

ST. EUSTATIUS



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SUMMARY

Twenty sites across four monitoring zones of St. Eustatius's marine ecosystem were assessed using the Global Coral Reef Monitoring Network Caribbean Initiative (GCRMN-Caribbean) guidelines between June and July 2017. The protocol extracted data that indicated the biomass of key fish species and overall reef health including but not limited to relative abundance of macroalgae and hard coral, coral disease prevalence, coral recruit density and water quality to name a few. Using the Reef Health Index (McField and Kramer 2007), St. Eustatius' coral reef ecosystem is in "critical" condition (RHI Score = 1). Coral cover continues to remain stable from previous estimates (2015 = 5.19%, 2016 = 4.99% and 2017 = 4.73%) with macroalgae continuing to dominate (2015 = 27.93%, 2016 = 27.92%, 2017 = 36.6%). Herbivorous fish (Parrotfish/surgeonfish) biomass which aid in keeping macroalgal biomass in check, has suffered a 58% reduction over the last 18 years. The impact of which is observed in the increased macroalgal cover suggesting that parrotfish were the dominant algal grazers in the past since the black urchin (*Diadema antillarum*) die off. Reports on coral reef surveys done on the island in 1999 described low macroalgal cover in the presence of very high parrotfish/surgeonfish biomass. Grouper/snapper biomass is also poor with no large grouper species being observed on any of our survey dives. Even though these species were observed in relatively frequent numbers in 1999 at similar survey sites. The northern reserve had the highest fish density but lowest biomass suggesting a greater number of smaller fish, possibly juveniles when compared to the other zones. The southern reserve had the greater density of larger individuals when compared to the Atlantic side suggesting that both reserves may be playing a role in maintaining fish biomass and density. The coral species assemblage on the island's reefs has changed from being dominated by primary reef building corals such as *Orbicella* spp, *Pseudodiploria strigosa* and *Montastrea cavernosa* to smaller boulder corals such as *Siderastrea siderea* and *Porites astreoides*. This is probably due to the cumulative impact of the 2005 bleaching event and structural damage by multiple hurricanes, hampering the recovery process. In brief, further studies into identifying the specific drivers of coral reef degradation and potential mitigation measures on the island of St. Eustatius are needed to lessen the blow on these limited and fragile ecosystems.

1. INTRODUCTION

This is the third consecutive year that the coral reef ecosystem of St. Eustatius was monitored using the Global Coral Reef Monitoring Network Caribbean Initiative (GCRMN-Caribbean) guidelines. This represents a committed effort by the Ministry of Economic Affairs, Agriculture, Nature and Food quality (LNV), St. Eustatius National Marine Parks (STENAPA) and the Caribbean Netherlands Science Institute (CNSI) to consistent and scientifically sound monitoring of this vulnerable marine environment that heavily supports St. Eustatius' tourism product and fisheries sector. This monitoring is especially important as the Caribbean's marine ecosystems are increasingly under threat by the effects of climate change, coastal development and overfishing. St. Eustatius is no exception. It is therefore important that this work continues and the results used to enhance management and sustainable use of the island's marine resources.

2. METHODS

The GCRMN-Caribbean protocol was executed within the St. Eustatius National Marine Park (SNMP) from June 8th to July 27, 2017. The marine park surrounds the island from the high water mark to a depth of 30 meters. The majority of Statia's coral reefs are not characteristic of a "true" coral reef and are described as coral communities on lava outcrops. To maximize comparability across the region, the data were collected solely at depths ranging from 8 – 18 meters. An effort was made to include sites within the relatively industrialized harbor area along with sites presumably exposed to lower anthropogenic influence on the east, north and south sides of the island. Within the SNMP the

20 sites selected for 2015-2016 were again monitored in 2017 (Figure 1): Crooks Castle, Humps, Twin Sisters, Ledges, Valley of the Sponges, Five Fingers South, Double Wreck, Northman, The Blocks, The Cave, Aquarium, Anchor Point, Dump, White Wall, Gibraltar, Outer Jenkins Bay, Barracuda Point, Triple Wreck, Mushroom Gardens and Hangover.

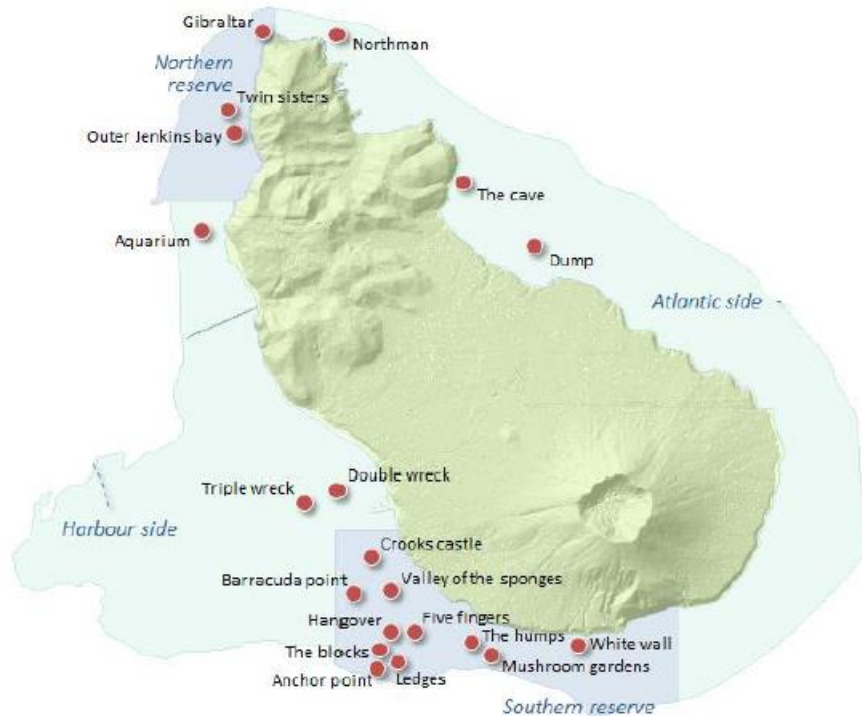


Figure 1 Map of the 20 survey sites in the four monitoring zones of St. Eustatius

The GCRMN-Caribbean guidelines utilize eight criteria when collecting data on coral reef ecosystems:

2.1 Abundance and biomass of reef fish taxa

To measure fish density, all fish (of all species) observed within a belt transect (30m length x 2m width) were counted, with the survey time limited to 6 - 8 minutes per transect. To measure size structure and calculate biomass, the length of each fish was estimated and assigned to the following size categories: <5cm, 6-10cm, 11-20cm, 21-30cm, 31-40cm and >41cm. For each monitoring zone, five belt transects were surveyed at each site and the data pooled to provide an average assessment of the density and size structure of all fishes observed for each zone. Such estimations of the fish assemblage provide the core information (snappers, groupers, parrotfish and surgeonfish), while also providing fundamental information about other members of the fish assemblage that may serve important roles in fisheries or ecosystem management.

2.2 Relative cover of reef-building organisms (corals) and their dominant competitors

Percent cover of key benthic taxa was assessed by taking digital photographs of the reef surface in standardized 0.9m x 0.6m quadrat areas. High resolution photographs were taken along the five fish density transect lines, capturing 15 images per transect (one image taken at every odd numbered meter mark on the 30m transect tape). Data was captured from the images through post – processing using Coral Point Count with Excel extension (CPCe) V4.1 software (Kohler and Gill 2006). Twenty-five software generated random points on each image were identified and classified into a

standardized benthic category, such as Seagrass, Sponge, Zooanthid or Cyanobacteria. Reef building corals were identified to species level; soft corals and macroalgae to genus level.

2.3 Health assessment of reef-building corals

Disease prevalence in corals was estimated using the photoquadrats from the benthic cover assessment. Data was recorded as the proportion of images collected that contained a coral with any disease pathology. For example, if there were four colonies in a particular photoquadrat and any of these colonies showed signs of disease, this image would be tagged as “with disease”. The number of images that were “with disease” was divided by the total number of images (1479) to generate a proportional estimate of disease prevalence.

2.4 Recruitment of reef-building corals

Coral recruits are defined operationally for this assessment as any stony coral (except *Favia fragum*) that is greater than 1.0 cm and less than 4.0 cm in length. Valuations of coral recruit density were recorded from replicate 25cm x 25cm (625cm²) quadrats. Five quadrats were surveyed along each of the first three transects used for fish and benthic surveys. The lower left corner of the quadrat was placed at the 2, 4, 6, 8 and 10 meter marks. Each coral within the target size range was recorded to species.

2.5 Abundance of key macro-invertebrate species (lobsters, queen conch, sea urchins and sea cucumbers)

The number of lobsters, queen conch, sea urchins and sea cucumbers was recorded along the 5 fish belt transects at each site. The density of which was calculated by dividing the number of each species by the total surveyed area (30m x 2m x 5 = 300m²).

2.6 Water quality (i.e. water turbidity)

A secchi disk (black and white disk 20cm in diameter) was used to estimate turbidity/visibility. The secchi disk was placed at the beginning of the first transect by the diver. The diver then swims away from the disk along the transect until the black and white markings of the disk cannot be seen. The distance at which the disk disappears and reappears as the diver swims towards the disk is recorded. The average of these two distances is called the Secchi depth. The shorter the distance recorded the greater the turbidity.

2.7 Macroalgae height

The canopy heights of the macroalgae were recorded at a maximum of 5 points in the five coral recruitment quadrats mentioned in section 3.4. The Macroalgal Index for each site was determined by finding the product of macroalgal cover (%) and the average macroalgal height. This index is used as a proxy for macroalgal biomass.

2.8 Rugosity

The three dimensional structure of the reef was measured using a weighted line. A ten-meter-long weighted line was laid along the benthos, following the contours of the reef, starting at the beginning of each transect. The distance covered by the weighted line was then measured linearly against the transect tape. The values obtained for each transect were averaged to give the rugosity of the site. A rugosity of 10m indicates that the reef is flat. The smaller the value the greater the topography of the reef.

The Reef Health Index was developed by the Healthy Reef Initiative (Kramer, 2003; McField & Kramer, 2007; Healthy Reef Initiative, 2008; www.healthyreef.org) and the description of the four key reef health indicators is given by Kramer et al. (2015).

The Reef Health Index (RHI) is based on four key coral reef health indicators:

- Coral cover - the proportion of benthic surface covered by live stony corals, contributors to the three-dimensional framework
- Fleshy macroalgae cover – the proportion of benthic surface cover by fleshy macroalgae, an increase in macroalgae limits stony coral recruitment and recovery
- Herbivorous fish – a measure of biomass of herbivorous reef fish (e.g. parrotfish and surgeonfish), these grazing species play a major role in controlling (macro)algae that could overgrow coral reefs
- Commercial fish – a measure of biomass of reef fish (e.g. groupers and snappers) with commercial importance to people

The mean values of the indicators are compared to the criteria listed in Table 1. The indicators are given a grade from one ('critical') to five ('very good'). The four grades are combined and equally weighted to obtain a RHI score. An overall score of 1-1.8 is "critical", >1.8-2.6 is "poor", >2.6-3.4 is "fair", >3.4-4.2 is "good" and >4.2-5 is "very good".

Table 1 Overview of the criteria for the four key coral reef health indicators

REEF HEALTH INDEX (RHI)					
Reef Health Index Indicators	Very good (5)	Good (4)	Fair (3)	Poor (2)	Critical (1)
Coral Cover (%)	≥40	20.0-39.9	10.0-19.9	5.0-9.9	<5
Fleshy Macroalgae Cover (%)	0-0.9	1.0-5.0	5.1-12.0	12.1-25	>25
Key Herbivorous Fish (g/100m ²) <i>(only parrotfish and surgeonfish)</i>	≥3480	2880-3479	1920-2879	960-1919	<960
Key Commercial Fish (g/100m ²) <i>(only snapper and grouper)</i>	≥1680	1260-1679	840-1259	420-839	<420

3 RESULTS

3.1 Abundance and biomass of reef fish taxa

Biomass

Based on surveys conducted on approximately 6000m² of coral reef habitat across 20 sites, the island of St. Eustatius has an average total fish biomass of 5334.52 g/100m² (Figure 2). The Harbour side had the highest biomass of all the zones (7676.85 g/100m²) with the Northern Reserve having the lowest (3540.86 g/100m²). The Southern Reserve, the island's largest no-take zone had the third highest biomass (5160.81 g/100m²) (Figure 2). There was no significant difference among the biomass for each zone (ANOVA $p = 0.25$). Parrotfish/surgeonfish biomass for all 20 sites ranged from 555.26-4478.77 g/100m². Grouper/snapper biomass ranged from 0-1504.67 g/100m². Based on the Reef Health Index developed by Healthy Reef Initiative (2008), parrotfish/surgeonfish biomass for the island is "Fair" (2095.93 g/100m²) while grouper/snapper is "Poor" (621 g/100m²). It must be noted that none of the larger grouper species were observed at any of the 20 survey sites. The Coney, *Cephalopholis fulva*, was the most dominant grouper species observed. Snappers were only observed at 5 sites, 4 of which are located in the Southern Reserve and the other being Aquarium in the Harbour Side zone. The snapper species observed were Schoolmaster (*Lutjanus apodus*), mahogany (*L. mahogoni*), mutton (*L. analis*) and yellowtail (*Ocyurus chrysurus*).

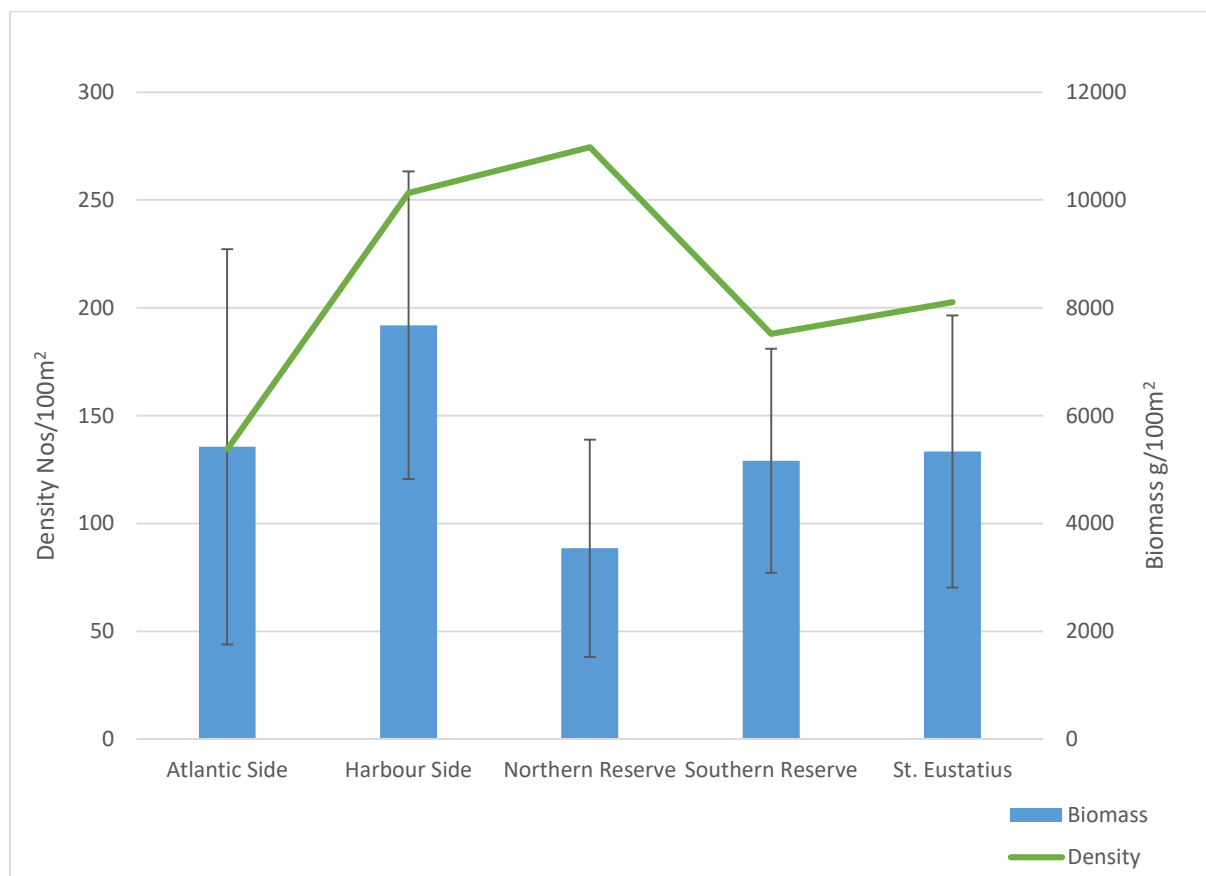


Figure 2 Average Biomass and Density of Fish in the Four Monitoring Zones of St. Eustatius. Error bars indicate the standard deviation for biomass estimates

The Southern Reserve had the highest average parrotfish/surgeonfish biomass of the four zones (2447.31 g/100m²), only marginally higher than the Atlantic side (2452.14 g/100m²) (Figure 3). The Harbour side had the lowest parrotfish/surgeonfish biomass (1074.62 g/100m²). For

grouper/snapper biomass, the Southern Reserve also reported the highest biomass (694.84 g/100m²), only marginally greater than the Northern Reserve (671.67 g/100m²). Both the Harbour side and the Atlantic Side recorded the lowest and a similar biomass (460.31 g/100m² and 460.30 g/100m² respectively). Parrotfish/surgeonfish or grouper/snapper biomass were not significantly different between zones (ANOVA $p = 0.19$ and $p = 0.68$ respectively).

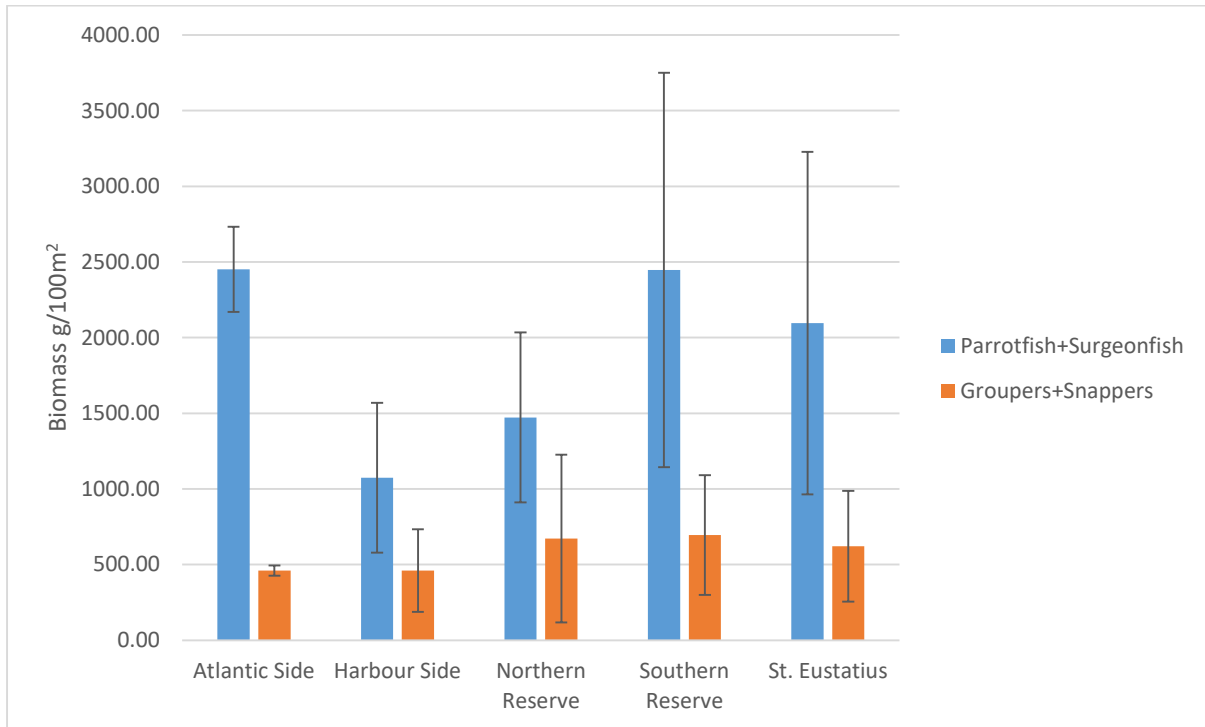


Figure 3 Average Biomass of Key Fish Species (Parrotfish and surgeonfish, groupers and snappers) at the Four Monitoring Zones of St. Eustatius. Error bars indicate the standard deviation of the biomass estimates

Trophic composition of species was approximately 50% Carnivore: 50% Herbivore of the biomass recorded across all zones except the Harbour Side where it was 82% Carnivore: 18% Herbivore. Parrotfish/surgeonfish accounted for $\geq 85\%$ of the total herbivore biomass in each zone except the Harbour side at 76%.

Density

A total of 12,161 fish were surveyed across 20 sites with an average density of 203 fish/100m². A total of 85 species across 33 families were recorded throughout the surveys. The Northern Reserve presented the highest density (274 fish/100m²) and the Atlantic side the lowest (134 fish/100m²). The Southern Reserve presented a density of 188 fish/100m² (Figure 2).

3.2 Relative cover of reef-building organisms (corals) and their dominant competitors

A total of 32,624 points were analyzed in CPCe V4.1 software to assess the relative cover of corals and their dominant competitors at 20 sites across the four monitoring zones of St. Eustatius' coastal marine ecosystem. Macroalgae were the most dominant competitor of corals, accounting for the highest benthic cover across all sites (65.35% including turf algae, 36.6% not including turf algae) resulting in a "Critical" score by the Reef Health Index. The Atlantic zone reported the highest macroalgae cover (76.8%) and the Harbour Zone, the lowest (45.65%) (Figure 4). Macroalgae cover was also significantly different across the zones (ANOVA, $p = 0.0019$) with the Southern Reserve and Harbour side being significantly different from all other zones after a post-hoc Tukey test. The Southern reserve had the highest coral cover of the four zones (5.33%) with the Harbour side having

the lowest (3.15%) (Figure 4). Coral cover was not significant among monitoring zones (ANOVA $p = 0.318$). The average coral cover across all sites, that is for the island, was 4.73% (SD = 1.98) resulting in a “Critical” score by the Reef Health Index. Gorgonians averaged 11.72% of the benthic cover across all sites with the Southern reserve having the highest gorgonian cover of 13.01%. Crustose Coralline Algae (CCA) had the highest cover in the Southern reserve (2.44%) and the lowest in the Northern reserve (0.02%). The overall cover of CCA across all sites was 1.64% and was not significant across monitoring zones (ANOVA $p = 0.059$). The Harbour side zone had the highest cover of seagrass (13.59%), predominantly the invasive *Halophila stipulacea*. All other sites had $\leq 0.02\%$ of seagrass.

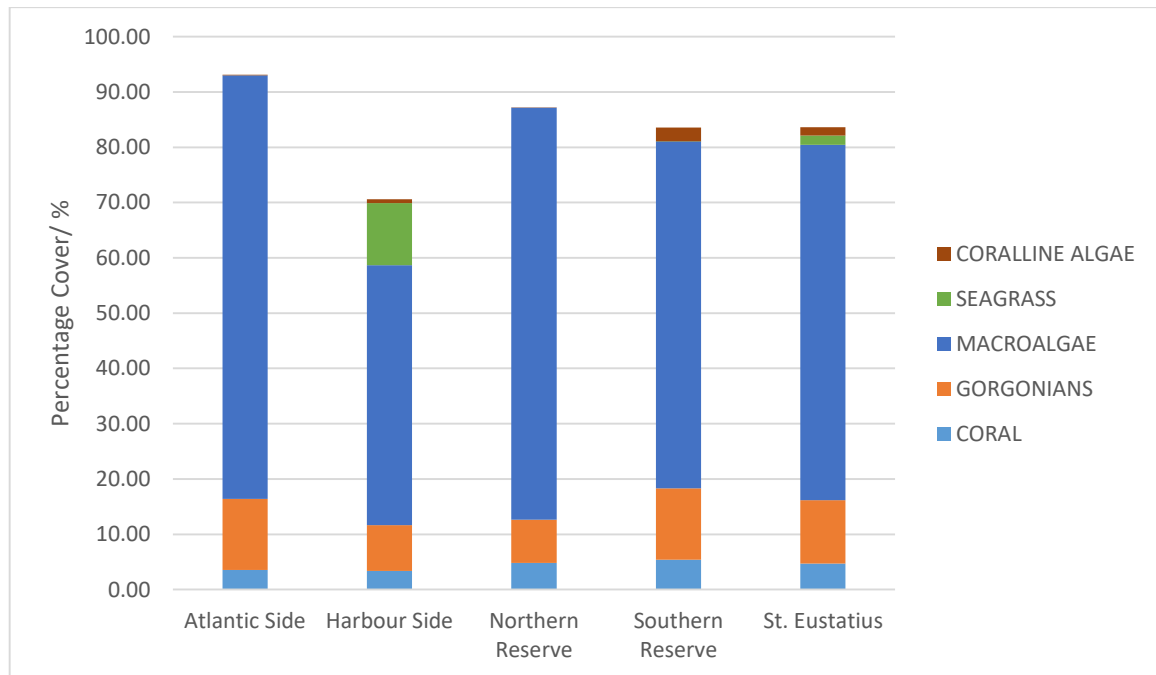


Figure 4 Composition of Key Benthic Categories across the Four Monitoring Zones and St. Eustatius. The remaining percentage composition in each monitoring zone consists of sponges, sand and zoanthids.

Coral Species Assemblage

Combined coral species richness was reported at 32 species. The Southern Reserve had the highest species richness of the four monitoring zones (30 species) while the Harbour side had the lowest (18 species) (Table 2). *Acropora cervicornis*, listed on Annex II of SPAW (Specially Protected Areas and Wildlife) Protocol was only recorded in the Southern Reserve. *Acropora palmata*, also on SPAW Annex II was not recorded in any transects. Other species on SPAW Annex II *Orbicella annularis* and *O. faveolata*, were found to have low cover. *Orbicella annularis* in particular was only observed in the Southern Reserve at $<1\%$. *Orbicella faveolata* observed in all zones except the Harbour side with cover ranging from 1.09% - 7.42%. Boulder coral such as *Porites astreoides* (19.29%), *Siderastrea siderea* (12.38%) and *Montastrea cavernosa* (11.73%) were the most dominant species recorded throughout the entire surveys. At the Atlantic side, *Porites astreoides*, *Montastrea cavernosa*, *Meandrina jacksoni*, *Siderastrea siderea* and *Pseudodiploria strigosa* accounted for 80% of the species recorded in that zone. All other species accounted for $\leq 4.04\%$ each. At the Harbour side, *Montastrea cavernosa*, *Siderastrea siderea* and *Pseudodiploria strigosa* accounted for 55.65% with all other species accounting for $\leq 8.8\%$ each. At the Northern Reserve, *Porites astreoides*, *Pseudodiploria strigosa* and *Montastrea cavernosa* accounted for 53.45% with all other species composing $\leq 7.38\%$. At the Southern Reserve, *Porites astreoides*, *Siderastrea siderea* and *Orbicella franksi* accounted for 46% with all other species accounting for $\leq 9.07\%$.

Table 2 Coral Species Composition of Total Coral Cover at the Four Monitoring Zones of St. Eustatius

Coral Species	Atlantic Side	Harbour Side	Northern Reserve	Southern Reserve	St. Eustatius
<i>Acropora cervicornis</i>	0.00%	0.00%	0.00%	0.18%	0.12%
<i>Agaricia spp.</i>	3.58%	3.62%	3.80%	7.52%	6.09%
<i>Colpophyllia natans</i>	3.17%	1.38%	1.57%	1.90%	1.94%
<i>Coral (general)*</i>	0.50%	0.00%	1.55%	0.36%	0.52%
<i>Coral juvenile</i>	1.54%	1.71%	0.42%	0.09%	0.48%
<i>Dichocoenia stokesi</i>	0.50%	1.49%	0.37%	0.58%	0.64%
<i>Pseudodiploria clivosa</i>	0.00%	0.00%	0.79%	0.09%	0.18%
<i>Diploria labyrinthiformis</i>	0.50%	3.07%	3.35%	2.80%	2.66%
<i>Psuedodiploria strigosa</i>	12.38%	15.76%	19.29%	6.19%	9.93%
<i>Eusmilia fastigiata</i>	0.00%	0.53%	0.39%	0.27%	0.29%
<i>Favia fragum</i>	0.54%	0.00%	0.00%	0.00%	0.06%
<i>Madracis decactis</i>	1.04%	7.01%	7.38%	1.99%	3.25%
<i>Madracis auretenra</i>	0.00%	0.53%	5.50%	0.54%	1.24%
<i>Manicina areolata</i>	0.00%	0.00%	0.00%	0.11%	0.07%
<i>Meandrina jacksoni</i>	0.00%	1.71%	0.76%	0.18%	0.41%
<i>Meandrina meandrites</i>	4.04%	1.91%	0.83%	0.58%	1.15%
<i>Millipora spp.</i>	15.78%	8.80%	6.99%	9.70%	9.88%
<i>Orbicella annularis</i>	0.00%	0.00%	0.00%	0.31%	0.19%
<i>Montastraea cavernosa</i>	17.89%	11.41%	20.81%	8.44%	11.73%
<i>Orbicella faveolata</i>	1.09%	0.00%	3.54%	7.42%	5.31%
<i>Orbicella franksi</i>	0.00%	0.00%	1.97%	11.52%	7.51%
<i>Mycetophyllia ferox</i>	0.00%	0.00%	0.00%	0.09%	0.06%
<i>Mycetophyllia lamarckiana</i>	0.00%	0.00%	0.00%	0.09%	0.06%
<i>Porites astreoides</i>	18.82%	5.64%	13.36%	23.17%	19.29%
<i>Porites digitate</i>	1.50%	5.03%	3.03%	3.24%	3.21%
<i>Scolymia lacera</i>	0.00%	0.00%	0.00%	0.18%	0.11%
<i>Siderastrea radians</i>	1.00%	1.05%	0.39%	0.18%	0.40%
<i>Siderastrea siderea</i>	15.09%	28.48%	3.54%	11.32%	12.38%
<i>Solenastrea bournoni</i>	0.00%	0.00%	0.00%	0.28%	0.17%
<i>Solenastrea hyades</i>	0.00%	0.00%	0.00%	0.09%	0.06%
<i>Stephanocoenia intersepta</i>	0.54%	0.86%	0.39%	0.54%	0.55%
<i>Tubastraea aurea</i>	0.50%	0.00%	0.00%	0.00%	0.06%
Species Richness	19	18	22	30	32

*Corals that could not be identified due to poor image quality.

Macroalgae Species and Turf Algae Assemblage

Dictyota sp. and turf algae were the most dominant of the macroalgal species recorded in each monitoring zone except for the Harbour side (Turf algae, 48% and Cyanocateria, 29%) (Figure 5). The Northern Reserve had the highest turf algae cover accounting for 75% of the total species assemblage recorded with the Southern Reserve having the lowest (32%). Cynaobacteria was the third most dominant coral competitor recorded across all sites, being the highest in the Harbour zone (29%) and lowest at both the Atlantic side and Northern Reserve zones. *Halimeda* spp. were recorded at $\leq 1\%$ in all zones. *Lobophora* spp. were recorded at 0-7% across the zones. *Peyssonnelia* spp. were recorded at 3-7% across the zones.

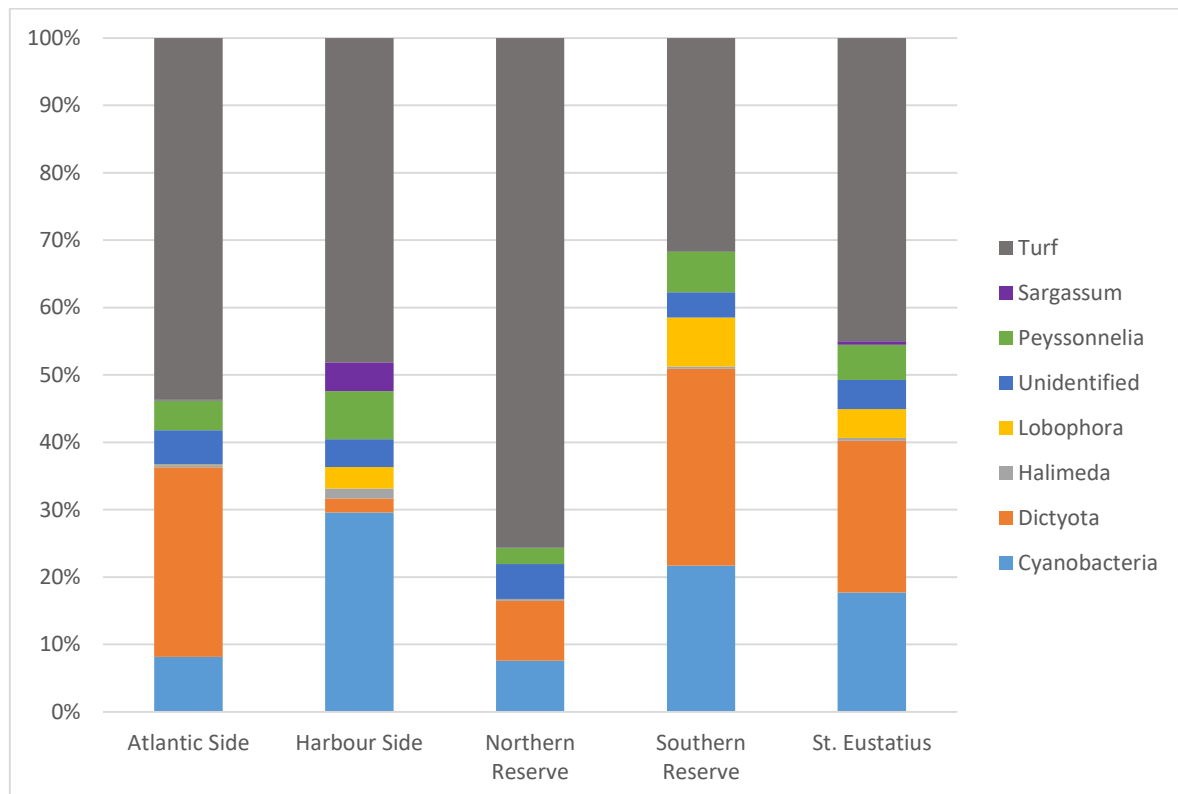


Figure 5 Macroalgae Species Assemblage across the Four Monitoring Zones and St. Eustatius

3.3 Health assessment of reef-building corals

A total of 1447 benthic photos were analyzed to determine disease prevalence. Three photos were found to have diseased corals resulting in a disease prevalence of 0.21%. *Montastrea cavernosa* appeared to be infected with Yellow Band Disease at the Dump site on the Atlantic side (Figure 6). A possible White Plague infection on a *Colpophyllia natans* at Ledges (Figure 7) and Black Band Disease on a *C. natans* at The Humps (Figure 8), both in the Southern Reserve.

As it relates to bleached coral, 6.31% of the island's coral cover were observed to be partially bleached. The highest percentage of bleached coral was observed at the Harbour side zone (8.95%) and the lowest in the Southern Reserve (5.43%). The Northern Reserve and Atlantic Side had 6.99% and 6.24% respectively, of coral cover being bleached. *Montastrea cavernosa* was observed as the species with the most incidences of bleaching.



Figure 6 Potential Yellow Band infection on a *Montastrea cavernosa*



Figure 7 Potential White Plague infection on a *Colpophyllia natans*



Figure 8 Black Band Disease infecting a *C. natans*

3.4 Recruitment of reef-building corals

A total of 159 coral recruits were observed in 300 quadrats (0.0625 m² per quadrat) across the 20 sites. The Harbour side had the highest coral recruit density of all the zones (19 recruits/m²) with the Atlantic side having the lowest (5 recruits/m²) (Figure 9). The island average is 9 recruits/m². A total of 10 coral recruit species were recorded. There was a significant difference observed among the recruit density across all zones (ANOVA, $p = 0.008$). Subsequent post-hoc tests determined that recruit density between the Harbour side was significantly different from the other zones ($p = 0.0001$). No correlation was detected between recruit density and percentage cover of crustose coralline algae. However, there was a negative relationship between macroalgal index and coral recruit density but this was not significant (Pearson's correlation, $p = 0.38$).

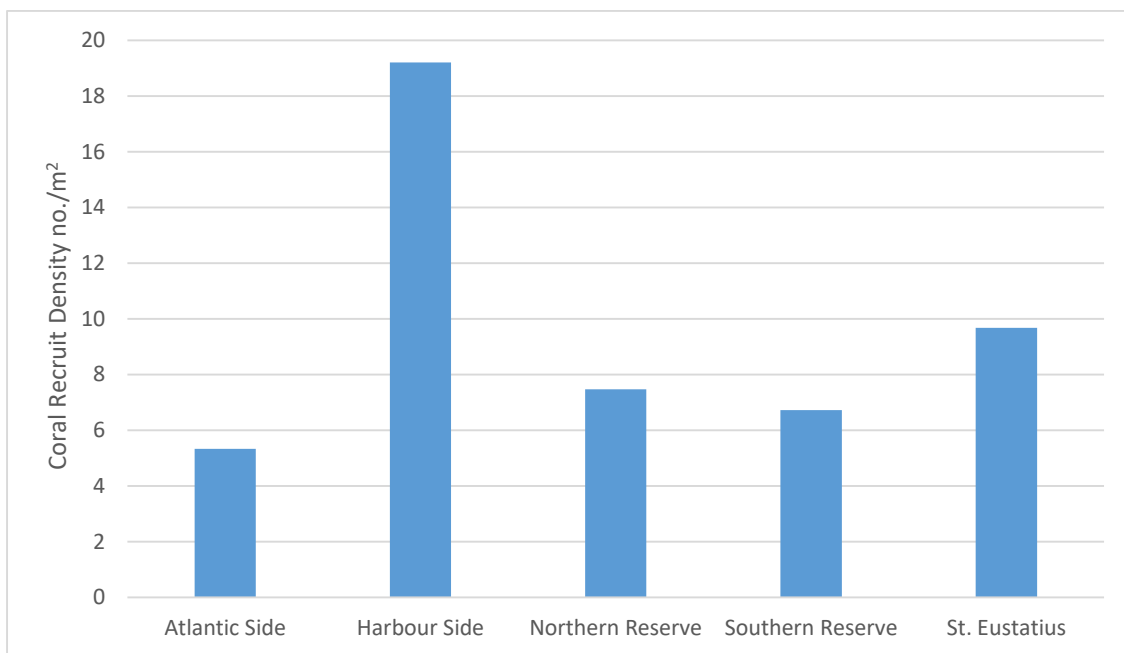


Figure 9 Average Coral Recruit Density in the Four Monitoring Zones of St. Eustatius

Siderastrea siderea was the most abundant recruit species observed throughout the survey (41%) followed by *Siderastrea radians* (21%) (Figure 10). *Meandrina meandrites*, *Mancicina areolata* and *Scolymia* spp each accounted for 1% of the species composition. *Siderastrea siderea* was the most abundant species in all the zones except the Northern Reserve where *Siderastrea radians* was the most abundant. *Agaricia* spp accounted for <10% of the recruits across all zones. *Madracis decactis* and *Stephanocoenia intersepta* was observed in all zones except the Atlantic side.

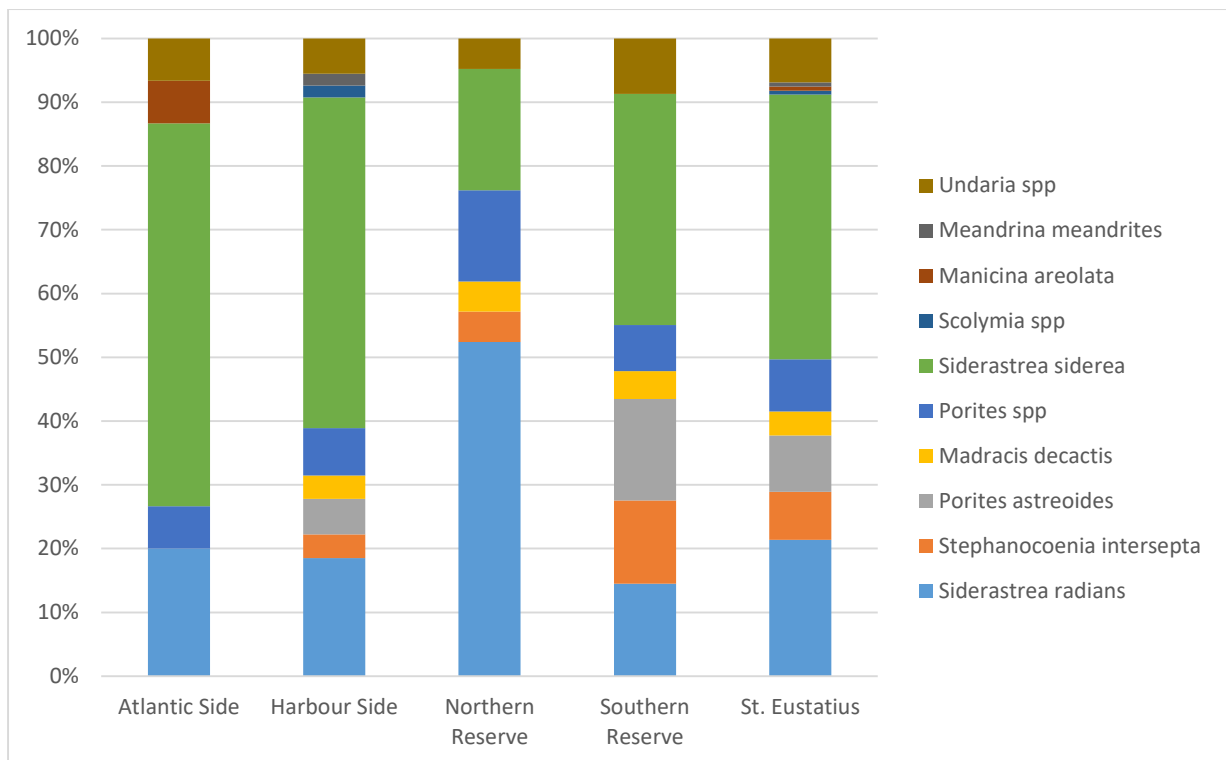


Figure 10 Species composition of Coral Recruits across the Four Monitoring Zones and St. Eustatius

3.5 Abundance of key macro-invertebrate species (lobsters, queen conch, sea urchins and sea cucumbers)

The abundance of key macro-invertebrates recorded were very low, especially for sea urchins and sea cucumbers. An area of 300m² was surveyed at each site. One adult *Diadema antillarum*, 3 juveniles, 6 other urchin species, 3 sea cucumbers, 1 queen conch and 10 lobsters were observed for the entire survey. *Diadema antillarum*, both adults and juveniles were observed at the Dump and Aquarium sites respectively. The sea cucumbers were observed at the Humps, Aquarium and Barracuda Reef, one at each site. The only queen conch recorded was observed at Twin Sisters. Lobsters were observed at Crook's Castle, Double Wreck, Northman, Blocks, Aquarium and Hangover (Figure 11).

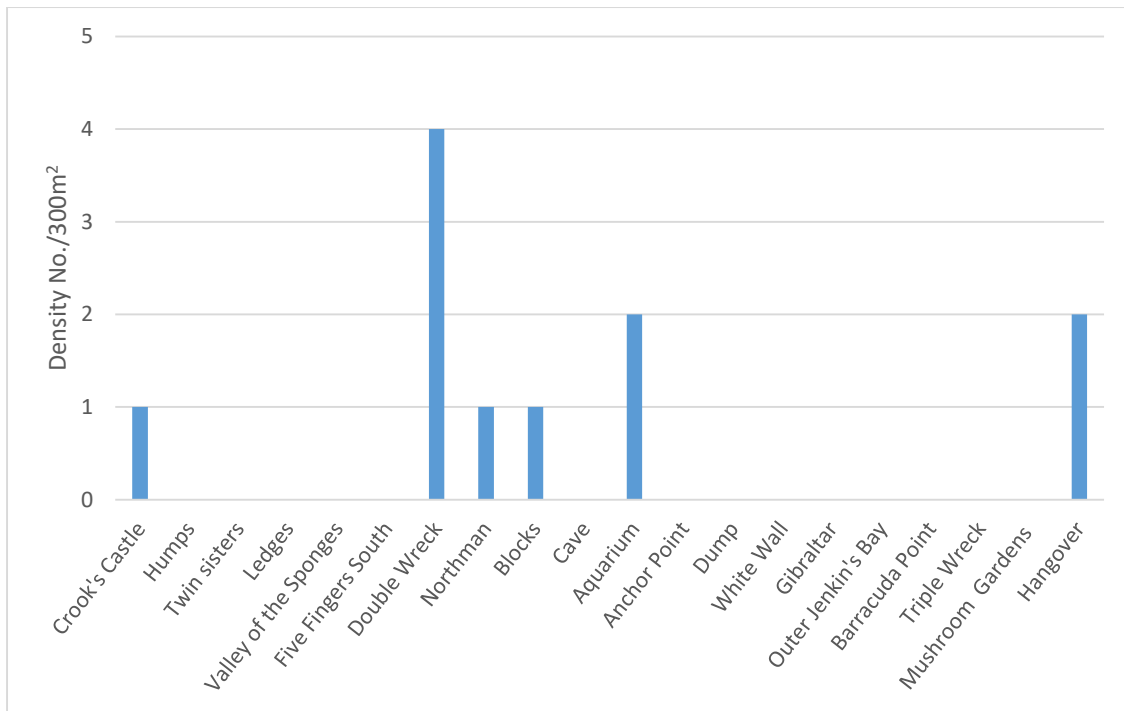


Figure 11 Density of Lobsters observed at the 20 GCRMN Sites

3.6 Water quality (i.e. water turbidity)

The Cave had the highest turbidity (Secchi disk visibility 13.5 m); with Blocks having the lowest turbidity (visibility 35 m; Figure 12). However, these values are highly influenced by the time of day and observer bias therefore, they must be interpreted with care. The average of the sites is 26 m with a standard deviation of 7 m. No significant difference was found among the average turbidity for each monitoring zone (ANOVA, $p = 0.175$)

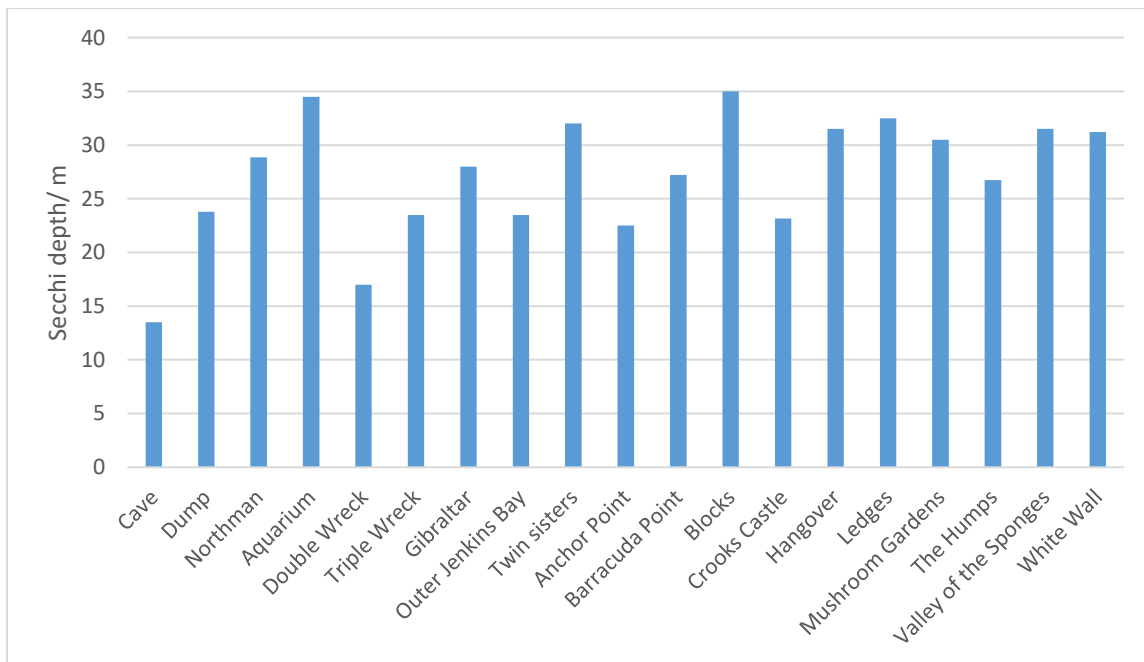


Figure 12 Secchi depth for the 20 monitoring sites around the island of St. Eustatius

3.7 Macroalgae height and Macroalgae Index

Average macroalgal heights ranged from 0.32cm - 3.25cm across all sites. Macroalgal indices across all sites ranged from 14 – 274.1 and suggests a high macroalgal standing stock. The highest macroalgal profile was observed at the Dump and the lowest at White Wall. The Atlantic side accounted for the highest macroalgal profile of the four zones (145.9) and the Harbour Side the lowest (49.1). The Northern and Southern Reserves reported indices of 54.1 and 116.4 respectively.

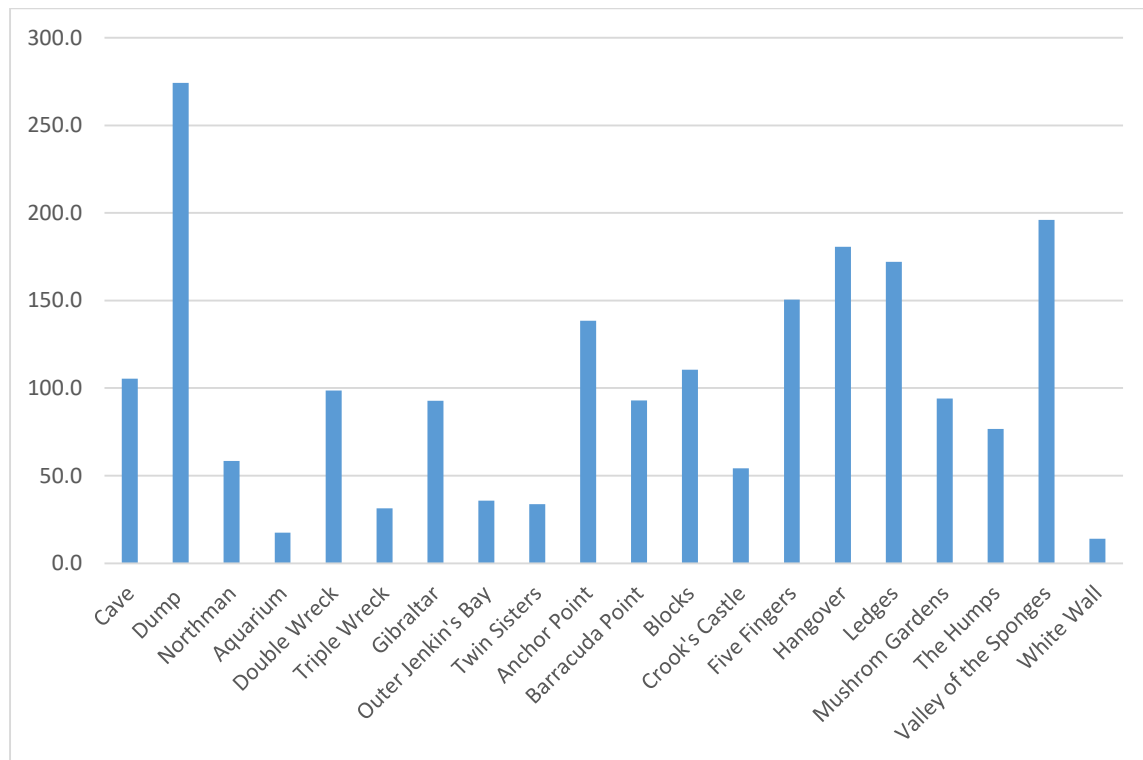
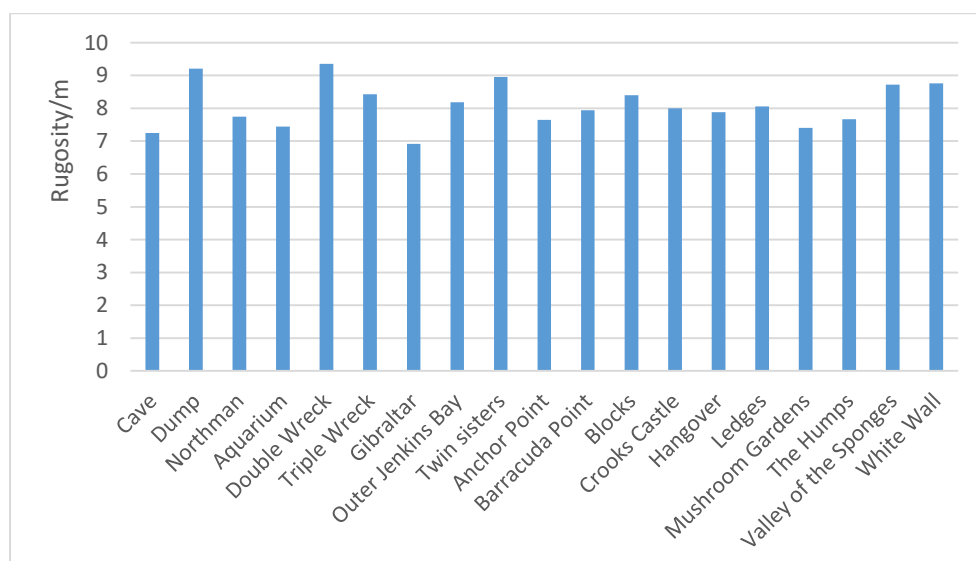


Figure 13 Macroalgal Index for the 20 monitoring sites around the island of St. Eustatius

3.8 Rugosity

Gibraltar had the greatest rugosity of the 20 sites (6.92m) indicating the site with the most structural relief. Double Wreck had the lowest rugosity of 9.35m. All other sites ranged from 7.4m – 9.21m. The average of the rugosity for each zone were not significantly different (ANOVA, $p = 0.886$).



4. DISCUSSION

According to the Reef Health Index (RHI), the island's coral reef habitat is in "critical" condition (RHI Score = 1). This is attributed to very low coral cover (4.94%), extensive macroalgal cover (36.6%), very low grouper/snapper biomass and "fair" parrotfish/surgeonfish biomass. The condition of Caribbean coral reef habitats has been on the decline over the last 30 years (Jackson et al. 2014) and St. Eustatius is no exception. Though not statistically significant, coral cover over the last three years has shown a marginal decline (2015 = 5.19%, 2016 = 4.99% and 2017 = 4.94%) with macroalgal cover remaining relatively the same in 2015 and 2016 (27.93% and 27.92% respectively) but increasing drastically in 2017. Therefore, the coral reefs of St. Eustatius continue to be macroalgae dominated. Despite recruit density in 2017 remaining relatively the same as 2016, recruitment may be affected over the long term as it was observed that recruit density decreased with increased macroalgal cover. Though this relationship was not significant, it is cause for concern. Crustose coralline algae cover, also important in coral recruitment (Tebben et al. 2015), was very low having been reported as 38% in 1999 by Klomp and Kooistra (2003) but is drastically lower in 2017 (1.64%).

The two marine reserves reported lower fish biomass than the two monitoring zones in which fishing is allowed (Atlantic and Harbour zones). The northern reserve had the lowest biomass but the highest fish density. This could be explained by a greater density of small individuals observed within the northern reserve when compared to other zones. Successful recruitment of juvenile fish into this zone is a possible cause for this, however research into the effect of fine-scale ocean currents on larval connectivity within Statia's territorial waters is needed to decipher this (Christie et al. 2010). Fish biomass of the southern reserve and the Atlantic zone were not vastly different, though the former had greater fish density. This suggests a greater density of smaller fish in the southern reserve when compared to the Atlantic zone. From these results it is implied that the marine reserves are playing a role in maintaining sustainable reef fish biomass and density in Statia's marine ecosystem, but not exclusively. That is to say the fishing pressure on Statia is relatively low when compared to other Eastern Caribbean territories (<10 active part-time fishermen). This allows fish stocks to remain relatively stable. The high biomass observed in the Harbour zone could be due to the spillover effect from both marine reserves (Russ and Alcalá 1996, McClanahan and Mangi 2000, Bohnsack 1998) as well as the availability of reef habitat (Gratwicke and Speight 2005). The southern reserve and Harbour zone have more available reef habitat due to the wide island shelf as opposed to the narrower shelf of the northern reserve and Atlantic zone.

After analyzing coral reef habitat and associated fish biomass data from across the Caribbean between 1970-2014, Jackson et al. (2014) attributed the degradation of Caribbean coral reefs to a number of reasons (ocean warming, invasive species, *Diadema* die-off, lack of good governance, coastal pollution and development). One reason in particular, was the increased fishing pressure on key herbivorous species such as the parrotfish and surgeonfish. This along with the die-off of the grazing sea urchin, *Diadema antillarum*, significantly reduced the number of large macroalgal grazers on coral reef habitat throughout the Caribbean (Jackson et al. 2014). Making way for an increase in macroalgal cover, consequently leading to reduced spatial availability for coral recruitment and survival. Our surveys indicated an absence of *Diadema* throughout the survey area and an approximate 58% reduction in parrotfish/surgeonfish biomass over the last 18 years. The scarcity of *Diadema* on St. Eustatius' reef habitat has not changed since the first report of Klomp and Kooistra (2003) in 1999. This suggests that parrotfish may have been the dominant grazers on the island's reef in the absence of *Diadema* for some time with any reduction in biomass having potential negative effects on long term reef health. This is supported by the low macroalgal cover (10%, not including turf algae) with high herbivore biomass (4977 g/100m²) reported on St. Eustatius' reefs in surveys completed in 1999 (Klomp and Kooistra 2003). Increased nutrient enrichment from surface run-off and the discharge of untreated wastewater into the marine

environment can also cause increased macroalgal cover and biomass via eutrophication. These are anthropogenic forces that currently impact Statia's marine environment. To give an indication of the level of impact, dissolved inorganic nitrogen (DIN) and soluble reactive phosphate (SRP) have been determined for sites within Statia's marine environment by the Caribbean Netherlands Science Institute. These nutrients are responsible for eutrophication when present in concentrations of $> \sim 1.0 \mu\text{M}$ and $> \sim 0.10 \mu\text{M}$ respectively (Lapointe, Littler, and Littler 1993). For July – December 2016, concentrations exceeded thresholds for both nutrients in Statia's Harbour, Jenkin's Bay, Zeelandia Bay and three sites in Oranje Bay indicating the need for mitigative measures. Fishing pressure may have affected the grouper/snapper biomass with an approximate 33% reduction since 1999. However, there is no fisheries data available to substantiate the impact of fishing pressure, as fisheries monitoring only began in 2012. In particular, the loss of larger grouper species which were observed in 1999 on 3-24% of dives depending on the species (Klomp and Kooistra 2003), were not observed in any of our transects. Yellowfin grouper were the only species observed with any frequency (Munro and Blok 2005) but have now become very rare. Munro and Blok (2005) reported Red hind and Rock hind as fairly common on the reefs of St. Eustatius. This seems to have remained the same for the 2017 survey period. This may be due to the possible inclusion of a spawning aggregation site in the Southern Reserve (Munro and Blok 2005). Recovery of the larger grouper species may be assisted by the extension of the island's no-take zones (no-take zones stop at 30m isobar) to include more deep reef habitat essential to these larger species (Thompson and Munro 1978) or the implementation of closed seasons during spawning events to allow for maximum reproduction and recruitment. Further research is needed to assess the effectiveness of deeper no-take zones as well as to determine suitable location and size.

Unfortunately, some coral species observed on St. Eustatius's reefs in the early benthic surveys of 1999 were not recorded in 2017. Klomp and Kooistra (2003) reported the dominance of boulder corals on St. Eustatius's reefs in 1999, in particular *Orbicella annularis*. No acroporid species were observed on St. Eustatius during these surveys in 1999 or this present study. This is due to the preference of these species to inhabit waters not deeper than 5 m. Dive sites surveyed in 1999 and this study did not go shallower than 12 m. While boulder corals still dominate on the reef, there has been a shift in species assemblage with no observations of *O. annularis* in any surveyed transect. Instead, *O. annularis*, *O. faveolata*, *O. franksi*, *Montastrea cavernosa* and *Pseudodiploria strigosa* which previously represented approximately 54% of species assemblage, now account for only 34% and no longer includes observations of *O. annularis*. The low relief boulder coral species such as *Porites astreoides* and *Siderastrea siderea* now dominate with *Montastrea cavernosa* being the only species of the primary reef builders to have maintained an individual dominance greater than 10%. Additionally, *M. cavernosa* was recorded as having the same percentage abundance as observed in 1999 (12%). However, this species may be under threat as one or more colonies experienced some degree of bleaching in 11% of the total benthic photos taken. Coral diseases may have also played a role in the degradation of Statia's coral reefs. The 1999 surveys reported less than 1% of coral colonies having been disease infected. In 2015, Piontek (2015) observed 2.2 % of benthic photos with diseased corals and 4.01 % in 2016. Therefore, diseases don't seem to have a significant impact on Statia's reef. However, further research is required to determine this. The change in boulder coral species assemblage could be as a result of the hurricanes which affected the island (Hurricanes Lenny and José in 1999 and Omar in 2008). Hurricanes not only cause major structural damage to reefs, but set back the recovery process for slow growing. Wave energy generated by hurricanes have the ability to break fragile branching corals such as the Acroporids and overturn large boulder colonies such as the *Orbicella* spp (Wilkinson and Souter 2008). This along with the devastating bleaching event of 2005 which affected 70-80% of corals and resulted in a 50% decrease in live coral cover (Wilkinson 2008). The cumulative impact of this bleaching event and the multiple hurricanes in the last two decades have severely impacted the island's reefs for the long term. The effects of

hurricanes Irma and Maria were assessed by conducting the GCRMN protocol on 10 sites in November 2017. Comparisons before and after these devastating hurricanes will be presented in a subsequent report.

Siltation caused by land erosion and surface run-off due to improper drainage system has the ability to smother reef habitat resulting in the death of coral or limiting the light available for the coral's symbiotic zooxanthellae to photosynthesize affecting coral nutrition. With large numbers of free roaming livestock (cows, goats, sheep) on the island, the marine environment experiences increased nutrient enrichment from animal excrement during precipitation events. The impact of this anthropogenic stress on St. Eustatius's marine ecosystems is still unknown. Further research into this is required to determine the level of impact this is having on Statia's coral reefs and the potential need for mitigative measures.

The results presented must be interpreted with caution due to limited sampling of all zones except the southern reserve. Eleven sites were sampled within the southern reserve while only 3 sites were sampled in all other zones. A rearrangement of sampling effort to include 1- 3 additional sites in the other zones may be done to achieve an even more representable survey.

5. RECOMMENDATIONS

Based on the results of the 2017 GCRMN surveys, the following points are recommended:

1. Reduction in fishing pressure of herbivorous species in particular the parrotfish. This can be done through the introduction of size limits, use of only sustainable fishing methods (ban use of spear guns on the species while freediving) or a closed season. An additional method is through a public awareness campaign on the importance of the species, significantly reducing the consumption of parrotfish by the general public. The desired goal of the campaign would be to reduce market demand which will discourage the capture of the species by fishermen.
2. Reduction in the fishing pressure of large groupers. Protection of larger grouper species is essential to increase grouper biomass. The current no-take zones of the island does not protect essential deep reef habitat used by the species. Extension of these zones are therefore needed. Research to determine the feasibility of a closed season and potential grouper spawning aggregation locations for their protection are methods that can be considered.
3. Conduct research to assess the impact of siltation by land erosion/surface run-off on the island's marine environment. Land erosion and surface run-off occur around the island during precipitation events consequently dumping unknown quantities of silt into the marine environment. This has and will continue to be an issue for the coral reef ecosystems of the island unless the level of impact is determined and mitigation strategies developed.
4. Habitat assessment beyond 20 m depth. Site selection is depth limited for diver safety. Little is known about the habitat deeper than 20 m depth. Using non-diver methods such as Baited Remote Underwater Video System (BRUVS) or video transects to assess fish stock and the benthos can be considered.

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