**Final Report**


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

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## I. Executive Summary

The 2017-18 coral reef monitoring event of the PRCRMP included 21 reef stations, with two (2) new baseline characterizations, 15 first monitoring surveys and four (4) recurring monitoring surveys. A total of 1,210 hard coral colonies distributed into 33 scleractinians and one hydrocoral species were intercepted by transects. Octocorals were represented by 13 species, including two encrusting and 11 vertically projected taxa. Other benthic categories included algae (13 taxa), sponges (52 spp), zoanthids (2 spp) and abiotic.

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 out 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 16.1%. 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*).

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, LPEN), and reductions of brown fleshy algae associated with corresponding increments of cyanobacteria (CROS10). It is unclear if such changes have been 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*. Increments of reef substrate cover by brown fleshy algae (*Dictyota sp.* + *Lobophora sp*.) and/or cyanobacteria were measured from 15 out of the 19 reefs for which comparative data was available. The larger increments of cover by fleshy algae were measured at ESPE10 (2,494%), LPEN05 (2,470%), DIAB05 (1,006%), PALN20 (714%), and RODR05 (447%). The larger increments of cover by cyanobacteria were measured at CROS10 (684%), DIAB05 (662%), MEXT10 (284%), and PALN20 (130%). Such increments may have been supported by nutrient enrichment and/or increased availability of reef primary substrates associated with the pass of huricanes and/or other extreme event(s) of wave action.

A total of 97 fish species distributed into 32 families were identified within belt-transects in 2018. Statistically significant differences of fish density between monitoring surveys were evidenced in 14 out of the 19 reef stations with available data for comparative analyses. In all cases a decline of fish density was noted during 2018 relative to previous survey(s). Differences were mostly associated with marked reductions of a previously numerically dominant species, the Masked Goby (*Coryphopterus personatus*). A general decline of fish species richness that was statistically significant for seven reef stations also contributed to the generalized pattern of reduced fish densities from reefs surveyed. It is here suggested that the declining pattern of fish density and species richness was directly related to the inability of small fishes to withstand the potentially extreme surge and abrasion effects caused by hurricanes and/or another wave storm events.

Presence of post settlement juvenile through adult stages, particularly of Stoplight, Redband and Bucktooth Parrotfishes (*Sparisoma viride, S. aurofrenatum, S. radians*) were observed on most reefs surveyed evidencing the recruitment and residential habitat function of these neritic reefs for these ecologically and commercially important species. Several very large (> 38 cm) Red Hinds (*Epinephelus guttatus*) were observed. This may be an indication of population stock recuperation for this commercially important species. Nevertheless, absence or very low abundance of large demersal fishes prevailed on the reef stations surveyed during 2018. Motile-megabenthic invertebrates were represented by 11 species within belt-transects. Long-Spined Urchin (*Diadema antillarum*) was observed from seven reef stations during the 2018 monitoring survey with peak densities at CIBU05 in Vega Baja (mean = 10.2 Ind/30m$^2$).

## II. **Resumen**

El evento de monitoreo 2017-18 del PRCRMP incluye 21 estaciones arrecifales, con dos (2) caracterizaciones iniciales, 15 primeros monitoreos y cuatro (4) monitoreos recurrentes. Un total de 1,210 colonias de corales pétreos distribuidas entre 33 especies escleractinias y un hidrocoral fueron interceptadas en los transectos estudiados. Los octocorales estuvieron representados por 13 especies, incluyendo dos (2) incrustantes y 11 de proyección vertical. Otras categorías bénticas incluyen algas bénticas (13 taxones), esponjas (52 spp), zoantidios (2 spp) y fondos abióticos.

Diferencias estadísticamente significativas en la cobertura total de corales pétreos medida entre los eventos de caracterización inicial de 2016 y este evento de monitoreo 2018 fueron detectadas para las estaciones en Isla de Vieques (ESPE10 y CANJ20) e Isla de Culebra (LPEN05), y para las estaciones en Isla Desecheo (BOTE15 y BOTE20) entre el evento de monitoreo del 2015 y el 2018. En todos los casos, las diferencias se relacionan a reducciones de la cobertura total de corales pétreos medidas en el evento de 2018, relativo a evento(s) previo(s). La reducción promedio en porcentajes de cobertura total de corales pétreos para el conjunto de 17 estaciones arrecifales para los cuales habían eventos previos de monitoreo fue de 16.1%. Las mayores reduciones fueron medidas para las estaciones LPEN05 en Isla de Culebra (-51.7%), DIAB05 en Fajardo (-38.9%) y BOTE20 en Isla Desecheo (-33.7%). Las especies *Porites porites* y *Orbicella annularis* mostraron las mayores reducciones en cobertura, pero otras especies también contribuyeron a la reducción general en porcentajes de cobertura por corales pétreos.

Diferencias estadísticamente significativas en densidades de colonias de octocorales (gorgónios) fueron medidas en cuatro estaciones arrecifales (e.g. LPEN05, DAKI20, PALN20, MEXT10), todas las cuales exhibieron reducciones en densidades durante el monitoreo de 2018. Las reducciones en cobertura de corales pétreos y octocorales se relacionan a desprendimientos y rupturas mecánicas de colonias aparentemente provocadas por los efectos abrasivos y las corrientes extremas de resaca que pudieron haber prevalecido durante el paso de los Huracanes Irma y Maria en septiembre 2017 y/u otro evento extremo de marejadas impactando las costas norte y oeste de Puerto Rico en marzo 2018, previo a nuestros trabajos de monitoreo. La prevalencia promedio de enfermedades en corales pétreos para las 21 estaciones arrecifales estudiadas fue de 5.3%, resultado de 64 colonias aparentemente enfermas de un total de 1,210 interceptadas por transectos. Aunque este estudio de monitoreo no estuvo enfocado en la evaluación comprensiva de enfermedades en corales, la presencia de multiples manchas negras en colonias de coral (particularmente *Siderastrea siderea*) sugieren que la enfermedad pudiera ser diagnosticada como el “Síndrome de Manchas Negras” (Dark-spot Syndrome).

Cambios en la contribución relativa de componentes taxonómicos a la cobertura total de algas bénticas fueron observados en ESPE10, LPEN05 y CROS10. Para estas estaciones se observaron reducciones marcadas en la cobertura promedio del alga roja crustosa *Ramicrusta sp*. como resultado del

sobrecrecimiento por algas carnosas pardas y rojas (ESPE10, LPEN05). Además, se observaron reducciones en la cobertura promedio de algas pardas carnosas asociadas con aumentos en cobertura de cianobacterias (CROS10). Es incierto al presente si estos cambios fueron influenciados por efectos físicos asociadas a las marejadas, o si forman parte de un proceso dinámico relacionado a la sucesión y/o competencia entre algas bénticas por espacios de crecimiento en los arrecifes estudiados. Diferencias estadísticamente significativas en la composición taxonómica de la cobertura de algas bénticas, que incluyeron desplazamiento de las predominantes "algas de alfombra" (turf algae) por algas Peysonnelidas crustosas (mayormente *Ramicrusta sp*), se evidenciaron durante el monitoreo del 2016 en las estaciones arrecifales de Isla de Vieques (CANJ20, ESPE10). No empece a la reducción en cobertura relativa al monitoreo del 2016, la cobertura de algas rojas crustosas prevaleció como el grupo taxonómico dominante en términos de cobertura del sustrato arrecifal para las estaciones de Isla de Vieques (CANJ20, ESPE10), y otras estaciones arrecifales estudiadas de la costa Este en Fajardo (PALT10, DIAB05) e Isla de Culebra (CROS10, LPEN05) durante el monitoreo de 2018. Sin embargo, las estaciones arrecifales de la costa Oeste estudiadas a profundidades similares (MEXT20, MEXT10, RODR05, GUAN20, NEGR05, NEGR10, BOTE20, BOTE15), al igual que las estaciones mesofóticas (CANO30, SECO 30) mostraron ensamblajes de algas bénticas dominados fuertemente por "algas de alfombra" o por algas párdas carnosas, con aportaciones relativamente menores de *Ramicrusta sp*. y otras algas rojas crustosas a la cobertura total.

Aumentos sustanciales en la cobertura de algas pardas carnosas (*Dictyota sp. + Lobophora sp*.) y/o cianobacterias fueron medidos en 15 de las 19 estaciones arrecifales para los cuales existen datos comparativos. Los mayores aumentos en algas pardas carnosas fueron medidos para ESPE10 (2,494%), LPEN05 (2,470%), DIAB05 (1,006%), PALN20 (714%) y RODR05 (447%). Los mayores aumentos en cianobacteria fueron medidos para CROS (684%), DIAB05 (662%), MEXT10 (284%) y PALN20 (130%). Estos aumentos pudieran relacionarse al enriquecimiento de nutrientes y/o a un aumento en sustratos primarios. Ambos factores associados a los efectos del paso de los huracanes y/u otros eventos de lluvias y/o marejadas excepcionales.

Un total de 97 especies de peces distribuídos entre 32 familias fueron identificados dentro de las áreas de transectos de correa estudiados en el monitoreo del 2018. Diferencias estadísticamente significativas de las densidades de peces entre monitoreos anuales fueron encontradas para 14 de las 19 estaciones arrecifales para las cuales existen datos comparativos. En todos los casos prevaleció una reducción en la densidad de peces durante el monitoreo del 2018 relativa a monitoreos previos. Las diferencias se relacionaron principalmente a disminuciones marcadas o ausencia de una especie numericamente dominante en monitoreos previos, el pez góbido, *Coryphopterus personatus*. Una reducción general de la riqueza de especies, la cual resultó estadísticamente significativa para siete estaciones arrecifales, también contribuyó al patrón generalizado de disminución en las densidades de peces en el monitoreo del 2018. Se sugiere que este patrón generalizado de reducción en densidades de peces está directamente

relacionado a la dificultad o incapacidad de peces pequeños para tolerar los efectos potencialmente extremos de abrasión y corrientes de resaca causados por los huracanes y/u otros eventos de marejadas extraordinarias, con impactos negativos para estas poblaciones locales.

La presencia de varias especies de peces loros en estados post-larvales, juveniles y adultos, particularmente *Sparisoma viride, S. aurofrenatum* y *S. radians* se observaron en la mayoría de las estaciones arrecifales, reflejando la función de estos sistemas como hábitats de reclutamiento y residenciales para estas especies de gran importancia ecológica y comercial. Varios individuos de la cabrilla (*Epinephelus guttatus*) de gran tamaño (>38 cm) fueron observados. Esto pudiera ser indicativo de una recuperación de la población de esta especie importante para la pesca comercial. Sin embargo, la ausencia o baja abundancia de peces demersales de gran tamaño prevaleció en las estaciones arrecifales estudiadas en 2018, lo cual constituye un indicio de la falta de integridad ecológica en estos sistemas arrecifales y requiere atención prioritaria de manejo.

Invertebrados mótiles megabénticos estuvieron representados por 11 especies dentro de los transectos de correa estudiados. El erizo *Diadema antillarum* fue observado en siete estaciones durante este monitoreo 2018 con densidades máximas en CIBU05 en Vega Baja (promedio = 10.2 Ind/30m$^2$).

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## III. Introduction

The Puerto Rico Coral Reef Monitoring Program (PRCRMP) sponsored by NOAA/CRCP and administered by the PR Department of Natural and Environmental Resources (PRDNER) started in 1999 with baseline characterizations of percent substrate cover by sessile-benthic categories and fish and motile megabenthic invertebrate taxonomic composition and densities determinations at a series of reefs located within PRDNER designated Natural Reserves. A total of 83 baseline characterizations have been performed throughout the duration of the monitoring program to date, including reef stations without the Natural Reserve designation. 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 present 2018 survey includes quantitative baseline characterizations at two reef stations located in coastal areas of Fajardo (Las Cabezas) and San Juan (Dominos).

The monitoring sampling program is designed for the analyses of temporal changes (between monitoring surveys) of the coral reef community in relation to water turbidity and light penetration gradients associated with depth, distance from shore and location relative to major river discharges. Such gradients have been shown to be relevant drivers of the spatial and temporal variability patterns of mortality, shifts of community structure and recuperation by corals and the coral reef community during the monitoring program (Esteves, 2013; Garcia-Sais et al., 2017). This sampling design also aims to detect, and discriminate changes of live coral cover associated with local environmental disturbances versus regional (climatological/oceanographic) factors to support and facilitate management actions regarding coral reef ecological health.

During September 2017, two category 4 - 5 hurricanes (Irma and Maria) impacted the Puertorrican coastlines. Irma impacted the northeast coastline with hurricane force winds, 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. During March 2018, an extreme event of exceptionally high waves associated with winter storm Riley in the North Atlantic impacted the north and west coast of Puerto Rico with potentially deleterious implications to shallow coral reef systems within the insular shelf. This monitoring event analyzes changes of coral reef community structure potentially driven by the mechanical forces of these extreme events, among other factors.

The fish component of the coral reef monitoring program was expanded in 2016 to provide a larger survey area and include size-frequency distributions of commercially important species, with particular attention to herbivore fish assemblages that are considered critically important in regulation of algal cover in the shallow (neritic) reefs surveyed. The species-specific size frequency observations contribute a new fisheries-independent data source that can used to support stock assessment analyses for the data-limited Puertorrican commercial fishery. Fish surveys are based on 10 m and 20 m long belt-transects centered along the line transects used for the sessile-benthic community characterizations allowing discrimination of density-dependent versus density-independent factors regulating fish community structure (Esteves, 2013).

This final report corresponding to the 2017-18 coral reef monitoring event includes percent cover data for sessile-benthic substrate categories and taxonomic composition, density and size-frequency data for the fish and motile megabenthic invertebrate components on a total of 21 reef stations surveyed from sites in Mayaguez, Cabo Rojo, Isla Desecheo, Fajardo, Isla de Culebra, Isla de Vieques, San Juan, and Vega Baja. Complete data sets for all reef sites can be found in previous annual monitoring reports prepared for the DNER by García-Sais et al. (2001a, 2001b, 2001c, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2012, 2014, 2015, 2016, 2017). Such information contributes to an existing network of U.S. coral reef monitoring sites sponsored by NOAA. A comprehensive data base with all quantitative transect data on percent cover by benthic categories, and taxonomic composition, density, and size frequency distribution of fishes from the 21 reef stations surveyed in 2018 has been prepared and is available in an electronic format.

## IV. **Coral Reef Monitoring Program Research Synthesis**

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 Cayo Coral in Guanica and West Reef of Isla Caja de Muerto in Ponce exhibited a moderate, yet statistically significant decline of live coral cover between their baseline survey and 2005. During a similar time-frame, reefs in the oceanic islands of Mona and Desecheo, as well as shelf-edge reefs in Mayaguez and Ponce, and reefs all around Vieques (Garcia-Sais et al. 2000, 2001d, 2004) maintained stable live coral cover.

A drastic decline of live coral cover was measured from reefs in Desecheo, Ponce, and Mayaguez 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 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 Derrumbadero in Ponce, Tourmaline Reef in Mayaguez and those in Vieques were the most severely affected.

A pattern of lower coral mortality with increasing depth, from 20 to 30 m was observed from Tourmaline Reef stations in Mayaguez, Puerto Canoas/Puerto Botes Reef stations in Isla Desecheo and the Canjilones and Boya Esperanza Reefs in Vieques. The Tres Palmas Reef system in Rincon, dominated in terms of substrate cover by Elkhorn coral, *Acropora palmata* at depths of 1-3 m, and by *M. cavernosa* at 10 m did not show any statistically significant decline of live coral cover. Reefs located near the coastline and/or influenced by estuarine conditions (El Palo, Resuellos) 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 the 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 have been measured from impacted reefs in subsequent monitoring surveys until 2017 (Garcia-Sais et al., 2017, 2016 and references therein). 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. A positive relationship was observed between coral cover increments at reefs impacted by bleaching and Kd 490, suggesting that in most instances, estuarine conditions influencing reefs near the coast provided more favorable conditions for coral recuperation of reef substrate cover. Since 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. An exception to this trend was observed at the

fringing *Acropora palmata* reef of Tres Palmas in Rincon, which presented a declining trend of live coral cover associated with a widespread infection of what appears to be “white pox”, a disease also known as “patchy necrosis” (Garcia-Sais et al. 2008). Despite the infection prevalence to the present date, the Tres Palmas fringing reef keeps thriving with active growth.

Phase shifts in the taxonomic composition of reef substrate cover by live corals have been noted for Tourmaline Reef 10m (Mayaguez) and at Puerto Botes Reef 15 m and 20m (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.

A total of 210 species of diurnal, non-cryptic fish species have been identified during the coral reef monitoring program at the reefs surveyed. Fish populations have presented in general 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 the Tres Palmas, Gallardo, Maria Langa, Ratones, Caribes, and Cayo Aurora reef systems. 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 reefs studied (Garcia-Sais, 2010; Esteves, 2013).

## V. Taxonomic updates

### A. 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 and Knowlton 1994) were reported as *Montastrea annularis* complex. The taxonomic classification of these species has since changed, and they are now under genus *Orbicella* (Huang et al., 2014). A decision has been made, from this point on (this volume), to report the data on reef substrate cover by the three separate sibling species. The three species will be reported under the more recently accepted "binomial name" of *Orbicella annularis, O. faveolata* and *O. franksi* (Ellis and 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 more 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.

### B. Fish

Beginning with this 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 recently 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).

## VI. Approach and Methodology

### A. Sampling Design

The 2017-18 PRCRMP monitoring event consisted of surveys at 21 reef stations, including baseline characterizations at two reef stations located in San Juan and Fajardo, and the first monitoring surveys of 12 reef stations from sites in Mayaguez, Cabo Rojo, Fajardo, and Isla de Culebra. Continued monitoring surveys were also performed at seven reef stations from Isla Desecheo, Isla de Vieques and Vega Baja to complete the 21-coral reef station plan for 2017-18. The locations of reef stations in the PRCRMP, highlighting those surveyed during the present 2017-18 event are shown in Figure 1. Geographic coordinates 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 systems included in this monitoring program are all shallower than 40m, and thus lie within the Caribbean Surface Mixed Layer (CSML) water mass with pycnocline at depths that vary seasonally 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 organic (phytoplankton) and inorganic (sediments) sources. Coral reefs located to the east of the mainland, such as those in the Cordillera de Fajardo (Palomino, Palominito, Diablo), and the islands of Vieques (Canjilones, Boya Esperanza and El Seco) and Culebra (Dakity, Carlos Rosario, Luis Pena) are at the head of the current and receive minor estuarine influence from land masses. Likewise, reefs located in the oceanic Isla Desecheo are also far from estuarine influences. Shelf-edge reefs associated with the mainland are intermediate across this inshore-offshore gradient and their estuarine influence is geographically 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 reefs located across inshore-offshore gradients, vertically (depth) stratified sampling stations on several

reef sites, and at similar depths on the east, west and south coasts to enable comparative analyses between depths and across natural turbidity gradients associated with riverine influences and island mass effects.

**Table 1.** Geographic coordinates and mean depths of coral reef stations included in the 2017-18 coral reef monitoring survey. Coordinates from transect 3 at the start rebar marker. Mean depths are from measurements at the start rebar markers of the five transects

| Site | Reef Stations | Station Code | Mean Depth (meters) | Latitude (degrees N) | Longitude (degrees W) |
|---|---|---|---|---|---|
| **Isla Desecheo** | Puerto Botes 15 | BOTE15 | 14.2 | 18.38200 | 67.48833 |
| | Puerto Botes 20 | BOTE20 | 17.4 | 18.38158 | 67.48860 |
| | Puerto Canoas 30 | CANO30 | 25.1 | 18.37747 | 67.48400 |
| **Mayaguez** | Bajo Rodriguez 5 | RODR05 | 1.7 | 18.18927 | 67.19185 |
| | Manchas Exteriores 10 | MEXT10 | 6.8 | 18.23353 | 67.20057 |
| | Manchas Exteriores 20 | MEXT20 | 16.4 | 18.23350 | 67.20092 |
| **Cabo Rojo** | El Negro 5 | NEGR05 | 6.1 | 18.14658 | 67.24758 |
| | El Negro 10 | NEGR10 | 10.1 | 18.14653 | 67.24803 |
| | Guanajibo 20 | GUAN20 | 16.3 | 18.17202 | 67.25297 |
| **Fajardo** | Cayo Diablo 5 | DIAB05 | 5.2 | 18.36033 | 65.53089 |
| | Palominito 10 | PALT10 | 10.7 | 18.33537 | 65.56555 |
| | Palomino 20 | PALN20 | 15.7 | 18.35466 | 65.56711 |
| | Las Cabezas 5 | CABE05 | 6.0 | 18.38544 | 65.62972 |
| **Culebra** | Luis Pena 5 | LPEN05 | 4.3 | 18.30493 | 65.32772 |
| | Carlos Rosario 10 | CROS10 | 9.1 | 18.32779 | 65.33200 |
| | Dakiti 20 | DAKI20 | 18.4 | 18.27587 | 65.27730 |
| **Vieques** | Boya Esperanza 10 | ESPE10 | 7.9 | 18.08057 | 65.48794 |
| | Canjilones 20 | CANJ20 | 15.1 | 18.08964 | 65.59008 |
| | El Seco 30 | SECO30 | 35.2 | 18.13869 | 65.19714 |
| **Vega Baja** | Cibuco 5 | CIBU05 | 3.0 | 18.48910 | 66.37418 |
| **San Juan** | Dominos 05 | DOMI05 | 1.5 | 18.46222 | 66.05170 |

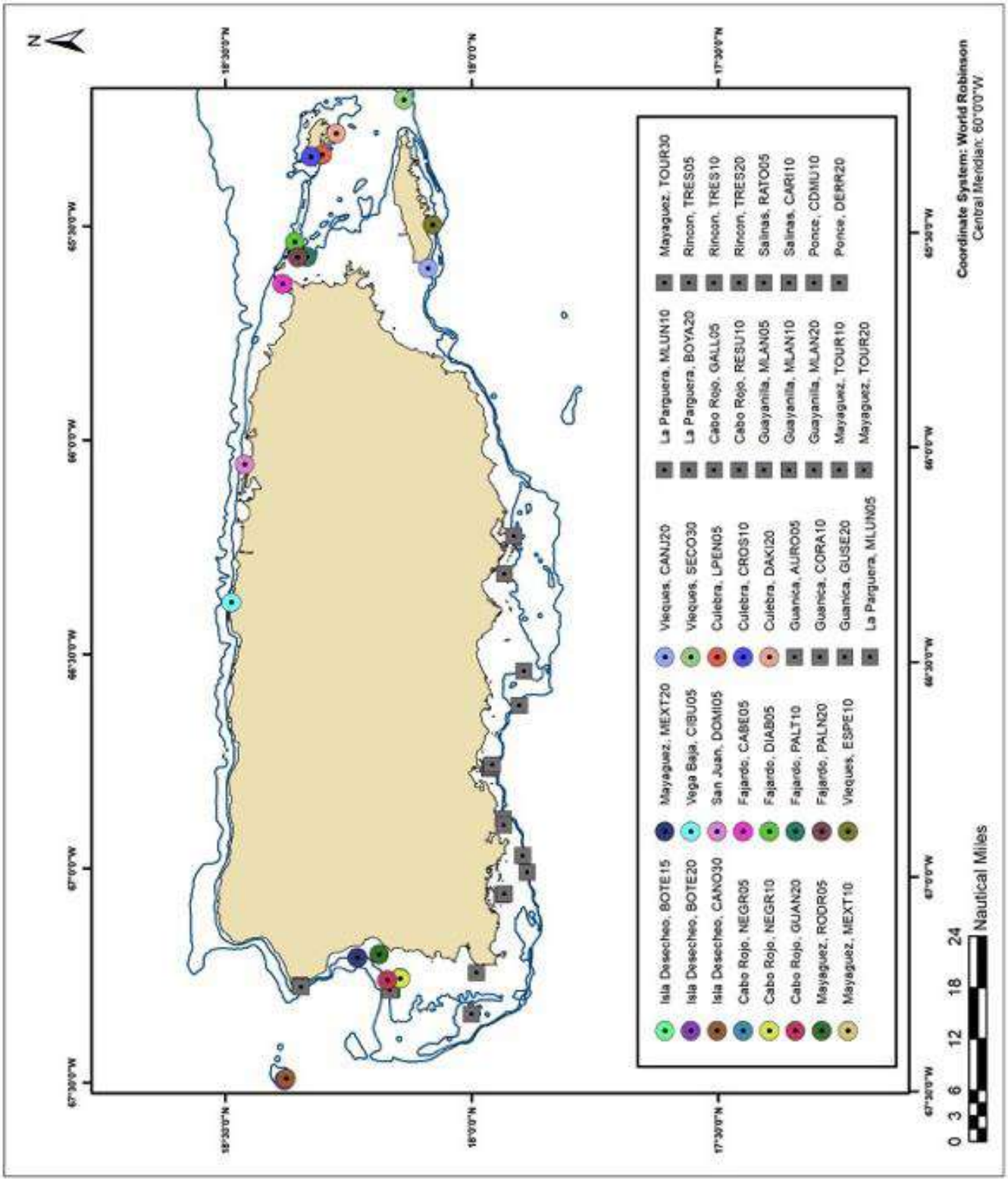



**Figure 1.** Map showing location of reef stations included in the Puerto Rico Coral Reef Monitoring Program (PRCRMP). Round - colored marks represent reef stations surveyed during the 2017-18 event.

### B. Sessile-benthic Reef Communities

At each reef station, a set of five 10 m long transects were surveyed. 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 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 then removed upon survey completion.

An effort is in progress to provide individual geographic coordinates for all transects surveyed at each reef station in the monitoring program. A time-synchronized GPS was placed inside a zip-lock bag and installed on a floater with a weighted line and allowed to collect geographic position data from each transect center point for five minutes with data records every 10 seconds. The mode of all position data points was selected as the most accurate georeference for 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 had links of 1.42 cm long, marked every 10 links for facilitation of counting underwater. The exact position of the chain was guided by a series of steel nails set into available hard (abiotic) substrates along transects. 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.

Determinations of % substrate cover by sessile-benthic categories at El Seco Reef (SECO30) in Isla de Vieques were obtained from Coral Point Count (CPC) analyses of digital photographic images due to the reduced bottom-times associated with SCUBA diving at mesophotic depths (>30 m). A total of 10 non-overlapping photos of the reef substrate were photographed over the permanent transect's reference line. A set of 25 random points was overlaid on each photo frame and sessile-benthic categories under each point classified following the same criteria used with

the chain-link method. The total number of points over each substrate category were divided by the total number of points applied to the images analyzed for each transect to obtain the data on percent cover by each substrate category.

Octocorals, with the exception of encrusting forms (e.g. *Erythropodium caribaeorum, Briareum asbestinum*) were counted as number of colonies intercepted per 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 calculated based on the total number of diseased colonies divided by the total number of colonies intercepted by the five transect array at each reef 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, the protocol is to re-install the marker in the same substrate position that it was before without any alteration of the transect path. In cases where the reef structure supporting the rebar was physically displaced, overturned, or collapsed, then the transect path was identified using the remaining marker and the sequence of existing nails and continued until a 10 m 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.

Temporal variations (between surveys) of the percent reef substrate cover by hard corals and octocorals were tested by Repeated Measurements Analysis of Variance (ANOVA) procedures on real values (un-transformed data) at each reef station. ANOVA p-values of $< 0.05$ were used to establish significant differences between surveys. For data sets with more than two annual surveys, the 95% confidence intervals calculated from the MS error of the ANOVA test were included to enable pair-way comparisons of annual survey data.

### C. Reef Fishes and Motile Megabenthic Invertebrates

Demersal diurnal non-cryptic reef fish populations and motile megabenthic invertebrates were surveyed by sets of five 10 m long by 3 m wide (30 $m^2$) belt-transects centered along the reference line of transects used for sessile-benthic characterizations at each reef station. Transect width was marked with flagging tape stretched and tied to weights on both transect ends. Each transect was surveyed for 12 - 15 minutes depending on the complexity of the fish community on each transect. The initial one or two minutes were dedicated to detection of elusive and/or transitory species that swim away of the "belt-transect" area as soon as they detect a diver (e.g. snappers, jacks, mackerels, groupers, hogfish, large parrotfishes, etc.). During the next three to 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 enter 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 four to six minutes in order to count demersal and territorial fishes (e.g. *Stegastes spp*, *Gramma loreto*, squirrelfishes, etc.) that remain within the transect area. The last two or three minutes were dedicated to counting the small gobies (e.g. *Coryphopterus spp*., *Elacatinus* spp.) associated with coral heads on both sides of transects.

Upon completion of the 10 meter belt-transect survey the diver swam along the same depth and physiographic reef zone for an extra 10 meters to identify fishes and megabenthic invertebrates of commercial value (snappers, groupers, hogfishes, barracuda, mackerels, sharks, lobsters and queen conch) and/or fish species that are considered important reef herbivores (parrotfishes, doctorfishes). For each fish individual within belt-transects, a visual total length (TL) estimate (in cm) was recorded. The cephalothorax length (measurement from tip of rostrum to end of thorax), also known as carapace length (CL) in cm was used to report the size of lobsters (*Panulirus spp., Scyllarides sp*) within belt-transects. Queen Conch (*Strombus gigas*) length was reported as the total (diagonal) shell length in cm. Precision of length estimates allowed discrimination between new recruits, small juveniles, juveniles, adult and large adult size classes.

Temporal variations (between surveys at each reef) of 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.

# VII. Quantitative Monitoring of Coral Reef Stations: Results and Analyses

## A. Mayaguez Coral Reef Systems

### 1.0 Manchas Exteriores 20 m, Mayaguez (MEXT20)

### 1.1 Physical Description

Manchas Exteriores Reef is located approximately 1.5 NM northwest of Punta Algarrobo, at the entrance of Mayaguez Bay (Figure 2). The reef runs roughly parallel to the shoreline and sits at the north end of a series of elongated fringing reefs that include Manchas Interiores and Manchas Grandes off the Mayaguez coastline. Manchas Exteriores 20 (MEXT20) rises from a sandy-silt bottom with scattered patch reefs at a depth of approximately 31 m to a depth of approximately 2 m. Permanent transects were set along the 16 – 17 m depth contour at the base of an abrupt reef slope that breaks into small patch reef structures. Transect arrangement followed a string pattern with one starting next to the end of the previous. The baseline survey was performed in July 2016. Panoramic images of MEXT20 are shown in Photo Album 1.

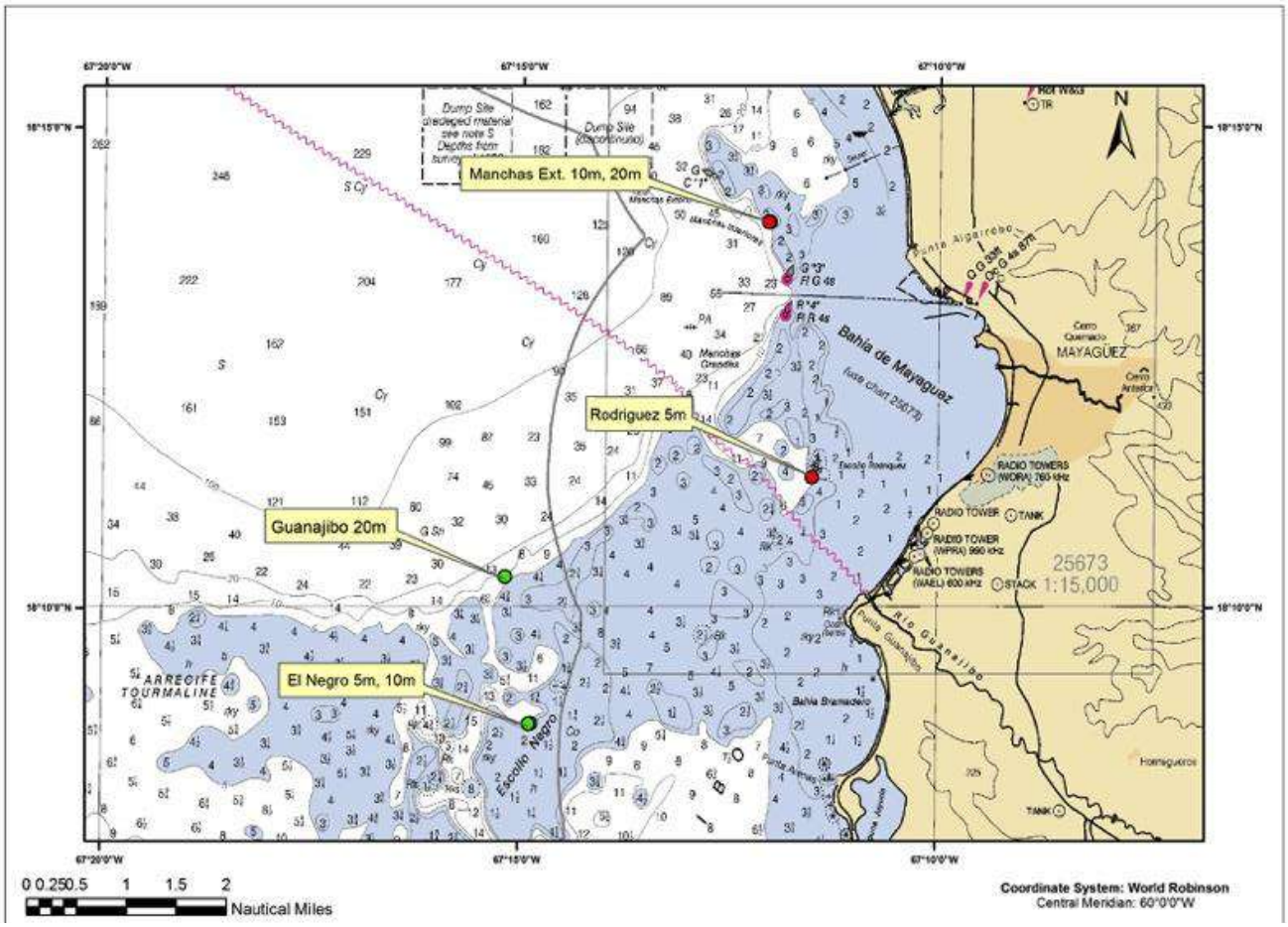



**Figure 2.** Location of monitoring stations in the Mayaguez and Cabo Rojo coral reef systems**.**

### 1.2 Sessile-benthic Reef Community

Reef substrate cover at MEXT20 was dominated by benthic algae with a mean substrate cover of 45.81%. The Y-Twig fleshy brown macroalga, *Dictyota sp*. and turf algae (mixed assemblage) were predomidant in all five transects surveyed with mean substrate cover of 22.91% and 21.77%, respectively. Red crustose coralline algae, including encrusting species of *Peyssonnelia sp*. and other unidentified species (CCA) were also present in all transects, but with a relatively lower combined mean of 1.13% (Table 2). A thick layer of fine sediments was noted overlying the algal turf and intermixed with the fleshy algae, indicative of a major event of sediment resuspension, probably associated with the pass of Hurricane Maria in September 2017. Cyanobacterial patches were present in all transects with a mean cover of 4.15%, which is above the 2018 PRCRMP average of 3.22%.

A total of 12 scleractinian coral species were intercepted by linear transects with a mean substrate cover of 17.81% (range: 13.04 – 21.76%). The combined cover by Lettuce corals (*Agaricia spp*) and star corals (*Orbicella spp*) represented 75.6% of the total cover by scleractinian corals within the surveyed reef section at MEXT20 (Figure 4). *Agaricia lamarki* was the dominant species among lettuce corals with a mean cover of 3.94%, whereas *O. faveolata* and *O. franksi* contributed a mean cover of 3.83% and 3.75%, respectively. Six out of the 67 coral colonies intercepted by transects showed signs of disease for a mean prevalence of 7.5%. Affected colonies with signs of recent tissue necrosis and/or dark spots included *Agaricia lamarki* and *S. siderea*.

Octocorals were present in all transects, but in low density (1.4 colonies/ transect), relative to the PRCRMP mean of 7.2 colonies/ transect and consistent with our previous observations in 2016 (Garcia-Sais et al., 2016). The encrusting species, *Briareum asbestinum* and *Erythropodium caribaeorum* were the most prominent octocorals with a combined mean cover of 2.25% (Table 2). A total of 11 species of sponges, mostly represented by small encrusting individuals were present along transects with a combined substrate cover of 1.17%. The sponge assemblage was highly variable between transects with only one species present in four transects (*Scopalina ruetzleri*) and another four species present in two transects. Reef overhangs associated with ledges of Boulder Star Coral, *Orbicella faveolata* and *O. franski* were the main components of the abiotic category with a mean cover of 16.58%, representing 67.9% of the total abiotic cover (Table 2). Large colonies of the aforementioned corals conferred MEXT20 a relatively high rugosity that averaged 5.20 m. Sand pockets were also present in all transects with a mean cover of 6.31%.

| **Table 2**. MEXT20. Percent cover by sessile-benthic categories at Manchas Exteriores Reef 20m, Mayaguez. Survey Date: 4/22/18 | | | | | | |
|---|---|---|---|---|---|---|
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | **16.7** | **16.1** | **16.7** | **16.7** | **15.8** | **16.40** |
| Rugosity (m) | 6.42 | 3.85 | 4.71 | 5.71 | 5.32 | **5.20** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 21.65 | 16.58 | 13.23 | 13.90 | 17.55 | **16.58** |
| Sand | 7.67 | 3.74 | 7.61 | 4.28 | 8.23 | **6.31** |
| Gap | | 1.82 | | 3.57 | 0.91 | **1.26** |
| Sand and rubble | | 1.42 | | | | **0.28** |
| **Total Abiotic** | **29.33** | **23.56** | **20.84** | **21.75** | **26.69** | **24.43** |
| **Benthic Algae** | | | | | | |
| *Dictyota* spp. | 8.01 | 41.25 | 23.03 | 22.99 | 19.28 | **22.91** |
| Turf algae (mixed) | 35.89 | 10.41 | 22.45 | 22.91 | 17.18 | **21.77** |
| Peyssonnelid (mixed) | 0.43 | 1.52 | 0.76 | 1.78 | 0.27 | **0.95** |
| CCA (mixed) | | | | 0.89 | | **0.18** |
| **Total Benthic Algae** | **44.33** | **53.18** | **46.25** | **48.57** | **36.74** | **45.81** |
| **Cyanobacteria** | **2.73** | **3.74** | **2.19** | **2.67** | **9.41** | **4.15** |
| **Hard Coral** | | | | | | |
| *Agaricia lamarcki* | 12.19 | | 4.47 | 2.14 | 0.91 | **3.94** |
| *Orbicella faveolata* | 1.19 | 7.58 | | 1.96 | 8.41 | **3.83** |
| *Orbicella franksi* | | | 9.23 | 6.51 | 3.02 | **3.75** |
| *Agaricia agaricites* | 1.36 | 2.12 | 2.00 | 0.89 | 2.74 | **1.82** |
| *Siderastrea siderea* | 2.05 | 2.02 | 0.19 | | 3.38 | **1.53** |
| *Montastraea cavernosa* | | 0.91 | 2.38 | 2.05 | | **1.07** |
| *Stephanocoenia intersepta* | 0.60 | 0.40 | 0.67 | 0.89 | 1.55 | **0.82** |
| *Madracis decactis* | 0.60 | | | 0.36 | 1.19 | **0.43** |
| *Porites astreoides* | | | 0.57 | 0.62 | | **0.24** |
| *Meandrina meandrites* | | | | 0.45 | 0.55 | **0.20** |
| *Agaricia fragilis* | 0.60 | | | | | **0.12** |
| *Scolymia cubensis* | | | 0.29 | | | **0.06** |
| **Total Hard Coral** | **18.58** | **13.04** | **19.79** | **15.86** | **21.76** | **17.81** |
| **# CoralColonies /Transect** | **14** | **9** | **16** | **15** | **13** | **13.40** |
| **# Diseased Coral Colonies** | **3** | **0** | **1** | **0** | **2** | |
| **Octocoral** | | | | | | |
| *Briareum asbestinum* | | 1.72 | 5.52 | 1.87 | 0.46 | **1.91** |
| *Erythropodium caribaeorum* | | 0.51 | | 1.16 | | **0.33** |
| **Total Octocoral** | **0.0** | **2.22** | **5.52** | **3.03** | **0.46** | **2.25** |
| **# Gorgonians/Transect** | **3** | **2** | **0** | **1** | **1** | **1.40** |
| **Sponges** | | | | | | |
| *Scopalina ruetzleri* | 0.17 | | 0.38 | 0.45 | 0.27 | **0.25** |
| *Petrosia sp.* | | 1.01 | | | | **0.20** |
| *Ircinia brown sp.* | 0.77 | | | | | **0.15** |
| *Plakortis sp.* | 0.34 | | | 0.27 | | **0.12** |
| *Amphimedon compressa* | 0.26 | 0.20 | | | | **0.09** |
| *Aiocholoria crassa* | | | | 0.45 | | **0.09** |
| *Niphates erecta* | | | 0.19 | 0.18 | | **0.07** |
| *Iotrochota birotulata* | | | 0.29 | | | **0.06** |
| *Monanchora arbuscula* | | | | 0.09 | 0.18 | **0.05** |
| *Biemna caribea* | | | | 0.18 | | **0.04** |
| *Chondrilla caribbaea* | 0.17 | | | | | **0.03** |
| **Total Sponges** | **1.71** | **1.21** | **0.86** | **1.60** | **0.46** | **1.17** |

Figure 3 presents the annual variations of mean substrate cover by sessile-benthic categories at MEXT20 during the 2016 baseline and the present 2018 monitoring survey. The relative composition of major benthic categories remained constant between surveys showing a strong dominance of reef substrate cover by benthic algae and a prominent occurrence of abiotic categories. Variations of the total benthic algae between surveys was small (5.9%), but a marked shift of relative contributions by taxonomic components to the total cover by benthic algae was noted. A 90.6% increase of brown fleshy algae (*Dictyota sp.)* was measured along with a corresponding decline of cover by turf algae. Also, cyanobacterial cover increased 53.7%, from 2.70% in 2016 to 4.15% in 2018. Since MEXT20 is in close proximity to major rivers that discharge into Mayaguez Bay, such increments of cover by fleshy algae and cyanobacteria may have been driven by nutrient inputs, particularly during and after the extreme rainfall associated with the pass of Hurricanes Irma and Maria. Increased availability of primary substrates produced by coral breakage may have also prompted cyanobacterial growth.

Reef substrate cover by live corals declined 12.7%, from 20.40% in 2016 to 17.81% in 2018, although not statistically significant. The most prominent reduction of reef substrate cover by hard corals (16.2%) was associated with boulder star corals, *Orbicella spp.* (Figure 4), but smaller reductions of cover were also measured for lettuce corals, *Agaricia lamarki*, *A. agaricites* and Great Star Coral, *Montastrea cavernosa*. Two overturned coral colonies (*Siderastrea siderea, Agaricia sp*) outside transect lines were observed. It is possible that the prevailing laminar and/or encrusting growth of scleractinian corals combined with the moderate depth served to protect the coral community at MEXT20.

### 1.3 Fishes and Motile Megabenthic Invertebrates

A total of 42 species of fish were identified within belt-transects from a mean depth of 16.4 m at MEXT20 (Table 3). Mean density was 63.8 Ind/transect (range: 40 – 100 Ind/transect) with a mean richness of 17.6 species per transect. The Masked Goby, *Coryphopterus personatus* was the dominant species present with a mean density of 22.0 Ind/transect, representing 34.5% of the total individuals. This is a small schooling zooplanktivore species that swarms over large coral colonies and below ledges. Despite the marked numerical dominance by zooplanktivore species driven by the combined abundance of *Coryphopterus personatus* and *Chromis cyanea*, the fish community structure at MEXT20 presented a well-balanced assemblage of trophic groups. Herbivores were represented by five species of parrotfishes (Scaridae), three species of doctorfishes (Acanthuridae) and two damselfishes. Small opportunistic carnivores were

represented by three species of hamlets and two small groupers (Serranidae), two species of gobies (Gobiidae), one puffer (Tetraodontidae), two grunts (Haemulidae), and one croaker (Sciaenidae). Medium sized piscivores included at least four species of snappers (Lutjanidae) and one grouper (Red Hind - Serranidae). The size-frequency distribution of commercially important fishes and the larger reef herbivores is presented in Table 4. Consistent with the previous survey, doctorfishes (Acanthuridae) were only observed as adults. Snappers (*Lutjanus synagris, L. jocu, L. apodus. Ocyurus chrysurus*) were present as late juveniles and adults. One very large Red Hind (*Epinephelus guttatus*) was observed. This estimated 46 cm (TL) Red Hind is the largest reported in the monitoring program thus far. Several parrotfishes, such as the Stoplight, Princess and Redband (*Sparisoma viride, S. aurofrenatum, Scarus taeniopterus*, respectively) were present across most of their size range, including the recruitment juvenile stages (Table 4). One small hogfish (26 cm) was observed outside transects. Motile megabenthic invertebrates were not observed within belt-transect areas (Table 3), but three adult Spiny Lobsters (*Panulirus argus*) were present outside transects.

Statistically significant differences of fish density within belt-transects resulted between the 2016 baseline and the present 2018 monitoring survey (ANOVA, $P < 0.0001$, see Appendix 3). Fish density declined 5.7-fold, from a mean of 367.6 Ind/transect during 2016 to 63.8 Ind/transect during the present survey (Figure 5). The driver of the marked density difference between surveys was the decline of Masked Goby (*Coryphopterus personatus*). The annual abundance fluctuations of *C. personatus* represent the main source of variability in the community structure of reef stations surveyed throughout the PRCRMP. Variations appear to be influenced by density independent factors, such as its recruitment dynamics and the influence of physical forcing variables, such as strong wave and surge energy (Esteves, 2013). We hypothesize that the extraordinary surge forces acting upon this reef during Hurricane Maria may have displaced large portions of the Masked Goby population with advective force (flushed) during the event. While statistically significant annual differences (between surveys) have been recorded before, this is certainly one of the largest recorded during the monitoring program. It is also relevant to consider that whereas variations of Masked Goby density were high, implications on the overall reef fish biomass may be relatively low, given the very small size of this species. Variations of fish species richness were insignificant (ANOVA, $p = 0.463$, Appendix 3), indicative that major disruptions of the fish community structure at MEXT20 were not observed.

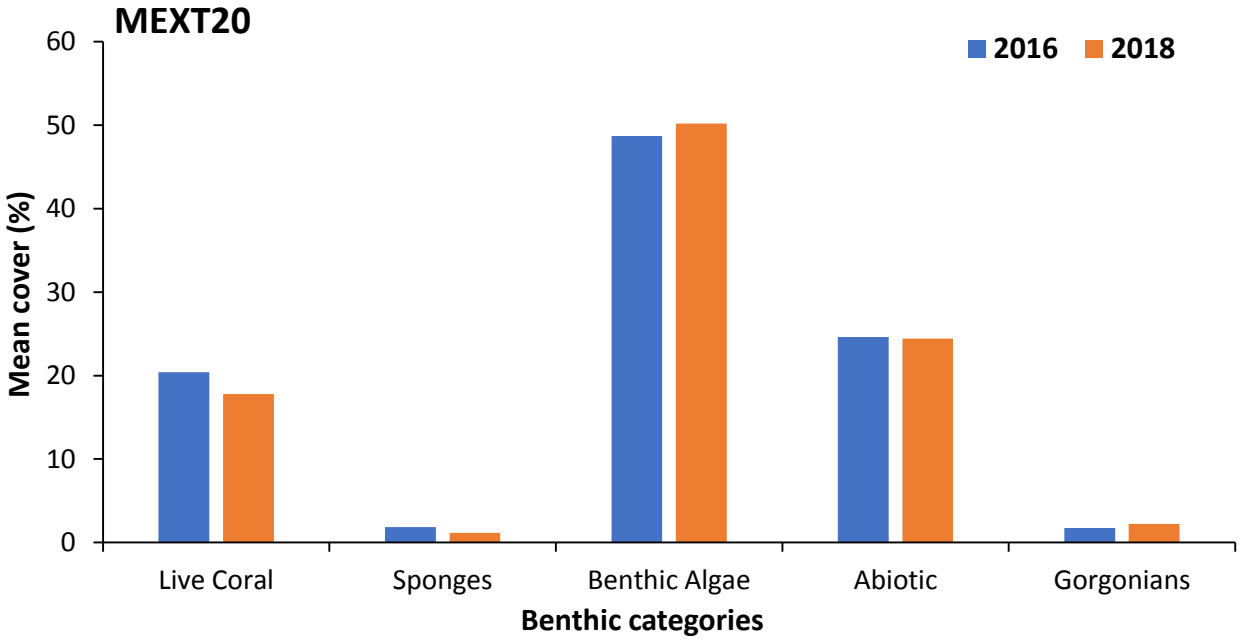



**Figure 3.** MEXT20. Annual variations of mean reef substrate cover by benthic categories at Manchas Exteriores Reef 20m, Mayaguez, 2016 – 2018

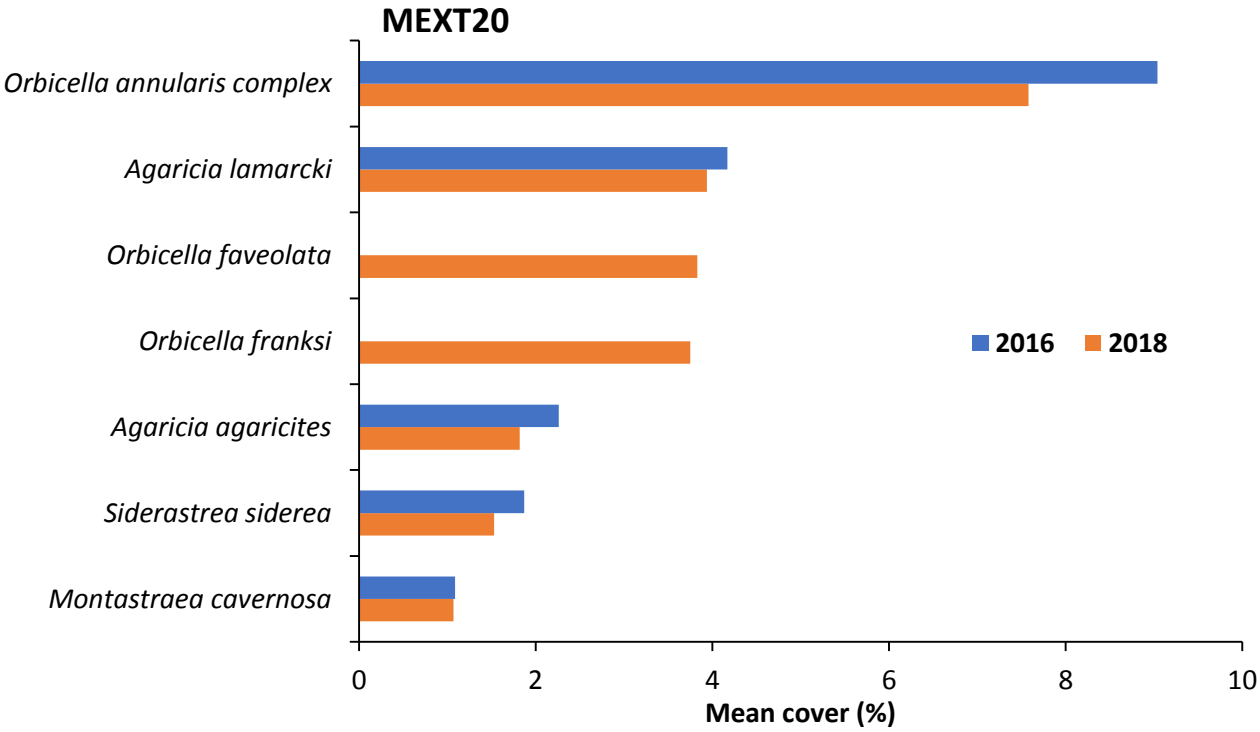



**Figure 4.** MEXT20. Annual variations of mean reef substrate cover by the main coral species intercepted by transects at Manchas Exteriores Reef 20m, Mayaguez, 2016 – 2018

**Table 3.** MEXT20. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Manchas Exteriores Reef 20m Mayaguez, April 2018

| Mean Depth: 16.4 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***FISH SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Coryphopterus personatus* | Masked Goby | 5 | 48 | 31 | 14 | 12 | **22.0** |
| *Chromis cyanea* | Blue Chromis | 15 | 18 | 6 | 22 | 9 | **14.0** |
| *Scarus taeniopterus* | Princess Parrotfish | 3 | 9 | | | 5 | **3.4** |
| *Thalassoma bifassiatum* | Bluehead Wrasse | 1 | 2 | 5 | 3 | 6 | **3.4** |
| *Stegastes leucostictus* | Beau Gregory | 1 | 4 | 2 | 5 | 4 | **3.2** |
| *Coryphopterus lipernes* | Peppermint Goby | 3 | 2 | 3 | 1 | 6 | **3.0** |
| *Stegastes partitus* | Bicolor Damselfish | 2 | 3 | 1 | 2 | 1 | **1.8** |
| *Gramma loreto* | Fairy Basslet | 1 | 1 | | 2 | 2 | **1.2** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | 2 | 1 | 1 | 1 | **1.0** |
| *Elacatinus evelynae* | Sharknose Goby | | 1 | 2 | 1 | 1 | **1.0** |
| *Canthigaster rostrata* | Caribbean Puffer | 2 | | 1 | 1 | | **0.8** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | 2 | | 1 | 1 | **0.8** |
| *Chromis multilineata* | Brown Chromis | | | 1 | | 3 | **0.8** |
| *Acanthurus tractus* | Five-band Surgeonfish | | 2 | 1 | | | **0.6** |
| *Cephalopholis cruentata* | Graysby | 1 | | | 1 | 1 | **0.6** |
| *Sparisoma viride* | Stoplight Parrotfish | | | | 2 | 1 | **0.6** |
| *Haemulon flavolineatum* | French Grunt | | 1 | | 1 | | **0.4** |
| *Halichoeres garnoti* | Yellow-head Wrasse | | 2 | | | | **0.4** |
| *Haemulon aurolineatum* | Tomtate | | 1 | | | 1 | **0.4** |
| *Holocentrus rufus* | Squirelfish | | 1 | | 1 | 1 | **0.4** |
| *Hypoplectrus niger* | Black Hamlet | | | 2 | 1 | | **0.4** |
| *Hypoplectrus unicolor* | Butter Hamlet | 2 | | | | | **0.4** |
| *Acanthurus chirurgus* | Doctorfish | 1 | | | | | **0.2** |
| *Cephalopholis fulva* | Coney | | | 1 | | | **0.2** |
| *Pomacanthus arcuatus* | Grey Angelfish | | | 1 | | | **0.2** |
| *Scarus iseri* | Striped Parrotfish | | | | 1 | | **0.2** |
| *Sparisoma radians* | Bucktooth Parrotfish | | | | | 1 | **0.2** |
| *Anisotremus virginicua* | Porkfish | | | 1 | | | **0.2** |
| *Bodianus rufus* | Spanish Hogfish | 1 | | | | | **0.2** |
| *Chaetodon aculeatus* | Longnose Butterflyfish | 1 | | | | | **0.2** |
| *Coryphopterus sp.* | Goby | | | 1 | | | **0.2** |
| *Gerres cinereus* | Yellowfin Mojarra | | | | | 1 | **0.2** |
| *Hypoplectrus puella* | Barred Hamlet | | | | | 1 | **0.2** |
| *Lutjanus jocu* | Dog Snapper | | | | | 1 | **0.2** |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1 | | | | | **0.2** |
| *Odontoscion dentex* | Reef Croaker | | | | | 1 | **0.2** |
| *Pomacanthus ciliaris* | French Angelfish | | | | | 1 | **0.2** |
| *Pseudupeneus maculatus* | Spotted Goatfish | | 1 | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | **40** | **100** | **60** | **58** | **61** | **63.8** |
| | **TOTAL SPECIES** | **15** | **17** | **16** | **18** | **22** | **17.6** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| none | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 0 | 0 | 0 | **0** |
| | **TOTAL SPECIES** | 0 | 0 | 0 | 0 | 0 | **0** |

**Table 4.** MEXT20. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 20 x 3 m belt-transects at Manchas Exteriores Reef 20m, Mayaguez, April 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 16.4 m | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | | | 1 - 12 | | 2 - 14 |
| | | | | 1 - 14 | | |
| *Acanthurus chirurgus* | Doctorfish | 2 - 14 | | | | |
| *Acanthurus coeruleus* | Blue Tang | 1 - 14 | | | | |
| *Cephalopholis cruentata* | Graysby | 1 - 12 | | | 1 - 7 | 1 - 7 |
| *Cephalopholis fulva* | Coney | | | 1 - 24 | | |
| *Epinephelus guttatus* | Red Hind | | | | 1 - 46 | |
| *Lutjanus apodus* | Schoolmaster | 1 - 30 | | | | |
| *Lutjanus jocu* | Dog Snapper | | | 1 - 17 | | |
| *Lutjanus synagris* | Lane Snaper | | 1 - 26 | | | |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1 - 8 | | | 1 - 12 | |
| *Scarus iseri* | Striped Parrotfish | | | | 1 - 14 | 1 - 14 |
| *Scarus taeniopterus* | Princess Parrotfish | 3 - 14 | 3 - 5 | 3 - 10 | 4 - 7 | |
| | | | 3 - 7 | | 3 - 10 | |
| | | | 1 - 10 | | 1 - 14 | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | 2 - 7 | | 1 - 7 | 1 - 7 |
| | | | 2 - 10 | | | 1 - 10 |
| *Sparisoma radians* | Bucktooth Parrotfish | | | | | 1 - 2 |
| *Sparisoma viride* | Stoplight Parrotfish | 1 - 30 | 1 - 12 | 1 - 12 | 2 - 1 | |
| | | | | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |
| **Outside Transects** | | | | | | |
| *Lachnolaimus maximus* | Hogfish | 1 - 26 | | | | |
| *Panulirus argus* | Spiny Lobster | 1 - 14 | | | | |
| | | 2 - 12 | | | | |
| TL = Fish Total Length (cm) | | | | | | |
| Lobster length is the carapace length in cm | | | | | | |

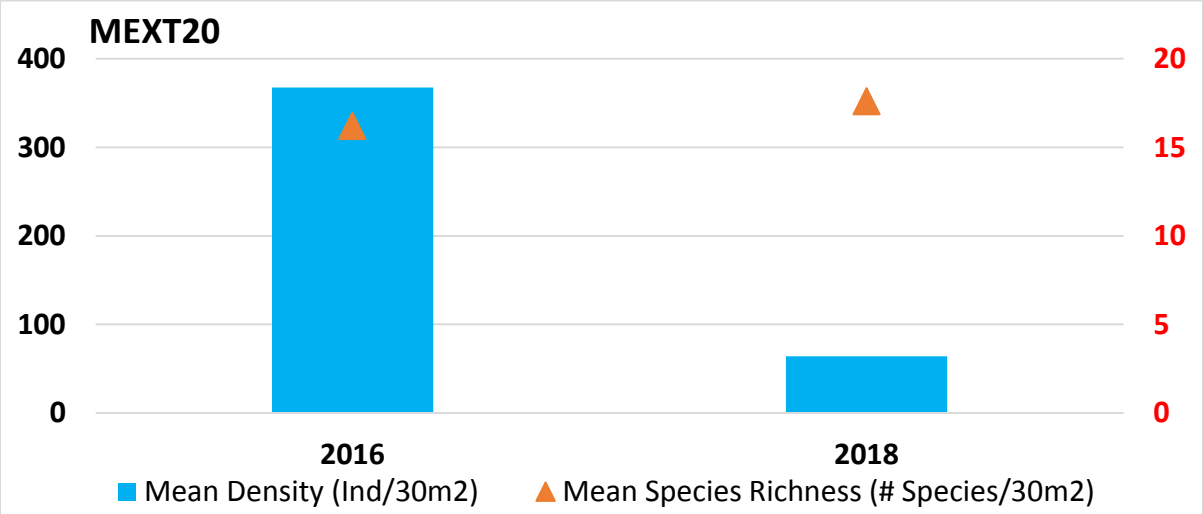



**Figure 5.** Monitoring trends (2016-18) of mean fish density and species richness within 10 x 3m belt-transects at Manchas Exteriores Reef 20m, Mayaguez

**Photo Album 1**

**Manchas Exteriores 20, Mayaguez (MEXT20)**

## 2.0 Manchas Exteriores 10, Mayaguez (MEXT10)

### 2.1 Physical Description

Manchas Exteriores Reef, at a depth of approximately 10m (MEXT10), corresponds to the mid-section of the fore-reef slope. It is a moderately abrupt slope with several narrow steps, one of which was at the 6 -10 m contour where the five permanent transects were established (Figure 2). The baseline survey at MEXT10 was performed on July 2016. Panoramic images of MEXT10 are shown in Photo Album 2.

### 2.2 Sessile-benthic Community

Benthic algae, comprised by turf (mixed assemblage), fleshy brown, and red macroalgae were the dominant biotic category covering reef substrate at MEXT10 with a combined mean cover of 54.59% (Figure 6). Turf algae, a mixed assemblage of short filamentous brown and red algae partially covered by fine sediments was the main component of the benthic algae, with a mean cover of 40.34%, representing 73.8% of the total cover by algae (Table 5). The Y-Twig fleshy brown macroalgae, *Dictyota sp*. was present in all five transects surveyed with a mean cover of 11.93%. Red crustose coralline algae, including *Ramicrusta sp*. among other Peyssonnelid taxa, were present in relatively small patches along four transects with a combined cover of 2.33%. Cyanobacterial patches were present in four transects with a mean cover of 8.06%, second highest among the PRCRMP reef stations surveyed in 2018 (mean: 3.22%).

Stony corals were represented by 13 scleractinian species and one hydrocoral within transects surveyed with a combined mean substrate cover of 25.25% (range: 22.35 – 32.34%). Boulder Star Coral (*Orbicella franksi*) and Mountainous Star Coral (*O. faveolata*) were the dominant species in terms of reef substrate cover with a combined mean of 11.88% (Table 5). Great Star Coral (*Montastrea cavernosa*), Mustard-Hill Coral (*Porites astreoides*), Greater Starlet Coral (*Siderastrea siderea*), Lettuce coral (*Agaricia agaricites*), and Ten-Ray Coral (*Madracis decactis*) were also prominent with colonies intercepted by at least three transects.

With a mean density of 15.2 colonies per transect, large, vertically projected octocorals were the main sessile-invertebrate assemblage contributing habitat complexity at MEXT10. Sea Rods (*Pseudoplexaura spp., Eunicea spp., E. flexuosa*) were the most prominent, but Sea Fans (*Gorgonia ventalina*) and Sea Plumes (*Antillogorgia spp*.) were also present. Encrusting species (*Briareum asbestinum*, *Erythropodium caribaeorum*) combined for a mean substrate cover of 3.36% (Table 5).

| **Table 5**. MEXT10. Percent cover by sessile-benthic categories at Manchas Exteriores Reef 10m, Mayaguez, Survey Date: 4/22/18 | | | | | | |
|---|---|---|---|---|---|---|
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 7.0 | 8.2 | 6.4 | 6.1 | 6.1 | **6.8** |
| Rugosity (m) | 3.76 | 3.34 | 3.06 | 3.52 | 4.07 | **3.55** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 5.90 | 6.72 | 4.82 | 2.59 | 2.49 | **4.50** |
| Rubble and sand | | | | 4.14 | | **0.83** |
| Gap | 0.61 | | | | | **0.12** |
| **Total Abiotic** | **6.51** | **6.72** | **4.82** | **6.73** | **2.49** | **5.45** |
| **Benthic Algae** | | | | | | |
| Turf algae (mixed) | 46.89 | 33.58 | 44.38 | 41.61 | 35.22 | **40.34** |
| *Dictyota* spp. | 12.21 | 13.01 | 15.86 | 9.11 | 9.45 | **11.93** |
| *Ramicrusta* sp. | 2.14 | 3.36 | | 0.83 | | **1.26** |
| CCA (mixed) | 0.31 | 0.31 | | | 3.98 | **0.92** |
| Peyssonnelid (mixed) | 0.20 | 0.52 | | | | **0.15** |
| **Total Benthic Algae** | **61.74** | **50.79** | **60.24** | **51.55** | **48.65** | **54.59** |
| **Cyanobacteria** | **1.93** | **14.90** | **5.57** | **12.01** | **5.87** | **8.06** |
| **Hard Coral** | | | | | | |
| *Orbicella franksi* | 7.83 | 0.63 | | 16.25 | 7.46 | **6.44** |
| *Orbicella faveolata* | 1.22 | 7.45 | 11.15 | | 7.36 | **5.44** |
| *Montastraea cavernosa* | 5.49 | | 4.29 | 1.76 | 8.46 | **4.00** |
| *Porites astreoides* | 4.88 | 3.36 | 5.57 | 1.55 | 3.28 | **3.73** |
| *Siderastrea siderea* | 1.63 | 3.15 | | 2.28 | 2.69 | **1.95** |
| *Agaricia agaricites* | | 2.83 | 1.50 | | 1.09 | **1.09** |
| *Pseudodiploria strigosa* | 2.24 | 0.21 | 1.07 | | 0.20 | **0.74** |
| *Madracis decactis* | 1.22 | 1.36 | | 0.62 | | **0.64** |
| *Dendrogyra cylindrus* | | 2.73 | | | | **0.55** |
| *Stephanocoenia intersepta* | 1.02 | | | | | **0.20** |
| *Millepora alcicornis* | | | | | 0.80 | **0.16** |
| *Agaricia fragilis* | | 0.63 | | | | **0.13** |
| *Orbicella annularis* | | | | | 0.60 | **0.12** |
| *Porites porites* | | | | | 0.40 | **0.08** |
| **Total Hard Coral** | **25.53** | **22.35** | **23.58** | **22.46** | **32.34** | **25.25** |
| **# CoralColonies /Transect** | 19 | 13 | 19 | 11 | 24 | **17.20** |
| **# Diseased Coral Colonies** | 0 | 0 | 0 | 1 | 2 | |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | | 3.99 | 1.93 | | 2.69 | **1.72** |
| *Briareum asbestinum* | 0.41 | 0.73 | 0.86 | 3.11 | 3.08 | **1.64** |
| *Pseudoplexaura* sp. | | | | 0.52 | 0.30 | **0.16** |
| *Eunicea* sp. | 0.71 | | | | | **0.14** |
| *Eunicea flexuosa* | | | | 0.10 | | **0.02** |
| **Total Octocoral** | **1.12** | **4.72** | **2.79** | **3.73** | **6.07** | **3.68** |
| **# Gorgonians/Transect** | **17** | **18** | **14** | **15** | **12** | **15.2** |
| **Sponges** | | | | | | |
| *Xestospongia muta* | | | | | 2.19 | **0.44** |
| *Scopalina ruetzerli* | 0.61 | 0.21 | 0.54 | 0.10 | 0.50 | **0.39** |
| *Amphimedon compressa* | 0.31 | 0.31 | | | 0.90 | **0.30** |
| *Ecytoplasia ferox* | 1.22 | | | | | **0.24** |
| *Iotrochota birotulata* | 0.20 | | 0.75 | | | **0.19** |
| *Cliona varians* | | | 0.21 | | 0.50 | **0.14** |
| *Svenzea zeai* | | | 0.64 | | | **0.13** |
| *Neopetrosia proxima* | | | | 0.52 | | **0.10** |
| *Monanchora arbuscula* | 0.20 | | | 0.31 | | **0.10** |
| *Neopetrosia smooth* sp. | | | | | 0.50 | **0.10** |
| *Niphates erecta* | 0.20 | | | 0.21 | | **0.08** |
| *Aplysina fistularis* | | | 0.21 | | | **0.04** |
| *Aplysina insularis* | | | 0.21 | | | **0.04** |
| *Mycale laevis* | | | 0.21 | | | **0.04** |
| *Chondrilla caribensis* | 0.20 | | | | | **0.04** |
| *Plakortis* sp. | 0.20 | | | | | **0.04** |
| **Total Sponges** | **3.15** | **0.52** | **2.79** | **1.14** | **4.58** | **2.44** |

Three (3) diseased coral colonies with signs of recent tissue necrosis and/or dark spots were observed within transects out of the 70 surveyed at MEXT10 yielding a disease prevalence of 3.5%. These included two *S. siderea* and one *O. franksi* (see Appendix 4). Dark spots on *S. siderea* may be indicative of "dark-spot syndrome".

A total of 16 species of sponges were present along transects with a combined substrate cover of 2.44%. With the exception of one large Basket Sponge, *Xestospongia muta* in transect five, sponges were mostly represented by small encrusting colonies growing intermixed with algal turf and another encrusting biota. *Scopalina ruetzerli* and *Amphimedon compressa* were the most common species, with colonies intercepted by five and three transects, respectively. Abiotic categories presented a mean substrate cover of 5.45% (range: 2.49 – 6.73%). Reef overhangs, largely produced by ledges of Mountainous Star Coral (*Orbicella faveolata*) were the main contribution to the abiotic category with a mean cover of 4.50%, representing 83.3% of the total (Table 5). Reef rugosity averaged 3.5 m influenced by coral growth and erosive shelf features.

Figure 6 presents the variations of benthic community structure between the 2016 baseline and this 2018 monitoring survey at MEXT10. Both the relative composition and the mean percent substrate cover for all major categories remained stable between surveys. A 68% increase of brown fleshy algae (*Dictyota sp.)* was noted within the benthic algae category, along with a corresponding decline of cover by turf algae. Cyanobacterial cover increased 2.8-fold, from 2.10% in 2016 to 8.06% in 2018. Such increments of cover by fleshy algae and cyanobacteria could have been associated with higher nutrients and/or increased availability of primary substrates produced upon coral breakage. Both conditions could have been driven by hurricanes and other extreme events of wave action and rainfall.

The main difference of benthic community structure between the 2016 baseline and the 2018 survey at MEXT10 was the 37.7% reduction in the density of octocorals from 24.4 colonies/transect in 2016 to 15.2 colonies/transect in 2018. The statistically significant decline (ANOVA; p= 0.024) may be related to mechanical detachment caused by extreme surge and abrasion under conditions of high wave energy. Variations of mean (total) live coral cover between surveys was -1.2%. This difference was within sampling variability error and statistically insignificant (ANOVA, p = 0.45, see Appendix 2). Differences of cover by the dominant coral species (Figure 7) show that the *Orbicella spp* assemblage remained virtually constant between surveys.

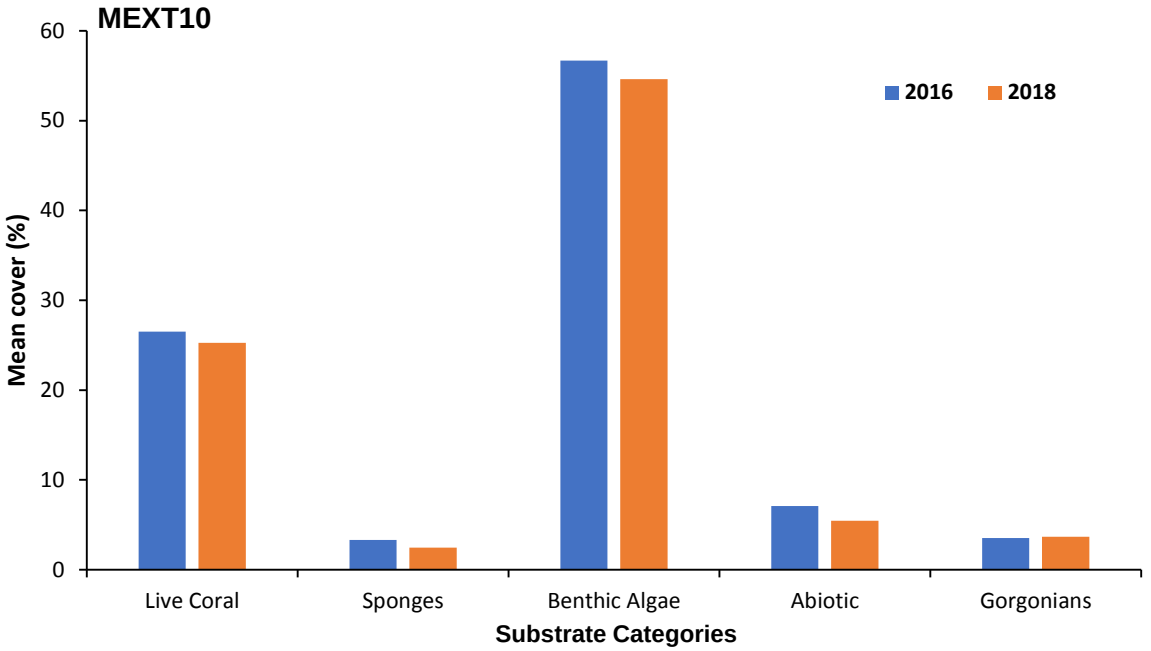



**Figure 6.** MEXT10. Annual variations (2016 – 2018) of mean substrate cover by sessile-benthic categories at Manchas Exteriores Reef 10m, Mayaguez

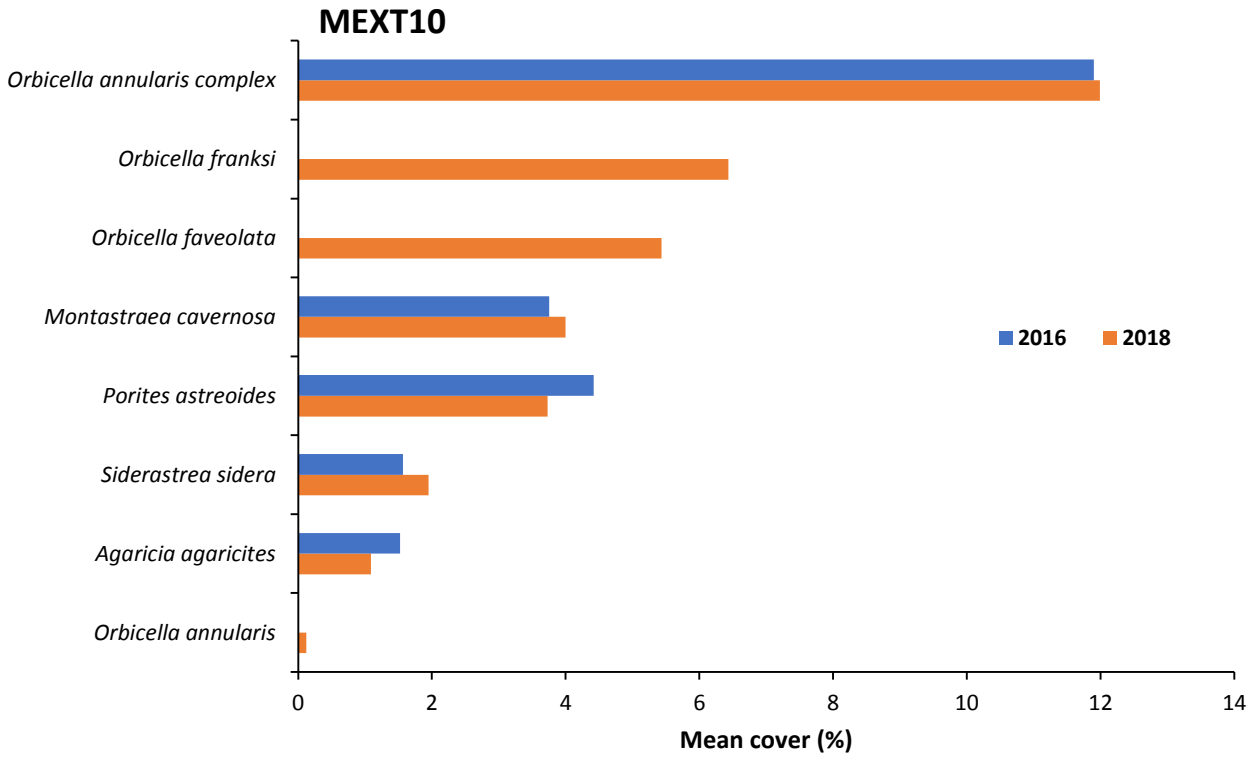



**Figure 7.** MEXT10. Annual variations (2016 – 2018) of mean substrate cover by the main coral species intercepted by transets at Manchas Exteriores Reef 10m, Mayaguez

### 2.3 Fishes and Motile Megabenthic Invertebrates

A total of 36 fish species were identified within belt-transects from a mean depth of 6.8 m at MEXT10 (Table 6). Mean density was 37.2 ind/transect (range: 25 – 55 ind/transect) with a mean richness of 17.0 species per transect. The fish community was numerically dominated by an assemblage of small territorial and transitory residential reef fishes that included the Bicolor and Beaugregory damselfishes (*Stegastes partitus, S. leucostictus*), the Princess and Redband parrotfishes (*Scarus taeniopterus, Sparisoma aurofrenatum*) and the Bluehead Wrasse (*Thalassoma bifasciatum*). Individuals of these resident species were present in all five transects surveyed with a combined mean density of 21.2 ind/transect, representing 57.0% of the total individuals within belt-transects. Other resident species of MEXT10 that were present in at least four out of the five transects included the Yellowhead Wrasse, Blue Chromis, Ocean Surgeon and Striped Parrotfish (Table 6). Sixteen species that were only present in one transect appear to be rare, or present in very low densities at MEXT10.

The trophic structure of the fish community at MEXT10 was numerically dominated by herbivores represented by five species of parrotfishes (Scaridae), four species of damselfishes (Pomacentridae) and three species of doctorfishes (Acanthuridae). Small opportunistic carnivores were also prominent, represented by two species of wrasses (Labridae), two species of hamlets, two squirrelfishes (Holocentridae), one small grouper (Serranidae), one puffer (Tetraodontidae), and one grunt (Haemulidae). Medium-sized piscivores included Red Hinds, Coneys (*Epinephelus guttatus, Cephalopholis fulva)*, and the Lane and Yellowtail Snappers (*Lutjanus synagris, Ocyurus chrysurus*). One Great Barracuda (*Sphyraena barracuda*) was observed outside transects. Zooplanktivores were represented by Blue Chromis and Bicolor Damselfish.

The size-frequency distribution of parrotfishes (Scaridae) and doctorfishes (Acanthuridae) suggests that the reef serves largely as a habitat for juvenile and adult individuals, and the recruitment habitat for Stoplight and Princess Parrotfishes (*Sparisoma viride, Scarus taeniopterus*) (Table 7). Red Hinds, Coneys, Lane and Yellowtail snappers were all present as juvenile and/or adult individuals. A total of seven adult Red Hinds (*E. guttatus*), including individuals out of transects were observed within the general survey area, including a very large specimen of 38 cm. This is the highest number of Red Hind individuals observed within the monitoring program at one reef station. This may be indicative of a recuperation trend for this population after more than 10 years of the fishing closure during their spawning season, or just that this reef is a preferred habitat for Red Hinds and possibly under low fishing pressure.

**Table 6**. MEXT10. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Manchas Exteriores Reef 10m, Mayaguez, April 2018

| Mean Depth: 6.8 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***FISH SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Stegastes partitus* | Bicolor Damselfish | 10 | 3 | 2 | 4 | 6 | **5.0** |
| *Thalassoma bifassiatum* | Bluehead Wrasse | 2 | 14 | | 3 | 5 | **4.8** |
| *Scarus taeniopterus* | Princess Parrotfish | 3 | 8 | 1 | 2 | 6 | **4.0** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 3 | 3 | 4 | 2 | 2 | **2.8** |
| *Stegastes leucostictus* | Beau Gregory | 3 | 3 | 3 | 2 | 2 | **2.6** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 1 | 8 | | 1 | | **2.0** |
| *Myripristis jacobus* | Black-bar Soldierfish | 3 | | 2 | 2 | 2 | **1.8** |
| *Chromis cyanea* | Blue Chromis | 3 | 1 | 1 | 1 | 1 | **1.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | 2 | 1 | 1 | | 2 | **1.2** |
| *Coryphopterus personatus* | Masked Goby | | 1 | 4 | 1 | | **1.2** |
| *Sparisoma viride* | Stoplight Parrotfish | | 4 | | 1 | 1 | **1.2** |
| *Stegastes planifrons* | Three-spot Damselfish | | 1 | 1 | 4 | | **1.2** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | 1 | | 2 | 2 | **1.0** |
| *Scarus iseri* | Striped Parrotfish | 1 | 1 | | 1 | 2 | **1.0** |
| *Elacatinus evelynae* | Sharknose Goby | | 2 | | 1 | 1 | **0.8** |
| *Acanthurus chirurgus* | Doctorfish | 1 | 1 | | | 1 | **0.6** |
| *Canthigaster rostrata* | Caribbean Puffer | | | 1 | | 2 | **0.6** |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1 | | 1 | | 1 | **0.6** |
| *Holocentrus rufus* | Squirelfish | | 1 | | | 1 | **0.4** |
| *Acanthurus coeruleus* | Blue Tang | | 1 | | | | **0.2** |
| *Cephalopholis fulva* | Coney | | | | | 1 | **0.2** |
| *Chaetodon striatus* | Banded Butterflyfish | 1 | | | | | **0.2** |
| *Epinephelus guttatus* | Red Hind | | | | | 1 | **0.2** |
| *Equetus punctatus* | Spotted Drum | | | 1 | | | **0.2** |
| *Haemulon flavolineatum* | French Grunt | | | 1 | | | **0.2** |
| *Hypoplectrus unicolor* | Butter Hamlet | | | | | 1 | **0.2** |
| *Lutjanus synagris* | Lane Snapper | | | 1 | | | **0.2** |
| *Monacanthus tuckeri* | Slender Filefish | | | | 1 | | **0.2** |
| *Pomacanthus arcuatus* | Grey Angelfish | 1 | | | | | **0.2** |
| *Pseudupeneus maculatus* | Spotted Goatfish | | 1 | | | | **0.2** |
| *Serranus tigrinus* | Harlequin Bass | | | | | 1 | **0.2** |
| *Sparisoma radians* | Bucktooth Parrotfish | | | | | 1 | **0.2** |
| *Stegastes adustus* | Dusky Damselfish | | | | 1 | | **0.2** |
| *Stegastes variabilis* | Cocoa Damselfish | | | 1 | | | **0.2** |
| *Hypoplectrus puella* | Barred Hamlet | | | | 1 | | **0.2** |
| | **TOTAL INDIVIDUALS** | **35** | **55** | **25** | **29** | **42** | **37.2** |
| | **TOTAL SPECIES** | **14** | **18** | **15** | **17** | **21** | **17.0** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| none | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 0 | 0 | 0 | **0** |
| | **TOTAL SPECIES** | 0 | 0 | 0 | 0 | 0 | **0** |

Motile megabenthic invertebrates were not observed within 10 x 3 m belt-transects. One Spiny Lobster (*Panulirus argus*) was observed in the extended transects (Table 7).

The 2016-2018 monitoring trends of fish mean density and species richness within belt-transects at MEXT10 are presented in Figure 8. Differences of fish density between the 2016 baseline and the present 2018 monitoring survey were statistically significant (ANOVA, $p < 0.0001$), see Appendix 3). Fish density declined by an order of magnitude, from 137.4 Ind/transect in 2016 to

37.2 Ind/transect in 2018. The difference was largely related to the order of magnitude decline of density by Masked Goby (*Coryphopterus personatus*), which was the numerically dominant species at MEXT10, representing 70% of the total fish density during the 2016 survey. Interannual fluctuations of Masked Goby have been previously recorded in the PRCRMP, but this was the most drastic observed so far. It is possible that such variation was influenced by the strong wave and surge acting to displace small fishes out of their residential habitats on the reef during the pass of hurricanes and/or exceptionally high waves associated with North Atlantic winter swells.

**Table 7.** MEXT10. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 20 x 3 m belt-transects at Manchas Exteriores Reef 10m, Mayaguez, April 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 6.8 m | | **1** | **2** | **3** | **4** | **5** |
| | | | (Ind/60 $m^2$ - TL in cm) | | | |
| ***FISH SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 1 - 5 | 1 - 5 | 2 - 12 | 1 - 10 | 1 - 10 |
| | | 2 - 7 | 1 - 10 | | | 2 - 12 |
| | | 1 - 12 | 1 - 14 | | | |
| *Acanthurus chirurgus* | Doctorfish | 1 - 10 | | | | 1 - 10 |
| *Acanthurus coeruleus* | Blue Tang | | 1 - 14 | | | |
| *Cephalopholis fulva* | Coney | | | 1 - 24 | | 1 - 26 |
| *Epinphelus guttatus* | Red Hind | | | | | 1 - 30 |
| | | | | | | 1 - 38 |
| *Lutjanus synagris* | Lane Snaper | | | 1 - 22 | | |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1 - 5 | | 1 - 12 | | 1 - 10 |
| | | 1 - 7 | | | | |
| *Scarus iseri* | Striped Parrotfish | 1 - 12 | | 1 - 24 | 1 - 7 | |
| | | 1 - 17 | | | 1 - 12 | |
| *Scarus taeniopterus* | Princess Parrotfish | 2 - 7 | 3 - 5 | 1 - 5 | 2 - 7 | 1 - 5 |
| | | 1 - 10 | 4 - 7 | 1 - 7 | | 3 - 7 |
| | | | 2 - 19 | | | 4- 10 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 2 - 7 | 1 - 7 | | 2 - 7 | 1 - 5 |
| | | 2 - 10 | 2 - 10 | | 1 - 10 | 1 - 7 |
| *Sparisoma radians* | Bucktooth Parrotfish | | | | | 1 - 5 |
| *Sparisoma viride* | Stoplight Parrotfish | | 2 - 1 | | 1 - 14 | 1 - 12 |
| | | | 2 - 19 | | 1 - 24 | 1 - 31 |
| | | | 1 - 26 | | | |
| | | | 1 - 31 | | | |
| **Invertebrates** | | | | | | |
| *Panulirus argus* | Spiny Lobster | 1 - 17 | | | | |
| **Out of Transects** | | | | | | |
| *Epinephelus guttatus* | Red Hind | 2 - 38 | | | | |
| | | 2 - 36 | | | | |
| TL = Fish Total Length (cm) | | 1 - 24 | | | | |

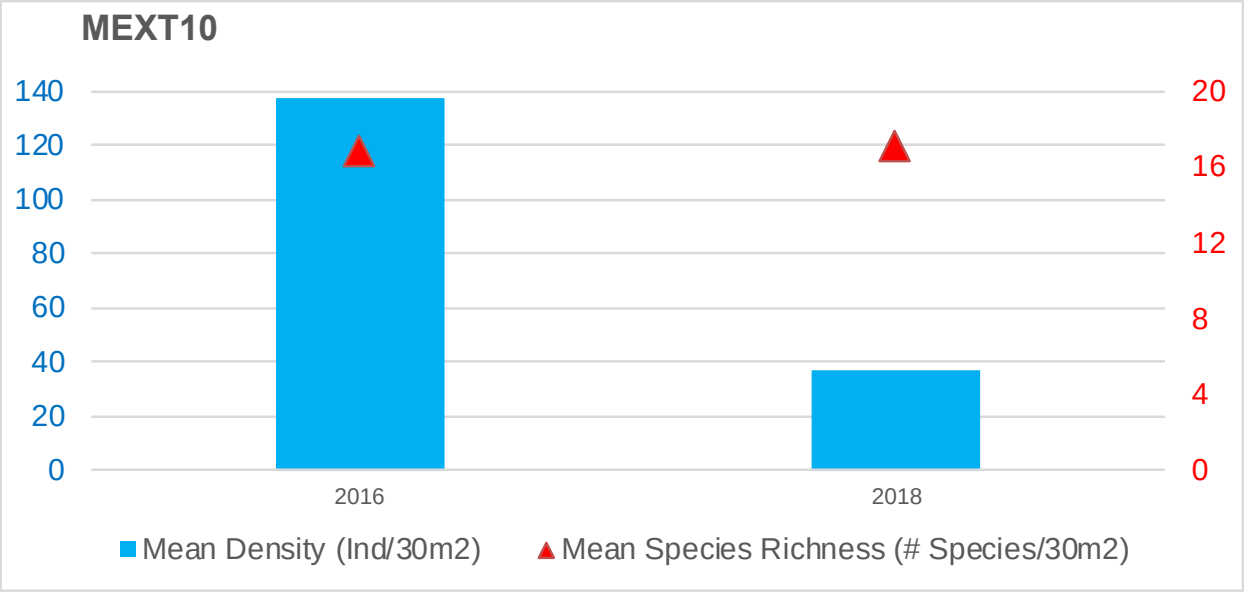



**Figure 8.** Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Manchas Exteriores Reef 10m, Mayaguez

**Photo Album 2**

**Manchas Exteriores 10, Mayaguez (MEXT10)**

## 3.0 Rodriguez Reef 5, Mayaguez (RODR05)

### 3.1 Physical Description

Rodriguez Reef (RODR05), also known as Escollo Rodriguez, is an emergent section of a discontinuous elongated ridge that runs almost parallel to the Mayaguez coastline, approximately 1.5 NM offshore between the mouths of the Yaguez and Guanajibo Rivers (Figure 2). Given the proximity of this reef to major rivers in Mayaguez Bay, it is expected that it is seasonally influenced by estuarine conditions. This reef is a hard ground platform with coral outcrops of moderate to large size growing at depths from 5 m up to the surface. The baseline survey was performed on July 2016. Permanent transects were set within a depth range of 1.5 – 3.0 m at the upper edge of the reef slope. Panoramic images of RODR05 are shown in Photo Album 3.

### 3.2 Sessile-benthic Reef Community

Benthic algae, with a combined mean substrate cover of 76.90% were the dominant biotic category covering reef substrate at RODR05 (Table 8). 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 57.77%, representing 75.2% of the total cover by algae. Y-Twig algae (*Dictyota sp.*) was present in three transects with a mean cover of 18.17%, including one transect where it was found covering 88.0% of the total substrate. Other minor components of the benthic algae with mean cover below 1% included calcareous green macroalgae (*Halimeda sp*.) and an assemblage of red coralline algae (CCA) and unidentified crustose Peyssonnelid taxa. Cyanobacterial films were present in two transects with a very low mean cover of 0.48%, compared to the 2018 PRCRMP average for all reef stations surveyed of 3.22%.

Hard (stony) corals were represented by 13 species intercepted by linear transects, including 12 scleractinians and one hydrocoral with a combined mean substrate cover of 20.22% (Table 8). The Mountainous Star Coral (*Orbicella faveolata*) was the dominant coral in terms of reef substrate cover with a mean of 7.01%, representing 35.0% of the total cover by live corals. Greater Starlet Coral (*Siderastrea siderea*) and Boulder Brain Coral (*Colpophyllia natans*) ranked second and third in substrate cover at RODR05 with mean cover of 4.52% and 3.22%, respectively (Figure 10). Other coral species present in at least three transects included the Mustard-Hill Coral (*Porites astreoides*) and Lettuce Coral (*Agaricia agaricites*) (Table 8). Very large and healthy colonies of Lobed Star Coral (*O. annularis*) were present growing close to the surface at RODR05.

| **Table 8**. RODR05. Percent cover by sessile-benthic categories at Rodriguez Reef 5m, Mayaguez, | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 4/22/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 1.5 | 1.8 | 2.1 | 1.5 | 1.5 | **1.7** |
| Rugosity (m) | 2.63 | 3.12 | 4.46 | 4.31 | 4.74 | **3.85** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 7.54 | 7.04 | 4.36 | 12.72 | 7.98 | **7.93** |
| Rubble and sand | | 10.67 | | | 3.32 | **2.80** |
| Gap | | 3.20 | | 1.96 | | **1.03** |
| **Total Abiotic** | **7.54** | **20.92** | **4.36** | **14.68** | **11.30** | **11.76** |
| **Benthic Algae** | | | | | | |
| Turf algae (mixed) | 65.30 | 56.35 | 72.12 | 38.65 | 56.41 | **57.77** |
| *Dictyota* spp. | | | 0.77 | 88.00 | 2.09 | **18.17** |
| Peyssonnelid (mixed) | 0.55 | 1.07 | 0.39 | | | **0.40** |
| *Halimeda* sp. | | | 0.39 | 1.57 | | **0.39** |
| CCA (mixed) | | | 0.29 | | 0.57 | **0.17** |
| **Total Benthic Algae** | **65.85** | **57.42** | **73.95** | **128.22** | **59.07** | **76.90** |
| **Cyanobacteria** | **0.0** | **1.07** | **1.36** | **0.0** | **0.0** | **0.48** |
| **Hard Coral** | | | | | | |
| *Orbicella faveolata* | 9.09 | | | 11.55 | 14.43 | **7.01** |
| *Siderastrea siderea* | 0.44 | | 2.71 | 14.58 | 4.84 | **4.52** |
| *Colpophyllia natans* | 6.43 | 5.34 | 4.36 | | | **3.22** |
| *Orbicella franksi* | | 7.90 | | 4.60 | | **2.50** |
| *Porites astreoides* | 0.22 | | | 1.08 | 3.42 | **0.94** |
| *Agaricia agaricites* | | 1.39 | 0.58 | 0.39 | 1.04 | **0.68** |
| *Stephanocoenia intersepta* | | | | 2.64 | | **0.53** |
| *Leptoseris cuculatta* | | | 1.45 | | | **0.29** |
| *Porites porites* | 0.78 | | | | | **0.16** |
| *Agaricia lamarcki* | | 0.75 | | | | **0.15** |
| *Millepora alcornis* | 0.55 | | | | | **0.11** |
| *Montastraea cavernosa* | 0.33 | | | | | **0.07** |
| *Siderastrea radians* | | | | 0.20 | | **0.04** |
| **Total Hard Coral** | **17.85** | **15.37** | **9.10** | **35.03** | **23.74** | **20.22** |
| **# CoralColonies /Transect** | **7** | **6** | **11** | **13** | **11** | **9.6** |
| **# Diseased Coral Colonies** | **0** | **0** | **1** | **1** | **4** | |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | | 1.92 | 5.03 | | 2.28 | **1.85** |
| *Briareum asbestinum* | 1.33 | 1.17 | 3.29 | | 0.57 | **1.27** |
| *Eunicea flexuosa* | | 0.21 | | | | **0.04** |
| **Total Octocoral** | **1.33** | **3.31** | **8.33** | **0.00** | **2.85** | **3.16** |
| **# Gorgonians/Transect** | **6** | **10** | **4** | **4** | **3** | **5.4** |
| **Other** | | | | | | |
| *Ricordea florida* | | | | | 0.95 | **0.19** |
| Tunicate | | | 0.29 | | | **0.06** |
| **Total Other** | | | **0.29** | | **0.95** | **0.25** |
| **Sponges** | | | | | | |
| *Chondrilla caribensis* | | 1.17 | 0.58 | 0.29 | 1.52 | **0.71** |
| *Niphates erecta* | 2.11 | 0.32 | 0.19 | | | **0.52** |
| *Spirastrella coccinae* | | | 1.26 | | | **0.25** |
| *Neopetrosia* smooth sp. | 1.11 | | | | | **0.22** |
| *Verongula rigida* | 0.89 | | | | | **0.18** |
| *Amphimedon compressa* | 0.55 | | 0.19 | | | **0.15** |
| *Aplysina insularis* | | | | 0.59 | | **0.12** |
| *Scopalina ruetzleri* | 0.55 | | | | | **0.11** |
| *Mycale laevis* | | 0.21 | 0.19 | | | **0.08** |
| *Ircinia* brown sp. | | | | 0.39 | | **0.08** |
| *Xestospongia muta* | | | | | 0.38 | **0.08** |
| *Aplysina cauliformis* | 0.22 | | | | | **0.04** |
| Sponge unknown | | 0.21 | | | | **0.04** |
| *Neopetrosia proxima* | | | 0.19 | | | **0.04** |
| *Aplysina fistularis* | | | | | 0.19 | **0.04** |
| **Total Sponges** | **5.43** | **1.92** | **2.61** | **1.27** | **2.09** | **2.67** |

The presence of exceptionally large and healthy colonies of Greater Starlet Coral (*S. siderea*) are indicative that the 2005 coral bleaching event had minor, if any degradation effect upon such massive corals at this reef. However, coral disease prevalence in RODR05 was 12.5%, resulting from six (6) diseased colonies out of the 48 intercepted (Appendix 4). The infected colonies included *S. siderea*, *Stephanocoenia intercepta* and *O. faveolata*. Dark spots on *S. siderea* suggest that the disease might be "Dark-Spot Syndrome" but this preliminary observation requires further evaluation. Colonies of Elkhorn and Staghorn Corals (*Acropora palmata, A. cervicornis*) were observed outside transects at RODR05. A total of 48 coral colonies were intercepted in the five-transect framework, including six (6) with apparent disease.

Vertically projected octocorals were present in all five transects surveyed at RODR05 with a mean density of 5.4 colonies/transect. Sea plumes (*Pseudopterogorgia spp*), sea rods (*Eunicea sp*), and sea fans (*Gorgonia ventalina*) were the most common. Encrusting gorgonians (*Erythropodium caribaeorum* and *Briareum asbestinum*) combined for a mean substrate cover of 3.12% (Table 8). Sponges represented by at least 15 species combined for a mean substrate cover of 2.67%. *Chondrilla caribensis* and *Niphates erecta* were the only sponges present in more than two transects and presented the highest reef substrate cover. 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 11.76% (range: 4.36 – 20.92%). Reef overhangs, associated with ledges of Mountainous Star Coral (*Orbicella faveolata*) were the main contribution to the abiotic category with a mean cover of 7.93%, representing 67.2% of the total (Table 8). Sections of coral rubble and sand (2.80%) and gaps (1.03%) also contributed to the total cover by abiotic categories at RODR05. Reef rugosity, largely driven by tall and large *Orbicella* coral outcrops averaged 3.85 m (range: 2.63 – 4.74 m).

Variations of the main benthic categories covering reef substrate at RODR05 between the 2016 baseline and the present 2018 monitoring survey are summarized in Figure 9. Variations of live coral cover were negligible (<1%) and statistically insignificant (ANOVA; p= 0.69, Appendix 2a). The most notable difference between surveys was associated with an increase of cover by benthic algae on abiotic substrates, with the concomitant reduction of substrate cover by the latter. Benthic algae increased 47.6% from 52.1% in 2016 to 76.9% in 2018. The difference was associated with a bloom of fleshy brown Y-Twig algae (*Dictyota sp*.) which increased its mean

substrate cover by 488.0%, from 3.18% in 2016 to 18.7% in 2018. Such difference in fleshy algal cover may be related to an increase in nutrient supply, decline of herbivore grazing pressure, or both. Hurricanes are divergent systems, and as such are known to promote nutrient upwelling. It is here suggested that the pass of Hurricane Maria may have influenced benthic algal growth in RODR05 due to its combined effects on nutrient upwelling and nutrient loadings delivered by rainfall runoff. Since this is the first monitoring survey at RODR05, it is unclear if these fluctuations of reef substrate cover by fleshy algae are normal at this reef.

### 3.3 Fishes and Motile Megabenthic Invertebrates

A total of 29 fish species were observed within belt-transects from a mean depth of 1.7 m at RODR05 (Table 9). Mean density was 30.0 ind/transect (range: 23 – 51 ind/transect) with a mean richness of 8.6 species per transect (range: 4 – 11 species/transect). The Bluehead Wrasse (*Thalassoma bifasciatum*) and the Dusky Damselfish (*Stegastes adustus*) were the numerically dominant species with mean densities of 11.6 and 10.2 ind/transect, respectively. These two species were present in all five transects. Their combined density represented 72.7% of the total individuals. In addition to the aforementioned species, the Three-spot and Cocoa Damselfishes (*S. planifrons, S. variabilis)* were also present in at least three transects. Sixteen fish species were only present in one transect (Table 9).

Consistent with previous characterizations of the reef fish community structure in Puerto Rican reefs (Esteves, 2013), the herbivorous assemblage was prominent at RODR05. Herbivores were represented by five species of parrotfishes (Scaridae), four damselfishes (Pomacentridae) and two doctorfishes (Acanthuridae), with a combined density of 14.8 ind/transect, representative of 49.3% of the total individuals within belt-transects. Small opportunistic carnivores were also prominent, as is typical of shallow reefs with high wave energy. These were represented by two wrasses (Labridae), two hamlets, one small sea bass and one small grouper (Serranidae), two grunts (Haemulidae), one puffer (Tetraodontidae), one mojarra (Gerreidae), and one squirrelfish (Holocentridae) with a mean density of 14.0 ind/transect or 46.7% of the total fish density. Medium sized piscivores included the Bar Jack (*Carangoides ruber*), and Grey, Dog and Yellowtail Snappers (*Lutjanus griseus, L. jocu*, *Ocyurus chrysurus*). Red Hinds (*Epinephelus guttatus*), Great Barracuda (*Sphyraena barracuda*) and Cero Mackerels (*Scomberomorus regalis*) comprised the larger reef predators, but these were observed outside transects. Zooplanktivores were only represented by one Masked Goby.

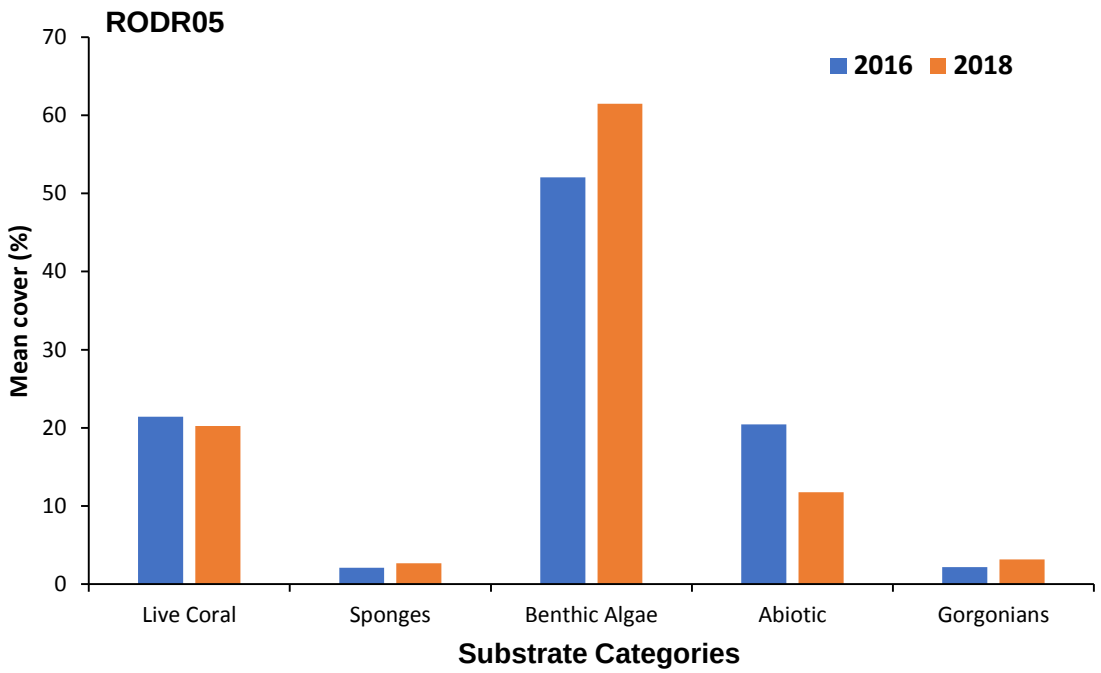



**Figure 9.** RODR05. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Rodriguez Reef 5m, Mayaguez

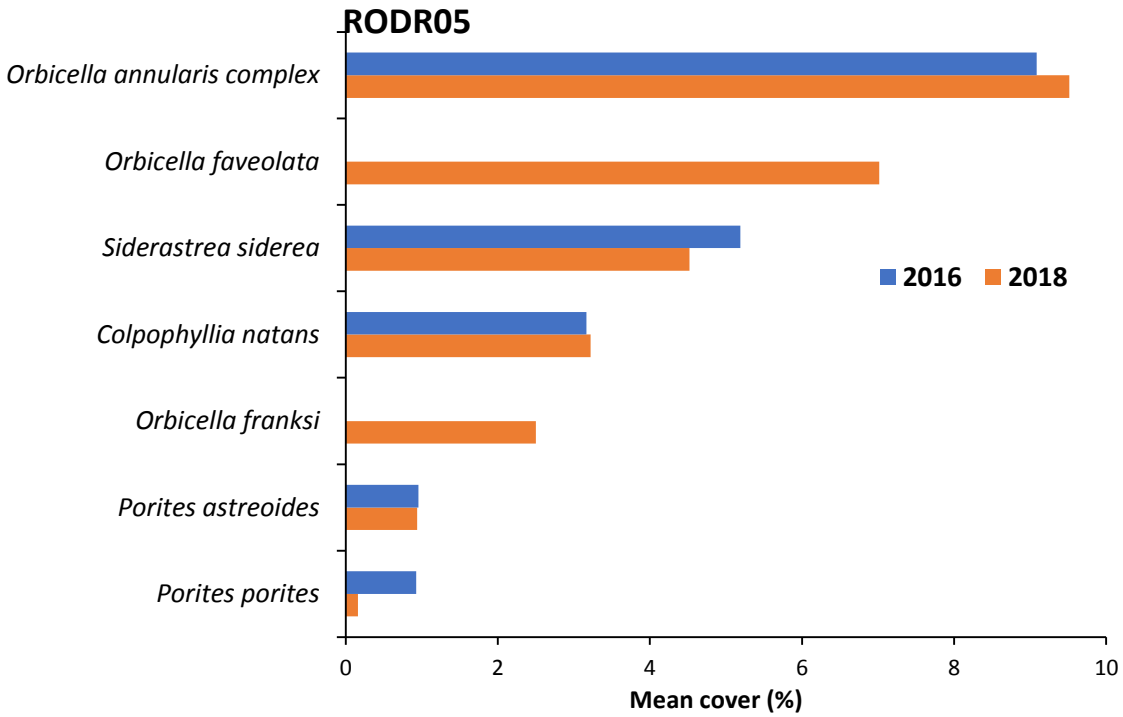



**Figure 10.** RODR05. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at Rodriguez Reef 5m, Mayaguez

| **Table 9.** RODR05. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Rodgriguez Reef 3m, Mayaguez, April 2018 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mean Depth: 1.7 m | | **TRANSECTS** | | | | | |
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Thalassoma bifassiatum* | Bluehead Wrasse | 12 | 9 | 6 | 7 | 24 | **11.6** |
| *Stegastes adustus* | Dusky Damselfish | 10 | 7 | 9 | 11 | 14 | **10.2** |
| *Acanthurus chirurgus* | Doctorfish | | | | | 5 | **1.0** |
| *Stegastes planifrons* | Three-spot Damselfish | | 1 | 2 | 1 | 1 | **1.0** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | 2 | | | 2 | **0.8** |
| *Acanthurus coeruleus* | Blue Tang | | | 1 | | 2 | **0.6** |
| *Stegastes variabilis* | Cocoa Damselfish | | 1 | 1 | | 1 | **0.6** |
| *Abudefduf saxatilis* | Sargent Major | | | 1 | 1 | | **0.4** |
| *Canthigaster rostrata* | Caribbean Puffer | 1 | | | 1 | | **0.4** |
| *Serranus tigrinus* | Harlequin Bass | | 2 | | | | **0.4** |
| *Sparisoma viride* | Stoplight Parrotfish | 1 | 1 | | | | **0.4** |
| *Anisotremus virginicus* | Porkfish | | | | 1 | | **0.2** |
| *Carangoides ruber* | Bar Jack | | 1 | | | | **0.2** |
| *Cephalopholis cruentata* | Graysby | | | | | 1 | **0.2** |
| *Coryphopterus personatus* | Masked Goby | | | 1 | | | **0.2** |
| *Gerres cinereus* | Yellowfin Mojarra | | | | 1 | | **0.2** |
| *Haemulon flavolineatum* | French Grunt | | | | 1 | | **0.2** |
| *Haemulon sciurus* | Bluestripped Grunt | | | | 1 | | **0.2** |
| *Halichoeres radiatus* | Puddinwife | | | | | 1 | **0.2** |
| *Hypoplectrus unicolor* | Butter Hamlet | | | 1 | | | **0.2** |
| *Neoniphon marianus* | Longjaw Squirrelfish | | 1 | | | | **0.2** |
| *Scarus taeniopterus* | Princess Parrotfish | | | 1 | | | **0.2** |
| *Scarus vetula* | Queen Parrotfish | | 1 | | | | **0.2** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | 1 | | | | **0.2** |
| *Hypoplectrus nigricans* | Black Hamlet | | | | 1 | | **0.2** |
| | **TOTAL INDIVIDUALS** | **24** | **27** | **23** | **25** | **51** | **30.0** |
| | **TOTAL SPECIES** | **4** | **11** | **9** | **10** | **9** | **8.6** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Panulirus argus* | Spiny Lobster | | | | 1 | 1 | **0.4** |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 0 | 1 | 1 | **0.4** |
| | **TOTAL SPECIES** | 0 | 0 | 0 | 0 | 0 | **0** |

One juvenile (7 cm) and one adult (15 cm) Spiny Lobsters (*Panulirus argus*) were observed within belt-transects (Table 9).

During the baseline survey of 2016, recruitment juveniles of several parrotfish species (3 cm) were common at RODR05. In contrast, these smaller size classes were absent from belt-transects surveyed in 2018, when mostly late juvenile and adult parrotfishes and doctorfishes were observed (Table 10). Small adult Grey and Dog Snappers (*Lutjanus griseus, L. jocu*) and one

Graysby (*Cephalopholis cruentata*) were also present. One juvenile Yellowtail Snapper (*Ocyurus chrysurus)* was also observed within extended belt-transects and several other juvenile and adults were present outside transects. One juvenile Rainbow Parrotfish (*Scarus guacamaia*) was observed outside transects during this survey.

Variations of fish mean density and species richness between the baseline 2016 and the present 2018 monitoring survey are shown in Figure 11. A marked density decline (- 47%) was measured between the 2016 and the 2018 survey, but this difference was not statistically significant (ANOVA; p = 0. 068; Appendix 3). A proportional decline of species richness was not observed. As previously noted for MEXT20 and MEXT10, differences of fish density between surveys was largely related to the drastic decline of density of Masked Goby (*Coryphopterus personatus*), which may have been displaced under strong surge and wave forces associated with either the pass of Hurricane Maria or the large winter swell that impacted the north and west coastline of Puerto Rico in March 2018. The same argument may be raised to explain the unexpected absence of recruitment juvenile parrotfishes from RODR05, compared with their prominent occurrence during the baseline survey. It is possible that while juvenile and adult individuals may avoid the strong surge and wave forces associated with extreme physical conditions by movements to deeper reef areas their smaller recruitment stages may not be capable to do so and either suffer high mortality rates or become displaced to other reef areas.

**Table 10.** RODR05. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 20 x 3 m belt-transects at Rodriguez Reef 3m, Mayaguez, April 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 1.7 m | | **1** | **2** | **3** | **4** | **5** |
| | | | (Ind/60 $m^2$ - TL in cm) | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus chirurgus* | Doctorfish | | | | | 2 - 10 |
| | | | | | | 2 - 12 |
| *Acanthurus coeruleus* | Blue Tang | | | 2 - 10 | | 2 - 10 |
| | | | | | | 1 - 12 |
| *Cephalopholis cruentata* | Graysby | | 1 - 17 | | | 1 - 12 |
| *Lutjanus griseus* | Grey Snapper | | | 1 - 29 | | |
| *Lutjanus jocu* | Dog Snapper | | | | 1 - 36 | |
| *Ocyurus chrysurus* | Yellowtail Snapper | | | | | 1 - 10 |
| *Scarus taeniopterus* | Princess Parrotfish | 1 - 5 | 1 - 14 | 1 - 7 | | |
| | | 1 - 7 | | | | |
| *Scarus vetula* | Queen Parrotfish | | 1 - 31 | | | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | 1 - 22 | 2 - 24 | 1 - 14 | 1 - 14 |
| *Sparisoma radians* | Bucktooth Parrotfish | | | | 1 - 5 | |
| *Sparisoma viride* | Stoplight Parrotfish | 1 - 26 | 1 - 10 | | | 1 - 26 |
| | | | | | | |
| **Invertebrates** | | | | | | |
| *Panulirus argus* | Spiny Lobster | | | | 1-7 | 1-15 |
| **Out of Transects** | | | | | | |
| *Scarus guacamaia* | Rainbow Parrotfish | 1 - 36 | | | | |
| *Epinphelus guttatus* | Red Hind | 1 - 36 | | | | |
| | | | | | | |
| TL = Fish Total Length (cm) | Lobster length is the carapace length in cm | | | | | |

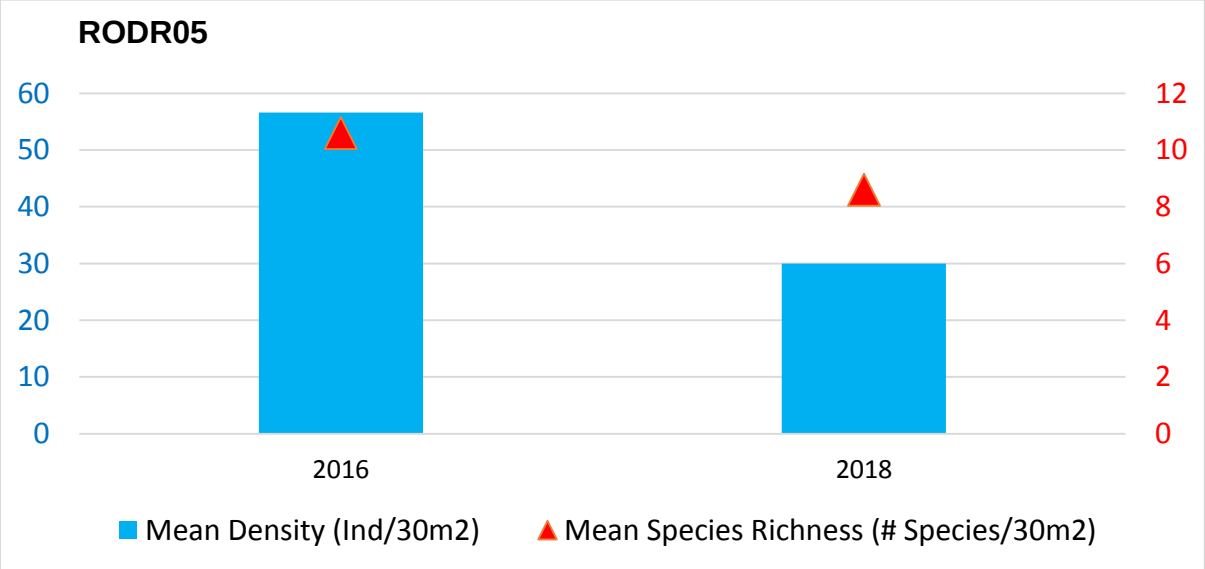
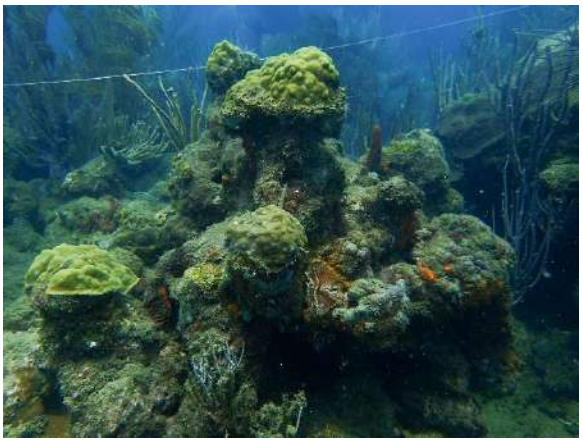



**Figure 11.** Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Bajo Rodriguez Reef 5m, Mayaguez

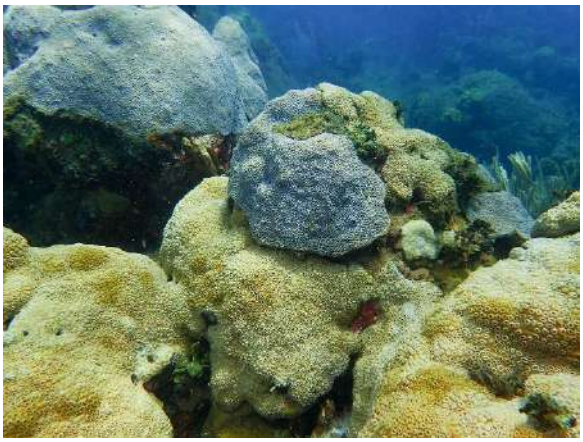
**Photo Album 3**

**Rodriguez Reef 5, Mayaguez (RODR05)**







## B. Cabo Rojo Coral Reef Systems

### 4.0 Guanajibo Reef 20, Cabo Rojo (GUAN20)

### 4.1 Physical Description

Guanajibo Reef (GUAN20) is a submerged coral bank formation that sits close to the shelf-edge approximately 4.2 NM off Pta. Guanajibo, Cabo Rojo. The reef sits on a narrow, gently sloping terrace that leads to the shelf break. The baseline survey was performed on July 2016. Five permanent transects were laid out running east to west encompassing depths between 15.2 – 21.8 m. Panoramic images of Guanajibo Reef are shown in Photo Album 4.

### 4.2 Sessile Benthic Reef Community

Benthic algae, comprised by fleshy brown (*Lobophora variegata*, *Dictyota sp*), turf (mixed assemblage), and red fleshy (*Gracilaria sp*) and crustose coralline algae (mixed assemblage) presented a combined mean substrate cover of 35.52% at GUAN20 (Table 11). The Encrusting Fan-leaf Alga (*L. variegata*) was the most prominent component with a mean cover of 16.48%, representing 46.5% of the total benthic algae. Y-Twig algae (*Dictyota sp*.) was also present in all five transects with a mean cover of 5.92%. Red crustose coralline algae were comprised by *Ramicrusta sp*. and other Peyssonnelid encrusting red algae with a combined cover of 3.38%.

A total of 75 colonies of scleractinian corals distributed into 13 species were intercepted by linear transects at GUAN20 (Table 11). Mountainous Star Coral (*Orbicella faveolata*) was the dominant coral in terms of reef substrate cover with a mean of 22.72%, representing 66.2% of the total cover by live corals. It was the only coral species present in all five transects (Table 11). Its sibling species, *O. franksi* was also prominent in terms of reef substrate cover with a mean of 6.63%. Great Star Coral (*Montastrea cavernosa*), Mustard-Hill Coral (*Porites astreoides*), Boulder Brain Coral (*Colpophyllia natans*) and Greater Starlet Coral (*Siderastrea siderea*) were present in at least three transects and along with the *Orbicella spp*. comprised the main coral assemblage at GUAN20. Although at shallower depths within the euphotic range, GUAN20 resembles mesophotic reefs such as El Seco (Vieques) and Lang Bank (St. Croix) due to the strong dominance of *O. faveolata and O. franksi* growing as flat, table-shaped colonies. Also, the relatively high substrate cover by live coral suggests that bleaching events have had minor impacts, if any, upon this reef. One coral colony intercepted by transects (*S. siderea*) had signs of apparent (“dark-spot syndrome”), for a coral disease prevalence of 1.3% (Appendix 4).

| **Table 11**. GUAN20. Percent cover by sessile-benthic categories at Guanajibo Reef 20m, Cabo Rojo | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 4/23/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 15.2 | 15.2 | 16.4 | 16.7 | 17.9 | **16.3** |
| Rugosity (m) | 5.09 | 6.31 | 5.13 | 6.59 | 7.08 | **6.04** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 11.41 | 18.71 | 18.87 | 27.00 | 31.23 | **21.44** |
| Sand | | 4.29 | | | 2.46 | **1.35** |
| Gap | 0.28 | | 1.76 | 0.25 | 0.33 | **0.52** |
| **Total Abiotic** | **11.69** | **23.00** | **20.63** | **27.25** | **34.02** | **23.32** |
| **Benthic Algae** | | | | | | |
| *Lobophora variegata* | 16.60 | 11.85 | 19.52 | 17.13 | 17.30 | **16.48** |
| Turf | 8.35 | 10.99 | 6.57 | 17.13 | 4.02 | **9.41** |
| *Dictyota* spp. | 8.07 | 9.87 | 4.16 | 3.97 | 3.52 | **5.92** |
| Peyssonnelid (mixed) | 3.15 | 1.29 | 0.65 | 1.60 | 0.74 | **1.49** |
| CCA (mixed) | 2.78 | 2.40 | | 1.27 | | **1.29** |
| *Ramicrusta* sp. | | 1.63 | | 1.35 | | **0.60** |
| *Gracilaria* sp. | 0.93 | | | | | **0.19** |
| Red algae (mixed) | | 0.43 | | | 0.33 | **0.15** |
| **Total Benthic Algae** | **39.89** | **38.46** | **30.90** | **42.45** | **25.90** | **35.52** |
| **Cyanobacteria** | **0.00** | **0.86** | **0.83** | **0.00** | **0.00** | **0.34** |
| **Hard Coral** | | | | | | |
| *Orbicella faveolata* | 20.50 | 18.37 | 26.09 | 21.52 | 27.13 | **22.72** |
| *Orbicella franksi* | 22.63 | 5.24 | 5.27 | | | **6.63** |
| *Montastraea cavernosa* | | 2.32 | 4.07 | 1.35 | 0.98 | **1.74** |
| *Porites astreoides* | | 1.46 | 0.37 | 0.84 | 2.30 | **0.99** |
| *Colpophyllia natans* | | 3.00 | 0.65 | | 1.07 | **0.94** |
| *Stephanocoenia intersepta* | | 0.52 | | | 1.39 | **0.38** |
| *Agarcia* agaricites | | | | 1.77 | | **0.35** |
| *Siderastrea siderea* | 0.46 | | 0.28 | 0.42 | | **0.23** |
| *Orbicella annularis* | | | 0.46 | | | **0.09** |
| *Agaricia lamarcki* | | | | | 0.41 | **0.08** |
| *Madracis decactis* | | | | | 0.33 | **0.07** |
| *Porites porites* | 0.19 | | | | | **0.04** |
| *Dichocoenia stokesi* | | | | 0.17 | | **0.03** |
| **Total Hard Coral** | **43.78** | **30.91** | **37.19** | **26.08** | **33.61** | **34.31** |
| **# Coral Colonies /Transect** | 19 | 16 | 18 | 11 | 11 | **15.0** |
| **# Diseased Coral Colonies** | 0 | 1 | 0 | 0 | 0 | |
| **Other** | | | | | | |
| Tunicate | | | 0.65 | | | **0.13** |
| *Trididemnum solidum* | 0.28 | | | | | **0.06** |
| **Total Other** | **0.28** | **0.00** | **0.65** | **0.00** | **0.00** | **0.19** |
| **Octocoral** | | | | | | |
| *Briareum asbestinum* | 2.13 | | 7.03 | 1.18 | 4.59 | **2.99** |
| *Erythropodium caribaeorum* | 1.67 | 6.09 | 1.39 | 2.28 | 1.89 | **2.66** |
| **Total Octocoral** | **3.80** | **6.09** | **8.42** | **3.46** | **6.48** | **5.65** |
| **# Gorgonians/Transect** | **5** | **6** | **4** | **3** | **5** | **4.6** |
| **Sponges** | | | | | | |
| *Ircinia brown sp.* | 0.56 | | 0.46 | | | **0.20** |
| *Neopetrosia smooth* | | | 0.93 | | | **0.19** |
| *Cliona caribbaea* | | | | 0.76 | | **0.15** |
| *Ectyoplasia ferox* | | 0.69 | | | | **0.14** |
| **Total Sponges** | **0.56** | **0.69** | **1.39** | **0.76** | **0.00** | **0.68** |

Vertically projected octocorals were present in all five transects surveyed with a mean density of 4.6 colonies per transect. Sea Plumes (*Pseudopterogorgia spp.*) and Sea Fans (*Gorgonia ventalina*) were the most common. The encrusting gorgonian species, *Briareum asbestinum* and *Erythropodium caribaeorum* were observed in at least four transects with combined mean substrate cover of 5.65% (Table 11). Sponges were mostly present at GUAN20 as small encrusting colonies growing intermixed with algal turf and other encrusting biota with a combined mean substrate cover of 0.68%. Only one species (*Ircinia sp.*) was observed in more than one transect. Abiotic substrate categories presented a mean substrate cover of 23.32% (range: 11.69 – 34.02%). Reef overhangs, associated with ledges of Mountainous and Boulder Star Corals (*Orbicella faveolata*, *O. franksi*) were the main component of the abiotic category with a mean cover of 21.44%, representing 91.9% of the total (Table 11). Reef rugosity contributed by growth of *Orbicella* coral colonies averaged 6.04 m (range: 5.09 – 7.08 m).

Annual variations of the sessile-benthic community structure between the 2016 baseline and the 2018 monitoring survey are presented in Figure 12. The rank order of benthic categories in terms of reef substrate cover remained stable between surveys at GUAN20 with benthic algae and hard corals essentially sharing similar status as the dominant components of reef substrate cover. Minor variations of percent substrate cover by total live coral (Figure 13) were statistically insignificant (ANOVA; p = 0.57, Appendix 2a). In the 2016 baseline survey, substrate cover by *Orbicella spp* was reported on the “species complex” as 31.70%. The combined mean cover by the three sibling species in the 2018 monitoring survey added up to 29.44%. Differences of octocoral density were statistically insignificant (ANOVA; p= 0.717, Appendix 2b).

### 4.3 Fishes and Motile Megabenthic Invertebrates

A total of 36 fish species were observed within belt-transects from a mean depth of 16.3 m at GUAN20 (Table 12). Mean density was 41.2 Ind/transect (range: 37 – 50 Ind/transect) with a mean richness of 16.2 species per transect. An assemblage of nine species, including the Blue Chromis (*Chromis cyanea*), Bluehead Wrasse (*Thalassoma bifasciatum*), Fairy Basslet (*Gramma loreto),* Peppermint Goby (*C. lipernes*), Princess Parrotfish (*Scarus taeniopterus*), Masked Goby (*Coryphopterus personatus*), Beaugregory (*Stegastes leucostictus*) and Striped Parrotfish (*Scarus iseri*) were all present in at least four transects and combined for a cumulative density of 31.8 ind/transect, representing 77.2% of the total individuals.

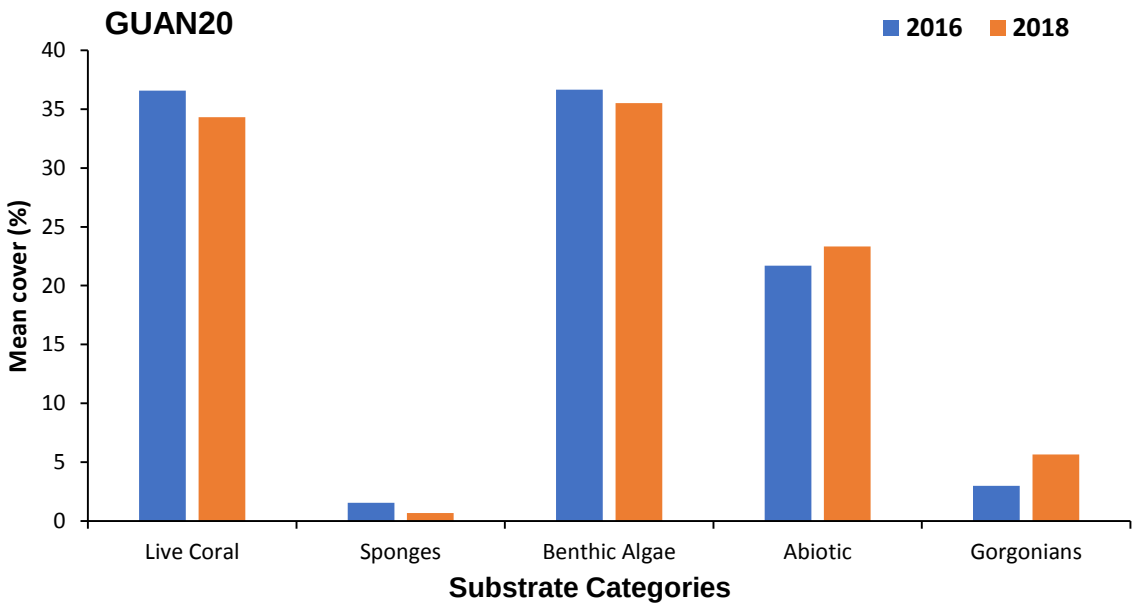



**Figure 12.** GUAN20. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Guanajibo Reef 20m, Cabo Rojo

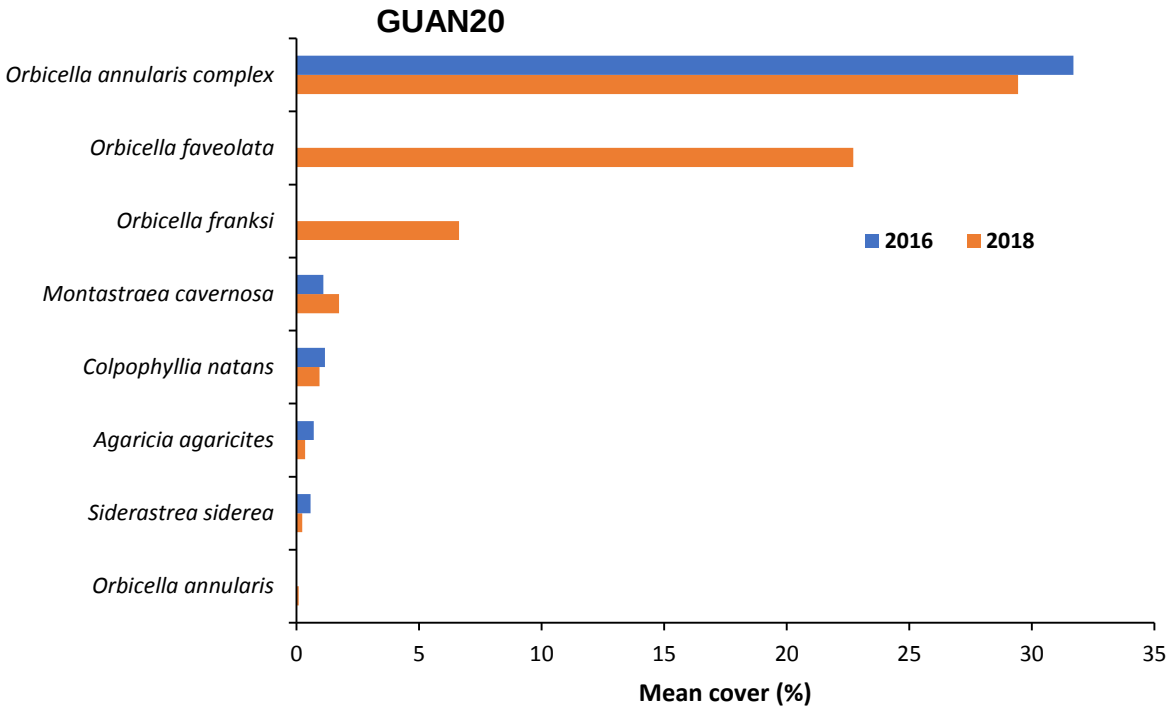



**Figure 13.** GUAN20. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at Guanajibo Reef 20m, Cabo Rojo

**Table 12.** GUAN20. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Guanajibo Reef 20m, Cabo Rojo, April 2018

| Mean Depth: 16.3 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Chromis cyanea* | Blue Chromis | 5 | 6 | 3 | 5 | 5 | **4.8** |
| *Thalassoma bifassiatum* | Bluehead Wrasse | 11 | 5 | 7 | | 1 | **4.8** |
| *Gramma loreto* | Fairy Basslet | 4 | 4 | 4 | 7 | 1 | **4.0** |
| *Coryphopterus lipernes* | Peppermint Goby | 2 | 8 | 6 | 2 | 1 | **3.8** |
| *Scarus taeniopterus* | Princess Parrotfish | 3 | 2 | 4 | 5 | 5 | **3.8** |
| *Coryphopterus personatus* | Masked Goby | | 1 | 3 | 4 | 9 | **3.4** |
| *Stegastes partitus* | Bicolor Damselfish | 5 | 5 | 3 | 2 | 2 | **3.4** |
| *Stegastes leucostictus* | Beau Gregory | 2 | 3 | 1 | 3 | 3 | **2.4** |
| *Scarus iseri* | Striped Parrotfish | | 1 | 1 | 2 | 3 | **1.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | 1 | | | 5 | | **1.2** |
| *Canthigaster rostrata* | Caribbean Puffer | 1 | 1 | 1 | 1 | 1 | **1.0** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 | 1 | 1 | | 2 | **1.0** |
| *Elacatinus evelynae* | Sharknose Goby | 1 | 1 | 1 | | | **0.6** |
| *Sparisoma viride* | Stoplight Parrotfish | 2 | | | | 1 | **0.6** |
| *Carangoides ruber* | Bar Jack | 1 | | | 1 | | **0.4** |
| *Cephalopholis fulva* | Coney | | | | 1 | 1 | **0.4** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | 1 | | | | 1 | **0.4** |
| *Chaetodon ocellatus* | Spotfin Butterflyfish | 2 | | | | | **0.4** |
| *Chromis multilineata* | Brown Chromis | 2 | | | | | **0.4** |
| *Hypoplectrus puella* | Barred Hamlet | 1 | 1 | | | | **0.4** |
| *Acanthurus chirurgus* | Doctorfish | | | | | 1 | **0.2** |
| *Acanthurus coeruleus* | Blue Tang | | 1 | | | | **0.2** |
| *Anisotremus virginicus* | Porkfish | 1 | | | | | **0.2** |
| *Aulostomus maculatus* | Trumpetfish | 1 | | | | | **0.2** |
| *Chaetodon aculeatus* | Longnose Butterflyfish | | | | 1 | | **0.2** |
| *Coryphopterus sp.* | Goby | | 1 | | | | **0.2** |
| *Epinephelus guttatus* | Red Himd | 1 | | | | | **0.2** |
| *Holocentrus adscensionis* | Squirrelfish | | 1 | | | | **0.2** |
| *Sargocentrum coruscum* | Reef Squirrelfish | | | 1 | | | **0.2** |
| *Hypoplectrus nigricans* | Black Hamlet | 1 | | | | | **0.2** |
| *Lutjanus apodus* | Schoolmaster | 1 | | | | | **0.2** |
| *Mycteroperca sp* | Juvenile grouper | | | | | 1 | **0.2** |
| *Pterois sp* | Lionfish | | | 1 | | | **0.2** |
| | **TOTAL INDIVIDUALS** | **50** | **42** | **37** | **39** | **38** | **41.2** |
| | **TOTAL SPECIES** | **22** | **16** | **14** | **13** | **16** | **16.2** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| none | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 0 | 0 | 0 | **0** |
| | **TOTAL SPECIES** | 0 | 0 | 0 | 0 | 0 | **0** |

The trophic structure at GUAN20 was dominated by zooplanktivores and small opportunistic carnivores. Zooplanktivores were comprised by two chromis (Pomacentridae), one basslet (Grammatidae), one goby (Gobiidae), and one damselfish representing approximately 30.6% of the total individuals. Small opportunistic carnivores were represented by one wrasse (Labridae), two hamlets and one small grouper (Serranidae), two squirrelfishes (Holocentridae), one puffer

(Tetraodontidae), one goby (Gobiidae), and one trumpetfish (Aulostomidae) with a combined density of 1.4 ind/transect, representative of 27.7% of the total individuals within belt-transects. Herbivores included five species of parrotfishes (Scaridae), three species of doctorfishes (Acanthuridae), and one damselfish (Pomacentridae) with a combined density of 8.2 Ind/transect, representative of 19.9% of the total individuals. Medium sized piscivores within transects included two groupers (*Epinephelus guttatus, Mycteroperca sp*. - Serranidae) and one snapper (*Lutjanus apodus* – Lutjanidae). Nurse Shark (*Ginglymostoma cirratum*), Nassau and Yellowfin Groupers (*Epinephelus striatus, Mycteroperca venenosa*), Great Barracuda (*Sphyraena barracuda*) and Cero Mackerels (*Scomberomorus regalis*) were observed during the 2016 baseline survey and appear to be the larger predators of the Cabo Rojo reef system.

The size-frequency distribution of parrotfishes (Scaridae) and doctorfishes (Acanthuridae) suggests that the reef functions largely as a habitat for adult individuals (Table 13). Juvenile Nassau Groupers and one adult Yellowfin Grouper were observed during the baseline survey. Motile megabenthic invertebrates were not observed within belt-transects.

Variations of fish density and species richness between the 2016 baseline and the 2018 monitoring survey are presented in Figure 14. Statistically significant differences of fish density (ANOVA; $p = 0.017$, Appendix 3) were evidenced between surveys, related to a marked decline of density during the 2018 survey. Mean fish density declined 72.2%, from 148.2 Ind/transect in 2016 to 41.2 Ind/transect in 2018. The main driver of the difference between surveys was the marked drop of density by Masked Goby (*Coryphopterus personatus*), from 70.2 Ind/transect in 2016 to 3.4 Ind/transect in 2018. Mackerel Scad (*Decapterus macarellus*), another numerically dominant species observed within 2016 transects was not observed during 2018. The latter is a transitory pelagic species that is only sporadically present in the reef, unlike the Masked Goby which is a reef resident. Its drastic decline of density may be associated with advective displacement of its population from reef habitats due to the high wave and surge forces that may have prevailed during the pass of Hurricane Maria in September 2017, and/or another event of extreme wave action impacting the west and north coast in March 2018.

Fish species richness remained stable between surveys, indicative that the fish community structure and biodiversity was not proportionately impacted. It is possible that larger species with better swimming capabilities were able to seek shelter in deeper waters to escape the surge and advective forces associated with extreme events and return to the reef later.

**Table 13.** GUAN20. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates within 20 x 3 m belt-transects at Guanajibo Reef 20m, Cabo Rojo, April 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 16.3 m | | 1 | 2 | 3 | 4 | 5 |
| | | | (Ind/60 $m^2$ - TL in cm) | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus chirurgus* | Doctorfish | | 1 - 17 | | 1 - 12 | 1 - 14 |
| *Acanthurus tractus* | Five-band Surgeonfish | 1 - 10 | | | 1 - 12 | |
| *Acanthurus coeruleus* | Blue Tang | | 2 - 12 | | | |
| *Cephalopholis fulva* | Coney | | | | 1 - 24 | |
| *Epinephelus guttatus* | Red Hind | 1 - 29 | | | | |
| *Lutjanus apodus* | Schoolmaster | 1 - 29 | | | | |
| | | 1 - 41 | | | | |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1 - 7 | | | | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | 1 - 10 | 2 - 7 | | 1 - 10 |
| *Scarus iseri* | Striped Parrotfish | 1 - 19 | 1 - 10 | 1 - 7 | 2 - 10 | 3- 12 |
| *Scarus taeniopterus* | Princess Parrotfish | 3 - 10 | 4 - 7 | 1 - 19 | 2 - 5 | 3 - 7 |
| | | | 1 - 10 | 3 - 10 | 3 - 7 | 1 - 22 |
| | | | | | 1 - 19 | 2 - 24 |
| *Scarus vetula* | Queen Parrotfish | | | | | 2 - 24 |
| *Sparisoma viride* | Stoplight Parrotfish | 1 - 12 | | | | |
| | | 1 - 24 | | | | |
| *Pterois sp* | Lionfish | | | 1 - 14 | | |
| | | | | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |
| **Out of Transects** | | | | | | |
| *Sphyraena barracuda* | Great Barracuda | 1 - 67 | | | | |
| | | | | | | |
| TL = Fish Total Length | | | | | | |

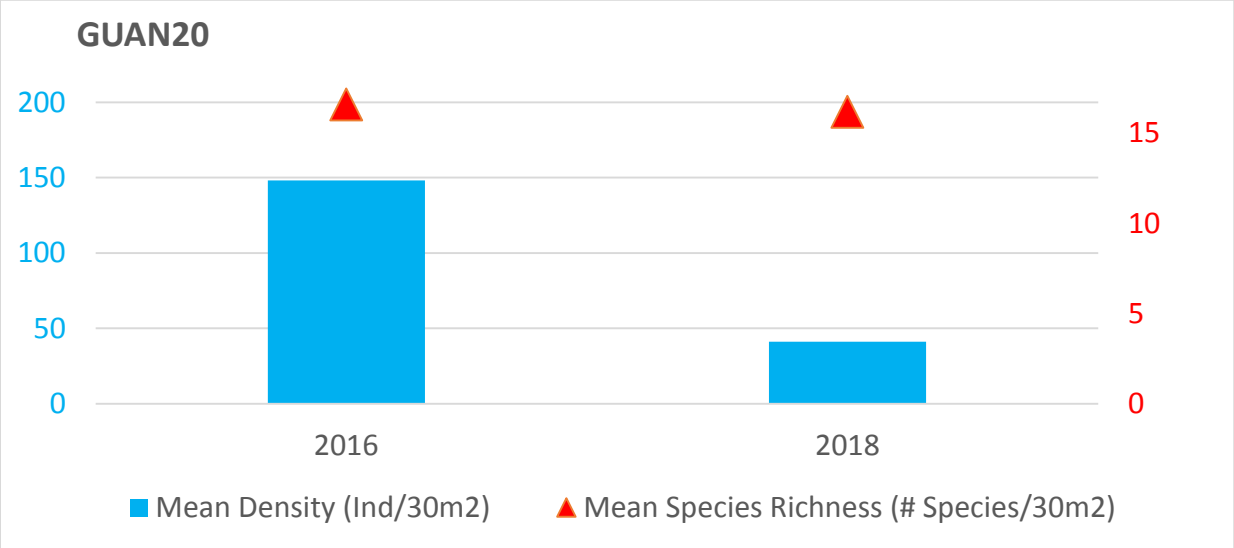


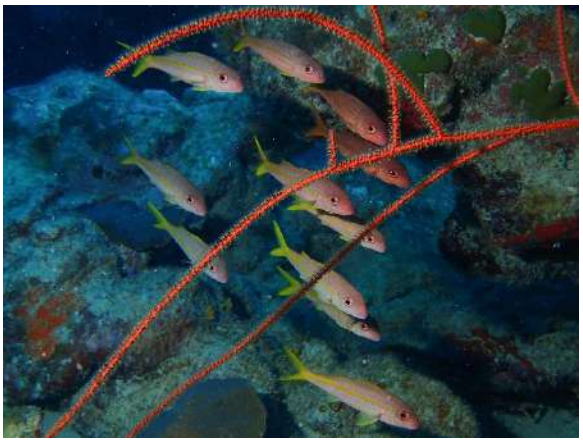

**Figure 14.** Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Guanajibo Reef 20m, Cabo Rojo

**Photo Album 4**

**Guanajibo Reef 20m, Cabo Rojo (GUAN20)**





## 5.0 El Negro Reef 10m, Cabo Rojo (NEGR10)

### 5.1 Physical Description

El Negro Reef, also known as Escollo Negro is a partially emergent fringing reef that runs parallel to the coastline, at about 3 NM west off Punta Arenas, Cabo Rojo (Figure 2). The reef's main structure appears to be of sedimentary origin with corals and another reef biota growing over a highly eroded submerged seascape. The baseline survey was performed on July 2016. Transects were set along an 8 – 11.5 m depth contour near the base of the fore-reef slope. Panoramic images of El Negro Reef 10m (NEGR10) are included as Photo Album 5.

### 5.2 Sessile-Benthic Reef Community

Turf algae, a mixed assemblage of short macroalgae growing as a carpet over hard substrates in the reef were the dominant sessile-benthic category at NEGR10 with a mean cover of 39.46%, representing 87.8% of the total cover by benthic algae (Table 14). Fleshy brown macroalgae, including the Y-Twig (*Dictyota sp*.) and the Encrusting Fan-leaf Alga (*Lobophora variegata*) presented a combined cover of 4.52%. Red crustose coralline algae, including *Ramicrusta sp*. and other Peyssonnelid algae were present in three transects with a combined mean cover of 0.66%. Cyanobacterial cover averaged 0.87%, well below the 2018 PRCRMP survey average of 3.22%.

Scleractinian corals were represented by 14 species intercepted by linear transects with a combined mean substrate cover of 21.82% (range: 14.19 – 27.55%). A total of 85 coral colonies were intercepted in the five transects for a mean coral density of 17 colonies/transect (Table 14). Lettuce Coral (*Agaricia agaricites*) and Boulder Star Coral (*Orbicella franksi*) were the dominant species in terms of reef substrate cover with means of 5.89% and 5.83%, respectively. Their combined cover represented 53.7% of the total cover by hard corals at NEGR10. Mustard-Hill Coral (*Porites astreoides*) and Great Star Coral (*Montastrea cavernosa*) were present in all transects. Massive Starlet Coral (*Siderastrea siderea*) and the Mountainous and Lobed Star corals (*O. faveolata*, *O. annularis*) were present in at least three transects and along with the aforementioned species comprised the main coral assemblage at NEGR10. In addition, seven (7) coral species were represented by one colony along transects. Four colonies showed signs of apparent disease, including *O. faveolata and O. franksi* (disease prevalence = 4.7%, see Appendix 4).

| **Table 14**. NEGR10. Percent cover by sessile-benthic categories at El Negro Reef 10m, Cabo Rojo | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 4/23/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 11.5 | 10.9 | 9.7 | 8.8 | 9.7 | **10.1** |
| Rugosity (m) | 6.38 | 9.19 | 5.81 | 6.45 | 6.16 | **6.80** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 20.17 | 25.38 | 6.64 | 16.43 | 16.98 | **17.12** |
| Sand | 8.38 | 8.46 | 2.66 | 4.09 | 5.20 | **5.76** |
| Rubble and sand | | | 3.99 | 8.17 | | **2.43** |
| Gap | 5.81 | | | | | **1.16** |
| Rubble | | 1.46 | | | | **0.29** |
| **Total Abiotic** | **34.36** | **35.30** | **13.29** | **28.68** | **22.18** | **26.76** |
| **Benthic Algae** | | | | | | |
| Turf algae (mixed) | 44.02 | 39.61 | 40.04 | 44.26 | 29.38 | **39.46** |
| *Dictyota* spp. | 2.31 | 0.36 | 4.78 | 2.55 | 6.41 | **3.28** |
| *Lobophora variegata* | | | 6.20 | | | **1.24** |
| CCA (mixed) | | 0.36 | 0.62 | | 0.61 | **0.32** |
| Peyssonnelid (mixed) | | | | | 1.47 | **0.29** |
| Macroalgae (mixed) | | 1.09 | 0.35 | | | **0.29** |
| *Ramicrusta* sp. | | | | | 0.26 | **0.05** |
| **Total Benthic Algae** | **46.33** | **41.42** | **51.99** | **46.81** | **38.13** | **44.94** |
| **Cyanobacteria** | **1.11** | **0.22** | **0.97** | **2.04** | **0.00** | **0.87** |
| **Hard Coral** | | | | | | |
| *Agaricia agaricites* | 7.78 | 5.25 | 7.88 | 3.06 | 5.46 | **5.89** |
| *Orbicella franksi* | | 4.67 | 7.79 | 10.98 | 5.72 | **5.83** |
| *Porites astreoides* | 0.77 | 2.92 | 7.26 | 1.45 | 1.82 | **2.84** |
| *Montastraea cavernosa* | 2.39 | 0.73 | 1.68 | 1.62 | 5.98 | **2.48** |
| *Siderastrea siderea* | 2.48 | 2.63 | 0.35 | 1.19 | | **1.33** |
| *Orbicella faveolata* | 0.77 | 1.02 | 2.21 | | 2.17 | **1.23** |
| *Orbicella annularis* | | 1.60 | 0.35 | | 1.73 | **0.74** |
| *Diploria labyrinthiformis* | | | | | 2.95 | **0.59** |
| *Mycetophyllia lamarckiana* | | | | 1.45 | | **0.29** |
| *Agaricia lamarcki* | | | | | 1.21 | **0.24** |
| *Porites porites* | | | | 1.02 | | **0.20** |
| *Agaricia fragilis* | | 0.29 | | | | **0.06** |
| *Madracis decactis* | | 0.29 | | | | **0.06** |
| *Leptoseris cucullata* | | | | 0.17 | | **0.03** |
| **Total Hard Coral** | **14.19** | **19.40** | **27.55** | **20.94** | **27.04** | **21.82** |
| **# CoralColonies /Transect** | **14** | **21** | **16** | **17** | **17** | **17.0** |
| **# Diseased Coral Colonies** | **0** | **2** | **0** | **1** | **1** | |
| **Octocoral** | | | | | | |
| *Briareum asbestinum* | | | 2.13 | | 0.95 | **0.62** |
| *Erythropodium caribaeorum* | | 0.73 | | | 1.04 | **0.35** |
| *Gorgonia ventalina* | | | 0.89 | | | **0.18** |
| **Total Octocoral** | **0.00** | **0.73** | **3.01** | **0.00** | **1.99** | **1.15** |
| **# Gorgonians/Transect** | **2** | **0** | **2** | **3** | **1** | **1.6** |
| **Sponges** | | | | | | |
| *Neopetrosia proxima* | 0.26 | 0.36 | 0.18 | | 4.25 | **1.01** |
| *Monanchora arbuscula* | 0.68 | 0.58 | 0.18 | | 1.30 | **0.55** |
| *Chondrilla caribensis* | 1.88 | | 0.27 | | 0.43 | **0.52** |
| *Iotrochota arenosa* | | | 0.44 | 0.26 | 1.65 | **0.47** |
| *Aplysina fistularis* | 0.68 | 0.44 | | | 0.52 | **0.33** |
| *Scopalina ruetzleri* | 0.17 | | | 0.26 | 0.69 | **0.22** |
| *Mycale laevis* | | | 0.53 | 0.34 | | **0.17** |
| *Niphates erecta* | | 0.22 | | | 0.52 | **0.15** |
| *Aplysina cauliformis* | 0.34 | 0.22 | | | | **0.11** |
| *Niphates* sp. | | | | | 0.52 | **0.10** |
| *Neopetrosia smooth* sp. | | 0.44 | | | | **0.09** |
| Encrusting sponge | | | | | 0.43 | **0.09** |
| *Cinachyrella kuekenthali* | | | 0.35 | | | **0.07** |
| *Ircinia felix* | | | 0.35 | | | **0.07** |
| *Plakortis* sp. | | | | 0.17 | 0.17 | **0.07** |
| *Verongula rigida* | | | | 0.34 | | **0.07** |
| Sponge unknown | | 0.29 | | | | **0.06** |
| *Iotrochota birotulata* | | | 0.27 | | | **0.05** |
| *Ircinia brown* sp. | | 0.22 | | | | **0.04** |
| *Amphimedon compressa* | | | | 0.17 | | **0.03** |
| **Total Sponges** | **4.02** | **2.77** | **2.57** | **1.53** | **10.49** | **4.27** |

Vertically projected octocorals were present in all five transects surveyed at NEGR10 with a mean density of 1.6 colonies/ transect. Sea Rods (*Plexaura spp*) and Sea Fans (*Gorgonia ventalina*) were the most common. The encrusting gorgonian species, *Briareum asbestinum* and *Erythropodium caribaeorum* combined for a mean substrate cover of 0.97% (Table 14). Sponges represented by at least 20 species combined for a mean substrate cover of 4.27%. *Neopetrosia sp.* and *Monachora arbuscula* were present in four transects each and were also the main species in terms of reef substrate cover. Along with the aforementioned species, *Chondrilla caribensis, Iotrochota arenosa, and Aplysina fistularis* were intercepted by at least three transects. In general, sponges were mostly represented by small encrusting colonies growing intermixed with algal turf with only minor contributions to the reef structural complexity and topographic relief.

Abiotic substrate categories presented a mean substrate cover of 26.76% (range: 13.29 – 35.30%). Reef overhangs, associated with coral ledges and overhangs were the main contribution to the abiotic category with a mean cover of 17.12%, representing 64.0% of the total abiotic category (Table 14). Sections of sand (5.76%) and mixed coral rubble with sand (2.43%) were also prominent at NEGR10. Reef rugosity averaged 6.80 m (range: 5.81 – 9.19 m) and was largely influenced by growth of *Orbicella* corals.

Variations of the sessile-benthic community structure between the 2016 baseline and the 2018 monitoring surveys are presented in Figure 15. The rank order of benthic categories, in terms of reef substrate cover, remained constant between surveys. A moderate increase of total benthic algal cover of 18.7% was measured during the 2018 survey associated with both turf algae and the appearance for the first time of CCA and other Peyssonnelid algae. Conversely, cyanobacterial cover declined 89.8%, from 8.5% in the 2016 baseline survey to 0.87% in the 2018 monitoring survey. Such decline of cyanobacteria may have been influenced by the strong surge and abrasion effects associated with the hurricanes and/or other extreme wave action event(s).

Total live coral cover varied from 20.71% in 2016 to 21.82% in 2018. The 5.4% difference was influenced by small increments of cover by Lettuce Coral (*Agaricia agaricites*) and Mustard-Hill Coral (*Porites astreoides*) (Figure 16), but differences of total live coral cover were not statistically significant (ANOVA; $p = 0.063$, Appendix 2a). Density of octocorals (gorgonians) remained constant between surveys (ANOVA; $p = 1.0$, Appendix 2b).

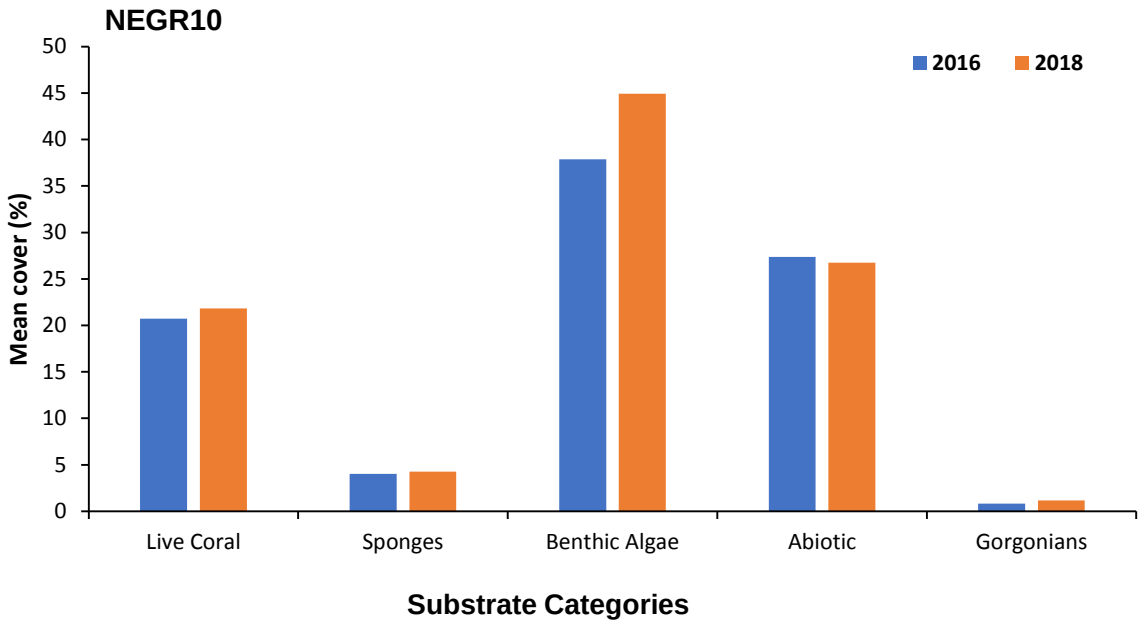



**Figure 15.** NEGR10. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Negro Reef 10m, Cabo Rojo

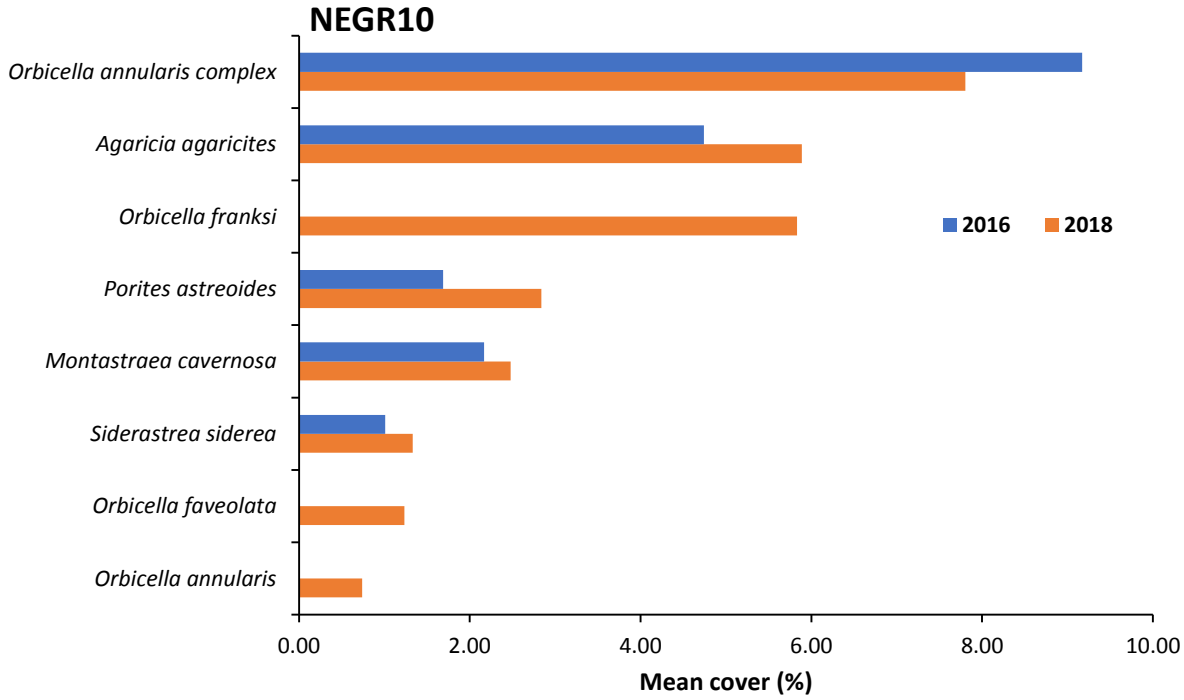



**Figure 16.** NEGR10. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at Negro Reef 10m, Cabo Rojo

### 5.3 Fishes and Motile Megabenthic Invertebrates

A total of 40 species of fishes were identified within belt-transects from a mean depth of 10.1 m at NEGR10 (Table 16). Mean density was 99.0 Ind/transect (range: 84 – 121 Ind/transect) with a mean richness of 17.6 species per transect. The Masked Goby (*Coryphopterus personatus*) was numerically dominant with a mean density of 34.4 Ind/transect, representing 34.7% of the total individuals. This is a small schooling zooplanktivore species that swarms over large coral colonies and below ledges. Along with Masked Goby, another four (4) species were present in all five transects at NEGR10. These include the Blue Chromis (*Chromis cyanea*), Bluehead Wrasse (*Thalassoma bifasciatum*), Beaugregory (*Stegastes leucostictus*), and Caribbean Puffer (*Canthigaster rostrata*). Another four (4) resident species were present in four transects, including the Princess Parrotfish (*Scarus taeniopterus*), Fairy Basslet (*Gramma loreto*), Peppermint Goby *(Coryphopterus lipernes*), and Three-spot Damselfish (*Stegastes planifrons*). The combined abundance of these nine species represented 81.6% of the total individuals within belt-transects. Sixteen species that were observed only in one transect appear to be rare or present in low densities at NEGR10 (Table 16).

The zooplanktivore fish trophic assemblage, comprised by three out of the four most abundant species within belt-transects (*Coryphopterus personatus, Chromis cyanea and Clepticus parrae*) represented 61.4% of the total fish density at NEGR10 (Table 16). Small opportunistic carnivores were also prominent, represented by two species of wrasses (Labridae), one hamlet and one small grouper (Serranidae), two squirrelfishes (Holocentridae), two gobies (Gobiidae), one puffer (Tetraodontidae), one mojarra (Gerreidae), one Trumpetfish (Aulostomidae), one porgy (Sparidae), one grunt (Haemulidae), one goatfish (Mullidae), and one lizardfish (Synodontidae) for a combined density of 21.0 Ind/transect, or 21.2% of the total individuals. Herbivores were represented by five species of parrotfishes (Scaridae), five species of damselfishes (Pomacentridae) and three species of doctorfishes (Acanthuridae). The combined density of herbivore species represented 15.8% of the total. Medium sized piscivores included the Yellowtail Snapper (*Ocyurus chrysurus*) and Great Barracuda (*Sphyraena barracuda*). Given the smaller size of zooplanktivores relative to herbivore and carnivore fish species present it can be argued that the trophic structure of fishes at NEGR10 was fairly well balanced, only lacking the larger demersal predators. Motile megabenthic invertebrates were not observed within belt-transects. Two adult Spiny Lobsters (*Panulirus argus*) were observed outside transects.

**Table 16.** NEGR10. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at El Negro Reef 10m, Cabo Rojo, April 2018

| Mean Depth: 10.1 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Coryphopterus persona* | Masked Goby | 46 | 34 | 15 | 33 | 44 | **34.4** |
| *Chromis cyanea* | Blue Chromis | 14 | 11 | 42 | 3 | 12 | **16.4** |
| *Thalassoma bifassiatun* | Bluehead Wrasse | 21 | 3 | 1 | 7 | 23 | **11.0** |
| *Clepticus parrae* | Creole Wrasse | | 2 | | 26 | | **5.6** |
| *Scarus taeniopterus* | Princess Parrotfish | 6 | | 6 | 4 | 6 | **4.4** |
| *Gramma loreto* | Fairy Basslet | 2 | 9 | 5 | | 2 | **3.6** |
| *Coryphopterus lipernes* | Peppermint Goby | 2 | 9 | | 3 | 2 | **3.2** |
| *Stegastes leucostictus* | Beau Gregory | 4 | 3 | 4 | 2 | 3 | **3.2** |
| *Stegastes planifrons* | Three-spot Damselfi | 3 | | 2 | 5 | 5 | **3.0** |
| *Canthigaster rostrata* | Caribbean Puffer | 3 | 2 | 1 | 1 | 1 | **1.6** |
| *Stegastes partitus* | Bicolor Damselfish | 1 | | | 4 | 2 | **1.4** |
| *Sparisoma aurofrenatur* | Redband Parrotfish | 3 | | 2 | 1 | | **1.2** |
| *Coryphopterus sp.* | Goby | | | | 5 | | **1.0** |
| *Sparisoma radians* | Bucktooth Parrotfish | | 5 | | | | **1.0** |
| *Elacatinus evelynae* | Sharknose Goby | 2 | 1 | | 1 | | **0.8** |
| *Cephalopholis cruentat* | Graysby | 1 | 1 | 1 | | | **0.6** |
| *Chromis multilineata* | Brown Chromis | 2 | | 1 | | | **0.6** |
| *Carangoides ruber* | Bar Jack | | 2 | | | | **0.4** |
| *Gerres cinereus* | Yellowfin Mojarra | | 1 | | | 1 | **0.4** |
| *Haemulon flavolineatur* | French Grunt | 2 | | | | | **0.4** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 1 | | | 1 | | **0.4** |
| *Holocentrus rufus* | Longspine Squirelfis | 1 | | 1 | | | **0.4** |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | | | 1 | 1 | 1 | **0.6** |
| *Pseudupeneus macula* | Spotted Goatfish | 1 | 1 | | | | **0.4** |
| *Stegastes variabilis* | Cocoa Damselfish | 1 | | | 1 | | **0.4** |
| *Abudefduf saxatilis* | Sargent Major | | | | 1 | | **0.2** |
| *Acanthurus chirurgus* | Doctorfish | 1 | | | | | **0.2** |
| *Aulostomus maculatus* | Trumpetfish | | 1 | | | | **0.2** |
| *Calamus pennatula* | Pluma | | 1 | | | | **0.2** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | | | | 1 | **0.2** |
| *Diodon histrix* | Porcupinefish | | | 1 | | | **0.2** |
| *Microspathodon chrysu* | Yellowtail Damselfis | 1 | | | | | **0.2** |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1 | | | | | **0.2** |
| *Pomacanthus arcuatus* | Grey Angelfish | | 1 | | | | **0.2** |
| *Pomacanthus ciliaris* | French Angelfish | 1 | | | | | **0.2** |
| *Scarus iseri* | Striped Parrotfish | | 1 | | | | **0.2** |
| *Sparisoma viride* | Stoplight Parrotfish | | 1 | | | | **0.2** |
| *Stegastes adustus* | Dusky Damselfish | | | 1 | | | **0.2** |
| *Synodus intermedius* | Lizardfish | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUAL** | **121** | **89** | **84** | **98** | **103** | **99.0** |
| | **TOTAL SPECIES** | **24** | **19** | **15** | **17** | **13** | **17.6** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| none | | | | | | | |
| | **TOTAL INDIVIDUAL** | 0 | 0 | 0 | 0 | 0 | **0** |
| | **TOTAL SPECIES** | 0 | 0 | 0 | 0 | 0 | **0** |

The size-frequency distribution of herbivores at NEGR10 showed that it is a recruitment and residential habitat for settlement, juvenile and adult parrotfishes (Scaridae), particularly for Stoplight, Bucktooth, and Princess Parrotfish (*Sparisoma viride, S. radians, Scarus taeniopterus*). Doctorfishes (Acanthuridae) were observed as juvenile and adult individuals (Table 17). Juvenile and adult Graysby (*Cephalopholis cruentata*), Lionfish (*Pterois sp*), and Yellowtail Snapper (*Ocyurus chrysurus)* were present.

Variations of fish density and species richness between the 2016 baseline and the 2018 monitoring survey are presented in Figure 17. Statistically significant differences of fish density (ANOVA; $p < 0.0001$, Appendix 3) were evidenced between surveys, related to a marked decline of density during the 2018 survey. Mean fish density declined 53.1%, from 211.2 Ind/transect in 2016 to 99.0 Ind/transect in 2018. The main driver of the difference between surveys was the marked drop of density by Masked Goby (*Coryphopterus personatus*), from 137.6 Ind/transect in 2016 to 34.4 Ind/transect in 2018.

As previously discussed for other west coast reefs, the marked density decline by *C. personatus* may be associated with advective displacement (flushing) during high wave and surge forces that must have prevailed during the pass of Hurricane Maria in September 2017, and/or another event of extreme wave action impacting the west and north coasts in March 2018. Conversely, fish species richness remained stable between surveys, indicative that the fish community structure and biodiversity was not compromised due to the impact of these mechanical forces. Most of the fish species (77.4%) observed within belt-transects during 2016 were present in the 2018 survey at NEGR10, including the 20 most abundant. An additional 13 species not observed within transects in 2016 were present in 2018, whereas only seven present within belt-transects in 2016 were not observed in 2018.

**Table 17.** NEGR10. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates within 20 x 3 m belt-transects at El Negro Reef 10m, Cabo Rojo, April 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 10.1 m | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus chirurgus* | Doctorfish | 1 - 14 | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 1 - 10 | | | | 1 - 12 |
| *Acanthurus coeruleus* | Blue Tang | | 1 - 12 | | | |
| *Cephalopholis cruentata* | Graysby | | 1 - 14 | 1 - 17 | | |
| *Lutjanus mahogony* | Mahogany Snapper | | | 1 - 22 | | |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1 - 12 | | | | |
| *Scarus iseri* | Striped Parrotfish | | 1 - 5 | | | |
| *Scarus taeniopterus* | Princess Parrotfish | 4 - 2 | 2 - 7 | 1 - 19 | 2 - 5 | 2 - 5 |
| | | 2 - 7 | | | 2 - 7 | 4 - 7 |
| | | 2 - 14 | | | 2 - 10 | 3 - 14 |
| | | 1 - 22 | | | 1 - 17 | 1 - 19 |
| | | 1 - 12 | | | | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 2 - 7 | | 1 - 10 | 1 - 14 | |
| | | 1 - 10 | | 1 - 14 | | |
| *Sparisoma radians* | Bucktooth Parrotfish | | 5 - 1 | | | |
| *Sparisoma viride* | Stoplight Parrotfish | | 1 - 1 | 1 - 31 | 2 - 2 | |
| | | | 1 - 5 | | 1 - 5 | |
| | | | 1 - 14 | | 1 - 36 | |
| *Sphyraena barracuda* | Great barrracuda | | | 1 - 48 | | |
| *Pterois sp* | Lionfish | 1 - 14 | | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |
| **Out of Transects** | | | | | | |
| *Panulirus argus* | Spiny Lobster | 2 - 10 | | | | |
| | | | | | | |
| TL = Fish Total Length | | | | | | |
| Lobster length is the carapace length in cm | | | | | | |

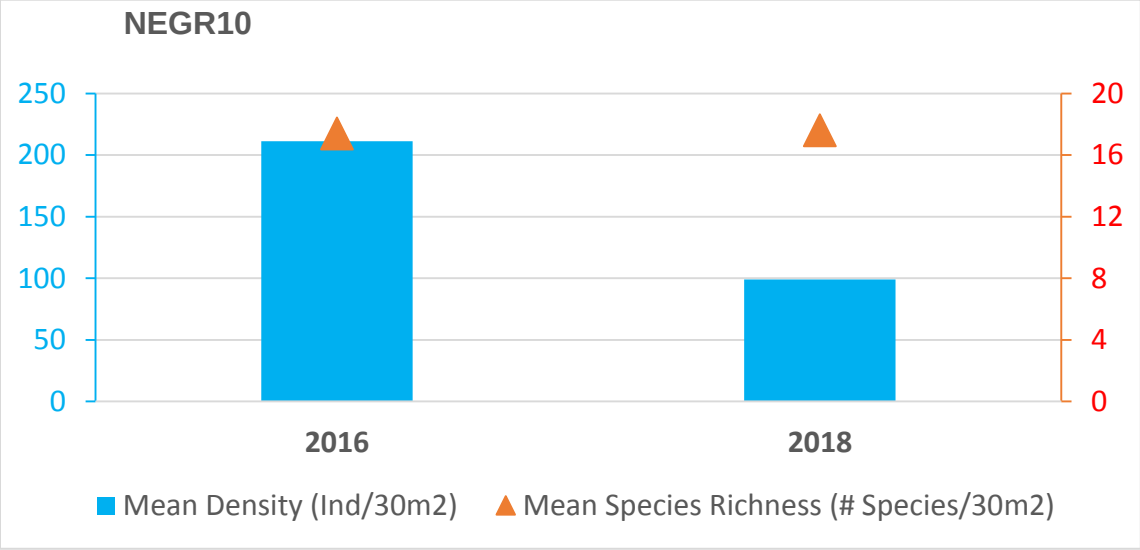
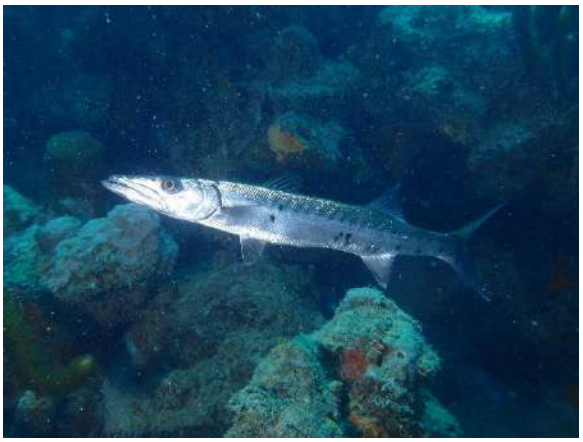
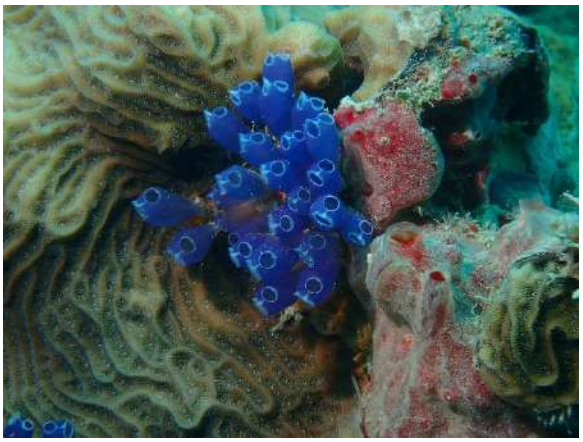



**Figure 17.** Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at El Negro Reef 10m, Cabo Rojo

**Photo Album 5**

**El Negro Reef 10m, Cabo Rojo (NEGR10)**





## 6.0 El Negro Reef 5m, Cabo Rojo (NEGR05)

### 6.1 Physical Description

El Negro Reef 5m (NEGR05) is the same reef formation described for 10m, but permanent transects were established at the upper edge of a moderately steep fore-reef slope along the 4 – 8 m depth contour (Figure 2). The baseline survey was performed on July 2016. Panoramic images of El Negro Reef 5 are included as Photo Album 6.

### 6.2 Sessile-benthic Reef Community

Benthic algae, comprised by turf, fleshy brown, calcareous green and red crustose coralline algae were the dominant biotic category covering reef substrate at NEGR05 with a combined mean substrate cover of 50.29% (Table 17). 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 46.09%, representing 91.6% of the total cover by algae. Fleshy brown macroalgae (mostly *Dictyota sp*) were present in all transects with a mean cover of 2.36%. Red crustose coralline algae, including *Ramicrusta sp*. were present in four transects with a combined cover of 1.66%. Calcareous macroalgae (*Halimeda sp*) and cyanobacterial patches were present with a mean cover below 1%.

A total of 62 coral colonies were intercepted by linear transects at NEGR05, for a mean density of 12.4 colonies/transect (range: 9 – 17). Corals were represented by 12 scleractinian and one hydrocoral species with a combined mean substrate cover of 27.32% (range: 19.56 – 34.36%). Lobed Star Coral (*Orbicella annularis*) was the dominant species in terms of reef substrate cover with a mean of 8.73%, representing 31.9% of the total cover by live corals and was intercepted by all five transects (Table 17). Lettuce Coral (*Agaricia agaricites*), Star Corals (*O. franski*, and *O. faveolata),* Great Star Coral (*Montastrea cavernosa*), and Mustard-Hill Coral (*Porites astreoides*) comprised along with *O. annularis* the main coral assemblage at NEGR05 in terms of substrate cover with a combined mean cover of 24.15%, or 88.5% of the total (Table 17). Colonies of Elkhorn and Staghorn Corals (*Acropora palmata, A. cervicornis*) were observed outside transects. As previously noted for RODR05 in Mayaguez Bay, large and healthy colonies of Lobed Star Coral (*O. annularis*) were observed growing close to the surface suggesting that the 2005 coral bleaching event had minor, if any, degradation effect upon such massive corals at this reef. Also, the relatively high coral cover by live *O. annularis* in a shallow coastal reef supports the argument of a limited impact by the 2005 coral bleaching phenomena.

| **Table 17**. NEGR05. Percent cover by sessile-benthic categories at El Negro Reef 5m, Cabo Rojo | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 4/23/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 4.8 | 4.8 | 7.6 | 7.9 | 5.4 | **6.1** |
| Rugosity (m) | 5.62 | 5.40 | 5.85 | 4.22 | 5.11 | **5.24** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Rubble and sand mix | 3.58 | 14.00 | 10.16 | 6.29 | | **6.81** |
| Reef overhang | 6.99 | 8.00 | 4.33 | 4.53 | 8.34 | **6.44** |
| Gap | | | 1.77 | 0.79 | | **0.51** |
| Sand | | | | 0.98 | | **0.20** |
| **Total Abiotic** | **10.57** | **22.00** | **16.25** | **12.59** | **8.34** | **13.95** |
| **Benthic Algae** | | | | | | |
| Turf algae (mix) | 44.80 | 41.56 | 38.07 | 50.30 | 55.70 | **46.09** |
| *Dictyota* spp. | 2.42 | 0.91 | 4.24 | 3.84 | 0.37 | **2.36** |
| *Ramicrusta* sp. | 0.54 | | | | 5.47 | **1.20** |
| CCA (mixed) | | 0.27 | 1.94 | | | **0.44** |
| *Halimeda* spp. | | | | 0.59 | | **0.12** |
| *Lobophora variegatus* | 0.45 | | | | | **0.09** |
| **Total Benthic Algae** | **48.21** | **42.74** | **44.26** | **54.72** | **61.54** | **50.29** |
| **Cyanobacteria** | 1.34 | 0.00 | 0.35 | 0.00 | 1.48 | **0.64** |
| **Hard Coral** | | | | | | |
| *Orbicella annularis* | 14.43 | 16.45 | 4.86 | 5.12 | 2.78 | **8.73** |
| *Agaricia agaricites* | 4.66 | 3.45 | 6.10 | 8.76 | 1.30 | **4.85** |
| *Orbicella franksi* | | 4.09 | 6.54 | | 4.17 | **2.96** |
| *Montastraea cavernosa* | 2.33 | | 11.31 | | | **2.73** |
| *Orbicella faveolata* | 2.06 | 3.00 | 3.18 | | 4.08 | **2.46** |
| *Porites astreoides* | 3.85 | | 1.68 | 2.76 | 3.80 | **2.42** |
| *Colpophyllia natans* | 1.79 | | | 6.00 | | **1.56** |
| *Porites porites* | | 0.73 | | 0.59 | 3.06 | **0.88** |
| *Siderastrea siderea* | 2.06 | | 0.18 | | | **0.45** |
| *Porites furcata* | 0.36 | | 0.35 | | | **0.14** |
| *Agaricia fragilis* | | | | | 0.37 | **0.07** |
| *Millepora alcicornis* | | 0.18 | | | | **0.04** |
| *Eusmilia fastigiata* | | | 0.18 | | | **0.04** |
| **Total Hard Coral** | **31.54** | **27.91** | **34.36** | **23.23** | **19.56** | **27.32** |
| **# CoralColonies /Transect** | **11** | **14** | **17** | **9** | **11** | **12.4** |
| **# Diseased Coral Colonies** | **1** | **1** | **0** | **0** | **0** | |
| **Other** | | | | | | |
| *Tridemnum solidum* | 2.06 | | | 0.59 | 1.48 | **0.83** |
| Tunicate | | 0.45 | | | 0.37 | **0.17** |
| **Total Other** | **2.06** | **0.45** | **0.00** | **0.59** | **1.85** | **0.99** |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | 0.36 | | 1.77 | 2.76 | | **0.98** |
| *Briareum asbestinum* | 1.88 | | | | | **0.38** |
| **Total Octocoral** | **2.24** | **0.00** | **1.77** | **2.76** | **0.00** | **1.35** |
| **# Gorgonians/Transect** | **0** | **2** | **5** | **5** | **1** | **2.6** |
| **Sponges** | | | | | | |
| *Chondrilla caribensis* | 1.25 | 0.55 | 0.27 | 0.79 | 4.26 | **1.42** |
| *Amphimedon compressa* | 0.18 | 2.91 | | 0.39 | 0.28 | **0.75** |
| *Mycale laevis* | 1.16 | 0.18 | 0.18 | 0.30 | 1.02 | **0.57** |
| *Niphates erecta* | 0.27 | 0.18 | | 1.77 | 0.19 | **0.48** |
| *Monanchora arbuscula* | | 0.27 | 1.06 | 0.30 | 0.65 | **0.46** |
| *Aplysina fistularis* | | 0.45 | | 0.79 | 0.46 | **0.34** |
| *Aplysina cauliformis* | 0.45 | | | 0.79 | 0.37 | **0.32** |
| *Ircinia brown* sp. | | 1.18 | | | | **0.24** |
| *Scopalina ruetzleri* | | 0.18 | 0.88 | | | **0.21** |
| *Smenospongia conulosa* | | 0.64 | | | | **0.13** |
| *Neopetrosia proxima* | | | 0.62 | | | **0.12** |
| *Aiocholoria crassa* | | | | 0.49 | | **0.10** |
| *Iotrochota birotulata* | 0.45 | | | | | **0.09** |
| *Verongula rigida* | | 0.36 | | | | **0.07** |
| Sponge unknown | | | | 0.30 | | **0.06** |
| *Cliona varians* | 0.27 | | | | | **0.05** |
| *Plakortis* sp. | | | | 0.20 | | **0.04** |
| **Total Sponges** | **4.03** | **6.91** | **3.00** | **6.10** | **7.23** | **5.46** |

Two out of the 48 coral colonies intercepted by transects (*Siderastrea siderea*) showed signs of apparent disease (dark spots), yielding a disease prevalence of 4.2% (Appendix 4).

Vertically projected octocorals were present in four transects surveyed at NEGR05 with a mean density of 2.6 colonies/transect. Sea Fans (*Gorgonia ventalina*) and Sea Rods (*Plexaura spp*) were the most common. The encrusting gorgonian species, *Erythropodium caribaeorum* and *Briareum asbestinum* were present in three transects with a combined mean substrate cover of 1.35% (Table 17). Sponges represented by at least 17 species combined for a mean substrate cover of 5.46%. *Chondrilla caribensis*, *Amphimedon compressa*, *Mycaele laevis, Niphates erecta*, and *Monachora arbuscula* were the most prominent in terms of reef substrate cover with a combined mean cover of 3.68%, or 67.4% of the total. In general, sponges were mostly comprised by small encrusting colonies growing intermixed with algal turf and other encrusting biota with minor contributions to the reef topographic relief and structural complexity. Abiotic substrate categories presented a mean substrate cover of 13.95% (range: 8.34 – 22.00%). Mixed coral rubble and sand, and reef overhangs were the main component the abiotic category with a mean cover of 13.25%, representing 94.6% of the total (Table 17). Reef rugosity averaged 5.24 m, influenced both by large coral mounds and the irregular reef topography associated with relict erosive features of the shelf.

Variations of sessile-benthic community structure between the 2016 baseline and the 2018 monitoring surveys at NEGR05 are presented in Figure 18. In terms of reef substrate cover, the rank order of benthic categories remained stable between surveys. Minor relative increments in cover by benthic algae and sponges, with a corresponding decline of the abiotic category were measured in the 2018 monitoring survey. Reef substrate cover by total live corals declined 3.2%, but this small difference was not statistically significant (ANOVA; $p = 0.55$, Appendix 2a). Minor reductions of cover by Lettuce Coral (*Agaricia agaricites*) and Mustard-Hill Coral (*Porites astreoides*) were measured (Figure 19). These reductions of reef substrate cover by coral species may be related to the loss of colonies associated with the exceptionally high wave and surge action that must have prevailed in this shallow reef during the pass of Hurricane Maria in September 2017 and or the extreme wave event impacting the north and west coast of PR in March 2018. Detached and overturned coral colonies of Massive Starlet Coral (*Siderastrea siderea*) and Lobed Star Coral (*Orbicella annularis*) were observed at NEGR05. Differences of density by octocorals were not statistically significant (ANOVA; $p = 0.199$, Appendix 2b)

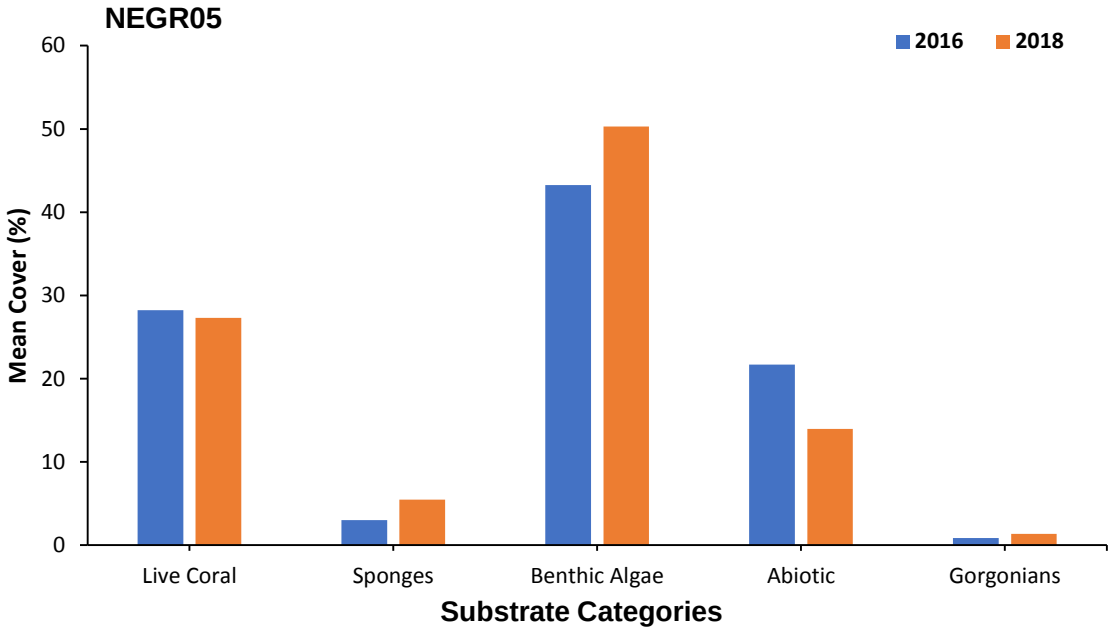



**Figure 18.** NEGR05. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Negro Reef 5m, Cabo Rojo

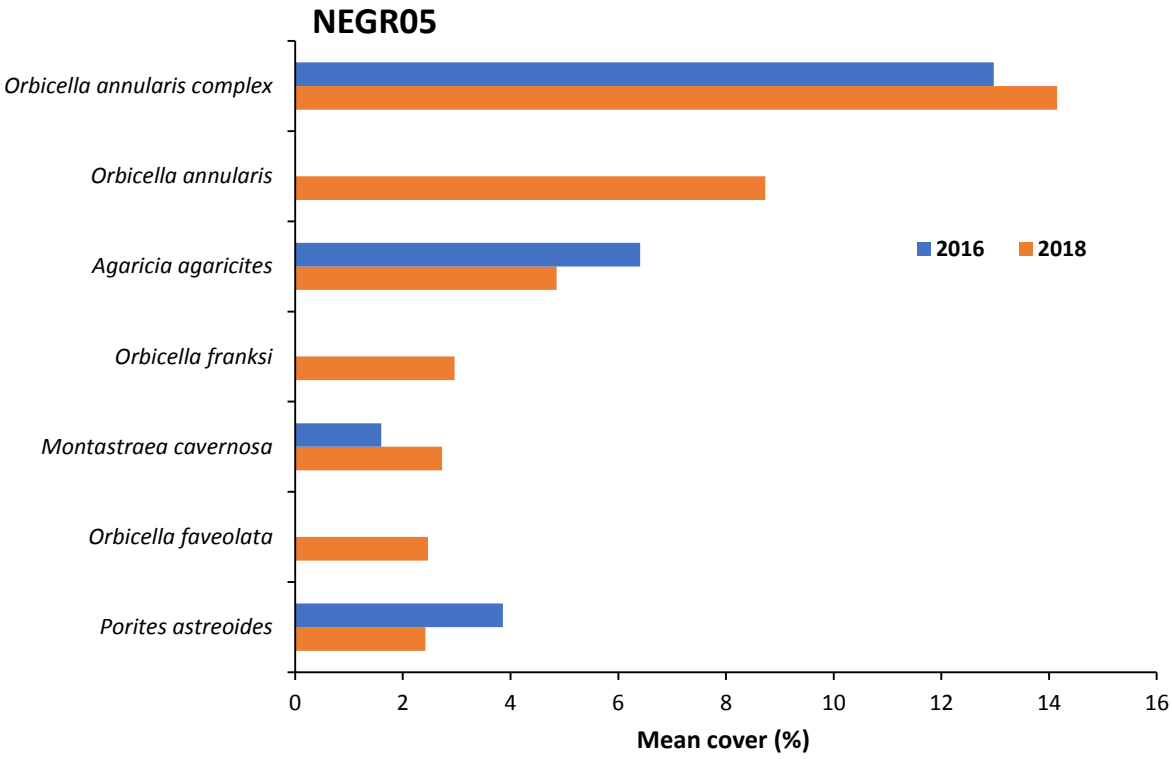



**Figure 19.** NEGR05. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at Negro Reef 5m, Cabo Rojo

### 6.3 Fishes and Motile Megabenthic Invertebrates

A total of 32 species of fish were identified within belt-transects from a mean depth of 6.1 m at NEGR05. Mean density was 60.6 Ind/transect (range: 41 – 75 Ind/transect) with a mean richness of 14.0 species/transect. Blue Chromis (*Chromis cyanea*), and Bluehead Wrasse (*Thalassoma bifasciatum*) were the numerically dominant species within belt-transects with a combined mean density of 24.6 Ind/transect, representing 40.6% of the total individuals (Table 18). The Masked Goby (*Coryphopterus personatus*) ranked third in density with a mean of 7.4 Ind/transect. Only three other species were present in at least four transects. These included the Princess Parrotfish (*Scarus taeniopterus*) and the Three-spot and Dusky Damselfishes (*Stegastes planifrons*, *S. adustus*). Ten species were only present in one transect.

Zooplanktivorous fishes, comprised by two of the three most abundant species within belt-transects (*Chromis cyanea* and *Coryphopterus personatus*) and by Brown Chromis (*C. multilineata*), Fairy Basslet (*Gramma loreto*), and Bicolor Damselfish (*Stegastes partitus*) represented the most prominent trophic assemblage within belt-transects at NEGR05 with a combined density of 22.2 Ind/transect, or 36.6% of the total. Herbivores were represented by five parrotfishes (Scaridae), three damselfishes (Pomacentridae) and two doctorfishes (Acanthuridae) with a combined mean density 19.2%, or 31.7% of the total. Small opportunistic carnivores comprised 29.4% of the total fish density and included at least 12 species within the Labridae (Wrasses), Serranidae (Hamlets and Sea Bases), Tetraodontidae (Puffers), Gerreidae (Mojarras) and Scorpaenidae (Scorpionfishes). Medium-sized piscivores included the Yellowtail and Schoolmaster Snappers (Lutjanidae). Given the smaller size of zooplanktivores relative to the herbivore and carnivore fish species present it can be argued that the trophic structure of fishes at NEGR05 was well balanced but lacking the larger demersal predators. Motile megabenthic invertebrates were represented by two sea cucumbers (*Holothuria mexicana*) within belt-transects (Table 18).

The size-frequency distribution of fish species of commercial value and reef herbivores is presented in Table 19. The wide size range observed for the Stoplight, Bucktooth and Princess Parrotfishes (*Sparisoma viride, S. radians, Scarus taeniopterus*) is indicative that NEGR05 functions as a recruitment and residential habitat for settlement, juvenile and adult individuals of these species. Juvenile and adult doctorfishes (Acanthuridae) were also present. Individuals of the Yellowtail and Schoolmaster Snappers were present as juveniles and young adults. The Lionfish (*Pterois sp*) was observed as a juvenile individual.

**Table 18.** NEGR05. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at El Negro Reef 5m, Cabo Rojo, April 2018

| Mean Depth: 6.1 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Chromis cyanea* | Blue Chromis | 15 | 4 | 7 | 6 | 30 | **12.4** |
| *Thalassoma bifassiatum* | Bluehead Wrasse | 32 | 5 | 12 | 3 | 9 | **12.2** |
| *Coryphopterus personatus* | Masked Goby | | | 26 | 6 | 5 | **7.4** |
| *Scarus taeniopterus* | Princess Parrotfish | | 10 | 8 | 6 | 3 | **5.4** |
| *Stegastes adustus* | Dusky Damselfish | 13 | 4 | | 2 | 5 | **4.8** |
| *Stegastes planifrons* | Three-spot Damselfish | 2 | 6 | 4 | 7 | 4 | **4.6** |
| *Sparisoma viride* | Stoplight Parrotfish | 5 | 2 | 3 | | | **2.0** |
| *Stegastes partitus* | Bicolor Damselfish | | 2 | | 1 | 6 | **1.8** |
| *Canthigaster rostrata* | Caribbean Puffer | | 1 | 1 | 2 | | **0.8** |
| *Coryphopterus lipernes* | Peppermint Goby | | | 2 | | 2 | **0.8** |
| *Elacatinus evelynae* | Sharknose Goby | 1 | | | 3 | | **0.8** |
| *Acanthurus coeruleus* | Blue Tang | | 1 | | 1 | 1 | **0.6** |
| *Chromis multilineata* | Brown Chromis | | 2 | | | 1 | **0.6** |
| *Clepticus parrae* | Creole Wrasse | | 2 | | | 1 | **0.6** |
| *Gramma loreto* | Fairy Basslet | 1 | | 2 | | | **0.6** |
| *Serranus tigrinus* | Harlequin Bass | | 1 | | 1 | 1 | **0.6** |
| *Stegastes leucostictus* | Beau Gregory | | 3 | | | | **0.6** |
| *Cephalopholis cruentata* | Graysby | 1 | | | 1 | | **0.4** |
| *Coryphopterus sp.* | Goby | | | 1 | | 1 | **0.4** |
| *Gerres cinereus* | Yellowfin Mojarra | | 2 | | | | **0.4** |
| *Halichoeres garnoti* | Yellow-head Wrasse | | 1 | | 1 | | **0.4** |
| *Pterois sp* | Lionfish | | 2 | | | | **0.4** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | | 1 | | 1 | **0.4** |
| *Sparisoma radians* | Bucktooth Parrotfish | 2 | | | | | **0.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | 1 | | | | | **0.2** |
| *Cantherhines pullus* | Tail-light Filefish | | | | 1 | | **0.2** |
| *Holocentrus rufus* | Longspine Squirelfish | | | 1 | | | **0.2** |
| *Hypoplectrus nigricans* | Black Hamlet | 1 | | | | | **0.2** |
| *Pomacanthus arcuatus* | Grey Angelfish | | | 1 | | | **0.2** |
| *Stegastes variabilis* | Cocoa Damselfish | 1 | | | | | **0.2** |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | | | | 1 | | **0.2** |
| | **TOTAL INDIVIDUALS** | **75** | **48** | **69** | **41** | **70** | **60.6** |
| | **TOTAL SPECIES** | **12** | **16** | **13** | **15** | **14** | **14.0** |
| | | | | | | | |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Holothuria mexicana* | Donkey's Dong | 1 | | 1 | | | |
| | **TOTAL INDIVIDUALS** | 1 | 0 | 1 | 0 | 0 | **0.4** |
| | **TOTAL SPECIES** | 1 | 0 | 1 | 0 | 0 | **0.4** |

Variations of fish density and species richness between the 2016 baseline and the 2018 monitoring survey are presented in Figure 20. Statistically significant differences of both fish density and species richness (ANOVA, $p < 0.05$; Appendix 3) were evidenced between surveys related to marked declines measured during the 2018 survey. Mean fish density declined 72.8%, from 223.0 Ind/transect in 2016 to 60.6 Ind/transect in 2018. As previously discussed for other

west coast reefs, the main driver of the difference between surveys was the marked density drop of Masked Goby (*Coryphopterus personatus*) from 83.0 Ind/transect in 2016 to 7.4 Ind/transect in 2018. Creole Wrasse (*Clepticus parrae*), another numerically dominant species in terms of fish density at NEGR05 also declined markedly in density from 27.6 Ind/transect in 2016 to 0.6 Ind/transect in 2018. Likewise, several other small fishes exhibited density reductions in 2018 as compared with the 2016 baseline survey, driving the overall community decline, both in terms of density and species richness.

Such temporal variations of fish density and species richness between surveys may be associated with advective displacement (flushing) during high wave and surge forces that must have prevailed during the pass of Hurricane Maria in September 2017, and/or another event of extreme wave action impacting the west and north coasts in March 2018. Compared to other reef stations NEGR05 was particularly exposed to mechanical forces due to its physiographic position in the fore-reef and shallow depth.

**Table 19.** NEGR05. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates within 20 x 3 m belt-transects at El Negro Reef 5m, Cabo Rojo, April 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 6.1 m | | **1** | **2** | **3** | **4** | **5** |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 1 - 12 | | | | |
| *Acanthurus coeruleus* | Blue Tang | | 1 - 5 | | 1 - 7 | |
| | | | | | 1 - 10 | |
| *Cephalopholis cruentata* | Graysby | 1 - 14 | | | | |
| *Lutjanus apodus* | Schoolmaster | | | | | 1 - 14 |
| *Ocyurus chrysurus* | Yellowtail Snapper | | | | | 2 - 7 |
| | | | | | | 3 - 10 |
| | | | | | | 1 - 12 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 - 10 | | 1 - 14 | | |
| *Sparisoma viride* | Stoplight Parrotfish | 1 - 1 | 1 - 2 | 1 - 2 | 3 - 29 | 1 - 26 |
| | | 2 - 5 | 1 - 7 | 1 - 10 | | |
| | | 1 - 19 | 1 - 22 | 1 - 26 | | |
| | | 1 - 26 | | | | |
| *Scarus taeniopterus* | Princess Parrotfish | 2 - 7 | 6 - 2 | 1 - 2 | 2 - 5 | 1 - 5 |
| | | 1 - 24 | 2 - 5 | 3 - 5 | 4 - 7 | 2 - 7 |
| | | | 2 - 7 | 6 - 7 | 2 - 10 | 1 - 10 |
| | | | 2 - 14 | 1 - 17 | 1 - 12 | |
| | | | 1 - 17 | | | |
| *Sparisoma radians* | Bucktooth Parrotfish | 1 - 1 | | | | |
| *Scarus iseri* | Stripped Parrotfish | 1 - 29 | | | | |
| *Pterois sp* | Lionfish | | 2 - 14 | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |

TL = Fish Total Length

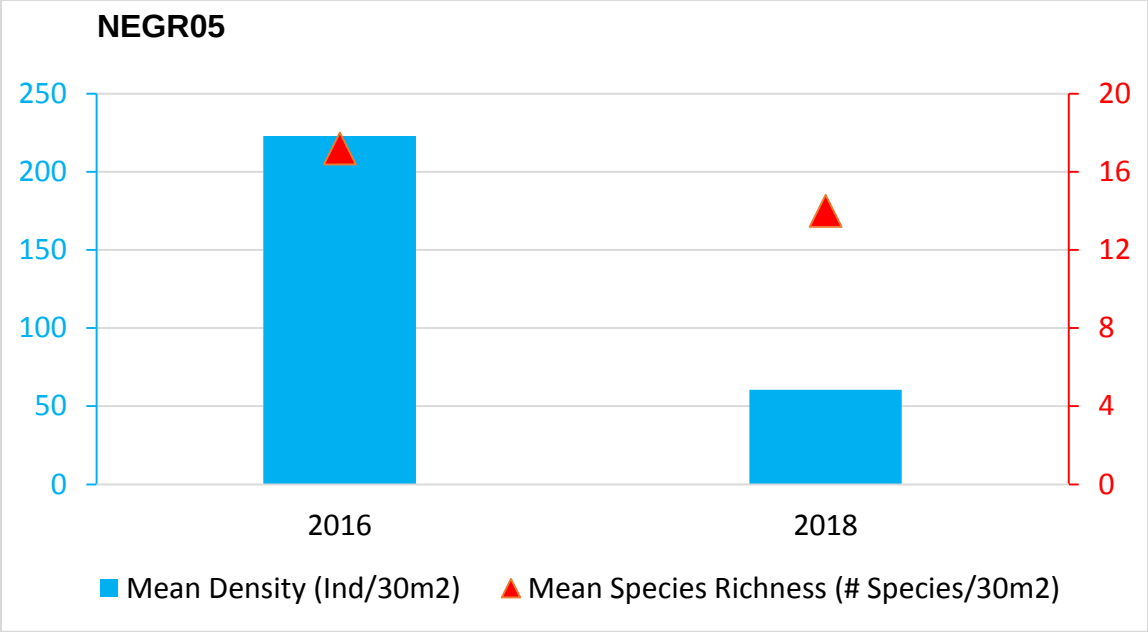



**Figure 20.** NEGR05. Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at El Negro Reef 5m, Cabo Rojo

**Photo Album 6**

**El Negro Reef 5m, Cabo Rojo (NEGR05)**






## C. Isla Desecheo Reef Systems

### 7.0 Puerto Canoas Reef 30m, Isla Desecheo (CANO30)

### 7.1 Physical Description

Isla Desecheo is an oceanic island in Mona Passage, located approximately nine nautical miles off Rincón, northwest coast of Puerto Rico. The island, which used to be a U. S. Navy shooting range during the Second World War, was designated as a Natural Reserve in 1999. Marine communities at Isla Desecheo are influenced by clear waters, strong currents and seasonally high wave action from North Atlantic winter swells (cold fronts). Coral reefs are established off the west coast at depths between 15 and (at least) 50 m (García-Sais et al., 2005 b). Coral monitoring surveys were performed at depths of 15 and 20 m off Puerto Botes, and at 30 m off Puerto Canoas, on the southwest coast of Isla Desecheo. The baseline monitoring survey for the Puerto Botes Reef at a depth of 20 m (BOTE20) was performed during June 2000 by García-Sais et al. (2001 b). For Puerto Botes Reef at 15 m (BOTE15) and for Puerto Canoas Reef at 30 m (CANO30) the baseline survey was performed during August 2004 by García-Sais et al. (2004 a). Figure 21 shows the location of coral reef monitoring stations at Isla Desecheo.

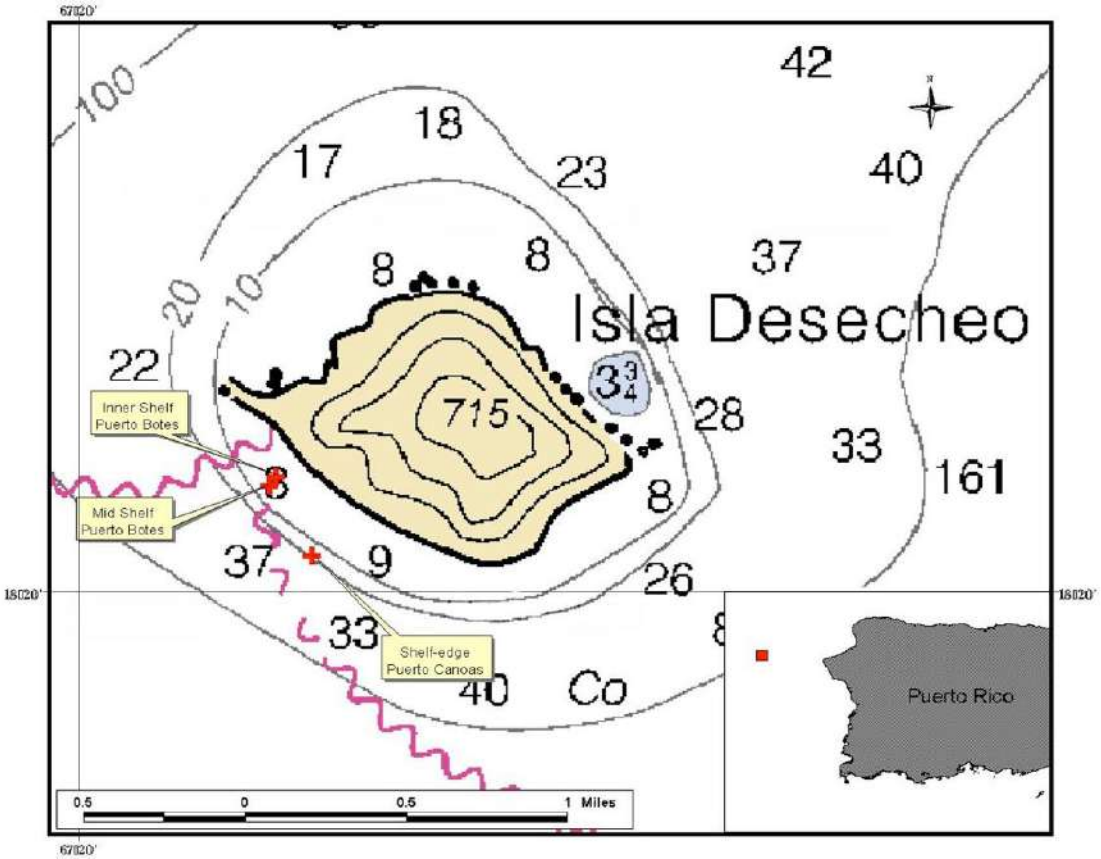



**Figure 21.** Location of coral reef survey stations at Puerto Canoas and Puerto Botes, Isla Desecheo.

The shelf-edge off Puerto Canoas is at the southwest end of a massive and impressive coral buildup that has developed as a series of patch reef promontories separated by coralline sand deposits. Coral promontories are typically comprised of several very large colonies of Mountainous Star Coral, *Orbicella faveolata*. There are colonies that rise from the bottom at least four meters and extend horizontally more than 5 meters, in some instances merging with other large colonies to form continuous laminar coral formations that are unique in Puerto Rico. Towards the northern end, the shelf-edge reef platform leads to an almost vertical wall with sparse coral growth down to a depth of 40 m. At the southern end, the reef platform ends in an extensive sand deposit that slopes down gently to a depth of about 70 m. Our survey was performed right at the end of the reef on the southern section. Transects were installed at a depth of 25 – 30 m, bordering the edge of three of the larger massive coral promontories. Panoramic views of the shelf edge reef at Puerto Canoas are presented as Photo Album 7.

**7.2 Sessile-benthic Reef Community**

Benthic macroalgae, comprised by an assemblage of fleshy brown, turf, and red crustose coralline algae were the dominant sessile-benthic category in terms of ref substrate cover at CANO30 with a combined mean cover of 51.36% (Table 20). The fleshy brown Encrusting Fan Alga (*Lobophora variegata*) was prominent in all five transects with a mean cover of 24.09%, representing 46.9% of the total cover by benthic algae. Another fleshy brown macroalga, the Y-Twig Alga (*Dictyota sp*.) was present in four transects with variable densities of up to 8.54% in transect 3. Turf algae, a mixed assemblage of short filamentous red and brown algae was also present in all transects with a mean cover of 20.00%. Red crustose coralline algae including Peyssonnelid and other CCA taxa were present with a combined cover of 5.24%. Cyanobacteria were observed overlying hard reef substrates in all transects with a relatively high mean cover of 5.31% compared to the PRCRMP mean of 3.22% for all stations during the 2018 survey. This represents a 55.0% decline from the previous survey in 2015, probably driven by the abrasive effects during high swells.

Hard corals were represented by 10 scleractinian species with a mean cover of 29.60% (range: 25.28 – 33.76%). A total of 57 colonies were intercepted by the five transects surveyed. Mountainous Star Coral (*Orbicella faveolata*), with a mean cover of 10.54% was the dominant coral species representing 39.2% of the total coral cover (Table 20). One colony of *Montastrea cavernosa* showed signs of an infectious disease, resulting in a coral disease prevalence of 1.8% for CANO30 (Appendix 4). Several colonies of Bushy Black Coral (*Antipathes caribbeana*) and Wire Coral (*Stichopathes lutkeni*) were observed near the base of the reef and within crevices.

**Table 20**. CANO30. Percent cover by sessile-benthic substrate categories at Puerto Canoas Reef 30 m Isla Desecheo. Survey Date: 5/26/18

| | | | Transects | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | **25.8** | **24.2** | **25.2** | **24.5** | **25.8** | **25.1** |
| Rugosity (m) | 4.00 | 0.98 | 1.63 | 2.03 | 3.92 | **2.51** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Sand | 3.00 | | | | | **0.60** |
| Gap | 0.60 | 0.51 | 0.36 | | | **0.29** |
| Reef overhang | 4.60 | | 7.82 | 2.91 | 5.43 | **4.15** |
| **Total Abiotic** | **8.20** | **0.51** | **8.18** | **2.91** | **5.43** | **5.05** |
| **Benthic Algae** | | | | | | |
| *Lobophora variegatus* | 29.10 | 26.91 | 26.11 | 15.48 | 22.84 | **24.09** |
| Turf algae (mixed) | 13.50 | 27.17 | 22.62 | 23.75 | 12.98 | **20.00** |
| Peyssonnelid | 4.00 | 4.97 | 3.25 | 2.68 | 4.43 | **3.87** |
| *Dictyota* spp. | 0.30 | 0.51 | 8.54 | 0.81 | | **2.03** |
| CCA (mixed) | 2.20 | 0.38 | | 2.44 | 1.81 | **1.37** |
| **Total Benthic Algae** | **49.10** | **59.95** | **60.52** | **45.17** | **42.05** | **51.36** |
| **Cyanobacteria** | **6.60** | **4.21** | **1.20** | **1.86** | **12.68** | **5.31** |
| **Hard Coral** | | | | | | |
| *Orbicella faveolata* | 8.60 | | 12.03 | 15.48 | 16.60 | **10.54** |
| *Orbicella franksi* | 2.50 | 21.05 | 4.81 | 6.17 | 3.32 | **7.57** |
| *Porites astreoides* | 4.40 | 1.02 | 4.21 | 8.85 | 3.12 | **4.32** |
| *Agaricia agaricites* | 7.40 | 3.95 | 2.89 | 0.70 | 6.54 | **4.30** |
| *Colpophyllia natans* | 6.90 | | | | | **1.38** |
| *Montastraea cavernosa* | | | | 2.56 | | **0.51** |
| *Pseudodiploria strigosa* | | | | | 2.31 | **0.46** |
| *Leptoseris cucullata* | | | 1.32 | | | **0.26** |
| *Meandrina meandrites* | | | | | 1.01 | **0.20** |
| *Porites porites* | | 0.26 | | | | **0.05** |
| **Total Hard Coral** | **29.80** | **26.28** | **25.26** | **33.76** | **32.90** | **29.60** |
| **# CoralColonies /Transect** | **8** | **10** | **10** | **15** | **14** | **11.4** |
| **# Diseased Coral Colonies** | **0** | **0** | **0** | **0** | **1** | |
| **Total Octocorals** | **0** | **0** | **0** | **0** | **0** | **0.0** |
| **Sponges** | | | | | | |
| *Agelas citrina* | | 2.81 | 4.21 | 6.87 | 1.31 | **3.04** |
| *Agelas clathrodes* | 2.50 | 1.02 | | 1.40 | 1.91 | **1.37** |
| Unknown sponge | 1.30 | 4.21 | | 0.93 | | **1.29** |
| *Svenzea zeai* | | | | 5.36 | | **1.07** |
| *Agelas conifera* | | 0.51 | | | 2.72 | **0.65** |
| *Scopalina ruetzerli* | 2.00 | 0.13 | | 0.58 | | **0.54** |
| *Dead sponge* | | | | 1.16 | | **0.23** |
| *Agelas sceptrum* | | | | | 1.01 | **0.20** |
| *Ircinia strobilina* | | | 0.60 | | | **0.12** |
| *Verongula rigida* | 0.50 | | | | | **0.10** |
| *Agelas dispar* | | 0.38 | | | | **0.08** |
| **Total Sponges** | **6.30** | **9.06** | **4.81** | **16.30** | **6.94** | **8.68** |

Octocorals were not intercepted by transects and are not common at CANO30. Branching, encrusting and erect sponges included at least 11 species within transects with a mean cover of 8.68%. An assemblage comprised of at least four *Agelas spp*. was the most prominent sponge taxa at CANO30. Abiotic cover mostly associated with reef overhangs averaged 5.05% and contributed to a mean reef substrate rugosity of 2.51 m.

Figure 22 shows the annual variations of mean percent cover by the main sessile-benthic categories from CANO30. Differences of mean substrate cover by stony corals, sponges and benthic algae between the 2004 baseline characterization and the 2005 monitoring surveys were within 1% and statistically insignificant. A sharp, statistically significant decline of mean live coral cover was observed between the 2005 (48.07%) and the 2006 (37.50%) survey (ANOVA; $p < 0.0001$, Appendix 2a). The decline of mean live coral cover was largely associated with the dominant reef building species, *Orbicella annularis* (complex), which varied from a mean cover of 32.7% in 2005 to 24.4% in 2006 (Figure 23). At the time of the 2006 monitoring survey (mid-June), *O. annularis* (complex) still showed partially bleached conditions representing 5.7% of its mean reef substrate cover, equivalent to 23.4% of the remaining live coral tissue within surveyed transects at 25 – 30 m. A mild trend of decreasing live cover was observed from 2006 until the 2010 survey. A corresponding increment of substrate cover by benthic algae, cyanobacteria, sponges and abiotic categories was noted during this period (Figure 22).

A recuperation trend of live coral cover, in part driven by increasing cover of *Orbicella spp.* (Figure 23) has been consistently measured since the 2013 monitoring survey at CANO30, however differences associated with the increasing coral cover are still not statistically significant. Interestingly, live coral cover increased 4.3%, from 28.38% in 2015 (previous monitoring survey) to 29.60% in 2018 despite partial breakage and displacement of large coral colonies in transects 2 and 3 associated with mechanical forces, perhaps caused by Hurricane Maria and/or other events of extreme wave action.

A 35.6% increase of reef substrate cover by benthic algae was strongly influenced by a 1.9-fold increase of brown fleshy algae (*Lobophora variegate* + *Dictyota sp*.). Despite the relatively small island mass of Isla Desecheo and its considerable distance from mainland river plumes increased nutrient availability for algal growth could have been brought by upwelling currents associated with the hurricane cyclonic divergence and/or organic sediment resuspension sources.

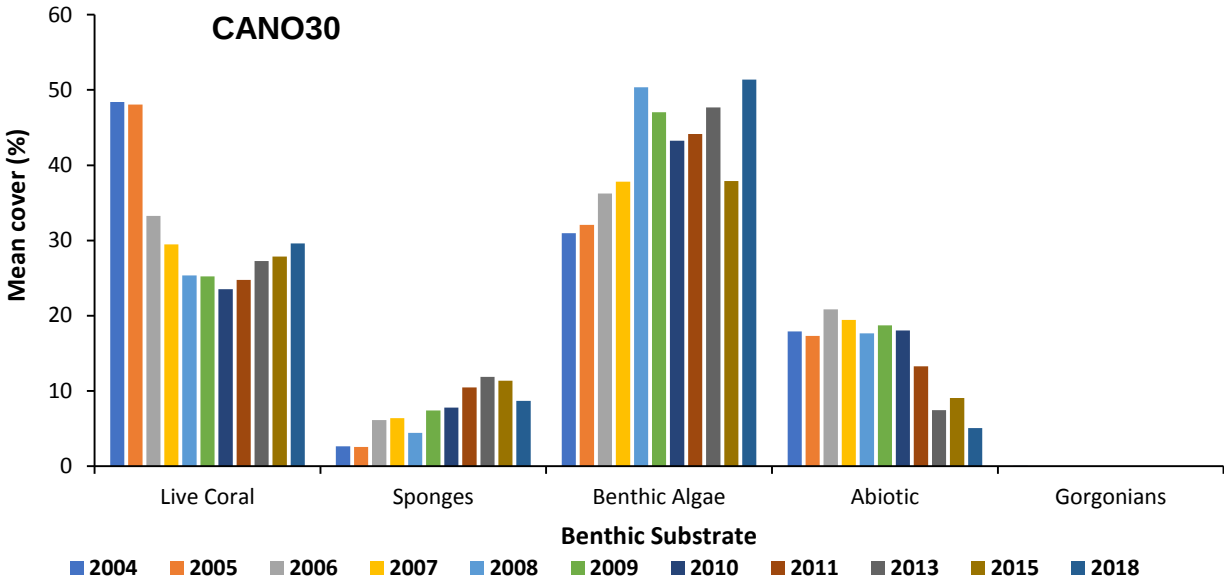



**Figure 22.** CANO30. Annual variations (2004 -18) of mean substrate cover by sessile-benthic categories at Puerto Canoas Reef 30m, Isla Desecheo

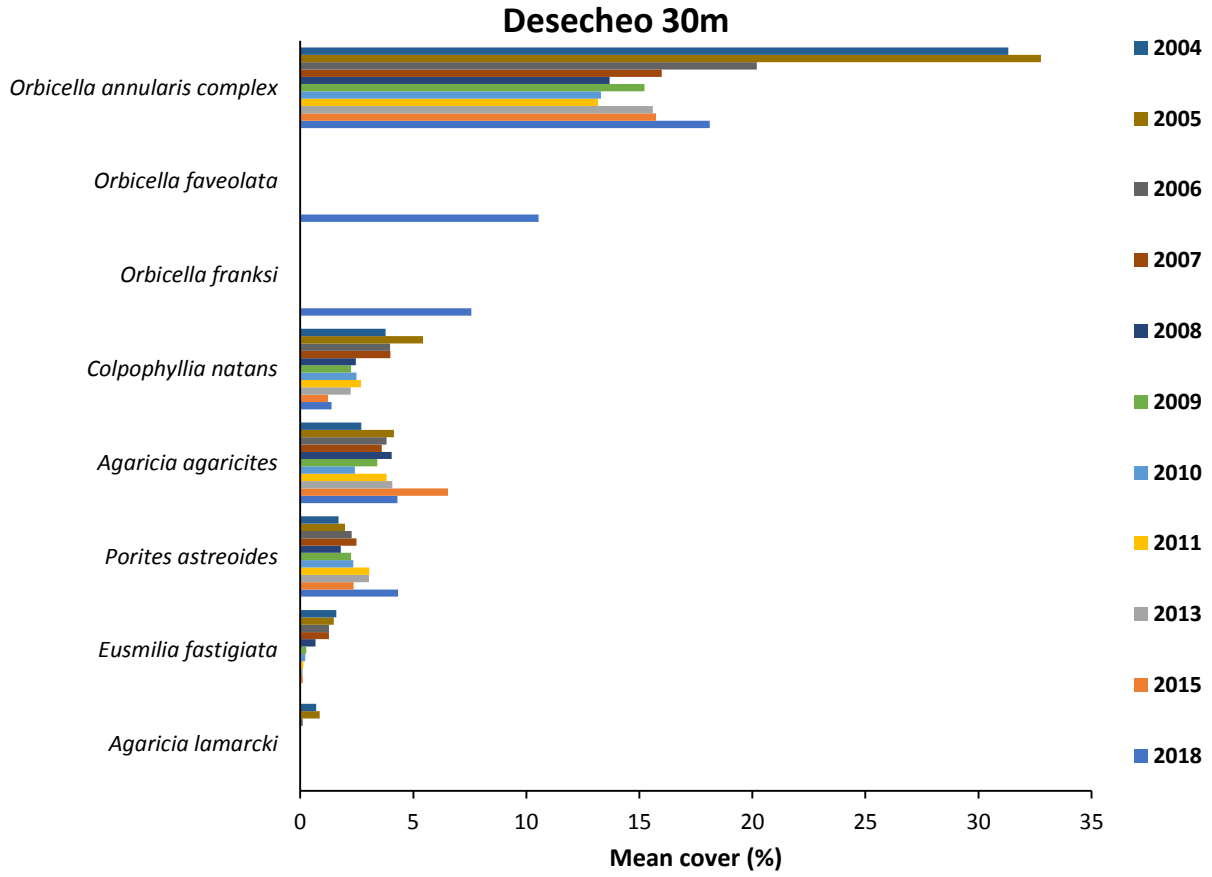



**Figure 23.** CANO30. Annual variations (2004 -18) of mean substrate cover by the main coral species intercepted by transects at Puerto Canoas Reef 30m, Isla Desecheo

### 7.3 Fishes and Motile Megabenthic Invertebrates

Density of fishes and motile megabenthic invertebrates within belt-transects surveyed at CANO30 during 2018 are presented in Table 21. Fish density averaged 76.4 Ind/30 $m^2$ (range: 65 – 94 Ind/30 $m^2$). The mean number of species per transect was 20.4 (range: 20 – 21). An assemblage of eight species, including the Blue Chromis, Creole, Bluehead and Yellowhead Wrasses, Peppermint and Sharknose Gobies, Fairy Basslet and Bicolor Damselfish were present in at least four transects and represented 68.3% of the total fish abundance within belt-transects. The aforementioned assemblage, perhaps with the exception of Creole Wrasse are small territorial species that occupy microhabitats within the reef structure. Swarms of early juvenile Creole Wrasse were also observed close to the reef.

The fish community structure at CANO30 was characterized by the high relative abundance of pelagic and demersal zooplanktivores, which comprised approximately 56.3% of the total individuals within transects. These included the Blue, Brown and Sunshine Chromis, Bicolor Damselfish (Pomacentridae), Fairy Basslet (Grammatidae), Masked Goby (Gobiidae) and Creole Fish (Serranidae). Small opportunistic carnivores included three wrasses (Labridae), two gobies (Gobiidae), two squirrelfishes (Holocentridae), one Hawkfish (Cirrhitidae), one puffer (Tetraodontidae) and one small grouper (Serranidae) with a combined density of 18.4 Ind/30 $m^2$, representing 24.1% of the total individuals within belt-transects. Herbivores included six parrotfishes (Scaridae), two damselfishes (Pomacentridae) and one doctorfish (Acanthuridae) with a combined density of 6.6 Ind/30 $m^2$, representing 8.6% of the total individuals. Small and medium sized piscivores were observed in extended belt-transects. These included four groupers (Serranidae) and two snappers (Lutjanidae). Large pelagic predators were represented by one Great Barracuda (Sphyraenidae).

Size distributions of commercially important fish species and the larger reef herbivores are indicative that this reef serves as a residential habitat for large demersal predators (Table 22). One adult Nassau grouper, Red Hinds, Coneys and Graysbys (Serranidae) were observed along with adult stages of several snappers (Lutjanidae). Other large groupers, snappers and sharks have been previously reported for this reef station (Garcia-Sais et al., 2015 and references therein). Reef herbivores, including parrotfishes (Scaridae) and doctorfishes (Acanthuridae) were mostly observed as late juvenile and adult stages, but recruitment juveniles of Bucktooth and Stoplight Parrotfishes have been previously observed at CANO30.

**Table 21.** CANO30. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Pto. Canoas Reef 30m, Isla Desecheo, May 2018

| Mean Depth: 25.1 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Chromis cyanea* | Blue Chromis | 14 | 21 | 11 | 6 | 12 | **12.8** |
| *Clepticus parrae* | Creole Wrasse | 4 | 3 | 3 | 20 | 19 | **9.8** |
| *Gramma loreto* | Fairy Basslet | 7 | 8 | 11 | 9 | 8 | **8.6** |
| *Thalassoma bifassiatum* | Bluehead Wrasse | 8 | 6 | 6 | 5 | | **5.0** |
| *Stegastes partitus* | Bicolor Damselfish | 5 | 3 | 9 | 4 | 3 | **4.8** |
| *Coryphopterus lipernes* | Peppermint Goby | 4 | 11 | 3 | 3 | 2 | **4.6** |
| *Elacatinus evelynae* | Sharknose Goby | 2 | 2 | 1 | 6 | 11 | **4.4** |
| *Coryphopterus personatus* | Masked Goby | | | | | 18 | **3.6** |
| *Mulloides martinicus* | Yellow Goatfish | | | 13 | | | **2.6** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 3 | 1 | 3 | 3 | 1 | **2.2** |
| *Chromis insolata* | Sunshine Chromis | 5 | | | | 5 | **2.0** |
| *Stegastes planifrons* | Three-spot Damselfish | | 2 | 1 | 2 | 3 | **1.6** |
| *Bodianus rufus* | Spanish Hogfish | | 2 | 5 | | | **1.4** |
| *Chromis multilineata* | Brown Chromis | 1 | 2 | 2 | 1 | | **1.2** |
| *Acanthurus coeruleus* | Blue Tang | 2 | 1 | 1 | 1 | | **1.0** |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 1 | | 3 | | 1 | **1.0** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 | | 1 | 2 | 1 | **1.0** |
| *Scarus iseri* | Striped Parrotfish | 1 | | 2 | | 1 | **0.8** |
| *Sparisoma radians* | Bucktooth Parrotfish | 2 | 1 | | | 1 | **0.8** |
| *Sparisoma viride* | Stoplight Parrotfish | 1 | | | 1 | 2 | **0.8** |
| *Amblychirrinus pinos* | Redspoted Hawkfish | 1 | 1 | | | 1 | **0.6** |
| *Cephalopholis cruentata* | Graysby | | 1 | 1 | 1 | | **0.6** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | 2 | | 1 | | **0.6** |
| *Melichthys niger* | Black Durgon | 1 | 1 | | | 1 | **0.6** |
| *Canthigaster rostrata* | Caribbean Puffer | | | 1 | 1 | | **0.4** |
| *Chaetodon aculeatus* | Longnose Butterflyfish | | | | 1 | 1 | **0.4** |
| *Chaetodon striatus* | Banded Butterflyfish | | 2 | | | | **0.4** |
| *Holacanthus tricolor* | Rock Beauty | | | 1 | 1 | | **0.4** |
| *Holocentrus rufus* | Longspine Squirelfish | | 1 | | | 1 | **0.4** |
| *Scarus taeniopterus* | Princess Parrotfish | | | 2 | | | **0.4** |
| *Halichoeres maculipinna* | Clown Wrasse | | 1 | | | | **0.2** |
| *Holacanthus ciliaris* | French Angelfish | | | | | 1 | **0.2** |
| *Kyphosus bermudensis* | Bermuda Chub | 1 | | | | | **0.2** |
| *Lactophrys triqueter* | Smooth Trunkfish | | | | 1 | | **0.2** |
| *Lutjanus apodus* | Schoolmaster | | | | | 1 | **0.2** |
| *Neoniphon marianus* | Longjaw Squirrelfish | | 1 | | | | **0.2** |
| *Paranthias furcifer* | Creole Fish | | | | 1 | | **0.2** |
| *Scarus vetula* | Queen Parrotfish | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | **65** | **73** | **80** | **70** | **94** | **76.4** |
| | **TOTAL SPECIES** | **20** | **21** | **20** | **20** | **21** | **20.4** |
| | | | | | | | |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Periclimenes pedersoni* | Cleaner Shrimp | | | | | 1 | 0.2 |
| *Diadema antillarum* | Longspine Urchin | | | | 1 | | 0.2 |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 0 | 1 | 1 | **0.4** |
| | **TOTAL SPECIES** | 0 | 0 | 0 | 1 | 1 | **0.4** |

Motile megabenthic invertebrates were represented by one Long-spined Urchin (*Diadema antillarum*) and Cleaner Shrimp (*Periclimenes pedersoni*) within belt-transects (Table 21). One adult Queen Conch (*Strombus gigas*) was observed in extended transects (Table 22). One Spiny Lobster (*Panulirus argus*) was observed outside transects.

Variations of fish abundance and species richness between monitoring surveys at CANO30 are presented in Figure 24. Statistically significant differences between surveys of both fish density and species richness were noted. Between 2004 and 2008, mean fish abundance fluctuated between 400 – 500 Ind/30 $m^2$ to stand as one of the reefs with highest fish abundance studied in the PRCRMP. During 2009 a declining trend of fish abundance continued until 2010, but record high abundance was observed during the 2012 survey driven by peak densities of Masked Goby (*Coryphopterus personatus*), which is a numerically dominant species. Such density fluctuations suggest that the recruitment dynamics of short-lived numerically dominant species may play an important role regulating the population abundance of zooplanktivorous fishes.

During 2018, historically low mean fish density and species richness were surveyed at CANO30. Fish density declined more than 5-fold, from 394.2 Ind/30 $m^2$ in 2015 (previous survey) to 76.4 Ind/30 $m^2$ in 2018. A corresponding decline in number of species per transect was not measured, but differences between the baseline richness at 36 species/transect and the present richness were statistically significant (ANOVA; $p < 0.0001$, Appendix 3). The reef structure at CANO30 has suffered substantial degradation since its baseline survey of 2004, particularly associated with marked loss of live coral cover during and after the bleaching event of late 2005. While the reef keeps showing slow but consistent recuperation of its live coral cover it is still well below its baseline condition. The implications upon the fish community are unclear and deserve further consideration.

The pass of Hurricane Maria in September 2017, and perhaps another event of extreme wave action in March 2018 may have impacted the reef community at CANO30 by advective displacement of small pelagic fishes that may have not withstood the exceptionally strong surge and abrasion forces that prevailed during these events, as evidenced by the physical destruction of large coral structures.

**Table 22.** CANO30. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates within 20 x 3 m belt-transects at Pto. Canoas Reef 30m, Isla Desecheo, May 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 25.1 m | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus coeruleus* | Blue Tang | 1 - 7 | | 1 - 10 | 1 - 7 | |
| | | 2 - 12 | | | 1 - 10 | |
| *Cephalopholis fulva* | Coney | | | | | 2 - 24 |
| *Cephalopholis cruentata* | Graysby | | 1 - 12 | 1 - 14 | 1 - 14 | |
| *Epinephelus guttatus* | Red Hind | | | | 1 - 29 | |
| *Epinephelus striatus* | Nassau Grouper | | 1 - 65 | | | |
| *Lutjanus apodus* | Schoolmaster | 3 - 24 | | 2 - 14 | 1 - 26 | 1 - 26 |
| | | 2 - 29 | | | | |
| *Lutjanus mahogony* | Mahogany Snapper | | | | | 1 - 29 |
| *Scarus iseri* | Striped Parrotfish | | 1 - 24 | 2 - 10 | | 1 - 7 |
| *Scarus taeniopterus* | Princess Parrotfish | | | 2 - 10 | 1 - 17 | |
| | | | | 1 - 12 | | |
| | | | | 1 - 19 | | |
| *Scarus vetula* | Queen Parrotfish | 1 - 34 | | | | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 - 19 | | 1 - 10 | 1 - 7 | 1 - 7 |
| | | 1 -24 | | 1 - 12 | 1 - 14 | |
| *Sparisoma radians* | Bucktooth Parrotfish | | 1 - 2 | | | 1 - 5 |
| *Sparisoma viride* | Stoplight Parrotfish | | | | 1 - 7 | 1 - 24 |
| | | | | | | 1 - 29 |
| | | | | | | 1 - 34 |
| *Sphyraena barracuda* | Great barrracuda | | 1 - 72 | | | |
| | | | | | | |
| **Invertebrates** | | | | | | |
| *Strombus gigas* | Queen Conch | | | | | 1 - 24 |
| **Out of Transects** | | | | | | |
| *Panulirus argus* | Spiny Lobster | 1 - 8 | | | | |
| | | | | | | |
| TL = Fish Total Length | | | | | | |
| Lobster length is the carapace length in cm | | | | | | |

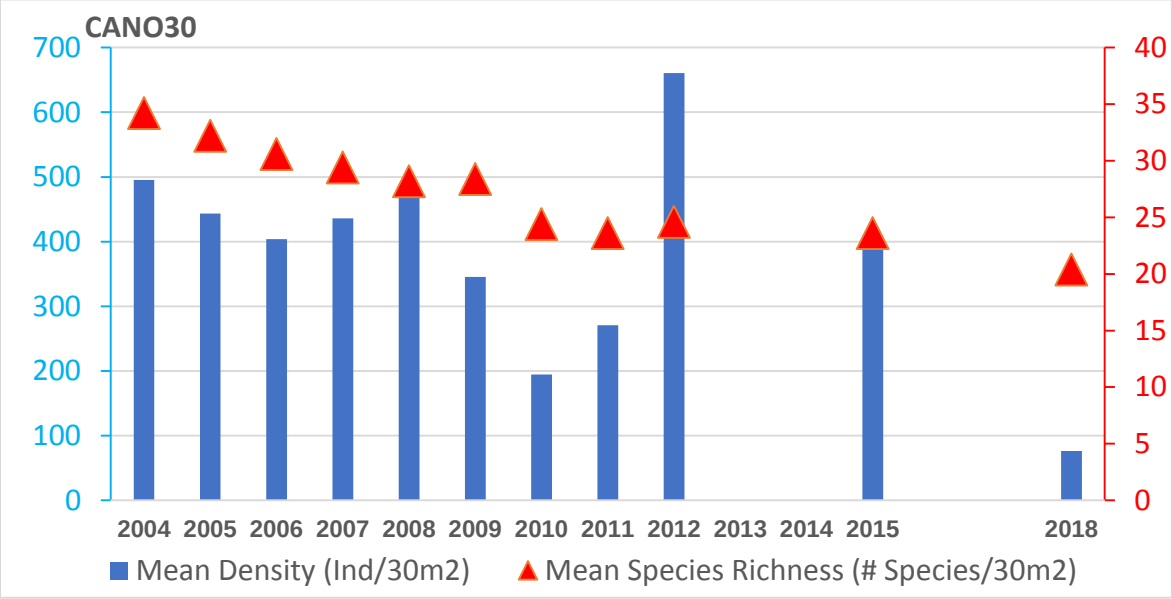


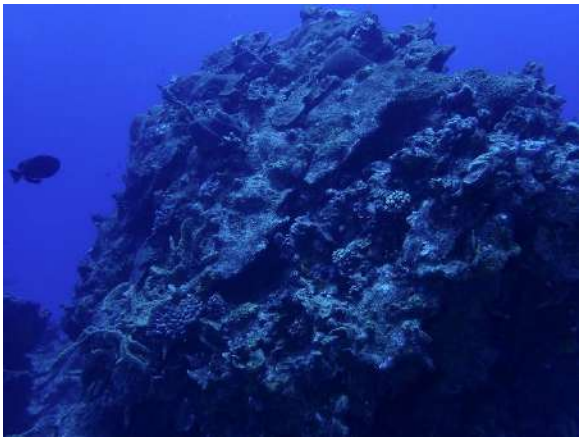

**Figure 24.** CANO30. Monitoring trends (2004 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Puerto Canoas Reef, Isla Desecheo

**Photo Album 7**

**Puerto Canoas Reef, Isla Desecheo (CANO30)**





## 8.0 Puerto Botes Reef 20m, Isla Desecheo (BOTE20)

### 8.1 Physical Description

A series of large submerged reef patches of massive, branching and encrusting coral buildup occupy most of the mid-shelf section off BOTE20 at depths between 17 - 23 meters on the west coast of Isla Desecheo. The coral reef system is exuberant, with large stony corals growing close together and forming large promontories that provide very high topographic relief. At some points, sand channels cut through the sloping terrace of the reef towards the shelf-edge. Permanent transects were installed over two adjacent patch reef promontories separated by a narrow sand channel. The five transects lie close to the border of each patch reef at depths between 17 -19 m (Figure 21). The initial baseline characterization was performed in June 2000 (García-Sais et al., 2001b). This is the 11$^{th}$ monitoring survey of BOTE20. Digital photos of BOTE20 at Isla Desecheo are shown as Photo Album 8.

### 8.2 Sessile-benthic Reef Community

A mixed assemblage of turf, fleshy brown, and red crustose coralline algae was the dominant sessile-benthic category covering reef substrate at BOTE20 with a combined mean cover by benthic algae of 81.23% (range: 73.99 - 84.48%). Turf algae was present in all surveyed transects as a dense carpet overlying dead coral sections with a mean cover of 38.87%, representing 47.9% of the total benthic algae (Table 23). The combined cover by fleshy brown macroalgae, including the Encrusting Fan Alga (*Lobophora variegata*), Y-Twig Alga (*Dictyota sp*.), and *Stypopodium sp*. was 37.75%, representing 46.5% of the total. Red crustose coralline algae, including Peyssonnelid and other mixed CCA were also present in all transects with a combined cover of 4.51%.

Cyanobacterial patches were present in two transects with a relatively low mean substrate cover of 0.48% compared to the PRCRMP mean for the 2018 survey (3.22%) and represents a marked decline of 87.0% from the previous 2015 monitoring survey at BOTE20 (e.g. 3.69%). This is consistent with the decline of cyanobacterial cover observed at CANO30 and supports the argument that strong surge and abrasive forces associated with the pass of hurricanes and/or other events of exceptionally high wave action could have been the main drivers of the cyanobacterial decline.

| **Table 23.** BOTE20. Percent cover by sessile-benthic categories at Puerto Botes Reef 20m, Isla Desecheo | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 5/26/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 17.3 | 17.6 | 17.3 | 17.3 | 17.6 | **17.4** |
| Rugosity (m) | 2.99 | 2.99 | 2.81 | 1.84 | 1.59 | **2.44** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 4.31 | 4.31 | 6.56 | | 5.80 | **4.20** |
| **Total Abiotic** | **4.31** | **4.31** | **6.56** | **0.00** | **5.80** | **4.20** |
| **Benthic Algae** | | | | | | |
| Turf algae (mixed) | 42.13 | 37.48 | 31.04 | 49.64 | 34.05 | **38.87** |
| *Lobophora variegata* | 25.00 | 26.72 | 29.84 | 13.83 | 30.31 | **25.14** |
| *Dictyota* spp. | 14.33 | 10.78 | 5.46 | 4.96 | 5.92 | **8.29** |
| *Stypopodium* sp. | 1.08 | 3.77 | 6.89 | 2.48 | 7.37 | **4.32** |
| Peyssonnelid | 1.51 | 2.80 | 5.14 | 0.71 | 2.90 | **2.61** |
| CCA (mixed) | 0.43 | 0.54 | 4.70 | 2.36 | 1.45 | **1.90** |
| *Galaxaura* sp. | | | 0.55 | | | **0.11** |
| **Total Benthic Algae** | **84.48** | **82.09** | **83.61** | **73.99** | **82.00** | **81.23** |
| **Cyanobacteria** | **0.54** | **0.00** | **1.86** | **0.00** | **0.00** | **0.48** |
| **Hard Coral** | | | | | | |
| *Porites porites* | | | | 14.30 | 2.29 | **3.32** |
| *Orbicella annularis* | 7.76 | | | | | **1.55** |
| *Orbicella franksi* | | 4.74 | | 2.48 | | **1.44** |
| *Porites astreoides* | 0.43 | | 1.86 | 0.59 | 4.23 | **1.42** |
| *Meandrina meandrites* | | | 1.97 | | 3.86 | **1.17** |
| *Orbicella faveolata* | 1.08 | 2.69 | 1.97 | | | **1.15** |
| *Agaricia agaricia* | | 3.45 | 0.44 | 0.59 | | **0.90** |
| *Diploria labyrinthiformis* | | | | 1.77 | | **0.35** |
| *Millepora alcicornis* | | 0.43 | | 0.47 | | **0.18** |
| *Stephanocoenia intersepta* | | | | 0.35 | | **0.07** |
| *Madracis decactis* | 0.32 | | | | | **0.06** |
| **Total Hard Coral** | **9.59** | **11.31** | **6.23** | **20.57** | **10.39** | **11.62** |
| **# CoralColonies /Transect** | **5** | **7** | **5** | **7** | **7** | **6.2** |
| **# Diseased Coral Colonies** | **0** | **2** | **1** | **1** | **1** | |
| **Total Octocoral** | **0** | **0** | **0** | **0** | **0** | **0.0** |
| **Sponges** | | | | | | |
| *Agelas citrina* | | 1.94 | | 0.71 | 0.24 | **0.58** |
| *Agelas sceptrum* | | | 0.44 | 1.89 | | **0.47** |
| *Agelas clathrodes* | | | 0.98 | | | **0.20** |
| *Scopalina ruetzleri* | | 0.32 | | | 0.48 | **0.16** |
| *Ircinia strobilina* | | | | | 0.72 | **0.14** |
| *Biemna* sp. | 0.43 | | | | | **0.09** |
| Unknown sponge | 0.43 | | | | | **0.09** |
| *Aplysina insularis* | | | | | 0.36 | **0.07** |
| *Aphimedon compressa* | | | 0.33 | | | **0.07** |
| **Total Sponges** | **0.86** | **2.26** | **1.75** | **2.60** | **1.81** | **1.86** |

Hard (stony) corals were represented by 10 species of scleractinians and one hydrocoral in transects at BOTE20. Live coral cover averaged 11.62% (range (6.23 – 20.57%) with a total of 31 coral colonies intercepted by the set of five transects (Table 23). Finger Coral (*Porites porites*) was the species with highest substrate cover with a mean of 3.32%, representing 28.5% of the total coral cover. It was present as a large colony and one smaller colony in two of the five transects surveyed. Mustard Hill Coral (*P. astreoides*), Mountainous Star Coral (*Orbicella faveolata*), and Lettuce Coral (*Agaricia agaricites*) were the only coral species present in at least three transects. Five (5) apparently diseased coral colonies (*O. franksi, O. faveolata, Meandrina meandrites, Stephanocoenia intersepta*) were observed at BOTE20, yielding a coral disease prevalence within transects of 16.1% (Appendix 4).

Branching and encrusting sponges presented a mean substrate cover of 1.86% at BOTE20 (Table 23). Tube sponges, *Agelas citrina, A. sceptrum,* and *A. clathrodes* comprised the main assemblage along transects surveyed with a combined cover of 1.25%. Erect gorgonians were not intersected by line transects and are not common at BOTE20. Reef overhangs largely associated with skeletal buildups of *O. faveolata* presented a mean cover of 4.20% and contributed to the reef rugosity of 2.44 m.

From the initial baseline characterization of 2000 until the 2005 survey, stony corals represented the most prominent sessile-benthic component at BOTE20 with a mean reef substrate cover that fluctuated slightly between 47.2 - 48.0% (Figure 25). Differences of live coral cover between monitoring surveys were minimal and statistically insignificant until the 2006 monitoring survey when live coral cover declined sharply to a mean of 22.4%, a loss of 52.4% from the mean live coral cover in 2005. Live coral cover continued its consistent decline until 2013 to a historical minimum of 10.9%. Differences of live coral between the 2000 – 2005 and the 2006 – 2015 monitoring surveys were statistically significant (ANOVA; $p < 0.0001$, Appendix 2a) reflecting the acute degradation experienced by the reef system after 2005.

The downfall of live coral at BOTE20 was triggered by the regional coral bleaching event that affected Puerto Rico and the USVI during late September through October 2005 (García et al., 2008) and lingering effects that carried further coral mortality up to the 2013 monitoring survey. The bleaching event affected several coral species in variable magnitude at BOTE20 but was mostly detrimental to the dominant species in terms of substrate cover, the *Orbicella spp* complex, particularly *O. faveolata*. This species complex declined in substrate cover from a mean of 25.2%

in 2005 to a mean of 1.2% in 2009 (Figure 26), a highly significant reduction (ANOVA; $p = < 0.001$). Reef substrate cover by the *Orbicella spp* complex represented more than 53% of the total cover by stony corals at BOTE20. Thus, its collapse after the 2005 monitoring survey would be expected to have an important ecological impact to the reef system. Due to the marked decline of the *Orbicella spp*. complex, Finger Coral (*Porites porites*) now stands as the main coral species in terms of live coral cover, which represents a taxonomic shift in the sessile-benthic community structure of the reef. Benthic algae, seemingly the fastest growing component of the sessile-benthos at BOTE20 has increased its substrate cover by 50.4% between the 2000 baseline survey and the present 2018 monitoring survey (Figure 25), mostly by colonizing dead coral sections.

During the previous 2015 monitoring survey live coral cover had increased 37.0%, from 10.9% in 2013 to 17.5% in 2015, mostly driven by an increase of cover by Finger Coral, a species with a relatively fast growth rate that had previously shown marked annual fluctuations (Figure 26). During the present 2018 survey, total live coral cover declined to 11.2%. Again, the decline of total live coral cover at BOTE20 was associated with a 60.2% reduction of reef substrate cover by Finger Coral, from 8.3% in 2015 to 3.3% in 2018. It is here suggested that the most recent loss of Finger Coral was due in part to the extreme surge and abrasion effects associated with the pass of Hurricane Maria in September 2017 and/or the wave storm event of March 2018, before our May 26, 2018 monitoring survey. More than a dozen massive coral colonies were observed detached and overturned within the BOTE20 reef section. The Finger Coral colonies exhibited intermixed live and dead coral sections that may have been caused by intense sand abrasion.

Reef substrate cover by benthic algae peaked in 2018 (relative to previous surveys) with a mean cover of 81.23%. This represents an increase of 35.6% from the previous survey of 2015. Such increase of the total cover by benthic algae was strongly influenced by a 1.9-fold increase of cover by brown fleshy algae (*Lobophora variegate* + *Dictyota sp*.). Despite the relatively small watershed of Isla Desecheo and its considerable distance from mainland river plumes increased nutrient availability for algal growth could have been brought by upwelling currents associated with Hurricane Maria cyclonic divergence, and/or organic sediment resuspension sources associated with the extreme surge.

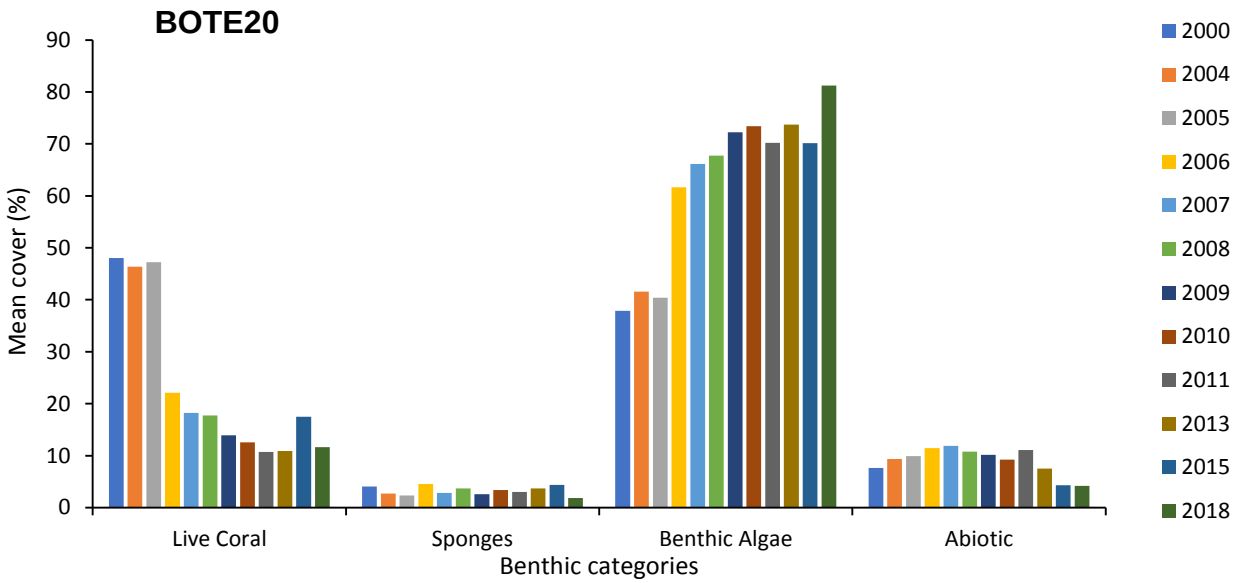



**Figure 25.** BOTE20. Annual variations (2000 -18) of mean substrate cover by sessile-benthic categories at Puerto Botes Reef 20m, Isla Desecheo

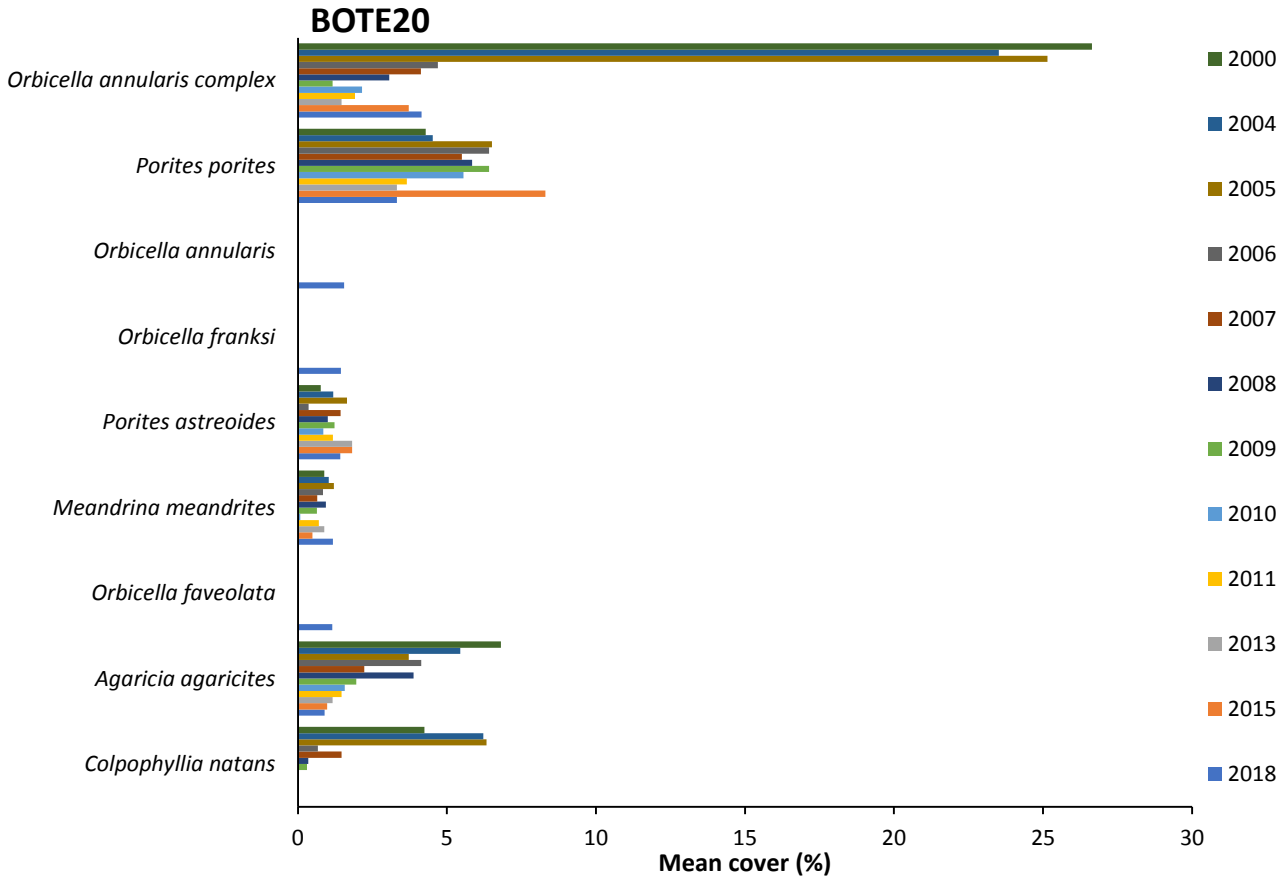



**Figure 26.** BOTE20. Annual variations (2000 -18) of mean substrate cover by the main coral species intercepted by transects at Puerto Botes Reef 20m, Isla Desecheo

### 8.3 Fishes and Motile Megabenthic Invertebrates

A total of 35 fish species were identified within belt-transects from BOTE20 during the 2018 monitoring survey with a mean density of 114.4 Ind/30 $m^2$ and a mean species richness of 19.2 species/transect (Table 24). Five species were present in all five transects surveyed with a combined abundance of 80.2 Ind/30 $m^2$, representative of 70.1% of the total individuals within belt-transects. These included the Blue and Brown Chromis (*Chromis cyanea, C. multilineata*), Bicolor Damselfish (*Stegastes partitus*), and the Bluehead and Creole Wrasses (*Thalassoma bifasciatum, Clepticus parrae*). Another seven (7) species were present in four transects, indicative of a species rich resident ichthyofauna at this reef site (Table 24).

Pelagic and demersal zooplanktivores were the most prominent trophic fish assemblage at BOTE20 with a combined density of 63.6 Ind/30 $m^2$, or 55.6% of the total fish density within belt-transects. These were represented by four damselfishes (Pomacentridae), one wrasse (Labridae) and one basslet (Grammatidae). Pelagic schools of adult Creole Wrasse (15 – 25 individuals) were observed throughout the water column, making frequent incursions over the reef. Schools of post-recruitment Creole Wrasse were observed intermixed with post-recruitment Blue Chromis close to the reef coral heads. Both of these fish taxa serve as forage for large pelagic predators, such as Cero Mackerels, Black Jacks and Great Barracudas observed during previous surveys in this reef (Garcia-Sais et al., 2015 and references therein). Swarms of mysid shrimps were observed below coral ledges and on reef crevices. These shrimps appear to be important forage for the demersal zooplanktivorous fishes.

A large variety of small invertebrate feeders were present, including three wrasses (Labridae), two gobies (Gobiidae), three soldierfishes (Holocentridae), and three small groupers and basses (Serranidae). Their combined density within belt-transects was 36.8 Ind/30 $m^2$, or 32.2% of the total fish density. Parrotfishes (five species), doctorfishes (two species), and damselfishes (one species) comprised the main herbivorous assemblage that represented 7.2% of the total individuals within belt-transects. Small piscivores were represented by few individuals of Coney (*Cephalopholis fulva*), Schoolmaster Snapper (*Lutjanus apodus*) and Bar Jack (*Carangoides ruber*). Large demersal predators, including the Nassau, Red Hind and Yellowfin groupers (*Epinephelus striatus, E. guttatus, Mycteroperca venenosa*), and Nurse Sharks (*Ginglymostoma cirratum*) have been previously reported for BOTE20 (Garcia-Sais et al., 2015 and references therein).

**Table 24.** BOTE20. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Pto. Botes Reef 20m, Isla Desecheo, May 2018

| Mean Depth: 17.4 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Chromis cyanea* | Blue Chromis | 18 | 18 | 12 | 50 | 15 | **22.6** |
| *Stegastes partitus* | Bicolor Damselfish | 17 | 14 | 20 | 33 | 22 | **21.2** |
| *Thalassoma bifassiatum* | Bluehead Wrasse | 15 | 16 | 18 | 15 | 17 | **16.2** |
| *Clepticus parrae* | Creole Wrasse | 5 | 26 | 15 | 5 | 12 | **12.6** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 4 | 1 | 6 | 18 | 9 | **7.6** |
| *Elacatinus evelynae* | Sharknose Goby | 6 | 5 | 3 | 19 | | **6.6** |
| *Chromis multilineata* | Brown Chromis | 2 | 3 | 8 | 2 | 4 | **3.8** |
| *Gramma loreto* | Fairy Basslet | | 3 | 9 | | 5 | **3.4** |
| *Scarus taeniopterus* | Princess Parrotfish | 4 | | 1 | 2 | 6 | **2.6** |
| *Sparisoma radians* | Bucktooth Parrotfish | 3 | | 3 | 3 | 3 | **2.4** |
| *Halichoeres maculipinna* | Clown Wrasse | 4 | 2 | 2 | 2 | | **2.0** |
| *Cephalopholis fulva* | Coney | 3 | 1 | | 2 | 1 | **1.4** |
| *Abudefduf saxatilis* | Sargent Major | 2 | | 2 | 1 | 1 | **1.2** |
| *Coryphopterus sp.* | Goby | 1 | 3 | | 2 | | **1.2** |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 1 | | | 3 | 2 | **1.2** |
| *Lactophrys triqueter* | Smooth Trunkfish | 1 | 1 | | 2 | 1 | **1.0** |
| *Melichthys niger* | Black Durgon | 1 | 3 | | 1 | | **1.0** |
| *Sparisoma viride* | Stoplight Parrotfish | | 2 | 3 | | | **1.0** |
| *Acanthurus coeruleus* | Blue Tang | | 1 | 1 | | 1 | **0.6** |
| *Holocentrus rufus* | Longspine Squirelfish | | 1 | 1 | | 1 | **0.6** |
| *Myripristis jacobus* | Black-bar Soldierfish | | | | 1 | 2 | **0.6** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | 1 | 1 | 1 | | **0.6** |
| *Chaetodon striatus* | Banded Butterflyfish | 2 | | | | | **0.4** |
| *Serranus tigrinus* | Harlequin Bass | | | | 2 | | **0.4** |
| *Acanthurus chirurgus* | Doctorfish | | | | | 1 | **0.2** |
| *Amblychirrinus pinos* | Redspoted Hawkfish | | | | 1 | | **0.2** |
| *Bodianus rufus* | Spanish Hogfish | | | 1 | | | **0.2** |
| *Carangoides ruber* | Bar Jack | 1 | | | | | **0.2** |
| *Cephalopholis cruentata* | Graysby | 1 | | | | | **0.2** |
| *Chaetodon aculeatus* | Longnose Butterflyfish | | | 1 | | | **0.2** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | | | 1 | | **0.2** |
| *Diodon holocanthus* | Balloonfish | | | | | 1 | **0.2** |
| *Holacanthus tricolor* | Rock Beauty | | 1 | | | | **0.2** |
| *Holocentrus adscensionis* | Squirrelfish | | | | | 1 | **0.2** |
| *Scarus iseri* | Striped Parrotfish | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | **92** | **102** | **107** | **166** | **105** | **114.4** |
| | **TOTAL SPECIES** | **20** | **18** | **18** | **21** | **19** | **19.2** |
| | | | | | | | |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Mithrax spinossisimo* | Clinging Crab | | | 1 | | | **0.2** |
| | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 1 | 0 | 0 | **0.2** |
| | **TOTAL SPECIES** | 0 | 0 | 1 | 0 | 0 | **0.2** |

Size distributions of commercially important fishes and large herbivores are presented in Table 25. The data for parrotfishes is indicative that BOTE20 functions as a recruitment and residential juvenile and adult habitat for several species, including the Stoplight, Redband, Bucktooth, and Princess Parrotfishes (*Sparisoma viride, S. aurofrenatum, S. radians, Scarus taeniopterus).* Doctorfishes (*Acanthurus spp*) were mostly observed as late juvenile and adult stages (> 10cm). Coneys (*Epinephelus fulva*) were observed as juvenile and adults. One Schoolmaster snapper (*Lutjanus apodus*) and one Graysby (*Cephalopholis cruentata*) were observed as adults within belt-transects. Both of the latter species were observed out of transects across their full juvenile and adult size classes. Commercially important species for the aquarium trade market, such as the Fairy Basslet (*Gramma loreto*), Queen Angelfish (*Holacanthus ciliaris*), Rock Beauty (*Holacanthus tricolor*), Blue Chromis (*Chromis cyanea*), Yellow-head Jawfish (*Opistognathus aurifrons*) and Peppermint Bass (*Liopropoma rubre*) were common. Motile megabenthic invertebrates were represented within belt-transects by one Clinging Crab (*Mithrax spinosissimus*) (Table 24).

Monitoring trends of fish density and species richness surveyed within belt-transects throughout the PRCRMP at BOTE20 are presented in Figure 27. Mean density (114.4 Ind/30 $m^2$) and species richness (19.2 species/transect) were the lowest ever recorded at BOTE20. Differences between surveys of both fish density and species richness were statistically significant (ANOVA; $p < 0.01$, Appendix 3). The collapse of the fish community at BOTE20 during the 2018 survey has to be analyzed from both a long-term and a short-term perspective. From the long-term perspective it can be argued that the substantial loss of live coral habitat may be diminishing the habitat structural complexity needed to sustain the highly biodiverse fish community that once characterized BOTE20. Ironically, both fish density and species richness during the previous 2015 survey were on the higher end of the range documented for this reef station. This leads to the conclusion that while a long-term degradation of the reef habitat quality has been in place and may be affecting the fish community, the 2018 results appear to be related to a shorter-term phenomenon, such as the pass of Hurricane Maria in September 2017 and/or the influence of an event of exceptionally high wave energy impacting the north and west coasts of Puerto Rico in March 2018. Both of these systems impose conditions of strong currents, severe abrasion and advective displacement associated with high wave energy and turbulence. Such conditions may have flushed small territorial fishes out of their residential microhabitats in the reef and influenced their reproductive behavior and recruitment dynamics for an undetermined period.

**Table 25.** BOTE20.Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates within 20 x 3 m belt-transects at Pto. Canoas Reef 20m, Isla Desecheo, May 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 17.4 m | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus chirurgus* | Doctorfish | | | | | 2 - 14 |
| *Acanthurus coeruleus* | Blue Tang | | 1 - 12 | 1 - 10 | | 1 - 12 |
| | | | 1 - 14 | 2 - 12 | | |
| *Cephalopholis fulva* | Coney | 2 - 12 | 1 - 19 | 1 - 24 | 1 - 24 | 1 - 31 |
| | | 1 - 19 | 1 - 24 | | 1 - 29 | |
| *Cephalopholis cruentata* | Graysby | 1 - 24 | | | | |
| *Lutjanus apodus* | Schoolmaster | | | | 1 - 19 | |
| *Scarus iseri* | Striped Parrotfish | 1 - 29 | | | 1 - 24 | |
| *Scarus taeniopterus* | Princess Parrotfish | 3 - 10 | 1 - 7 | 1 - 12 | 1 - 7 | 6 - 7 |
| | | 2 - 12 | | 1 - 22 | 1 - 10 | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 - 17 | 1 - 7 | 1 - 7 | 1 - 14 | 1 - 7 |
| | | | | | 1 - 19 | |
| *Sparisoma radians* | Bucktooth Parrotfish | | | 3 - 2 | 3 - 2 | 2 - 1 |
| | | | | | | 1 - 7 |
| *Sparisoma viride* | Stoplight Parrotfish | | 1 - 2 | 2 - 2 | | 2 - 5 |
| | | | 1 - 5 | 1 - 36 | | |
| | | | 1 - 34 | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |

TL = Fish Total Length

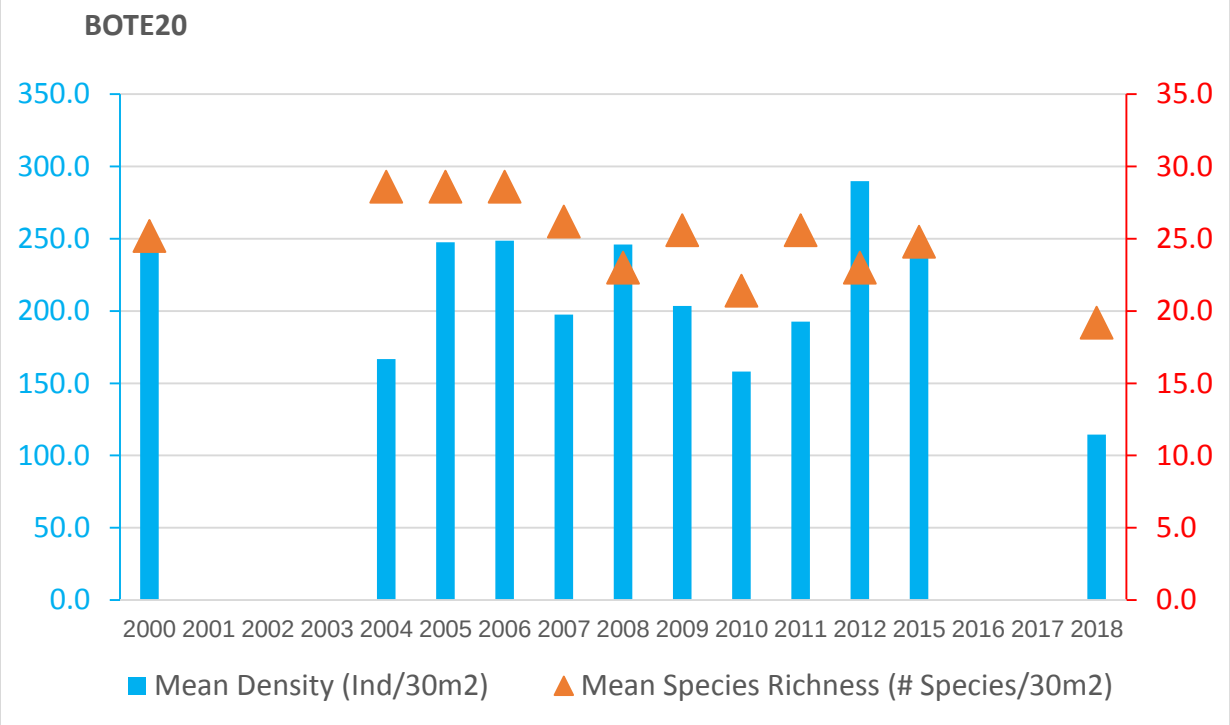
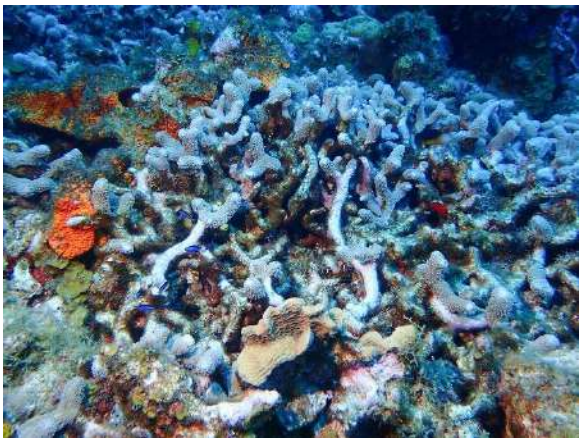



**Figure 27.** BOTE20. Monitoring trends (2000 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Puerto Botes Reef 20m, Isla Desecheo

**Photo Album 8**

**Puerto Botes Reef 20m, Isla Desecheo (BOTE20)**



## 9.0 Puerto Botes Reef 15m, Isla Desecheo (BOTE15)

### 9.1 Physical Description

The rocky shoreline off Puerto Botes leads to a gently sloping hard ground terrace colonized by corals and other encrusting biota. With increasing depth, the hard ground terrace breaks into several large promontories with a marked increment of stony coral buildup. The southern section of the terrace presents a more abrupt slope from the shoreline towards deeper waters and is heavily colonized by octocorals (gorgonians). The baseline characterization of BOTE15 was performed on August 2004. This is the 10$^{th}$ monitoring survey of this reef station. Five permanent transects were installed along the northern section almost parallel to each other oriented north-south at depths of 13.6 – 14.5m (Figure 21). Panoramic views of the inner shelf reef at BOTE15 are presented in Photo Album 9.

### 9.2 Sessile-benthic Reef Community

Benthic algae, represented by a mixed assemblage of turf, fleshy brown and red coralline macroalgae were the main sessile-benthic category in terms of reef substrate cover at BOTE15 with a combined mean of 79.84% (Table 26). Turf algae were the dominant component of benthic algae with a mean cover of 41.66%, representing 52.2% of the total benthic algae. Fleshy brown macroalgae, mostly comprised by *Lobophora variegata, Dictyota sp*., and *Stypopodium sp*. combined for a substrate cover of 35.53%, or 44.5% of the total assemblage. Encrusting patches of red crustose calcareous algae, including Peyssonnelid and other mixed CCA, were present in all five transects with a combined cover of 1.76% (Table 26). Cyanobacterial patches were present in only one transect with a relatively low mean substrate cover of 0.12%, compared to other reef stations surveyed in the 2018 PRCRMP (mean: 3.22%).

A total of 12 hard corals, including 11 scleractinians and one hydrocoral were intersected by line transects at BOTE15 during the 2018 monitoring survey (Table 26). Mean reef substrate cover by the total coral assemblage was 9.98% (range: 6.24 – 12.62%). Mustard-Hill Coral (*Porites astreoides*), Mountainous Star Coral (*Orbicella faveolata*) and Great Star Coral (*Montastraea cavernosa*) comprised the main coral assemblage with a combined reef substrate cover of 6.57%, representative of 65.7% of the total cover by live corals. Corals typically exhibited encrusting growth and small to moderate colony sizes, perhaps as adaptations to the strong wave and surge action seasonally acting at the shallower reef zone. A total of 37 coral colonies were intercepted, including three (*Siderastrea siderea, Meandrina meandrites)* with an apparent disease (dark spots), yielding a coral disease prevalence of 8.1% (Appendix 4).

| **Table 26**. BOTE15. Percent cover by sessile-benthic categories at Puerto Botes Reef 15m, Isla Desecheo | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 5/26/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 14.5 | 14.2 | 14.5 | 14.2 | 13.6 | **14.2** |
| Rugosity (m) | 2.64 | 0.95 | 2.64 | 4.59 | 1.76 | **2.52** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Sand | | 7.03 | 3.77 | 4.13 | | **2.98** |
| Reef overhang | 2.21 | | 2.21 | 1.92 | 0.95 | **1.46** |
| **Total Abiotic** | **2.21** | **7.03** | **5.98** | **6.05** | **0.95** | **4.45** |
| **Benthic Algae** | | | | | | |
| Turf algae (mixed) | 50.27 | 47.96 | 40.42 | 38.58 | 31.07 | **41.66** |
| *Lobophora variegatus* | 15.73 | 23.35 | 26.58 | 19.77 | 30.83 | **23.25** |
| *Dictyota* spp. | 14.40 | 3.94 | 9.30 | 11.32 | 7.38 | **9.27** |
| *Stypopodium* sp. | 2.21 | 1.41 | 3.32 | 1.54 | 6.55 | **3.01** |
| Peyssonnelid | 0.44 | 0.28 | 0.55 | 1.54 | 2.38 | **1.04** |
| CCA (mixed) | 0.66 | | 1.44 | 0.67 | 0.83 | **0.72** |
| *Jania marina* | | | 1.11 | 0.96 | 1.43 | **0.70** |
| Macroalgae (mixed) | | | | 0.96 | | **0.19** |
| **Total Benthic Algae** | **83.71** | **76.93** | **82.72** | **75.34** | **80.47** | **79.84** |
| **Cyanobacteria** | **0.00** | **0.00** | **0.00** | **0.00** | **0.60** | **0.12** |
| **Hard Coral** | | | | | | |
| *Porites astreoides* | 2.44 | 6.61 | 3.88 | 2.69 | 5.36 | **4.19** |
| *Orbicella faveolata* | | | 1.55 | | 5.36 | **1.38** |
| *Montastraea cavernosa* | 2.10 | 0.56 | 1.99 | | 0.36 | **1.00** |
| *Pseudodiploria strigosa* | | 3.23 | | | | **0.65** |
| *Colpophyllia natans* | | 0.70 | | 1.82 | | **0.51** |
| *Siderastrea siderea* | 2.44 | | | | | **0.49** |
| *Diploria labyrinthiformis* | 1.88 | | | | | **0.38** |
| *Meandrina meandrites* | 0.66 | 0.42 | | 0.77 | | **0.37** |
| *Millepora alcicornis* | | | 1.66 | | | **0.33** |
| *Madracis decactis* | 0.89 | 0.00 | | 0.29 | 0.36 | **0.31** |
| *Agaricia agaricites* | | | | 0.67 | 0.48 | **0.23** |
| *Orbicella annularis* | | | | | 0.71 | **0.14** |
| **Total Hard Coral** | **10.41** | **11.53** | **9.08** | **6.24** | **12.62** | **9.98** |
| **# CoralColonies /Transect** | **9** | **6** | **7** | **10** | **5** | **7.4** |
| **# Diseased Coral Colonies** | **1** | **0** | **1** | **1** | **0** | |
| **# Gorgonians/Transect** | **0** | **0** | **1** | **0** | **0** | **0.2** |
| **Sponges** | | | | | | |
| *Xestospongia muta* | 0.66 | | | 10.56 | | **2.24** |
| *Agelas conifera* | | | | | 4.64 | **0.93** |
| *Neofibularia nolitangere* | | 2.95 | | | | **0.59** |
| *Agelas citrina* | 2.33 | | 0.44 | | | **0.55** |
| *Aplysina insularis* | 0.33 | 1.55 | 0.55 | 0.19 | | **0.52** |
| *Svenzea zeai* | | | 0.89 | 1.63 | | **0.50** |
| *Neopetrosia* smooth sp. | | | | | 0.48 | **0.10** |
| *Amphimedon compressa* | 0.33 | | | | | **0.07** |
| *Verongula rigida* | | | | | 0.24 | **0.05** |
| *Scopalina ruetzleri* | | | 0.22 | | | **0.04** |
| Unknown sponge | | | 0.11 | | | **0.02** |
| **Total Sponges** | **3.65** | **4.50** | **2.21** | **12.38** | **5.36** | **5.62** |

Sponges contributed a mean substrate cover of 5.62%. The dominant assemblage included *Xestospongia muta*, *Neofibularia sp., Aplysina insularis* and *Agelas spp*. Only one octocoral (gorgonian) colony was intercepted by transects at BOTE15. Total abiotic cover averaged 4.45%, contributed by sand patches and reef overhangs.

Figure 28 presents the variations of mean percent cover by the main sessile-benthic categories from BOTE15 surveyed during the period between 2004 -18. Mean reef substrate cover by hard corals, sponges and benthic algae remained virtually stable between the 2004 baseline and the 2005 monitoring survey. Differences during 2005 were all within 1% of the baseline and statistically insignificant (García-Sais et al., 2005 a). A reduction 49.2% of mean live coral cover was measured during the 2006 monitoring event, from 19.5% in 2005 to 9.9% in 2006. Corresponding increments of substrate cover by benthic algae and abiotic categories were also recorded. An additional decline of 17.3% mean live coral cover was measured during the 2007 survey, from 9.8% in 2006 to 8.1% in 2007. Differences of total live coral cover between surveys were statistically significant (ANOVA; $p = <0.0001$; Appendix 2a). After 2007, statistically significant declines of substrate cover by live corals have not been observed. Between 2010 and the previous 2015 survey an increasing trend of live coral cover, influenced by increments of cover by *O. annularis* (complex) and *P. astreoides* were measured but differences were not statistically significant.

The historical decline of live coral cover at BOTE15 was largely associated with a reduction of cover by the previously dominant species complex of *Orbicella spp.* which collapsed from a mean of 11.5% in 2005 to a mean of 2.6% in 2006 (Figure 29). Additional declines of substrate cover down to a minimum of 1.5% were measured for *O. annularis* complex until the 2009 survey. The declining trend for this coral species ended during the 2010 survey with a mild, yet statistically insignificant fractional increment of mean substrate cover that remained stable until the 2015 monitoring survey. At present, the dominant coral species in terms of reef substrate cover at present is the Mustard-Hill Coral, *Porites astreoides*, which implies a phase shift in the sessile-benthic community structure of the reef.

During the 2018 monitoring survey, total live coral cover declined 28.5%, from 14.0% in 2015 to 10.0% in 2018, largely influenced by further reduction of cover by *Orbicella spp*., from 3.5% in 2015 to 1.5% in 2018. Nevertheless, reductions of coral cover were noted for several other coral species within transects, suggesting that the coral cover decline at BOTE15 was driven by an environmental stressor acting upon the entire coral reef community. We propose that surge and abrasive effects caused by extreme wave energy events related with the pass of Hurricane Maria in September 2017 and/or another extreme wave storm event impacting the north and west coasts in March 2018 could have been relevant factors for the measured coral decline at BOTE15 and other reef systems in the west coast of Puerto Rico in 2018.

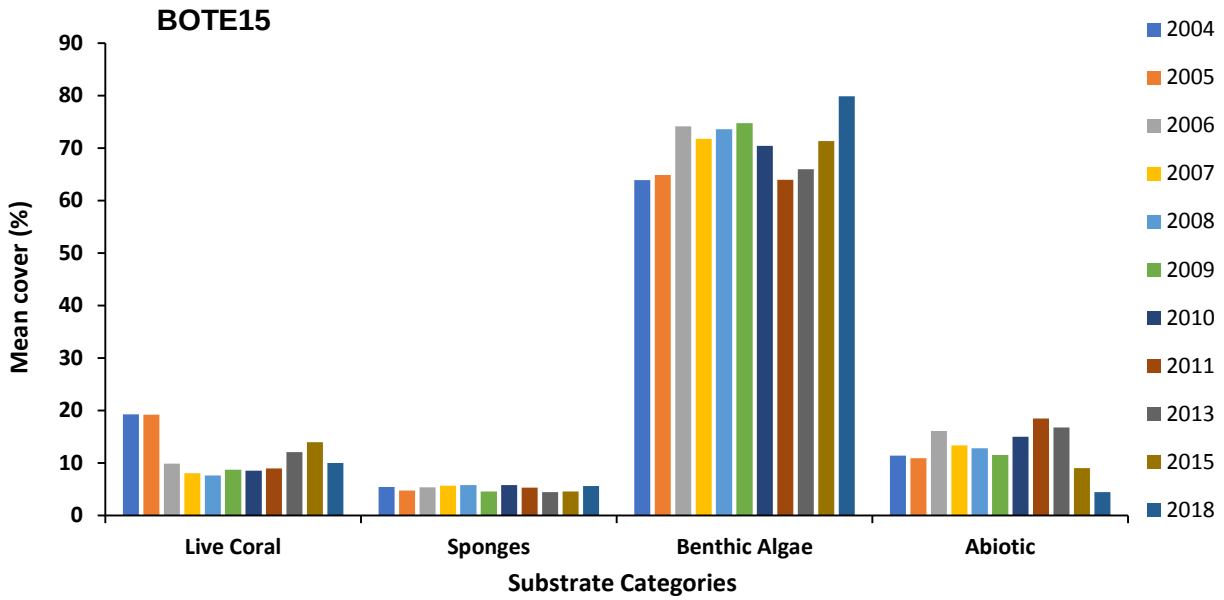



**Figure 28.** BOTE15. Annual variations (2004 -18) of mean substrate cover by sessile-benthic categories at Puerto Botes Reef 15m, Isla Desecheo

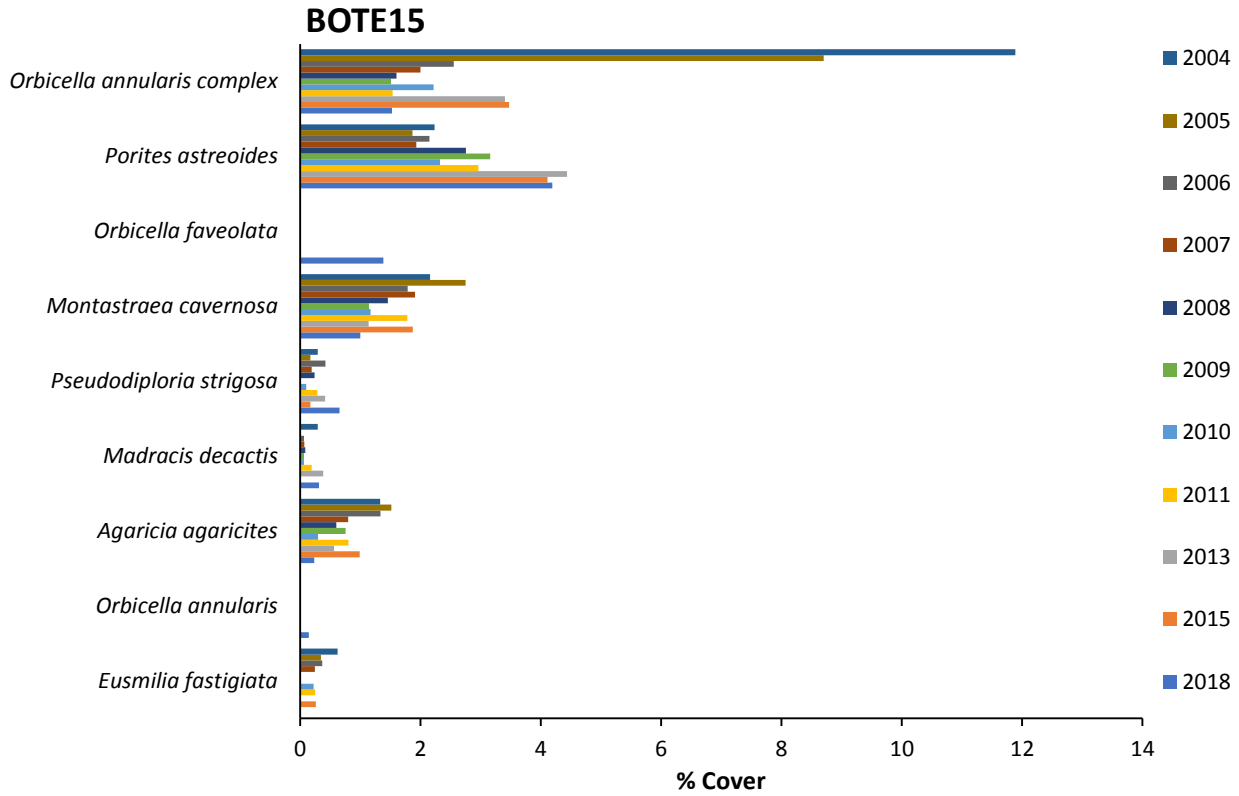



**Figure 29.** BOTE15. Annual variations (2004 -18) of mean substrate cover by the main coral species intercepted by transects at Puerto Botes Reef 15m, Isla Desecheo

As previously noted for BOTE20, reef substrate cover by benthic algae peaked at BOTE15 in 2018 (relative to previous surveys) with a mean cover of 79.84% (Figure 28). This represents an increase of 11.8% from the previous survey of 2015. Such increase of the total cover by benthic algae was influenced by a 42.4 increase of cover by brown fleshy algae (*Lobophora variegate* + *Dictyota sp*.). Despite the relatively small watershed of Isla Desecheo and its considerable distance from mainland river plumes increased nutrient availability for algal growth could have been brought by upwelling currents associated with Hurricane Maria cyclonic divergence, and/or organic sediment resuspension sources associated with the extreme surge.

### 9.3 Fishes and Motile Megabenthic Invertebrates

A total of 33 fish species were identified within belt-transects from BOTE15 during the 2018 monitoring survey (Table 27). Mean fish density within belt-transects was 116.0 Ind/30 $m^2$ (range: 92 - 160 Ind/30 $m^2$). The mean number of species per transect was 17.6 (range: 17 - 19). The combined density of the Bicolor Damselfish (*Stegastes partitus*), Bluehead Wrasse (*Thalassoma bifasciatum*) and Blue Chromis (*Chromis cyanea*) represented 66.9% of the total individuals within belt-transects. Six additional species were present in at least four out of the five transects surveyed. These included the Yellow-head Wrasse, Sharknose Goby, Clown Wrasse, Coney, Longspine Squirrelfish, and an unidentified goby (*Coryphopterus sp*).

The trophic structure of BOTE15 was strongly dominated in terms of fish density within transects by zooplankton feeders, such as the Bicolor Damselfish, Blue and Brown Chromis and Creole Wrasse with a combined density of 59.4 Ind/30 $m^2$, representative of 51.2% of the total individuals within transects. These are important prey items of mid-size demersal piscivores that are commercially exploited, such as the Yellowtail and Schoolmaster Snappers, Red Hind and Coneys, as well as for juvenile and adult stages of pelagic fishes associated with the reef food web, such as the Great Barracuda, Cero Mackerels and jacks. Also, open water zooplanktivores, such as the Mackerel Scad (*Decapterus macarellus*) have been previously observed outside transects in large aggregations. This pattern of planktivore fish dominance is consistent with previous fish surveys at BOTE15 and other reef stations included in the PRCRMP from Isla Desecheo (e.g. BOTE20, CANO30).

**Table 27.** BOTE15. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Pto. Botes Reef 15m, Isla Desecheo, May 2018

| Mean Depth: 14.2 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Stegastes partitus* | Bicolor Damselfish | 35 | 21 | 23 | 26 | 31 | **27.2** |
| *Thalassoma bifassiatum* | Bluehead Wrasse | 33 | 26 | 21 | 39 | 12 | **26.2** |
| *Chromis cyanea* | Blue Chromis | 11 | 19 | 13 | 10 | 68 | **24.2** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 8 | 3 | 7 | 10 | 6 | **6.8** |
| *Clepticus parrae* | Creole Wrasse | | | 6 | 8 | 19 | **6.6** |
| *Elacatinus evelynae* | Sharknose Goby | 7 | 4 | 4 | 3 | 3 | **4.2** |
| *Halichoeres maculipinna* | Clown Wrasse | 5 | 4 | 3 | 2 | 4 | **3.6** |
| *Cephalopholis fulva* | Coney | 5 | 4 | 4 | 2 | 2 | **3.4** |
| *Coryphopterus sp.* | Goby | 2 | 1 | 3 | 2 | | **1.6** |
| *Chromis multilineata* | Brown Chromis | 2 | | | | 5 | **1.4** |
| *Sparisoma radians* | Bucktooth Parrotfish | 3 | | 2 | 2 | | **1.4** |
| *Bodianus rufus* | Spanish Hogfish | 1 | 5 | | | | **1.2** |
| *Holocentrus rufus* | Longspine Squirelfish | 1 | 1 | | 1 | 1 | **0.8** |
| *Lactophrys triqueter* | Smooth Trunkfish | | 2 | 1 | | 1 | **0.8** |
| *Acanthurus coeruleus* | Blue Tang | 1 | | | 2 | | **0.6** |
| *Microspathodon chrysurus* | Yellowtail Damselfish | | 1 | 1 | | 1 | **0.6** |
| *Sparisoma viride* | Stoplight Parrotfish | | 1 | | 1 | 1 | **0.6** |
| *Xanthichthys ringens* | Sargassum Triggerfish | 1 | 1 | | 1 | | **0.6** |
| *Amblychirrinus pinos* | Redspoted Hawkfish | 1 | | 1 | | | **0.4** |
| *Halichoeres radiatus* | Puddinwife | 1 | | 1 | | | **0.4** |
| *Holacanthus tricolor* | Rock Beauty | | 1 | | 1 | | **0.4** |
| *Melichthys niger* | Black Durgon | | | 1 | 1 | | **0.4** |
| *Scarus iseri* | Striped Parrotfish | | 1 | | 1 | | **0.4** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 | 1 | | | | **0.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | | 1 | | | | **0.2** |
| *Aulostomus maculatus* | Trumpetfish | | | | | 1 | **0.2** |
| *Cephalopholis cruentata* | Graysby | | | | | 1 | **0.2** |
| *Diodon histrix* | Porcupinefish | | | | | 1 | **0.2** |
| *Diodon holocanthus* | Balloonfish | | | | | 1 | **0.2** |
| *Holacanthus ciliaris* | French Angelfish | | | | | 1 | **0.2** |
| *Lutjanus apodus* | Schoolmaster | | | | | 1 | **0.2** |
| *Gymnothorax miliaris* | Goldentail Moray | | | 1 | | | **0.2** |
| *Serranus tigrinus* | Harlequin Bass | | | | 1 | | **0.2** |
| | **TOTAL INDIVIDUALS** | **118** | **97** | **92** | **113** | **160** | **116.0** |
| | **TOTAL SPECIES** | **17** | **18** | **16** | **18** | **19** | **17.6** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| None | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 0 | 0 | 0 | **0** |
| | **TOTAL SPECIES** | 0 | 0 | 0 | 0 | 0 | **0** |

A specious assemblage of small opportunistic carnivores, represented by four species of wrasses (Labridae), two gobies (Gobiidae), two balloonfishes (Diodontidae), one hawkfish (Cirrhitidae), one trumpetfish (Aulostomidae), one bass (Serranidae), and one squirrelfish (Holocentridae) were also highly prominent at BOTE15, with a combined density of 45.4 Ind/30 $m^2$, representative of 39.1% of the total individuals within belt-transects. The herbivore assemblage was comprised by four species of parrotfishes (Scaridae), two species of doctorfishes (Acanthuridae) and one damselfish presented a combined density 5.4 Ind/30 $m^2$, representative of 4.7% of the total

individuals. Mid-size piscivores included the Coney, Graysby, Red Hind (Serranidae) and Schoolmaster (Lutjanidae). A school of large adult Yellowtail Snappers (*Ocyurus chrysurus*), one juvenile Nurse Shark (*Ginglymostoma cirratum*) and one Great Barracuda (*Sphyraena barracuda*) were observed out of transects. Motile megabenthic invertebrates were not observed within belt-transects at BOTE15 during the 2018 survey.

The size distribution of reef fish herbivores and commercially important species at BOTE15 is included in Table 28. Recruitment, juvenile and adult stages of Stoplight and Bucktooth Parrotfishes (*Sparisoma viride, S. radians*) were observed within belt-transects indicative that BOTE15 is the recruitment and residential habitat for these species throughout their life history. Although recruitment juvenile stages of doctorfishes have not been yet recorded, an early juvenile (7 cm) of the Blue Tang (*Acanthurus coeruleus*) was observed. Several adult size individuals of the Doctorfish and Ocean Surgeon (*A. chirurgus, A. tractus*) were also present. Coneys (*Cephalopholis fulva*) were observed throughout their early juvenile to adult size range (7 – 29 cm), which is indicative that BOTE15 is a preferred residential habitat for this species throughout most of its life cycle. Likewise, Graysby (*C. cruentata*) were observed as adults within transects, but smaller individuals were seen out of transects. Adult stages of Red Hind (*Epinephelus guttatus*) and one Schoolmaster Snapper (*Lutjanus apodus*) were also present within transects.

Annual monitoring trends of fish density and species richness surveyed within belt-transects are presented in Figure 30. The mean number of fish species within transects (species richness) has fluctuated historically between 17.6 and 25.2, and mean density has varied between 120.4 Ind/30 $m^2$ and 307.6 Ind/30 $m^2$ during the 10-year of monitoring previous to the 2018 survey. Both the mean fish density (116.0 Ind/30 $m^2$) and species richness (17.6 Ind/transect) are at or below the lowest ever recorded for BOTE15. Differences between monitoring surveys for both fish density and richness were statistically significant (ANOVA; $p < 0.05$, Appendix 3). The pattern of historically low fish densities and species richness was consistent at the three reef stations surveyed from Isla Desecheo (CANO30, BOTE20 and BOTE15) and is indicative of a major disturbance of the fish community. Since the previous inference from the Isla Desecheo reef fish communities was gathered during the 2015 survey, further evaluations will be required to evaluate if this pattern is transitional (short-term) and driven by physical mechanical displacement associated with Hurricane Maria and other exceptionally high wave storm event, or if it is related to other factors with long-term consequences.

**Table 28.** BOTE15. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates within 20 x 3 m belt-transects at Pto. Canoas Reef 15m, Isla Desecheo, May 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 14.2 m | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus chirurgus* | Doctorfish | | | | 1 - 14 | |
| *Acanthurus tractus* | Five-band Surgeonfish | | 1 - 14 | | | |
| *Acanthurus coeruleus* | Blue Tang | 1 - 12 | 1 - 12 | 1 - 12 | 1 - 7 | |
| | | | | | 1 - 12 | |
| *Cephalopholis fulva* | Coney | 1 - 7 | 1 - 7 | 2 - 7 | 2 - 17 | 1 - 14 |
| | | 1 - 10 | 1 - 10 | 2 - 12 | | 1 - 17 |
| | | 4 - 14 | 1 - 22 | 1 - 19 | | 1 - 24 |
| | | 1 - 19 | 2 - 26 | 1 - 24 | | |
| | | 1 - 24 | 1 - 29 | | | |
| *Cephalopholis cruentata* | Graysby | 1 - 17 | | | | 1 - 17 |
| *Epinephelus guttatus* | Red Hind | | | | | 1 - 24 |
| *Lutjanus apodus* | Schoolmaster | | 1 - 24 | | | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 2 - 12 | 1 - 17 | | | 1 - 14 |
| | | 1 - 19 | | | | |
| *Sparisoma viride* | Stoplight Parrotfish | | 1 - 29 | 1 - 24 | 1 - 22 | 1 - 5 |
| | | | | | | 2 - 7 |
| *Scarus taeniopterus* | Princess Parrotfish | | | | 1 - 19 | |
| *Sparisoma radians* | Bucktooth Parrotfish | 3 - 2 | | 1 - 1 | 2 - 1 | 2 - 2 |
| | | | | 1 - 2 | | |
| *Scarus iseri* | Striped Parrotfish | | 1 - 24 | 1 - 14 | 1 - 24 | |
| **Invertebrates** | | | | | | |
| none | | | | | | |

TL = Fish Total Length

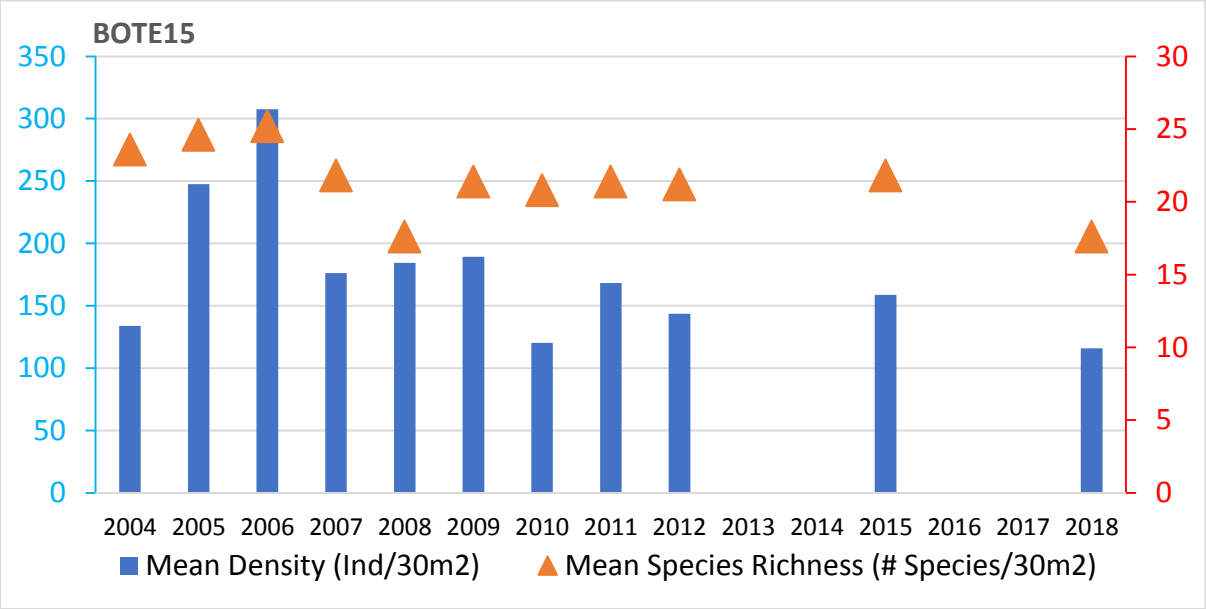
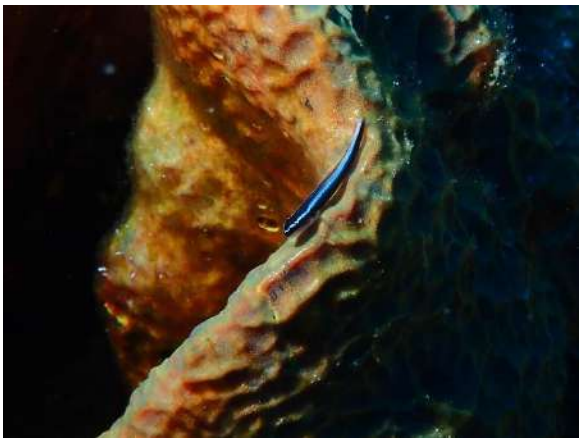



**Figure 30.** BOTE15. Monitoring trends (2004 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Puerto Botes Reef 15m, Isla Desecheo

**Photo Album 9**

**Puerto Botes Reef 15m, Isla Desecheo (BOTE15)**



## D. Fajardo Coral Reef Systems

### 10.0 Palomino Reef 20m, Fajardo (PALN20)

### 10.1 Physical Description

Isla Palominos is located inside the chain of island reefs that form the “Cordillera Natural Reserve”. The reef platform includes two emergent zones, the largest of which is Palominos, with the smaller sandy islet, Palominitos located due south of Palominos (Figure 31). Fringing and patch coral reef formations are found along the north and eastern sections of the island. The baseline survey of Palominos Reef (PALN20) was performed on September 2016. Permanent transects were set on the northern section the island following a linear (contour) pattern at the base of the reef in the 14.8 – 17.0 m depth range. Panoramic views of the reef community at PALN20 are shown in Photo Album 10.

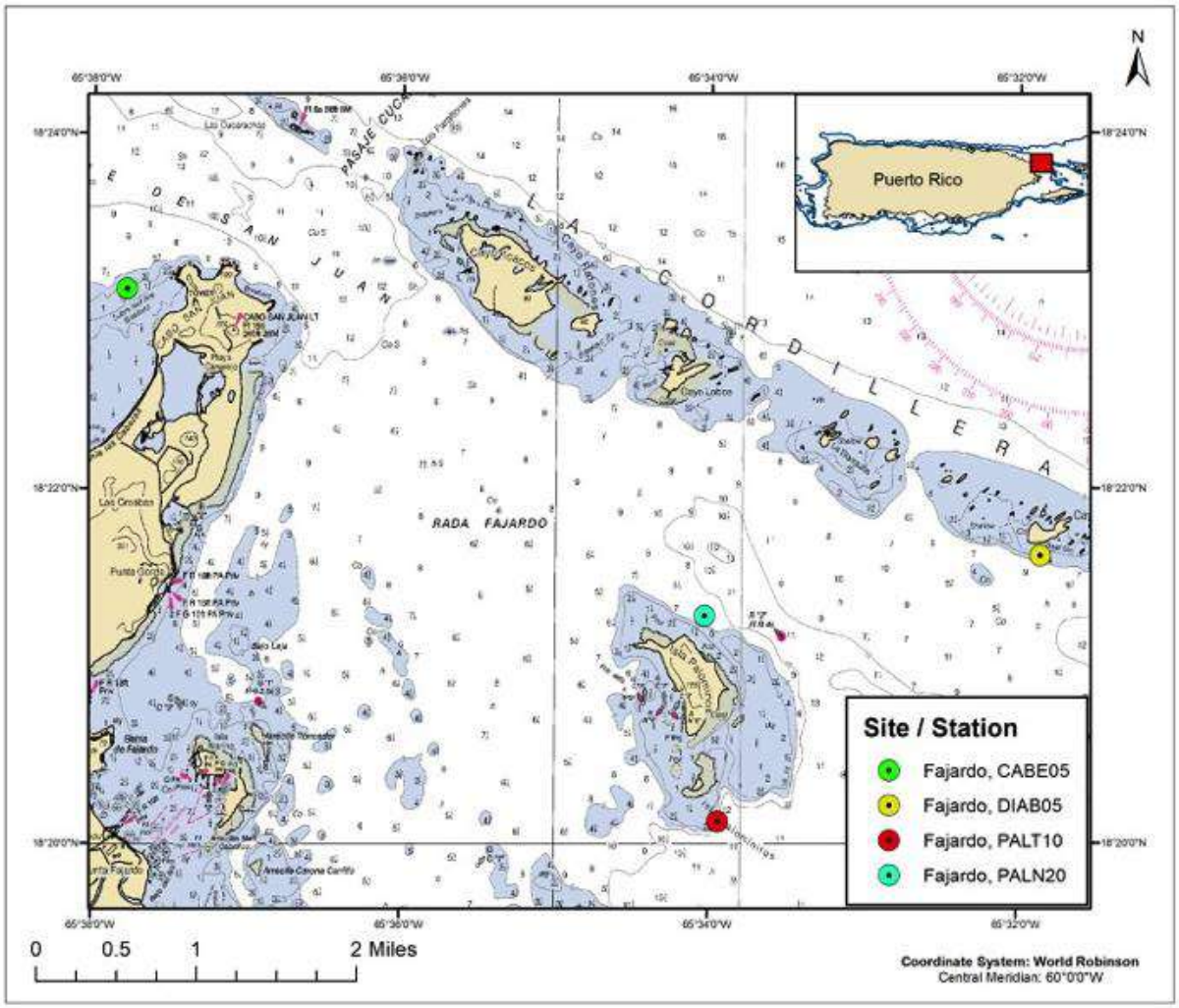



**Figure 31.** Location of coral reef monitoring stations within the Cordillera de Fajardo Natural Reserve

### 10.2 Sessile Benthic Reef Community

A mixed assemblage of benthic algae, comprised by turf, encrusting red calcareous algae (mostly *Ramicrusta sp*) and fleshy brown macroalgae (*Dictyota sp*), was the dominant biological category covering substrate at PALN20 with a combined mean cover of 48.93% (Table 29). Turf algae were the largest component with a mean cover of 30.15%, representative of 61.6% of the total cover by benthic algae. A substantial portion of the turf algae was observed almost buried by fine sediments. The Peyssonnelid crustose coralline alga, *Ramicrusta sp*. was present in all transects with a mean cover of 12.69% (range: 6.99 – 16.69%). The fleshy brown Y-Twig Alga (*Dictyota sp*.) was also present in all five transects with a mean cover of 2.36%.

Hard (stony) corals were represented in transects by 14 scleractinians and one hydrocoral (*Millepora alcicornis*) at PALN20 with a mean reef substrate cover of 27.13% (range: 20.45 – 34.74%). Dimpled Sheet Coral (*Agaricia grahamae*) presented the highest mean reef substrate cover with 8.80%, representing 32.4% of the total cover by live corals (Table 29). Along with *A. grahamae*, Mustard-Hill Coral (*Porites astreoides*), and Great Star Coral (*Montastrea cavernosa*) were present in all five transects with a combined cover of 5.43%. Mountainous Star Coral (*Orbicella faveolata*), Massive Starlet Coral (*Siderastrea siderea*), and Ten-Ray Star Coral (*Madracis decactis*) were present in three transects with a combined cover of 4.00%. Large patches of Yellow-Pencil Coral (*Madracis auretenra*) were intercepted by two transects for a mean cover of 7.35% (Table 29). Six coral colonies, out of 75 intercepted by transects showed signs of infectious diseases, yielding a coral disease prevalence of 8.0% (Appendix 4).

Erect octocorals were prominent in all transects surveyed with a mean density of 11.8 col/transect. Sea Rods (*Eunicea spp, Pseudopterogorgia spp*) were the most abundant in transects. Sea Plumes (*Antillogorgia sp*.) and the Sea Fan (*Gorgonia ventalina*) were common outside of transects. Encrusting octocoral species, *Briareum asbestinum* and *Erythropodium caribaeorum* were present in all transects with a combined mean cover of 7.11% (Table 29). Sponges were represented by 17 species in transects with a combined mean cover of 2.58%. *Aplysina cauliformis, Niphates erecta,* and *Clathria* were observed in three transects. In general, sponges were present as small, encrusting colonies with minor contributions to the overall reef benthic habitat complexity (Table 35). Abiotic substrate categories were contributed by reef overhangs (6.47%), sand (3.15%) and coral rubble (2.58%). The mean reef rugosity of 3.92 m was influenced by the irregular reef bottom topography and small to moderate sized coral colonies.

| **Table 29**. PALN20. Percent cover by sessile-benthic categories at Palomino Reef 20m, Fajardo. | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 7/12/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 17 | 14.8 | 15.2 | 15.4 | 16.1 | **15.7** |
| Rugosity (m) | 5.82 | 4.35 | 3.61 | 2.25 | 3.55 | **3.92** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 5.13 | 7.51 | 8.54 | 2.06 | 9.09 | **6.47** |
| Sand | | 0.59 | 5.04 | | 10.12 | **3.15** |
| Rubble | 7.96 | 3.90 | 1.03 | | | **2.58** |
| **Total Abiotic** | **13.10** | **12.00** | **14.61** | **2.06** | **19.21** | **12.20** |
| **Benthic Algae** | | | | | | |
| Turf (mixed) | 36.46 | 34.73 | 8.13 | 7.66 | 0.93 | **17.58** |
| *Ramicrusta* | 6.99 | 15.12 | 12.24 | 16.69 | 12.40 | **12.69** |
| Turf (mixed) with sediment | 1.50 | 3.51 | 17.70 | 3.77 | 36.36 | **12.57** |
| CCA (mixed) | 2.39 | 1.56 | 2.26 | 12.46 | | **3.73** |
| *Dictyota* spp. | 2.48 | 2.44 | 0.62 | 2.86 | 3.41 | **2.36** |
| **Total Benthic Algae** | **49.82** | **57.37** | **40.95** | **43.43** | **53.10** | **48.93** |
| **Cyanobacteria** | 0.71 | 0.98 | 0.00 | 5.94 | 0.00 | **1.53** |
| **Hard Coral** | | | | | | |
| *Agaricia grahamae* | 16.46 | 7.41 | 9.36 | 3.31 | 7.44 | **8.80** |
| *Madracis aurentenra* | | | 13.68 | 23.09 | | **7.35** |
| *Porites astreoides* | 5.84 | 6.05 | 2.88 | 0.46 | 2.48 | **3.54** |
| *Montastraea cavernosa* | 1.33 | 0.59 | 4.32 | 2.17 | 1.03 | **1.89** |
| *Orbicella faveolata* | 1.68 | | | 1.37 | 5.37 | **1.68** |
| *Siderastrea siderea* | 0.88 | 1.46 | | | 3.62 | **1.19** |
| *Madracis decactis* | | 1.46 | 0.51 | 3.66 | | **1.13** |
| *Porites porites* | 0.44 | 2.73 | | | | **0.63** |
| *Stephanocoenia intersepta* | 1.06 | | | | | **0.21** |
| *Meandrina meandrites* | | 0.98 | | | | **0.20** |
| *Millepora alcicornis* | | | | 0.69 | | **0.14** |
| *Porites divaricata* | | | 0.62 | | | **0.12** |
| *Agaricia lamarcki* | 0.53 | | | | | **0.11** |
| *Eusmilia fastigiata* | | | | | 0.52 | **0.10** |
| *Scolymia cubensis* | 0.18 | | | | | **0.04** |
| **Total Hard Coral** | **28.41** | **20.68** | **31.38** | **34.74** | **20.45** | **27.13** |
| **# Coral Colonies /Transect** | **20** | **17** | **14** | **13** | **11** | **15.0** |
| **# Diseased Coral Colonies** | **2** | **0** | **3** | **1** | **0** | |
| **Zoanthid** | | | | | | |
| *Palythoa caribaeorum* | 0.35 | | | | | **0.07** |
| **Octocoral** | | | | | | |
| *Briaerium asbestinum* | 2.48 | 1.85 | 4.94 | 7.77 | 1.65 | **3.74** |
| *Erythropodium caribaeorum* | 1.42 | 4.10 | 5.56 | 5.14 | 0.62 | **3.37** |
| *Pseudopterogorgia acerosa* | | | | | 1.14 | **0.23** |
| *Eunicea* sp. | 0.18 | 0.39 | | | | **0.11** |
| *Pseudopterogorgia americana* | | | 0.41 | | | **0.08** |
| *Psuedoplexauara* sp. | 0.18 | | | | | **0.04** |
| **Total Octocoral** | **4.25** | **6.34** | **10.91** | **12.91** | **3.41** | **7.56** |
| **# Gorgonians/Transect** | 14 | 15 | 12 | 5 | 13 | **11.8** |
| **Sponges** | | | | | | |
| *Agelas conifera* | | | | | 1.45 | **0.29** |
| *Aplysina cauliformis* | 0.27 | 0.29 | | | 0.83 | **0.28** |
| *Iotrochota birotulata* | | | 1.03 | 0.34 | | **0.27** |
| *Niphates erecta* | | 0.29 | | 0.23 | 0.62 | **0.23** |
| *Clathria* spp. | 0.53 | | 0.21 | | 0.31 | **0.21** |
| *Verongula rigida* | | 0.39 | 0.62 | | | **0.20** |
| *Callyspongia plicifera* | 0.27 | | | | 0.62 | **0.18** |
| *Amphimedon compressa* | 0.88 | | | | | **0.18** |
| *Aiolochroia crassa* | | 0.68 | | | | **0.14** |
| *Callyspongia vaginalis* | 0.27 | | 0.31 | | | **0.11** |
| *Scopalina ruetzerli* | 0.53 | | | | | **0.11** |
| *Monanchora arbuscula* | 0.18 | 0.29 | | | | **0.09** |
| *Agelas citrina* | | 0.39 | | | | **0.08** |
| *Mycale laevis* | | | | 0.34 | | **0.07** |
| *Ircinia* brown sp. | | 0.29 | | | | **0.06** |
| *Plakortis sp.* | 0.27 | | | | | **0.05** |
| Red sponge | 0.18 | | | | | **0.04** |
| **Total Sponges** | **3.36** | **2.63** | **2.16** | **0.91** | **3.82** | **2.58** |

Variations of the benthic community structure between the 2016 baseline and the 2018 monitoring survey are shown in Figure 32. The rank order of reef substrate cover by benthic categories remained constant between surveys. The most notable difference in percent substrate cover was associated with an increase of benthic algal cover of 12.9% contributed by turf and fleshy brown algae, and a decline of abiotic cover. Cyanobacterial cover also increased from a mean of 0.64% in 2016 to a mean of 1.53% in 2018, suggesting that enhanced nutrient availability and/or increased primary substrate may have favored both cyanobacterial and benthic algal cover at PALN20.

The most important change of the sessile-benthic community structure between monitoring surveys at PALN20 was a 34.4% density decline of erect octocorals colonies along transects, from a mean of 18.0 colonies/transect in 2016 to 11.8 colonies/transect in 2018. The difference was statistically significant (ANOVA, p = 0.003; Appendix 2b) and probably influenced by the intense surge and abrasive forces that the reef must have experienced during the pass of Hurricanes Irma and Maria in September 2017 and other event of exceptionally strong wave action in March 2018. Hard (stony) corals declined from a mean of 30.7% in 2016 to a mean of 27.1% in 2018. The difference of 11.7% was statistically insignificant (ANOVA; p = 0.072). Differences were mostly associated with small reductions of cover by Great Star Coral (*Montastrea cavernosa*) and Dimpled Sheet Coral (*Agaricia grahamae*) (Figure 33).

### 10.3 Fishes and Motile Megabenthic Invertebrates

A total of 40 species of fish were identified within belt-transects from a depth of 15 - 17 m at PALN20 (Table 30). Mean density was 314.4 Ind/transect (range: 209 – 452 Ind/transect) with a mean richness of 17.6 species per transect. The Masked Goby (*Coryphopterus personatus*) was the numerically dominant species with a mean density of 280.0 Ind/transect, representing 89.0% of the total fish density. Schools of Blue Chromis (*Chromis cyanea*) were observed over three transects with an average density of 8.6 Ind/transect, ranking second. In addition to the aforementioned species, an assemblage of eight (8) species were present in at least four transects with a combined density of 13.0 Ind/transects, contributing an additional 4.1% to the total fish density. This assemblage included the Beau Gregory and Cocoa Damselfishes (*Stegastes leucostictus, S. variabilis*), Yellowhead Wrasse (*Halichoeres garnoti*), Sharknose Goby (*Elacatinus evelynae*), Unidentified goby (*Coryphopterus sp*), Barred Hamlet (*Hypoplectrus puella*), and Bucktooth Parrotfish (*Sparisoma radians*).

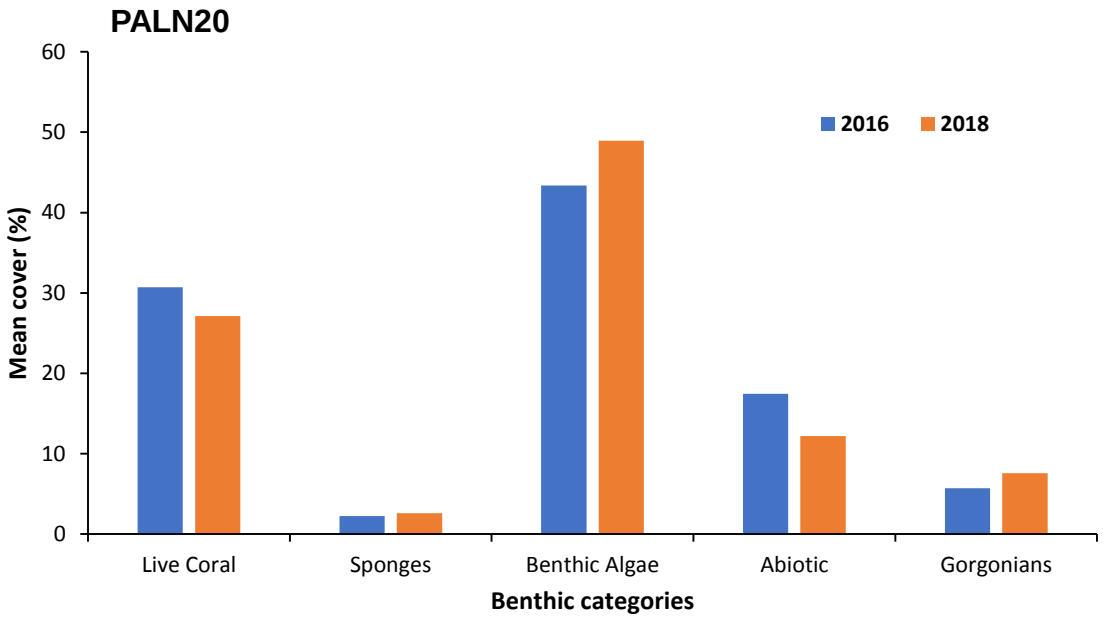



**Figure 32.** PALN20. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Palomino Reef 20m, Fajardo

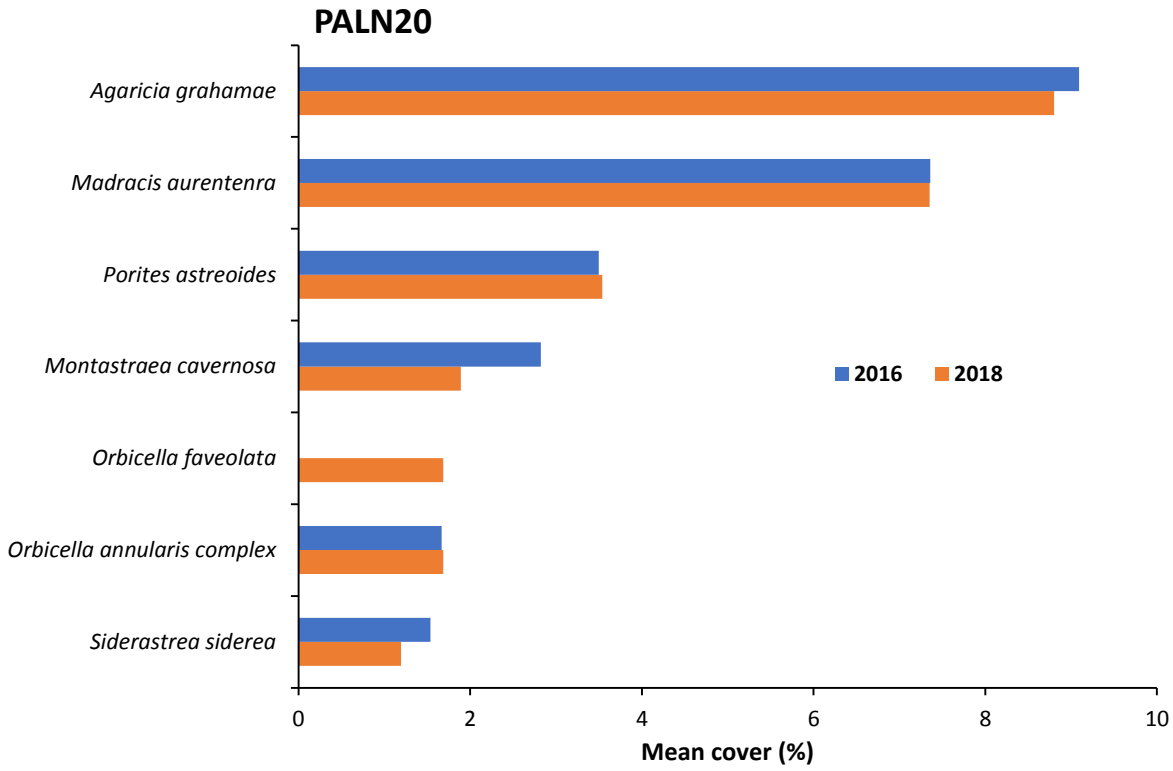



**Figure 33.** PALN20. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at Palomino Reef 20m, Fajardo

**Table 30**. PALN20. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Palomino Reef 20m, Fajardo, July 2018

| Mean Depth: 15.7 m | | | | TRANSECTS | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | | | (Individuals/30 m2) | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Coryphopterus personatus* | Masked Goby | 180 | 210 | 410 | 250 | 350 | **280.0** |
| *Chromis cyanea* | Blue Chromis | 1 | | 18 | 14 | 10 | **8.6** |
| *Stegastes leucostictus* | Beau Gregory | 5 | 3 | 3 | 2 | 3 | **3.2** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 1 | 2 | 3 | 2 | 3 | **2.2** |
| *Stegastes partitus* | Bicolor Damselfish | | 1 | 3 | 5 | | **1.8** |
| *Elacatinus evelynae* | Sharknose Goby | 3 | 1 | 1 | 1 | 2 | **1.6** |
| *Stegastes adustus* | Dusky Damselfish | 2 | 5 | | 1 | | **1.6** |
| *Coryphopterus sp.* | Goby | 3 | 2 | 1 | | 1 | **1.4** |
| *Gramma loreto* | Fairy Basslet | | | | 7 | | **1.4** |
| *Hypoplectrus puella* | Barred Hamlet | 1 | 1 | 1 | 1 | 1 | **1.0** |
| *Sparisoma radians* | Bucktooth Parrotfish | 1 | | 1 | 2 | 1 | **1.0** |
| *Stegastes variabilis* | Cocoa Damselfish | 2 | 1 | | 1 | 1 | **1.0** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | 2 | | 1 | 1 | | **0.8** |
| *Sparisoma viride* | Stoplight Parrotfish | 1 | 2 | | 1 | | **0.8** |
| *Canthigaster rostrata* | Caribbean Puffer | | 1 | 1 | | 1 | **0.6** |
| *Haemulon aurolineatum* | Tomtate | 1 | | | 2 | | **0.6** |
| *Hypoplectrus nigricans* | Black Hamlet | | 1 | | | 2 | **0.6** |
| *Scarus iseri* | Striped Parrotfish | 2 | | 1 | | | **0.6** |
| *Scarus taeniopterus* | Princess Parrotfish | | 2 | | 1 | | **0.6** |
| *Acanthurus chirurgus* | Doctorfish | | 1 | 1 | | | **0.4** |
| *Epinephelus guttatus* | Red Hind | | | 1 | | 1 | **0.4** |
| *Haemulon flavolineatum* | French Grunt | 1 | | 1 | | | **0.4** |
| *Pseudupeneus maculatus* | Spotted Goatfish | | | 2 | | | **0.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | | | 1 | | | **0.2** |
| *Acanthurus coeruleus* | Blue Tang | 1 | | | | | **0.2** |
| *Aulostomus maculatus* | Trumpetfish | | | | 1 | | **0.2** |
| *Bodianus rufus* | Spanish Hogfish | | 1 | | | | **0.2** |
| *Calamus pennatula* | Pluma | | | | | 1 | **0.2** |
| *Cantherhines pullus* | Tail-light Filefish | | | | 1 | | **0.2** |
| *Cephalopholis cruentata* | Graysby | | 1 | | | | **0.2** |
| *Chaetodon ocellatus* | Spotfin Butterflyfish | 1 | | | | | **0.2** |
| *Haemulon macrostomum* | Spanish Hogfish | | | | | 1 | **0.2** |
| *Halichoeres maculipinna* | Clown Wrasse | | | | | 1 | **0.2** |
| *Holacanthus ciliaris* | French Angelfish | | | | 1 | | **0.2** |
| *Holocentrus rufus* | Longspine Squirelfish | | | 1 | | | **0.2** |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | | | | | 1 | **0.2** |
| *Lachnolaimus maximus* | Hogfish | | | | | 1 | **0.2** |
| *Malacoctenus triangulatus* | Saddled Blenny | | 1 | | | | **0.2** |
| *Serranus tigrinus* | Harlequin Bass | | | 1 | | | **0.2** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 209 | 236 | 452 | 294 | 381 | **314.4** |
| | **TOTAL SPECIES** | 17 | 17 | 19 | 18 | 17 | **17.6** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Panulirus argus* | Spiny Lobster | | 2 | | | | **0.4** |
| | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 2 | 0 | 0 | 0 | **0.4** |
| | **TOTAL SPECIES** | | 1 | | | | **0.2** |

The trophic structure of fishes at PALN20 was strongly comprised by zooplanktivorous fishes due to the numerical dominance of the Masked Goby, Blue Chromis, Bicolor Damselfish and Fairy Basslet which represented 92.8%% of the total fishes within transects. Small opportunistic carnivores were represented by a highly specious assemblage that included at least 15 species with a combined density of 10.2 Ind/transect, or 3.2% of the total within belt-transects. The assemblage included five species of hamlets and sea basses (Serranidae), two wrasses (Labridae), two gobies (Gobiidae), one squirrelfish (Holocentridae), one grunt (Haemulidae), one blenny (Blenniidae), one porgy (Sparidae), one puffer (Tetraodontidae) and one trumpetfish (Aulostomidae). Herbivores were represented by six species of parrotfishes (Scaridae), two doctorfishes (Acanthuridae) and two damselfishes (Pomacentridae) with a combined density of 8.4 Ind/transect, representing 2.7% of the total density within belt-transects. Medium sized piscivores included the Red Hind (Serranidae), and the Yellowtail Snapper (Lutjanidae) in extended transects. Motile megabenthic invertebrates were represented by two Spiny Lobsters (*Panulirus argus*) in transect 2 (Table 30).

The size distribution of commercially important fishes and the larger reef herbivores is presented in Table 31. Doctorfishes (Acanthuridae) were represented by early juvenile and adult individuals. The Stoplight, Bucktooth, and Princess Parrotfishes were observed as recruitment juvenile and early adult stages, but adult sizes have also been previously reported (Garcia-Sais et al., 2016), indicative that this reef represents the residential habitat for these species throughout their benthic life cycle. Yellowtail Snapper, Graysby, Red Hind and Hogfish were observed as adults.

Variations of fish density and species richness within belt-transects between the 2016 baseline and the 2018 monitoring surveys are presented in Figure 34. Differences between both surveys were relatively small and statistically insignificant (ANOVA; $p > 0.05$, Appendix 3). Interestingly, numerically dominant fish species, such as Masked Goby (*Coryphopterus personatus*) that exhibited drastically decimated densities during the 2018 survey in reef systems of the west coast presented similar or slightly higher densities between surveys at PALN20 suggesting that Hurricane Maria and or other storm events had minor, if any effects upon the fish community at this reef station.

**Table 31.** PALN20. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Palomino Reef 20m, Fajardo, July 2018

| Mean Depth: 15.7 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | | 1-10 | 1-12 | | |
| *Acanthurus chirurgus* | Doctorfish | 1-12 | 1-5 | 1-12 | | |
| | | | | 1-17 | | |
| *Acanthurus coeruleus* | Blue Tang | 1-14 | | | | |
| *Cephalopholis cruentata* | Graysby | | 1-26 | | | 1-29 |
| *Epinephelus guttatus* | Red Hind | | | 1-26 | | 1-29 |
| *Lachnolaimus maximus* | Hogfish | | | | | 1-62 |
| *Ocyurus chrysurus* | Yellowtail Snapper | | | | 1-24 | |
| *Scarus iseri* | Striped Parrotfish | 2-2 | | 1-12 | | |
| | | | | 1-14 | | |
| *Scarus taeniopterus* | Princess Parrotfish | 1-12 | 1-7 | | 1-10 | |
| | | | 2-12 | | 1-19 | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1-17 | | | 1-12 | |
| *Sparisoma radians* | Bucktooth Parrotfish | 1-2 | | 1-2 | 2-2 | 1-1 |
| | | | | | | 3-2 |
| *Sparisoma viride* | Stoplight Parrotfish | 1-10 | 1-7 | | 1-2 | |
| | | 1-14 | 1-14 | | | |
| **Invertebrates** | | | | | | |
| *Panulirus argus* | Spiny Lobster | | 1-7 | | | |
| | | | 1-8 | | | |

TL = Fish Total Length
Lobster length is the carapace length in cm

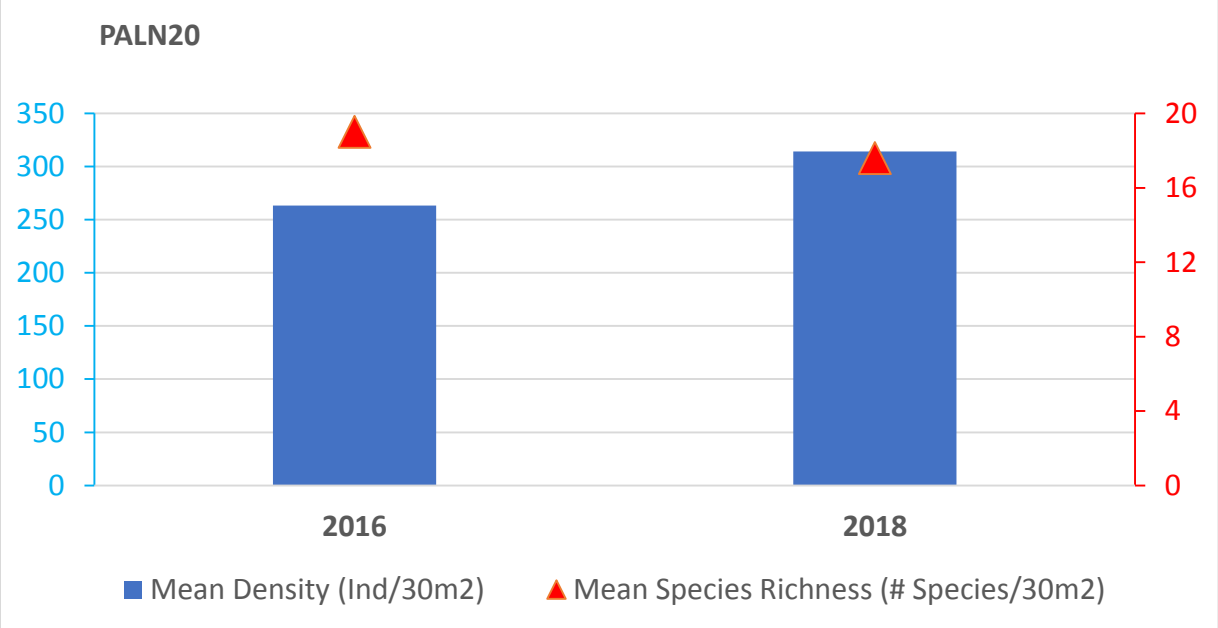



**Figure 34.** PALN20. Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Palomino Reef 20m, Fajardo

**Photo Album 10**

**Palomino Reef 20m, Fajardo (PALN20)**

## 11.0 Palominito Reef 10, Fajardo (PALT10)

### 11.1 Physical Description

Isla Palominitos sits in the same reef platform with Palominos (Figure 31). A shallow sand channel separates both islands. Coral reefs occur to the northeast, east and south of Palominitos. There is a large fringing reef that breaks down into a series of small submerged patch reefs, particularly to the east and south of the island. The largest and best developed coral reef is located to the northeast and it is the one included in our survey (PALT10). This is a fringing coral formation overlying the fore-reef slope with massive coral build-up. The reef structure is characterized by steep spurs and deep grooves with sandy sediments. It was not possible to corroborate how much of this structure is actually coral build-up. Massive stony corals grow on top and along the sides of the spurs providing substantial topographic relief and habitat to the reef community. Turtle seagrass occurs along the south coast in close proximity with scattered patch reefs. The west section of the island presents scattered coral growth below depths of 5 - 6 m and features a small coralline sandy beach that is a recreational hotspot for tourists in the area. The baseline survey of PALT10 was performed on September 2016. Images of the reef community at PALT10 are shown in Photo Album 11.

### 11.2 Sessile Benthic Reef Community

A mixed assemblage of benthic algae comprised by red crustose coralline algae, turf, fleshy brown and calcareous green macroalgae was the dominant benthic category covering reef substrate at PALT10 with a combined mean cover of 58.11% (range: 55.34 – 65.29%). Encrusting red crustose coralline algae, largely comprised by *Ramicrusta sp*, was the dominant taxa with a mean cover of 39.20%, representative of 67.5% of the total benthic algae (Table 32). Fleshy brown macroalgae, particularly *Dictyota sp*. and *Lobophora variegata* were observed growing over uncolonized reef hard substrates, and also growing over hard substrates colonized by *Ramicrusta sp.* Fleshy brown macroalgae presented a combined mean substrate cover of 7.86%, representative of 13.5% of the total benthic algae. Red fleshy alga, *Asparagopsis taxiformis* and the calcareous green alga, *Halimeda opuntia* were also observed overgrowing *Ramicrusta sp*.

Cyanobacterial patches were intercepted by four transects with a relatively high mean substrate cover of 4.26%, compared to the 2018 PRCRMP average of 3.22%. This may be related to increased availability of nutrients and/or appropriate substrate for growth. Both of these conditions may have been influenced by the pass of hurricanes given their nutrient loading potential due to rainfall runoff and upwelling. Increased primary substrates are produced upon coral detachment.

| **Table 32**. PALT10. Percent cover by sessile-benthic categories at Palominito Reef 10m, Fajardo. | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 7/12/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 10.3 | 10.9 | 10.6 | 10.9 | 10.6 | **10.7** |
| Rugosity (m) | 2.39 | 2.31 | 5.33 | 2.21 | 4.56 | **3.36** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 3.05 | 1.93 | 2.74 | | 7.31 | **3.01** |
| Gap | 0.68 | | | | | **0.14** |
| **Total Abiotic** | **3.73** | **1.93** | **2.74** | **0.00** | **7.31** | **3.14** |
| **Benthic Algae** | | | | | | |
| *Ramicrusta* | 27.80 | 38.23 | 45.57 | 32.57 | 51.83 | **39.20** |
| Turf (mixed) | 9.60 | 7.05 | 3.56 | 15.71 | 1.73 | **7.53** |
| *Dictyota* sp. on *Ramicrusta* | 8.70 | 6.26 | 3.01 | 4.01 | 2.02 | **4.80** |
| *aragopsis taxiformis* on *Ramicrusta* | 2.94 | 4.44 | | | 6.54 | **2.78** |
| *Dictyota* spp. | | | 3.20 | 3.78 | 1.06 | **1.61** |
| *obophora variegatus* on *Ramicrusta* | 6.78 | | | | | **1.36** |
| Turf (mixed) with sediment | 1.13 | | | | | **0.23** |
| *Asparagopsis taxiformis* | 0.45 | | | | 0.48 | **0.19** |
| Turf (mided) on *Ramicrusta* | | | | | | **0.00** |
| CCA (mixed) | | | | | 0.77 | **0.15** |
| *Halimeda* spp. on *Ramicrusta* | | | | | 0.58 | **0.12** |
| *Lobophora variegatus* | 0.45 | | | | | **0.09** |
| *Halimeda* spp. | | | | | 0.29 | **0.06** |
| **Total Benthic Algae** | **57.85** | **55.97** | **55.34** | **56.08** | **65.29** | **58.11** |
| **Cyanobacteria** | 0.00 | 2.62 | 5.21 | 0.57 | 12.88 | **4.26** |
| **Hard Coral** | | | | | | |
| *Orbicella faveolata* | 18.42 | 22.98 | 6.48 | 16.40 | 4.62 | **13.78** |
| *Orbicella annularis* | | 7.39 | 11.96 | | | **3.87** |
| *Porites astreoides* | 0.56 | 1.25 | 3.84 | 7.34 | 5.67 | **3.73** |
| *Colpophyllia natans* | | | 6.03 | 6.88 | | **2.58** |
| *Orbicella franksi* | 6.55 | | 0.91 | 1.72 | | **1.84** |
| *Siderastrea siderea* | 5.31 | | | | | **1.06** |
| *Porites porites* | 0.34 | | 0.82 | 0.34 | 0.19 | **0.34** |
| *Millepora alcicornis* | | 0.34 | | | | **0.07** |
| *Agaricia fragilis* | | | | | 0.29 | **0.06** |
| **Total Hard Coral** | **31.19** | **31.97** | **30.05** | **32.68** | **10.77** | **27.33** |
| **# CoralColonies /Transect** | **13** | **10** | **15** | **8** | **4** | **10.0** |
| **# Diseased Coral Colonies** | **0** | **1** | **0** | **0** | **0** | |
| **Zoanthid** | | | | | | |
| *Condominium* spp. | 0.00 | 0.23 | 0.00 | 0.00 | 0.29 | **0.10** |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | 2.60 | 7.17 | 5.02 | 8.03 | 2.40 | **5.04** |
| *Briaerium asbestinum* | 1.36 | | 0.46 | | | **0.36** |
| *Pseudoplexaura* spp. | | | 0.18 | 0.34 | 0.19 | **0.14** |
| *Gorgonia ventalina* | | | | | 0.38 | **0.08** |
| *Eunicea flexuosa* | | | | 0.34 | | **0.07** |
| *Eunicea tourneforti* | 0.23 | | | | | **0.05** |
| **Total Octocoral** | **4.18** | **7.17** | **5.66** | **8.72** | **2.98** | **5.74** |
| **# Gorgonians/Transect** | 16 | 20 | 14 | 15 | 21 | **17.20** |
| **Sponges** | | | | | | |
| *Chondrilla caribensis* | 2.26 | | | | | **0.45** |
| *Niphates erecta* | 0.79 | 0.11 | | | 0.29 | **0.24** |
| *Monanchora arbuscula* | | | | 0.69 | | **0.14** |
| *Plakortis* sp. | | | 0.46 | | 0.19 | **0.13** |
| *Scopalina ruetzleri* | | | 0.18 | 0.23 | | **0.08** |
| *Dictyonella funicularis* | | | 0.37 | | | **0.07** |
| *Amphimedon compressa* | | | | 0.23 | | **0.05** |
| **Total Sponges** | **3.05** | **0.11** | **1.00** | **1.15** | **0.48** | **1.16** |

Eight scleractinian corals and one hydrocoral were intercepted by transects at PALT10 with a combined mean substrate hard coral cover of 27.33% (range: 10.77 – 32.68%). Mountainous Star Coral (*Orbicella faveolata*) was the dominant coral intercepted by transects with a mean substrate cover of 13.78%, representing 50.5% of the total cover by corals (Table 32). Boulder Star Coral (*O. franksi*) was present in three transects with a mean cover of 1.84%. Large massive colonies of Lobed Star Coral (*O. annularis*) and Boulder Brain Coral (*Colpophyllia natans*) were intercepted in two transects each with a mean cover of 3.87% and 2.58%, respectively. Mustard-Hill Coral (*Porites astreoides*) and Finger Coral (*P. porites*) were present in five and four transects, respectively with a combined mean cover of 4.07%. Fire Coral (*Millepora* spp.) was present as small branching colonies with low substrate cover (0.07%). One coral colony out of the 50 intercepted by transects was observed with an apparent disease infection (disease prevalence = 2.0%)

Erect octocorals were prominent in all transects surveyed with a mean density of 17.2 col/transect at PALT10 (Table 32). Sea Rods (*Eunicea spp, Pseudoplexaura sp*) and the Sea Fan (*Gorgonia ventalina*) were the most abundant in transects. The Encrusting Gorgonian (*Erythropodium caribaeorum*) was present in all transects with a mean cover of 5.04%. Another encrusting species (*Briareum asbestinum*) was observed in two transects with a mean cover of 0.36%. Sponges were represented by seven (7) species in transects with a combined mean cover of 1.16%. *Niphates erecta, Plakortis sp.,* and *Scopalina ruetzleri* were the only species observed in more than one transect. In general, sponges were present as small and mostly encrusting colonies with minor contributions to the overall reef benthic habitat complexity and topographic relief.

Variations of reef substrate cover by the major sessile-benthic categories between the 2016 baseline and the 2018 monitoring surveys at PALT10 are shown in Figure 35. The rank order of major benthic categories remained stable between surveys. Total cover by benthic algae varied only 9.4% between surveys, but differences of the percent reef substrate cover by specific algal components were noted. In the 2016 baseline, the combined cover by red crustose coralline algae was 46.0%, representative of 86.6% of the total benthic algae at PALT10. In 2018, the total red crustose coralline algae declined by 14.4%. The reduction of cover by coralline algae resulted from overgrowth by other fleshy brown and red and turf algae over *Ramicrusta sp*. This is relevant from the standpoint that the recent bloom of coralline algae reported for coral reefs of the east coast (Garcia-Sais et al., 2016) has not stabilized and intraspecific competition appears to be occurring.

Differences of substrate cover by coral species between surveys are shown in Figure 36. Total live coral declined 17.8% between surveys, but such difference was not statistically significant (ANOVA, p = 0.129; Appendix 2a). The dominant *Orbicella spp* complex cover reported in the 2016 baseline survey remained constant at 19.49% in the 2018 monitoring survey when the individual contributions by the three species (*O. faveolata, O. annularis, O. franksi*) are added. The main difference was associated with a reduction of cover by *Porites porites* and *P. astreoides* (Figure 36). Particularly the former is a fast-growing branching species that may have been impacted by the strong surge and sand abrasion effects associated with the pass of hurricanes and other wave storm events. Differences of octocoral density between surveys were not statistically significant (ANOVA; p = 0.199; Appendix 2b).

### 11.3 Fishes and Motile Megabenthic Invertebrates

A total of 33 fish species were identified within belt-transects from a depth of 9 – 10 meters at PALT10 (Table 33). Mean density was 37.0 Ind/transect (range: 24 – 53 Ind/transect) with a mean richness of 14.8 species/transect. The Three-spot and Dusky Damselfish (*Stegastes planifrons*) and the Sharknose Goby (*Elacatinus evelynae*) were the only species present in all transects. In addition to the aforementioned species, the main assemblage in terms of density within belt-transects included the Yellowtail Snapper (*Ocyurus chrysurus*), Masked Goby (*Coryphopterus personatus*), Striped, Stoplight and Bucktooth Parrotfishes (*Scarus iseri, Sparisoma viride, S. radians*), Bluehead Wrasse (*Thalassoma bifasciatum*), Blue Chromis (*Chromis cyanea*) and the Dusky Damselfish (*Stegastess adustus*). The combined density of this assemblage represented 70.8% of the total individuals (Table 33).

The herbivore fish assemblage, integrated by five parrotfishes (Scaridae), three damselfishes (Pomacentridae) and three doctorfishes (Acanthuridae) dominated the trophic structure at PALT10 in terms of their cumulative density representing 49.7% of the total individuals within belt-transects. Small opportunistic carnivores were represented by 13 species with a combined density of 9.0 Ind/transects, or 24.3% of the total individuals. These included three sea basses and a small grouper (Serranidae), two wrasses (Labridae), two squirrelfishes (Holocentridae), two gobies (Gobiidae), one grunt (Haemulidae) and one puffer (Tetraodontidae). Medium sized piscivores were represented within belt-transects only by the Yellowtail Snapper (*Ocyurus chrysurus*) and the Red Hind (*Epinephelus guttatus*). Large demersal or pelagic predators were not observed in the 2018 survey. Four Long-Spined Urchins (*Diadema antillarum*) were observed within belt-transects (Table 33).

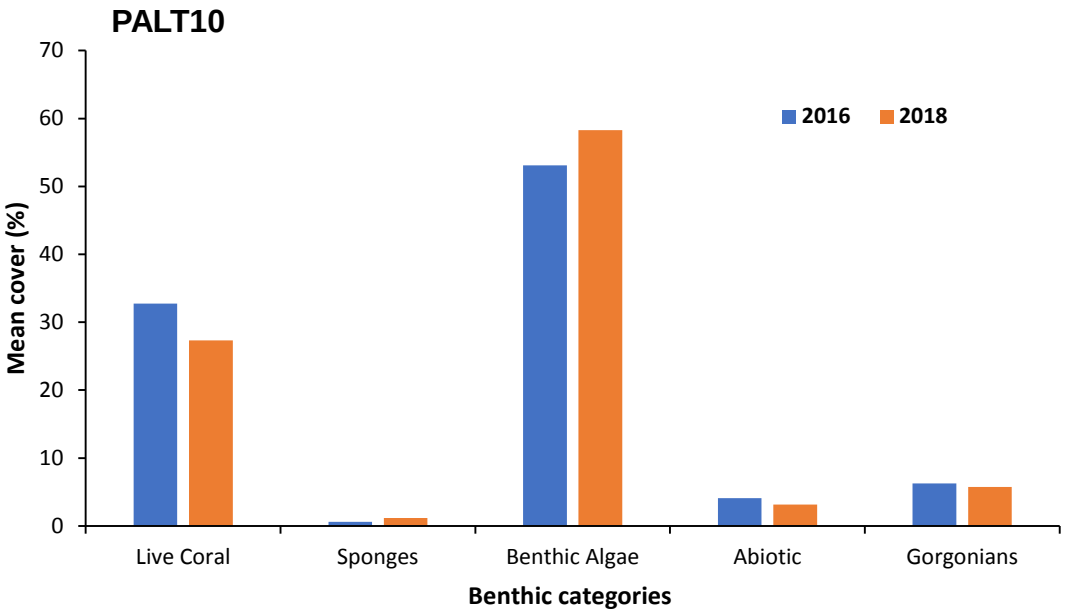



**Figure 35.** PALT10. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Palominito Reef 10m, Fajardo

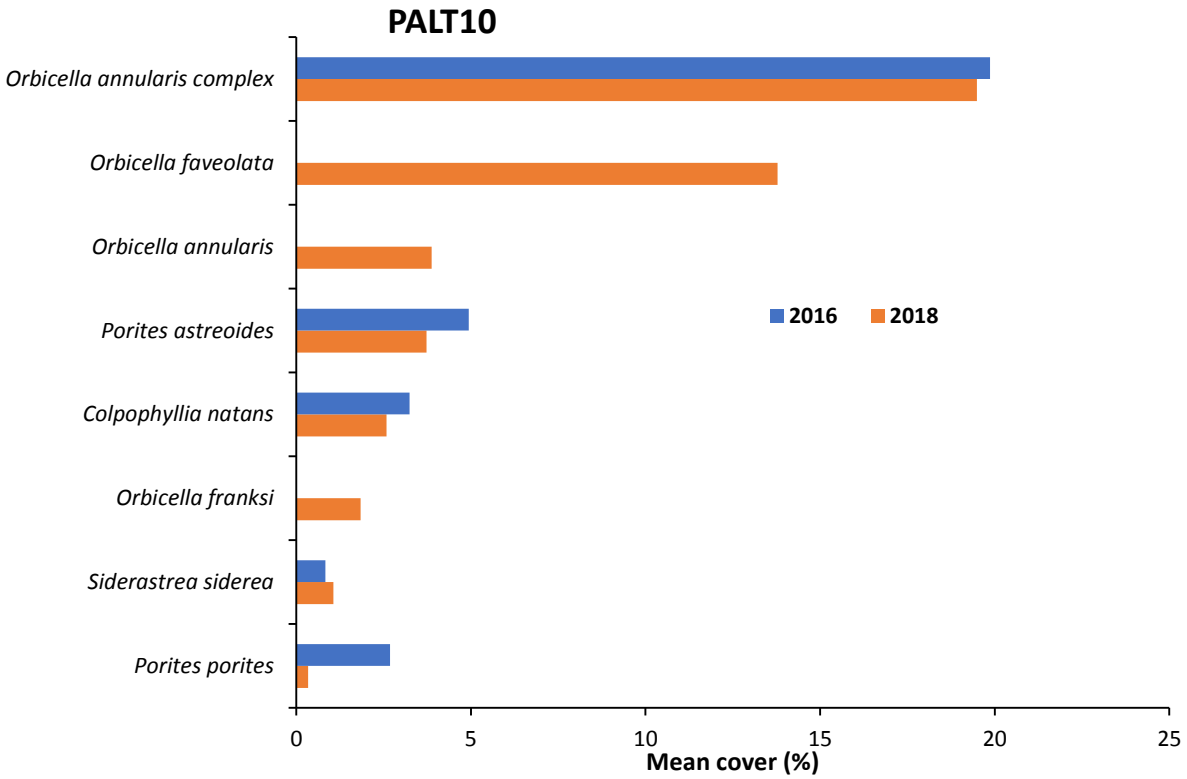



**Figure 36.** PALT10. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at Palominito Reef 10m, Fajardo

**Table 33**. PALT10. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Palominito Reef10m, Fajardo, July 2018

| Mean Depth: 10.7 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Stegastes planifrons* | Three-spot Damselfish | 2 | 1 | 8 | 6 | 1 | **3.6** |
| *Ocyurus chrysurus* | Yellowtail Snapper | 6 | | | 4 | 7 | **3.4** |
| *Elacatinus evelynae* | Sharknose Goby | 2 | 2 | 8 | 2 | 2 | **3.2** |
| *Coryphopterus personatus* | Masked Goby | | 14 | | | | **2.8** |
| *Scarus iseri* | Striped Parrotfish | | 5 | 3 | 1 | 5 | **2.8** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | | 7 | | | 7 | **2.8** |
| *Sparisoma radians* | Bucktooth Parrotfish | 1 | 5 | 3 | | 2 | **2.2** |
| *Chromis cyanea* | Blue Chromis | | | 1 | | 8 | **1.8** |
| *Sparisoma viride* | Stoplight Parrotfish | | | 6 | | 3 | **1.8** |
| *Stegastes adustus* | Dusky Damselfish | 3 | 4 | 2 | | | **1.8** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 | 2 | | 3 | 1 | **1.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | 2 | 1 | 1 | 1 | 1 | **1.2** |
| *Acanthurus coeruleus* | Blue Tang | 1 | 1 | 1 | 2 | | **1.0** |
| *Stegastes leucostictus* | Beau Gregory | 1 | 2 | | | 2 | **1.0** |
| *Acanthurus chirurgus* | Doctorfish | 2 | 1 | 1 | | | **0.8** |
| *Scarus taeniopterus* | Princess Parrotfish | 1 | 2 | | 1 | | **0.8** |
| *Cantherhines pullus* | Tail-light Filefish | | 1 | 1 | | 1 | **0.6** |
| *Canthigaster rostrata* | Caribbean Puffer | | 1 | | 1 | | **0.4** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | 2 | | | | | **0.4** |
| *Clepticus parrae* | Creole Wrasse | | | | | 2 | **0.4** |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | 1 | | | 1 | | **0.4** |
| *Abudefduf saxatilis* | Sargent Major | | | | | 1 | **0.2** |
| *Carangoides ruber* | Bar Jack | | | | | 1 | **0.2** |
| *Cephalopholis cruentata* | Graysby | | | 1 | | | **0.2** |
| *Coryphopterus lipernes* | Peppermint Goby | | 1 | | | | **0.2** |
| *Epinephelus guttatus* | Red Himd | | 1 | | | | **0.2** |
| *Haemulon sciurus* | Bluestripped Grunt | 1 | | | | | **0.2** |
| *Halichoeres garnoti* | Yellow-head Wrasse | | | | | 1 | **0.2** |
| *Holocentrus adscensionis* | Squirrelfish | | 1 | | | | **0.2** |
| *Holocentrus rufus* | Longspine Squirelfish | | 1 | | | | **0.2** |
| *Hypoplectrus nigricans* | Black Hamlet | | | | 1 | | **0.2** |
| *Hypoplectrus puella* | Barred Hamlet | | | | 1 | | **0.2** |
| *Stegastes partitus* | Bicolor Damselfish | | | | | 1 | **0.2** |
| | **TOTAL INDIVIDUALS** | 26 | 53 | 36 | 24 | 46 | **37.0** |
| | **TOTAL SPECIES** | 14 | 19 | 12 | 12 | 17 | **14.8** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Diadema antillarum* | Long-spined Urchin | | | 1 | 3 | | **0.8** |
| | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 1 | 3 | 0 | **0.8** |
| | **TOTAL SPECIES** | | | 1 | 1 | | **0.4** |

The size distribution of commercially important fishes and the larger reef herbivores is presented in Table 34. The Stoplight, Redband and Princess Parrotfishes were observed throughout their entire size range, including recruitment juveniles and full adults. Doctorfishes (Acanthuridae) were represented by adults and early juvenile stages of Blue Tang and Ocean Surgeon. Individuals of the Yellowtail and Schoolmaster Snappers (Lutjanidae) were mostly present as juveniles and young adults in the 5 – 29 cm range. The Red Hind and Graysby (Serranidae) were observed as small adults in the 25 – 29 cm range.

A marked reduction of fish density between the 2016 baseline and the 2018 monitoring surveys was evidenced (Figure 37). Fish density declined by 56.8%, from 85.6 Ind/transect in 2016 to 37.0 Ind/transect in 2018. The difference was largely driven by the density decline of Masked Goby (*Coryphopterus personatus*) which was the numerically dominant species in 2016, representing 60.5% of the total individuals. This pattern was consistent throughout many reefs surveyed in 2018 and appears to be related (with exceptions) to an island-wide collapse of the Masked Goby population. It is proposed that this may be a lingering effect of the impact of hurricanes and other wave storm events acting over shallow reefs around Puerto Rico prior to the 2018 monitoring survey. Overall species richness did not change at PALT10.

**Table 34.** PALT10. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Palominito Reef 10m, Fajardo, July 2018

| Mean Depth: 10.7 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 1-5 | 1-10 | 1-10 | 1-14 | 1-14 |
| | | 1-7 | 1-12 | 1-12 | | |
| | | 1-10 | | | | |
| *Acanthurus chirurgus* | Doctorfish | 1-7 | 1-10 | 1-12 | | |
| | | 1-12 | | | | |
| *Acanthurus coeruleus* | Blue Tang | 1-12 | 1-7 | 1-7 | 1-10 | 1-14 |
| | | 1-14 | | | 2-12 | |
| *Cephalopholis cruentata* | Graysby | | | 1-26 | | |
| *Epinephelus guttatus* | Red Hind | | 1-29 | | | |
| *Lutjanus apodus* | Schoolmaster | | | | 1-24 | 1-19 |
| | | | | | | 1-29 |
| *Ocyurus chrysurus* | Yellowtail Snapper | 3-7 | 3-7 | | 1-10 | 1-5 |
| | | 2-12 | | | 2-17 | 3-14 |
| | | 1-19 | | | 1-24 | 2-19 |
| | | 1-24 | | | | 1-24 |
| *Scarus iseri* | Striped Parrotfish | | 6-2 | 8-1 | 1-12 | |
| | | | 2-5 | | | |
| *Scarus taeniopterus* | Princess Parrotfish | 1-19 | 2-10 | | 1-19 | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1-14 | 1-7 | | 1-2 | 1-12 |
| | | | 1-12 | | 1-12 | |
| | | | | | 1-25 | |
| *Sparisoma radians* | Bucktooth Parrotfish | 1-5 | | 4-1 | | 2-2 |
| | | | | 3-2 | | |
| *Sparisoma viride* | Stoplight Parrotfish | | 1-1 | 6-1 | (2) | 1-1 |
| | | | 2-5 | 1-5 | | 2-2 |
| | | | 1-7 | 1-24 | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |

TL = Fish Total Length

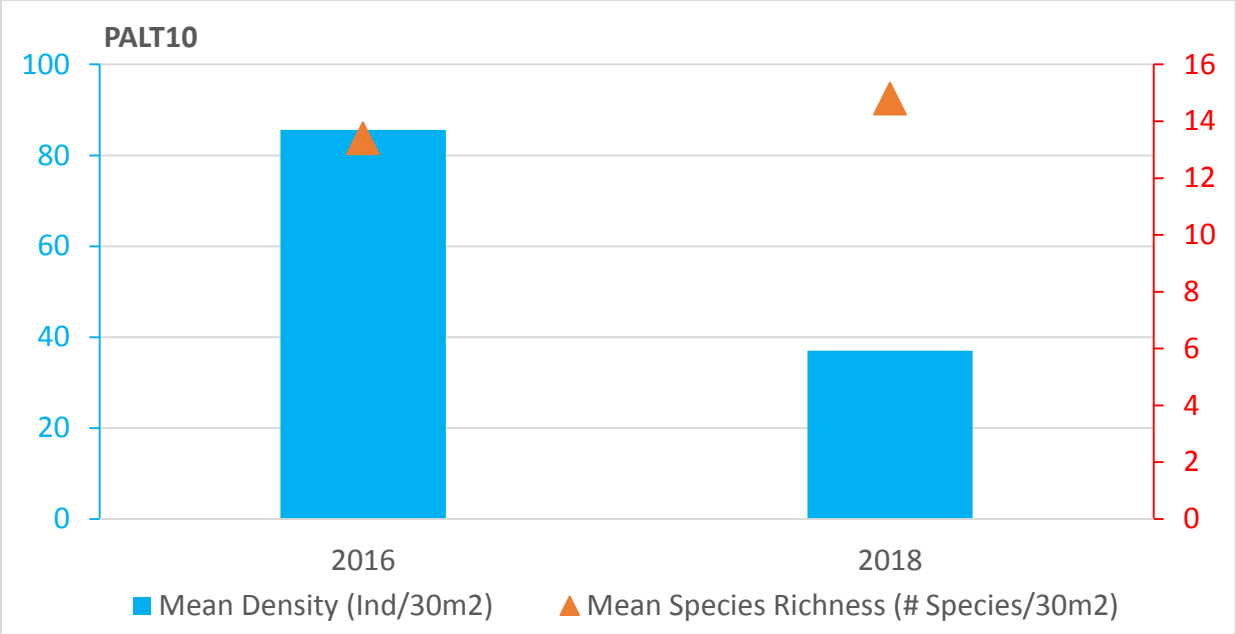
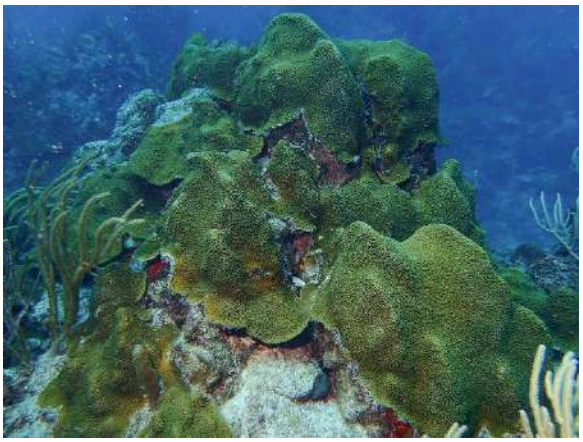


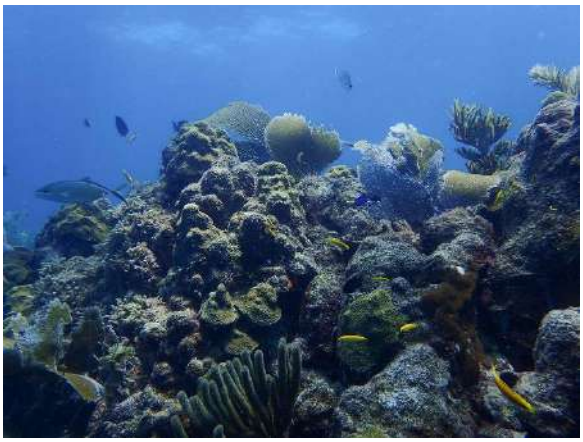

**Figure 37.** PALT10. Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Palominito Reef 10m, Fajardo

**Photo Album 11**

**Palominito Reef 10m, Fajardo (PALT10)**





## 12.0 Cayo Diablo 5, Fajardo (DIAB05)

## 12.1 Physical Description

Cayo Diablo is the easternmost emergent key of the "Cordillera de Fajardo". It is a mostly un-vegetated island with many rocky outcrops and a sandy beach on the southeast coastline. The northern section of the island (windward) has a narrow reef platform with a rocky shoreline exposed to seasonally strong wave action. Coral reefs are found on the southern (leeward) section of the island. Patch reefs represent the main coral reef formation at Cayo Diablo. These reefs lie submerged at variable depths along the backreef zone intermixed with seagrass in some areas. Patch reefs emerge from a white coralline sandy bottom at depths of 10-12 meters. The baseline survey at Cayo Diablo (DIAB05) was performed on September 2016. Transects were installed along an east-west axis on the top of adjacent patch reef promontories at a depth of 3.9 – 6.4 m in the backreef zone (Figure 31). Images of the DIAB05 reef community are presented in Photo Album 12.

## 12.2 Sessile Benthic Reef Community

Benthic algae were the dominant sessile-benthic category in terms of reef substrate cover at DIAB05. The mixed assemblage, comprised by crustose coralline algae, turf algae, fleshy brown, red and green fleshy and calcareous macroalgae presented a combined mean cover of 73.19%. A highly calcified encrusting red algae (*Ramicrusta sp.*) was found as a dark reddish crust overgrowing most available hard bottom in all five transects with a mean cover of 34.18%, representing 46.7% of the total cover by benthic algae (Table 35). The encrusting red algae appeared to be mostly overgrowing dead coral sections. Turf algae, a mixed assemblage of short filamentous red and brown macroalgae was also present in all five transects with a mean substrate cover of 23.36%, or 32.0% of the total benthic algae. Fleshy brown macroalgae (mostly *Dictyota sp*) was observed growing over abiotic hard substrates and also overgrowing *Ramicrusta sp* with a combined mean cover of 7.96%. Calcareous (*Halimeda sp*), fleshy green (*Caulerpa sp*), and fleshy red (*Galaxaura sp*) macroalgae were also observed overgrowing *Ramicrusta sp*. Patches of cyanobacteria were present in all five transects with a mean cover of 3.59%, slightly above the 2018 PRCRMP average of 3.22%.

| **Table 35**. DIAB05. Percent cover by sessile-benthic categories at Cayo Diablo Reef 5m, Fajardo. | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 7/12/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 5.4 | 3.9 | 4.2 | 6.4 | 6.1 | **5.2** |
| Rugosity (m) | 5.64 | 1.87 | 2.46 | 3.08 | 3.94 | **3.4** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 7.79 | 5.90 | 3.37 | 3.21 | 1.00 | **4.25** |
| Rubble | | 0.59 | 7.64 | | | **1.65** |
| Sand | | | 1.80 | | | **0.36** |
| **Total Abiotic** | **7.79** | **6.49** | **12.81** | **3.21** | **1.00** | **6.26** |
| **Benthic Algae** | | | | | | |
| *Ramicrusta* | 30.80 | 35.97 | 46.96 | 33.19 | 24.00 | **34.18** |
| Turf (mixed) | 25.78 | 17.33 | 17.42 | 24.63 | 31.63 | **23.36** |
| *Dictyota* spp. on *Ramicrusta* | | 17.92 | | 1.07 | 1.00 | **4.00** |
| Dictyota spp. | 0.36 | 2.36 | 6.18 | 7.07 | 3.82 | **3.96** |
| *Halimeda* spp. | 6.09 | 1.06 | 1.01 | 1.07 | 5.62 | **2.97** |
| Turf (mixed) with sediment | | | 1.57 | | 8.03 | **1.92** |
| Peyssonnelid (mixed) | 3.58 | | | | 3.21 | **1.36** |
| CCA (mixed) | 0.98 | 1.42 | 0.34 | 0.64 | 0.30 | **0.74** |
| *Caulerpa* sp. on *Ramicrusta* | | 2.36 | | | | **0.47** |
| *Galaxaura* sp. on *Ramicrusta* | | 0.71 | | | | **0.14** |
| *Galaxaura* sp. | | 0.47 | | | | **0.09** |
| **Total Benthic Algae** | **67.59** | **79.60** | **73.48** | **67.67** | **77.61** | **73.19** |
| **Cyanobacteria** | 1.07 | 3.30 | 4.61 | 8.24 | 0.70 | **3.59** |
| **Hard Coral** | | | | | | |
| *Orbicella faveolata* | 6.00 | 6.72 | | 20.02 | 10.54 | **8.66** |
| *Porites porites* | 1.52 | 1.53 | 6.07 | 0.43 | 1.41 | **2.19** |
| *Orbicella annularis* | 5.82 | | | | | **1.16** |
| *Millepora alcicornis* | 5.64 | | | | | **1.13** |
| *Porites astreoides* | 1.34 | | | 0.43 | | **0.35** |
| *Agaricia agaricites* | 0.36 | | | | 0.30 | **0.13** |
| *Agaricia fragilis* | 0.18 | | 0.34 | | | **0.10** |
| *Acropora cervicornis* | | | 0.22 | | | **0.04** |
| **Total Hard Coral** | **20.86** | **8.25** | **6.63** | **20.88** | **12.25** | **13.77** |
| **# CoralColonies /Transect** | **10** | **2** | **4** | **5** | **4** | **5.0** |
| **# Diseased Coral Colonies** | **0** | **0** | **0** | **0** | **0** | |
| **Zoanthid** | | | | | | |
| *Palythoa caribaeorum* | 0.98 | | 2.25 | | | **0.65** |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | | 0.59 | | | 1.81 | **0.48** |
| *Briareum asbestinum* | 0.90 | 0.35 | | | | **0.25** |
| *Eunicea succinea* | | 0.24 | | | | **0.05** |
| **Total Octocoral** | **0.90** | **1.18** | **0.00** | **0.00** | **1.81** | **0.78** |
| **# Gorgonians/Transect** | 1 | 11 | 3 | 4 | 6 | **5.0** |
| **Sponges** | | | | | | |
| *Cinchyrella kuekenthali* | 0.81 | | | | | **0.16** |
| *Niphates erecta* | | | | | 0.40 | **0.08** |
| Red sponge | | | 0.22 | | | **0.04** |
| Yellow sponge | | | | | 0.20 | **0.04** |
| **Total Sponges** | **0.81** | **0.00** | **0.22** | **0.00** | **0.60** | **0.33** |

Hard corals were represented by seven species of scleractinians and one hydrocoral (*Millepora alcicornis*) with a combined mean substrate cover of 13.77% (range: 8.25 – 20.86%). Mountainous Star Coral (*Orbicella faveolata*) was the dominant coral intercepted by transects with a mean substrate cover of 8.66%, representing 63.0% of the total cover by corals. Finger Coral (*P. porites*) was the only coral species present in all transects with a mean cover of 2.19%. The combined cover of *O. faveolata* and *P. porites* represented 78.8% of the total cover by live corals at DIAB05. One small colony of Staghorn Coral (*Acropora cervicornis*) was intercepted at transect 3 and small colonies were observed to be common at DIAB05. Dead and live colonies of Elkhorn Coral (*A. palmata*) were also observed in shallow sections of the backreef. Massive coral promontories, most likely *O. faveolata* buildups were seen in advanced stages of degradation and overgrown by turf algae and *Ramicrusta.*

Octocorals were present in all transects surveyed with a mean density of 5.0 col/transect at DIAB05 (Table 35). Sea Rods (*Eunicea spp, Plexaura spp*) and the Sea Fan (*Gorgonia ventalina*) were the most common. The encrusting octocoral species, *Erythropodium caribaeorum* and *Briareum asbestinum* were observed in three transects with a combined mean cover of 0.73%. Sponges were represented by four species with a combined mean cover of 0.33%. In general, sponges were present as small and mostly encrusting colonies with minor contributions to the overall reef benthic habitat complexity and topographic relief. Abiotic substrate categories were largely contributed by reef overhangs (4.25%) and coral rubble (1.65%). The mean reef rugosity of 3.4 m was mostly influenced by coral ledges and overhangs.

Temporal variations of reef substrate cover by sessile-benthic categories between the 2016 baseline and the 2018 monitoring survey are presented in Figure 38. The rank order of major benthic categories in terms of reef substrate cover remained stable at DIAB05, as well as the relative differences between categories. Although differences of cover by the total benthic algal assemblage were below 1% between surveys, major differences in the relative contribution of taxonomic components to the total cover were measured. There was a 10.1-fold increase of cover by brown and green fleshy algae (*Dictyota sp*. + *Caulerpa sp*) during 2018, and an 8.4-fold increase by turf algae relative to the 2016 baseline survey. A corresponding decline of cover was measured for *Ramicrusta sp*., from 63.04% in 2016 to 34.18% in 2018. The decline of *Ramicrusta sp*. resulted both from overgrowth by fleshy algae and an apparent gain of space by turf algae.

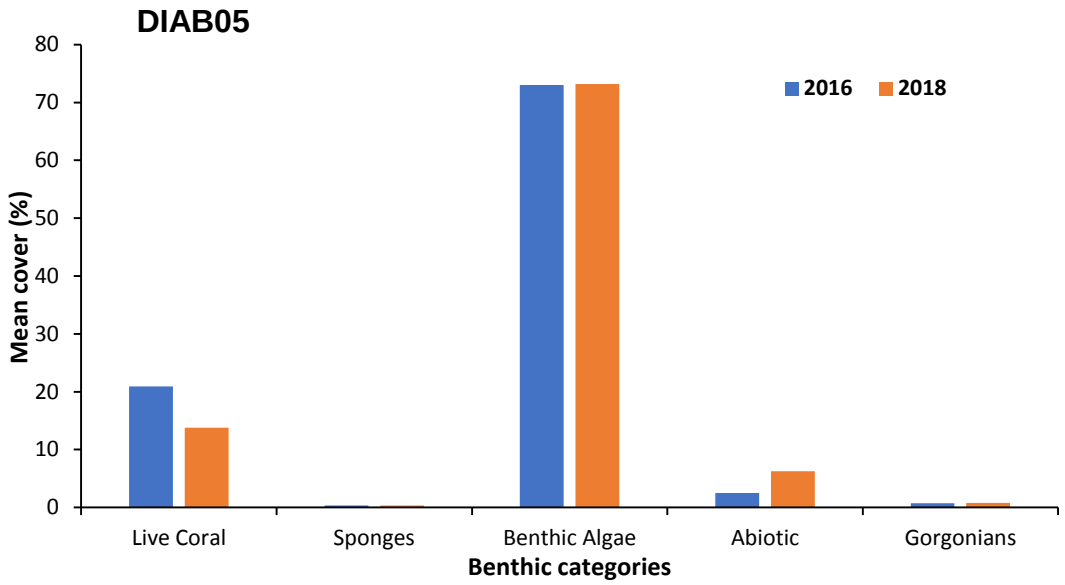



**Figure 38.** DIAB05. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Cayo Diablo Reef 5m, Fajardo

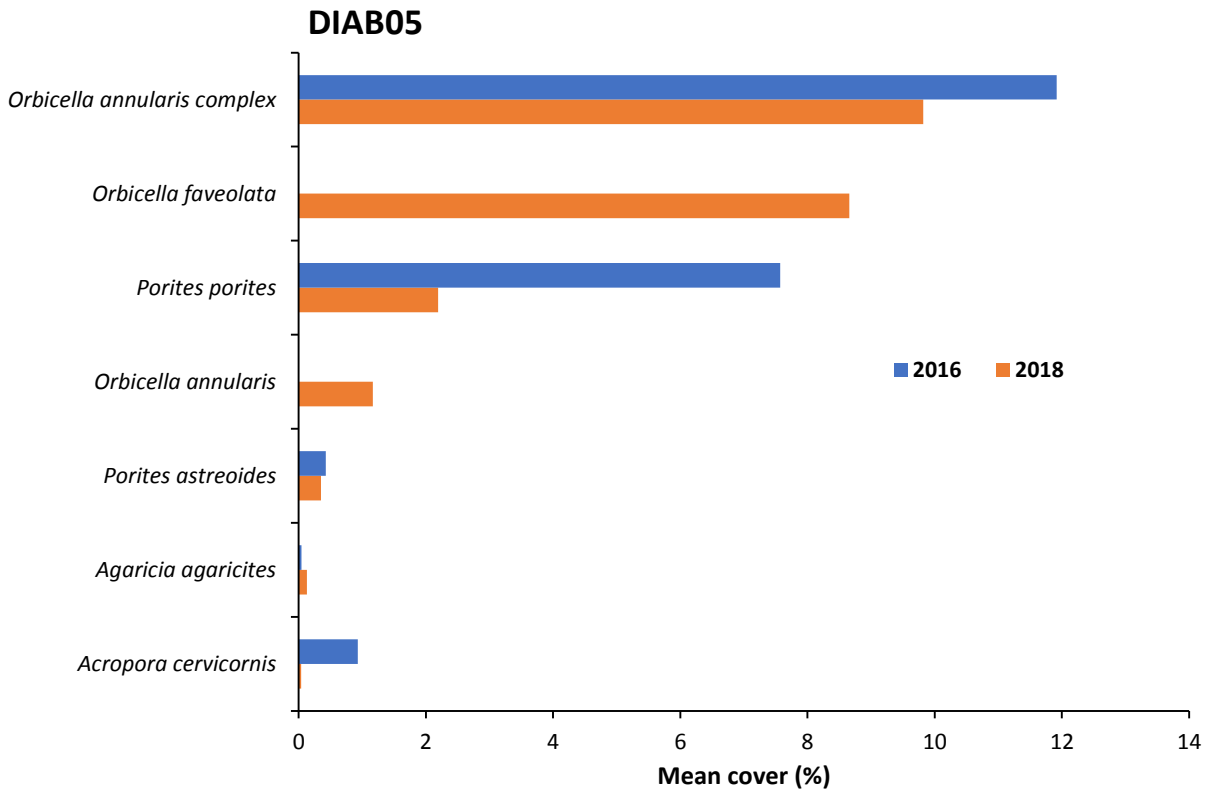



**Figure 39.** DIAB05. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at Cayo Diablo Reef 5m, Fajardo

Reef substrate cover by cyanobacteria increased 6.6-fold during the 2018 monitoring survey (mean: 3.59%), relative to the 2016 baseline (0.47%). Increased cover by cyanobacteria, as well as fleshy macroalgae may have been influenced by nutrient enrichment and/or increased availability of primary reef substrates for growth. Both conditions may be associated with the pass of huricanes and/or other extreme event(s) of wave action. Reef primary substrates become available upon death and/or mechanical detachment of coral colonies and nutrient enrichment occurs via upwelling and rainfall runoff, among other sources associated with intense storms.

### 12.3 Fishes and Motile Megabenthic Invertebrates

A total of 44 fish species were identified within belt-transects from a depth of 5 – 6 m at DIAB05 (Table 36). Mean density was 80.0 Ind/transect (range: 52 – 106 Ind/transect) with a mean richness of 17.2 species/ transect. The Bluehead Wrasse (*Thalassoma bifasciatum*) was the numerically dominant species with a mean density of 20.8 Ind/transect, representative of 26.0% of the total fish individuals and along with Brown Chromis (*Chromis multilineata*) was present in all five transects surveyed. In addition, an assemblage of eight species presented densities above 2.0 Ind/transect. These included the Blue and Brown Chromis (*C. cyanea, C. multilineata*), Bicolor and Dusky Damselfishes (*Stegastes partitus, S. adustus*), Stoplight and Bucktooth Parrotfishes (*Sparisoma viride*, *S. radians*), juvenile Grunts (*Haemulon sp*.) and Clown Wrasse (*Halichoeres maculipinna*).

The trophic structure of fishes at DIAB05 was fairly well balanced between zooplanktivores and small carnivores, with a lower density of herbivores and mostly lacking the large demersal and/or pelagic predators. Zooplanktivores included eight species, four of which ranked among the top five in terms of density within belt-transects with a combined density of 35.0 Ind/transect, or 43.8% of the total. These included four damselfishes (Pomacentridae), recruitment juvenile grunts (Haemulidae), one basslet (Grammatidae), one goby (Gobiidae) and one wrasse (Labridae). Small opportunistic carnivores were represented by 16 species with a combined density of 28.2 Ind/transect, representative of 35.2% of the total. The small carnivore assemblage included four wrasses (Labridae), two squirrelfishes (Holocentridae), one blenny (Blenniidae), one goby (Gobiidae), one grunt (Haemulidae), one puffer (Tetraodontidae), one flounder (Bothidae), one trumpetfish (Aulostomidae), one hawkfish (Cirrhitidae), two sea basses and small grouper (Serranidae), and one goatfish (Mullidae). Herbivores were represented by 12 species with a combined density of 13.4 Ind/transect, or 16.8% of the total fish density. These included five parrotfishes (Scaridae), four damselfishes (Pomacentridae), and three doctorfishes

(Acanthuridae). Medium sized piscivores included one Red Hind (Serranidae) and three Schoolmaster Snappers (Lutjanidae) observed in extended belt-transects. Five Long-Spined Urchins (*Diadema antillarum*) were observed in one transect at DIAB05 (Table 36).

The size frequency distributions of the commercially important fish species and the larger reef herbivore are presented in Table 37. Doctorfishes (Acanthuridae) were present across their entire size range from recruitment juveniles to adults. Parrotfishes were represented by five species. Early recruits (1 – 5 cm) of the five species were present. Late juveniles and adults of the Redband and Stoplight Parrotfishes were also present. One adult Red Hind and late juvenile and adult Schoolmaster and Yellowtail Snappers were also present within extended belt-transects.

Variations of fish density and species richness between the 2016 baseline and the 2018 monitoring survey at DIAB05 are presented in Figure 40. Both fish density and species richness were significantly higher during the 2018 survey (ANOVA, $p < 0.05$; Appendix 3). Fish density increased by 60.6%, from 49.8 Ind/transect in 2016 to 80.0 Ind/Ind/transect in 2018. Differences were driven by higher density of the numerically dominant Bluehead Wrasse, but more importantly by a significantly higher number of species per transect, from 13.0 species/transect in 2016 to 17.2 species/transect in 2018, an increase of 32.3%. These fluctuations of fish density and species richness are common in shallow reefs and are mostly driven by physical conditions, such as the prevailing surge and water currents at the time of the survey (Garcia-Sais et al., 2017 and references therein).

**Table 36**. DIAB05. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Diablo Reef 5m, Fajardo, July 2018

| Mean Depth: 5.2 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 16 | 26 | 8 | 42 | 12 | **20.8** |
| *Chromis cyanea* | Blue Chromis | | 7 | 12 | 21 | 16 | **11.2** |
| *Haemulon sp. (juv)* | Juvenile Grunts | | | 50 | | | **10.0** |
| *Chromis multilineata* | Brown Chromis | 13 | 5 | 5 | 4 | 2 | **5.8** |
| *Stegastes partitus* | Bicolor Damselfish | | 4 | 11 | 5 | 6 | **5.2** |
| *Sparisoma viride* | Stoplight Parrotfish | | 9 | 2 | | 4 | **3.0** |
| *Stegastes adustus* | Dusky Damselfish | 4 | 2 | | 5 | 3 | **2.8** |
| *Halichoeres maculipinna* | Clown Wrasse | | | 3 | 3 | 4 | **2.0** |
| *Sparisoma radians* | Bucktooth Parrotfish | | 1 | | 4 | 5 | **2.0** |
| *Elacatinus evelynae* | Sharknose Goby | | | | 4 | 4 | **1.6** |
| *Acanthurus coeruleus* | Blue Tang | 1 | 1 | 2 | 1 | 1 | **1.2** |
| *Gramma loreto* | Fairy Basslet | 2 | | | | 4 | **1.2** |
| *Carangoides ruber* | Bar Jack | 1 | | 2 | 1 | 1 | **1.0** |
| *Coryphopterus personatus* | Masked Goby | | | | | 5 | **1.0** |
| *Scarus taeniopterus* | Princess Parrotfish | | | 5 | | | **1.0** |
| *Acanthurus chirurgus* | Doctorfish | | 2 | 1 | 1 | | **0.8** |
| *Halichoeres radiatus* | Puddinwife | 1 | | 2 | 1 | | **0.8** |
| *Cantherhines pullus* | Tail-light Filefish | | 2 | | 1 | | **0.6** |
| *Haemulon flavolineatum* | French Grunt | 3 | | | | | **0.6** |
| *Scarus iseri* | Striped Parrotfish | | | | 3 | | **0.6** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | 2 | | 1 | | **0.6** |
| *Stegastes variabilis* | Cocoa Damselfish | | 2 | 1 | | | **0.6** |
| *Abudefduf saxatilis* | Sargent Major | 1 | | | 1 | | **0.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | | 1 | | 1 | | **0.4** |
| *Aulostomus maculatus* | Trumpetfish | 1 | | | | 1 | **0.4** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | 2 | | | | **0.4** |
| *Halichoeres garnoti* | Yellow-head Wrasse | | 2 | | | | **0.4** |
| *Pomacanthus paru* | Queen Angelfish | 2 | | | | | **0.4** |
| *Amblychirrinus pinos* | Redspotted Hawkfish | 1 | | | | | **0.2** |
| *Bothus lunatus* | Peacock Flounder | | | | | 1 | **0.2** |
| *Canthigaster rostrata* | Caribbean Puffer | 1 | | | | | **0.2** |
| *Cephalopholis cruentata* | Graysby | 1 | | | | | **0.2** |
| *Chaetodon striatus* | Banded Butterflyfish | | | | 1 | | **0.2** |
| *Clepticus parrae* | Creole Wrasse | | | | 1 | | **0.2** |
| *Halichoeres bivittatus* | Slippery Dick | | | 1 | | | **0.2** |
| *Holocentrus rufus* | Longspine Squirelfish | | | | 1 | | **0.2** |
| *Kyphosus bermudensis* | Bermuda Chub | 1 | | | | | **0.2** |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 1 | | | | | **0.2** |
| *Myripristis jacobus* | Black-bar Soldierfish | 1 | | | | | **0.2** |
| *Ophioblennius macclurei* | Redlip Blenny | | | | | 1 | **0.2** |
| *Pomacanthus arcuatus* | Grey Angelfish | | | | 1 | | **0.2** |
| *Pseudupeneus maculatus* | Spotted Goatfish | 1 | | | | | **0.2** |
| *Serranus tigrinus* | Harlequin Bass | | | 1 | | | **0.2** |
| *Stegastes leucostictus* | Beau Gregory | | 1 | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 52 | 69 | 106 | 103 | 70 | **80.0** |
| | **TOTAL SPECIES** | 18 | 16 | 15 | 21 | 16 | **17.2** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Diadema antillarum* | Long-spined Urchin | 5 | | | | | **1.0** |
| | | | | | | | |
| | **TOTAL INDIVIDUALS** | 5 | 0 | 0 | 0 | 0 | **1.0** |
| | **TOTAL SPECIES** | 1 | 0 | 0 | 0 | 0 | **0.2** |

**Table 37.** DIAB05. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Diablo Reef 5m, Fajardo, July 2018

| Mean Depth: 5.2 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 1-14 | 1-12 | 1-7 | 1-10 | |
| | | | | 1-12 | 1-12 | |
| *Acanthurus chirurgus* | Doctorfish | 3-2 | 1-7 | 1-10 | 1-7 | |
| | | | 2-12 | | | |
| | | | 1-14 | | | |
| *Acanthurus coeruleus* | Blue Tang | 1-7 | | 2-5 | 3-7 | 1-5 |
| | | 1-10 | | 1-10 | 1-14 | 1-7 |
| | | 1-12 | | | | |
| *Cephalopholis cruentata* | Graysby | 1-24 | | | | |
| *Epinephelus guttatus* | Red Hind | | | 1-31 | | |
| *Lutjanus apodus* | Schoolmaster | | | | | 1-24 |
| | | | | | | 1-26 |
| | | | | | | 1-34 |
| *Ocyurus chrysurus* | Yellowtail Snapper | | 1-12 | | | 1-26 |
| *Scarus iseri* | Striped Parrotfish | | 1-2 | | 3-2 | |
| *Scarus taeniopterus* | Princess Parrotfish | | 2-5 | 4-5 | | |
| | | | 1-7 | 1-7 | | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1-10 | 2-2 | | 1-29 | |
| *Sparisoma radians* | Bucktooth Parrotfish | | 1-2 | | 2-2 | 3-2 |
| | | | | | 2-5 | 2-5 |
| *Sparisoma viride* | Stoplight Parrotfish | | 4-1 | 1-2 | 2-1 | 2-1 |
| | | | 2-2 | 2-5 | | 2-2 |
| | | | 2-5 | | | 1-29 |
| | | | 1-25 | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |

TL = Fish Total Length

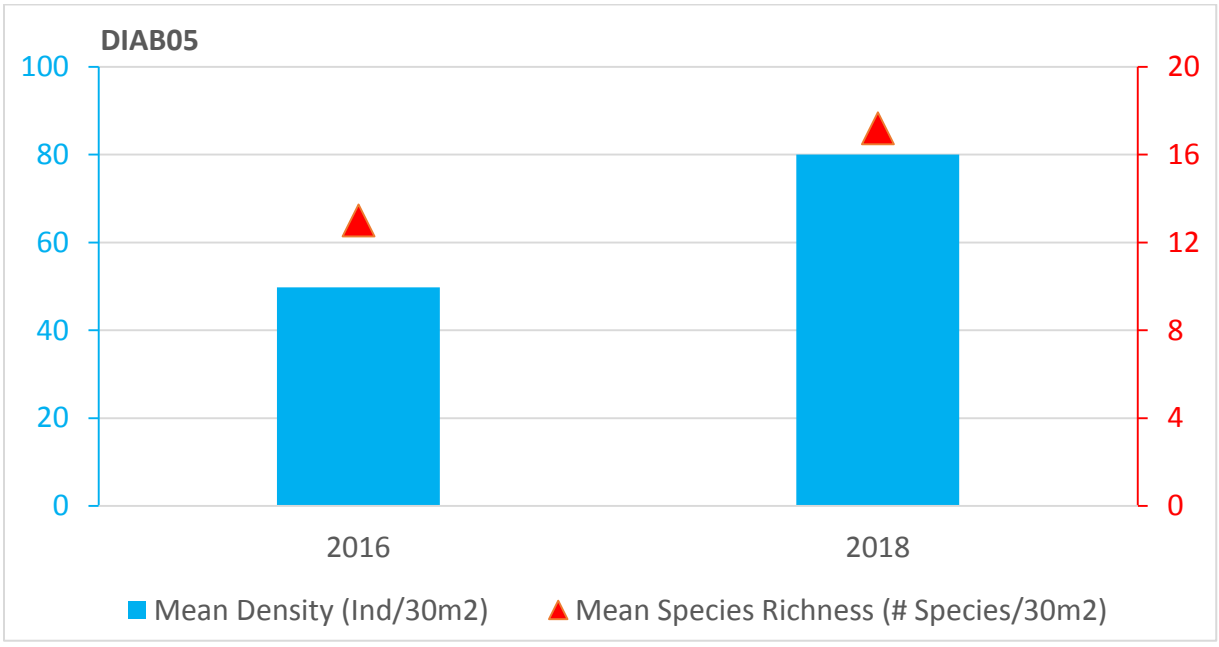
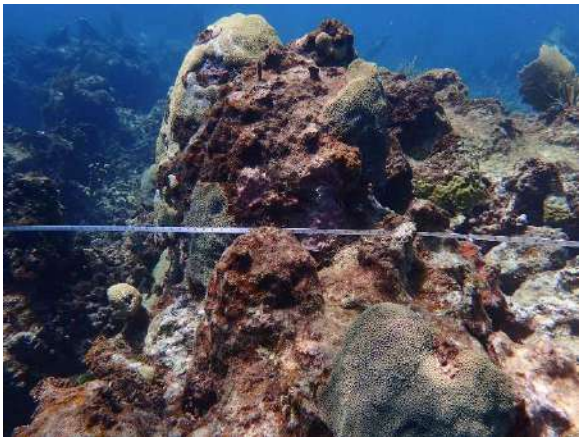
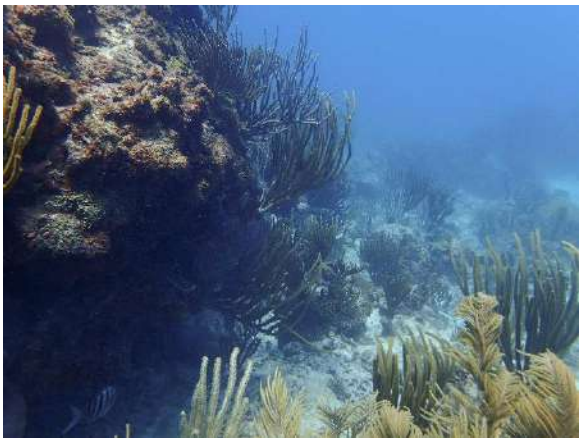



**Figure 40.** DIAB05. Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Cayo Diablo Reef 5m, Fajardo

**Photo Album 12**

**Cayo Diablo Reef 5m, Fajardo (DIAB05)**





## 13.0 Las Cabezas Reef 5m, Fajardo (CABE05)

### 13.1 Physical Description

Las Cabezas Reef (CABE05) is located about 0.3 NM off the western tip of Cabo San Juan, the easternmost corner of mainland Puerto Rico (Figure 31). This is a high wave energy zone, with breakers across most of the shelf and onto the shoreline. There is a shallow (< 3.0 m) and narrow hard-ground platform that extends offshore about 0.5 NM and then drops abruptly onto soft bottom. This is the first survey of CABE05 and therefore is the baseline survey for the PRCRMP, which was performed on July 2018. Permanent transects were established on colonized pavement habitat close to the border of the hard-ground shelf at depths of 5.8 – 6.1 m.

### 13.2 Sessile-benthic Reef Community

The reef system at Las Cabezas (CABE05) is a colonized pavement habitat with some topographic relief provided by coral heads and basket sponges. The seafloor appears to be a submerged continuation of the highly eroded eolianite shoreline with many crevices and sand pockets. The reef community is evidently influenced by strong surge and sand abrasion due to strong wave action over a relatively shallow shelf.

The dominant sessile-benthic category of the seafloor at CABE05 was benthic algae, with a mean substrate cover of 79.90% (Figure 41). Benthic algae were comprised by a mixed assemblage of turf, red crustose coralline, and brown fleshy macroalgae. Turf algae, a mixed assemblage of short articulate red and brown macroalgae was the main component with a mean cover of 44.44%, representative of 55.6% of the total benthic algae (Table 38). Red crustose coralline algae, mostly *Ramicrusta sp*., were present in all five transects surveyed growing encrusted over available reef hard substrates, particularly dead corals with a mean cover of 22.83%, or 28.6% of the total benthic algae. Other Peyssonnelid and mixed CCA were also observed as encrusting patches over hard substrates. The fleshy brown, Y-Twig Alga (*Dictyota sp*.) was present in all transects with a mean cover of 9.56%.

Hard (stony) corals were represented by eight scleractinians and one hydrocoral along transects surveyed at CABE05 with a combined substrate cover of 13.30% (Table 38). Symmetrical Brain Coral (*Pseudodiploria strigosa*) and Massive Starlet Coral (*Siderastrea siderea*) were the dominant coral species with a combined mean cover of 9.16%, representative of 68.9% of the total cover by live corals at CABE05 (Figure 42). Small encrusting colonies of Mustard-Hill Coral

(*Porites astreoides*) was present in all transects with a mean cover of 1.49%. Greater Star Coral, (*Montastraea cavernosa*) and Branching Fire Coral (*Millepora alcicornis*) were both present in three transects with a combined cover of 1.47% (Table 38). Small colonies of Staghorn Coral (*Acropora cervicornis*) were observed growing in grooved and other substrate anomalies. Several Staghorn Coral (*A. palmata*) colonies were observed standing dead in advanced stage of degradation. A total of 31 hard coral colonies were intercepted by transects, including three (*S. siderea, P. strigosa*) with apparent disease infection for a coral disease prevalence of 9.6%. The appearance of dark spots on two colonies of *S. siderea* suggest possible infection by “dark-spot syndrome”.

Erect octocorals were not abundant at CABE05. Small colonies were present in four transects with a mean density of 6.2 colonies/transect. Sea rods (*Eunicea spp*) and sea fans (*Gorgonia spp*) were the most common. Encrusting Zoanthid (*Palythoa caribaeorum*) was intercepted by one transect with a mean cover of 0.75%. Eleven sponge species were identified along transects at CABE05 with a combined cover of 2.80%. *Ircinia felix* was the only one present in more than two transects and the dominant species in terms of reef substrate cover with a mean of 1.0% (Table 38). Some large Giant Basket Sponges (*Xestospongia muta*) were observed out of transects and contributed to the reef topography and structural complexity.

### 13.3 Fishes and Motile Megabenthic Invertebrates

A total of 16 fish species were observed within belt-transects at CABE05 with a combined mean density of 25.8 Ind/transect and a mean species richness of 8.8 species/transect (Table 39). The Bluehead Wrasse (*Thalassoma bifasciatum*) was the numerically dominant species with a mean density of 10.6 Ind/transect, or 41.1% of the total fish density. In addition to the Bluehead Wrasse six additional species were present in at least four transects and comprised the main residential fish assemblage at CABE05. These included the Dusky and Cocoa Damselfishes (*Stegastes partitus, S. variabilis*), Slippery Dick and Clown Wrasse (*Halichoeres bivittatus, H. maculipinna*), Ocean Surgeon (*Acanthurus tractus*) and Bucktooth Parrotfish (*Sparisoma radians*).

Motile megabenthic invertebrates were represented within belt-transects by one Long-Spined Urchin (*Diadema antillarum*) and the Flamingo Tongue (*Ciphoma gibbosum*) (Table 39).

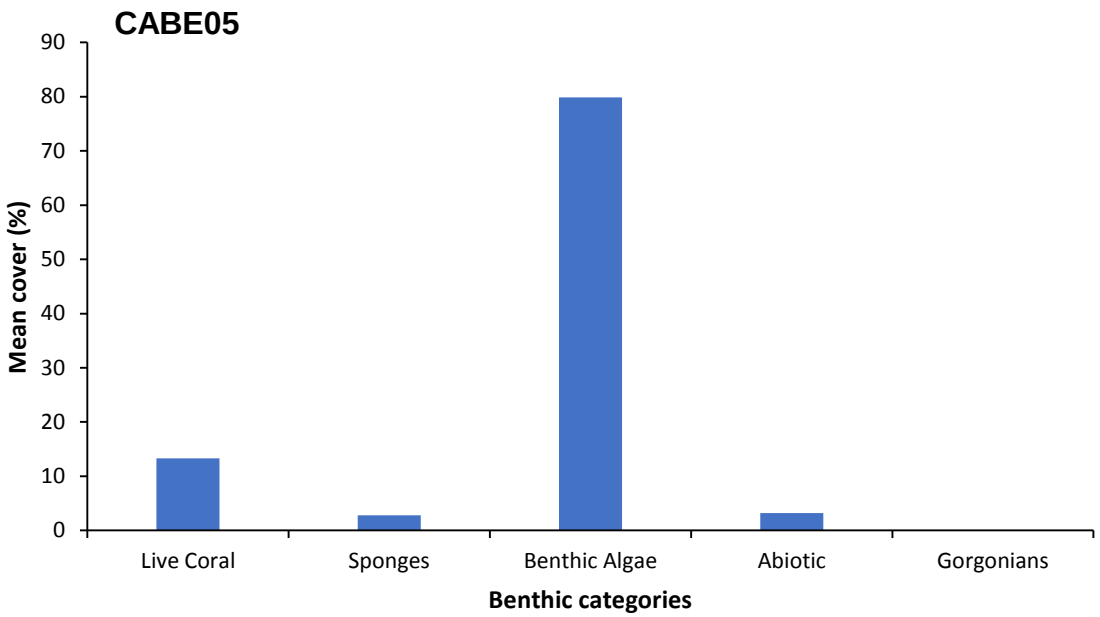



**Figure 41.** CABE05. Mean percent cover by the main sessile-benthic substrate categories at Las Cabezas Reef 5m, Fajardo during the baseline survey, July 2018

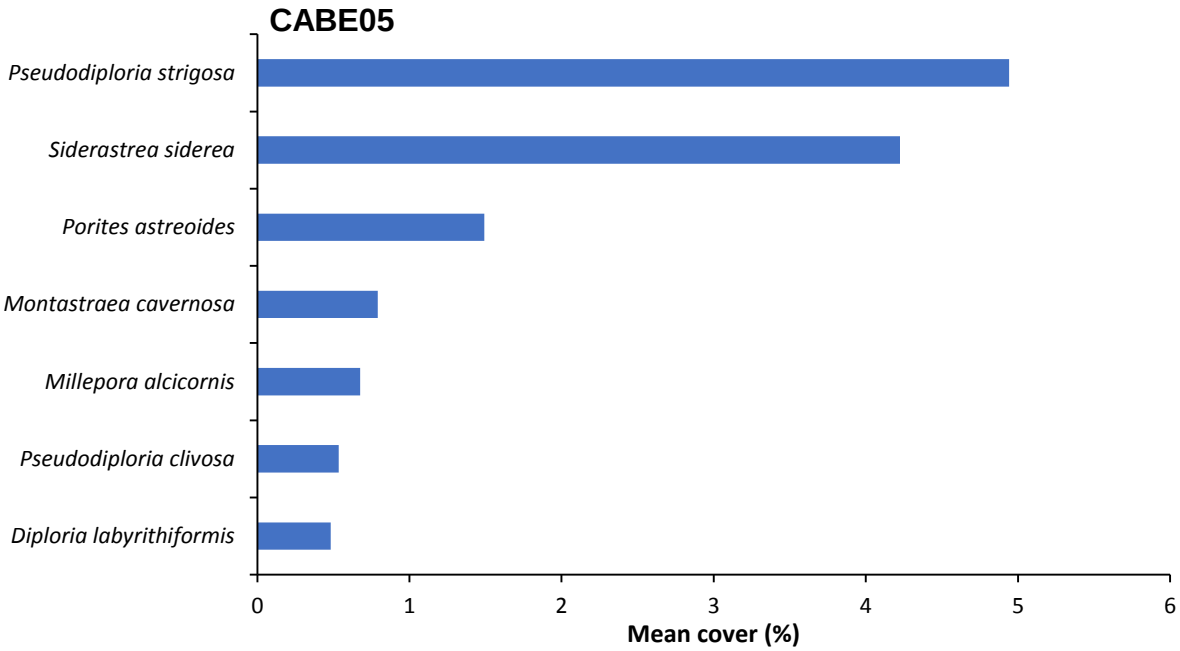



**Figure 42.** CABE05. Mean percent cover by the main coral species intercepted by transects at Las Cabezas Reef 5m, Fajardo during the baseline survey, July 2018

| **Table 38**. CABE10. Percent cover by sessile-benthic categories at Las Cabezas Reef 5m, Fajardo. | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 7/12/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 6.1 | 5.8 | 6.1 | 5.8 | 6.1 | **6.0** |
| Rugosity (m) | 0.78 | 0.71 | 0.26 | 0.46 | 0.82 | **0.6** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Sand | | 2.22 | 0.55 | 3.61 | 3.36 | **1.95** |
| Reef overhang | | 2.22 | 1.36 | | | **0.72** |
| Rubble | | 1.31 | 1.36 | | | **0.53** |
| **Total Abiotic** | **0.00** | **5.75** | **3.27** | **3.61** | **3.36** | **3.20** |
| **Benthic Algae** | | | | | | |
| Turf (mixed) with sediment | 42.08 | 27.19 | 60.85 | 49.80 | 42.30 | **44.44** |
| *Ramicrusta* | 14.03 | 39.22 | 19.92 | 17.40 | 20.18 | **22.15** |
| *Dictyota* spp. | 19.61 | 2.61 | 6.68 | 7.10 | 11.77 | **9.56** |
| Turf (mixed) | 8.05 | 2.75 | | 0.27 | 2.98 | **2.81** |
| Peyssonnelida (mixed) | | 0.52 | 0.55 | | 1.29 | **0.47** |
| *Stypopodium* sp. | 0.91 | | | | 0.39 | **0.26** |
| CCA (mixed) | 0.39 | 0.65 | | | | **0.21** |
| **Total Benthic Algae** | **85.06** | **72.94** | **87.99** | **74.56** | **78.91** | **79.90** |
| **Cyanobacteria** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| **Hard Coral** | | | | | | |
| *Pseudodiploria strigosa* | 3.38 | 11.63 | | | 9.70 | **4.94** |
| *Siderastrea siderea* | 1.69 | 1.83 | 3.41 | 14.19 | | **4.22** |
| *Porites astreoides* | 2.47 | 0.52 | 0.27 | 1.74 | 2.46 | **1.49** |
| *Montastraea cavernosa* | 1.04 | 1.83 | 1.09 | | | **0.79** |
| *Millepora alcicornis* | 2.34 | 0.26 | | | 0.78 | **0.68** |
| *Pseudodiploria clivosa* | | | 1.64 | | 1.03 | **0.53** |
| *Diploria labyrithiformis* | | | | 2.41 | | **0.48** |
| *Siderastrea radians* | 0.26 | | | 0.27 | | **0.11** |
| *Agaricia agaricites* | | | | 0.27 | | **0.05** |
| **Total Hard Coral** | **11.17** | **16.08** | **6.41** | **18.88** | **13.97** | **13.30** |
| **# Coral Colonies /Transect** | **3** | **10** | **4** | **7** | **7** | **6.2** |
| **# Diseased Coral Colonies** | **0** | **2** | **0** | **0** | **1** | |
| **Zoanthid** | | | | | | |
| *Palythoa caribaeorum* | 2.47 | 1.31 | 0.00 | 0.00 | 0.00 | **0.75** |
| **Octocoral** | | | | | | |
| *Eunicea flexuosa* | | | | | 0.26 | **0.05** |
| **Total Octocoral** | **0.00** | **0.00** | **0.00** | **0.00** | **0.26** | **0.05** |
| **# Gorgonians/Transect** | 2 | 0 | 1 | 3 | 1 | **1.40** |
| **Sponges** | | | | | | |
| *Ircinia felix* | | 0.52 | 1.91 | | 2.46 | **0.98** |
| *Neofibularia nolitangere* | | 2.75 | | | | **0.55** |
| *Desmapsamma anchorata* | | 0.26 | | 1.74 | | **0.40** |
| *Xestospongia muta* | | | | | 1.03 | **0.21** |
| *Monanchora arbuscula* | 0.26 | 0.39 | | 0.27 | | **0.18** |
| *Clathria sp.* | 0.39 | | | 0.27 | | **0.13** |
| *Ircinia brown sp.* | | | 0.41 | | | **0.08** |
| *Neopetrosia carbonaria* | | | | 0.40 | | **0.08** |
| *Mycale laevis* | 0.39 | | | | | **0.08** |
| Unknown sponge | | | | 0.27 | | **0.05** |
| *Niphates erecta* | 0.26 | | | | | **0.05** |
| **Total Sponges** | **1.30** | **3.92** | **2.32** | **2.95** | **3.49** | **2.80** |

**Table 39** . CABE05. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Las cabezas Reef 5m, Fajardo, July 2018

| Mean Depth: 6.0 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 11 | 8 | 13 | 5 | 16 | **10.6** |
| *Stegastes adustus* | Dusky Damselfish | 4 | 7 | 1 | 1 | 3 | **3.2** |
| *Halichoeres bivittatus* | Slippery Dick | 2 | 9 | 2 | | 3 | **3.2** |
| *Acanthurus tractus* | Five-band Surgeonfish | 2 | 1 | 2 | 2 | 1 | **1.6** |
| *Halichoeres maculipinna* | Clown Wrasse | 3 | 2 | 1 | | 2 | **1.6** |
| *Stegastes variabilis* | Cocoa Damselfish | 2 | 1 | 2 | | 2 | **1.4** |
| *Malacoctenus triangulatus* | Saddled Blenny | | | 1 | 2 | 2 | **1.0** |
| *Sparisoma radians* | Bucktooth Parrotfish | 1 | 2 | 1 | 1 | | **1.0** |
| *Cephalopholis fulva* | Coney | 2 | | | | | **0.4** |
| *Elacatinus evelynae* | Sharknose Goby | | 1 | | 1 | | **0.4** |
| *Sparisoma viride* | Stoplight Parrotfish | 1 | | | 1 | | **0.4** |
| *Cantherhines pullus* | Tail-light Filefish | | | | 1 | | **0.2** |
| *Chaetodon striatus* | Banded Butterflyfish | | | 1 | | | **0.2** |
| *Chromis cyanea* | Blue Chromis | | | | | 1 | **0.2** |
| *Epinephelus guttatus* | Red Hind | 1 | | | | | **0.2** |
| *Halichoeres radiatus* | Puddinwife | | | | 1 | | **0.2** |
| | **TOTAL INDIVIDUALS** | 18 | 23 | 11 | 10 | 14 | **25.8** |
| | **TOTAL SPECIES** | 10 | 8 | 9 | 9 | 8 | **8.8** |
| **Motile Megabenthic** | | | | | | | |
| | **Motile Megabenthic** | | | | | | |
| **Invertebrates** | **Invertebrates** | | | | | | |
| *Diadema antillarum* | Long-spined Urchin | | | | | 1 | **0.2** |
| *Ciphoma gibbosum* | Flamingo Tongue | | | 1 | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 1 | 0 | 1 | **0.4** |
| | **TOTAL SPECIES** | 0 | 0 | 1 | 0 | 1 | **0.4** |

Small opportunistic carnivores were the dominant trophic fish assemblage at CABE05 with six species and a combined density of 17.0 Ind/transect, or 65.9% of the total individuals within belt-transects. The assemblage included four wrasses (Labridae), one goby (Gobiidae) and one blenny (Blenniidae). Wrasses are small but fast and strong swimmers that thrive in high energy environments, such as CABE05 feeding upon small infaunal invertebrates and worms that become exposed with the waves and surge action. Herbivores were represented by two parrotfishes (Scaridae), one damselfish (Pomacentridae), and one doctorfish (Acanthuridae) with a combined density of 4.4 Ind/transect, representative of 17.0% of the total fish density. Zooplanktivores were only represented by two species (Pomacentridae) with a combined density of 3.4 Ind/transect. Medium sized piscivores included two small groupers (Serranidae).

The size distribution of commercially important fishes and the larger reef herbivores is presented in Table 40. The data suggests that CABE05 functions as a recruitment habitat for Stoplight and Bucktooth Parrotfishes (*Sparisoma viride, S. radians*) and as a recruitment and

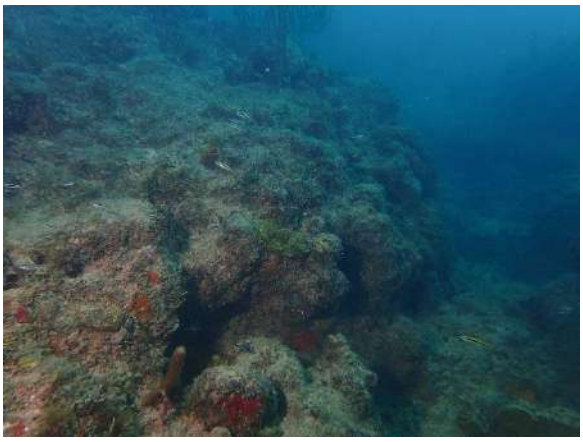
foraging/residential habitat for the Ocean Surgeon and Doctorfish (*Acanthurus tractus, A. chirurgus*). Both Red Hind and Coney (*Epinephelus guttatus, Cephalopholis fulva*) were present as adults (>30 cm) and appear to represent some of the larger demersal predators of the reef.

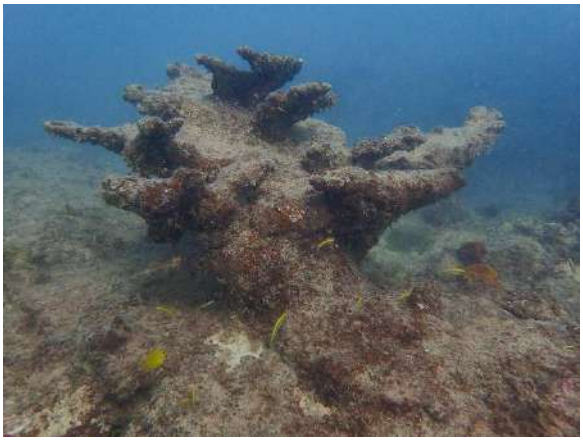
**Table 40.** CABE05. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Las Cabezas Reef 5m, Fajardo, July 2018

| Mean Depth: 6.0 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| | | | (Ind/60 $m^2$ - TL in cm) | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | | 3 - 5 | 1 - 5 | 1 - 5 | 1 - 2 |
| | | | 1 - 7 | 1 - 7 | 1 - 7 | 4 - 5 |
| | | | | 2 - 10 | | 3 - 7 |
| *Acanthurus chirurgus* | Doctorfish | 1- 7 | | | | |
| | | 1 - 12 | | | | |
| *Acanthurus coeruleus* | Blue Tang | | 1 - 10 | 1 - 12 | 1 - 5 | 1 - 2 |
| *Cephalopholis fulva* | Coney | 1 - 34 | | | | |
| | | 1 - 7 | | | | |
| *Dasyatis americana* | Southern Stingray | | | | 1 - 72 | |
| *Epinephelus guttatus* | Red Hind | 1 - 34 | | | | |
| *Sparisoma radians* | Bucktooth Parrotfish | 1 - 5 | | | 1 -2 | |
| *Sparisoma viride* | Stoplight Parrotfish | 1 - 5 | | | 1 - 2 | |
| | | | | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |
| | | | | | | |
| | | | | | | |
| TL = Fish Total Length | | | | | | |
| *CL = Carapace length* | | | | | | |
| A-Adult | | | | | | |

**Photo Album 13**

**Las Cabezas Reef 5m, Fajardo (CABE05)**





## E. Isla de Culebra Coral Reef Systems

### 14.0 Dakiti Reef, Isla de Culebra (DAKI20)

### 14.1 Physical Description

Dakiti Reef (DAKI20) is a submerged coral reef formation located about 0.9 NM southwest of the entrance channel to Ensenada Honda, on the south coast of Isla de Culebra (Figure 43). The reef rises from a soft sediment bottom at a depth of 25 – 27 m and rises to a depth of about 3 m. There is a navigation buoy anchored at the reef to mark a pass through “Canal del Oeste”. The coral reef formation is continuous down to depths of at least 25 m. The baseline survey was performed on September 2016. Transects were placed down the reef slope on top of irregular spurs at depths between 17 – 19 meters. Images of the reef community at DAKI20 are shown in Photo Album 14.

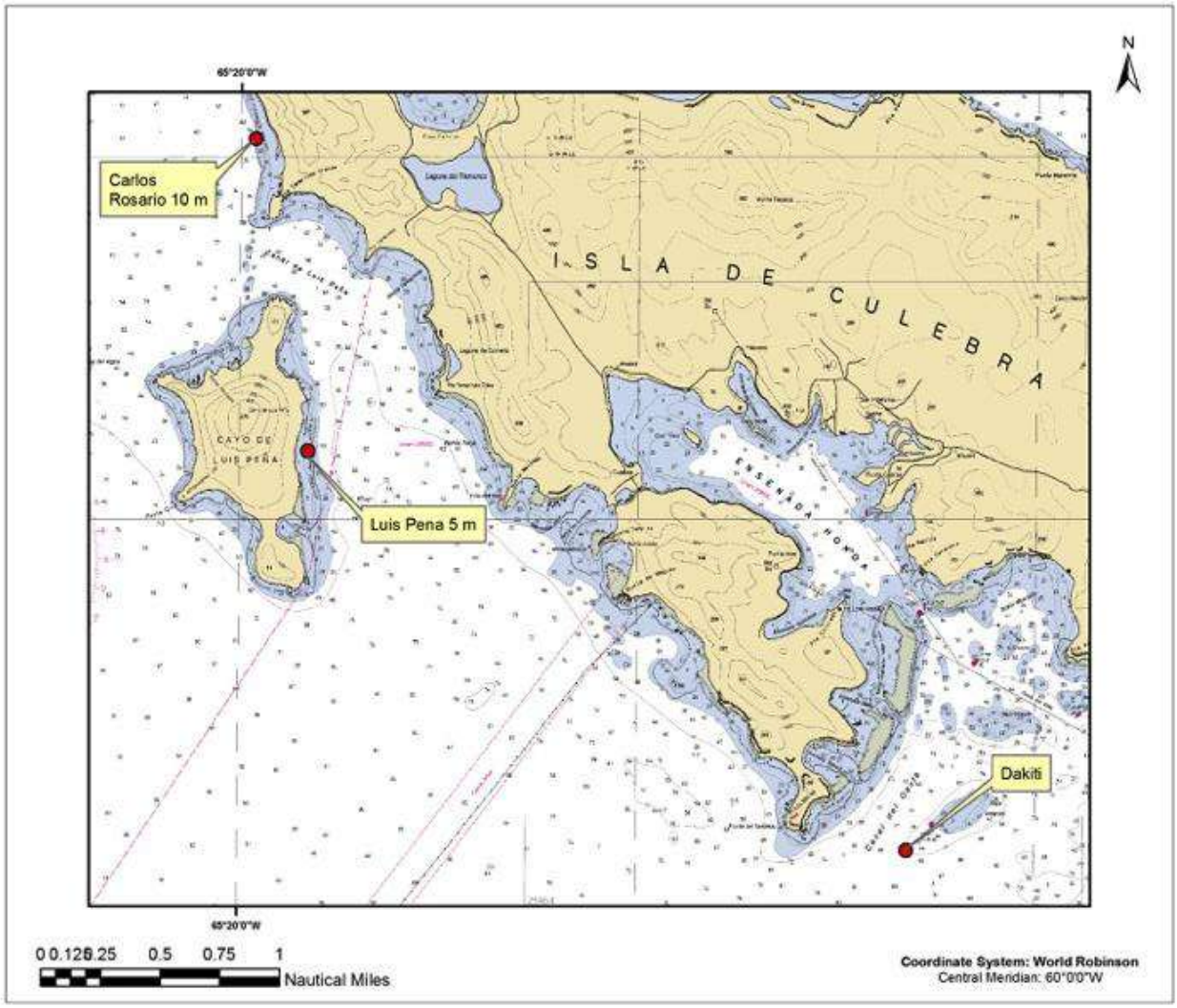



**Figure 43.** Location of coral reef monitoring stations in Isla de Culebra

### 14.2 Sessile-Benthic Reef Community

A mixed assemblage of benthic algae largely comprised by fleshy brown macroalgae, mostly *Lobophora variegata* and *Dictyota sp*, and the encrusting red algae *Ramicrusta sp*., was the dominant sessile-benthic category covering reef substrate at DAKI20 with a mean cover of 73.96% (Table 41). The combined cover by *L. variegata* and *Ramicrusta sp*. was 60.54%, representing 81.8% of the total cover by benthic algae. Turf algae were present in all five transects with a mean substrate cover of 6.78%. Red crustose coralline algae, including a Peyssonnelid species were also present in all transects with relatively lower substrate cover (<1%). Cyanobacterial patches were intersected by four out of the five transects surveyed with a mean cover of 1.39%, moderately lower than the 2018 PRCRMP average of 3.22%.

A total of 12 hard (stony) corals, including 11 scleractinians and one hydrocoral (*Millepora alcicornis*) were intercepted by transects with a combined mean substrate cover of 13.76% (range: 9.15 – 17.26%). Boulder and Mountainous Star Corals (*Orbicella franksi, O. faveolata*) were the dominant species in terms of reef substrate cover with a combined mean of 9.22%, representing 67.0% of the total cover by corals (Table 41). Small encrusting colonies of Mustard-Hill Coral (*Porites astreoides*) were intercepted by all five transects with a mean cover of 1.42%. Greater Starlet Coral (*Siderastrea siderea*), Lettuce Coral (*Agaricia agaricites*) and Finger Coral (*P. porites)* were intersected by at least three transects with a combined cover of 1.82%. Five species were only represented by one colony along transects. One coral colony (*S. siderea*) out of the 50-total intercepted by transects at DAKI20 showed an apparent disease infection (coral disease prevalence = 2.0%). The appearance of dark brown spots on *S. siderea* suggests that it may be an infection by “dark-spot syndrome”.

It is evident that reef substrate cover by live corals was much higher at DAKI20 some years ago, since a large fraction of the cover by benthic algae has resulted from colonization over dead coral structures. The reef itself appears to be of sedimentary origin, but massive coral buildup is substantial and still represents an important contribution to the overall reef rugosity and habitat complexity. Erect octocorals were present in all transects surveyed with a mean density of 2.0 col/transect. Sea Fan (*Gorgonia ventalina*) and Sea Plumes (*Antillogorgia sp*., *Pseudopterogorgia spp*) were the most abundant in transects. The encrusting species, *Erythropodium caribaeorum* was present in two transects with a mean cover of 0.15% (Table 41).

| **Table 41**. DAKI20. Percent cover by sessile-benthic categories at Dakiti Reef 20m, Isla Culebra | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 6/29/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 17.6 | 18.5 | 19.1 | 18.8 | 18.2 | **18.4** |
| Rugosity (m) | 3.59 | 5.90 | 5.41 | 2.71 | 3.48 | **4.22** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| | | | | | | |
| Reef overhang | 8.34 | 7.83 | 10.90 | 4.85 | 1.56 | **6.70** |
| Gap | 2.99 | | 0.82 | 2.09 | | **1.18** |
| Sand | | 1.67 | | 2.20 | | **0.78** |
| Rubble | | | | | 2.08 | **0.42** |
| **Total Abiotic** | **11.33** | **9.51** | **11.72** | **9.14** | **3.63** | **9.07** |
| **Benthic Algae** | | | | | | |
| *Lobophora variegata* | 37.59 | 39.61 | 32.70 | 38.66 | 33.13 | **36.34** |
| *Ramicrusta sp.* | 24.72 | 21.04 | 27.34 | 17.07 | 30.84 | **24.20** |
| Turf (mixed) | 1.24 | 2.90 | 1.82 | 6.39 | 12.67 | **5.00** |
| *Dictyota* spp. | 3.60 | 7.22 | 2.36 | 3.30 | 2.91 | **3.88** |
| CCA (mixed) | 2.78 | 5.28 | 0.64 | 1.32 | | **2.00** |
| Turf (mixed) with sediment | | 1.50 | | 6.39 | 1.04 | **1.78** |
| Peyssonnelid (mixed) | 0.31 | 0.70 | 2.09 | 0.22 | 0.42 | **0.75** |
| **Total Benthic Algae** | **70.24** | **78.26** | **66.94** | **73.35** | **81.00** | **73.96** |
| **Cyanobacteria** | 1.65 | 2.29 | 0.00 | 1.98 | 1.04 | **1.39** |
| **Hard Coral** | | | | | | |
| *Orbicella franksi* | 11.95 | | 7.54 | 5.62 | 3.12 | **5.64** |
| *Orbicella faveolata* | 3.19 | 3.79 | 5.63 | 1.98 | 3.32 | **3.58** |
| *Porites astreoides* | 0.62 | 2.90 | 0.91 | 1.65 | 1.04 | **1.42** |
| *Siderastrea siderea* | | 1.58 | | 0.44 | 2.28 | **0.86** |
| *Porites porites* | | 0.35 | | 1.65 | 0.52 | **0.50** |
| *Agaricia agaricites* | | 0.18 | 0.18 | 1.43 | 0.52 | **0.46** |
| *Pseudodiploria strigosa* | | | | 2.20 | | **0.44** |
| *Diploria labyrinthiformis* | | | 1.82 | | | **0.36** |
| *Millepora alcicornis* | | 0.18 | | | 0.83 | **0.20** |
| *Colpophyllia natans* | | | 1.00 | | | **0.20** |
| *Mussa angulosa* | | | 0.18 | | | **0.04** |
| *Leptoseris cucullata* | | 0.18 | | | | **0.04** |
| **Total Hard Coral** | **15.76** | **9.15** | **17.26** | **14.98** | **11.63** | **13.76** |
| **# CoralColonies /Transect** | **11** | **10** | **13** | **9** | **7** | **10.0** |
| **# Diseased Coral Colonies** | **0** | **1** | **0** | **0** | **0** | |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | | | 0.45 | | 0.31 | **0.15** |
| *Gorgonia ventalina* | | | | | 0.21 | **0.04** |
| **Total Octocoral** | **0.00** | **0.00** | **0.45** | **0.00** | **0.52** | **0.19** |
| **# Gorgonians/Transect** | 1 | 4 | 1 | 2 | 2 | **2.0** |
| **Sponges** | | | | | | |
| *Plakortis sp.* | | | | 0.55 | 0.83 | **0.28** |
| *Svenzea zeai* | | | | | 1.04 | **0.21** |
| *Clathria sp.* | 0.10 | | 0.91 | | | **0.20** |
| *Amphimedon compressa* | 0.31 | 0.18 | 0.18 | | 0.31 | **0.20** |
| *Verongula rigida* | | | 0.64 | | | **0.13** |
| Red sponge | 0.41 | 0.18 | | | | **0.12** |
| *Aplysina sp.* | | | 0.54 | | | **0.11** |
| *Agelas dispar* | | | 0.45 | | | **0.09** |
| *Aplysina archeri* | 0.21 | | 0.18 | | | **0.08** |
| *Monanchora arbuscula* | | | 0.36 | | | **0.07** |
| *Agelas citrina* | | 0.26 | | | | **0.05** |
| *Iotrochota birotulata* | | | 0.18 | | | **0.04** |
| *Ircinia felix* | | | 0.18 | | | **0.04** |
| *Mycale laevis* | | 0.18 | | | | **0.04** |
| **Total Sponges** | **1.03** | **0.79** | **3.63** | **0.55** | **2.18** | **1.64** |

Sponges were represented by 14 species in transects with a combined mean cover of 1.64%. *Plakortis sp, Clathria sp, Aplysina archeri, Amphimedon compressa* and an unidentified red sponge were present in at least two transects. In general, sponges were present as small and mostly encrusting colonies with minor contributions to the overall reef topographic relief and benthic habitat complexity. Abiotic substrate categories mostly contributed by reef overhangs (6.70%) presented a mean substrate cover of 9.07%. The mean reef rugosity of 4.22 m was influenced by the irregular reef bottom topography and massive coral colonies.

Variations of reef substrate cover by sessile-benthic categories are shown in Figure 44. The rank order of major sessile-benthic components remained stable, with minor increments of cover by benthic algae (10.8%) that could be associated to increased nutrient availability and/or higher availability of attachment substrates. Cyanobacterial cover declined 70.7%, from 4.74% during the 2016 baseline survey to 1.39% in the 2018 monitoring survey. Such decline is opposite to the pattern of increased cyanobacterial cover measured in the Cordillera de Fajardo reef stations (PALN20, PALT10, DIAB05). Given the closer proximity of Cordillera reefs to a major river plume (e.g. Rio Fajardo), it is suggested that nutrient enrichment associated with river discharge could have played a major role in the increased cover by cyanobacteria in the Cordillera reefs, but not in DAKI20 due to its upcurrent location and greater distance from major rivers.

Total cover by live corals declined 8.6%, from 15.1% during the 2016 baseline to 13.8% in the 2018 monitoring survey. Such difference was statistically insignificant (ANOVA, $p = 0.43$, Appendix 2a) and mostly related to small variations of cover by several species, including the *Orbicella spp* complex, and *Agaricia agaricites* (Figure 45). The most relevant change of the sessile-benthic community structure between the 2016 baseline and the 2018 monitoring survey was a 56.5% decline in density of octocorals from 4.6 colonies/transect in 2016 to 2.0 colonies/transect in 2018. The difference was statistically significant (ANOVA, $p < 0.001$; Appendix 4) and probably associated with mechanical detachment due to exceptionally strong surge and abrasion during the pass of hurricanes and/or another extreme wave events.

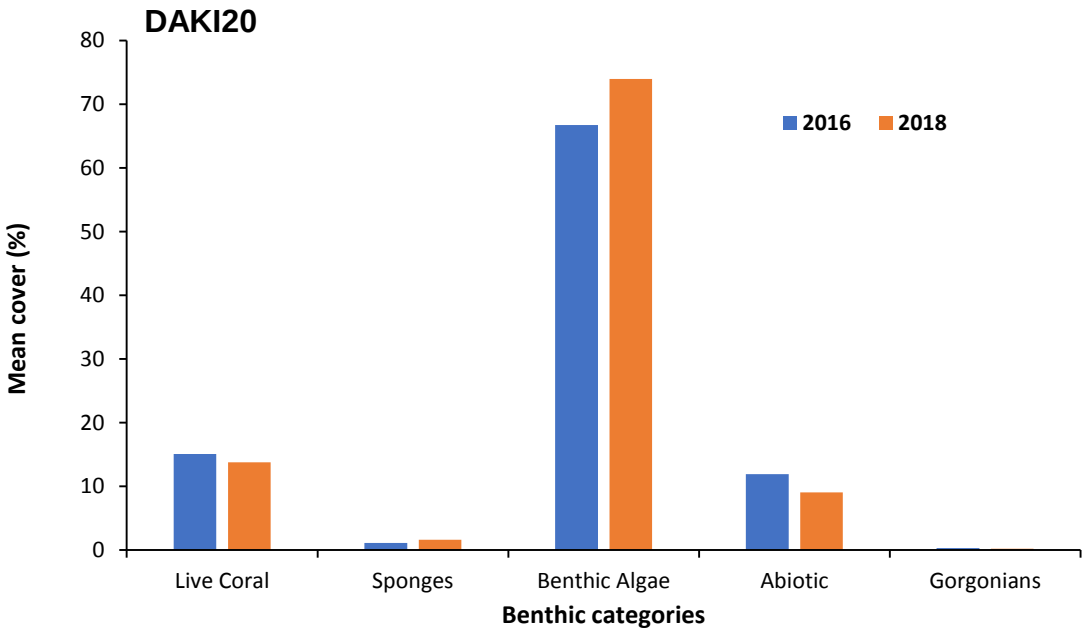



**Figure 44.** DAKI20. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Dakity Reef 20m, Isla de Culebra

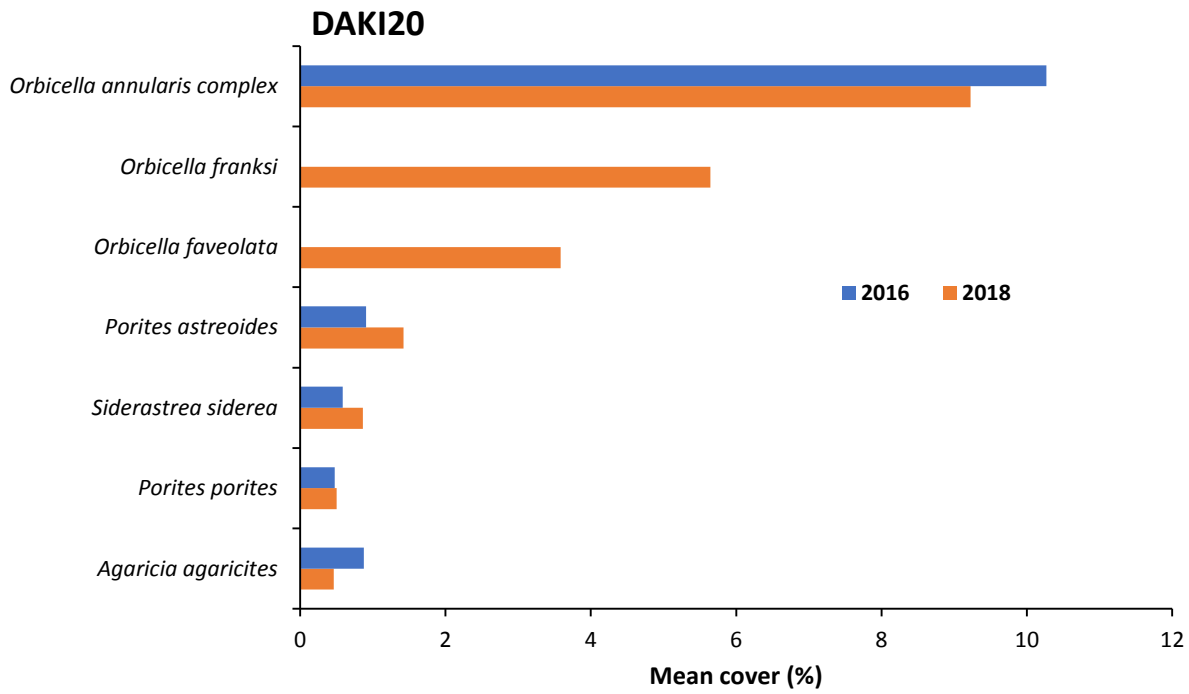



**Figure 45.** DAKI20. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at Dakity Reef 20m, Isla de Culebra

### 14.3 Fishes and Motile Megabenthic Invertebrates

A total of 35 fish species were identified within belt-transects at a depth of 18 - 20 m at DAKI20 (Table 42). Mean density was 546.6 Ind/transect (range: 416 – 714 Ind/transect) with a mean species richness of 15.8 species per transect. The Masked Goby (*Coryphopterus personatus*) was the numerically dominant species with a mean density of 516.0 Ind/transect, representing 94.4% of the total fish density. An assemblage of six species were present in at least four transects with a combined density of 16.2 Ind/transects, contributing 2.9% to the total fish density. This assemblage included the Three-spot, Beaugregory and Sargent Major Damselfishes (*Stegastes planifrons, S. leucostictus, Abudefduf saxatilis),* Fairy Basslet (*Gramma loreto*), Princess Parrotfish (*Scarus taeniopterus*), and Yellowhead Wrasse (*Halichoeres garnoti*).

The trophic structure of fishes at DAKI20 was strongly represented by zooplanktivorous fishes due to the numerical dominance of the Masked Goby and, to a lesser extent, Fairy Basslet, Sargent Major, Blue Chromis, and Bicolor Damselfish, which combined made up 95.0% of the total fishes within transects. Herbivores were represented by four species of parrotfishes (Scaridae), three doctorfishes (Acanthuridae) and three damselfishes (Pomacentridae) with a combined density of 16.4 Ind/transect, representing 3.0% of the total density within belt-transects. Small opportunistic carnivores were represented by a specious assemblage of at least 15 species with a combined density of 8.8 Ind/transect, representing 1.6% of the total fishes within belt-transects and included five hamlets and a small grouper (Serranidae), three wrasses (Labridae), three squirrelfishes (Holocentridae), two gobies (Gobiidae), one grunt (Haemulidae), and one puffer (Tetraodontidae). Medium and large sized fish predators were represented by the Schoolmaster Snapper (Lutjanidae) and by the Great Barracuda (Sphyraenidae) in extended belt-transects.

The size-frequency distribution of commercially important fishes and the larger reef herbivores is presented in Table 43. Recruitment juvenile (< 3 cm) and adult stages of Striped, Princess, Bucktooth and Stoplight Parrotfishes were observed. Previous observations of both juvenile and adult individuals of the aforementioned species is indicative that DAKI20 functions as a recruitment and permanent residential habitat for these species throughout their life cycle. One adult Yellowtail Parrotfish (~36 cm) was also observed. Schoolmaster Snappers and a Great Barracuda were observed as adults. Motile megabenthic invertebrates were represented within belt-transects by one Arrow Crab (Table 43).

**Table 42.** DAKI20. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Dakiti Reef 20m, Isla de Culebra, June 2018

| Mean Depth: 18.4 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Coryphopterus personatus* | Masked Goby | 680 | 400 | 550 | 380 | 570 | **516.0** |
| *Stegastes planifrons* | Three-spot Damselfish | 6 | 5 | 9 | 11 | 7 | **7.6** |
| *Scarus taeniopterus* | Princess Parrotfish | 3 | 8 | 2 | 2 | | **3.0** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 3 | | 1 | 2 | 3 | **1.8** |
| *Stegastes leucostictus* | Beau Gregory | 3 | 2 | 2 | 1 | 1 | **1.8** |
| *Gramma loreto* | Fairy Basslet | 1 | 2 | 2 | 1 | | **1.2** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | 2 | | 2 | 2 | **1.2** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 2 | | | 1 | 3 | **1.2** |
| *Abudefduf saxatilis* | Sargent Major | 2 | 1 | 1 | 1 | | **1.0** |
| *Carangoides ruber* | Bar Jack | | | | 5 | | **1.0** |
| *Elacatinus evelynae* | Sharknose Goby | 3 | | 2 | | | **1.0** |
| *Canthigaster rostrata* | Caribbean Puffer | | 1 | 2 | 1 | | **0.8** |
| *Scarus iseri* | Striped Parrotfish | 1 | 1 | 1 | | 1 | **0.8** |
| *Stegastes adustus* | Dusky Damselfish | | 3 | 1 | | | **0.8** |
| *Coryphopterus lipernes* | Peppermint Goby | 1 | | 2 | | | **0.6** |
| *Halichoeres maculipinna* | Clown Wrasse | 3 | | | | | **0.6** |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | | | | 1 | 2 | **0.6** |
| *Hypoplectrus nigricans* | Black Hamlet | 1 | | | 1 | 1 | **0.6** |
| *Hypoplectrus puella* | Barred Hamlet | 1 | | 1 | 1 | | **0.6** |
| *Cantherhines pullus* | Tail-light Filefish | 2 | | | | | **0.4** |
| *Chromis cyanea* | Blue Chromis | 1 | | | | 1 | **0.4** |
| *Equetus punctatus* | Spotted Drum | | 1 | 1 | | | **0.4** |
| *Holocentrus rufus* | Longspine Squirelfish | | | | 2 | | **0.4** |
| *Pomacanthus arcuatus* | Grey Angelfish | | | 1 | 1 | | **0.4** |
| *Sparisoma viride* | Stoplight Parrotfish | | | | | 2 | **0.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | | | | | 1 | **0.2** |
| *Acanthurus chirurgus* | Doctorfish | | 1 | | | | **0.2** |
| *Acanthurus coeruleus* | Blue Tang | | | 1 | | | **0.2** |
| *Cephalopholis cruentata* | Graysby | | | 1 | | | **0.2** |
| *Haemulon sciurus* | Bluestripped Grunt | 1 | | | | | **0.2** |
| *Lutjanus apodus* | Schoolmaster | | | | 1 | | **0.2** |
| *Myripristis jacobus* | Black-bar Soldierfish | | | 1 | | | **0.2** |
| *Sargocentrum coruscum* | Reef Squirrelfish | | | | 1 | | **0.2** |
| *Sparisoma rubripinne* | Yellowtail Parrotfish | | | | 1 | | **0.2** |
| *Stegastes partitus* | Bicolor Damselfish | | | | | 1 | **0.2** |
| | **TOTAL INDIVIDUALS** | 714 | 427 | 581 | 416 | 595 | **546.6** |
| | **TOTAL SPECIES** | 17 | 12 | 18 | 19 | 13 | **15.8** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Stenorhynchus seticornis* | Arrow Crab | | | 1 | | | **0.2** |
| *Eucidaris tribuloides* | Slate-pencil Urchin | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 1 | 0 | 1 | 0 | 0 | **0.4** |
| | **TOTAL SPECIES** | 1 | 0 | 1 | 0 | 0 | **2.0** |

Variations of fish density and species richness between the 2016 baseline and the 2018 monitoring survey at DAKI20 are presented in Figure 46. Statistically significant differences of fish density were measured. Fish density increased 92.3%, from 284.2 Ind/transect in 2016 to 546.6 Ind/transect in 2018 (ANOVA, $p < 0.0001$; Appendix 3). The difference was driven by the density increase of Masked Goby (*Coryphopterus personatus*) from 238.4 Ind/transect in 2016 to 516.0 Ind/transect in 2018. Differences of fish species richness within belt-transects were not statistically significant (ANOVA, $p = 0.874$; Appendix 3) and the mean remained within 3% between surveys. Such fluctuations of a numerically dominant species, particularly Masked Goby, strongly influences the temporal variations of fish density at reefs surveys. Interestingly, a consistent pattern of declining density of Masked Goby was measured in West coast reefs of Puerto Rico presumably related with hurricane and extreme wave force events. The fact that Masked Goby increased its density in DAKI20 during 2018 suggests that the physical forces associated with such extreme climatological events were somehow minimized at this reef. The minimal changes associated with the benthic community structure, including the coral assemblage support this contention.

**Table 43.** DAKI20. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Dakiti Reef 20m, Isla de Culebra, June 2018

| Mean Depth: 18.4 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 1-10 | 1-7 | | | 1-10 |
| *Acanthurus chirurgus* | Doctorfish | | 1 - 10 | | | |
| *Acanthurus coeruleus* | Blue Tang | | | 1 - 12 | | |
| *Cephalopholis cruentata* | Graysby | | | 1 - 14 | | |
| *Lutjanus apodus* | Schoolmaster | | | | 1-29 | |
| | | | | | 1-34 | |
| *Scarus iseri* | Striped Parrotfish | 1-12 | 1-14 | 1-2 | | 1-22 |
| *Scarus taeniopterus* | Princess Parrotfish | 4-7 | 5-2 | 2-10 | 3-5 | 3-5 |
| | | 1-12 | 3-5 | 1-12 | 5-7 | |
| | | | 1-10 | 1-19 | 1-14 | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | | | 1-10 | 1-14 |
| | | | | | 1-14 | 1-19 |
| | | | | | 1-22 | |
| *Sparisoma radians* | Bucktooth Parrotfish | | 3-2 | | | |
| *Sparisoma rubripinne* | Yellowtail Parrotfish | | | | 1-36 | |
| *Sparisoma viride* | Stoplight Parrotfish | | 1-2 | | | |
| | | | 1-19 | | | 2-2 |
| *Sphyraena barracuda* | Great barrracuda | | | 1-58 | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |

TL = Fish Total Length

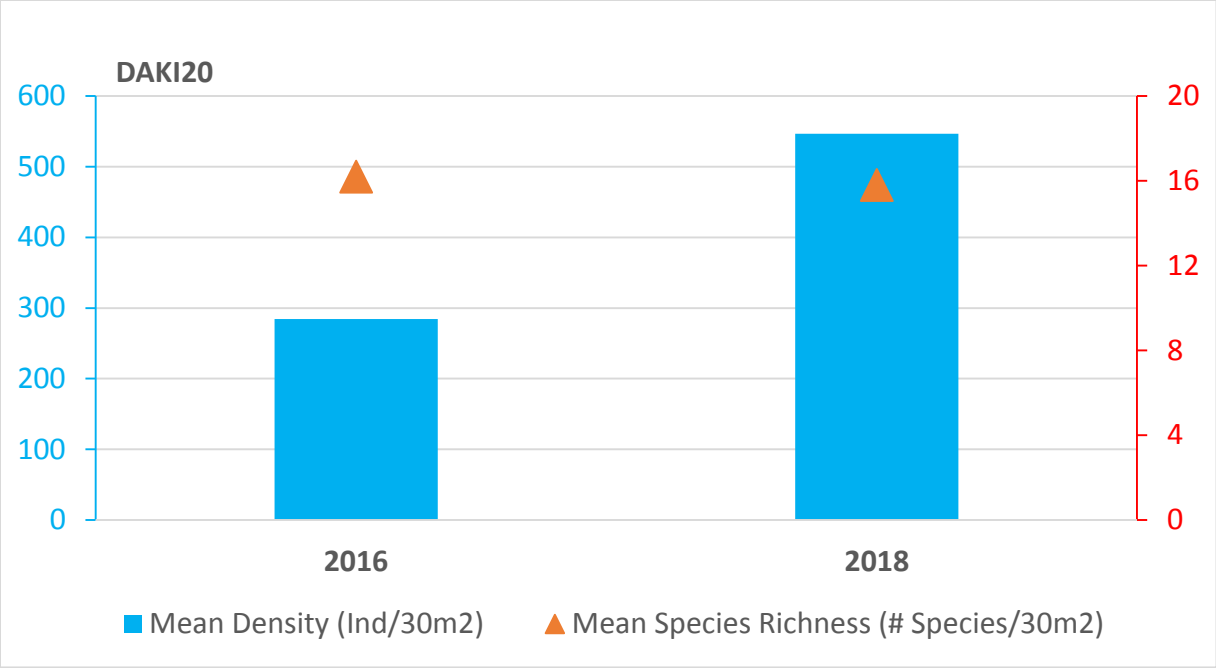
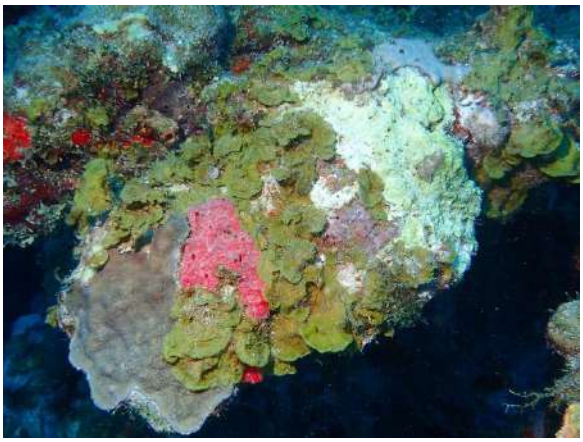
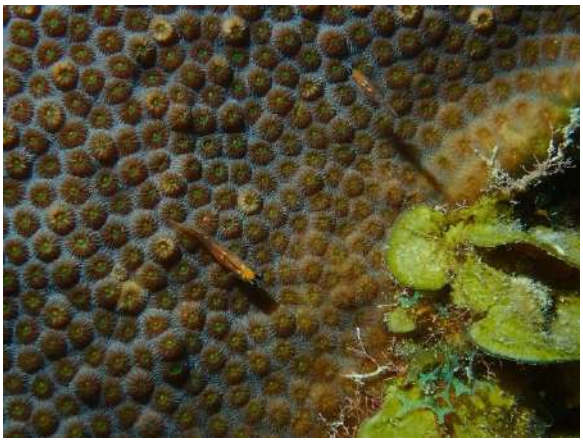



**Figure 46.** DAKI20. Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Dakity Reef 20m, Isla de Culebra

**Photo Album 14**

**Dakiti Reef 20m, Isla de Culebra (DAKI20)**





## 15.0 Carlos Rosario Reef 10, Isla de Culebra

### 15.1 Physical Description

Carlos Rosario Reef (CROS10) is a coastal fringing reef within the Luis Pena Natural Reserve. It is located about 0.2 NM north of Pta. Tamarindo in the main island of Culebra (Figure 43). The reef rises from a sandy bottom at a depth of 9.0 m up to the surface across a steep fore-reef slope with several narrow terraces. The reef has significant structural buildup by scleractinian corals, particularly pillar growth of Lobed Star Coral (*Orbicella annularis*). The reef is an important tourist attraction and several anchoring buoys support charter operations that bring divers to the reef. The baseline survey at CROS was performed on September 2016. Permanent transects were set very close to the reef base along the 8 - 10 m depth contour. Images of the CROS10 reef community are presented in Photo Album 15.

### 15.2 Sessile Benthic Reef Community

Benthic algae comprised by an assemblage of red crustose and encrusting coralline algae, turf, and fleshy brown macroalgae was the dominant sessile-benthic category covering substrate at CROS10 with a combined mean cover of 46.87%. The encrusting red coralline alga, *Ramicrusta sp*. was the most prominent in all transects with a mean cover of 21.54% (range: 19.61– 31.67%), representing 46.0% of the total cover by benthic algae (Table 44). Fleshy brown macroalgae comprised by the Encrusting Fan Alga (*Lobophora variegata*) and Y-Twig Alga (*Dictyota sp*.) were also prominent in all transects surveyed with a combined cover of 14.73%. Turf algae were also intercepted by all five transects with a mean cover of 8.92%. Patches of cyanobacteria were present in all transects with a mean cover of 17.63%, the highest among all reef stations surveyed during the 2018 PRCRMP (mean: 3.22%).

Hard (stony) corals intercepted by transects at CROS10 were represented by 15 species, including 14 scleractinians and one hydrocoral (*Millepora alcicornis*) with a combined mean substrate cover of 16.85% (Table 44). Boulder Star Coral (*Orbicella franksi)* was the dominant coral intercepted by transects with a mean substrate cover of 5.30%, representing 31.5% of the total cover by hard corals. Two other *Orbicella* sibling species (*O. faveolata and O. annularis*) were also intercepted by transets at CROS10 with a combined mean cover of 3.40%. Mustard-Hill Coral (*Porites astreoides*), Greater Starlet Coral (*Siderastrea siderea*), and Lettuce Coral (*Agaricia agaricites*) were present in at least three transects with a combined cover of 5.23%.

| **Table 44**. CROS10. Percent cover by sessile-benthic categories at Carlos Rosario Reef 10m, Isla Culebra | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 6/29/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 8.8 | 9.1 | 9.7 | 8.5 | 9.4 | **9.1** |
| Rugosity (m) | 5.22 | 3.06 | 6.24 | 6.28 | 7.37 | **5.63** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 1.56 | 8.57 | 7.93 | 9.29 | 13.38 | **8.15** |
| Rubble | | | | 3.44 | 4.43 | **1.57** |
| Sand | 3.31 | | 2.59 | | | **1.18** |
| Gap | | 0.21 | | | 0.32 | **0.11** |
| **Total Abiotic** | **4.88** | **8.79** | **10.52** | **12.73** | **18.13** | **11.01** |
| **Benthic Algae** | | | | | | |
| *Ramicrusta sp.* | 25.11 | 19.61 | 10.60 | 20.72 | 31.67 | **21.54** |
| *Lobophora variegata* | 6.72 | 13.61 | 7.24 | 20.72 | 6.20 | **10.90** |
| Turf (mixed) | 4.78 | 8.36 | 12.59 | 4.30 | 4.51 | **6.91** |
| *Dictyota* spp. | 4.23 | 5.25 | 2.67 | 3.44 | 3.55 | **3.83** |
| Turf (mixed) with sediment | 1.56 | 5.89 | 1.72 | 0.86 | | **2.01** |
| Peyssonnelid (mixed) | 1.10 | | 1.29 | 0.95 | 1.21 | **0.91** |
| CCA (mixed) | 1.56 | 0.86 | 0.78 | | 0.64 | **0.77** |
| **Total Benthic Algae** | **45.08** | **53.59** | **36.90** | **50.99** | **47.78** | **46.87** |
| **Cyanobacteria** | 22.63 | 16.83 | 20.34 | 12.55 | 15.79 | **17.63** |
| **Hard Coral** | | | | | | |
| *Orbicella franksi* | 2.58 | 5.79 | 11.12 | 5.59 | 1.45 | **5.30** |
| *Porites astreoides* | 5.52 | 0.86 | 3.88 | 1.98 | 1.85 | **2.82** |
| *Orbicella faveolata* | | 3.22 | 3.28 | 4.73 | 2.34 | **2.71** |
| *Siderastrea siderea* | | 2.14 | 2.33 | 0.77 | 3.87 | **1.82** |
| *Montastraea cavernosa* | 7.64 | | | | 0.32 | **1.59** |
| *Orbicella annularis* | | | 1.72 | 1.46 | 0.24 | **0.69** |
| *Agaricia agaricites* | 0.55 | | | 2.06 | 0.32 | **0.59** |
| *Porites porites* | | | 1.55 | 0.60 | 0.16 | **0.46** |
| *Colpophyllia natans* | | | 0.86 | | 0.32 | **0.24** |
| *Millepora alcicornis* | | | 0.52 | | 0.32 | **0.17** |
| *Meandrina meandrites* | | | | | 0.81 | **0.16** |
| *Scolymia sp.* | | | | 0.69 | | **0.14** |
| *Porites furcata* | 0.46 | | | | | **0.09** |
| *Eusmilia fastigiata* | 0.18 | | | | | **0.04** |
| *Porites divaricata* | | | | | 0.16 | **0.03** |
| **Total Hard Coral** | **16.93** | **12.00** | **25.26** | **17.88** | **12.17** | **16.85** |
| **# CoralColonies /Transect** | **14** | **10** | **17** | **14** | **9** | **12.8** |
| **# Diseased Coral Colonies** | **0** | **4** | **4** | **0** | **1** | |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | 2.94 | 4.50 | 2.16 | 3.70 | 3.95 | **3.45** |
| *Pseudoplexaura americana* | 1.29 | | 0.69 | | | **0.40** |
| *Briareum asbestinum* | | | | 1.63 | 0.32 | **0.39** |
| *Plexaura homalla* | 0.64 | | | | | **0.13** |
| *Eunicea* sp. | | 0.21 | | | | **0.04** |
| *Gorgonia ventalina* | | 0.21 | | | | **0.04** |
| *Plexaura kuekenthali* | 0.18 | | | | | **0.04** |
| **Total Octocoral** | **5.06** | **4.93** | **2.84** | **5.33** | **4.27** | **4.49** |
| **# Gorgonians/Transect** | 22 | 17 | 16 | 12 | 7 | **14.8** |
| **Sponges** | | | | | | |
| *Amphimedon compressa* | 1.01 | 1.29 | 0.52 | 0.17 | | **0.60** |
| *Clathria* sp. | 1.56 | 0.64 | 0.34 | | 0.16 | **0.54** |
| *Chondrilla caribensis* | 0.37 | | 0.52 | | 0.64 | **0.31** |
| *Verongula rigida* | 1.10 | | | | | **0.22** |
| *Mycale laevis* | | | 0.60 | 0.17 | 0.32 | **0.22** |
| *Verongula reiswigi* | | 1.07 | | | | **0.21** |
| *Dictyonella funicularis* | | | 0.86 | 0.17 | | **0.21** |
| *Aplysina cauliformis* | | | 0.52 | | 0.24 | **0.15** |
| *Monanchora arbuscula* | 0.74 | | | | | **0.15** |
| *Spirastrella coccinea* | | 0.32 | 0.26 | | | **0.12** |
| *Plakortis* sp. | | 0.32 | | | 0.24 | **0.11** |
| *Niphates erecta* | | 0.21 | 0.34 | | | **0.11** |
| *Biemna sp.* | 0.28 | | 0.17 | | | **0.09** |
| *Niphates digitalis* | 0.37 | | | | | **0.07** |
| *Agelas citrina* | | | | | 0.24 | **0.05** |
| **Total Sponges** | **5.43** | **3.86** | **4.14** | **0.52** | **1.85** | **3.16** |

As was noted for DAKI20 in 2018, it is evident that this reef had a much higher cover by live corals, since the carbonate structural buildup, particularly of *Orbicella spp.* is still standing, but presently overgrown by *Ramicrusta sp.* and another encrusting reef biota. Branching Fire Coral (*M. alcicornis*) was present as small branching colonies with low substrate cover (0.17%). A total of 64 coral colonies were intercepted by transects at CROS10, including nine (9) with apparent disease infections (coral disease prevalence = 14.1%). Diseased coral species included *O. franksi, O. faveolata, P. astreoides*, and *Siderastrea siderea* (Appendix 4).

Octocorals were prominent in all transects surveyed with a mean density of 12.8 col/transect at CROS10 (Table 44). Sea Rods (*Eunicea spp, Pseudoplexaura sp*) and the Sea Fan (*Gorgonia ventalina*) were the most abundant in transects. The Encrusting Gorgonian (*Erythropodium caribaeorum*) and the Corky Sea Finger (*Briareum asbestinum*) were present in in five and three transects, respectively with a combined mean cover of 3.84%. Sponges were represented by 15 species with a combined mean cover of 3.16%. *Amphimedon compressa, Clathria sp., Chondrilla caribensis* and *Mycaele laevis* were observed in at least three transects. In general, sponges were present as small and mostly encrusting colonies with minor contributions to the overall reef topography and benthic habitat complexity. Abiotic substrate categories averaged a mean reef substrate cover of 11.01%, largely influenced by reef overhangs (8.15%). Sand and coral rubble were also present in most transects with a combined cover of 2.75% (Table 44).

Temporal variations of reef substrate cover by major sessile-benthic categories between the 2016 baseline and the 2018 monitoring survey at CROS10 are shown in Figure 47. The rank order of reef substrate cover and relative contribution of the total cover by major categories remained stable between surveys. A 15.6% reduction of live coral cover was measured, from a mean of 19.9% in 2016 to a mean of 16.8% in 2018, but this difference was not statistically significant (ANOVA, $p = 0.475$; Appendix 2a). The main species contributing to the decline of live coral cover at CROS10 was the Finger Coral (*Porites porites*). The 67.8% reduction of cover by *P. porites* accounted for 32.3% of the difference of live coral cover between surveys (Figure 48). The decline of cover by Finger Coral has been a recurring observation of the 2018 monitoring survey and appear to be associated with the extreme climatological events affecting Puerto Rico between surveys, including the pass of Hurricanes Irma and Maria in September 2017 and another swell event affecting the west and north coasts of the Island in March 2018. The sum of mean cover by *Orbicella spp*. in 2018 (e.g. 8.7%) was within 1% of the mean cover by *Orbicella spp* complex in 2016 (e.g. 9.4%).

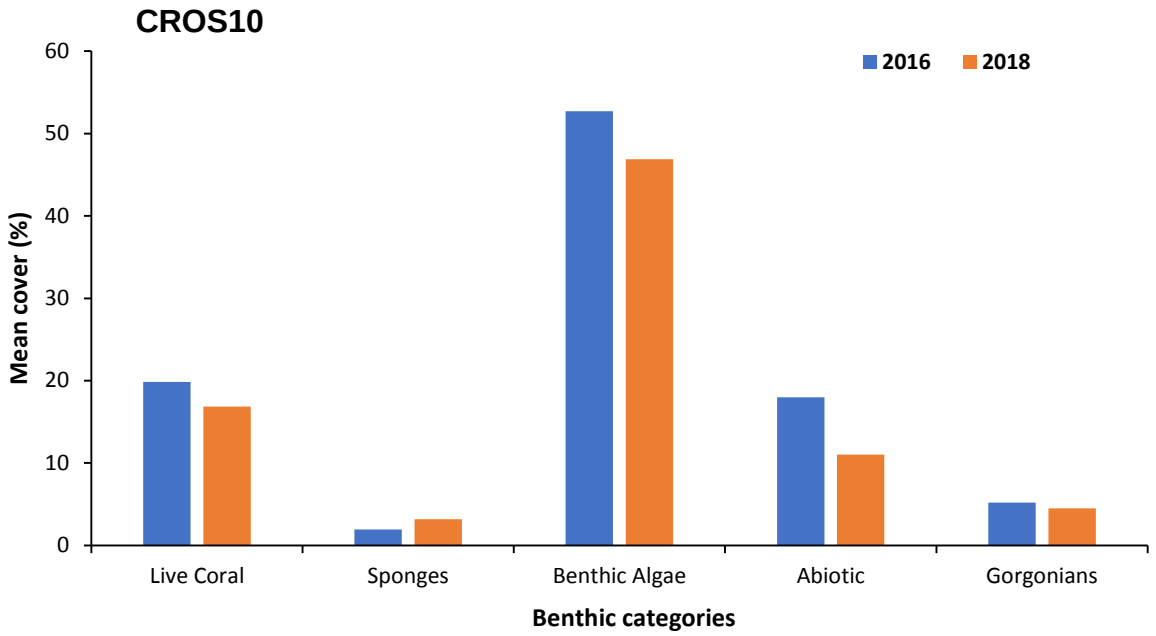



**Figure 47.** CROS10. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Carlos Rosario Reef 10m, Isla de Culebra

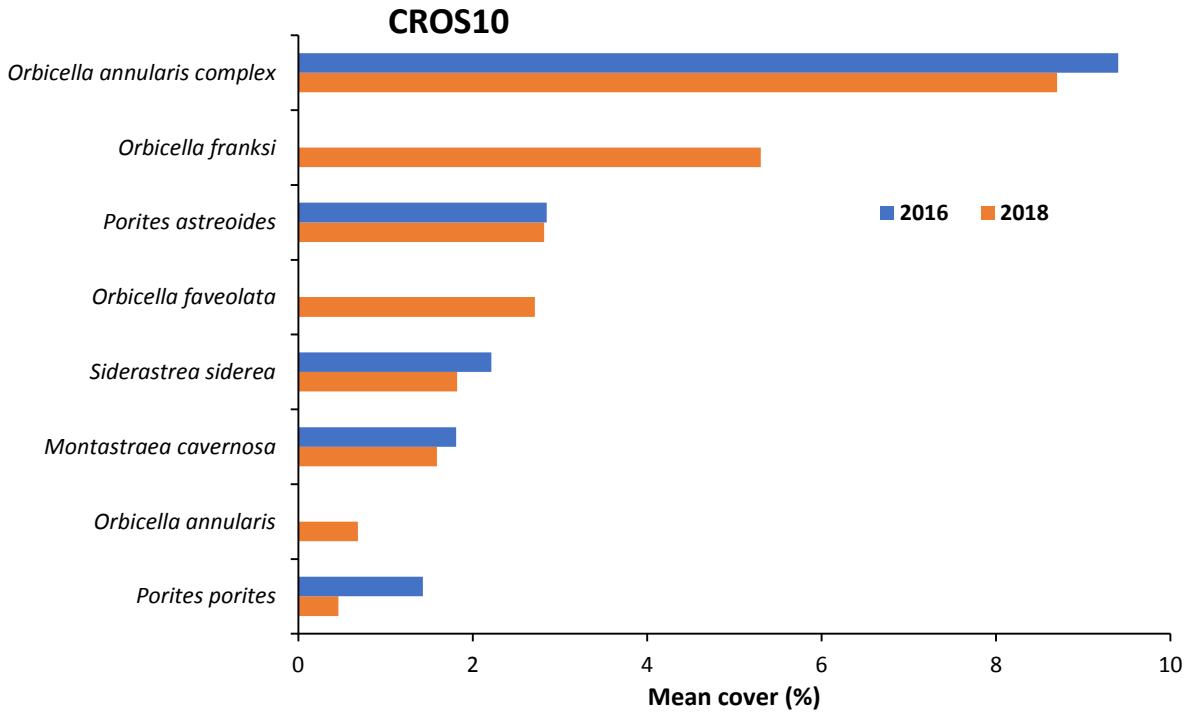



**Figure 48.** CROS10. Annual variations (2016 -18) of mean substrate cover by coral species at Carlos Rosario Reef 10m, Isla de Culebra

The main difference of benthic community structure between the 2016 baseline and the 2018 monitoring survey was an eight-fold increase in cover by cyanobacteria, from 2.2% in 2016 to 17.6% in 2018. The high increase in mean cover by cyanobacteria explained the loss of mean cover by abiotic categories and benthic algae, particularly the brown fleshy *Dictyota sp.* (-76.7%). This difference may have resulted from mechanical displacement of the fleshy algae by strong surge and colonization by cyanobacteria of the primary substrate previously occupied by fleshy algae and hard corals. Since this is only the first monitoring survey of CROS10, the resilience and potential implications of the marked increase of cyanobacterial cover are unclear and will require additional monitoring observations.

### 15.3 Fishes and Motile Megabenthic Invertebrates

A total of 35 species of fish were identified within belt-transects from a mean depth of 9.1 m at CROS10 (Table 45). Mean density was 1,064.2 Ind/transect (range: 893 – 1,258 Ind/transect) with a mean richness of 20.0 species/transect. This is the highest fish density ever recorded in the PRCRMP. The Masked Goby (*Coryphopterus personatus*) was the numerically dominant species with a mean density of 1,018.0 Ind/transect, representing 95.6% of the total fish density. Swarms of Masked Goby each with approximately 50 – 100 individuals were observed under ledges and reef overhangs on all transects surveyed at CROS10. Another 14 fish species that appear to be reef residents were present in at least four out of the five transects surveyed.

The trophic structure of fishes at CROS10 was strongly represented by zooplanktivores due to the numerical dominance of the Masked Goby and to a lesser extent of Fairy Basslet and Blue Chromis, which combined for approximately 96.7% of the total fish density within transects (Table 45). Herbivores were represented by a five parrotfishes (Scaridae), two doctorfishes (Acanthuridae) and four damselfishes (Pomacentridae) with a combined density of 16.0 Ind/transect, representing 1.9% of the total density within belt-transects. Small opportunistic carnivores were represented by 17 species with a combined density of 13.8 Ind/transect, representing 1.3% of the total fishes within belt-transects. The assemblage included three species of hamlets and one sea bass and one small grouper (Serranidae), three wrasses (Labridae), two grunts (Haemulidae), two squirrelfishes (Holocentridae), two gobies (Gobiidae), one puffer (Tetraodontidae), one trumpetfish (Aulostomidae), and one goatfish (Mullidae). Medium and large sized fish predators were represented by Bar Jacks (Carangidae), Red Hind (Serranidae), and Yellowtail Snappers (Lutjanidae) observed in extended transects.

**Table 45.** CROS10. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Carlos Rosario Reef 10m, Isla Culebra, June 2018

| Mean Depth: 9.1 m | | | | TRANSECTS | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | | | (Individuals/30 m2) | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Coryphopterus personatus* | Masked Goby | 1100 | 940 | 850 | 1000 | 1200 | **1018.0** |
| *Gramma loreto* | Fairy Basslet | 8 | 11 | 3 | 2 | 9 | **6.6** |
| *Scarus taeniopterus* | Princess Parrotfish | 6 | | 8 | 5 | 4 | **4.6** |
| *Chromis cyanea* | Blue Chromis | 10 | | 2 | 5 | 4 | **4.2** |
| *Stegastes leucostictus* | Beau Gregory | 4 | 4 | 1 | 2 | 3 | **2.8** |
| *Scarus iseri* | Striped Parrotfish | 3 | 2 | 5 | 3 | | **2.6** |
| *Stegastes variabilis* | Cocoa Damselfish | 5 | 1 | 4 | | 2 | **2.4** |
| *Haemulon flavolineatum* | French Grunt | 3 | 3 | | 2 | 2 | **2.0** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 2 | 2 | 2 | 2 | 2 | **2.0** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | | | 6 | 1 | 3 | **2.0** |
| *Halichoeres garnoti* | Yellow-head Wrasse | | 1 | 3 | 2 | 2 | **1.6** |
| *Stegastes adustus* | Dusky Damselfish | 2 | | | 2 | 4 | **1.6** |
| *Elacatinus evelynae* | Sharknose Goby | | 3 | 1 | | 3 | **1.4** |
| *Sparisoma radians* | Bucktooth Parrotfish | 3 | 1 | 1 | 2 | | **1.4** |
| *Acanthurus coeruleus* | Blue Tang | 2 | 1 | | 1 | 2 | **1.2** |
| *Canthigaster rostrata* | Caribbean Puffer | 1 | 2 | | 2 | 1 | **1.2** |
| *Cephalopholis cruentata* | Graysby | 1 | | 1 | 2 | 1 | **1.0** |
| *Holocentrus rufus* | Longspine Squirelfish | 2 | 1 | 1 | 1 | | **1.0** |
| *Hypoplectrus nigricans* | Black Hamlet | 2 | | | 1 | 1 | **0.8** |
| *Stegastes planifrons* | Three-spot Damselfish | 2 | | | | 2 | **0.8** |
| *Hypoplectrus puella* | Barred Hamlet | | | 1 | 1 | 1 | **0.6** |
| *Sparisoma viride* | Stoplight Parrotfish | 1 | | | | 2 | **0.6** |
| *Acanthurus chirurgus* | Doctorfish | | | 1 | | 1 | **0.4** |
| *Carangoides ruber* | Bar Jack | | | | | 2 | **0.4** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | 1 | | | 1 | **0.4** |
| *Haemulon aurolineatum* | Tomtate | | | 1 | | 1 | **0.4** |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | | 1 | | | 1 | **0.4** |
| *Mulloides martinicus* | Yellow Goatfish | | | | | 2 | **0.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | | 1 | | | | **0.2** |
| *Aulostomus maculatus* | Trumpetfish | | | 1 | | | **0.2** |
| *Coryphopterus lipernes* | Peppermint Goby | | | | | 1 | **0.2** |
| *Halichoeres radiatus* | Puddinwife | | | 1 | | | **0.2** |
| *Ocyurus chrysurus* | Yellowtail Snapper | | | | 1 | | **0.2** |
| *Sargocentrum coruscum* | Reef Squirrelfish | | | | | 1 | **0.2** |
| *Serranus tigrinus* | Harlequin Bass | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 1158 | 975 | 893 | 1037 | 1258 | **1064.2** |
| | **TOTAL SPECIES** | 19 | 16 | 19 | 19 | 27 | **20.0** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Echinometra viridis* | Reef Urchin | | | | | 1 | **0.2** |
| *Stenopus hispidus* | Banded Coral Shrimp | | 1 | | | | **0.2** |
| *Stenorhynchus seticornis* | Arrow Crab | | 1 | | | | **0.2** |
| *Panulirus argus* | Spiny Lobster | | | 1 | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 0 | 2 | 1 | 0 | 1 | **0.8** |
| | **TOTAL SPECIES** | 0 | 2 | 1 | 0 | 1 | **0.8** |

A large population of Yellowtail Snappers (*Ocyurus chrysurus)* and Bar Jacks (*Carangoides ruber*) is associated with this reef, yet their high densities appear to be influenced by tourists feeding the fishes with prepared food from charter boats. This activity represents a productivity subsidy, and the increase turbidity and organic matter input associated with defecation by relatively large schooling fishes and food may have implications on the reef community. This must be considered as CROS10 exhibited one of the highest coral disease prevalence (14.1%) of the 2018 PRCRMP monitoring survey. Motile megabenthic invertebrates were represented by four species within belt-transects, including one Reef Urchin, one Coral Shrimp, one Arrow Crab, and one Spiny Lobster, with a combined density of 0.8 Ind/transect (Table 45).

The size-frequency distribution of commercially important fishes and the larger reef herbivores is presented in Table 46. Parrotfishes, represented by Princess, Striped, Bucktooth, Redband and Stoplight (*Scarus taeniopterus, S. iseri, Sparisoma aurofrenatum, S. radians, S. viride*) were present throughout most of their size range (1 – 27 cm), including early recruitment juveniles to mid-sized adults. Doctorfishes (*Acanthurus spp*.) were mostly observed as juvenile and adults (7 – 14 cm). Graysbys (14 – 26 cm) and Red Hind (34 cm) were present as adults. The Yellowtail Snapper and Bar Jack population observed out of transects consisted of more than 200 individuals with a size range concentrated on juveniles and adults (12 – 35 cm).

Variations of fish density and species richness between the 2016 baseline and the 2018 monitoring survey at CROS10 are presented in Figure 49. Slight increments of both fish density and species richness were observed during the 2018 monitoring survey as compared with the 2016 baseline survey, but neither were statistically significant (ANOVA' p > 05, Appendix 3), this could indicate that the extreme climatological events affecting other reef fish communities around the island did not have a similar impact on the fish community at CROS10.

**Table 46.** CROS10. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Carlos Rosario Reef 10m, Isla Culebra, June 2018

| Mean Depth: 9.1 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | | 1-10 | | | |
| *Acanthurus chirurgus* | Doctorfish | 1-14 | | 1-12 | | 1-14 |
| *Acanthurus coeruleus* | Blue Tang | 1-7 | 2-14 | | 1-7 | 2-7 |
| | | 1-12 | | | 1-10 | 1-10 |
| *Cephalopholis cruentata* | Graysby | 1-14 | 1-24 | 1-14 | 1-14 | 1-24 |
| | | | 1-26 | | 1-19 | |
| *Epinephelus guttatus* | Red Hind | | | 1-34 | | |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1-29 | | | 1-24 | |
| *Scarus iseri* | Striped Parrotfish | 2-7 | 2-1 | 3-1 | 3-2 | |
| | | 1-10 | | 2-2 | | |
| *Scarus taeniopterus* | Princess Parrotfish | 4-7 | | 7-7 | 1-12 | 4-5 |
| | | 1-12 | | 1-26 | 3-14 | 4-7 |
| | | 2-17 | | | 2-19 | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1-14 | 1-10 | 1-10 | 2-10 | 1-5 |
| | | 1-22 | 3-14 | 1-12 | 1-14 | 1-7 |
| | | | 1-26 | | | 1-19 |
| *Sparisoma radians* | Bucktooth Parrotfish | 1-2 | | | | |
| | | 2-5 | | 1-5 | 2-2 | |
| *Sparisoma viride* | Stoplight Parrotfish | 1-7 | 1-2 | | 1-29 | 1-2 |
| | | 1-17 | 1-12 | | | 1-5 |
| **Invertebrates** | | | | | | |
| *Panulirus argus* | Spiny Lobster | | | 1-12 | | |

TL = Fish Total Length

Lobster length is the carapace length in cm

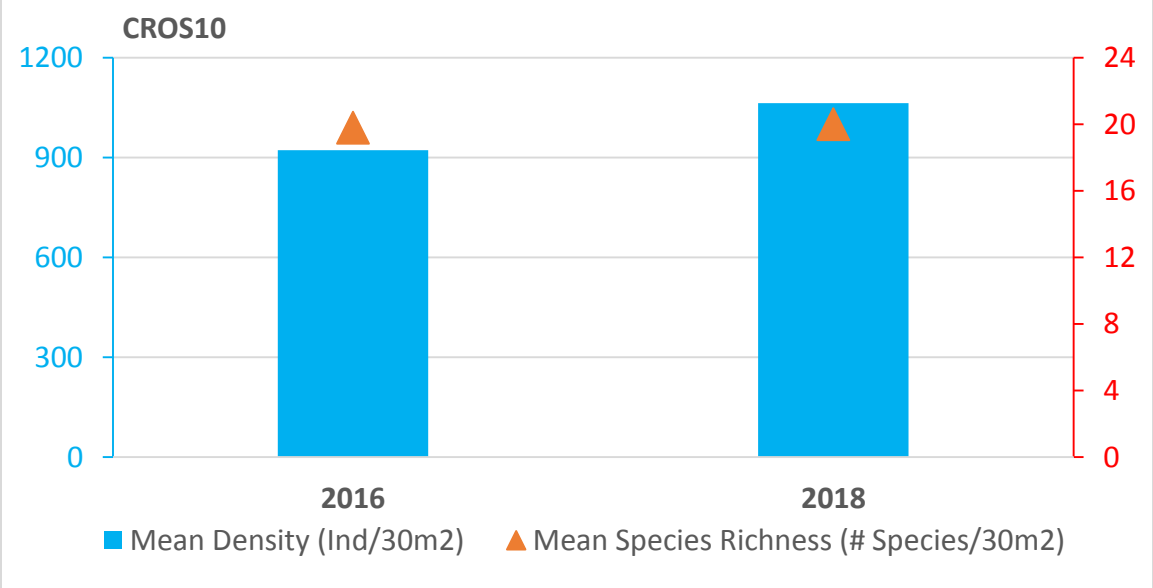



**Figure 49.** CROS10. Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Carlos Rosario Reef 10m, Isla de Culebra

**Photo Album 15**

**Carlos Rosario Reef 10m, Isla de Culebra (CROS10)**

## 16.0 Luis Pena Reef 5, Isla de Culebra

### 16.1 Physical Description

Luis Pena Island is located about 0.3 – 0.5 NM off the west coast of Isla de Culebra. Shallow water coral reefs fringe the eastern shoreline from the surface down to a depth of approximately 7.0 m (Figure 43). The main coral formation is an irregular and patchy pillar growth of Lobed Star Coral (*Orbicella annularis*) with areas dominated by thickets of Finger Coral (*Porites porites*). The baseline survey at LPEN05 was performed on the central eastern coastline of Cayo Luis Pena, within the LP Marine Reserve on September 2016. Transects were run perpendicular to the shoreline over a set of discontinuous patches of *O. annularis* coral buildups. Panoramic views of LPEN05 Reef community are shown in Photo Album 16.

### 16.2 Sessile Benthic Reef Community

Benthic algae, a mixed assemblage of encrusting red alga (*Ramicrusta sp*), turf algae, green calcareous algae (mostly *Halimeda spp*), fleshy brown macroalgae (mostly *Dictyota sp*) and crustose coralline algae was the dominant sessile-benthic category covering the reef substrate at LPEN05 with a combined mean cover of 72.00% (Table 47). The encrusting red alga, *Ramicrusta sp*. was strongly dominant in all transects with a mean cover of 42.80% (range: 32.74– 49.58%), representing 59.4% of the total cover by benthic algae. *Ramicrusta sp*. was observed as a dark burgundy crust over all available hard surfaces, but particularly over abundant dead (relict) Lobed Coral structures. Most of the reef substrate covered by turf algae was packed with sediments, evidencing conditions of strong surge and sediment resuspension prior to this 2018 monitoring survey. Patches of cyanobacteria were present in all transects with a mean cover of 3.72%, similar to the 2018 PRCRMP average (3.22%).

Hard (stony) corals were represented by 10 scleractinian species in transects surveyed at LPEN05 with a combined mean substrate cover of 8.26% (range: 4.54 – 10.95%). Lobed Star Coral (*Orbicella annularis*) was the dominant coral intercepted by transects with a mean substrate cover of 4.67%, representing 56.6% of the total cover by corals (Table 47). Sibling species *O. faveolata* and *O. franksi* were also intercepted by transects. The combined cover by *Orbicella spp.* was 5.57%. Mustard-Hill and Finger Corals (*Porites astreoides*, *P. porites*) were present in four transects each, with substrate cover means of 1.25% and 0.30%, respectively. Large colonies of Boulder Brain Coral (*Colpophyllia natans*) were intercepted by two transects with a combined mean cover of 0.54%.

| **Table 47**. LPEN05. Percent cover by sessile-benthic categories at Luis Pena Reef 5m, Isla Culebra | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 6/29/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 4.2 | 4.5 | 4.5 | 3.6 | 4.5 | **4.3** |
| Rugosity (m) | 3.30 | 3.41 | 4.45 | 4.18 | 4.45 | **3.96** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 1.26 | 5.64 | 7.07 | 1.88 | 5.14 | **4.20** |
| Sand | 1.26 | 5.64 | 7.07 | 1.88 | 5.14 | **4.20** |
| Rubble | 4.00 | 3.76 | 2.23 | 0.99 | 4.84 | **3.16** |
| Gaps | 1.37 | 0.42 | 0.97 | | 0.97 | **0.74** |
| **Total Abiotic** | **7.89** | **15.45** | **17.34** | **4.74** | **16.09** | **12.30** |
| **Benthic Algae** | | | | | | |
| *Ramicrusta* | 32.74 | 49.58 | 46.80 | 48.08 | 36.82 | **42.80** |
| Turf (mixed) with sediment | 25.05 | 10.33 | 11.14 | 13.13 | 12.21 | **14.37** |
| *Dictyota* spp. | 5.58 | 9.60 | 10.76 | 8.88 | 6.98 | **8.36** |
| Turf (mixed) | 10.84 | 2.71 | 1.45 | 3.26 | 4.94 | **4.64** |
| *Halimeda* spp. | 1.05 | 1.67 | | 0.39 | 2.52 | **1.13** |
| *Caulerpa* sp. | 1.89 | | | | | **0.38** |
| Peyssonnelid | | 0.52 | 0.48 | | | **0.20** |
| Unidentified | | | | | 0.58 | **0.12** |
| **Total Benthic Algae** | **77.16** | **74.43** | **70.64** | **73.74** | **64.05** | **72.00** |
| **Cyanobacteria** | 6.95 | 0.84 | 2.13 | 4.44 | 4.26 | **3.72** |
| **Hard Coral** | | | | | | |
| *Orbicella annularis* | 4.32 | 3.97 | 4.46 | 2.67 | 7.95 | **4.67** |
| *Porites astreoides* | | 1.57 | 2.33 | 1.38 | 0.97 | **1.25** |
| *Orbicella faveolata* | 0.74 | | 2.42 | | 0.39 | **0.71** |
| *Colpophyllia natans* | | 2.51 | | 0.20 | | **0.54** |
| *Siderastrea siderea* | | 2.09 | | | | **0.42** |
| *Porites porites* | | 0.31 | 0.19 | 0.30 | 0.68 | **0.30** |
| *Orbicella franksi* | | | | | 0.97 | **0.19** |
| *Acropora cervicornis* | 0.42 | | | | | **0.08** |
| *Agaricia fragilis* | | | 0.29 | | | **0.06** |
| *Porites furcata* | 0.21 | | | | | **0.04** |
| **Total Hard Coral** | **5.68** | **10.44** | **9.69** | **4.54** | **10.95** | **8.26** |
| **# CoralColonies /Transect** | **7** | **7** | **7** | **8** | **11** | **8.0** |
| **# Diseased Coral Colonies** | **1** | **0** | **0** | **0** | **0** | |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | 0.95 | 0.84 | 3.20 | 1.09 | 3.78 | **1.97** |
| *Eunicea sp.* | 0.21 | 0.21 | | | | **0.08** |
| *Briareum asbestinum* | | 0.31 | | | | **0.06** |
| **Total Octocoral** | **1.16** | **1.36** | **3.20** | **1.09** | **3.78** | **2.12** |
| **# Gorgonians/Transect** | 16 | 18 | 12 | 20 | 14 | **16.0** |
| **Sponges** | | | | | | |
| *Clathria sp.* | 0.32 | 0.84 | | | | **0.23** |
| *Mycale laevis* | | | | 1.09 | | **0.22** |
| *Dictyonella funicularis* | | | 0.39 | | | **0.08** |
| *Chondrilla caribensis* | | 0.21 | | | | **0.04** |
| *Amphimedon compressa* | | | | 0.20 | | **0.04** |
| **Total Sponges** | **0.32** | **1.04** | **0.39** | **1.28** | **0.00** | **0.61** |

As was noted for other reef stations surveyed from Isla de Culebra (e.g. DAKI20 and CROS10), it is evident that this reef had a much higher cover by live corals, since the carbonate structural buildup, particularly of *O. annularis* is still standing, but presently overgrown by the red alga, *Ramicrusta sp* and another encrusting reef biota. From the 40 total coral colonies intercepted by transects one *O. faveolata* colony was observed with an apparent disease infection at LPEN05 (coral disease prevalence = 2.5%). Dozens of coral colonies were observed detached from their base in the reef and overturned due to mechanical forces, including several large Lobed Coral colonies within transects, but other branching (*Porites porites*) and massive corals (*Pseudodiploria strigosa, Colpophyllia natans*) were also severely impacted.

Erect octocorals were prominent in all transects surveyed with a mean density of 16.0 col/transect at LPEN05 (Table 47). Sea Rods (*Eunicea spp, Pseudoplexaura sp*) and the Sea Fan (*Gorgonia ventalina*) were the most abundant in transects. The Encrusting Gorgonian (*Erythropodium caribaeorum*) was present in all five transects with a mean cover of 1.97%. Another encrusting species, the Corky Sea Finger (*Briareum asbestinum*) was present in two transects with a mean cover below 1%. Sponges were represented by five species in transects with a combined mean cover of 0.61%. *Clathria sp.* was the only species observed in more than one transect. In general, sponges were present as small and mostly encrusting colonies with minor contributions to the overall reef topographic relief and benthic habitat complexity. Abiotic substrate categories were mostly contributed by reef overhangs (4.20%) and sand (4.20%) and presented a mean reef substrate cover of 12.30% (Table 50). The mean reef rugosity of 3.96 m was mostly contributed by coral ledges and overhangs.

Variations of reef substrate cover by sessile-benthic categories at LPEN05 between the 2016 baseline and the 2018 monitoring survey are summarized in Figure 50. Shifts on the rank order of benthic categories were evidenced in terms of reef substrate cover as abiotic cover surpassed cover by live corals in the 2018 survey. Statistically significant differences of substrate cover by total live corals were evidenced. Differences were associated with a 51.7% reduction of coral cover, from 17.2% in 2016 to 8.3% in 2018 (ANOVA, $p = 0.011$, Appendix 2a). Such decline was related to loss of cover by several species, including *Orbicella annularis, Porites porites* and *Colpophyllia natans* (Figure 51). This reduction of cover was caused by mechanical damage associated with events of extreme wave and surge action capable of detaching and overturning large colonies of *O. annularis* and *C. natans*, while dead patches of *P. porites* appeared to have been mostly affected by sand abrasion.

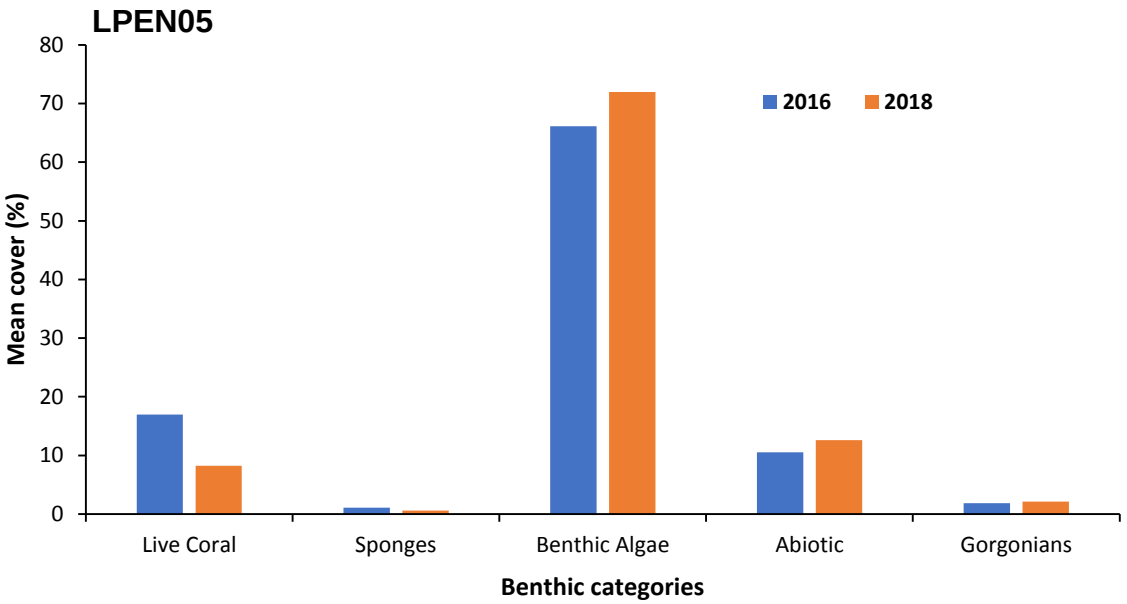



**Figure 50.** LPEN05. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at Luis Pena Reef 5m, Isla de Culebra

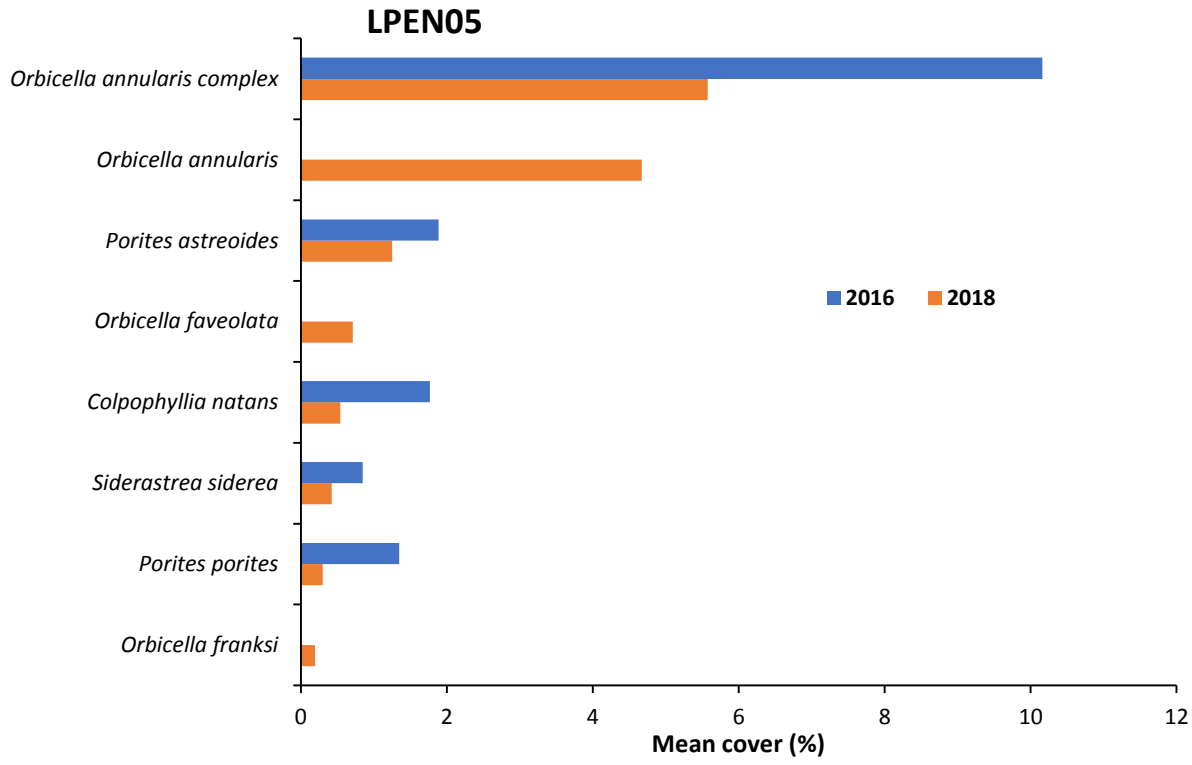



**Figure 51.** LPEN05. Annual variations (2016 -18) of mean substrate cover by the main coral species ntercepted by transects at Luis Pena Reef 5m, Isla de Culebra

The density of octocorals declined 16.7% between surveys, from 19.2 colonies/transect in 2016 to 16.0 colonies/transect in 2018. The difference was statistically significant (ANOVA, p = 0.02, Appendix 2b) and as with hard corals, may have been driven by conditions of extreme surge and abrasion that must have prevailed during the pass of Hurricanes Irma and Maria in September 2017 and/or with another extraordinarily high swells event that impacted the north and west coasts of Puerto Rico in March 2018.

The community structure of benthic algae also exhibited changes in the relative composition of the main constituents at LPEN05 during 2018, relative to the 2016 baseline survey. The 8.9% increase of cover by total benthic algae was expected due the decline of coral cover, since there has been sufficient time for algae to colonize available surfaces provided by coral loss. But cover by *Ramicrusta sp*. declined 24.7% and a corresponding increase in cover by fleshy algae (*Dictyota sp*.) and turf algae were measured (Table 47). It is unknown if such changes have been influenced by nutrient enrichment and/or mechanical forces associated with the pass of hurricanes, or if they are part of a dynamic process involving benthic algae succession and competition for available reef hard bottom at LPEN05. Further monitoring observations will be required for a more comprehensive analysis of changes in the percent cover and relative contribution of taxonomic components to the total benthic algal cover at LPEN05.

### 16.3 Fishes and Motile Megabenthic Invertebrates

A total of 37 species of fish were identified within belt-transects from a mean depth of 4.3 m at LPEN05 (Table 48). Mean density was 43.0 Ind/transect (range: 26 – 63 Ind/transect) with a mean richness of 17.0 species/ transect. The Masked Goby (*Coryphopterus personatus*) was the numerically dominant species with a mean density of 11.8 Ind/transect, representing 27.4% of the total fish density. An assemblage of 11 fish species (including the Masked Goby) were present in at least four transects with a combined density of 33.0Ind/transect, representing 76.7% of the total individuals within belt-transects. These included the Three-spot and Dusky Damselfishes (*Stegastes planifrons, S. adustus),* Stoplight and Redband Parrotfishes (*Sparisoma viride, S. aurofrenatum*), Bluehead and Yellowhead Wrasses (*Thalassoma bifasciatum*, *Halichoeres garnoti*), Blue Tang (*Acanthurus coeruleus*), Butter Hamlet (*Hypoplectrus unicolor*), Longspine Squirrelfish (*Holocentrus rufus*) and Caribbean Puffer (*Canthigaster rostrata*). Fifteen species were only observed in one transect.

**Table 48.** LPEN05. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Luis Pena Reef 5m, Isla Culebra, June 2018

| Mean Depth: 4.3 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Coryphopterus personatus* | Masked Goby | 13 | | 1 | 19 | 26 | **11.8** |
| *Stegastes planifrons* | Three-spot Damselfish | 3 | 4 | 8 | 5 | 7 | **5.4** |
| *Sparisoma viride* | Stoplight Parrotfish | 3 | 2 | 4 | 2 | 4 | **3.0** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 2 | | 5 | 4 | 4 | **3.0** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 2 | 2 | 2 | 4 | 2 | **2.4** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 3 | | 4 | 3 | 1 | **2.2** |
| *Acanthurus coeruleus* | Blue Tang | 1 | 2 | 1 | 1 | 4 | **1.8** |
| *Holocentrus rufus* | Longspine Squirelfish | 1 | 1 | 2 | | 2 | **1.2** |
| *Stegastes adustus* | Dusky Damselfish | 1 | 1 | 2 | 2 | | **1.2** |
| *Hypoplectrus unicolor* | Butter Hamlet | 1 | | 2 | 1 | 1 | **1.0** |
| *Canthigaster rostrata* | Caribbean Puffer | | 2 | 1 | 1 | | **0.8** |
| *Haemulon flavolineatum* | French Grunt | 1 | 2 | | | 1 | **0.8** |
| *Acanthurus chirurgus* | Doctorfish | 1 | | 1 | | 1 | **0.6** |
| *Elacatinus evelynae* | Sharknose Goby | | 2 | | 1 | | **0.6** |
| *Haemulon aurolineatum* | Tomtate | | 1 | | | 2 | **0.6** |
| *Hypoplectrus nigricans* | Black Hamlet | | 1 | | | 2 | **0.6** |
| *Abudefduf saxatilis* | Sargent Major | | | | 1 | 1 | **0.4** |
| *Acanthurus tractus* | Five-band Surgeonfish | 1 | 1 | | | | **0.4** |
| *Cantherhines pullus* | Tail-light Filefish | | 2 | | | | **0.4** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | 1 | 1 | | | **0.4** |
| *Chromis cyanea* | Blue Chromis | | | | | 2 | **0.4** |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 1 | 1 | | | | **0.4** |
| *Scarus iseri* | Striped Parrotfish | 1 | | 1 | | | **0.4** |
| *Scarus taeniopterus* | Princess Parrotfish | | | 2 | | | **0.4** |
| *Sparisoma radians* | Bucktooth Parrotfish | | | | 2 | | **0.4** |
| *Aulostomus maculatus* | Trumpetfish | | | | 1 | | **0.2** |
| *Carangoides ruber* | Bar Jack | 1 | | | | | **0.2** |
| *Epinephelus striatus* | Nassau Grouper | 1 | | | | | **0.2** |
| *Gramma loreto* | Fairy Basslet | | | | | 1 | **0.2** |
| *Halichoeres bivittatus* | Slippery Dick | 1 | | | | | **0.2** |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | | | 1 | | | **0.2** |
| *Hypoplectrus puella* | Barred Hamlet | | | | | 1 | **0.2** |
| *Lactophrys triqueter* | Smooth Trunkfish | | 1 | | | | **0.2** |
| *Lutjanus apodus* | Schoolmaster | 1 | | | | | **0.2** |
| *Myripristis jacobus* | Black-bar Soldierfish | | | | | 1 | **0.2** |
| *Stegastes leucostictus* | Beau Gregory | | | 1 | | | **0.2** |
| *Stegastes partitus* | Bicolor Damselfish | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 40 | 26 | 39 | 47 | 63 | **43.0** |
| | **TOTAL SPECIES** | 20 | 16 | 17 | 14 | 18 | **17.0** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Echinometra viridis* | Reef Urchin | 1 | | 1 | | | **0.4** |
| *Diadema antillarum* | Long-Spined Urchin | 2 | | | | | **0.4** |
| | **TOTAL INDIVIDUALS** | 3 | 0 | 1 | 0 | 0 | **0.8** |
| | **TOTAL SPECIES** | 2 | 0 | 1 | 0 | 0 | **0.6** |

The trophic structure of fishes at LPEN05 in 2018 was dominated by herbivores comprised by 11 species and a combined mean density of 16.6 Ind/transect, or 38.6% of the total individuals. The herbivore assemblage included five parrotfishes (Scaridae), three damselfishes (Pomacentridae), and three doctorfishes (Acanthuridae). The zooplanktivore assemblage included the Blue and Brown Chromis and Bicolor Damselfish (Pomacentridae) and Fairy Basslet (Grammatidae) with a combined density of 13.0 Ind/transect, or 30.2% of the total individuals. Small opportunistic carnivores were represented by 13 species with a combined density of 11.6 Ind/transect, representative of 27.0% of the total density, and included four hamlets (Serranidae), three wrasses (Labridae), two squirrelfishes (Holocentridae), one puffer (Tetraodontidae), one grunt (Haemulidae), one goby (Gobiidae), and one trumpetfish (Aulostomidae). Medium sized piscivores included one Schoolmaster Snapper (*L. apodus*), one Bar Jack (Carangidae) and one Nassau Grouper (Serranidae). Motile megabenthic invertebrates were represented by four urchins within belt-transects (Table 48).

The size frequency distributions of the commercially important fish species and larger reef herbivores are presented in Table 49. Parrotfishes were represented by six species. Early recruits (2 – 5 cm) of the Princess, Bucktooth and Stoplight Parrotfishes were present. Juvenile and adult stages (12 - 27cm) of the Redband, Yellowtail and Stoplight Parrotfishes were also observed. Recruitment juvenile stages (2 – 5 cm) of the Blue Tang were common in LPEN05, and juvenile through adult stages were also present from all *Acanthurus spp*. Schoolmaster Snappers were present mostly as juveniles. One relatively small adult Nassau Grouper was also observed.

Variations of fish density and species richness within belt-transects between the 2016 baseline and the 2018 monitoring survey are shown in Figure 52. Mean fish density declined 4-fold, from 179.0 Ind/transect in 2016 to 43.0 Ind/transect in 2018. The difference was statistically significant (ANOVA, $p = 0.003$; Appendix 3) and largely driven by an order of magnitude decline of density by Masked Goby (*Coryphopterus personatus*), from 118.0 Ind/transect in 2016 to 11.8 Ind/transect in 2018. This decline of the population density of Masked Goby was observed to be a consistent pattern in most shallow reefs surveyed during 2018. It is here proposed that the population of Masked Goby was severely depleted from shallow reefs due to the surge and abrasive effects brought about by Hurricanes and other extreme wave action events between the 2016 baseline and the 2018 monitoring surveys. Differences of fish species richness between surveys were relatively small and not statistically significant (Figure 52), indicative that a major ecological impact on the fish community structure at LPEN05 was not observed.

**Table 49.** LPEN05. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Luis Pena Reef 5m, Isla Culebra, June 2018

| Mean Depth: 4.3 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 1-7 | 2-10 | | | |
| *Acanthurus chirurgus* | Doctorfish | 1-7 | | 1-5 | | 2-12 |
| *Acanthurus coeruleus* | Blue Tang | 1-7 | 1-2 | 1-5 | 2-7 | 2-5 |
| | | 1-12 | 1-5 | 1-10 | | 1-7 |
| | | | | | | 1-12 |
| *Epinephelus striatus* | Nassau Grouper | 1-43 | | | | |
| *Lutjanus apodus* | Schoolmaster | 1-7 | | | | |
| | | 1-10 | | | | |
| *Scarus iseri* | Striped Parrotfish | 1-12 | | 1-10 | | |
| *Scarus taeniopterus* | Princess Parrotfish | 1-10 | | 3-5 | | |
| | | | | 1-7 | | |
| | | | | 1-10 | | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 2-5 | 2-5 | 1-7 | 1-5 | 2-10 |
| | | | | 1-12 | 1-7 | |
| | | | | | 1-10 | |
| | | | | | 2-12 | |
| *Sparisoma radians* | Bucktooth Parrotfish | | | | 1-2 | |
| | | | | | 1-5 | 1-2 |
| *Sparisoma rubripinne* | Yellowtail Parrotfish | | 1-29 | | | |
| *Sparisoma viride* | Stoplight Parrotfish | 2-5 | 2-2 | 1-2 | 1-2 | 5-2 |
| | | 1-10 | | 1-5 | 1-10 | 1-7 |
| | | | | 1-12 | | 1-26 |
| **Invertebrates** | | | | | | |
| none | | | | | | |

TL = Fish Total Length

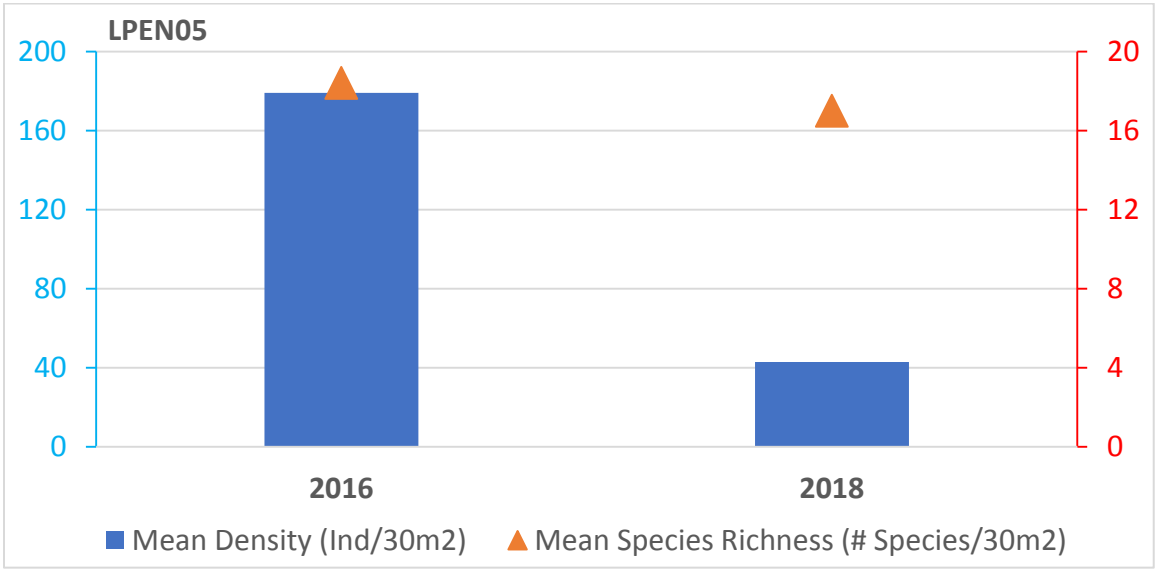


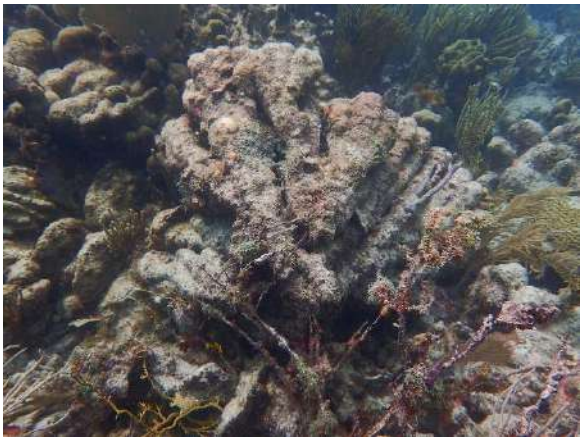

**Figure 52.** LPEN05. Monitoring trends (2016 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Luis Pena Reef 5m, Isla de Culebra

**Photo Album 16**

**Luis Pena Reef 5m, Isla de Culebra (LPEN05)**





## 17.0 El Seco Reef-Vieques

### 17.1 Physical Description

"El Seco" is a submerged promontory, or ridge that rises from a deep outer shelf basin at the southeastern tip of the Vieques shelf, approximately 6 km from Punta del Este. The promontory with an elliptical shape runs along a north-south axis and rises from the basin at depths of 33 – 36 m to a mostly flat hard ground reef top at depths of 23 – 28 m (Figure 53). Depth increases towards the shelf-edge to the east and south of the ridge, and decreases towards the north, where an extensive mesophotic coral reef system consisting of several benthic habitats was discovered (Garcia-Sais et al., 2011). The coral reef system ends as patch reef spurs separated by coralline sand pools at depths between 40 – 45 m. Clear waters prevail at "El Seco" with underwater visibility exceeding the 30 - 40 m range.

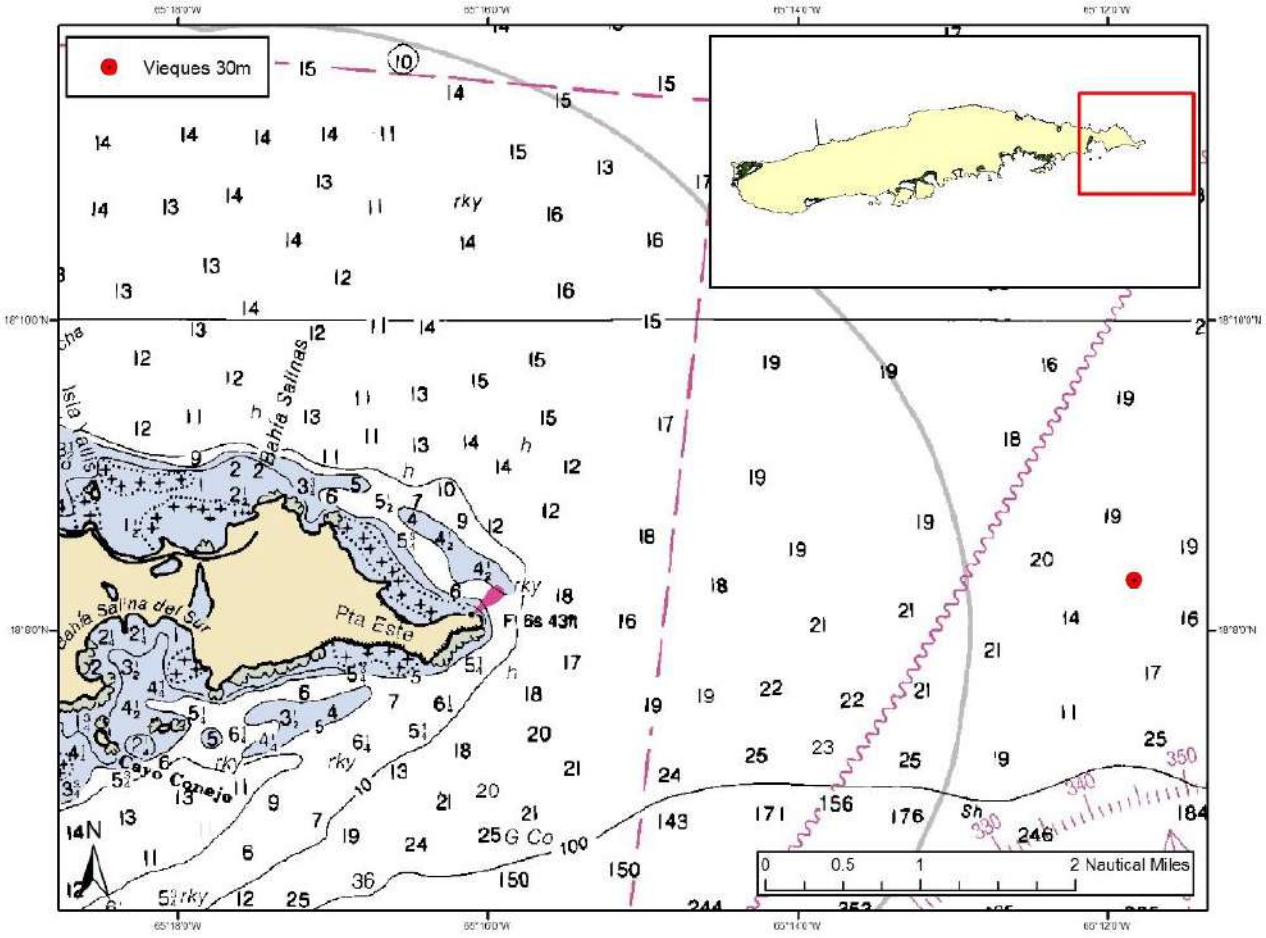



**Figure 53**. Location of coral reef monitoring station at El Seco Reef (SECO30), Isla de Vieques.

The coral bank reef habitat at El Seco (SECO30) is an impressive continuous formation of scleractinian corals growing at depths of 33 – 41 m (110 – 135 ft) throughout the northern and northeastern sections of the study area. The coral reef is largely a biotope of Boulder Star Coral, *Orbicella franksi* growing as laminar planks of up to 1 m of diameter, supported by pedestals of unknown origin and variable heights. Even though its entire areal extension has not been mapped, the coral reef formation off southeast Vieques represents the largest continuous coral reef benthic habitat reported for Puerto Rico (Garcia-Sais et al. 2011). This is the third monitoring survey of SECO30 after the initial baseline survey in October 2011. Images of the coral reef community at SECO30 are presented as Photo Album 17.

### 17.2 Sessile-Benthic Reef Community

Substrate cover by sessile-benthic categories from transects surveyed at SECO30 are presented in Table 50. The combined assemblage of benthic algae, comprised by fleshy brown, turf, red crustose calcareous, and red coralline algae (CCA) was the dominant category in terms of percent cover with a mean of 61.50% (range: 54.89 – 65.22%). The Encrusting Fan Alga (*Lobophora variegata*) was the main component of the benthic algae with a mean cover of 29.31%, representing 47.6% of the total cover by benthic macroalgae. Turf algae, a mixed assemblage of short filamentous algae were observed overgrowing relict and/or recently dead coral sections in all transects with a mean cover of 14.96%. Encrusting crustose calcareous algae, *Ramicrusta sp*. were observed in all transects with a combined mean cover of 13.97%, representing 22.8% of the total benthic algae. Cyanobacterial patches were intercepted by all five transects, but with a relatively low substrate cover (mean: 1.72%), compared to the 2018 PRCRMP average of 3.22%.

A total of 137 coral colonies, representing nine (9) scleractinians and one hydrocoral (*Millepora alcicornis*) were intercepted by transects at SECO30 with a mean cover of 33.75% (range: 28.06 – 41.66%). Reef substrate cover by live corals was strongly dominated by Boulder Star Coral, (*Orbicella franksi*) growing in table shaped colonies side by side, sometimes slightly overlapping and producing an impressive continuous live mesophotic coral system resembling that described by Smith et al. (2010) for the MCD Hind Bank in St. Thomas, USVI. Mean substrate cover by *O. franksi* was 30.36% (range: 24.84 – 40.34%), representing 90.0% of the total cover by live corals (Table 50). Mustard-hill Coral (*Porites astreoides*) and Lettuce Coral (*Agaricia agaricites*) were intersected (along with *O. franksi*) by at least four transects with a combined mean cover of 2.49%. Whitestar Sheet Coral (*A. lamarki*) and Massive Starlet Coral (*Siderastrea siderea*) were present in three and two transects.

| **Table 50**. SECO30. Percent cover by sessile-benthic categories at El Seco Reef 30m, Isla Vieques | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 6/30/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 35.8 | 33.6 | 35.8 | 35.4 | 35.4 | **35.2** |
| Rugosity (m) | n/d | n/d | n/d | n/d | n/d | **n/d** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Sand | 1.80 | | 2.84 | 3.78 | 0.83 | **1.85** |
| **Total Abiotic** | **1.80** | **0.00** | **2.84** | **3.78** | **0.83** | **1.85** |
| **Benthic Algae** | | | | | | |
| *Lobophora variegatus* | 40.91 | 31.18 | 24.70 | 25.28 | 24.48 | **29.31** |
| Turf (mixed) | 9.15 | 10.08 | 17.60 | 21.77 | 16.22 | **14.96** |
| *Ramicrusta* | 11.92 | 9.75 | 13.35 | 16.48 | 18.37 | **13.97** |
| CCA (mixed) | 2.98 | 3.88 | 4.09 | 1.69 | 3.27 | **3.18** |
| *Halimeda* sp. | | | 0.35 | | | **0.07** |
| **Total Benthic Algae** | **64.96** | **54.89** | **60.09** | **65.22** | **62.34** | **61.50** |
| **Cyanobacteria** | 3.41 | 2.98 | 0.69 | 0.67 | 0.83 | **1.72** |
| **Hard Coral** | | | | | | |
| *Orbicella franksi* | 25.67 | 40.34 | 30.62 | 24.84 | 30.35 | **30.36** |
| *Porites astreoides* | 0.88 | 1.32 | 1.84 | 1.35 | 1.62 | **1.40** |
| *Agaricia agaricites* | 0.90 | | 1.42 | 0.71 | 2.40 | **1.09** |
| *Agaricia lamarcki* | 0.30 | | 1.14 | 0.69 | | **0.43** |
| *Siderastrea siderea* | | | 0.67 | 1.03 | | **0.34** |
| *Porites porites* | | | | 0.35 | | **0.07** |
| *Millepora alcicornis* | 0.31 | | | | | **0.06** |
| **Total Hard Coral** | **28.06** | **41.66** | **35.69** | **28.97** | **34.37** | **33.75** |
| **# CoralColonies /Transect** | **36** | **26** | **35** | **20** | **20** | **27.4** |
| **# Diseased Coral Colonies** | **0** | **0** | **0** | **0** | **0** | |
| **Other** | | | | | | |
| *Tridemnum solidum* | | | | **0.68** | | **0.14** |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | 1.49 | | | 0.35 | 1.22 | **0.61** |
| **Total Octocoral** | **0.61** | **1.22** | **0.33** | **2.06** | **0.87** | **0.61** |
| **# Gorgonians/Transect** | 0 | 0 | 0 | 0 | 0 | **0.0** |
| **Sponges** | | | | | | |
| *Agelas conifera* | | 0.48 | | | | **0.10** |
| *Cliona delitrix* | | | | | 0.42 | **0.08** |
| *Svenzea zeai* | | | 0.35 | | | **0.07** |
| *Geodia neptuni* | | | 0.35 | | | **0.07** |
| *Aplysina cauliformis* | | | | 0.33 | | **0.07** |
| *Agelas citrina* | 0.29 | | | | | **0.06** |
| **Total Sponges** | **0.29** | **0.48** | **0.70** | **0.33** | **0.42** | **0.44** |

Diseased coral colonies were not observed at SECO30 (Appendix 4), but some discoloration and presence of necrotic tissue was observed in many colonies. Also, we observed small bleached patches in some colonies, but could not relate these features with any coral infectious disease. Recently dead coral colonies were observed overgrown by turf and fleshy algae.

Vertically projected octocorals were not intercepted by line transects at SECO30. The Encrusting Gorgonian (*Erythropodium caribaeorum*) was present in three transects with a mean cover of 0.61%. Sponges were represented by six species with a combined mean cover of 0.44%. Abiotic substrates were largely contributed by sand (1.85%). Reef overhangs were very prominent, but not quantified by the CPC image analisis technique used to estimate cover by substrate categories at SECO30.

Variations of percent cover by sessile-benthic substrate categories between monitoring surveys at SECO30 are presented in Figure 54. The rank order of benthic categories has remained stable between monitoring surveys since 2013, when benthic algae exceeded substrate cover by corals at SECO30. Intraspecific variations within the benthic algae community structure were reported by Garcia-Sais et al. (2016) related to a shift of dominance from mixed turf algae in the 2013 baseline to a fleshy brown/calcareous red macroalgae (*Lobophora*/Peyssonnelid) dominance in terms of reef substrate cover. Such pattern of dominance by fleshy brown/calcareous red macroalgae prevailed at SECO30 in the 2018 monitoring survey.

Live coral cover declined 17.8%, from 41.1% in 2016 to 33.8% in 2018. Temporal differences between surveys were statistically insignificant, but marginal at $p = 0.07$ (ANOVA, $p = 0.07$, see Appendix 2a). The largest difference (- 21.8%) stands between the 2011 baseline and the most recent 2018 monitoring survey. Although differences were not very high, the 2018 reductions of coral cover were consistent across all five transects relative to the 2011 baseline survey driven mostly by variations of cover by dominant coral species *Orbicella franksi* (Figure 55).

Fluctuations of reef substrate cover by live corals have been previously reported for SECO30, both in magnitude and direction (Garcia-Sais et al., 2014, 2016) reaching a historical minimum cover in 2018. Given the lack of pattern, these fluctuations may be related to high variability of the analytical method, since substrate cover by benthic categories at SECO30 were produced by CPC image analyses (see methods) of overlapping photos (photo-transects) and not by chain link counts. Widespread prevalence of infectious diseases could not be ascertained for SECO30 in 2018, but a considerable amount of necrotic tissue, discoloration and some small bleached patches were noted in coral colonies within the analyzed images. Therefore, continued monitoring will be required to establish if the 2016 to 2018 decline of coral cover represents a real trend, or if it is related to analytical variability.

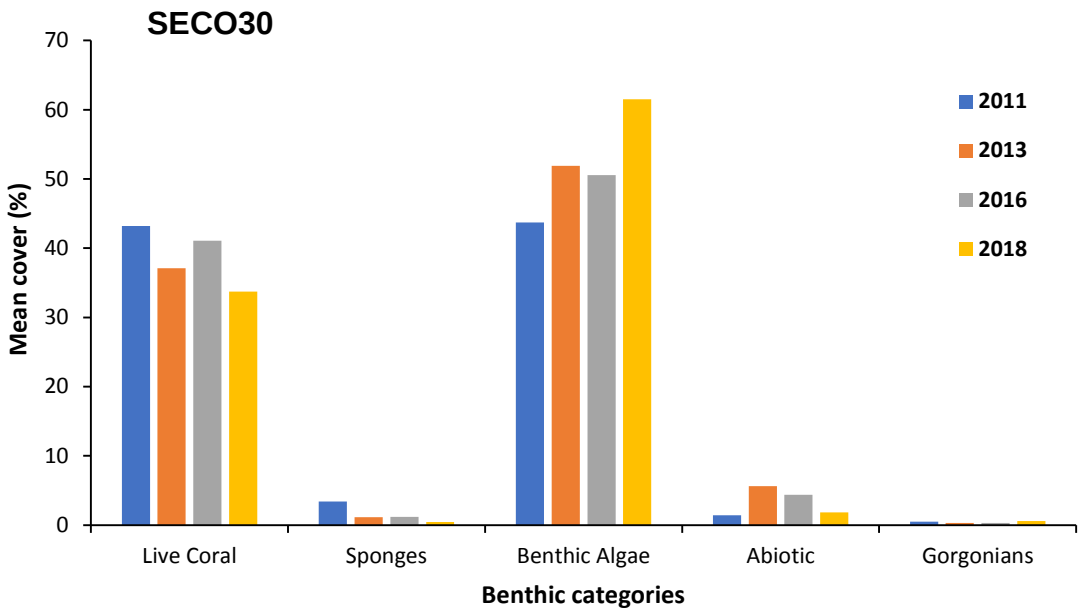



**Figure 54. S**ECO30. Annual variations (2016 -18) of mean substrate cover by sessile-benthic categories at El Seco Reef 30m, Isla de Vieques

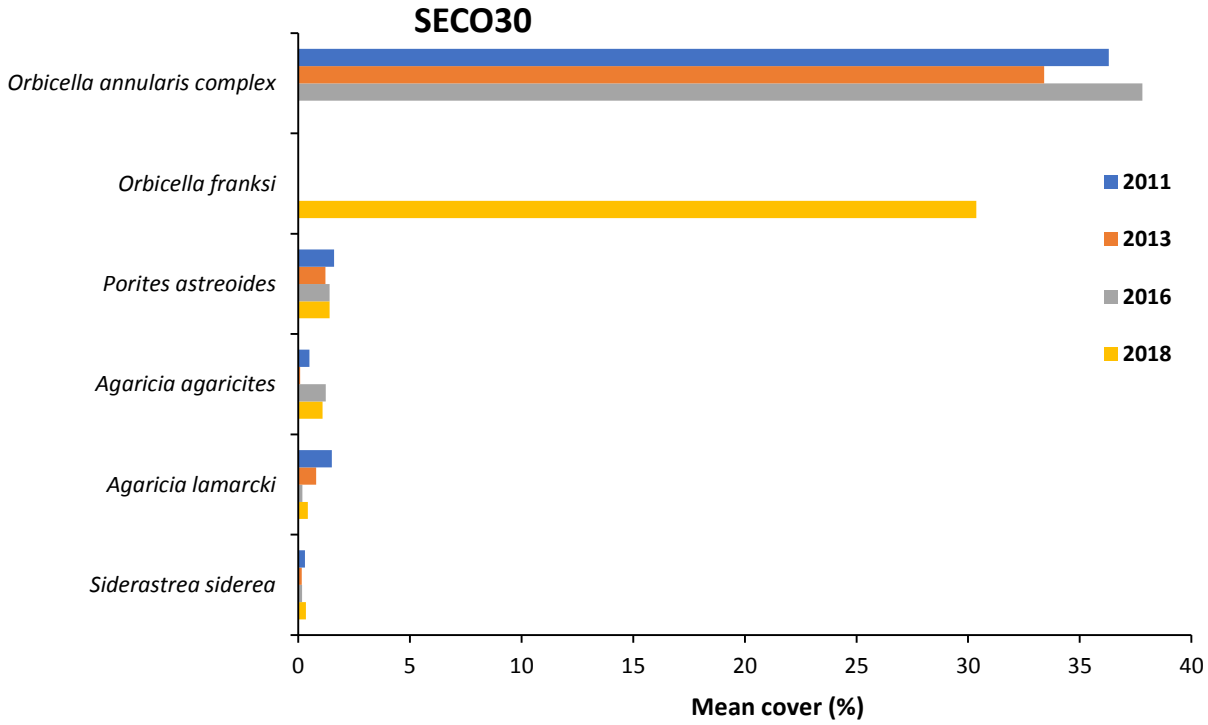



**Figure 55.** SECO30. Annual variations (2016 -18) of mean substrate cover by the main coral species intercepted by transects at El Seco Reef 30m, Isla de Vieques

### 17.3 Fishes and Motile Megabenthic Invertebrates

A total of 31 fish species were identified within belt-transects at SECO30 (Table 51). Mean abundance within belt-transects was 38.0 Ind/30m$^2$ (range: 12 - 97 Ind/30m$^2$). Mean species richness was 11.8 spp/30m$^2$ (range: 9 – 14 spp/30m$^2$). The combined density within belt-transects of seven species represented 75.3% of the total fish density. These included the Blue Chromis (*Chromis cyanea*), Creole and Bluehead Wrasse, (*Clepticus parrae, Thalassoma bifasciatum*), Masked Goby (*Coryphopterus personatus*), Princess Parrotfish (*Scarus taeniopterus*), Bicolor Damselfish (*Stegastes partitus*), and Fairy Basslet (*Gramma loreto*). Sixteen species were only observed in one out of the five transects surveyed. Motile megabenthic invertebrates were not observed within belt-transects (Table 51).

Zooplanktivorous fishes dominated the trophic community structure at SECO30. Four of the top five species in terms of density within belt-transects were zooplanktivores. The entire assemblage included three damselfishes (Pomacentridae), one wrasse (Labridae), one goby (Gobiidae), and one basslet (Grammatidae). Their combined abundance (22.4 Ind/transect) represented 58.9% of the total individuals. Small opportunistic carnivores included eight species with a combined density of 7.0 Ind/transect, representative of 18.4% of the total fishes within belt-transects. These included two wrasses (Labridae), two gobies (Gobiidae), one puffer (Tetraodontidae), two squirrelfishes (Holocentridae), and one goatfish (Mullidae). Herbivores were represented by five parrotfishes (Scaridae) and three doctorfishes (Acanthuridae) with a combined density of 6.2 Ind/transect, or 16.3% of the total individuals. Medium size piscivores included the Queen Triggerfish (Balistidae), Lionfish (Scorpaenidae), and Coney (Serranidae). Mutton Snappers (*Lutjanus analis*) and one Red Hind (*Epinephelus guttatus*) were observed out of transects.

The size-frequency distributions of fish species of commercial value and larger reef fish herbivores is presented in Table 52. Recruitment stages (2 cm) of Bucktooth Parrotfish (*Sparisoma radians*) were observed within belt-transects. Otherwise, all other parrotfishes (*Sparisoma spp, Scarus spp*) and doctorfishes (*Acanthurus spp*) were observed as juveniles and/or adults. Queen Triggerfish, Coney, Yellowtail Snapper, Great Barracuda and Lionfish were observed as adults.

**Table 51.** SECO30. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at El Seco Reef 30m, Isla Vieques, June 2018

| Mean Depth: 35.2 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Chromis cyanea* | Blue Chromis | 23 | 10 | 2 | 1 | | **7.2** |
| *Clepticus parrae* | Creole Wrasse | 30 | | | | | **6.0** |
| *Coryphopterus personatus* | Masked Goby | 12 | | | 2 | 6 | **4.0** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 10 | 8 | | | 1 | **3.8** |
| *Stegastes partitus* | Bicolor Damselfish | 1 | 6 | 3 | 2 | 2 | **2.8** |
| *Scarus taeniopterus* | Princess Parrotfish | 1 | | 6 | | 6 | **2.6** |
| *Gramma loreto* | Fairy Basslet | 10 | 1 | | | | **2.2** |
| *Coryphopterus lipernes* | Peppermint Goby | 1 | | 2 | 1 | 1 | **1.0** |
| *Halichoeres garnoti* | Yellow-head Wrasse | | | 2 | 1 | 1 | **0.8** |
| *Acanthurus chirurgus* | Doctorfish | | | 1 | 1 | 1 | **0.6** |
| *Acanthurus coeruleus* | Blue Tang | | 1 | | 1 | 1 | **0.6** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | 1 | 2 | | | | **0.6** |
| *Holocentrus rufus* | Longspine Squirelfish | | | | 2 | 1 | **0.6** |
| *Scarus tractus* | Stripped Parrotfish | 3 | | | | | **0.6** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | | 1 | | 2 | **0.6** |
| *Sparisoma radians* | Bucktooth Parrotfish | | 1 | 2 | | | **0.6** |
| *Acanthurus tractus* | Five-band Surgeonfish | | | 1 | | 1 | **0.4** |
| *Chaetodon striatus* | Banded Butterflyfish | 2 | | | | | **0.4** |
| *Balistes vetula* | Queen Triggerfish | | | | | 1 | **0.2** |
| *Bodianus rufus* | Spanish Hogfish | | | 1 | | | **0.2** |
| *Cantherhines pullus* | Tail-light Filefish | | | | | 1 | **0.2** |
| *Carangoides ruber* | Bar Jack | 1 | | | | | **0.2** |
| *Cephalopholis fulva* | Coney | | 1 | | | | **0.2** |
| *Chromis multilineata* | Brown Chromis | | 1 | | | | **0.2** |
| *Elacatinus evelynae* | Sharknose Goby | | | 1 | | | **0.2** |
| *Haemulon flavolineatum* | French Grunt | | | 1 | | | **0.2** |
| *Holacanthus tricolor* | Rock Beauty | | | | 1 | | **0.2** |
| *Myripristis jacobus* | Black-bar Soldierfish | 1 | | | | | **0.2** |
| *Mulloides martinicus* | Yellow Goatfish | | 1 | | | | **0.2** |
| *Pterois sp* | Lionfish | 1 | | | | | **0.2** |
| *Sparisoma viride* | Stoplight Parrotfish | | 1 | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 97 | 33 | 23 | 12 | 25 | **38.0** |
| | **TOTAL SPECIES** | 14 | 11 | 12 | 9 | 13 | **11.8** |
| | | | | | | | |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *none* | | | | | | | |
| | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 0 | 0 | 0 | **0.0** |
| | **TOTAL SPECIES** | 0 | 0 | 0 | 0 | 0 | **0.0** |

Previous assessments of the fish community at SECO30 have shown that this reef functions as the residential habitat of several commercially important medium and large demersal reef fish predators, such as Red Hind (*Epinephelus guttatus*), Hogfish (*Lachnolaimus maximus),* Schoolmaster, Dog and Cubera snappers (*Lutjanus apodus, L. jocu, L. cyanopterus*), Tiger and Yellowfin Groupers (*Mycteroperca tigris, M. venenosa*), and Nurse Shark (*Ginglymostoma cirratum*). In addition to ballyhoo (Hemiramphidae) and flying-fishes (Exocoetidae) small schools

of mackerel scad (*Decapterus macarelus*) and creole wrasse (*Clepticus parrae*) have been observed in mid-water. These serve as potential forage species for the larger pelagic predators, such as Great Barracuda (Sphyraenidae) and Cero Mackerel (Scombridae). Several large hawksbill turtles (*Eretmochelys imbricata*) were present at SECO30 during the 2011 baseline survey (Garcia-Sais et al., 2012).

Figure 56 shows the temporal variations of fish abundance and species richness at SECO30. A pattern of declining fish density and species richness was observed in successive monitoring surveys since the baseline characterization in 2011. Density reductions have been related with abundance fluctuations of numerically dominant species, such as the Masked Goby (*Coryphopterus personatus*), but were also related to an overall statistically significant decline of species richness (ANOVA, $p = 0.047$; Appendix 3). The marginally significant difference of species richness resulted between the 2011 baseline and the 2018 monitoring survey. It is possible that the recruitment dynamics of short-lived reef fish species may have been affected by the extreme physical/climatological events that impacted coral reef systems around Puerto Rico during the period between September 2017 and March 2018. Continued monitoring will be required to establish if the declining pattern of fish density and species richness at SECO30 is a permanent condition or associated with short/medium-term oceanographic-climatological effects.

**Table 52** SECO30. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at El Seco Reef 30m, Isla Vieques, June 2018

| Mean Depth: 35.2 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus chirurgus* | Doctorfish | | | 1-12 | 1-7 | 1-12 |
| *Acanthurus coeruleus* | Blue Tang | | 2-7 | | 1-10 | |
| *Acanthurus tractus* | Five-band Surgeonfish | | | 1 - 10 | | 1-10 |
| *Balistes vetula* | Queen Triggerfish | | | | | 1-43 |
| *Cephalopholis fulva* | Coney | | 1-29 | | | |
| *Ocyurus chrysurus* | Yellowtail Snapper | | | 1-24 | | 1-26 |
| *Scarus iseri* | Stripped Parrotfish | 3-10 | | | | |
| *Scarus taeniopterus* | Princess Parrotfish | 1-14 | | 2-7 | | 2-7 |
| | | | | 4-12 | | 4-10 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | | | 1-14 | 1-10 | 1-10 |
| | | | | | | 1-14 |
| *Sparisoma radians* | Bucktooth Parrotfish | | | 2-2 | | |
| *Sparisoma viride* | Stoplight Parrotfish | | 1-14 | | | |
| *Sphyraena barracuda* | Great barrracuda | | | | 1-53 | |
| *Pterois sp* | Lionfish | 1-22 | | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |
| **Out of Transects** | | | | | | |
| *Epinephelus guttatus* | Red Hind | | | | | |
| *Lutjanus analis* | Mutton Snaper | | | | | |
| | | | | | | |
| TL = Fish Total Length | | | | | | |

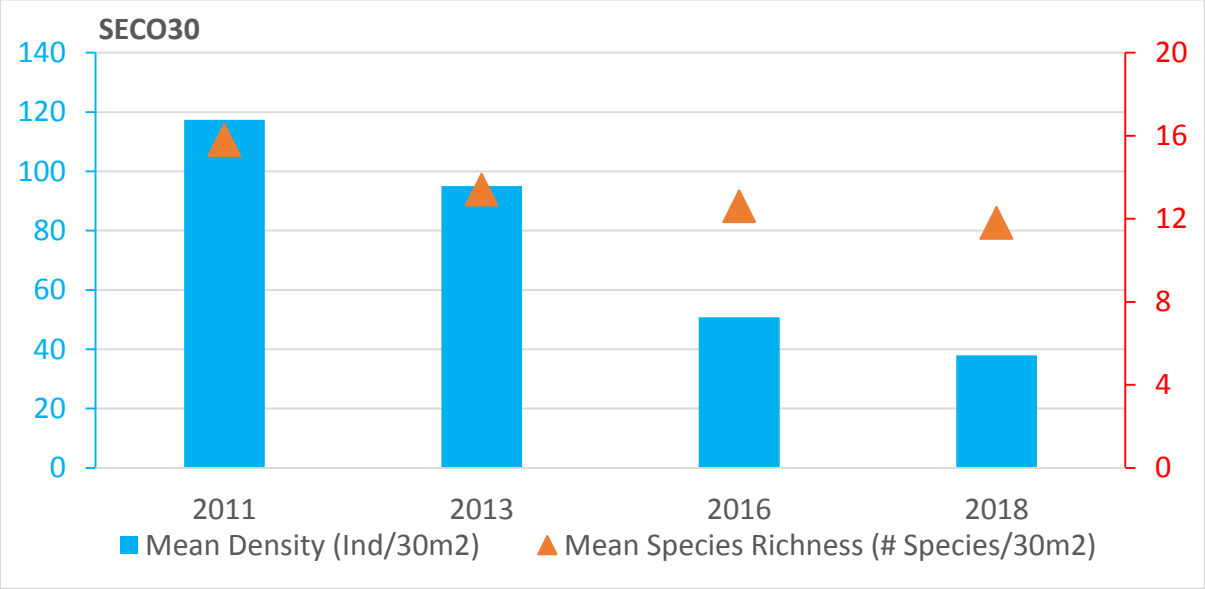
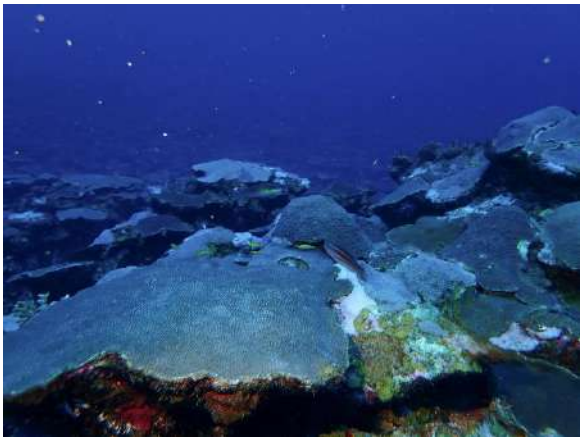
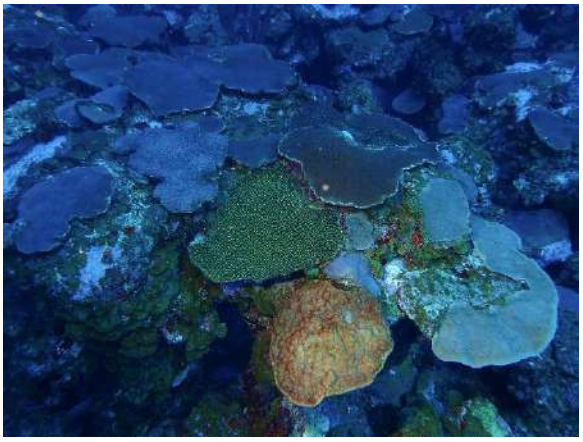



**Figure 56.** SECO30. Monitoring trends (2011 – 18) of mean fish density and species richness within 10 x 3m belt-transects at El Seco Reef 30m, Isla de Vieques

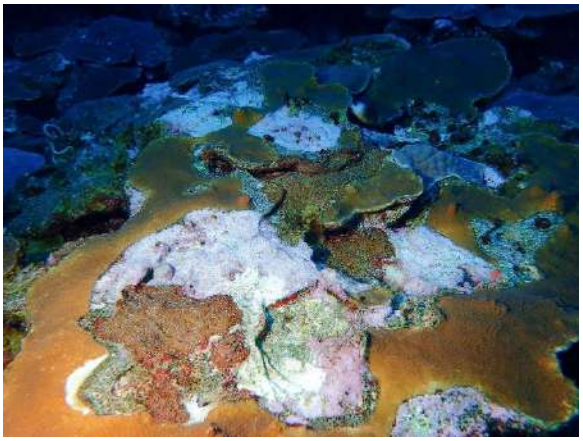
**Photo Album 17**

**El Seco Reef 30m, Isla de Vieques (SECO30)**



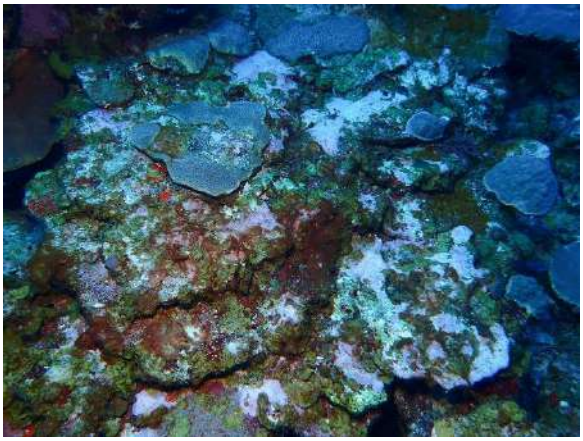
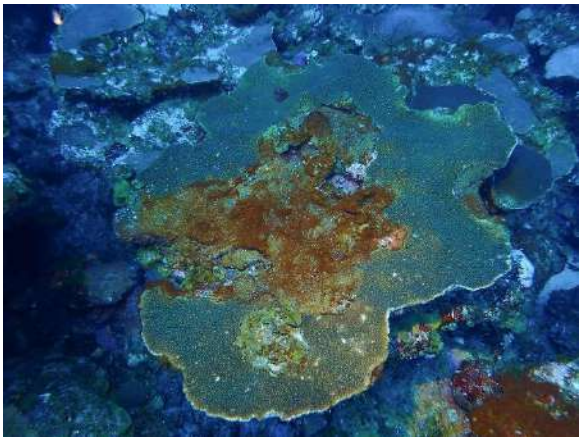











## 18.0 Canjilones Reef, Vieques (CANJ20)

### 18.1 Physical Description

Canjilones Reef (CANJ20) is a diffuse "spur-and-groove" coral reef system located at the base of the southern edge of a rather long and narrow rocky ridge that runs along an east-west axis off Punta Arenas, on the southwest coast of Vieques (Figure 57). The ridge presents an almost flat, hard-ground terrace with sparse gorgonians and coral heads at depths of 9 -11 meters and slopes down to a depth of 15 - 16 meters where the spur-and-groove coral reef formation has developed. The spurs rise about 2 - 3 meters from the narrow sandy channels that separate them at the base. The baseline survey at CANJ20 was performed on February 2001. Permanent transects were established along five consecutive spurs at a mean depth of 15.2 meters. During 2018, rebar markers at transect 5 were not found and new markers were set on a nearby location adjacent to transect #1. Images of CANJ20 reef community are included as Photo Album 18.

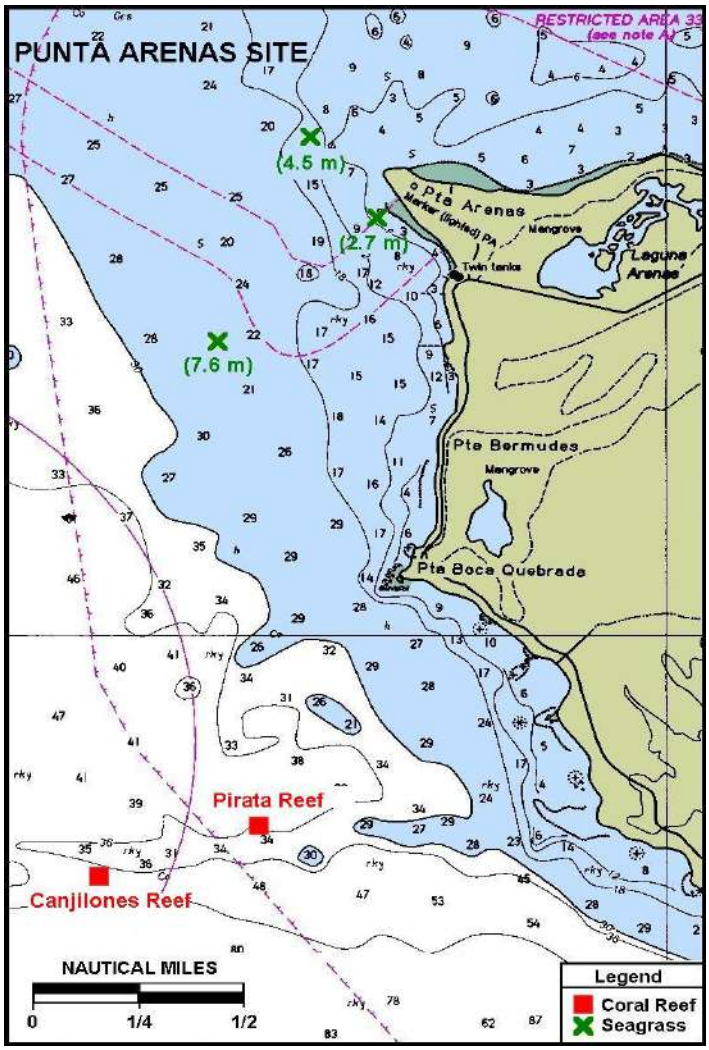



**Figure 57.** Location map of Canjilones Reef along the western coast of Vieques.

### 18.2 Sessile Benthic Reef Community

Reef substrate cover at CANJ20 was dominated by an assemblage of benthic algae that included red crustose and coralline, turf, and fleshy brown macroalgae, with a combined mean of 65.55% (range: 60.24 – 70.03%). The encrusting crustose calcareous red alga (*Ramicrusta sp*.) was the dominant algal taxon in all transects with a mean cover of 30.48%, representing 46.5% of the total cover by benthic algae (Table 53). Fleshy brown macroalgae, mostly comprised by the Encrusting Fan-Leaf Alga (*Lobophora variegata*) and the Y-Twig Alga (*Dictyota sp*.) presented a combined cover of 15.28%, representative of 23.3% of the total. Turf algae, the dominant algal taxon in the 2001 baseline survey was present in all transects with a mean cover of 15.08%. Other encrusting red crustose (Peyssonnelid) and coralline algae (CCA) were also present along transects with a mean cover of 1.65% and 3.05%, respectively. Cyanobacterial patches were present in four transects with a mean cover of 4.70%, relatively higher than the 2018 PRCRMP mean of 3.22%.

The sessile-benthic community at CANJ20 was characterized by a high density and specious assemblage of erect octocorals with a mean of 19.4 colonies/transect. Sea Fans (*Gorgonia ventalina*) and Sea Rods (*Eunicea spp*) were the most prominent in transects. The Encrusting Gorgonian (*Erythropodium caribaeorum*) and the Corky Sea Finger (*Briareum asbestinum*) were present in five and two transects, respectively with a combined mean cover of 3.57%. Erect and encrusting sponges were present in all five transects with a mean cover of 2.26%. *Amphimedon compressa*, *Aplysina cauliformis*, *Callyspongia vaginalis* and an unidentified red sponge were the most prominent along transects.

Hard (stony) corals were represented by 13 species in transects surveyed at CANJ20, including 12 scleractinians and one hydrocoral (*Millepora alcicornis*) with a combined mean cover of 13.32% (range 7.13% – 19.68%). Mountainous Star Coral (*Orbicella faveolata*) was the main coral species with a mean cover of 4.16%, representing 31.2% of the total reef substrate cover by stony corals (Table 53). The sibling *Orbicella* species (*O. annularis* and *O. franksi*) were also prominent with a combined cover of 4.33%, representative of 32.6% of the total coral cover at CANJ20. Mustard-Hill Coral (*Porites astreoides*), Lettuce Coral (*Agaricia agaricites*) and the Branching Fire Coral (*M. alcicornis*) were present in at least three transects, with a combined substrate cover of 3.14%. A total of 75 coral colonies were intercepted by transects at CANJ20, including two (*O. faveolata, O. franksi*) with an apparent disease infection (coral disease prevalence = 2.7%).

| **Table 53**. CANJ20. Percent cover by sessile-benthic categories at Canjilones Reef 20m, Isla Vieques | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 7/1/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 15.2 | 15.2 | 14.8 | 15.2 | 15.2 | **15.1** |
| Rugosity (m) | 2.22 | 4.14 | 3.45 | 5.93 | 4.15 | **3.98** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 5.50 | 5.74 | 8.84 | 8.17 | 3.96 | **6.44** |
| Rubble | 0.57 | 5.64 | 3.54 | 5.80 | 3.96 | **3.90** |
| Sand | 1.15 | 0.50 | | 2.81 | 4.75 | **1.84** |
| Gap | | | 1.04 | | 0.69 | **0.35** |
| **Total Abiotic** | **7.22** | **11.88** | **13.42** | **16.78** | **13.35** | **12.53** |
| **Benthic Algae** | | | | | | |
| *Ramicrusta* | 34.02 | 26.73 | 24.77 | 38.49 | 28.39 | **30.48** |
| *Lobophora variegata* | 9.51 | 10.20 | 12.17 | 5.45 | 11.67 | **9.80** |
| Turf (mixed) with sediment | 10.19 | 15.84 | 9.57 | 6.06 | 1.19 | **8.57** |
| Turf (mixed) | 2.98 | 8.22 | 8.95 | 3.51 | 8.90 | **6.51** |
| *Dictyota* spp. | 3.89 | 3.07 | 7.80 | 5.62 | 7.02 | **5.48** |
| CCA (mixed) | 1.83 | 3.17 | 4.99 | 2.99 | 2.27 | **3.05** |
| Peyssonnelid (mixed) | 0.92 | 2.57 | 1.77 | 2.20 | 0.79 | **1.65** |
| **Total Benthic Algae** | **63.34** | **69.80** | **70.03** | **64.32** | **60.24** | **65.55** |
| **Cyanobacteria** | 12.60 | 0.00 | 3.54 | 2.81 | 4.55 | **4.70** |
| **Hard Coral** | | | | | | |
| *Orbicella faveolata* | 6.99 | 2.77 | 2.91 | 0.79 | 7.32 | **4.16** |
| *Orbicella annularis* | 3.55 | 0.89 | 2.91 | 3.95 | | **2.26** |
| *Orbicella franksi* | 0.69 | 1.98 | 2.71 | 3.78 | 1.19 | **2.07** |
| *Porites astreoides* | 1.03 | 0.89 | 0.83 | 1.32 | 6.03 | **2.02** |
| *Montastraea cavernosa* | | | | 2.81 | 2.47 | **1.06** |
| *Agaricia agaricites* | | 0.59 | 1.98 | | 2.08 | **0.93** |
| *Millepora alcicornis* | 0.46 | | 0.21 | | 0.30 | **0.19** |
| *Madracis decactis* | 0.80 | | | | | **0.16** |
| *Colpophyllia natans* | | | | 0.79 | | **0.16** |
| *Agaricia lamarcki* | 0.57 | | | | | **0.11** |
| *Porites porites* | 0.34 | | | 0.18 | | **0.10** |
| *Stephanocoenia intersepta* | | | | | 0.30 | **0.06** |
| *Siderastrea siderea* | | | | 0.18 | | **0.04** |
| **Total Hard Coral** | **14.43** | **7.13** | **11.55** | **13.80** | **19.68** | **13.32** |
| **# CoralColonies /Transect** | **19** | **16** | **18** | **11** | **11** | **15.0** |
| **# Diseased Coral Colonies** | **0** | **0** | **1** | **0** | **1** | |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | 3.89 | 10.00 | 0.83 | 0.44 | 2.87 | **3.61** |
| *Briareum asbestinum* | | | 0.21 | 0.35 | | **0.11** |
| *Gorgonia ventalina* | 0.34 | | 0.21 | | | **0.11** |
| *Eunicea flexuosa* | 0.23 | | | 0.18 | | **0.08** |
| *Eunicea mammosa* | | 0.20 | | | | **0.04** |
| *Eunicea sp.* | | 0.20 | | | | **0.04** |
| **Total Octocoral** | **4.47** | **10.40** | **1.25** | **0.97** | **2.87** | **3.99** |
| **# Gorgonians/Transect** | 15 | 27 | 23 | 15 | 17 | **19.4** |
| **Sponges** | | | | | | |
| *Amphimedon compressa* | 1.26 | | | 0.18 | | **0.29** |
| Red sponge | | | | 0.70 | 0.49 | **0.24** |
| *Aplysina cauliformis* | | 0.20 | | 0.53 | 0.40 | **0.22** |
| *Callyspongia vaginalis* | 0.34 | | | 0.35 | 0.40 | **0.22** |
| *Verongula rigida* | 0.34 | | 0.52 | | | **0.17** |
| *Mycale laevis* | 0.46 | | 0.31 | | | **0.15** |
| *Petrosia sp* | 0.69 | | | | | **0.14** |
| *Clathria* spp. | | | 0.62 | | | **0.12** |
| *Agelas dispar* | | 0.59 | | | | **0.12** |
| *Scopalina ruetzleri* | 0.23 | | | 0.35 | | **0.12** |
| *Neopetrosia* smooth sp. | 0.57 | | | | | **0.11** |
| *Ectyoplasmia ferox* | 0.34 | | | | | **0.07** |
| *Svenzea zeai* | | | 0.31 | | | **0.06** |
| *Callyspongia plicifera* | | | | | 0.30 | **0.06** |
| *Ircinia strobilina* | | | | 0.26 | | **0.05** |
| *Spirastella hartmani* | | | 0.21 | | | **0.04** |
| *Niphates erecta* | | | | 0.18 | | **0.04** |
| *Smenospongia conulosa* | | | | 0.18 | | **0.04** |
| **Total Sponges** | **4.24** | **0.79** | **1.98** | **2.72** | **1.58** | **2.26** |

Temporal variations of percent cover by the major sessile-benthic substrate categories between monitoring surveys at CANJ20 are summarized in Figure 58. Live coral evidenced a sharp decline between the 2004 and 2013 monitoring surveys. As for other reefs in the monitoring program, such decline was largely associated with the regional 2005 coral bleaching event (Garcia-Sais et al. 2015 and references therein). Differences of total live coral cover between surveys were statistically significant (ANOVA, $p < 0.0001$; Appendix 2a) and related to higher cover during the 2001 and 2004 surveys, relative to other subsequent monitoring surveys, including 2018. A corresponding increase in cover by benthic algae was measured (Figure 58).

Differences of live coral cover between the most recent monitoring surveys (2013, 2016, and 2018) are within sampling variability error (Appendix 5). As with many other reefs included in the PRCRMP, the main coral species associated with the marked decline of live coral cover at CANJ20 was the *Orbicella spp* complex (Figure 59), which declined from a maximum mean cover of 17.2% measured in the 2001 baseline survey to a minimum of 8.5% (combined cover by *Orbicella* spp) measured in the most recent 2018 monitoring survey.

Statistically significant variations of benthic community structure between monitoring surveys were reported for CANJ20 (Garcia-Sais et al., 2016). The main factor contributing to dissimilarity between years was the phase shift of turf algal dominance towards *Ramicrusta sp*. Such shift in benthic community structure associated with the benthic algae community remained consistent during 2018.

### 18.3 Fishes and Motile Megabenthic Invertebrates

A total of 37 fish species were identified within belt-transects at CANJ20 with a mean density of 45.0 Ind/transect and a mean richness of 17.4 species/transect (Table 54). The most abundant species included the Bicolor Damselfish (*Stegastes partitus*), Blue Chromis (*Chromis cyanea*), Yellowhead, Bluehead and Creole Wrasses *(Halichoeres garnoti, Thalassoma bifasciatum, Clepticus parrae*), and the Princess and Redband Parrotfishes (*Scarus taeniopterus, Sparisoma aurofrenatum*) with a combined density of 28.2 Ind/transect, representative of 62.7% of the total individuals. The Sharknose Goby (*Elacatinus evelynae*), Doctorfish (*Acanthurus chirurgus*) and Stoplight Parrotfish (*S. viride*) were present in at least four transects with a combined density of 4.8 Ind/transect, or 10.7%. Twelve species were only represented by individuals in one transect. Motile megabenthic invertebrates were not observed within belt-transects (Table 54).

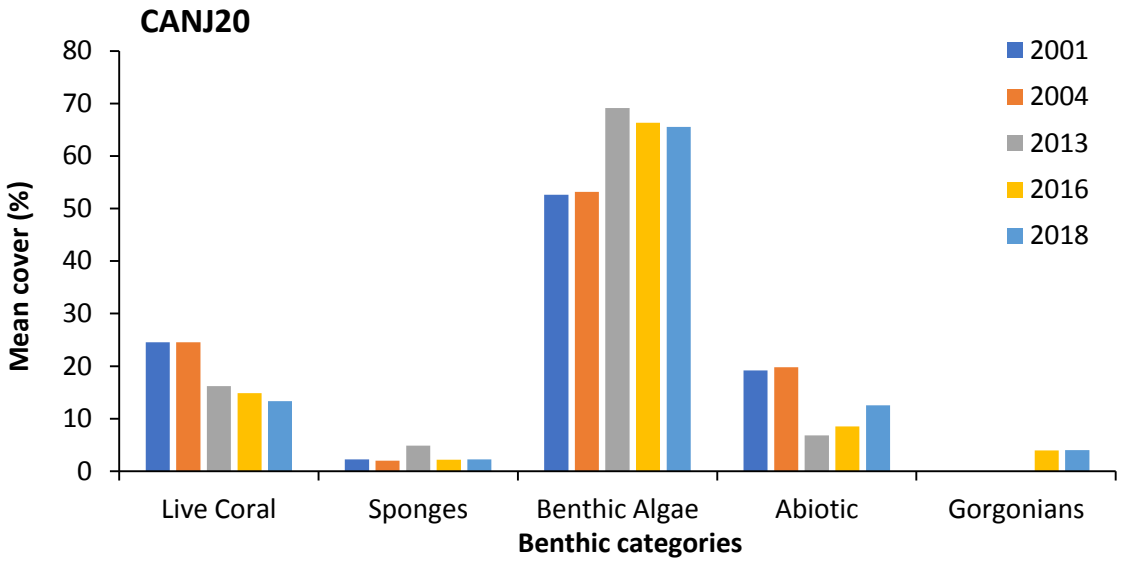



**Figure 58.** CANJ20. Annual variations (2001 -18) of mean substrate cover by sessile-benthic categories at Canjilones Reef 20m, Isla de Vieques

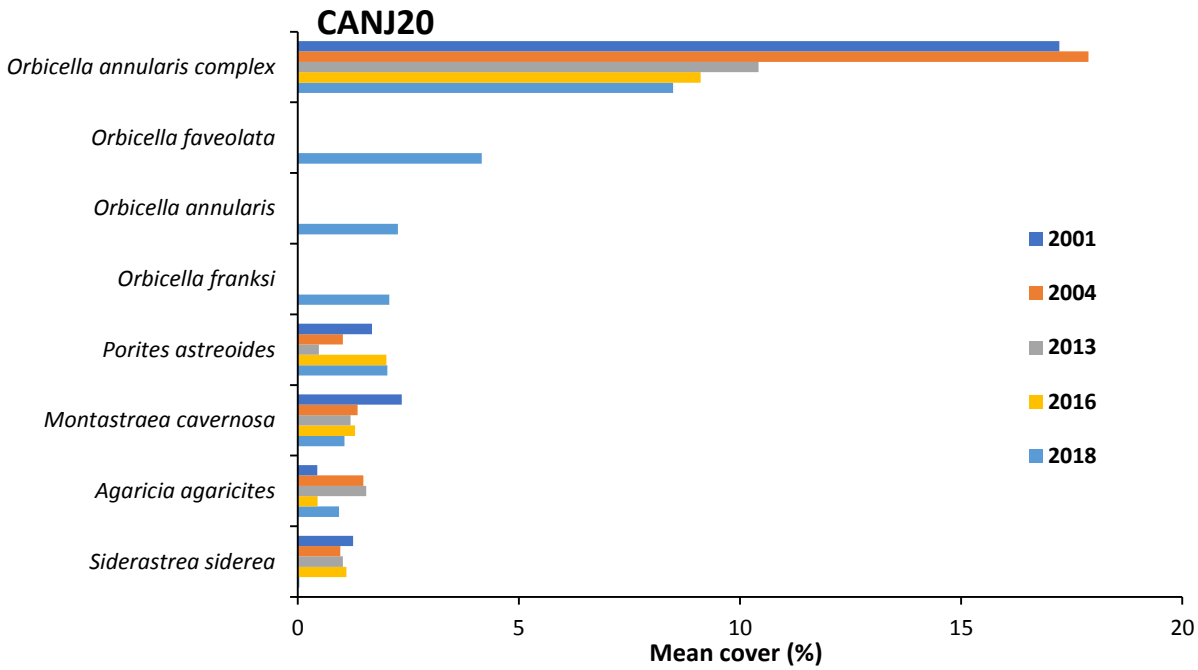



**Figure 59.** CANJ20. Annual variations (2001 -18) of mean substrate cover by the main coral species intercepted by transects at Canjilones Reef 20m, Isla de Vieques

**Table 54.** CANJ20. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Canjilones Reef 20m, Isla Vieques, July 2018

| Mean Depth: 15.1 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Stegastes partitus* | Bicolor Damselfish | 6 | 6 | 5 | 9 | 3 | **5.8** |
| *Chromis cyanea* | Blue Chromis | 11 | 2 | 1 | | 14 | **5.6** |
| *Halichoeres garnoti* | Yellow-head Wrasse | 5 | 3 | 4 | 6 | 3 | **4.2** |
| *Scarus taeniopterus* | Princess Parrotfish | 5 | 4 | 2 | 5 | 5 | **4.2** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 3 | 4 | 5 | 9 | | **4.2** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 | 2 | 4 | 3 | 1 | **2.2** |
| *Clepticus parrae* | Creole Wrasse | | 10 | | | | **2.0** |
| *Acanthurus chirurgus* | Doctorfish | 1 | 4 | 1 | 3 | | **1.8** |
| *Elacatinus evelynae* | Sharknose Goby | 2 | 2 | 1 | 1 | 2 | **1.6** |
| *Sparisoma viride* | Stoplight Parrotfish | | 1 | 4 | 1 | 1 | **1.4** |
| *Sparisoma sp. (juv)* | Juvenile parrotfish | | | | 7 | | **1.4** |
| *Chaetodon capistratus* | Four-eye Butterflyfish | | 2 | | | 2 | **0.8** |
| *Sparisoma radians* | Bucktooth Parrotfish | 2 | 2 | | | | **0.8** |
| *Canthigaster rostrata* | Caribbean Puffer | 1 | | | 1 | 1 | **0.6** |
| *Cephalopholis cruentata* | Graysby | | | 1 | 2 | | **0.6** |
| *Coryphopterus personatus* | Masked Goby | | | | 3 | | **0.6** |
| *Holocentrus rufus* | Longspine Squirelfish | 1 | 2 | | | | **0.6** |
| *Lutjanus apodus* | Schoolmaster | | 1 | | 1 | 1 | **0.6** |
| *Stegastes leucostictus* | Beau Gregory | | 1 | | 1 | 1 | **0.6** |
| *Acanthurus tractus* | Five-band Surgeonfish | | | | 1 | 1 | **0.4** |
| *Acanthurus coeruleus* | Blue Tang | 1 | | 1 | | | **0.4** |
| *Coryphopterus lipernes* | Peppermint Goby | | | | | 2 | **0.4** |
| *Epinephelus guttatus* | Red Hind | | | 1 | 1 | | **0.4** |
| *Haemulon flavolineatum* | French Grunt | | 1 | 1 | | | **0.4** |
| *Haemulon plumieri* | White Grunt | | | | 1 | 1 | **0.4** |
| *Hypoplectrus unicolor* | Butter Hamlet | | 1 | 1 | | | **0.4** |
| *Pseudupeneus maculatus* | Spotted Goatfish | 1 | | 1 | | | **0.4** |
| *Stegastes adustus* | Dusky Damselfish | | | | 1 | 1 | **0.4** |
| *Aulostomus maculatus* | Trumpetfish | 1 | | | | | **0.2** |
| *Balistes vetula* | Queen Triggerfish | | | | | 1 | **0.2** |
| *Cephalopholis fulva* | Coney | | | 1 | | | **0.2** |
| *Coryphopterus sp.* | Goby | | | 1 | | | **0.2** |
| *Lutjanus mahogony* | Mahogany Snapper | | 1 | | | | **0.2** |
| *Myripristis jacobus* | Black-bar Soldierfish | | | | 1 | | **0.2** |
| *Pomacanthus ciliaris* | Queen Angelfish | | | 1 | | | **0.2** |
| *Scarus iseri* | Striped Parrotfish | 1 | | | | | **0.2** |
| *Serranus tigrinus* | Harlequin Bass | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 43 | 49 | 36 | 57 | 40 | **45.0** |
| | **TOTAL SPECIES** | 16 | 18 | 18 | 19 | 16 | **17.4** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *none* | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 0 | 0 | 0 | 0 | **0.0** |
| | **TOTAL SPECIES** | | | | | | **0.0** |

The trophic structure of the fish community at CANJ20 was characterized by numerically balanced carnivore, zooplanktivore and herbivore assemblages. Small opportunistic carnivores were represented by 14 species including two wrasses (Labridae), two gobies (Gobiidae), two squirrelfishes (Holocentridae), two grunts (Haemulidae), one puffer (Tetraodontidae), one trumpetfish (Aulostomidae) and a small grouper, sea bass and hamlet (Serranidae) with a combined abundance of 14.6 Ind/transect, or 32.4% of the total fish individuals within belt-transects. Zooplanktivores were represented by four species with a combined density of 14.0 Ind/transect, representative of 31.1% of the total individuals. These included the Bicolor Damselfish and Blue Chromis (Pomacentridae), Creole Wrasse (Labridae) and Masked Goby (Gobiidae). The herbivore assemblage included six parrotfishes (Scaridae), three doctorfishes (Acanthuridae), and one damselfish (Pomacentridae), with a combined density of 13.8 Ind/transect, or 30.7% of the total individuals. Medium sized piscivores included Red Hinds (Serranidae), Queen Triggerfish (*Balistes vetula*) and Mahogoni and Schoolmaster Snappers (Lutjanidae). One Coney (*Cephalopholis fulva*) was observed in extended transects and one Nassau Grouper (*Epinephelus striatus*) was observed out of transects (Table 55). Top demersal and pelagic predators, such as the Reef and Nurse Sharks (*Carcharhinus perezi, Ginglymostoma cirratum*) and Great Barracuda (*Sphyraena barracuda*) were previously reported for CANJ20 (Garcia-Sais et al., 2001a, 2012, 2016).

Size frequency distributions of commercially important fishes and larger reef herbivores are included in Table 55. Recruitment juveniles (1 – 5 cm) of the Stoplight, Redband and Princess Parrotfishes (*Sparisoma viride, S. aurofrenatum, Scarus taeniopterus*) were present at CANJ20, and along with observations of juveniles and adults is indicative that these species spend their entire life cycle at this reef habitat. Doctorfishes (*Acanthurus spp*), and the Schoolmaster and Mahogoni Snappers (*Lutjanus apodus, L. mahogoni*) were observed as late juveniles and adults. Red Hind (*Epinephelus guttatus*), Coney (*Cephalopholis fulva*), Queen Triggerfish (*Balistes vetula*), Hogfish (*Lachnolaimus maximus*) and Nassau Grouper (*E. striatus*) were observed as adults in CANJ20.

**Table 55. CANJ20.** Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Canjilones Reef 20m, Isla Culebra, July 2018

| Mean Depth: 15.1 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | | (Ind/60 $m^2$ - TL in cm) | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | | | | 1-7 | 1-12 |
| | | | | | | 1-14 |
| *Acanthurus chirurgus* | Doctorfish | 1-12 | 3-7 | 3-7 | 3-7 | |
| | | | 1-12 | 1-10 | 1-14 | 1-14 |
| *Acanthurus coeruleus* | Blue Tang | 1-10 | | 1-10 | | |
| | | | | 1-12 | | |
| *Balistes vetula* | Queen Triggerfish | | | 1-48 | | |
| *Cephalopholis cruentata* | Graysby | 1-10 | | 1-7 | 1-7 | |
| | | | | | 1-10 | |
| *Cephalopholis fulva* | Coney | | | 1-24 | | |
| *Epinephelus guttatus* | Red Hind | | | 1-46 | 1-31 | |
| *Lachnolaimus maximus* | Hogfish | 1-38 | | | | |
| *Lutjanus apodus* | Schoolmaster | 1-14 | 1-19 | | 1-12 | 1-24 |
| *Lutjanus mahogony* | Mahogany Snapper | | 1-24 | | | |
| *Scarus iseri* | Striped Parrotfish | 1-22 | 1-24 | | | |
| *Scarus taeniopterus* | Princess Parrotfish | 5-7 | 1-7 | 2-7 | 5-5 | 4-12 |
| | | | 4-10 | 1-24 | | 5-14 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1-10 | 1-7 | 3-5 | 1-5 | 1-12 |
| | | | 1-10 | 1-7 | 2-7 | |
| | | | | 1-12 | | |
| *Sparisoma viride* | Stoplight Parrotfish | | 1-1 | 2-1 | 1-2 | 1-17 |
| | | | | 1-31 | | 1-29 |
| *Sparisoma spp. (juv)* | Parrotfishes (juveniles) | | | | 7-1 | |
| **Invertebrates** | | | | | | |
| none | | | | | | |
| **Out of Transects** | | | | | | |
| *Epinephelus striatus* | Nassau Grouper | 1 - 48 | | | | |
| *Epinephelus guttatus* | Red Hind | 4 - 29 | | | | |
| | | | | | | |
| TL = Fish Total Length | | | | | | |

Figure 60 presents the variations of fish species richness and abundance between monitoring surveys. Significantly higher fish densities were measured during the 2004 and 2016 surveys relative to the baseline, 2013 and 2018 surveys. Differences were driven by density fluctuations of Masked Goby and Blue Chromis, both of which are schooling species with highly aggregated distributions. Such fluctuations are probably associated to density independent factors, including recruitment success variability and physical climatological/oceanographical conditions at the time of the visual survey. These fish density fluctuations appear to be common features of the inter-

annual variability dynamics of fish community structure in Caribbean reefs (Esteves 2013). During 2018, the population stocks of these small schooling species may have been impacted by mechanical advection and mortality induced by exceptionally strong surge and abrasive effects associated with hurricanes and/or other wave storm events affecting shallow reef systems previous to the 2018 survey.

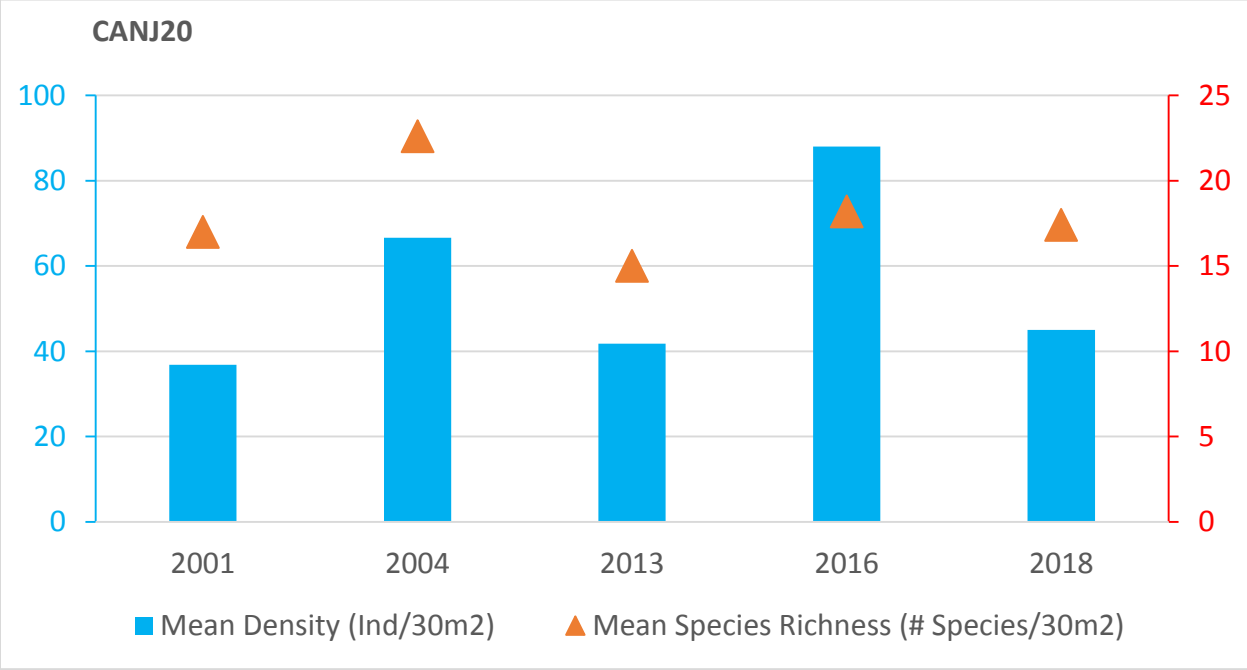
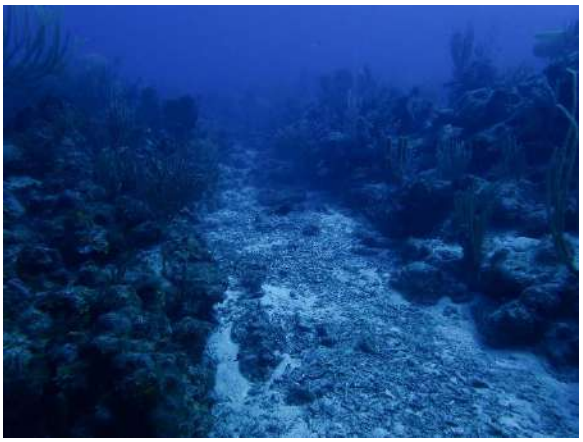



**Figure 60.** CANJ20. Monitoring trends (2011 – 18) of mean fish density and species richness within 10 x 3 m belt-transects at Canjilones Reef 20m, Isla de Vieques

**Photo Album 18**

**Canjilones Reef 20m, Isla de Vieques (CANJ20)**








## 19.0 Boya Esperanza Reef – Vieques (ESPE10)

### 19.1 Physical Description

Boya Esperanza Reef (ESPE10) is a submerged patch reef sitting at the edge of a hard-ground platform located about 0.8 nautical miles off Puerto Esperanza, on the south coast of Vieques (Figure 61). A green navigation buoy used to mark the eastern boundary of the reef and the entrance channel to Puerto Esperanza, but after Hurricane Maria in September 2017, the buoy disappeared. The reef has a highly irregular bathymetry, with large coral outcrops rising more than three meters from the base of the reef platform and reaching to about 3 - 4 meters from the surface. Extensive coralline sand pools are found at the base of the reef on its northern boundary. Large crevices are found at the interface of the sandy bottom and the rock/coral outcrops. Transects were established on top of large coral outcrops of Mountainous Star Coral (*Orbicella faveolata*) at a mean depth of 7.9 m. The baseline survey of ESPE10 was performed on February 2001. This is the fourth monitoring survey. Panoramic images of ESPE10 are included as Photo Album 19.

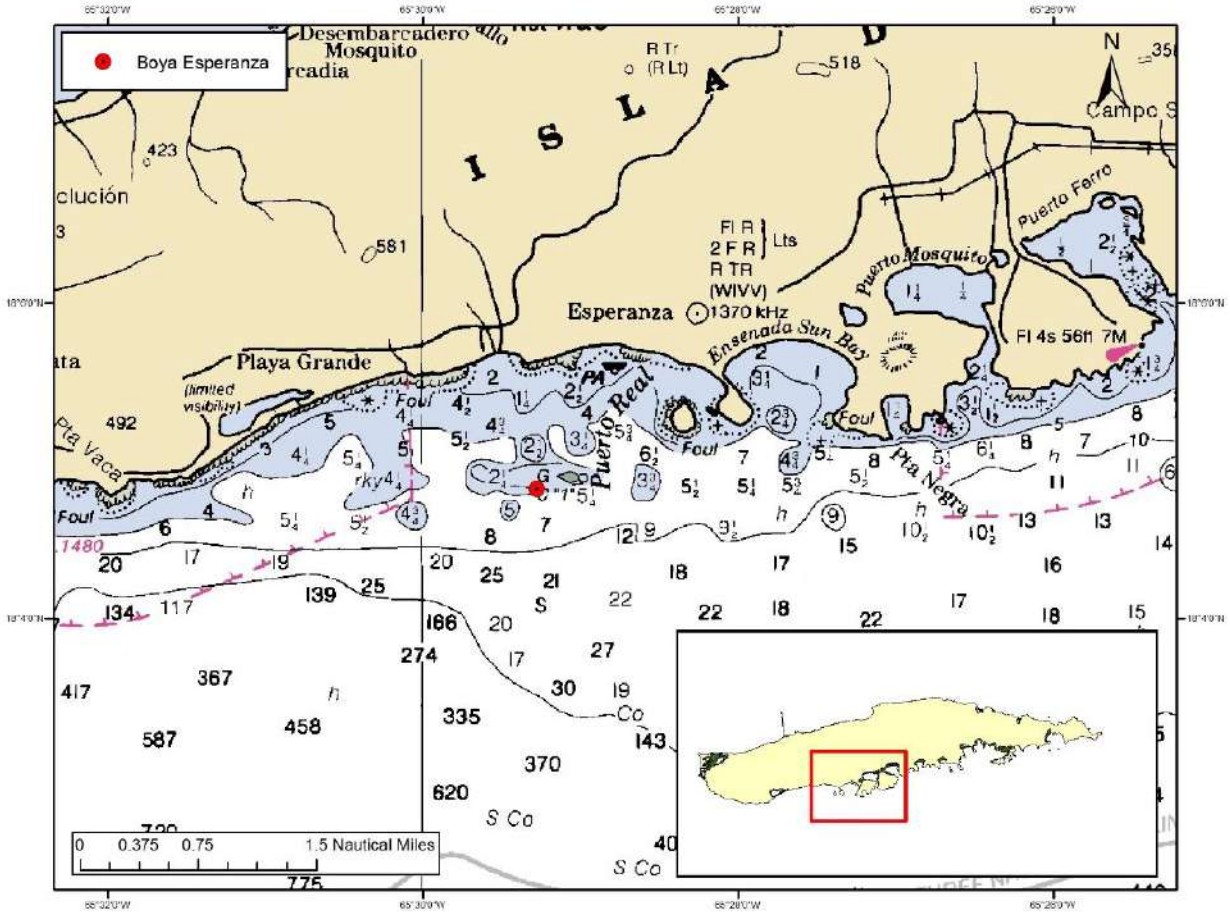



**Figure 61.** Location of the coral reef monitoring station at Boya Esperanza 10, Vieques.

### 19.2 Sessile-Benthic Reef Community

Reef substrate cover at ESPE10 was dominated by an assemblage of benthic algae that included red calcareous encrusting algae, turf algae, fleshy brown, and coralline algae with a combined mean cover of 77.62% (range: 70.80 – 82.85%). *Ramicrusta sp.,* a Peyssonnelid crustose calcareous red alga was the dominant algal taxon with a mean cover of 30.98%, representing 39.9% of the total cover by benthic algae (Table 56). Fleshy brown macroalgae, mostly Y-Twig Alga (*Dictyota sp*.) were present in four transects with a mean cover of 26.56%, representing 34.2%. *Dictyota sp*. was observed growing over abiotic substrates but was mostly observed growing over *Ramicrusta sp*. Turf algae, the dominant algal component in previous surveys was present in all transects with a mean cover of 19.32%, or 24.9% of the total cover by benthic algae. Cyanobacterial patches were present in all five transects, but with a relatively low mean cover (2.04%), compared to the 2018 PRCRMP mean of 3.22%.

The sessile-benthic community at ESPE10 was characterized by high densities and a specious assemblage of octocorals, or gorgonians with a mean of 17.2 colonies/transect (Table 56). Knobby Sea Rods (*Eunicea spp*), Sea Rods (*Plexaura spp, Pseudoplexaura spp*.), and Sea Fans (*Gorgonia ventalina*) were the most prominent in transects. The encrusting gorgonians, *Erythropodium caribaeorum* and *Briareum asbestinum* presented a combined reef substrate cover of 0.89%. Erect and encrusting sponges were represented by 11 species with a mean cover of 0.86%. The Orange Icing Sponge (*Mycaele laevis*) was the only species observed in more than two transects with mean cover of 0.3%.

Hard (stony) corals were represented by nine (9) species of scleractinians and one hydrocoral (*Millepora alcicornis*) with a combined mean cover of 9.58% (range 3.94 – 15.23%). Mountainous Star Cora (*Orbicella faveolata*) was the main coral species with a mean cover of 4.56%, representing 47.9% of the total surface cover by stony corals (Table 56). The combined cover by Star Corals (*Orbicella spp*.) was 5.23%. Massive Starlet Coral (*Siderastrea siderea*) and Mustard-Hill Coral (*Porites astreoides*) were present in four and five transects, respectively with a combined cover of 2.60%. Staghorn and Elkhorn corals (*Acropora palmata*, *A. cervicornis*) were observed outside transects. Five out of the 37 coral colonies intercepted by transects at ESPE10 exhibited apparent disease infections (coral disease prevalence = 13.5%). Four colonies of Massive Starlet Coral (*S. siderea*) were observed with what could be an infection by “dark-spot syndrome”. Blushing Star Coral (*Stephanocoenia intercepta*) was also observed with an apparent infectious disease.

| **Table 56**. ESPE10. Percent cover by sessile-benthic categories at Boya Esperanza Reef 10m, Isla Vieques. Survey Date: 7/1/18 | | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 7.9 | 6.7 | 8.5 | 7.9 | 8.5 | **7.9** |
| Rugosity (m) | 2.03 | 3.13 | 2.66 | 2.45 | 3.33 | **2.72** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Rubble | 5.12 | 3.20 | 4.76 | 2.25 | 4.62 | **3.99** |
| Sand | 5.01 | 1.07 | | 2.36 | 2.63 | **2.21** |
| Reef overhang | 0.93 | 5.01 | | 3.37 | 1.05 | **2.07** |
| **Total Abiotic** | **11.06** | **9.28** | **4.76** | **7.99** | **8.30** | **8.28** |
| **Benthic Algae** | | | | | | |
| *Ramicrusta* | 31.43 | 16.74 | 26.99 | 47.81 | 31.93 | **30.98** |
| *Dictyota* spp. on *Ramicrusta* | 19.91 | 44.88 | 35.18 | | 12.61 | **22.51** |
| Turf (mixed) with sediment | 20.02 | 11.19 | 13.61 | 19.57 | 21.11 | **17.10** |
| *Dictyota* spp. | 1.75 | 2.24 | 5.75 | 6.75 | 3.57 | **4.01** |
| Turf (mixed) | 0.47 | 6.18 | 0.22 | 3.37 | 0.84 | **2.22** |
| Peyssonnelid | | | 1.11 | | 0.74 | **0.37** |
| CCA (mixed) | | | | 1.12 | | **0.22** |
| *Lobophora variegatus* | | | | 1.01 | | **0.20** |
| **Total Benthic Algae** | **73.57** | **81.24** | **82.85** | **79.64** | **70.80** | **77.62** |
| **Cyanobacteria** | 1.16 | 4.69 | 1.55 | 0.67 | 2.10 | **2.04** |
| **Hard Coral** | | | | | | |
| *Orbicella faveolata* | 4.42 | 1.28 | 3.21 | 2.25 | 11.66 | **4.56** |
| *Siderastrea siderea* | 3.73 | 0.64 | | 3.15 | 0.74 | **1.65** |
| *Porites astreoides* | 0.70 | 0.96 | 1.00 | 0.22 | 1.89 | **0.95** |
| *Orbicella annularis* | | | 1.33 | 2.02 | | **0.67** |
| *Pseudodiploria strigosa* | | | 1.44 | 1.24 | | **0.54** |
| *Millepora alcicornis* | | 1.07 | 0.88 | | 0.53 | **0.50** |
| *Diploria labyrithiformis* | 1.86 | | 0.33 | | | **0.44** |
| *Stephanocoenia intersepta* | 0.23 | | | | 0.42 | **0.13** |
| *Dendrogyra cylindrus* | 0.47 | | | | | **0.09** |
| *Porites furcata* | 0.23 | | | | | **0.05** |
| **Total Hard Coral** | **11.64** | **3.94** | **8.19** | **8.89** | **15.23** | **9.58** |
| **# CoralColonies /Transect** | 8 | 5 | 7 | 8 | 9 | **7.4** |
| **# Diseased Coral Colonies** | 1 | 0 | 0 | 3 | 1 | |
| **Zoanthid** | | | | | | |
| *Palythoa caribaeorum* | 1.05 | | | | 2.00 | **0.61** |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | | 0.21 | 2.32 | 0.45 | | **0.60** |
| *Briareum asbestinum* | 0.35 | 0.64 | | 0.45 | | **0.29** |
| *Eunicea flexuosa* | | | | 0.34 | | **0.07** |
| *Plexaura homomalla* | | | 0.33 | | | **0.07** |
| **Total Octocoral** | **0.35** | **0.85** | **2.65** | **1.24** | **0.00** | **1.02** |
| **# Gorgonians/Transect** | 32 | 10 | 13 | 15 | 16 | **17.2** |
| **Sponges** | | | | | | |
| *Mycale laevis* | 0.35 | | | 0.67 | 0.32 | **0.27** |
| *Neopetrosia proxima* | | | | | 0.42 | **0.08** |
| *Aplysina insularis* | 0.35 | | | | | **0.07** |
| *Agelas conifera* | | | | 0.34 | | **0.07** |
| *Topsentia ophiraphidites* | | | | 0.34 | | **0.07** |
| *Amphimedon compressa* | | | | | 0.32 | **0.06** |
| *Spirastrella coccinea* | | | | | 0.32 | **0.06** |
| *Chondrilla caribensis* | 0.23 | | | | | **0.05** |
| *Ircinia felix* | 0.23 | | | | | **0.05** |
| *Smenospongia conulosa* | | | | 0.22 | | **0.04** |
| Black sponge | | | | | 0.21 | **0.04** |
| **Total Sponges** | **1.16** | **0.00** | **0.00** | **1.57** | **1.58** | **0.86** |

Temporal variations of reef substrate cover by sessile-benthic categories at ESPE10 between the 2016 and subsequent monitoring baselines are presented in Figure 62. The rank order of substrate cover by benthic categories has remained stable between surveys, but the relative contributions to the total cover has varied markedly between monitoring surveys. Differences of cover by total live corals were highly significant (ANOVA, p = 0.001, Appendix 2a) and highlighted by a marked drop of cover after the 2004 survey, when mean cover declined more than 3-fold, from 33.1% in 2004 to 10.4% in 2013. The reduction of total coral cover was largely associated with *Orbicella annularis* (complex) which presented a reduction of almost 6-fold, from 28.3% in 2004 to 4.8% in 2013 (Figure 63). Since reef substrate cover by *O. annularis* represented 46.2% of the total cover by corals at ESPE10 in 2004, its collapse had very pronounced implications on the benthic community structure of this reef.

Both the magnitude of the decline of total cover loss and the coral species affected (*Orbicella spp* complex) point out to the 2005 regional coral bleaching event as the probable cause of the coral deterioration. Differences of live coral cover between the 2018 and monitoring surveys after 2004 were small and not statistically significant (see Appendix 5). Still, many massive coral colonies were observed broken from their attachment pedestals and overturned by what appears to have been an extreme mechanical stressor compatible with storm surge. Densities of erect octocorals (gorgonians) declined 23.9% between the previous 2016 (22.6 Ind/transect) and the 2018 (17.2 Ind/transect) monitoring surveys, but the differences were statistically insignificant (ANOVA, p = 0.164; Appendix 2b).

Statistically significant variations of reef substrate cover by benthic categories have been also related to the benthic algae community (Garcia-Sais et al., 2016). Turf algae was the dominant component of reef substrate cover at ESPE10 in the 2001 baseline and also during the 2004 monitoring survey. In the next monitoring survey of 2013 (Garcia-Sais et al., 2014) *Ramicrusta sp*. had displaced turf algae as the dominant category of reef substrate cover at ESPE10. In the most recent 2018 survey, a decline of cover by *Ramicrusta sp*. resulted due to a massive overgrowth by brown fleshy algae (mostly *Dictyota sp*), which increased in mean cover by 24.9-fold between the previous 2016 (mean: 1.03%) the 2018 monitoring survey (26.72%). Further monitoring events will be required to establish if the fleshy algal overgrowth is a transitional (successional) feature, or if cover by *Ramicrusta sp*. will be resilient to competition by other macroalgae.

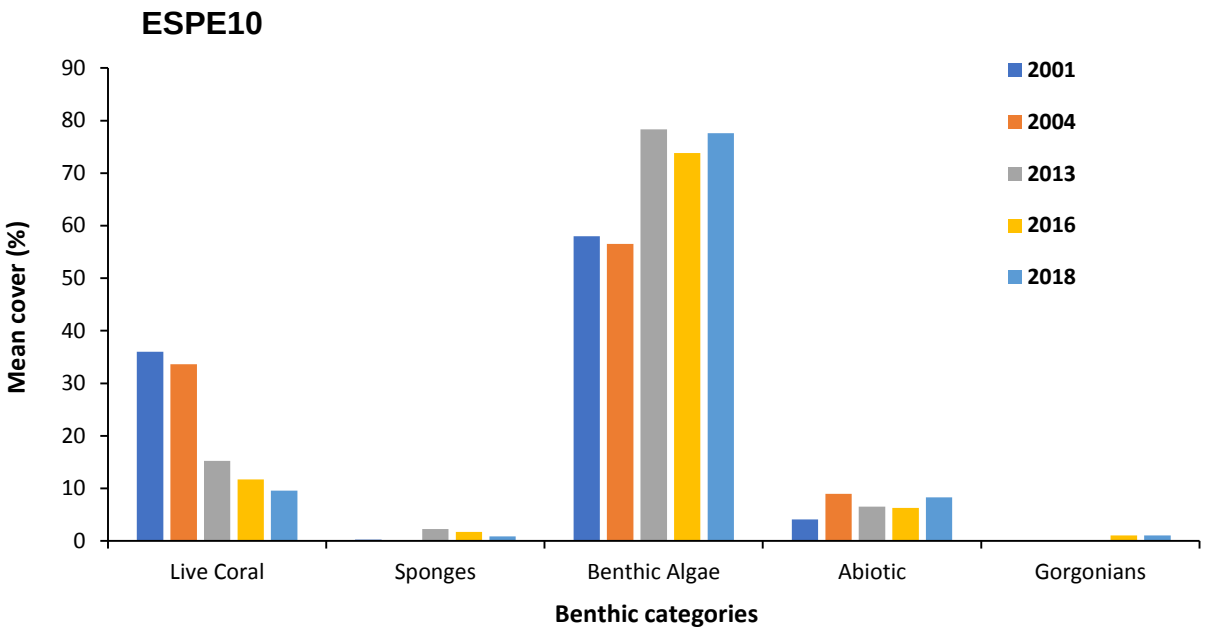



**Figure 62.** ESPE10. Annual variations (2001 -18) of mean substrate cover by sessile-benthic categories at Boya Esperanza Reef 10m, Isla de Vieques

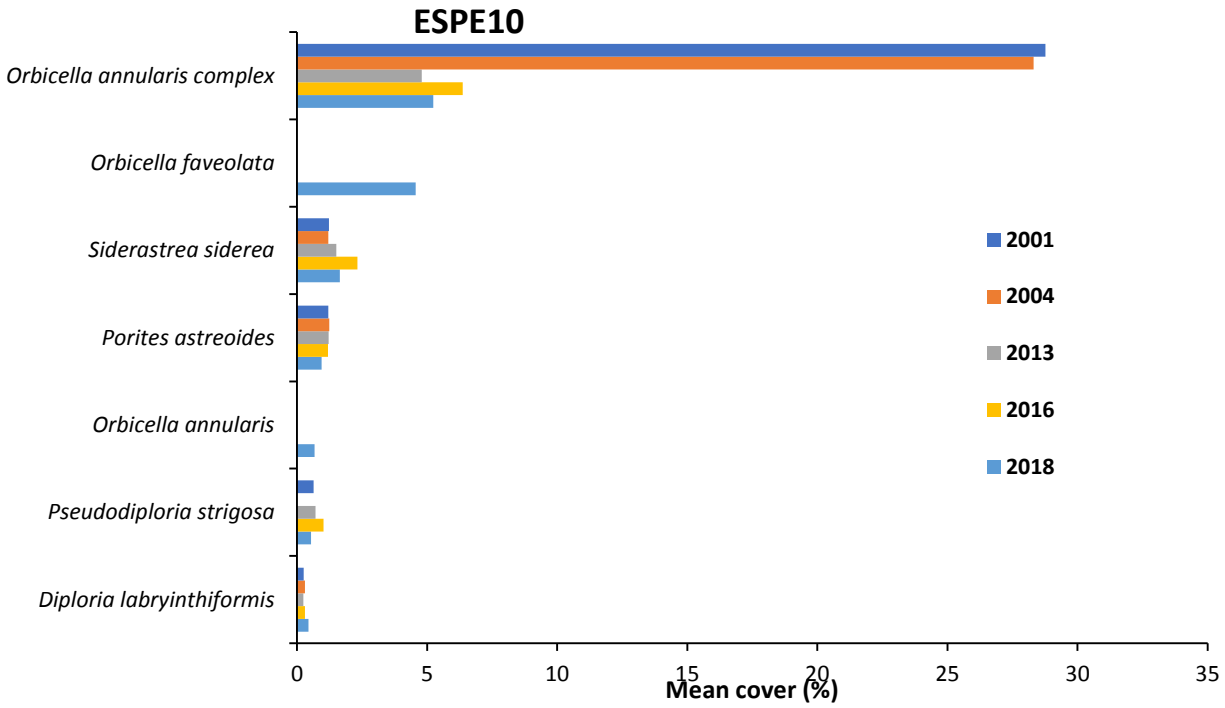



**Figure 63.** ESPE10. Annual variations (2001 -18) of mean substrate cover by the main coral species intercepted by transects at Boya Esperanza Reef 10m, Isla de Vieques

### 19.3 Fishes and Motile Megabenthic invertebrates

A total of 30 fish species were observed within belt-transect at ESPE10 with a mean density of 39.8 Ind/transect and a mean richness of 15.4 species/transect (Table 57). The Bluehead Wrasse (*Thalassoma bifasciatum*) was the numerically dominant species with a mean density of 9.0 Ind/transect, representing 22.6% of the total fishes within transects. In addition to the Bluehead Wrasse, other 10 species were present in at least four transects with a combined density of 19.8 Ind/transect, representing an additional 49.7% of the total fish density. One Spiny Lobster (*Panulirus argus*) was observed within belt-transects (Table 57).

A specious assemblage of small benthic invertebrate feeders represented by 13 species was the numerically dominant fish trophic group with a combined density of 16.0 Ind/transect, representing 40.2% of the total individuals within belt-transects. The assemblage included three wrasses (Labridae), two grunts (Haemulidae), one squirrelfish (Holocentridae), one goby (Gobiidae), one sea bass and two hamlets (Serranidae), one goatfish (Mullidae), one puffer (Tetraodontidae) and one glasseye (Priacanthidae). The herbivore assemblage included four parrotfishes (Scaridae), three doctorfishes (Acanthuridae) and three Damselfishes (Pomacentridae) with a combined density of 11.8 Ind/transect, or 29.6% of the total individuals. Zooplanktivores included three damselfishes (Pomacentridae) with a cumulative density of 9.6 Ind/transect, representing 24.1% of the total fish density. Mid-size piscivores included one Coney (*Serranidae*), and Bar Jacks (Carangidae). Red Hinds (Serranidae) and Schoolmaster Snappers (Lutjanidae) were observed in extended transects (Table 58). Pelagic top predators including Great Barracuda (*Sphyraena barracuda*) and the Cero Mackerel (*Scomberomorus regalis*) have been previously reported (Garcia-Sais et al., 2014).

The size-frequency distributions of commercially exploited reef fishes and the larger reef herbivores are shown in Table 58. Recruitment juvenile stages (1 – 2 cm) of Stoplight and Bucktooth Parrotfish (*Sparisoma viride, S, radians*) were observed. Other herbivore species of parrotfishes (Scaridae) and doctorfishes (Acanthuridae) were observed in late juvenile and adult stages. Medium-size carnivores, such as Graysby, Coney, Red Hind (Serranidae) and Schoolmaster Snappers (Lutjanidae) were observed as adults. Two large adult lobsters (12 -15 cm CL) were present outside transects. Juvenile Queen Conch (*Strombus gigas*) were observed outside transects in previous surveys (Garcia-Sais et al., 2016).

**Table 57.** ESPE10. **T**axonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Boya Esperanza Reef 10m, Isla Vieques, July 2018

| Mean Depth: 7.9 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 7 | 14 | 5 | 13 | 6 | **9.0** |
| *Stegastes partitus* | Bicolor Damselfish | 3 | 7 | 11 | 4 | 3 | **5.6** |
| *Chromis cyanea* | Blue Chromis | | 6 | 4 | 4 | 5 | **3.8** |
| *Stegastes adustus* | Dusky Damselfish | 4 | 1 | 4 | 3 | 2 | **2.8** |
| *Halichoeres garnoti* | Yellow-head Wrasse | | 1 | 3 | 4 | 2 | **2.0** |
| *Sparisoma radians* | Bucktooth Parrotfish | 2 | | 3 | 4 | | **1.8** |
| *Halichoeres maculipinna* | Clown Wrasse | 3 | 4 | | 1 | | **1.6** |
| *Acanthurus chirurgus* | Doctorfish | 1 | 1 | | 3 | 2 | **1.4** |
| *Acanthurus coeruleus* | Blue Tang | 2 | 2 | 2 | | 1 | **1.4** |
| *Carangoides ruber* | Bar Jack | | | 7 | | | **1.4** |
| *Sparisoma viride* | Stoplight Parrotfish | 1 | 3 | 1 | 2 | | **1.4** |
| *Haemulon flavolineatum* | French Grunt | | 1 | 1 | 1 | 2 | **1.0** |
| *Microspathodon chrysurus* | Yellowtail Damselfish | | 1 | 2 | | 1 | **0.8** |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 | | 1 | 1 | 1 | **0.8** |
| *Acanthurus tractus* | Five-band Surgeonfish | | 2 | | 1 | | **0.6** |
| *Cephalopholis fulva* | Coney | | 1 | | 1 | | **0.4** |
| *Elacatinus evelynae* | Sharknose Goby | 1 | | 1 | | | **0.4** |
| *Holocentrus rufus* | Longspine Squirelfish | 1 | | | | 1 | **0.4** |
| *Pomacanthus arcuatus* | Grey Angelfish | | 1 | | | 1 | **0.4** |
| *Pseudupeneus maculatus* | Spotted Goatfish | 1 | 1 | | | | **0.4** |
| *Scarus taeniopterus* | Princess Parrotfish | 1 | | | 1 | | **0.4** |
| *Stegastes leucostictus* | Beau Gregory | | | 1 | 1 | | **0.4** |
| *Canthigaster rostrata* | Caribbean Puffer | | 1 | | | | **0.2** |
| *Chromis multilineata* | Brown Chromis | | 1 | | | | **0.2** |
| *Haemulon plumieri* | White Grunt | | | | 1 | | **0.2** |
| *Heteropriacanthus cruentata* | Glasseye | | 1 | | | | **0.2** |
| *Hypoplectrus nigricans* | Black Hamlet | | | | 1 | | **0.2** |
| *Hypoplectrus unicolor* | Butter Hamlet | | 1 | | | | **0.2** |
| *Pomacanthus ciliaris* | Queen Angelfish | 1 | | | | | **0.2** |
| *Serranus tigrinus* | Harlequin Bass | | | | | 1 | **0.2** |
| | **TOTAL INDIVIDUALS** | 29 | 50 | 46 | 46 | 28 | **39.8** |
| | **TOTAL SPECIES** | 14 | 19 | 14 | 17 | 13 | **15.4** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Panulirus argus* | Spiny Lobster | | 1 | | | | **0.2** |
| | | | | | | | |
| | **TOTAL INDIVIDUALS** | 0 | 1 | 0 | 0 | 0 | **0.2** |
| | **TOTAL SPECIES** | | 1 | | | | **0.2** |

Monitoring trends of fish density and species richness within belt-transects at ESPE10 are shown in Figure 64. Statistically significant differences of both fish density and species richness were found between monitoring surveys (ANOVA, $p < 0.005$; Appendix 3). Differences were associated with lower densities and richness during the 2018 survey relative to the peak values in monitoring surveys of 2004 and 2016. As previously suggested for other shallow reef systems in the PRCRMP, it is possible that many small fishes were unable to withstand the mechanical stress associated with hurricanes or other wave storm events and suffered significant population mortality. Replenishment of these shallow reef populations will vary between species and inferences of progress will require prospective monitoring observations.

**Table 58.** ESPE10. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Boya Esperanza Reef 10m, Isla Vieques, July 2018

| Mean Depth: 7.9 m | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 2-10 | 1-7 | | | |
| | | | 1-14 | | | |
| *Acanthurus chirurgus* | Doctorfish | 1-10 | | | 1-7 | 1-10 |
| | | | | | 2-12 | 1-14 |
| *Acanthurus coeruleus* | Blue Tang | 2-7 | 1-7 | 2-7 | 1-12 | 1-12 |
| | | | 1-10 | 1-10 | | |
| | | | 2-12 | | | |
| *Cephalopholis cruentata* | Graysby | | | | 1-14 | |
| *Cephalopholis fulva* | Coney | | 1-24 | | 1-26 | 1-24 |
| *Epinephelus guttatus* | Red Hind | 1-41 | | | | 1-48 |
| *Lutjanus apodus* | Schoolmaster | 1-34 | | | | 1-29 |
| *Scarus iseri* | Striped Parrotfish | | | | 1-24 | |
| *Scarus taeniopterus* | Princess Parrotfish | 1-14 | | | 1-26 | |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1-12 | 1-14 | 1-7 | 1-10 | 1-7 |
| | | 1-14 | | 1-12 | | |
| | | | | 1-14 | | |
| *Sparisoma radians* | Bucktooth Parrotfish | | | 3-2 | 2-1 | |
| | | | | | 2-2 | |
| *Sparisoma viride* | Stoplight Parrotfish | 1-1 | 3-2 | 1-1 | 1-2 | |
| | | 1-24 | | 1-14 | 1-5 | |
| | | | | | 1-24 | |
| **Invertebrates** | | | | | | |
| *Panulirus argus* | Spiny Lobster | | 1-8 | | | |

TL = Fish Total Length
Lobster length is the carapace length in cm

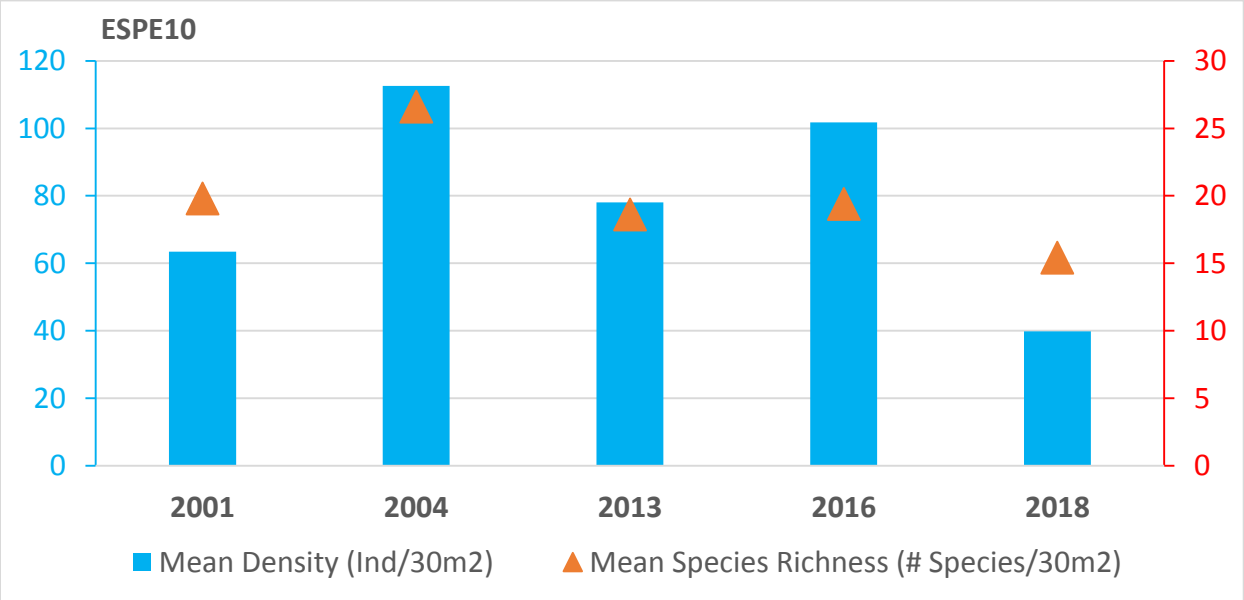
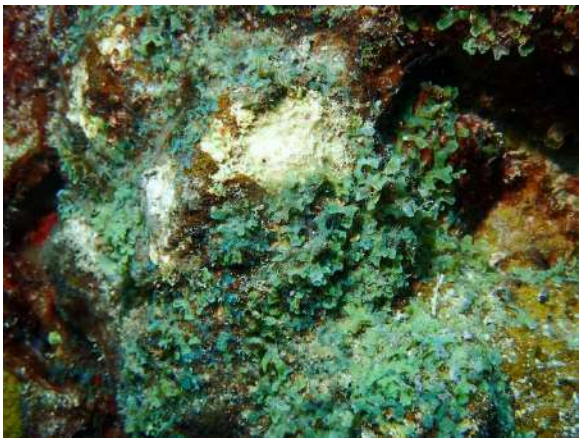
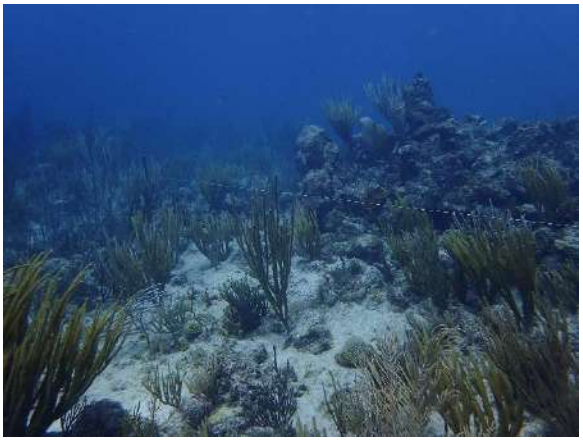


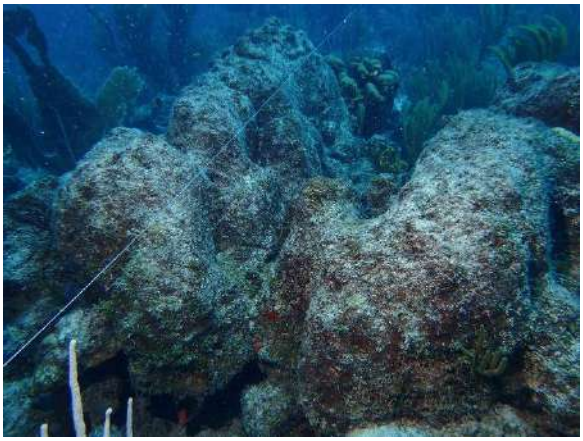

**Figure 64.** ESPE10. Monitoring trends (2001 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Boya Esperanza Reef 10m, Isla de Vieques

**Photo Album 19**

**Boya Esperanza Reef 10m, Isla de Vieques (ESPE10)**







## 20.0 Cibuco Reef 5, Vega Baja (CIBU05)

### 20.1 Physical Description

At approximately 0.5 km off the Vega Baja coastline lie a small group of emergent reefs known as Isletas de Garza (Figure 65). These appear to be relict structures of cemented sand dunes (eolianites) that run roughly parallel to the coastline. Due west of the isletas lies the mouth of Rio Cibuco, which discharges into a small embayment partially closed by an extensive sand bar. The reef community associated with the Isletas de Garza receives strong wave action from north Atlantic swells during the winter (October – April) and is subjected to estuarine conditions during the rainy season. Despite such environmentally rough conditions an impressive coral reef system developed along the leeward section of the Isletas, and since it lies within the Cibuco River plume we have named this system as Cibuco Reef (CIBU05). The baseline characterization of Cibuco Reef was performed during October 2011 (Garcia-Sais et al., 2012). During 2013, transect 2 could not be found and a new transect was installed in the vicinity of T2. The exact location of transects is shown in Table 1. Panoramic views of the reef are shown in Photo Album 20.

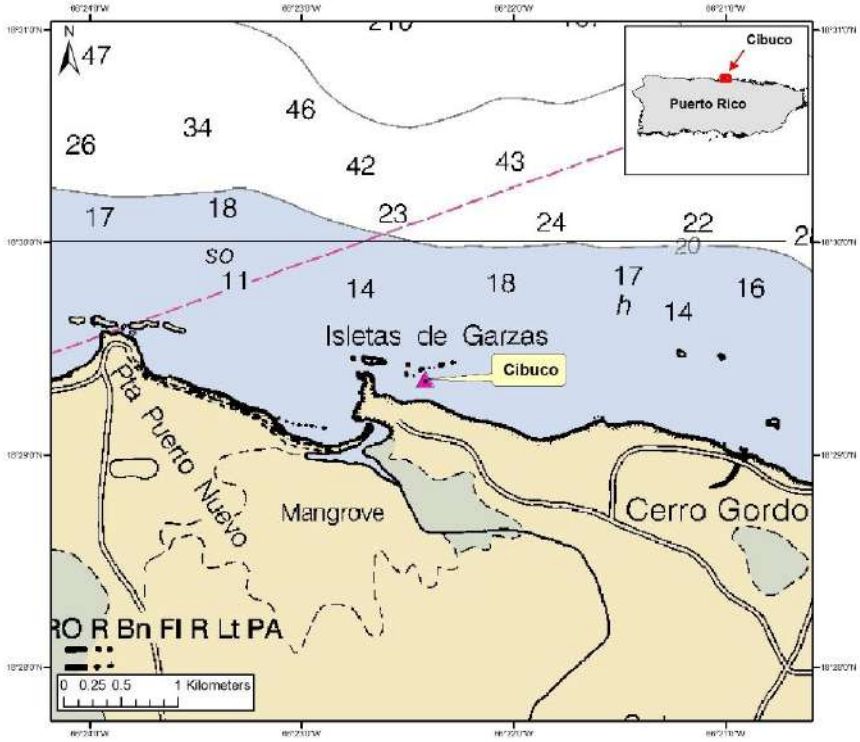



**Figure 65.** Location of Cibuco Reef at Isletas de Garza off Vega Baja in the north coast of Puerto Rico.

### 20.2 Sessile-Benthic Reef Community

A total of seven scleractinian corals and one hydrocoral (*Millepora alcicornis*) were intercepted by transects at CIBU05 with a mean substrate cover of 39.32% (range: 30.12 – 47.46%). Finger Coral (*Porites porites*) was the main species in terms of substrate cover with a mean of 16.19%, representing 41.2% of the total cover by stony corals (Table 59). Extensive thickets of Finger Coral were observed overlying the eolianite rock at depths between 1 - 3 m. Thickets were at least 40 cm thick and exhibited continuous linear extensions of more than 10 m (3 - 4 m wide) in various sections of the reef.

Lobed and Mountainous Star Corals (*Orbicella annularis, O. faveolata*) were present along four and three transects, respectively with a combined mean cover of 16.83%. Star Corals were observed growing mostly as mound colonies of small to moderate size, but several massive boulders with overhangs were also present. Recently dead colonies and sections of live *Orbicella sp.* colonies were observed, evidencing considerable tissue mortality during recent years. Symmetrical Brain Coral (*Pseudodiploria strigosa*) was also prominent at CIBU05, with colonies intercepted by four transects and a mean cover of 3.69%. Mustard Hill Coral (*Porites astreoides*) and Lettuce Coral (*Agaricia agaricites*) were present in two transects. Several encrusting and erect colonies of Elkhorn Coral (*Acropora palmata*) were present in the shallowest sections of the reef (< 1 m), some of which were recently broken and overturned. Vertically projected octocorals were present in three transects with a mean density of 2.0 colonies/transect. Colonies of the Encrusting Gorgonian (*Erythropodium caribaeorum*) growing as a hairy rug over hard abiotic substrates were intercepted by one transect with a mean over of 0.88%. Encrusting zoanthids (*Palythoa caribbea*) were also present at CIBU05 with mean cover below 1% (Table 59).

Turf algae, a mixed assemblage of short filamentous macroalgae that is highly resilient to wave action were present in all five transects with a mean cover of 32.27%, representing 89.2% of the total cover by benthic macroalgae (Table 59). Some of the turf algae was packed with fine sediments at CIBU05. Red crustose calcareous algae, including *Ramicrusta sp*. and other Peyssonnelid and crustose coralline algae (CCA) were present in all five transects with a combined cover of 3.03%. Fleshy brown macroalgae (mostly *Dictyota sp*) contributed a mean cover of 0.31%. Small patches of Turtle Grass (*Thalassia testudinum*) were intercepted by two transects with a mean cover of 0.14%. Cyanobacterial patches were intercepted by two transects with a relatively low cover of 1.05%, compared to the 2018 PRCRMP mean of 3.22%.

| **Table 59**. CIBU05. Percent cover by sessile-benthic categories at Cibuco Reef 5m, Vega Baja. | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 8/24/18 | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | 1.5 | 1.5 | 1.8 | 2.7 | 2.7 | **2.04** |
| Rugosity (m) | 1.76 | 2.95 | 5.26 | 3.94 | 2.31 | **3.24** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 10.71 | 5.73 | 11.19 | 20.08 | 8.65 | **11.27** |
| Sand | 19.52 | 2.16 | | 20.78 | 5.92 | **9.68** |
| Rubble | | | | 1.00 | | **0.20** |
| Gap | 0.48 | | | | | **0.10** |
| **Total Abiotic** | **30.71** | **7.89** | **11.19** | **41.87** | **14.56** | **21.25** |
| **Benthic Algae** | | | | | | |
| Turf (mixed) | 19.76 | 26.38 | 23.21 | 13.05 | 20.14 | **20.51** |
| Turf (mixed) with sediment | 1.43 | 7.35 | 11.47 | 12.05 | 26.51 | **11.76** |
| Peyssonnelid (mixed) | 2.86 | 3.78 | 0.55 | | 1.14 | **1.67** |
| CCA (mixed) | | | 3.76 | | 0.34 | **0.82** |
| *Ramicrusta* | 0.24 | 0.32 | 0.64 | 0.90 | 0.57 | **0.54** |
| *Caulerpa sp.* | | 1.62 | | 1.00 | | **0.53** |
| *Dictyota* spp. | | 0.54 | | 1.00 | | **0.31** |
| Red algae | | 0.32 | | | | **0.06** |
| **Total Benthic Algae** | **24.29** | **40.32** | **39.63** | **28.01** | **48.69** | **36.19** |
| **Cyanobacteria** | 0.00 | 4.11 | 0.00 | 0.00 | 1.14 | **1.05** |
| **Seagrass** | | | | | | |
| *Thalassia testudinum* | 0.48 | 0.22 | 0.00 | 0.00 | 0.00 | **0.14** |
| **Hard Coral** | | | | | | |
| *Porites porites* | 17.98 | 46.27 | 16.70 | | | **16.19** |
| *Orbicella annularis* | 20.71 | | 8.99 | 15.56 | 12.51 | **11.56** |
| *Orbicella faveolata* | | | 5.96 | 10.04 | 10.35 | **5.27** |
| *Pseudodiploria strigosa* | 4.64 | 0.97 | 5.32 | | 7.51 | **3.69** |
| *Montastraea cavernosa* | | | | 4.32 | | **0.86** |
| *Porites astreoides* | 1.19 | | 2.94 | | | **0.83** |
| *Agaricia agaricites* | | 0.22 | 3.39 | 0.20 | | **0.76** |
| *Millepora alcicornis* | | | 0.83 | | | **0.17** |
| **Total Hard Coral** | **44.52** | **47.46** | **44.13** | **30.12** | **30.38** | **39.32** |
| **# CoralColonies /Transect** | n/d | n/d | n/d | n/d | n/d | n/d |
| **# Diseased Coral Colonies** | **1** | **0** | **1** | **0** | **3** | |
| **Zoanthid** | | | | | | |
| *Palythoa caribaeorum* | | | 0.64 | | 2.62 | **0.65** |
| **Octocoral** | | | | | | |
| *Erythropodium caribaeorum* | 0.00 | 0.00 | 4.40 | 0.00 | 0.00 | **0.88** |
| **# Gorgonians/Transect** | 0 | 3 | 0 | 4 | 3 | **2.0** |
| **Sponges** | | | | | | |
| *Cliona caribbaea* | 0.00 | 0.00 | 0.00 | 0.00 | 1.71 | **0.34** |
| *Neopetrosia proxima* | 0.00 | 0.00 | 0.00 | 0.00 | 0.91 | **0.18** |
| **Total Sponges** | **0.00** | **0.00** | **0.00** | **0.00** | **2.62** | **0.52** |

Abiotic substrates mostly contributed by reef overhangs (11.27%) and sand (9.68%) were intercepted in all five transects with a mean cover of 21.25%.

Temporal variations of reef substrate cover by sessile benthic categories and coral species between monitoring surveys at CIBU05 are shown in Figures 66 and 67. Total live coral and benthic algae have remained as the dominant assemblages of reef substrate cover at CIBU05 since the baseline survey in 2011. During 2018 reductions of cover by both live coral and benthic algae were measured, but differences were not statistically significant (ANOVA, $p = 0.747$; Appendix 2a). A corresponding increase of abiotic cover (mostly sand) was measured at CIBU05 in 2018 (Figure 66). This implies a massive movement of sand over the reef that covered sections colonized by turf algae and live corals.

Mean cover by live coral declined 12.3%, from 44.7% in 2016 to 39.2% in 2018 and was strongly influenced by reductions of cover by Finger Coral (*Porites porites*). Sections of Finger Coral colonies in transect 3 were detached from the main colony and overturned in the sand. Several colonies of Symmetrical Brain Coral (*Pseudodiploria strigosa*) were observed broken at the base and overturned. Such effects appear to have been induced by an exceptionally strong wave and surge energy acting over the entire reef. Corals and turf algal communities established at CIBU05 are adapted to thrive in the high energy environment of a north coast reef crest that is seasonally impacted by high waves. Thus, the impact was probably associated with an extreme event compatible with Hurricane Maria (September 2017) and/or other exceptionally strong wave storm event affecting the north and west coast of Puerto Rico in March 2018.

### 20.3 Fishes and Motile Megabenthic Invertebrates

A total of 28 fish species were identified within belt-transects surveyed at CIBU10 with a mean density of 36.2 Ind/30 $m^2$ (range: 29 - 43 Ind/30 $m^2$), and a mean species richness of 12.8 species/transect (Table 60). The Bluehead Wrasse (*Thalassoma bifasciatum*) was the numerically dominant species with a mean density of 8.0 Ind/transect, followed by the Dusky Damselfish (*Stegastes adustus*) with 5.0 Ind/transect. In addition to the aforementioned species, an assemblage of five species were present in at least four transects. These include the Stoplight Parrotfish (*Sparisoma viride*), Sharknose Goby (*Elacatinus evelynae*), Schoolmaster (*Lutjanus apodus*), and the Yellowtail Damselfish (*Microspathodon chrysurus*). Thirteen species were observed in one transect, including one school of 10 Grey Snappers (*Lutjanus griseus*) in transect 2, and another school of eight Bar Jacks (*Carangoides ruber*) in transect 4 (Table 60)

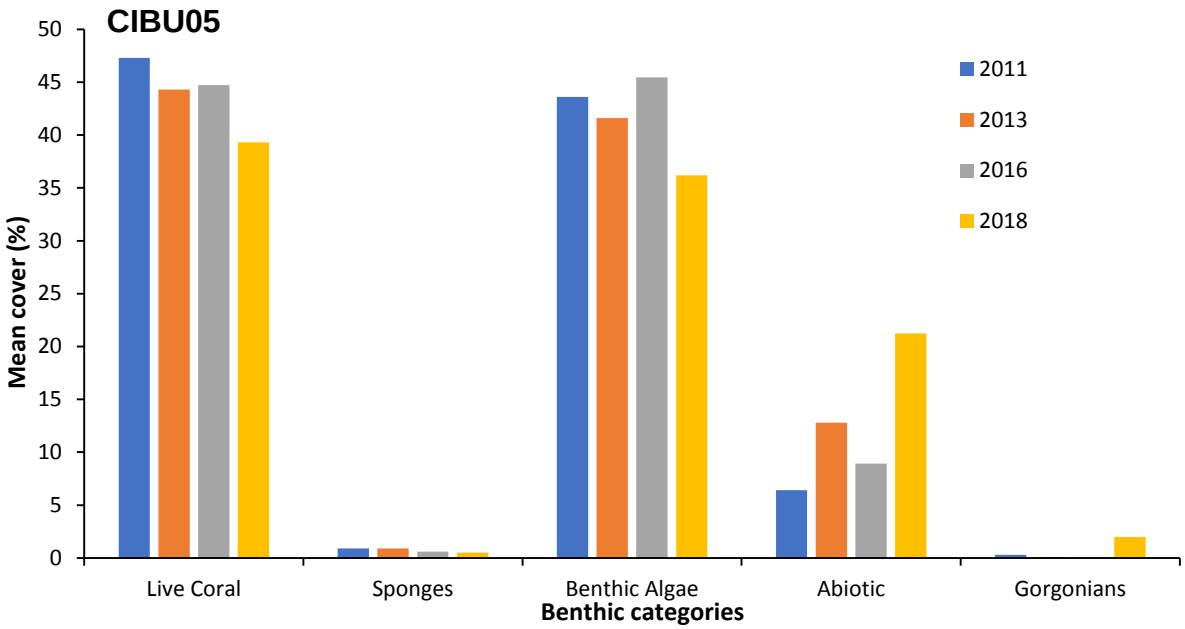



**Figure 66.** CIBU05. Annual variations (2011 -18) of mean substrate cover by sessile-benthic categories at Cibuco Reef 5m, Vega Baja

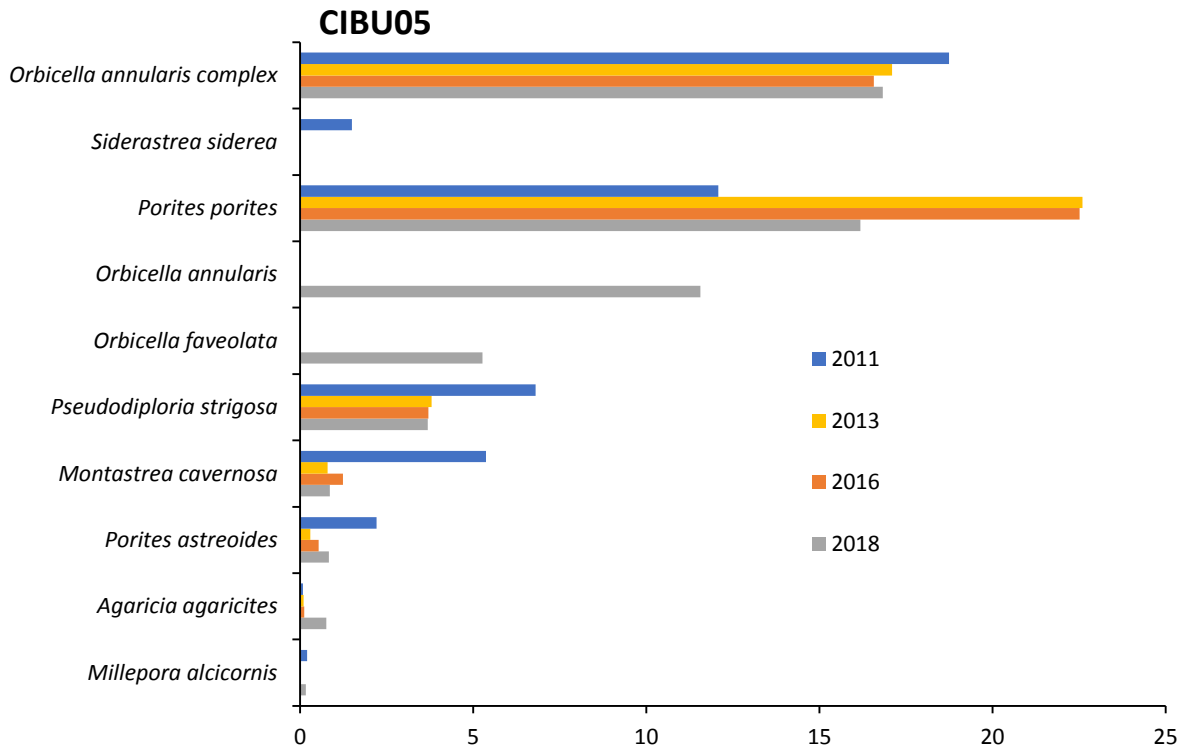



**Figure 67.** CIBU05. Annual variations (2011 -18) of mean substrate cover by the main coral species intercepted by transects at Cibuco Reef 5m, Vega Baja

**Table 60.** CIBU05. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Cibuco Reef 5m, Vega Baja, August 2018

| Mean Depth: 2.0 m | | TRANSECTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| | | (Individuals/30 m2) | | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 5 | 2 | 17 | 7 | 9 | **8.0** |
| *Stegastes adustus* | Dusky Damselfish | 6 | 3 | 7 | 5 | 4 | **5.0** |
| *Lutjanus griseus* | Grey Snapper | | 10 | | 5 | | **3.0** |
| *Halichoeres maculipinna* | Clown Wrasse | 4 | 2 | 5 | | | **2.2** |
| *Sparisoma viride* | Stoplight Parrotfish | 2 | 5 | | 1 | 3 | **2.2** |
| *Elacatinus evelynae* | Sharknose Goby | 4 | | 1 | 1 | 3 | **1.8** |
| *Carangoides ruber* | Bar Jack | | | | 8 | | **1.6** |
| *Lutjanus apodus* | Schoolmaster | 4 | | 1 | 1 | 2 | **1.6** |
| *Acanthurus tractus* | Five-band Surgeonfish | 6 | 1 | | | | **1.4** |
| *Halichoeres bivittatus* | Slippery Dick | | | 3 | 2 | 1 | **1.2** |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 1 | 1 | 2 | 1 | 1 | **1.2** |
| *Abudefduf saxatilis* | Sargent Major | | 1 | 2 | 1 | 1 | **1.0** |
| *Cephalopholis fulva* | Coney | | 2 | | | 2 | **0.8** |
| *Haemulon macrostomum* | Spanish Grunt | | | 4 | | | **0.8** |
| *Halichoeres radiatus* | Puddinwife | | 2 | | 1 | 1 | **0.8** |
| *Acanthurus chirurgus* | Doctorfish | 2 | | | | | **0.4** |
| *Bodianus rufus* | Spanish Hogfish | | 1 | | | 1 | **0.4** |
| *Cantherhines pullus* | Tail-light Filefish | 1 | | | 1 | | **0.4** |
| *Canthigaster rostrata* | Caribbean Puffer | 1 | | | 1 | | **0.4** |
| *Haemulon flavolineatum* | French Grunt | | | | 2 | | **0.4** |
| *Anisotremus virginicus* | Porkfish | | 1 | | | | **0.2** |
| *Gerres cinereus* | Yellowfin Mojarra | | | | | 1 | **0.2** |
| *Holocentrus adscensionis* | Squirrelfish | 1 | | | | | **0.2** |
| *Holocentrus rufus* | Longspine Squirelfish | | | 1 | | | **0.2** |
| *Kyphosus bermudensis* | Bermuda Chub | | 1 | | | | **0.2** |
| *Mulloides martinicus* | Yellow Goatfish | | | | 1 | | **0.2** |
| *Pterois sp* | Lionfish | | 1 | | | | **0.2** |
| *Sparisoma rubripinne* | Yellowtail Parrotfish | 1 | | | | | **0.2** |
| | **TOTAL INDIVIDUALS** | **38** | **33** | **43** | **38** | **29** | **36.2** |
| | **TOTAL SPECIES** | **13** | **14** | **10** | **15** | **12** | **12.8** |
| | | | | | | | |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Diadema antillarum* | Long-Spined Urchin | 8 | 6 | 15 | 9 | 13 | **10.2** |
| *Eucidaris tribuloides* | Slate-Pencil Urchin | 1 | | 1 | | | **0.4** |
| *Panulirus guttatus* | Spotted Spiny Lobster | | | 1 | | | **0.2** |
| *Tripneustes esculentus* | White Urchin | | | 1 | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 9 | 6 | 18 | 9 | 13 | **11.0** |
| | **TOTAL SPECIES** | 1 | 0 | 1 | 0 | 0 | **0.4** |

The trophic structure of the fish community at CIBU05 was strongly influenced by the species richness and numerical dominance within belt-transects of opportunistic carnivores. The assemblage of 14 species included four wrasses and one hogfish (Labridae), two grunts (Haemulidae), two squirrelfishes (Holocentridae), one goby (Gobiidae), one mojarra (Gerreidae), one puffer (Tetraodontidae), one porkfish (Sparidae), and one goatfish (Mullidae) with a combined density of 17.0 Ind/transect, representing 47.0% of the total individuals within belt-transects. The herbivore assemblage was comprised by six species, including two parrotfishes (Scaridae), two damselfishes (Pomacentridae) and two doctorfishes (Acanthuridae) with a combined density of 10.4 Ind/transect, representing 28.7% of the total individuals. The zooplanktivorous component was represented by only one species (*Abudefduf saxatilis*) with a relatively low density within transects. Schooling zooplanktivore estuarine species, such as anchovies (Engraulidae) were observed in large aggregations in the vicinity of the reef over sandy bottom (Garcia-Sais et al., 2016). Small and mid-size piscivores were represented by snappers (Lutjanidae), jacks (Carangidae) and small groupers (Serranidae). Mid-water piscivores, such as the Great Barracuda (*Sphyraena barracuda*) and the Cero Mackerel (*Scomberomorus regalis*) were observed out of transects. The Yellowfin Mojarra (*Gerres cinereus*) and other species of mojarras (*Eucinostomus spp*) were observed to be abundant over the sandy bottom surrounding the reef.

The Long-spined Urchin (*Diadema antillarum*) was the most prominent motile megabenthic invertebrate within belt-transects with a mean density of 10.2 Ind/30 $m^2$ (Table 60). Two other urchin species (*Eucidaris tribuloides, Tripneustes esculentus*) and one Spotted Spiny Lobster (*Panulirus guttatus*) were also present within belt-transects at CIBU05.

The size frequency distributions of commercially exploited species and the larger reef herbivores are presented in Table 61. Recruitment juvenile stages (1 – 2 cm) of Stoplight Parrotfish (*Sparisoma viride*) were observed within belt-transects, and juvenile sizes of Yellowtail Parrotfish and doctorfishes (*Acanthurus spp*) were also present. Juvenile and adult Grey and Schoolmaster Snappers (*Lutjanus griseus, L. apodus*), and Coney (*Cephalopholis fulva*) were observed. From these and previous data on size-frequency distributions CIBU05 appears to be an important recruitment habitat for the Coney (*C. fulva*) and also for juvenile snappers (*Lutjanus analis, L. synagris, L. griseus*), parrotfishes (*S. viride*) and grunts (Haemulidae), observed in very small sizes at the reef and in the adjacent seagrass habitats.

The temporal variations of mean fish density and species richness between monitoring surveys at CIBU05 are presented in Figure 68. Marked fluctuations of fish density and species richness have been documented between monitoring surveys. Such fluctuations are a common feature of the fish community structure in shallow reefs due to the mechanical influence of wave action on small fish individuals, particularly those that dwell in the water column out of protective microhabitats. During 2018, conditions were mostly calm and clear and fish density and species richness approached the peak values produced during the baseline survey (Figure 68).

**Table 61.** CIBU05. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates within 20 x 3 m belt-transects at Cibuco Reef 5m, Vega Baja, August 2018

| | | TRANSECTS | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 2.0 m | | **1** | **2** | **3** | **4** | **5** |
| | | (Ind/60 $m^2$ - TL in cm) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus tractus* | Five-band Surgeonfish | 1 - 14 | 2 - 12 | 1 - 14 | 1 - 14 | 2 - 14 |
| | | | | 1 - 19 | | |
| *Acanthurus coeruleus* | Blue Tang | 1 - 14 | | 1 - 17 | | |
| *Acanthurus chirurgus* | Doctorfish | 3 - 14 | | | 1 - 12 | |
| *Cephalopholis fulva* | Coney | 1 - 26 | 1 - 26 | | | 1 - 19 |
| | | | 1 - 29 | | | 1 - 26 |
| *Cephalopholis cruentata* | Graysby | | | 1 - 19 | | |
| *Lutjanus apodus* | Schoolmaster | 1 - 10 | 2 - 19 | 2 - 14 | | 1 - 14 |
| | | 3 - 24 | 1 - 26 | 1 - 22 | | 1 - 22 |
| *Lutjanus griseus* | Grey Snapper | | 1 - 24 | | 1 - 12 | |
| | | | | | 2 - 17 | |
| *Pterois sp* | Lionfish | | 1 - 26 | | | |
| *Sparisoma rubripinne* | Yellowtail Parrotfish | 1 - 22 | | | 1 - 7 | |
| | | | | | 1 - 29 | |
| *Sparisoma viride* | Stoplight Parrotfish | 2 - 2 | 1 - 1 | | 1 - 2 | |
| | | | | | | |
| **Invertebrates** | | | | | | |
| *Panulirus guttatus* | Spotted Spiny Lobster | | | 1 - 7 | | |
| | | | | | | |
| TL = Fish Total Length | | | | | | |
| Lobster length is the carapace length in cm | | | | | | |

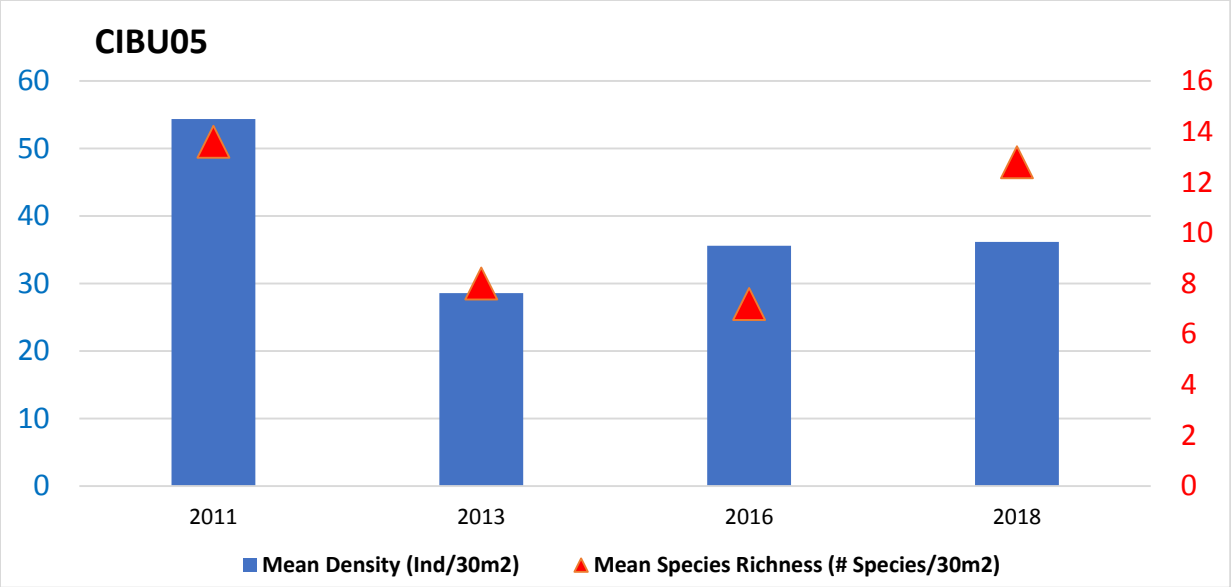


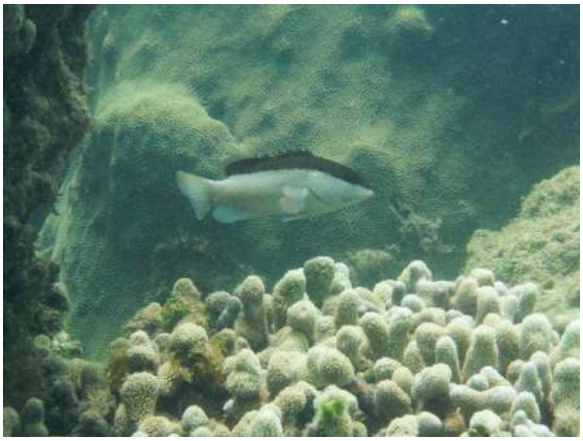

**Figure 68.** CIBU05. Monitoring trends (2011 – 18) of mean fish density and species richness within 10 x 3m belt-transects at Cibuco Reef 5m, Vega Baja

**Photo Album 20**

**Cibuco Reef, Vega Baja (CIBU05)**





## 21.0 Dominos Reef, San Juan (DOMI05)

### 21.1 Physical Description

Fringing the San Juan coastline are a series of submerged and emergent patch reefs of sedimentary origin (eolianites) which exhibit variable colonization by algae, sponges, corals, and other benthic reef biota that serve as an important habitat for fishes and invertebrates and protect the coastline from wave action and erosion. Dominos Reef (DOMI05) is one of these patch reefs, located about 0.9 NM to the northwest off Punta Las Marias, San Juan. The reef rises from a sandy bottom at a depth of about 7 – 9 m to a hard ground platform at a depth of 1.5 – 2.0 m. The slope is abrupt with substantial colonization by reef biota and particularly brain corals (*Pseudodiploria strigosa, P. clivosa*) and octocorals (gorgonians) at the edge of the reef top. The reef interface with the sandy bottom is irregular with crevices and undercuts that are erosive features of a relict structure subjected to heavy wave action. At the reef top, there are sections heavily colonized by thickets of Elkhorn Coral (*Acropora palmata*) and sections with high density of brain and encrusting coral colonies (*P. strigosa, P. clivosa, Porites astreoides*). The contribution of scleractinian corals to the reef topographic relief and overall habitat complexity is substantial and consistent with the definition of this habitat as a coral reef. The baseline survey was performed on August 2018. Transects were installed over five thickets of Elkhorn Coral at a depth of 1.5 m. Images of the DOMI05 reef community during the baseline survey are exhibited as Photo Album 21.

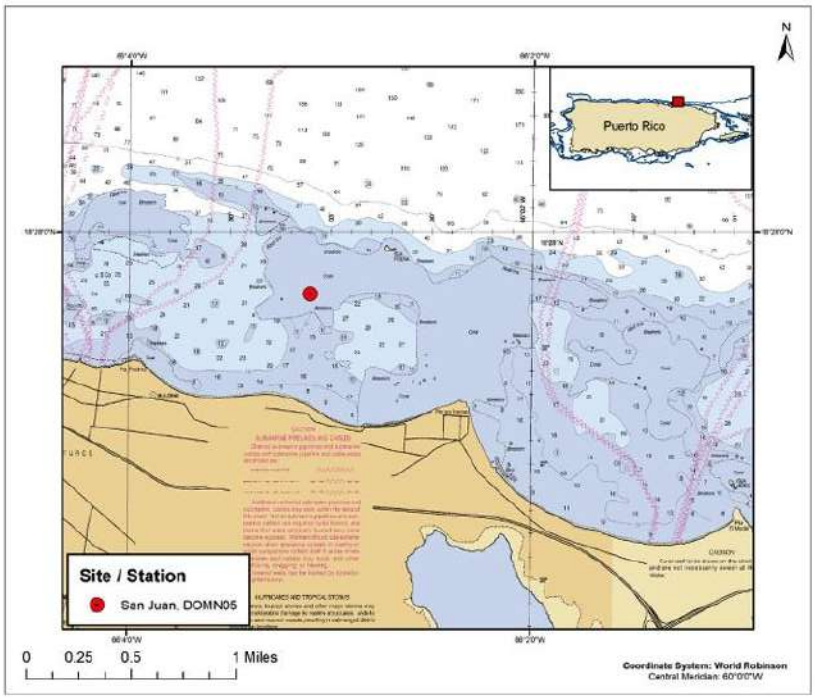



**Figure 69.** Location of Dominos Reef (DOMI05) station off the San Juan coastline.

### 21.2 Sessile-benthic Reef Community

Hard (stony) corals, represented by seven scleractinian species were the dominant sessile-benthic category intercepted by transects at DOMI05 with a mean cover of 58.34% (range: 38.63 – 71.76%) (Figure 70). Elkhorn coral (*Acropora palmata*) was the dominant species of the coral assemblage with a mean cover of 52.47%, representing 89.9% of the total cover by corals (Figure 71). Elkhorn Coral was observed growing mostly in low relief laminar planks, with sections of encrusting growth forming thickets extending more than 10.0 m in some cases. The typical "elkhorn" type growth was also observed, but with short branches and low relief. Coral fragments (particularly *A. palmata*) of variable sizes were scattered all over the reef top, evidencing a large-scale breakage induced by extreme wave action. Symmetrical Brain Coral (*Pseudodiploria strigosa*) was also intercepted by all five transects with a mean cover of 4.22%, representative of 7.2% of the total coral cover. Knobby Brain Coral (*P. clivosa*) and Mustard-Hill Coral (*Porites astreoides*) were present in four and three transects, respectively, but with mean cover below 1% (Table 62). A total of 72 coral colonies were intercepted by transects, including three (3) with an apparent infectious disease (coral disease prevalence = 4.2%).

Benthic algae, comprised by turf, fleshy brown and red crustose calcareous and coralline macroalgae were intercepted by all five transects at DOMI05 with a combined mean cover of 30.99% (range: 23.95 – 42.17%). Turf algae, a mixed assemblage of short, articulated red and brown macroalgae were the dominant component with a mean cover of 23.25%, representing 74.8% of the total cover by benthic algae (Table 62). Red encrusting coralline algae (CCA) were present in all five transects with a mean cover of 2.63%. Fleshy brown macroalgae (*Dictyota sp, Padina sp.*) were present in four transects with a combined mean cover of 4.28%. Other red crustose calcareous algae (Peyssonnelid) were present in four transects with a mean cover of 0.83%. Cyanobacterial patches were intercepted by four transects with a mean reef substrate cover of 0.53% (Table 62).

Vertically projected octocorals exhibited a patchy distribution at DOMI05 with a mean density of 2.6 colonies/transect. Octocorals were more abundant at the edge of the reef top and protected by crevices and other substrate discontinuities. The main species included the Wide-Mesh and Common Sea Fan (*Gorgonia mariae, G. ventalina*) and Sea Rods (*Eunicea spp*). Patches of the Encrusting Zoanthid (*Palythoa caribaeorum*) was intercepted by two transects with a mean cover of 0.73%. Abiotic substrates were mostly associated with reef overhangs and gaps with a mean combined cover of 9.41% at DOMI05 (Table 62).

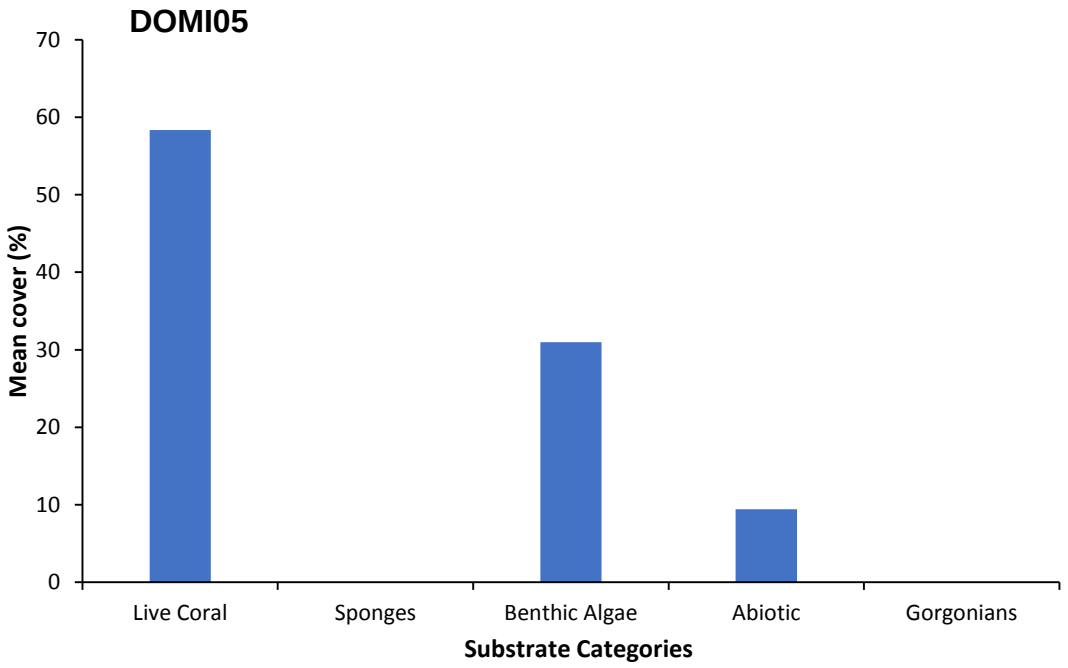



**Figure 70.** DOMI05. Mean substrate cover by sessile-benthic categories at Dominos Reef 5m, San Juan, during the baseline survey, August 2018

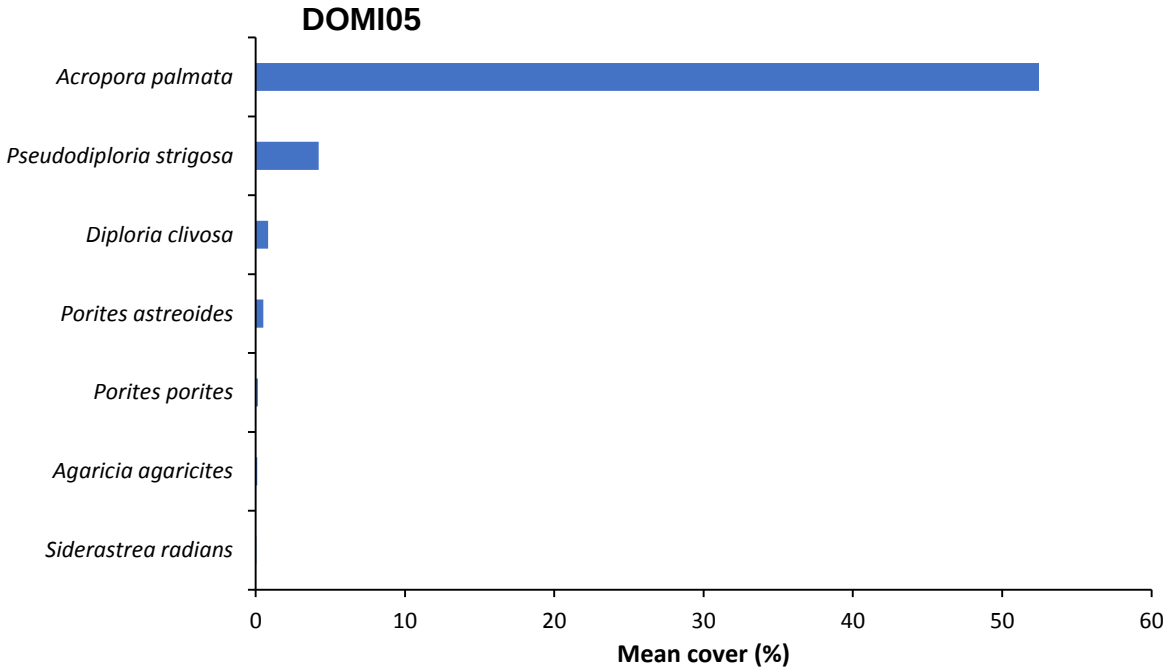



**Figure 71**. DOMI05. Mean substrate cover by coral species intercepted by transects at Dominos Reef 5m, San Juan, during the baseline survey, August 2018

| **Table 62**. DOMI05. Percent cover by sessile-benthic categories at Domino's Reef 5m, San Juan. | | | | | | |
|---|---|---|---|---|---|---|
| Survey Date: 8/10/18 | | | | | | |
| | | | | | | |
| | | | **Transects** | | | |
| | **1** | **2** | **3** | **4** | **5** | **Mean** |
| Depth (m) | | | | | | |
| Rugosity (m) | 3.38 | 2.85 | 2.39 | 3.05 | 2.82 | **2.90** |
| **BENTHIC CATEGORIES** | | | | | | |
| **Abiotic** | | | | | | |
| Reef overhang | 1.57 | 7.52 | 10.96 | 17.06 | 5.35 | **8.49** |
| Gap | | 1.42 | 1.24 | 1.93 | | **0.92** |
| **Total Abiotic** | **1.57** | **8.93** | **12.20** | **18.99** | **5.35** | **9.41** |
| **Benthic Algae** | | | | | | |
| Turf (mixed) | 20.61 | 20.48 | 19.32 | 33.26 | 22.60 | **23.25** |
| *Dictyota* spp. | | 5.77 | 7.91 | 1.93 | 5.46 | **4.21** |
| CCA (mixed) | 3.35 | 1.42 | 2.15 | 5.04 | 1.20 | **2.63** |
| Peyssonnelid (mixed) | | 0.98 | 0.45 | 1.93 | 0.76 | **0.83** |
| *Padina* sp. | | | 0.34 | | | **0.07** |
| **Total Benthic Algae** | **23.95** | **28.65** | **30.17** | **42.17** | **30.02** | **30.99** |
| **Cyanobacteria** | 0.31 | 0.54 | 1.58 | 0.21 | | **0.53** |
| **Hard Coral** | | | | | | |
| *Acropora palmata* | 70.29 | 60.46 | 44.41 | 25.75 | 61.46 | **52.47** |
| *Pseudodiploria strigosa* | 0.52 | 0.98 | 8.93 | 9.12 | 1.53 | **4.22** |
| *Diploria clivosa* | 0.42 | 0.44 | | 2.58 | 0.76 | **0.84** |
| *Porites astreoides* | | | 0.90 | 0.75 | 0.87 | **0.51** |
| *Porites porites* | | | 0.34 | 0.43 | | **0.15** |
| *Agaricia agaricites* | 0.52 | | | | | **0.10** |
| *Siderastrea radians* | | | 0.23 | | | **0.05** |
| **Total Hard Coral** | **71.76** | **61.87** | **54.80** | **38.63** | **64.63** | **58.34** |
| **# Coral Colonies /Transect** | **10** | **14** | **16** | **15** | **17** | **14.40** |
| **# Diseased Coral Colonies** | **0** | **2** | **0** | **0** | **1** | |
| **Zoanthid** | | | | | | |
| *Palythoa caribaeorum* | 2.41 | 0.00 | 1.24 | 0.00 | 0.00 | **0.73** |
| **Octocoral** | | | | | | |
| **# Gorgonians/Transect** | 0 | 0 | 1 | 0 | 12 | **2.6** |

## 21.3 Fishes and Motile Megabenthic Invertebrates

A total of 18 fish species were observed within belt-transects at DOMI05 with a mean density of 24.6 Ind/transect and a mean richness of 9.0 species/transect (Table 63). The Dusky Damselfish (*Stegastes adustus*) and the Bluehead Wrasse (*Thalassoma bifasciatum*) were the numerically dominant species with mean densities of 7.6 Ind/transect and 5.4 Ind/transect, respectively. In addition to the aforementioned species, the Slippery Dick (*Halichoeres bivittatus*) and the Yellowtail Damselfish (*Microspathodon chrysurus*) were observed in all surveyed transects with a combined abundance of 5.0 Ind/transect. Four other species were observed in three transects. These included the Clown and Puddinwife Wrasses (*H. maculipinna, H. radiatus*), Reef Squirrelfish (*Sargocentron coruscum*), and Bar Jack (*Carangoides ruber*). The combined density of the aforementioned assemblage (22.0 Ind/transect) represented 89.4% of the total individuals within belt-transects.

**Table 63** . DOMI05. Taxonomic composition and abundance of fishes and motile megabenthic invertebrates surveyed within 3 x 10m belt-transects at Dominos Reef 5m, San Juan, August 2018

| | | | | TRANSECTS | | | |
|---|---|---|---|---|---|---|---|
| Mean Depth: 1.5 m | | 1 | 2 | 3 | 4 | 5 | |
| | | | (Individuals/30 m2) | | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | | **MEAN** |
| *Stegastes adustus* | Dusky Damselfish | 7 | 12 | 3 | 8 | 8 | **7.6** |
| *Thalassoma bifasciatum* | Bluehead Wrasse | 6 | 13 | 4 | 3 | 1 | **5.4** |
| *Halichoeres bivittatus* | Slippery Dick | 3 | 5 | 2 | 4 | 2 | **3.2** |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 3 | 1 | 1 | 2 | 2 | **1.8** |
| *Carangoides ruber* | Bar Jack | 1 | | 6 | 1 | | **1.6** |
| *Halichoeres maculipinna* | Clown Wrasse | | | 2 | 1 | 2 | **1.0** |
| *Sargocentron coruscum* | Reef Squirrelfish | 1 | | 1 | 2 | | **0.8** |
| *Halichoeres radiatus* | Puddinwife | 1 | 1 | 1 | | | **0.6** |
| *Acanthurus coeruleus* | Blue Tang | 1 | 1 | | | | **0.4** |
| *Cephalopholis fulva* | Coney | | 1 | 1 | | | **0.4** |
| *Sparisoma viride* | Stoplight Parrotfish | | | 1 | | 1 | **0.4** |
| *Anisotremus virginicus* | Porkfish | | | | 1 | | **0.2** |
| *Aulostomus maculatus* | Trumpetfish | | 1 | | | | **0.2** |
| *Gerres cinereus* | Yellowfin Mojarra | | 1 | | | | **0.2** |
| *Gymnothorax miliaris* | Goldentail Moray | | | | | 1 | **0.2** |
| *Lactophrys triqueter* | Smooth Trunkfish | | | | | 1 | **0.2** |
| *Mulloides martinicus* | Yellow Goatfish | 1 | | | | | **0.2** |
| *Sparisoma rubripinne* | Yellowtail Parrotfish | | | 1 | | | **0.2** |
| | **TOTAL INDIVIDUALS** | 24 | 36 | 23 | 22 | 18 | **24.6** |
| | **TOTAL SPECIES** | 9 | 9 | 11 | 8 | 8 | **9.0** |
| **Motile Megabenthic Invertebrates** | | | | | | | |
| *Diadema antillarum* | Long-spined Urchin | | | | 1 | | **0.2** |
| *Eucidaris tribuloides* | Slate-Pencil Urchin | | | 1 | | | |
| *Echinometra spp* | Rock-boring urchin | 9 | 26 | 18 | 15 | 28 | **19.2** |
| | **TOTAL INDIVIDUALS** | 9 | 26 | 19 | 16 | 28 | **19.6** |
| | **TOTAL SPECIES** | 1 | 1 | 2 | 2 | 1 | **1.4** |

Motile-megabenthic invertebrates were represented by three species of urchins (Echinoidea) within belt-transects at DOMI05, with a combined density of 19.6 Ind/transect. Rock-Boring urchins (*Echinometra spp*), a mixed assemblage of *E. lucunter* and *E. viridis* was the most abundant, with a mean density of 19.2 Ind/transect, or 98.0% of the total. Slate-Pencil Urchin (*Eucidaris tribuloides*) and Long-Spined Urchin (*Diadema antillarum*) were also observed within belt-transects.

The fish trophic structure at DOMI05 was fairly well balanced between carnivores and herbivores. The carnivore assemblage was comprised by 13 out of the 18 species within belt-transects with a combined density of 14.2, representative of 57.7% of the total individuals. These included small infaunal invertebrate feeders such as the Bluehead, Slippery Dick, Clown and Puddinwife Wrasses (Labridae), Reef Squirrelfish (Holocentridae), Porkfish (Sparidae), Yellow Goatfish

(Mullidae), Trumpetfish (Aulostomidae), and Smooth Trunkfish (Ostraciidae), and small piscivores, such as the Coney (Serranidae) and Bar Jack (Carangidae). Herbivores were represented by Dusky and Yellowtail Damselfishes (Pomacentridae), Stoplight and Yellowtail Parrotfishes (Scaridae), and the Blue Tang (Acanthuridae) with a combined density of 10.4 Ind/transect, representative of 42.3% of the total individuals within belt-transects. The herbivore assemblage was well supplemented by high densities of sea urchins and by large schools of doctorfishes (Acanthuridae) observed outside transects off the reef - top. A specious assemblage of parrotfishes was also observed associated with deeper sections of DOMI05, particularly the reef slope and sandy interface at the base of the reef.

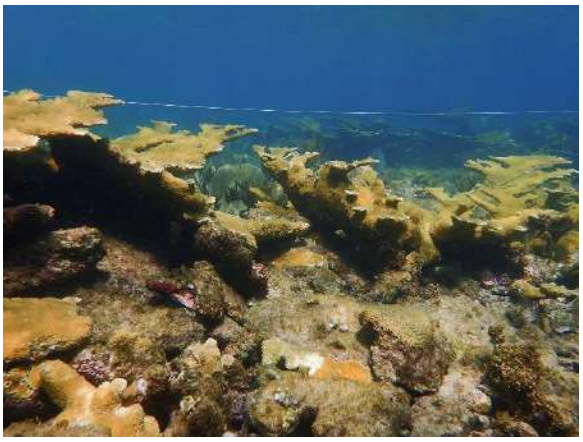
The size-frequency distribution of commercially exploited fishes and the larger reef herbivores observed within belt-transects at DOMI05 is presented in Table 64. Recruitment juvenile stages (< 2 cm) of the Blue Tang (*Acanthurus coeruleus*) and the Stoplight Parrotfish (*Sparisoma viride*) were observed. Juvenile and adult stages of these species were also present outside transects, indicative that DOMI05 represents both a recruitment and residential habitat for these species throughout their life cycles. Coneys (*Cephalopholis fulva*) were only observed as large adults (26 – 29 cm) occupying microhabitats below Elkhorn Coral ledges. Rock-Boring Urchins (*Echinometra spp*) were present from their recruitment juvenile sizes (< 1 cm) to their full adult sizes (e.g. approx. 10 cm diameter). Given their small size at recruitment, their real densities at DOMI05 were probably underestimated.

**Table 64.** DOMI05. Taxonomic composition and size frequency of fishes and motile megabenthic invertebrates surveyed within 3 x 20m belt-transects at Dominos Reef 5m, San Juan, August 2018

| | | | | | | |
|---|---|---|---|---|---|---|
| Mean Depth: 1.5 m | | | **TRANSECTS** | | | |
| | | **1** | **2** | **3** | **4** | **5** |
| | | | (Ind/60 $m^2$ - Length in cm) | | | |
| ***SPECIES*** | **COMMON NAME** | | | | | |
| *Acanthurus coeruleus* | Blue Tang | 1 - 2 | 1 - 2 | | | |
| *Cephalopholis fulva* | Coney | | 1 - 26 | | 1 - 29 | |
| *Sparisoma ribripinne* | Yellowtail Parrotfish | | | 1 - 7 | | |
| *Sparisoma viride* | Stoplight Parrotfish | | | 1 - 2 | | 1 - 2 |
| | | | | | | |
| **Invertebrates** | | | | | | |
| none | | | | | | |
| | | | | | | |
| TL = Fish Total Length | | | | | | |

**Photo Album 21**

**Dominos Reef, San Juan (DOMI05)**



## VIII. Conclusions from the 2018 Monitoring Survey

1. Statistically significant reductions 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 live coral cover in 2018 relative to the previous survey.
2. Loss of total live coral cover was measured in 17 out of the 19 reef stations surveyed in 2018 where previous assessments were available for comparison. The mean decline of coral cover from the 19-reef station dataset was 16.1%. The largest losses of live coral cover were measured at LPEN05 in Culebra (52.0%), DIAB05 in Fajardo (38.9%), and BOTE20 in Isla Desecheo (33.7%).
3. Finger Coral (*Porites porites*) and Lobed Star Coral (*Orbicella annularis*) were the main coral species associated with loss of substrate cover at reef stations, but several other species contributed to the decline of hard coral cover.
4. Statistically significant differences of octocoral densities between monitoring surveys were evidenced at four reef stations (e.g. LPEN05, DAKI20, PALN20, MEXT10), all of which resulted from declining densities during the 2018 survey.
5. The general decline of live hard coral cover (%) and octocoral densities appear to be directly related to mechanical breakage of colonies due to extreme surge and abrasion effects that may have prevailed during the pass of Hurricanes Irma and Maria in September 2017 and/or the extreme wave storm event impacting the north and west coasts of PR in March 2018, prior to our reef monitoring survey.
6. Increments of reef substrate cover by brown fleshy algae (*Dictyota sp.* + *Lobophora sp*.) and/or cyanobacteria were measured from 15 out of the 19 reefs for which comparative data was available. The larger increments of cover by fleshy algae were measured at LPEN05 and ESPE10 (24.7-fold), DIAB05 (10.1-fold), PALN20 (7.1-fold), and RODR05 (4.5-fold), The larger increments of cover by cyanobacteria were measured at CROS10 (6.8-fold), DIAB05 (6.6-fold), MEXT10 (2.8-fold), and PALN20 (1.3-fold), Such increments may have been supported by nutrient enrichment and/or increased availability of reef primary substrates associated with the pass of huricanes and/or other extreme event(s) of wave action. Reef primary substrates were produced by in-situ mortality and/or mechanical breakage of coral colonies, whereas nutrient enrichment may have occured via river loading, laminar watershed rainfall runoff, and/or upwelling currents. The relative influence of these potential factors at the specific reef stations requires further analysis supported by physical oceanographic data.
7. Major shifts in the relative composition of benthic algal assemblages involving displacement of previously dominant turf algae by encrusting crustose Peyssonnelid red algae (mostly *Ramicrusta sp*) observed from the reefs of Vieques (CANJ20, ESPE10) and that also characterized the Fajardo and Culebra reefs of during the 2016 survey prevailed in the 2018 survey. However, a general decline of cover by *Ramicrusta* associated with overgrowth by brown and red fleshy macroalgae was measured in several east coast reefs during the 2018 survey. This may be indicative of a transitional stage of benthic algal succession and/or competition for hard ground space at the east coast reefs.

8. Mean prevalence of coral disease for the 21-reef PRCRMP data set in 2018 was 5.2%, resulting from 64 diseased colonies out of a total of 1,210 coral colonies intercepted by transects. Although a comprehensive evaluation of coral disease infections was not part of the scope of work in this survey, the ubiquitous appearance of dark spots, particularly on Massive Starlet Coral (*Siderastrea siderea*) colonies suggests a high prevalence of the "dark spot syndrome".
9. Statistically significant differences of fish densities between monitoring surveys were evidenced in 14 out of the 19 reef stations with available data for comparative analyses. In all cases a decline of fish density was noted during 2018 relative to previous surveys. Differences were mostly associated with a marked reduction or absence of a previously numerically dominant species, the Masked Goby (*Coryphopterus personatus*). A general decline of fish species richness that was statistically significant for seven (7) reef stations also contributed to the generalized declining pattern of fish density in reefs surveyed during 2018.
10. We suggest that the declining pattern of fish density and species richness was directly related to the inability of small fish individuals to withstand the probably extreme surge and abrasion effects caused by hurricanes and/or another wave storm event.
11. Presence of post settlement juvenile through adult stages, particularly of Stoplight, Redband and Bucktooth Parrotfishes (*Sparisoma viride, S. aurofrenatum, S. radians*, respectively) were observed on most reefs surveyed evidencing the recruitment habitat function of these neritic reefs for these ecologically and commercially important species.
12. Some very large (> 38cm) Red Hinds (*Epinephelus guttatus*) were observed in several reefs. This may be an indication of population stock recuperation for this commercially important species. Nevertheless, the very low density or absence of large reef fishes, such as groupers, snappers, hogfishes, green moray eels, and sharks remains as a prevailing condition of the fish community structure from the coral reefs surveyed and represents an important concern regarding the coral reef ecosystem integrity.

## 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. For the particular objective of re-stocking coral reef systems that were strongly impacted by bleaching mortality it is recommended that coral colonies of highly vulnerable species (*Orbicella faveolata, O. annularis, Colpophyllia natans*) that were resilient to bleaching be identified and studied, as these colonies may be harboring strains of zooxanthellae that were tolerant to the specific stressors causing bleaching in other colonies of their species. These tolerant colonies should be selected for coral farming projects directed for re-stocking reefs of similar environmental conditions.

5. 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 calcareous crustose algae on PR reefs, as well as potential manipulations to reduce their populations, including sea urchin seedings on highly colonized reefs.

6. 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.

7. 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 Longspined 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.

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 germaine 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 appropiate 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 recruitment 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 prefered 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 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 productyivity dynamics.

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# XI. **Appendices**

## Appendix 1. Geographic coordinates of permanent transects at reef stations surveyed in 2017-18

*Delivered digitally*

## Appendix 2a. Repeated measures analysis of variance (ANOVA) testing for differences of total average live coral cover between monitoring surveys at reef stations during 2017-18

| Reef Stations | Station Code | SS | df | MS | F | p-value |
|---|---|---|---|---|---|---|
| El Negro 5m | NEGR05 | 2.81 | 1 | 2.81 | 0.42 | 0.550 |
| El Negro 10m | NEGR10 | 0.002 | 1 | 0.002 | 6.52 | 0.063 |
| Guanajibo 20m | GUAN20 | 12.59 | 1 | 21.59 | 0.38 | 0.570 |
| Bajo Rodriguez 5m | RODR05 | 3.58 | 1 | 3.58 | 0.19 | 0.690 |
| Mancha Exteriores 10m | MEXT10 | 3.81 | 1 | 3.81 | 0.71 | 0.450 |
| Mancha Exteriores 20m | MEXT20 | 16.8 | 1 | 16.8 | 2.44 | 0.190 |
| Puerto Botes 15m | BOTE15 | 1.37 | 10 | 0.12 | 11.39 | <0.0001* |
| Puerto Botes 20m | BOTE20 | 4.09 | 10 | 0.37 | 14.91 | <0.0001* |
| Puerto Canoas 30m | CANO30 | 0.619 | 10 | 0.062 | 5.836 | <0.0001* |
| Luis Pena 5m | LPEN05 | 0.338 | 1 | 0.338 | 20.466 | 0.011* |
| Carlos Rosario 10m | CROS10 | 0.006 | 1 | 0.006 | 0.621 | 0.475 |
| Dakiti 20m | DAKI20 | 0.017 | 1 | 0.017 | 0.768 | 0.430 |
| Esperanza 10m | ESPE10 | 1.612 | 4 | 0.403 | 8.983 | 0.001* |
| Canjilones 20m | CANJ20 | 0.3 | 4 | 0.075 | 9.483 | <0.0001* |
| El Seco 30m | SECO30 | 0.033 | 3 | 0.011 | 3.05 | 0.070 |
| Cayo Diablo 5m | DIAB05 | 0.107 | 1 | 0.107 | 4.207 | 0.110 |
| Palominito 10m | PALN20 | 0.024 | 1 | 0.024 | 3.641 | 0.129 |
| Palomino 20m | PALT10 | 0.008 | 1 | 0.008 | 5.888 | 0.072 |
| Cibuco 5m | CIBU05 | 0.016 | 3 | 0.005 | 0.412 | 0.747 |
| * Statistically significant differences at p < 0.05 | | | | | | |

## Appendix 2b. Repeated measures analysis of variance (ANOVA) testing for differences of Octocoral densities between monitoring surveys at reef stations surveyed during 2017-18

| Reef Stations | Station Code | SS | df | MS | F | p-value |
|---|---|---|---|---|---|---|
| El Negro 5m | NEGR05 | 16.9 | 1 | 16.9 | 2.364 | 0.199 |
| El Negro 10m | NEGR10 | 0 | 1 | 0 | 0 | 1.00 |
| Guanajibo 20m | GUAN20 | 0.4 | 1 | 0.4 | 0.151 | 0.717 |
| Bajo Rodriguez 5m | RODR05 | 0.1 | 1 | 0.1 | 0.074 | 0.799 |
| Mancha Exteriores 10m | MEXT10 | 211.6 | 1 | 211.6 | 12.558 | 0.024* |
| Mancha Exteriores 20m | MEXT20 | 2.5 | 1 | 2.5 | 3.33 | 0.142 |
| Puerto Botes 15m | BOTE15 | 0.1 | 1 | 0.1 | 1 | 0.374 |
| Puerto Botes 20m | BOTE20 | n/a | n/a | n/a | n/a | n/a |
| Puerto Canoas 30m | CANO30 | n/a | n/a | n/a | n/a | n/a |
| Luis Pena 5m | LPEN05 | 25.6 | 1 | 25.6 | 13.838 | 0.020* |
| Carlos Rosario 10m | CROS10 | 8.1 | 1 | 8.1 | 1.976 | 0.233 |
| Dakiti 20m | DAKI20 | 16.9 | 1 | 16.9 | 112.667 | <0.0001* |
| Esperanza 10m | ESPE10 | 72.9 | 1 | 72.9 | 2.899 | 0.164 |
| Canjilones 20m | CANJ20 | 19.6 | 1 | 19.6 | 0.34 | 0.591 |
| El Seco 30m | SECO30 | 0.9 | 1 | 0.9 | 1 | 0.374 |
| Cayo Diablo 5m | DIAB05 | 8.1 | 1 | 8.1 | 1.862 | 0.233 |
| Palominito 10m | PALN20 | 16.9 | 1 | 16.9 | 2.364 | 0.199 |
| Palomino 20m | PALT10 | 96.1 | 1 | 96.1 | 40.894 | 0.003* |
| Cibuco 5m | CIBU05 | 0.4 | 1 | 0.4 | 0.242 | 0.648 |
| * Statistically significant differences at p < 0.05 | | | | | | |

## Appendix 3. Factorial analysis of variance (ANOVA) testing for differences of fish density and species richness between monitoring surveys at reef stations during 2018

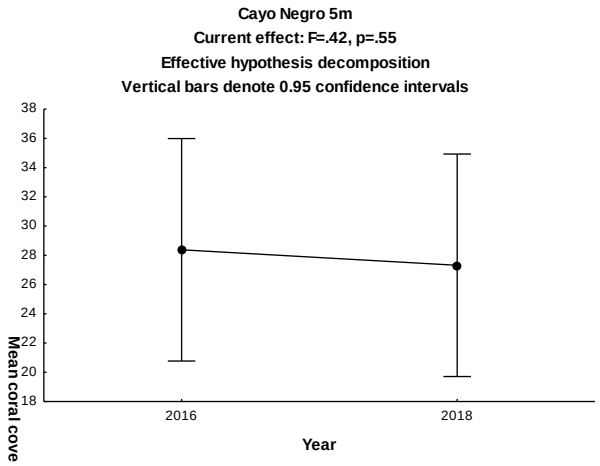
| Reef Station | Station Code | Factor | SS | DF | MS | F | p - value |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Manchas Exteriores 20 | MEXT20 | | | | | | |
| | | Density | 2.31E+05 | 1 | 2.31E+05 | 36.51 | .000* |
| | | richness | 4.9 | 1 | 4.9 | 0.594 | 0.463 |
| Manchas Exteriores 10 | MEXT10 | | | | | | |
| | | Density | 2.51E+04 | 1 | 2.51E+04 | 29.9 | .001* |
| | | Richness | 0.1 | 1 | 0.1 | 0.022 | 0.886 |
| Escollo Rodriguez 5 | RODR05 | | | | | | |
| | | Density | 1769 | 1 | 1769 | 4.429 | 0.068 |
| | | Richness | 10 | 1 | 10 | 1.047 | 0.336 |
| Guanajibo 20 | GUAN20 | | | | | | |
| | | Density | 2.86E+04 | 1 | 2.86E+04 | 9.12 | .017* |
| | | Richness | 0.4 | 1 | 0.4 | 0.053 | 0.823 |
| El Negro 10 | NEGR10 | | | | | | |
| | | Density | 3.15E+04 | 1 | 3.15E+04 | 42.54 | .000* |
| | | Richness | 0 | 1 | 0 | 0 | 1 |
| El Negro 5 | NEGR05 | | | | | | |
| | | Density | 6.59E+04 | 1 | 6.59E+04 | 19.13 | .002* |
| | | Richness | 25.6 | 1 | 25.6 | 8.258 | .021* |
| Puerto Canoas 30 | CANO30 | | | | | | |
| | | Density | 1.25E+06 | 10 | 1.25E+05 | 10.26 | .000* |
| | | Richness | 897.9 | 10 | 89.79 | 6.456 | .000* |
| Puerto Botes 20 | BOTE20 | | | | | | |
| | | Density | 1.35E+05 | 11 | 1.23E+04 | 3.861 | .001* |
| | | Richness | 478.6 | 11 | 43.51 | 2.931 | .005* |
| Puerto Botes 15 | BOTE15 | | | | | | |
| | | Density | 1.63E+05 | 10 | 1.63E+04 | 5.099 | .000* |
| | | Richness | 294.4 | 10 | 29.44 | 2.476 | .019* |
| Palomino 20 | PALN20 | | | | | | |
| | | Density | 6502 | 1 | 6502 | 1.01 | 0.344 |
| | | Richness | 4.9 | 1 | 4.9 | 0.737 | 0.416 |
| Palominito 10 | PALT10 | | | | | | |
| | | Density | 5905 | 1 | 5905 | 2.13 | 0.183 |
| | | Richness | 4.9 | 1 | 4.9 | 0.754 | 0.411 |
| Cayo Diablo 5 | DIAB05 | | | | | | |
| | | Density | 2280 | 1 | 2280 | 6.124 | .038* |
| | | Richness | 44.1 | 1 | 44.1 | 9.587 | .015* |
| El Seco 30 | SECO30 | | | | | | |
| | | Density | 2.08E+04 | 3 | 6920 | 2.721 | 0.079 |
| | | Richness | 44.8 | 3 | 14.93 | 3.319 | .047* |
| Canjilones 20 | CANJ20 | | | | | | |
| | | Density | 9135 | 4 | 2284 | 6.296 | .002* |
| | | Richness | 157.8 | 4 | 39.44 | 16.03 | .000* |
| Boya Esperanza 10 | ESPE10 | | | | | | |
| | | Density | 1.71E+04 | 4 | 4287 | 5.883 | .003* |
| | | Richness | 335.4 | 4 | 83.84 | 6.266 | .002* |
| Dakity 20 | DAKI20 | | | | | | |
| | | Density | 1.72E+05 | 1 | 1.72E+05 | 12.15 | .008* |
| | | Richness | 0.4 | 1 | 0.4 | 0.027 | 0.874 |
| Carlos Rosario 10 | CROS10 | | | | | | |
| | | Density | 5.01E+04 | 1 | 5.01E+04 | 1.442 | 0.264 |
| | | Richness | 0.1 | 1 | 0.1 | 0.009 | 0.928 |
| Luis Pena 5 | LPEN05 | | | | | | |
| | | Density | 4.62E+04 | 1 | 4.62E+04 | 18.37 | .003* |
| | | Richness | 4.9 | 1 | 4.9 | 0.483 | 0.507 |
| Cibuco 5 | CIBU05 | | | | | | |
| | | Density | 1822 | 3 | 607.3 | 2.703 | 0.08* |
| | | Richness | 160 | 3 | 53.33 | 17.49 | 0.0001* |

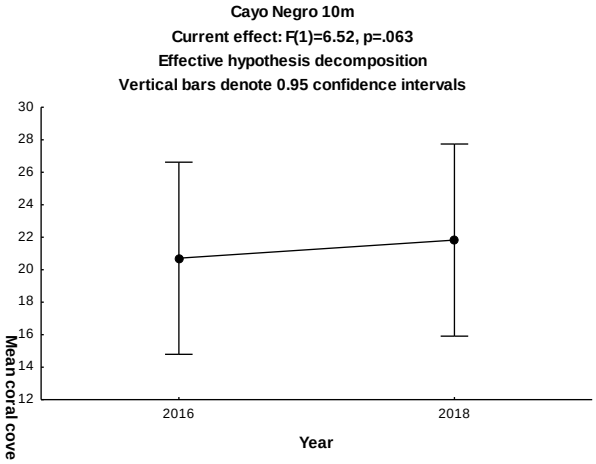
* Statistically significant differences at $p < 0.05$

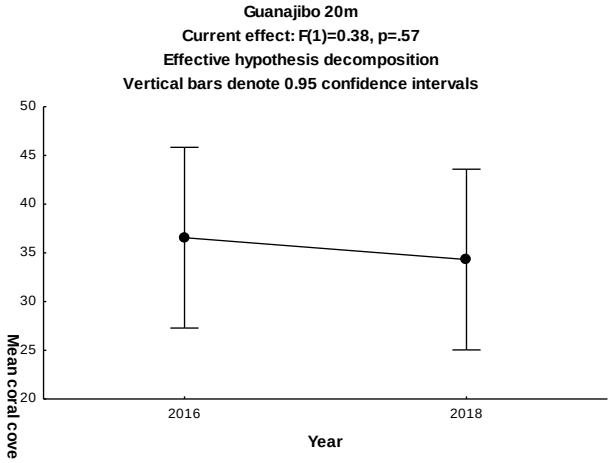
## Appendix 4. Prevalence of apparent infectious diseases on coral species at reef stations surveyed during 2017-18

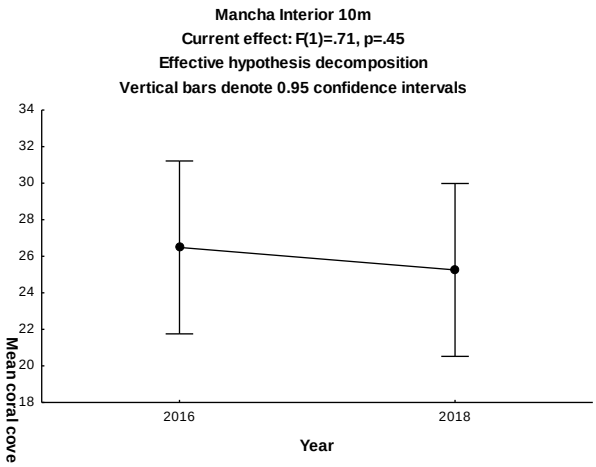
| Appendix 4. Prevalence of apparent infectuos diseases on coral species at reef sites surveyed in 2017-18 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | CORAL SPECIES | | | | | | | | |
| **Reef Stations** | *Agaricia* | *Agaricia* | *Siderastrea* | *Orbicella* | *Orbicella* | *Orbicella* | *Meandrina* | *Montastrea* | *Stephanocoenia* | *Pseudodiploria* | *Porites* | Total Diseased | Total Coral | Coral Disease |
| | *lamarki* | *agaricites* | *Siderea* | *franski* | *faveolata* | *annularis* | *meandrites* | *cavernosa* | *intercepta* | *strigosa* | *astreoides* | Coral Colonies | Colonies | Prevalence (%) |
| **El Negro 5** | | | 1 | | | 1 | | | | | | 2 | 62 | 3.2 |
| **El Negro 10** | | | 2 | 1 | 1 | | | | | | | 4 | 85 | 4.7 |
| **Guanajibo 20** | | | 1 | | | | | | | | | 1 | 75 | 1.3 |
| **Escollo Rodriguez 5** | | | 3 | | 2 | | | | 1 | | | 6 | 48 | 12.5 |
| **Manchas Exteriores 10** | 1 | | 2 | | | | | | | | | 3 | 86 | 3.5 |
| **Manchas Exterioesr 20** | | | 3 | 3 | | | | | | | | 6 | 67 | 9.0 |
| **Puerto Botes 15** | | | 2 | | | | 1 | | | | | 3 | 37 | 8.1 |
| **Puerto Botes 20** | | | | 1 | 2 | | 1 | | 1 | | | 5 | 31 | 16.1 |
| **Puerto Canoas 30** | | | | | | | | 1 | | | | 1 | 57 | 1.8 |
| **Luis Pena 5** | | | | | 1 | | | | | | | 1 | 40 | 2.5 |
| **Carlos Rosario 10** | | | 3 | 2 | 3 | | | | | | 1 | 9 | 64 | 14.1 |
| **Dakiti 20** | | | 1 | | | | | | | | | 1 | 50 | 2.0 |
| **Esperanza 10** | | | 3 | | | | | | 2 | | | 5 | 37 | 13.5 |
| **Canjilones 20** | | | | | 1 | 1 | | | | | | 2 | 75 | 2.7 |
| **El Seco 30** | | | | | | | | | | | | 0 | 137 | 0.0 |
| **Cayo Diablo 5** | | | | | | | | | | | | 0 | 25 | 0.0 |
| **Palominito 10** | | | | | 1 | | | | | | | 1 | 50 | 2.0 |
| **Palomino 20** | | | | | | | | | | | | 6 | 40 | 15.0 |
| **Cibuco 5** | | 2 | | | 1 | 1 | | | | | 1 | 5 | 41 | 12.2 |
| **Cabezas 5** | | | 2 | | | | | | | 1 | | 3 | 31 | 9.7 |
| **Dominos 5** | | | | | | | | | | | | 0 | 72 | 0.0 |
| | | | | | | | | | | | Totals = | 64 | 1210 | |
| | | | | | | | | | | | Mean (%) = | 5.3 | | |

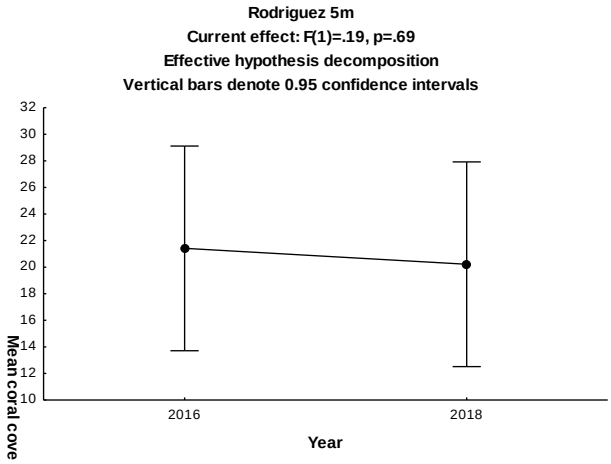
**Appendix 5. Temporal variations of the percentage of total reef substrate cover by hard corals at reef stations surveyed during 2017-18. Error bars are 95% confidence limits.**

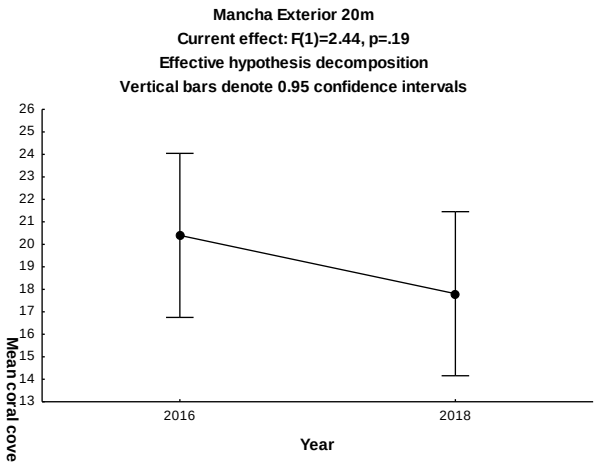


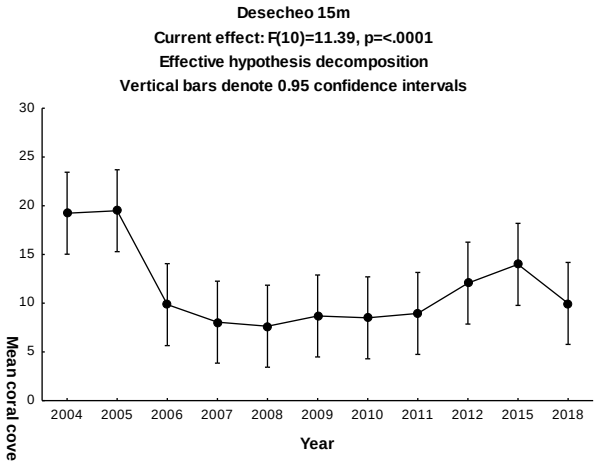



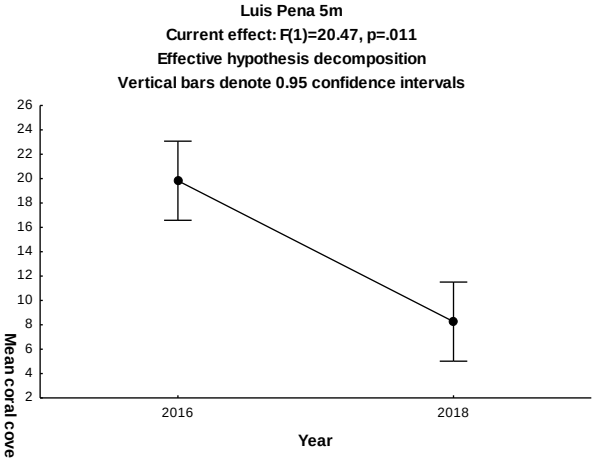



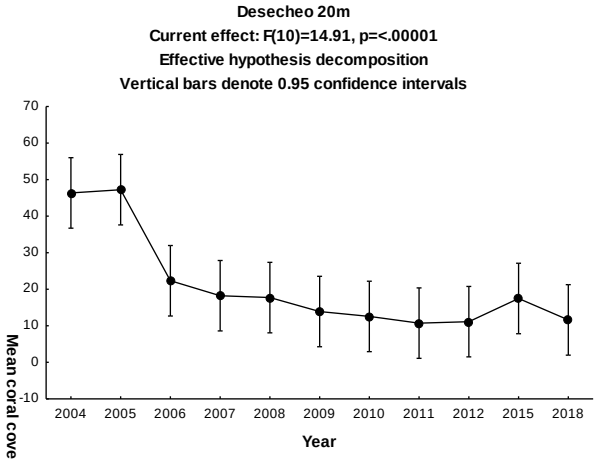



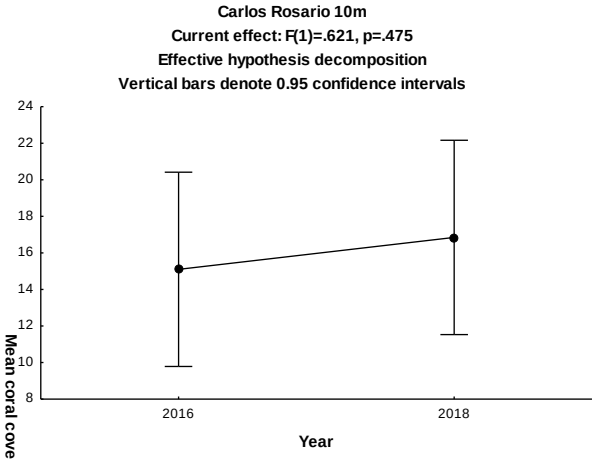



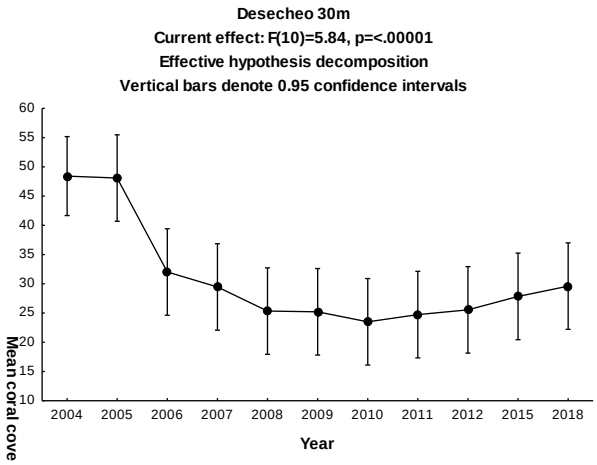



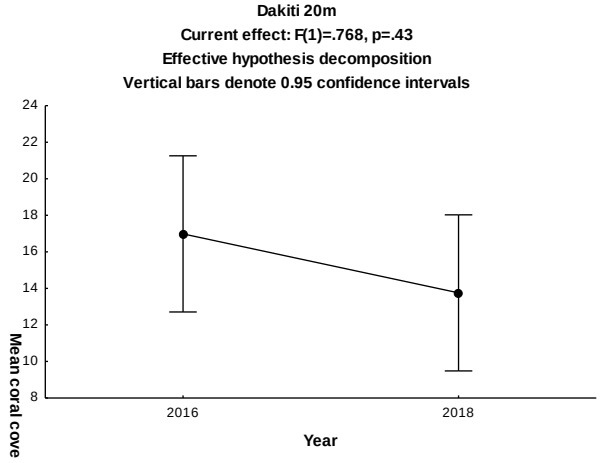

Desecheo 15m
Current effect: F(10)=11.39, p=<.0001
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2004 2005 2006 2007 2008 2009 2010 2011 2012 2015 2018

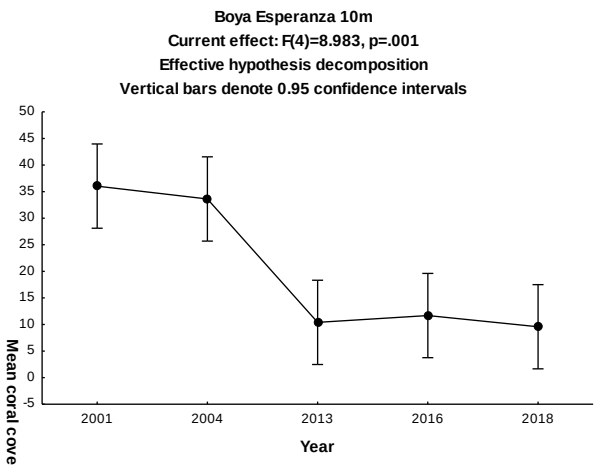

Luis Pena 5m
Current effect: F(1)=20.47, p=.011
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2016 2018

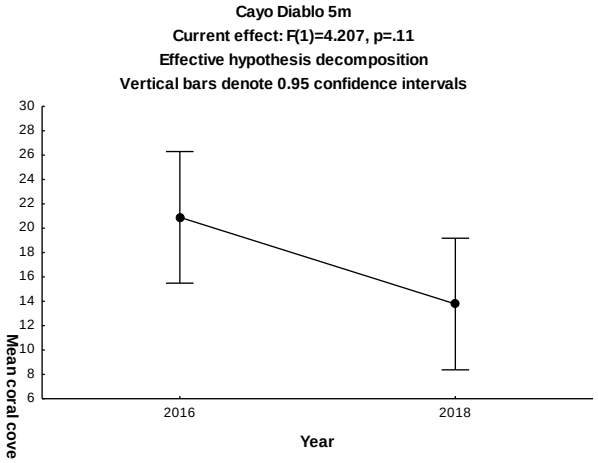

Desecheo 20m
Current effect: F(10)=14.91, p=<.00001
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2004 2005 2006 2007 2008 2009 2010 2011 2012 2015 2018

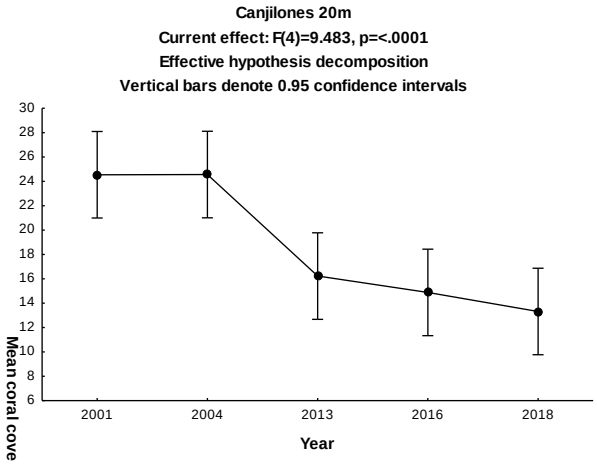

Carlos Rosario 10m
Current effect: F(1)=.621, p=.475
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2016 2018

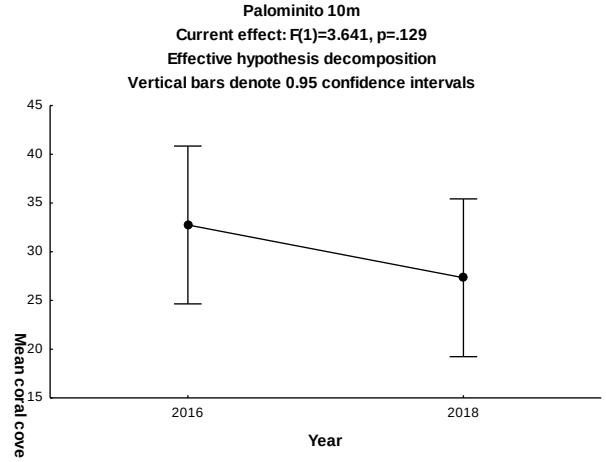

Desecheo 30m
Current effect: F(10)=5.84, p=<.00001
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2004 2005 2006 2007 2008 2009 2010 2011 2012 2015 2018

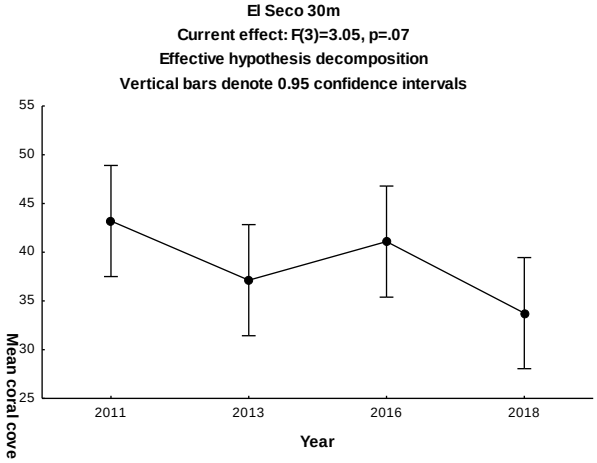

Dakiti 20m
Current effect: F(1)=.768, p=.43
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2016 2018

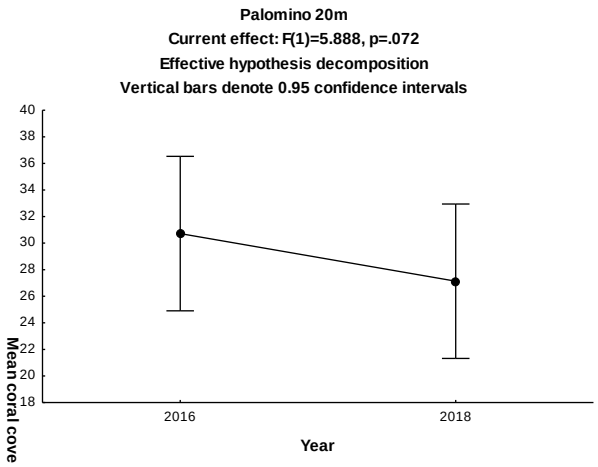

Boya Esperanza 10m
Current effect: F(4)=8.983, p=.001
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2001
2004
2013
2016
2018


Cayo Diablo 5m
Current effect: F(1)=4.207, p=.11
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2016
2018


Canjilones 20m
Current effect: F(4)=9.483, p=<.0001
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2001
2004
2013
2016
2018


Palominito 10m
Current effect: F(1)=3.641, p=.129
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2016
2018


El Seco 30m
Current effect: F(3)=3.05, p=.07
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2011
2013
2016
2018


Palomino 20m
Current effect: F(1)=5.888, p=.072
Effective hypothesis decomposition
Vertical bars denote 0.95 confidence intervals
Mean coral cove
Year
2016
2018