers (Lutjanidae).

Table 63. Taxonomic composition and density of fishes and motile megabenthic invertebrates surveyed within 3x10m belt-transects at RATO10, Salinas.

Cayo Ratones (RATO05)						
Survey Date: 9-6-19			**Belt-Transects**			
			(# Individuals/30m^2)			
Fish Species	**1**	**2**	**3**	**4**	**5**	**MEAN**
Thalassoma bifasciatum	7	4	11	9	8	**7.8**
Scarus taeniopterus	0	3	2	4	8	**3.4**
Haemulon spp.	16	0	0	0	0	**3.2**
Stegastes adustus	3	4	1	5	3	**3.2**
Sparisoma viride	0	3	1	4	3	**2.2**
Halichoeres maculipinna	0	2	2	1	3	**1.6**
Halichoeres poeyi	1	0	3	2	2	**1.6**
Acanthurus chirurgus	1	0	2	1	1	**1.0**
Acanthurus coeruleus	2	1	0	0	1	**0.8**
Holocentrus rufus	0	1	0	1	1	**0.6**
Sparisoma aurofrenatum	0	1	2	0	0	**0.6**
Stegastes leucostictus	1	1	0	0	1	**0.6**
Stegastes partitus	0	1	0	1	1	**0.6**
Acanthurus tractus	1	1	0	0	0	**0.4**
Elacatinus evelynae	2	0	0	0	0	**0.4**
Lutjanus apodus	2	0	0	0	0	**0.4**
Malacoctenus triangulatus	0	1	1	0	0	**0.4**
Sparisoma radians	2	0	0	0	0	**0.4**
Chaetodon capistratus	0	0	1	0	0	**0.2**
Chromis multilineata	1	0	0	0	0	**0.2**
Coryphopterus spp.	0	0	1	0	0	**0.2**
Halichoeres garnoti	1	0	0	0	0	**0.2**
Halichoeres radiatus	1	0	0	0	0	**0.2**
Holacanthus ciliaris	1	0	0	0	0	**0.2**
Hypoplectrus puella	1	0	0	0	0	**0.2**
Ocyurus chrysurus	1	0	0	0	0	**0.2**
Pseudupeneus maculatus	0	0	0	1	0	**0.2**
Stegastes planifrons	0	0	1	0	0	**0.2**
Synodus intermedius	1	0	0	0	0	**0.2**
Total Individuals	45	23	28	29	32	**31.4**
Total Species	18	12	12	10	11	**12.6**
Invertebrates						
none observed						

Temporal variations of fish density and species richness between monitoring surveys are shown in Figure 73. Density differences were small and statistically insignificant (ANOVA, p = 0.231; Appendix 5). Mean density during the 2019 monitoring survey (31.4 Ind/30m^2) was well within one standard deviation of the study mean (37.0 +/- 15.5 SD). Differences of species richness were statistically significant (ANOVA, p= 0.042; Appendix 6) and related to the lower richness measured during the baseline survey compared to the most recent 2017 and 2019 monitoring surveys. More observations of the fish community at RATO05 are needed to establish any real trend as physical conditions of wave, currents and underwater visibility markedly influence abundance and species richness in shallow reefs such as RATO05.

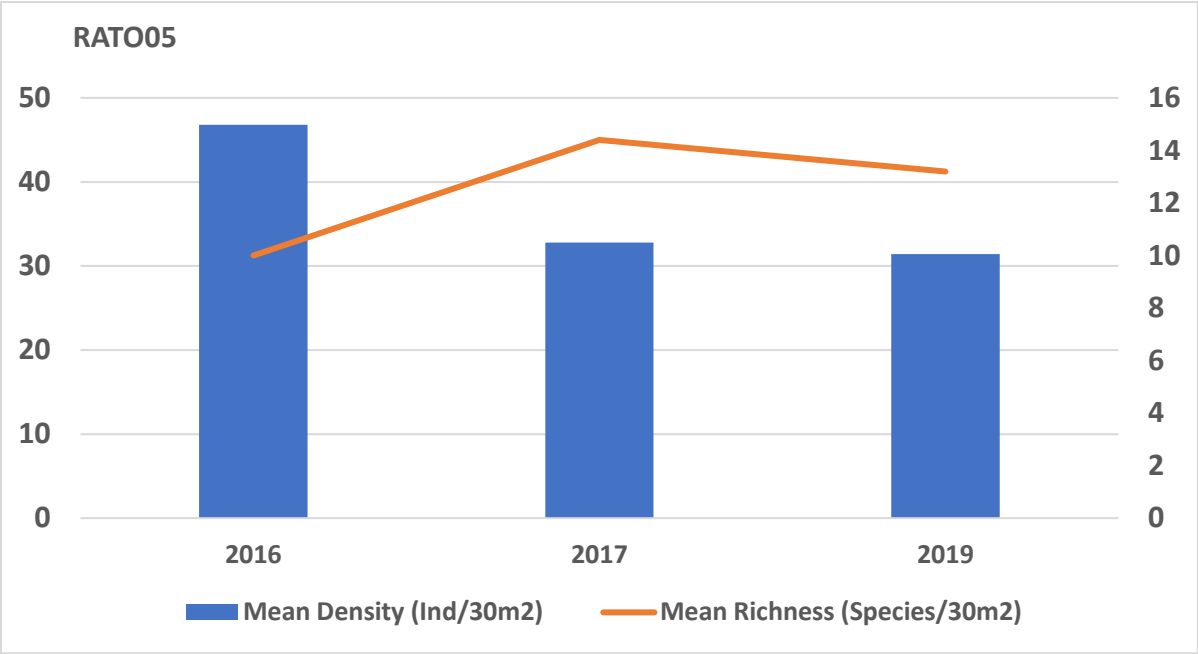


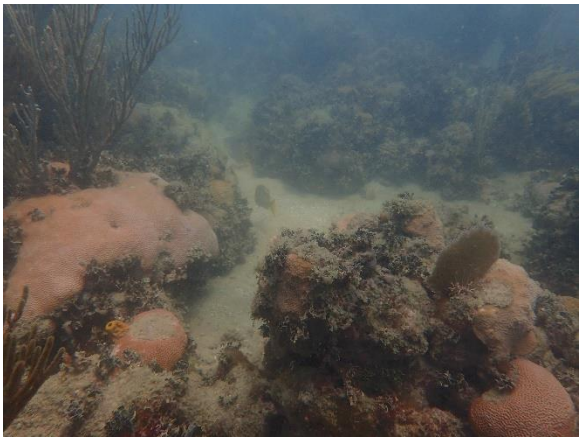
Figure 70. Monitoring trends (2016 – 2019) of mean fish density (Ind/30m^2) and species richness (# Species/30m^2) within 3x10 m belt-transects at CARI10, Salinas.

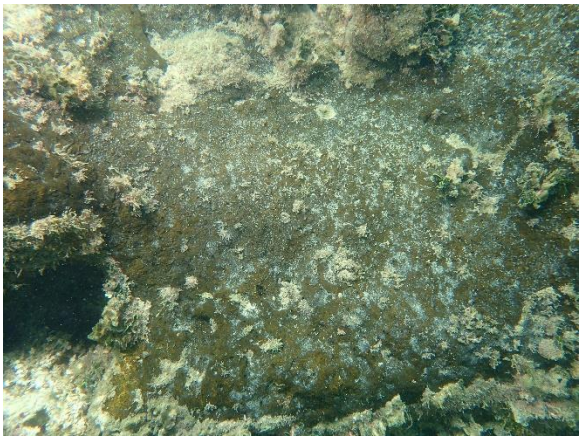
Table 64. Size-frequency distributions of commercially important fishes observed within 20x3m belt-transects at RATO05, Salinas.

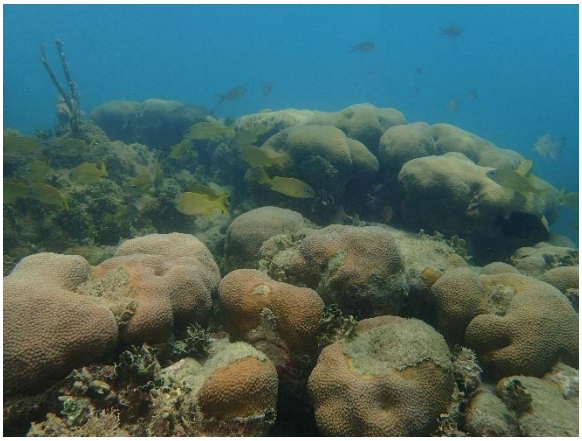
Cayo Ratones (RATO05)									
Survey Date: 9-6-19					**TRANSECTS**				
		Size	**Life**		**(Ind/60m^2)**				
Species	**Family**	**Range (cm)**	**Stage**	**1**	**2**	**3**	**4**	**5**	**MEAN**
Acanthurus chirurgus c1	Acanthuridae	1-5	Recruit	1	0	2	1	2	**1.2**
Acanthurus chirurgus c2	Acanthuridae	6-10	Juvenile	0	0	0	1	0	**0.2**
Acanthurus coeruleus c1	Acanthuridae	1-5	Recruit	0	1	0	1	2	**0.8**
Acanthurus tractus c1	Acanthuridae	1-5	Recruit	0	1	0	0	0	**0.2**
Acanthurus tractus c2	Acanthuridae	6-10	Juvenile	0	1	0	0	0	**0.2**
Acanthurus tractus c3	Acanthuridae	11-15	Juvenile	1	0	0	0	0	**0.2**
Acanthurus tractus c4	Acanthuridae	16-20	Adult	1	0	1	1	0	**0.6**
Lutjanus apodus c5	Lutjanidae	21-25	Juvenile	1	0	0	0	1	**0.4**
Lutjanus apodus c6	Lutjanidae	26-30	Adult	0	1	0	0	1	**0.4**
Ocyurus chrysurus c3	Lutjanidae	11-15	Juvenile	2	0	1	0	0	**0.6**
Ocyurus chrysurus c5	Lutjanidae	21-25	Adult	2	0	0	0	0	**0.4**
Scarus taeniopterus c1	Scaridae	1-5	Recruit	0	7	2	4	8	**4.2**
Scarus taeniopterus c2	Scaridae	6-10	Juvenile	0	0	0	0	2	**0.4**
Sparisoma aurofrenatum c1	Scaridae	1-5	Recruit	0	0	1	0	0	**0.2**
Sparisoma aurofrenatum c2	Scaridae	6-10	Juvenile	0	0	1	0	0	**0.2**
Sparisoma aurofrenatum c3	Scaridae	11-15	Juvenile	0	0	1	0	1	**0.4**
Sparisoma aurofrenatum c4	Scaridae	16-20	Adult	0	1	1	0	0	**0.4**
Sparisoma radians c1	Scaridae	1-5	Recruit	2	0	0	2	0	**0.8**
Sparisoma radians c2	Scaridae	6-10	Juvenile	0	0	0	1	0	**0.2**
Sparisoma viride c1	Scaridae	1-5	Recruit	0	2	0	2	1	**1.0**
Sparisoma viride c2	Scaridae	6-10	Juvenile	0	1	0	1	2	**0.8**
Sparisoma viride c3	Scaridae	11-15	Juvenile	0	0	0	1	1	**0.4**
Sparisoma viride c4	Scaridae	16-20	Adult	0	0	0	1	0	**0.2**
Sparisoma viride c7	Scaridae	31-35	TPM	0	0	1	1	0	**0.4**
			Totals	**10**	**15**	**11**	**17**	**21**	**14.8**

TPM = Terminal phase male

21.4 Photo Album 21. RATO05







VIII. Conclusions

1. The most relevant change of sessile-benthic reef community structure measured during the 2019 monitoring survey was the loss of soft coral densities in 13 out of the 21 reef stations surveyed. The largest density reductions were measured from TRES05 (-46.15%), MLUN05 (-30.95%), BERI20 (-24.63%), TRES20 (-23.08%) and DERR20 (-22.62%). Such reductions may have been driven by the extreme wave and surge energy associated with the pass of Hurricane Irma and/or Maria in September 2017 and winter storm Riley in March 2018.
2. Reef substrate cover by hard corals declined at 15 reef stations relative to the previous 2017 monitoring survey, but differences were generally small and statistically insignificant. The mean hard coral cover loss on the 15-reef stations with loss measurements was -9.73%. Overall, the net change of hard coral cover between the previous 2017 and the present 2019 monitoring survey for the 21-reef matrix was - 4.09%. These data shows that the overall impact of hurricanes and/or winter storm event(s) on the hard coral communities from reef stations included in the 2019 monitoring survey were minimal.
3. A notable exception to the generally mild changes of hard coral cover measured in the PRCRMP 2019 survey that appear linked to extreme physical disturbances was the Gallardo Reef (GALL05) coral community. The exact coral loss at GALL05 could not be measured because all transect markers were lost, but the visual estimate of hard coral loss, particularly elkhorn coral (*Acropora palmata*) was roughly 50%. The massive rupture, overturn, and displacement of coral colonies at GALL05 suggest exposure to an extreme event(s) of mechanical force in the form of wave and surge action to which that coral community was not adapted, resulting in a large-scale degradation.
4. A total of 54 hard coral colonies out of the 1,112 intercepted by transects were observed to be apparently affected by infectious disease(s) resulting in a mean coral disease prevalence of 4.86% for the 21 reef stations surveyed in the 2019 PRCRMP event. Massive starlet coral (*Siderastrea siderea*) with 20 infected colonies by what appeared to be “Dark Spot Disease” was the most affected coral species accounting for 37.0% of all diseased coral colonies. Prospective monitoring surveys will be needed in order to evaluate the ecological implications of this potential disease outbreak on *S. siderea* colonies. Partially bleached hard coral colonies were observed from MLAN20 (4), MLAN10 (6) and DERR20 (2).

5. The red crustose coralline alga, *Ramicrusta sp*. was intercepted by transects from 15 reef stations with an overall mean substrate cover of 1.95%. Order of magnitude increments of cover by *Ramicrusta sp*. relative to the previous 2017 survey were measured at TRES05, TOUR20, TOUR10 and MLUN05. An increasing trend of reef substrate cover by *Ramicrusta sp*. may be in place for the west and south coast shallow reefs included in the 2019 monitoring survey, but still at much lower magnitude that the condition prevailing on shallow reefs of the east coast.
6. Temporal variations of fish density between monitoring surveys were statistically significant at 11 reef stations. Differences were mostly related to density fluctuations of numerically dominant fishes with highly aggregated distributions, such as the masked goby (*Coryphopterus personatus*), which presented generally low densities or absence from most reef stations during the 2019 survey. Such marked Island-wide population declines may be related to meso-scale oceanographic phenomena, such as the physical disturbance(s) caused by the pass of Hurricane Maria and Irma in 2017 and/or winter storm Riley in March 2018.
7. Statistically significant differences of fish species richness were measured from 13 reef stations, eight of which also exhibited fish density reductions. It is possible that the extreme physical disturbances to which shallow reef systems were exposed previous to our 2019 survey had negative implications (advective displacement) on a suite of small fish populations. In turn, population declines of these small fishes may have influenced/regulated the occurrence and density of potential fish predators that also contribute to the reef ichthyofaunal biodiversity (cascading effects).
8. The fish size-frequency distribution data show that most of the reefs surveyed function as recruitment, nursery and residential habitats for a wide variety of the larger reef fish herbivores, such as parrotfishes (*Scarus spp, Sparisoma spp*) and doctorfishes (*Acanthurus spp*). Recruitment size classes (1-5cm) of parrotfishes and doctorfishes were most abundant at CARI10 (19.2 Ind/60m^2), WEST10 (9.2 Ind/60m^2) and RATO05 (8.4 Ind/60m^2). Terminal phase male (TPM) stages were observed for five parrotfish species (*Sparisoma viride, S. aurofrenatum, Scarus vetula, S. taeniopterus, S. iseri*).
9. Mid-sized piscivorous fishes, such as yellowtail and schoolmaster snappers (*Ocyurus chrysurus, Lutjanus apodus*), hogfish (*Lachnolaimus maximus*) and red hind (*Epinephelus guttatus*) were observed as juvenile and/or adults in many of the reefs surveyed without any evident pattern associated with depth and/or distance from shore.

10. Large demersal predators were generally absent from belt-transect areas of the reefs surveyed with the exception of two adult Nassau groupers (*Epinephelus striatus*) observed at CORA10 and at TOUR20. These data are indicative of the still critical condition of neritic reefs surveyed regarding the presence and densities of large demersal predators, particularly the large groupers (*Epinephelus spp, Mycteroperca spp*).

IX. Research Priorities and Management Recommendations

1. The highest research priority of the PRCRMP should be the understanding of oceanographic processes that have influenced the large-scale degradation of coral reef systems in Puerto Rico (PR) and that still represent their mayor threat. The 2005 regional coral bleaching event has been identified as the main driver of coral degradation in PR for which quantitative evidence is available in peer-reviewed sources. Previous coral bleaching events of 1988 and 1990 were less quantitatively characterized, but still provide relevant evidence that such bleaching events had significant implications for coral degradation in PR previous to the PRCRMP baseline surveys beginning in 1999.

2. Climate change and its effects on higher than normal seawater surface temperatures (SST) were advanced as a generic explanation to regional coral bleaching events. Coral monitoring data from the PRCRMP has shown that increased SST was not the sole factor influencing coral degradation of PR reefs, as distinct gradients of coral mortality related with depth, distance from shore and away from riverine discharges were evidenced within the mixed conservative features of the Caribbean Surface Mixed layer water mass (0 – 60m). Therefore, it is here recommended that in-situ water quality information, such as water temperature, pH, salinity, chlorophyll-a concentrations and light penetration be included as part of the PRCRMP, in addition to applications of available remote satellite derived information to support ongoing field surveys on the coral reef community.

3. The PRCRMP has identified a differential resilience/vulnerability of coral species to environmental stressors, such as bleaching and hurricanes. Supported by reef-specific, in-situ water quality information determinations can be made from the PRCRMP database to select particular coral species that have been shown to be more resilient to the specific water quality features of insular shelf areas where high coral degradation has been observed and replenish these areas with the more resilient coral species from (coral)

nursery sources. The end result should be a fast-track increment of reef substrate cover by resilient corals for the specific water quality conditions of particular reefs.

4. Since the 2016 monitoring survey, the PRCRMP has detected a marked increment of encrusting red crustose coralline algae, particularly Ramicrusta sp. in shallow reefs of the east coast, including Fajardo, Isla de Culebra, and Isla de Vieques. Ramicrusta sp. is known capable of overgrowing and killing entire coral colonies of several species common in PR reefs and is considered at present a threat to shallow coral reef systems of the PR east coast. The resilience of the Ramicrusta sp. outbreak is at present unknown, as well as the magnitude of its potential threat on coral degradation. Therefore, we propose that DNER support research efforts directed to understand the prevalence of Ramicrusta sp. and other encrusting crustose coralline algae on PR reefs, as well as potential manipulations to reduce their populations, including sea urchin seedings on highly colonized reefs.

5. To better understand the ecological factors influencing the distribution, growth dynamics, and potential implications of the Ramicrusta sp. threat on coral reefs we recommend that DNER expand the number of reef monitoring stations within the east coast of PR. Specifically, the inclusion of reef stations in Isla de Vieques where existing baseline surveys and monitoring surveys were performed during the 2000 – 2004 period under the PRCRMP and have not been re-visited. These include reef stations at Monte Pirata, Caballo Blanco (reef slope and reef crest), Mosquito, Corona, Comandante, and Black-Jack. Geographic coordinates of permanent transects at these locations are available.

6. Preservation of the PR coral reef system's ecological integrity has been severely compromised both due to the population crash of its keystone grazer, the long-spined urchin (Diadema antillarum) during the 1983-84 regional mass mortality, and by the drastic decline of the large reef demersal predators, particularly groupers and snappers after more than a decade of intense fishing exploitation during their seasonal spawning aggregations. Despite active state and federal seasonal fishing closure regulations, fishing pressure still occurs due to the lack of enforcement. Therefore, the specific recommendation is to establish an effective surveillance program during the species seasonal spawning aggregations facilitated by drones, remote sensing, land-based telescopic monitoring, and other direct and indirect surveillance strategies.

7. The Caribbean Fishery Management Council (CFMC) has active regulations of annual catch limits and seasonal closures on many of the commercially exploited coral reef fish and shellfish populations occurring within the federal Exclusive Economic Zone (EEZ) that includes shelf habitats outside a nine-nautical mile boundary around PR. We recommend that DNER should work in closer association with the CFMC to convey parallel regulation criteria on coral reef fishery management, research, and enforcement.

8. In line with the goal objective of preservation of the coral reef system's ecological integrity, the DRNER should consider the creation of across-shelf marine conservation districts (MCD). These are conceptualized as entire shelf areas (from the shoreline to the shelf-edge) closed to fishing and of limited recreational uses. Such MCDs would be managed for intense coral reef related research, with particular attention on the reef ecosystem's response to a large area fishing closure and recreational constraints, such as what has been achieved in the USVI for the Saint Thomas MCD, where a bold recuperation of its fishery resources has been achieved.

9. Understanding of the dispersal forces, such as wind, currents and eddies acting during the reef fish species seasonal spawning aggregations is a research priority of outmost relevance for designation of specific localities and areal extensions of MCDs. Such investigations must identify pelagic larval sinks, where fish/shellfish recruitment success is enhanced by both current drift and presence of ideal benthic habitats for post-larval recruitment. To this effect, it is essential to produce comprehensive water current dynamics studies during and shortly after the species' spawning events on strategic localities as to establish, relative to the fish larval duration periods (PLD's) local and regional (larval) connectivity maps. This data, in conjunction with existing, improved, and prospective information on benthic habitat maps should identify the most appropriate locations and geographical extensions of MCDs.

10. For several of the most desired species, such as large groupers (Nassau, yellowfin, black, jewfish, red hind) it is possible that the recuperation of these populations is presently limited due to the prolonged periods of recruitment overfishing for which a critical mass of reproducing populations is lacking within the dispersal range desired. To counteract this effect, the possibility of seeding the MCDs with juvenile stages of these species may be

an effective management strategy for stocks replenishment where appropriate recruitment and residential habitats are available.

11. Research efforts are needed for better understanding of the recruitment dynamics of commercially exploited reef fish and shellfish populations, such as large groupers, snappers, hogfish, lobsters, and queen conch. Information is critically lacking regarding their pelagic larval dispersal dynamics, factors influencing larval and post larval survival, and identification of preferred benthic recruitment habitats. The latter is of outmost management concern, since it is possible that such recruitment habitats may not be adequately protected due to the lack of information regarding such critically relevant function for coral reef ecosystems.

12. The PRCRMP has identified the masked goby (Coryphopterus personatus) as a numerically dominant species that drives statistically significant fluctuations of total fish density and possibly ichthyofaunal community biodiversity associated with cascading effects in many of our monitored reef stations. Its role in the trophodynamics of our reef systems is poorly understood and requires particular research attention. Information regarding fundamental aspects of its life history and its role as a forage species for coral reef demersal piscivores is needed for understanding coral reef food webs and the reef system productivity dynamics.

X. Literature Cited

CARICOMP. 1994. Manual of methods for mapping and monitoring of physical and biological parameters in the coastal zone of the Caribbean. Caribbean Coastal Marine Productivity: Data Management Center. Centre for Marine Sciences. U. West Indies. Mona, Kingston, Jamaica and Florida Institute of Oceanography. U.S. Florida. 68 p.

Eakin CM, Morgan JA, Heron SF, Smith TB, Liu G, Alvarez-Filip L, et al. (2010) Caribbean Corals in Crisis: Record Thermal Stress, Bleaching, and mortality in 2005. PLoS ONE 5(11):e13969. https:doi.org/10.1371redre

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

Caribbean Fishery Management Council (CFMC). 1996. Regulatory amendment to the fishery management plan for the reef fish fishery of Puerto Rico and the United States Virgin Islands concerning red hind spawning aggregation closures including a regulatory impact review and an environmental assessment. Caribbean Fishery Management Council, San Juan, Puerto Rico. 27 pp. + Appendices.

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

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. 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., 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

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

García-Sais, J. R., R. Esteves, S. Williams J. Sabater Clavell and M. Carlo. 2015. Monitoring of coral reef communities from Natural Reserves in Puerto Rico 2015. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 285 p

García-Sais, J. R., R. Esteves, S. Williams J. Sabater Clavell and M. Carlo. 2014. Monitoring of coral reef communities from Natural Reserves in Puerto Rico 2012 - 13. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 301 p

García-Sais, J. R., R. Castro, J. Sabater Clavell, M. Carlo, R. Esteves and, S. Williams. 2012. Monitoring of coral reef communities from Natural Reserves in Puerto Rico: Isla Desecheo, Rincón, Guánica, Ponce, Caja de Muerto, Vega Baja, Vieques and Mayaguez. 2010-11. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 205 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., R. Castro, J. Sabater Clavell, M. Carlo, R. Esteves and, S. Williams. 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), 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, (2008). 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, M. Carlo, R. Esteves and, S. Williams. 2008. 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), 212 p

García-Sais, J. R., R. Castro, J. Sabater Clavell, R. Esteves and M. Carlo. 2007. Monitoring of coral reef communities at Isla Desecheo, Rincón, Ponce, Isla Caja de Muerto, Guánica, and Mayaguez. 2006-07. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 148 p

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. Appeldoorn, A. Bruckner, C. Caldow, J. D. Christensen, C. Lilyestrom, M. E. Monaco, J. Sabater, E. Williams, and E. Díaz. 2005. The State of Coral Reef Ecosystems of the Commonwealth of Puerto Rico. pp 91-134. In: J. Waddell (ed.), The State of Coral Reef Ecosystems of the Unites States and Pacific Freely Associated States: NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD.

García-Sais, J. R., R. Castro, J. Sabater Clavell, R. Esteves and M. Carlo. 2005. Monitoring of coral reef communities at Isla Desecheo, Rincón, Mayaguez Bay, Guánica, Ponce and Isla Caja de Muerto, Puerto Rico, 2005. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 126 p

García-Sais, J. R., R. Castro, J. Sabater and M. Carlo. 2004 a. Baseline characterization and monitoring of coral reef communities at Isla Desecheo, Rincón and Mayaguez Bay, Puerto Rico, 2004. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), Puerto Rico Coral Reef Monitoring Program (PRCRMP, 89 p

García-Sais, J. R., J. Sabater-Clavel, M. Canals and C. Pacheco. 2005. Habitat use – habitat zoning study: Cayos de Cana Gorda, Guanica Natural Reserve. Informe Final sometido a Louis Berger Foundation 60 pp

García-Sais, J. R. and J. Sabater-Clavell. 2004. Distribucion y caracterizacion biologica de los principales habitats marinos en la Reserve Natural de La Parguera, Lajas, Puerto Rico. Informe Final sometido al Departamento de Recursos Naturales y Ambientales (DRNA). 140 pp

García-Sais, J. R., R. Castro, and M. Carlo. 2004 b. Monitoring of coral reef communities from Isla de Vieques, Puerto Rico, 2004. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 118 p

García-Sais, J. R., R. Castro, J. Sabater and M. Carlo. 2003. Survey of Marine Communities in Jobos Bay. Aguirre Power Plant 316 Demonstration Studies. Final Report submitted to Washington Group International, Inc. 80 p.

García-Sais, J. R., R. Castro and J. Sabater. 2001a. Coral reef communities from Natural Reserves in Puerto Rico: a baseline quantitative assessment for prospective monitoring programs. Vol. 1 - Cordillera de Fajardo, Guánica, Bahía de Mayagüez, Caja de Muerto. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 232 pp.

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 and M. Carlo. 2001c. Coral reef communities from Natural Reserves in Puerto Rico: a baseline quantitative assessment for prospective monitoring programs. Vol. 3. Ponce, Guayanilla, Guayama, Arroyo. Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 68 pp.

García-Sais, J. R, R. Castro, J. Sabater and M. Carlo. 2001d. Baseline characterization of coral reef and seagrass communities from Isla de Vieques, Puerto Rico Puerto Rico Coral Reef Monitoring Program (PRCRMP). Final Report submitted to the Department of Natural and Environmental Resources (DNER), 108 pp.

García-Sais, J. R., J. Morelock, R. Castro, C. Goenaga and E. Hernández-Delgado. 2003. Puertorrican Reefs: research synthesis, present threats and management perspectives. Latin American Coral Reefs. J. Cortez (Ed.) Elsevier Science. p. 111-130

Garcia-Sais, J. R. and R. Castro. 1995. Survey of marine communities associated with coral reefs, seagrass/macroalgal beds and mangrove root habitats at Jobos Bay Natural Estuarine Research Reserve (JOBANERR). Final Report. 70 p.

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.

Grimont, P. A. and F. Grimont. 1994. (cited in Patterson et. al. 2002).

InfoStat, 2004. Estadística y diseño. Universidad Nacional de Córdova. www.infostat.com.ar

HernándezDelgado EA, Toledo C, Claudio HJ, Lassus J, Lucking MA, FonsecaJ, Hall K, Rafolo S J, Horta H, Sabat AM. 2006. Spatial and taxonomic patterns of coral bleaching and mortality in Puerto Rico during year 2005. In: NOAA-NESDIS-CRWP. NOAA, US Virgin Islands, St. Croix, USA.

Leis, J. M._1982. Nearshore distributional patterns of larval fish (15 taxa) and planktonic crustaceans (6 taxa) in Hawaii. Marine Biology, 72:89-97

Leis, J. M. and J. M. Miller. 1976. Offshore distributional patterns of Hawaiian fish larvae. Marine Biology, 36;359-367

Miller J, Muller E, Rogers C, Waara R, Atkinson A, Whelan KRT, Patterson M, Witcher B. 2009. Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin Islands. *Coral Reefs* 28:925-937

Nemeth, M. 2002. Monitoring data of coral reefs within Natural Reserves of Puerto Rico surveyed during 2001. Department of Natural and Environmental Resources (DNER) Internal Report. DNER, San Juan, P. R.

Ogden, J. C., P. M. Alcolado +39 other authors (1997). Caribbean Coastal Marine Productivity (CARICOMP): A research and monitoring network of marine laboratories, parks and reserves. Research Gate https://www.researchgate.net/publication/262686971

NOAA, 2005. Major coral bleaching event expands across Caribbean, severe in Puerto Rico and the U. S. Virgin Islands. www.noaanews.noaa.gov/stories2005/s2526.htm

Paddack, Michelle J., John D. Reynolds, Consuelo Aguilar, Richard S. Appeldoorn, Jim Beets, Edward W. Burkett, Paul M. Chittaro, Kristen Clarke, Rene Esteves, Ana C. Fonseca, Graham E. Forrester, Alan M. Friedlander, Jorge García-Sais, Gaspar González-Sansón, Lance K.B. Jordan, David B. McClellan, Margaret W. Miller, Phil P. Molloy, Peter J. Mumby[4], Ivan Nagelkerken, Michael Nemeth, Raúl Navas-Camacho, Joanna Pitt,

Nicholas V.C. Polunin, Maria Catalina Reyes-, D. Ross Robertson, Alberto Rodríguez-Ramírez, Eva Salas, Struan R. Smith, Richard E. Spieler, Mark A. Steele, Ivor D. Williams[23], Clare L. Wormald, Andrew R. Watkinson, Isabelle M. Côté. 2009. Recent region-wide declines in Caribbean reef fish abundance. Current Biol.,19: 1-6

Patterson, K. L., J. W. Porter, K. B. Ritchie, S. B. Polson, E. Mueller, E. C. Peters, D. L. Santavy, and G. W. Smith. 2002. The etiology of white pox a lethal disease of the Caribbean elkhorn coral Acropora palmata. Proc. Natl. Acad. Sci., USA 99: 8725-8730

Porter, J. W. 1972. Patterns of species diversity in Caribbean Reef Corals. Ecology, 53: 745-748.

Randall, J. E. 1967. Food Habits of Reef Fishes of the West Indies. U. Miami. 183 p.

Ramirez-Mella, J. T. and J. R. Garcia-Sais. 2003. Offshore dispersal of Caribbean Reef Fish Larvae: haw far is it? Bulletin of Marine Science, 72(3): 997-1017

Raymundo, L. J., C. S. Couch and C. D. Harvel (Eds.). 2008. Coral Disease Handbook. www. gefcoral.org. 121p.

Rodriguez, Y. 2004. Zooplankton communities of Isla Desecheo and adjacent waters of the Mona Passage. M. S. Thesis. Department of Marine Sciences, UPRM 85 p.

Weil E, Croquer A, Urreiztieta I. 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

Villamil, J., M. Canals, S. Silander, M. Del Llano, R. Martínez, A. García, A. Molinares, J. González, E. Questell y M. González. 1980. Suplemento técnico para la Reserva Caja de Muerto. Informe interno del Departamento de Recursos Naturales y Ambientales (DNER), San Juan, P. R. 247

Williams, E. H. And L. Bunkley-Williams. 1990. Coral reef bleaching alert. Nature, 346: 225

Williams, S. M. 2017. A novel approach to the restoration of Diadema antillarum on coral reefs in the Caribbean. Reef Encounter1 31 (2): 48-50

XI. Appendixes

Appendix 1. Life history characteristics and feeding habits of commercially and/or ecologically important fishes. From: Froese, R. & D. Pauly (Editors). 2019. FishBase. World Wide Web electronic publication. Version (02/2019). *http://www.fishbase.org*

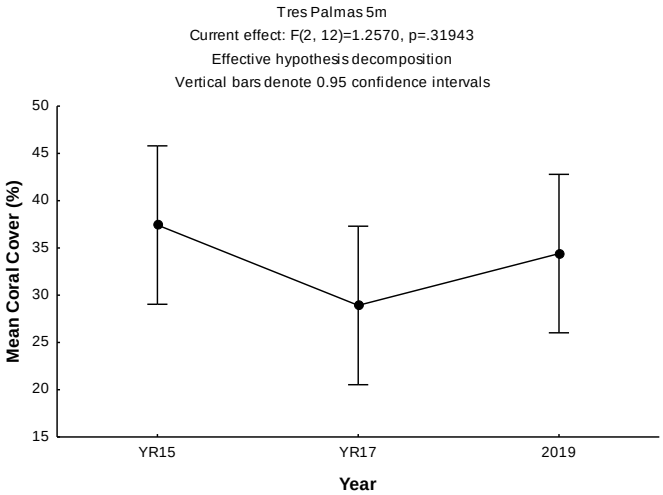
Fish Species	Common Name	Length at maturity (cm)	Maximum Length (cm)	Main Diet
Acanthostracion polygonia	Honeycomb Cowfish	n/d	50	Sponges/shrimp
Acanthurus chirurgus	Doctorfish	17	39	Algae
Acanthurus coeruleus	Blue Tang	13	39	Algae
Acanthurus tractus	Five-band Surgeonfish	15.5	38.1	Algae
Caranx ruber	Bar-Jack	26	73.0	Nekton
Cephalopholis cruentata	Graysbe	16	42.6	Nekton
Cephalopholis fulva	Coney	14.7	41	Nekton
Epinephelus guttatus	Red Hind	25	76	Zoobenthos
Epinephelus striatus	Nassau Grouper	48	122	Nekton
Gymnothorax moringa	Spotted Moray	n/d	200	Nekton
Lachnolaimus maximus	Hogfish	18.1	91	Zoobenthos
Lutjanus analis	Mutton Snapper	28	94	Nekton
Lutjanus apodus	Schoolmaster	25	67.2	Nekton
Lutjanus jocu	Dog Snapper	31	128	Nekton
Lutjanus mahogoni	Mahogany Snapper	n/d	48	Nekton
Lutjanus synagris	Lane Snapper	16	60	Nekton
Mycteroperca interstitialis	Yellowmouth Grouper	40	84	Nekton
Ocyurus chrysurus	Yellowtail Snapper	15	83.6	Nekton
Pterois sp.	Lionfish	16	38	Nekton
Scarus iseri	Striped Parrotfish	16	35	Algae
Scarus taeniopterus	Princess Parrotfish	17	35	Algae
Scarus vetula	Queen Parrotfish	n/d	61	Algae
Scomberomorus regalis	Cero	38	183	Nekton
Sparisoma aurofrenatum	Redband Parrotfish	15	28	Algae
Sparisoma chrysopterum	Redtail Parrotfish	n/d	46	Algae
Sparisoma radians	Bucktooth Parrotfish	n/d	20	Algae
Sparisoma rubripinne	Yellowtail Parrotfish	16	47.8	Algae
Sparisoma viride	Stoplight Parrotfish	16.3	64	Algae

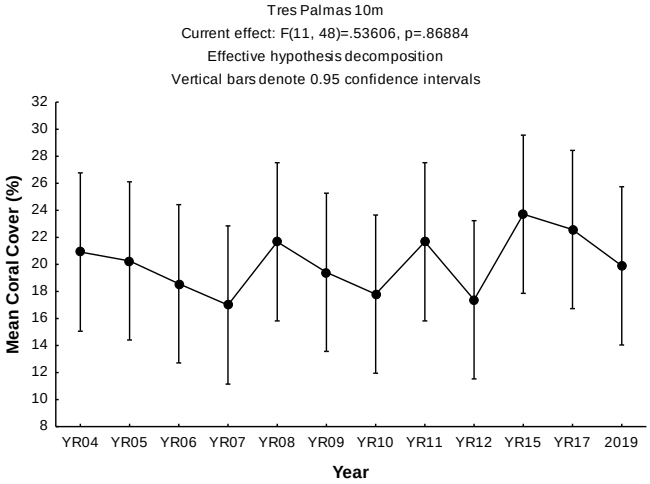
Appendix 2. Prevalence of diseased hard coral colonies at reef stations monitored. PRCRMP 2019 Survey

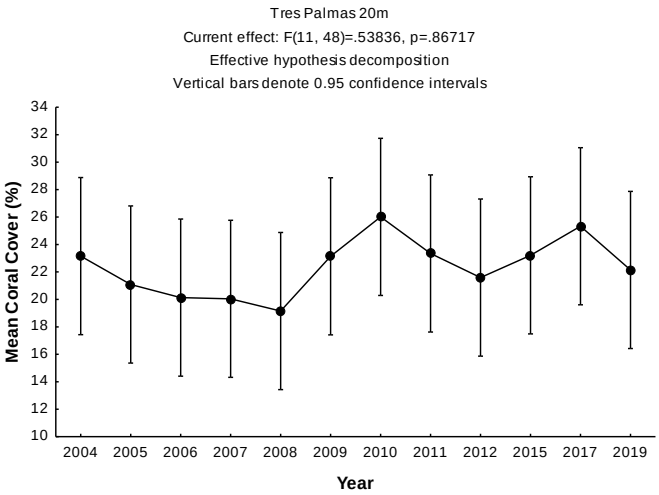
Sites	Reef Stations	Number of Diseased Colonies	Number of Hard Coral Colonies	Hard Coral Disease Prevalence (%)	Coral Species Diseased
Rincon	TRES05	1	24	8.3	*Acropora palmata*
		1			*Pseudodiploria strigosa*
	TRES10	1	60	6.7	*Stephanocoenia intersepta*
		1			*Pseudodiploria strigosa*
		1			*Siderastrea siderea*
		1			*Montastraea cavernosa*
	TRES20	2	66	4.5	*Siderastrea siderea*
		1			*Stephanocoenia intersepta*
Mayaguez	TOUR30	1	74	1.4	*Orbicella faveolata*
	TOUR20	2	63	9.5	*Montastraea cavernosa*
		1			*Siderastrea siderea*
		2			*Orbicella faveolata*
		1			*Orbicella franksi*
	TOUR10	0	96	0.0	none
Cabo Rojo	GALL05	0	46	0.0	none
	RESU10	2	54	3.7	*Siderastrea siderea*
Parguera	BOYA20	1	70	1.4	*Siderastrea siderea*
	MLUN10	1	61	1.6	*Porites astreoides*
	MLUN05	1	24	4.2	*Siderastrea siderea*
Guánica	AURO05	1	57	7.0	*Porites astreoides*
		2			*Acropora cervicornis*
		1			*Acropora palmata*
	CORA10	2	37	8.1	*Porites astreoides*
		1			*Siderastrea siderea*
	BERI20	1	49	6.1	*Porites astreoides*
		1			*Siderastrea siderea*
		1			*Orbicella faveolata*
Guayanilla	MLAN20	5	44	16.6	*Siderastrea siderea*
		1			*Orbicella faveolata*
	MLAN10	1	47	12.8	*Pseudodiploria strigosa*
		1			*Stephanocoenia intersepta*
		1			*Porites astreoides*
		1			*Diploria labyrinthiformis*
		1			*Siderastrea siderea*
		1			*Montastraea cavernosa*

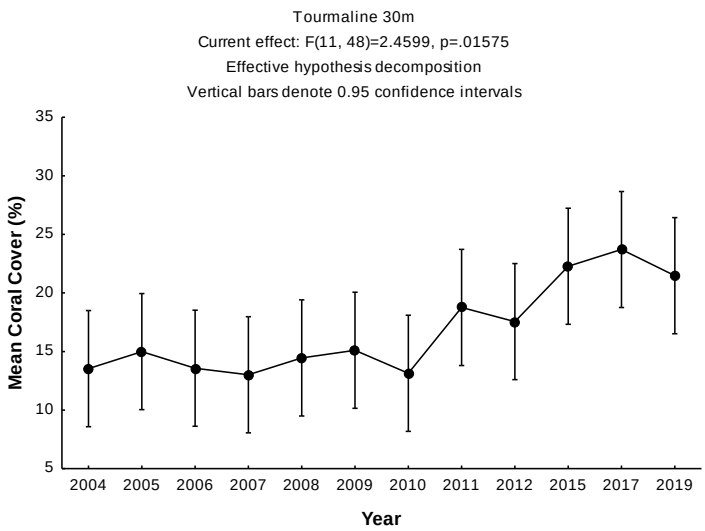
Sites	Reef Stations	Number of Diseased Colonies	Number of Hard Coral Colonies	Hard Coral Disease Prevalence (%)	Coral Species Diseased
	MLAN05	0	19	0	
Ponce	WEST10	1	51	5.9	*Orbicella faveolata*
		1			*Porites astreoides*
		1			*Montastraea cavernosa*
	DERR20	1	69	4.3	*Orbicella faveolata*
		1			*Orbicella franksi*
		1			*Siderastrea siderea*
Salinas	CARI10	1	51	2.0	*Siderastrea siderea*
	RATO05	4	50	8.0	*Siderastrea siderea*
	Totals	**54**	**1112**	**4.86**	

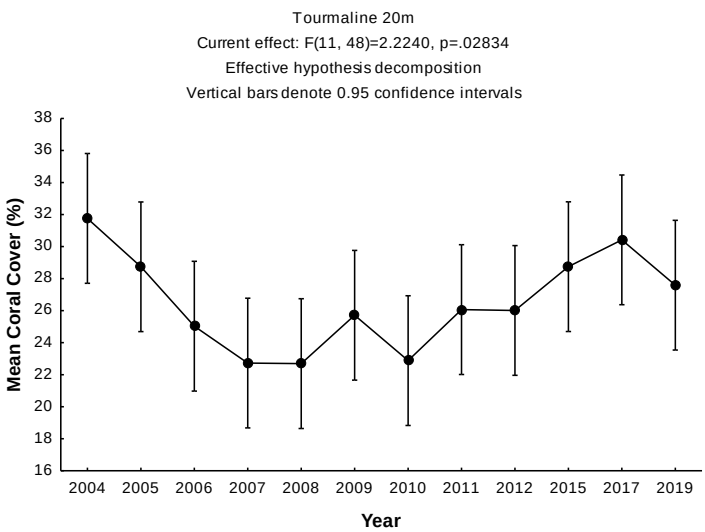
Appendix 3. Factorial analyses of variance (ANOVA) testing for differences of hard coral % cover between monitoring surveys at reef stations monitored. PRCRMP 2019 Survey

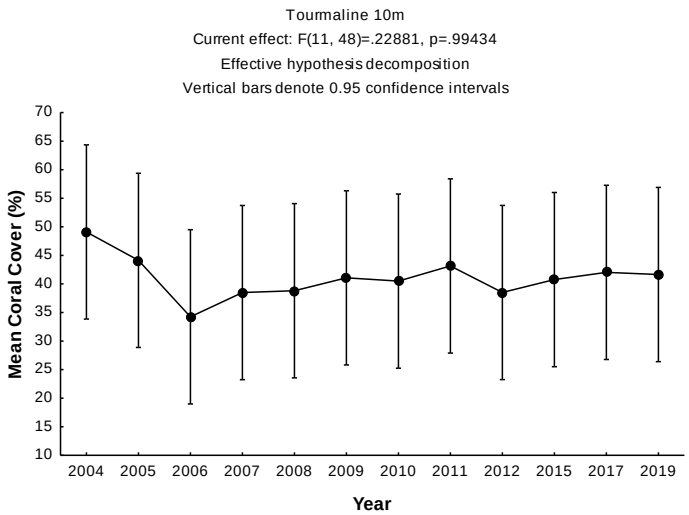


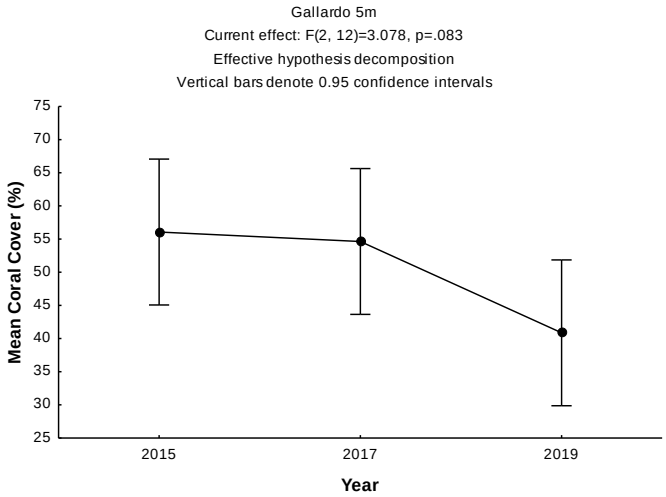


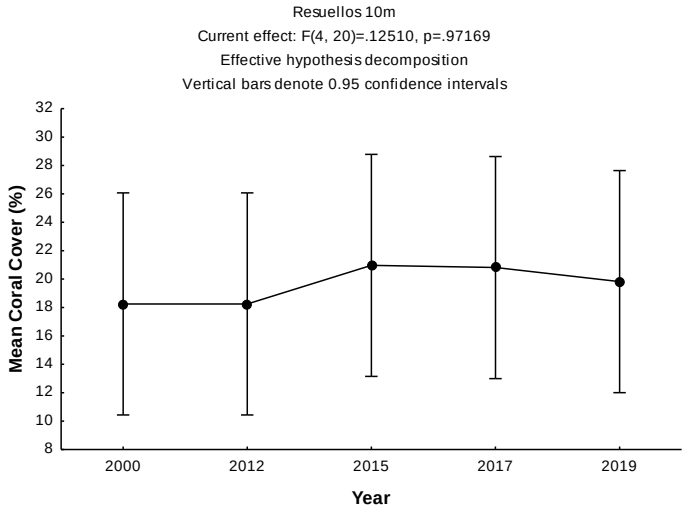


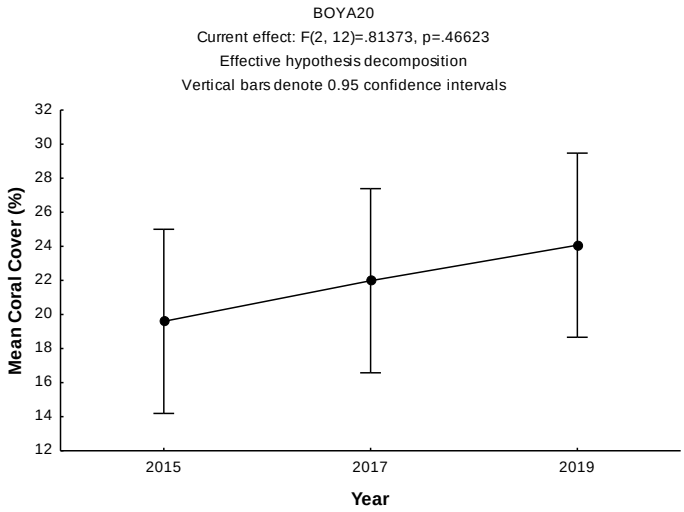

Tourmaline 30m
Current effect: F(11, 48)=2.4599, p=.01575
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
35
30
25
20
15
10
5
2004 2005 2006 2007 2008 2009 2010 2011 2012 2015 2017 2019
Year

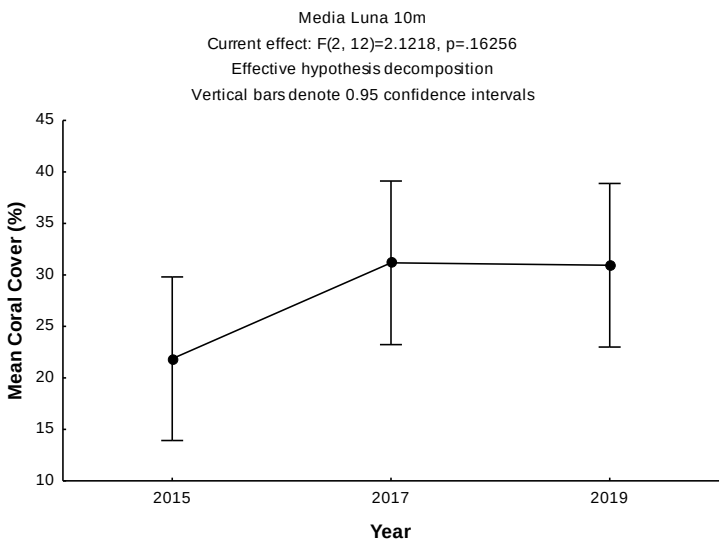

Tourmaline 20m
Current effect: F(11, 48)=2.2240, p=.02834
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
38
36
34
32
30
28
26
24
22
20
18
16
2004 2005 2006 2007 2008 2009 2010 2011 2012 2015 2017 2019
Year

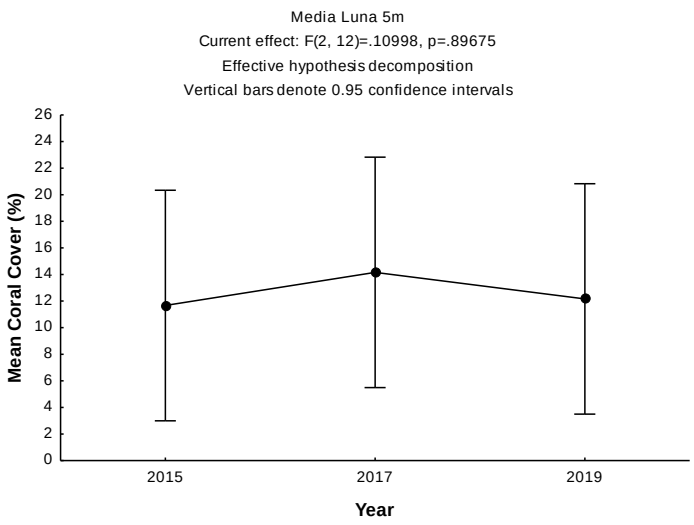

Tourmaline 10m
Current effect: F(11, 48)=.22881, p=.99434
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
70
65
60
55
50
45
40
35
30
25
20
15
10
2004 2005 2006 2007 2008 2009 2010 2011 2012 2015 2017 2019
Year

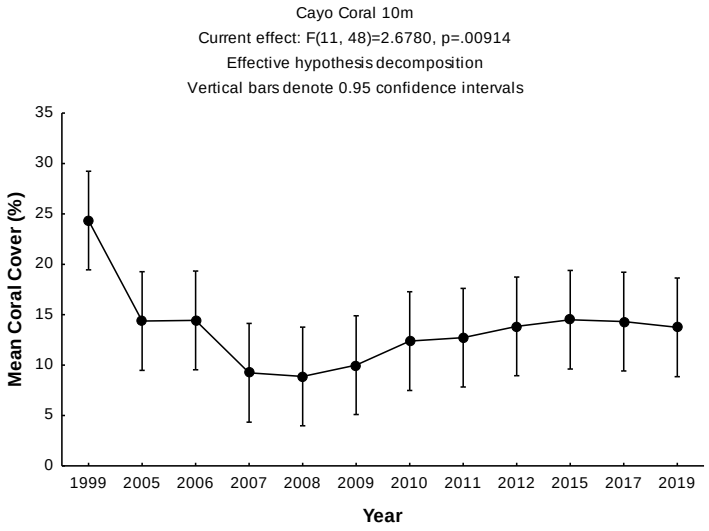

Gallardo 5m
Current effect: F(2, 12)=3.078, p=.083
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
75
70
65
60
55
50
45
40
35
30
25
2015
2017
2019
Year

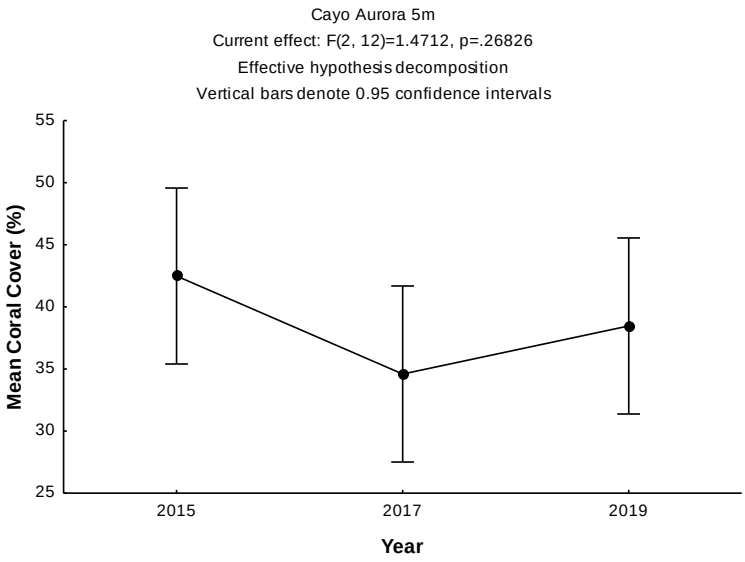

Resuellos 10m
Current effect: F(4, 20)=.12510, p=.97169
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
32
30
28
26
24
22
20
18
16
14
12
10
8
2000
2012
2015
2017
2019
Year

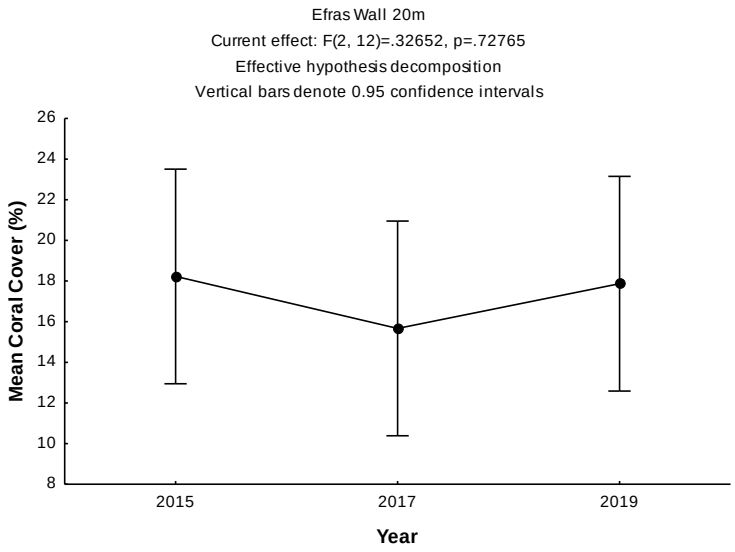

BOYA20
Current effect: F(2, 12)=.81373, p=.46623
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
32
30
28
26
24
22
20
18
16
14
12
2015
2017
2019
Year

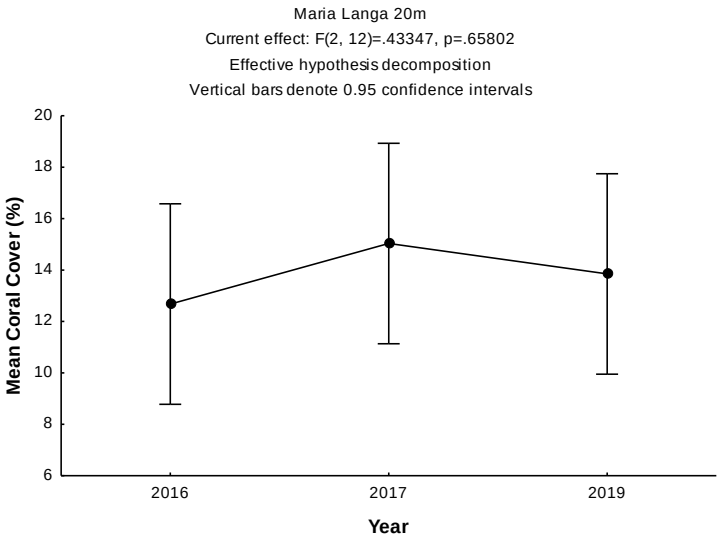

Media Luna 10m
Current effect: F(2, 12)=2.1218, p=.16256
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
45
40
35
30
25
20
15
10
2015
2017
2019
Year

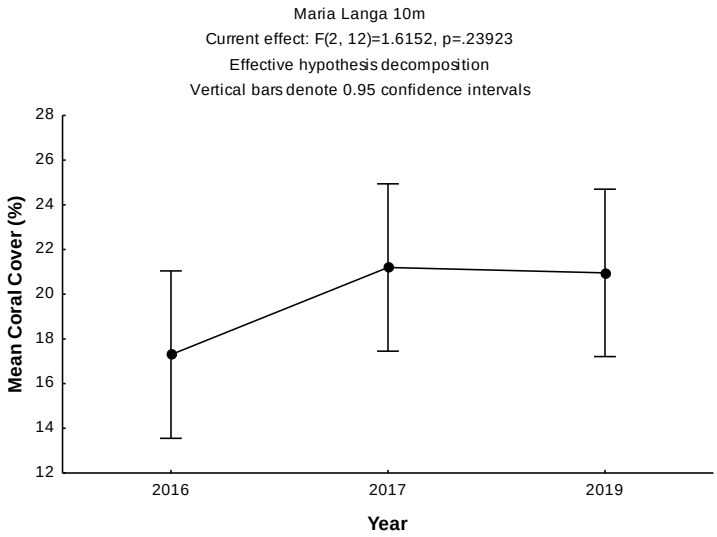

Media Luna 5m
Current effect: F(2, 12)=.10998, p=.89675
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
2015
2017
2019
Year

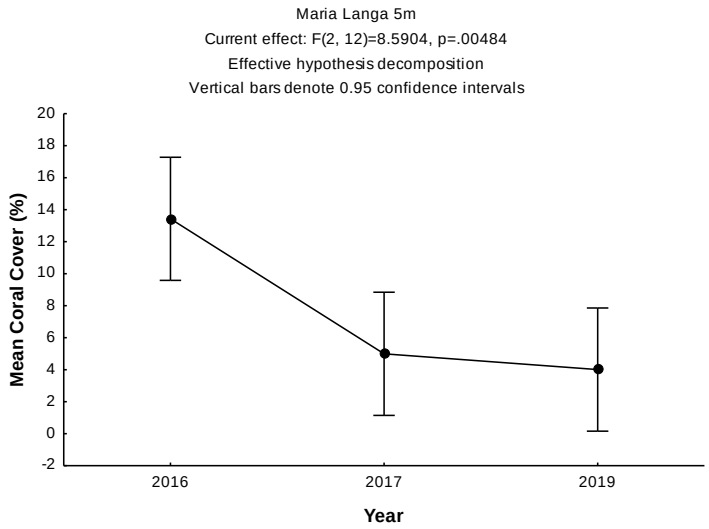

Cayo Coral 10m
Current effect: F(11, 48)=2.6780, p=.00914
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
35
30
25
20
15
10
5
0
1999
2005
2006
2007
2008
2009
2010
2011
2012
2015
2017
2019
Year

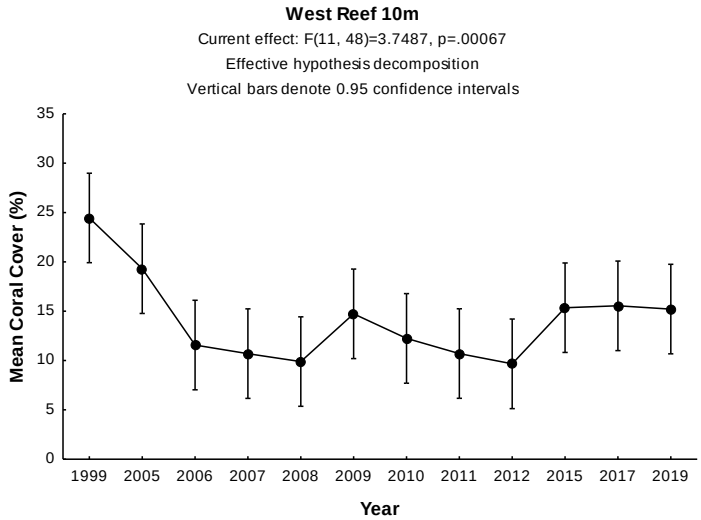

Cayo Aurora 5m
Current effect: F(2, 12)=1.4712, p=.26826
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
55
50
45
40
35
30
25
2015
2017
2019
Year

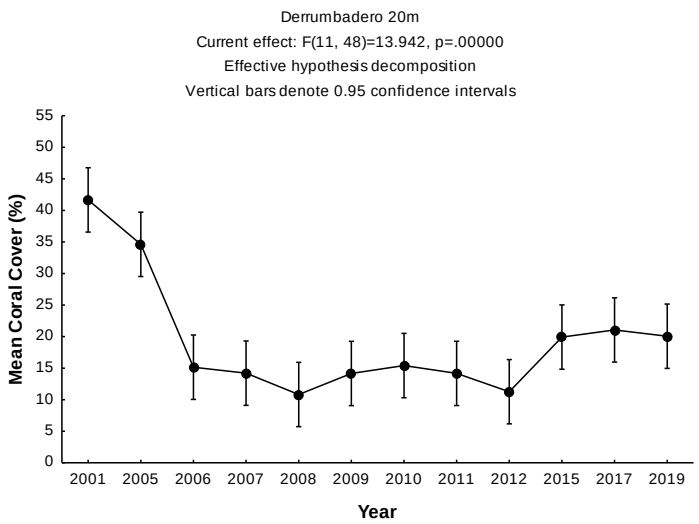

Efras Wall 20m
Current effect: F(2, 12)=.32652, p=.72765
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
26
24
22
20
18
16
14
12
10
8
2015
2017
2019
Year

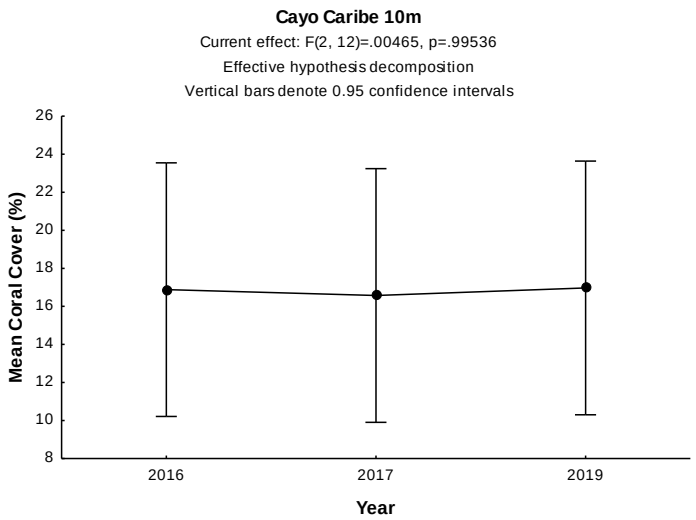

Maria Langa 20m
Current effect: F(2, 12)=.43347, p=.65802
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
20
18
16
14
12
10
8
6
2016
2017
2019
Year

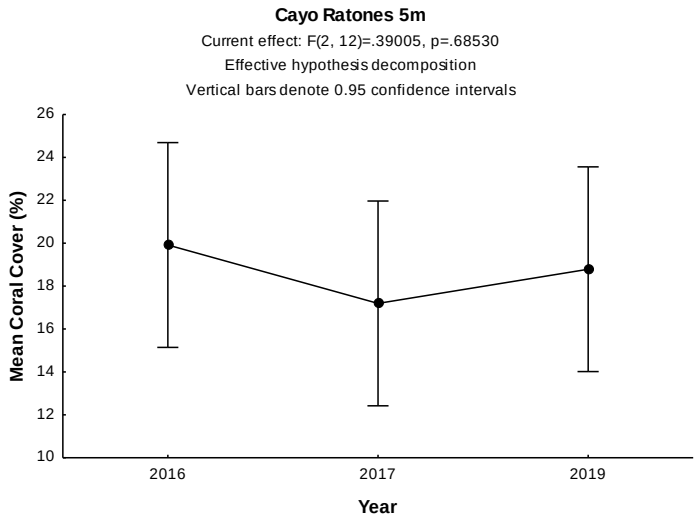

Maria Langa 10m
Current effect: F(2, 12)=1.6152, p=.23923
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
28
26
24
22
20
18
16
14
12
2016
2017
2019
Year


Maria Langa 5m
Current effect: F(2, 12)=8.5904, p=.00484
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
20
18
16
14
12
10
8
6
4
2
0
-2
2016
2017
2019
Year


West Reef 10m
Current effect: F(11, 48)=3.7487, p=.00067
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
35
30
25
20
15
10
5
0
1999
2005
2006
2007
2008
2009
2010
2011
2012
2015
2017
2019
Year


Derrumbadero 20m
Current effect: F(11, 48)=13.942, p=.00000
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
55
50
45
40
35
30
25
20
15
10
5
0
2001
2005
2006
2007
2008
2009
2010
2011
2012
2015
2017
2019
Year


Cayo Caribe 10m
Current effect: F(2, 12)=.00465, p=.99536
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
26
24
22
20
18
16
14
12
10
8
2016
2017
2019
Year


Cayo Ratones 5m
Current effect: F(2, 12)=.39005, p=.68530
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean Coral Cover (%)
26
24
22
20
18
16
14
12
10
2016
2017
2019
Year

Appendix 4. Factorial analyses of variance (ANOVA) testing for temporal differences of soft coral densities between montoring surveys at reef stations in the PRCRMP 2019 survey

Site	Reef Station	Mean Density in 2017 (Col/Transect)	Mean Density in 2019 (Col/Transect)	Mean Density Study Period (Col/Transect)	Std. Deviation Study Period	ANOVA p-value
Rincon	TRES05	2.6	1.4	3.0	2.2	0.017
	TRES10	19.8	21.8	21.8	4.6	0.01
	TRES20	15.6	12.0	12.9	4.3	0.152
Mayaguez	TOUR10	14.6	13.8	23.2	9.0	<0.0001
	TOUR20	11	10.2	14.4	6.0	<0.0001
	TOUR30	10.2	10.0	13.5	5.3	<0.0001
Cabo Rojo	GALL05	0	0.2	0.3	0.9	0.286
	RESU10	24.2	19.6	27.3	12.6	<0.0001
La Parguera	BOYA20	10.8	8.8	10.5	3.8	0.248
	MLUN 10	22.4	31.4	33.3	12.2	0.002
	MLUN05	16.8	11.6	16.9	6.5	0.023
Guanica	BERI20	26.8	20.2	21.9	5.4	0.029
	CORA10	23.4	20.0	23.0	6.7	0.109
	AURO05	0.4	1.0	0.5	1.3	0.487
Guayanilla	MLAN20	24.6	27.4	24.8	3.7	0.127
	MLAN10	42.4	43.2	43.6	8.3	0.704
	MLAN05	1.6	1.8	1.7	1.2	0.815
Ponce	WEST10	13	13.0	21.6	8.9	0.050
	DERR20	33.6	26.0	28.0	7.5	0.020
Salinas	CARI10	21.4	17.6	18.1	4.5	0.095
	RATO05	10.2	10.2	11.6	4.2	0.647

Appendix 5. Analysis of variance (ANOVA) procedures testing differences of fish densities between monitoring surveys

Site	Reef Station	Mean Density in 2019 (# Ind/30m^2)	Mean Density Study Period (# Ind/30m^2)	Standard Deviation Study Period	ANOVA p-value
Rincon	TRES05	45	51.13	29.54	0.080
	TRES10	57.4	80.41	40.91	< 0.0001
	TRES20	91.4	227.33	150.88	< 0.0001
Mayaguez	TOUR10	67.8	84.14	32.23	0.342
	TOUR20	67.2	166.33	107.70	< 0.0001
	TOUR30	71.6	185.15	135.63	< 0.0001
Cabo Rojo	GALLA5	51.2	63.70	31.24	< 0.0001
	RESU10	20.8	26.76	8.10	0.607
Parguera	MLUN05	47.0	49.00	16.47	0.060
	MLUN10	34.4	31.67	7.5	0.617
	BOYA20	69.6	72.80	35.52	0.006
Guánica	AURO05	69.4	55.07	14.6	0.001
	CORA10	42.8	48.17	23.68	< 0.0001
	BERI20	43.2			0.010
Guayanilla	MLAN05	51.2	45.80	8.94	0.257
	MLAN10	21.2	24.27	7.13	0.062
	MLAN20	21.4	30.93	22.37	0.319
Ponce	WEST10	159.4	132.82	103.64	< 0.0001
	DERR20	78.6	89.02	52.28	< 0.0001
Salinas	RATO05	31.4	37.00	15.46	0.231
	CARI10	53.2	45.73	11.65	0.212

Appendix 6. Analysis of variance (ANOVA) procedures testing differences of fish species richness between monitoring surveys

Site	Reef Station	Mean Spp. Richness in 2019 (# Spp30m^2)	Mean Spp Richness Study Period (# Spp/30m^2)	Standard Deviation Study Period	ANOVA p-value
Rincon	TRES05	8.8	9.40	2.75	0.812
	TRES10	13.8	13.55	4.22	< 0.0001
	TRES20	17.8	21.08	4.97	0.013
Mayaguez	TOUR10	16.0	18.66	4.27	< 0.0001
	TOUR20	17.8	19.78	4.20	< 0.0001
	TOUR30	17.8	18.35	4.00	< 0.0001
Cabo Rojo	GALLA5	11.6	11.60	1.93	0.556
	RESU10	12.2	13.20	2.43	0.123
Parguera	MLUN05	12.6	14.87	2.45	0.010
	MLUN10	14.8	13.67	1.84	0.060
	BOYA20	18.2	17.47	2.26	0.707
Guánica	AURO05	14.2	13.00	2.83	0.259
	CORA10	14.4	17.58	4.61	< 0.0001
	BERI20	14.8	13.13	2.97	0.015
Guayanilla	MLAN05	12.4	10.93	2.52	0.046
	MLAN10	13.4	12.20	1.78	0.022
	MLAN20	11.6	13.20	2.60	0.248
Ponce	WEST10	21.0	20.67	103.64	< 0.0001
	DERR20	18.2	20.07	4.13	< 0.0001
Salinas	RATO05	13.2	12.53	2.85	0.042
	CARI10	16.8	14.80	2.46	< 0.0001

XII. Definitions

Active Search Census (ASEC)- Time-sensitive visual fish census approach to target large elusive commercially important species.

Black corals – sessile-benthic marine animals in the Class Anthozoa, Order Antipatharia that grow as flexible vertically projected aposymbiotic 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 (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).

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

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

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.

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”.

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

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

XIII. Acronyms and abbreviations

ANOVA – Analisis of variance

ASEC – Active Search Census.

CARICOMP – Caribbean Coastal Marine Productivity

CCA- Crustose coralline algae

CRCP – Coral Reef Conservation Program

CI – Confidence Interval

CL- Carapace Length

FL- Fork Length

NOAA – National Oceanic and Admospheric Administration

PRDNER – Puerto Rico Natural and Environmental Resources

PRCRMP – Puerto Rico Coral Reef Monitoring Program

TPM- terminal phase male

Abbreviations

cm- centimeters

e.g.- for example

et al.- other authors

Sp. – Species