

8-2019

Characterization of Red Mangrove Propropoot Epibiont Communities of St. Johns USVI

Alan M. Buob
Montclair State University

Follow this and additional works at: <https://digitalcommons.montclair.edu/etd>



Part of the [Marine Biology Commons](#)

Recommended Citation

Buob, Alan M., "Characterization of Red Mangrove Propropoot Epibiont Communities of St. Johns USVI" (2019). *Theses, Dissertations and Culminating Projects*. 319.
<https://digitalcommons.montclair.edu/etd/319>

This Thesis is brought to you for free and open access by Montclair State University Digital Commons. It has been accepted for inclusion in Theses, Dissertations and Culminating Projects by an authorized administrator of Montclair State University Digital Commons. For more information, please contact digitalcommons@montclair.edu.

Abstract

In May 1989, Hurricane Hugo impacted St. Johns USVI destroying the Red Mangrove (*Rhizophora mangle*) Forest of Great Lameshur Bay. The impact restricted the tidal flow and caused massive destruction in the mangroves. Hurricane Marilyn (1995) hit St. John causing the storm wall formed by Hugo to be washed out. It returned limited tidal flow to the dead forest. It was not until a subsequent hurricane in 2010 broke down the sediment wall and natural flow returned. Up to that point, water quality restricted any fouling organisms' survival on the prop roots. By using photo identification, three different bays of St. John were assessed to identify the local fouling community diversity; comparing the new fouling communities of Great Lameshur to that of Hurricane Holes community. The second objective of this study was to use remote sensing data to map the growth rate of the forest. The subsequent Great Lameshur study years showed an increase in similarity to Hurricane Hole as the years progressed. Which is in line with the remote sensing data showing the forest slowly recovering. Given enough time, Great Lameshur Bay's fouling community is expected to increase in diversity and become similar to undisturbed sites.

Montclair State University

Characterization of Red Mangrove Proproot Epibiont Communities of St. Johns USVI

By

Alan M. Buob

A Master's Thesis Submitted to the Faculty of

Montclair State University

In Partial Fulfillment of the Requirements

For the Degree of

Masters of Science

August 2019

College of Science and Mathematics

Department Marine Biology and Coastal Science

Thesis Committee


Paul A. X. Bologna, Thesis Advisor


Jennifer Krumins, Committee Member


Jorge Trueba, Committee Member

Characterization of Red Mangrove Proproot Epibiont Communities of St. Johns USVI

A THESIS

Submitted in partial fulfillment of the requirements

For the degree of Masters of Science

by

Alan M. Buob

Montclair State University

Montclair, NJ

2019

Acknowledgments

Dr. Paul Bologna my thesis advisor, for help in facilitating and directing my research topic.

My thesis committee for agreeing to be apart and providing feedback on my topic of research.

The 2015, 2016, and 2017 Marine Biolab for their assistance.

The Marine Biology classes of 2015, 2016, and 2017 for their assistance in field work and background information.

Contents

1.0 Introduction	7
1.1 Mangroves Ecosystem Services	8
1.1.1 Blue Carbon and Coastal Protection	8
1.1.2 Sessile Community	10
1.2 Rhizophora mangle, The Red Mangrove: Proproots and Mortality	10
2.0 Study Sites	12
2.1 Hurricane Hole	13
2.2 Great Lameshur	13
2.3 Coral Bay	14
3.0 Research Objectives	14
4.0 Methodology	14
4.1 Fouling Community Assessment	14
4.2 Mangrove Forest Recovery	16
5.0 Results	17
5.2 2016 Community Assessment	20
5.3 2017 Community Assessment	21
5.4 Hurricane Hole vs. Great Lameshur all years	22
5.5 Cluster Analysis	23
5.6 Mangrove Forest Recovery	23
6.0 Discussion	26
7.0 Literature Cited	30
8.0 Appendix A	33
9.0 Appendix B	34
10.0 Appendix C	37

Table of Figures

Figure 1. Map of Study Sites.	12
Figure 2. Satellite image of Coral Bay St. John, USVI	13
Figure 3. Changes in canopy cover of Great Lameshur Bay over time.	17
Figure 4. GL Species Accumulation Curve, all years.	18
Figure 5. HH Species Accumulation Curve,	19
Figure 6. CB Species Accumulation, 2015.	19
Figure 7. 2015 species comparison.....	20
Figure 8. 2016 species comparison.....	21
Figure 9. 2017 Species comparison	21
Figure 10. All years HH vs GL.....	22
Figure 11. Cluster analysis of similarity	23
Figure 12. Linear regression between year of observation and canopy area	24
Figure 13. Perimeter to Area Ratios for sample collections.	25
Figure 14. Coral Bay historical rain data July '14-July '17	25

List of Tables

Table 1. GL mangrove growth values.....	26
---	----

1.0 Introduction

Tropical ecosystems represent a mosaic of diverse communities. These communities are extremely susceptible to climatological events and anthropogenic impacts that can cause damage or death. Mangroves, seagrass beds, and coral reefs are dominant aspects of tropical coastal communities, as they provide valuable resources to fish and other aquatic life. There are three native mangrove species associated with the Virgin Islands: red (*Rhizophora mangle*), white (*Laguncularia racemosa*), and black (*Avicennia germinans*). Specifically, mangrove estuaries are among the most diverse and productive environments on the planet. The underwater proproot structure host nitrogen fixing bacteria along the outer layers of the root, enhancing primary production and is used as a primary food source for various fish, crustaceans, and micro-invertebrates (Perry 1988). Fish utilize the interlocking prop root structure to feed and hide from predators until they reach maturity (Bologna 2014, Nanjo et al. 2011). These forests' unique root structures provide valuable ecosystem services hosting a vast number of different biotic and abiotic roles; such as providing nursery habitats, surfaces for epibiont species, storm surge mitigation, sequestration of carbon and stabilization of coastlines.

Mangroves represent a large group of trees that have adapted to a very specific niche, brackish to hypersaline intertidal coastal zones of tropical and subtropical biomes. Mangroves are halotolerant and adaptable to a wide range of salt concentrations. In order to survive in these hostile hypersaline environments, mangrove species have evolved very specialized adaptations to avoid high salt conditions within their cell physiology. By maintaining a low water potential, mangroves minimize diffusion to the outside environment, thus maintaining their water balance (Reef and Lovelock 2014). Reef and Lovelock (2014) also found that by maintaining dephosphorylation within the root system, the mangroves minimize water loss under hyperosmotic conditions present in the soil allowing the tree to survive. Many of these species have the ability to exclude up to 95% of the NaCl in the waters around their root systems, allowing active uptake of water for photosynthesis while minimizing salt loads to keep

their water/carbon intake in balance (Alongi, 2002). These adaptations allow the trees to live in very hostile habitats, in which most plants could not survive.

1.1 Mangroves Ecosystem Services

1.1.1 Blue Carbon and Coastal Protection

The ocean is the largest ecosystem on the planet. It is estimated to contain 38,000 gigatons of carbon, an order of magnitude larger than the geological carbon pool with an estimated value of 4,000 gigatons (Mcleod et al. 2011). With climate change continuing to impact the globe and society, it is critical that carbon sequestering habitats are protected, and actions taken to enhance their effectiveness (e.g., habitat restoration). Aquatic habitats such as mangroves, seagrass beds, salt marshes, and coral reefs represent a valuable niche within the carbon sequestration community. These habitats are far more efficient at removing carbon from the atmosphere and water than their terrestrial counterparts. Mangrove and seagrass habitats effectively remove the carbon permanently from the system through burial in anoxic sediments where decomposition is minimal (Mcleod et al. 2011), unlike terrestrial communities which only remove it on a decadal time scale (Fourqurean et al. 2012, Lavery et al. 2013).

These systems, however, are constantly under threat from urban development because of the economic incentive of their locations. Coastal mangrove forests are prime real estate for developers looking for waterfront property and potentially valuable habitat for aquaculture. As such, a significant decline in forests has occurred globally (Valiela et al. 2001). Deforestation has the potential to become a significant carbon balance problem. While living forests are active in the uptake and sequestering of carbon, destruction of forests not only stops uptake, but also exposes the buried carbon in the sediments to decomposition and release back to the atmosphere. It also can cause turbidity, limiting light in adjacent waters impacting seagrasses and coral reefs. With the tightly coupled relationship of mangrove forests and near shore seagrass beds, the destruction of a mangrove forest could have the potential to create two sources of carbon release instead of two sinks.

Aquatic inshore habitats like mangroves and seagrass beds also face some of the most extreme storm impacts from hurricanes and cyclones. These habitats are usually the frontline defense against storm forces like wind, waves and storm surge. Since these systems will be the first “structures” a hurricane hits, they experience the full force of these physical forces. Mangrove forests and seagrass beds act as bioshields, breaking up the storm surge, waves and winds through the dissipation of tidal forces across the tree structures and physical blockers. Many coastal communities globally have seen the benefits of having established mangroves planted along their coasts, reducing damage to inland human structures.

An example of this is southeast Asia which holds over 41% of the world’s total mangroves, with Bangladesh holding approximately 24.6% of the worldwide mangrove coverage (Carter et al. 2015). This makes the coastline of Bangladesh a largely diverse ecosystem providing valuable habitat and ecosystem services. The Bangladesh Government consider the primary value of the forests as a form of natural storm control that dense mangrove forest can provide. Since the 1960s, the Bangladeshi government has been directly responsible and a primary care giver of mangrove forests along the coasts in order to create a “greenbelt” to protect and preserve property and communities along the shoreline (Carter et al. 2015). However, mangrove protection and valuation has often been overlooked.

Over a third of the worldwide mangrove forest, salt marsh, and seagrass beds have been lost because of various natural and anthropogenic impacts these habitats face (Mcleod et al. 2011). Chief among these impacts is the threat of urbanization and habitat modification for coastal development by humans. Anthropogenic activities like dredging, drainage, and diking seek to stabilize coastal shoreline for infrastructure development at the cost of the natural coastal processes that govern these ecosystems. These destructive activities have slowed in recent years because of the recognition potential role mangroves can have in climate change (Mcleod et al. 2011). This has helped extensively to keep diversity and fish populations up. With the unique interaction’s seagrass beds have with mangrove forest in close proximity of each other,

a loss of one has the high probability of a die off event at the other (Mcleod et al. 2011, Fourqurean et al. 2012, Larvey et al. 2013).

1.1.2 Sessile Community

Sessile communities are found throughout the world growing on any hard substrate within the water column. While community structure on hard substrate like the rocky intertidal zone and subtidal rocky bottoms (e.g. kelp beds) are well studied, less is known about 'biogenic' plant hard substrate as habitat for various organism. In particular, mangrove prop roots provide a stable structure for species to attach to including corals (Rogers and Miller 2001). The Caribbean is home to hundreds of different sessile species ranging from micro and macroalgae to sponges, mollusks, tunicates, and corals. The fouling community found within the mangrove forest is a contributing factor towards the coastal biodiversity and why these forests are counted as some of the most diverse in the world.

The mangrove forests and epibiont communities represent a fundamental niche within tropical environments but they are also some of the most imperiled. These habitats suffer heavily from anthropogenic impacts like run-off (e.g., oil, soil, sewage), sediment disturbances, and deforestation (Diaz et al. 2004, Linton et al. 2003). Mangroves are also influenced by tidal currents that highly influence larval delivery of sessile species and thus community richness (Ellison et al. 1996). With such potential of damage and outside stressors to these systems, the relative health of these forests can be of great concern to local economies and ecology. The root structures are home to some of the most diverse ecological habitats in the world and if these forests face destruction, the Caribbean islands could face a substantial drop in diversity.

1.2 Rhizophora mangle, The Red Mangrove: Proproots and Mortality

The Red Mangroves' unique root structures provide surfaces where sessile organisms can settle and become established, thereby increasing the diversity of life among these roots. The system also provides a valuable and safe habitat for epibionts (algae, sponges, oysters) to grow. The roots also provide a food source to the local

wildlife in the form of bacteria found growing on the roots on the trees (Perry 1988). Not only do these roots provide a space for epibionts to grow, the trees also have a highly symbiotic relationship with the various organisms found growing on them. An interesting relationship the mangroves have are with sponges. Mangrove micro-branchlets grow into the sponge to facilitate nutrient transport, forming a tree/sponge symbiosis. The micro-branchlets provide nutrient highways for the symbiosis to take place. Passive carbon leaks from the roots and is absorbed by the sponges, while the sponges transfer ammonium to the rootlets, along with providing a physical barrier blocking harmful borrowing organisms (Ellison et al. 1996).

Red mangrove forests are on the outermost ocean side of coastlines often times making the red mangrove the first natural structure hurricanes encounter when they make landfall. The trees are put under an enormous amount of stress from the storm event's brunt force. Although these trees have the unique ability to survive in this particular environment, they also face some of the highest mortality rates (36-85%) of any tropical tree species (4-39%) (Baldwin et al. 2001, Sherman, et al. 2001).

The Caribbean is subject to a large number of hurricanes each year which have the potential to greatly harm the local ecology. Between the years of 1899 and 1987 there were approximately 5 to 9 hurricanes per decade (Sherman et al. 2001). St. John suffered two major hurricanes in the recent past including Hurricane Hugo (1989) and Hurricane Marilyn (1995). Both caused catastrophic damage to the island and the mangrove forest on the coastlines. The Great Lameshur mangrove forest was greatly damaged by the storm, leaving only 34 red mangroves in the now dammed forest (Devine and Blondeau 2004). Leaving much of the damaged forests' ecology also damaged or dead. More recently, Hurricanes Irma and Maria (2017) also hit St. John and the wider Caribbean causing wide-spread damage in the region.

2.0 Study Sites



Figure 1. Map of Study Sites. Great Lameshur (GL) Hurricane Hole (HH) Coral Bay (CB)

Three coastal mangrove forests on St. John, USVI were investigated to assess their prop root fouling community (Figure 1). Two sites, Great Lameshur and Hurricane Hole, were sampled multiple years, while Coral Bay was only sampled once. Coral Bay unfortunately was only sampled once due to time constraints during 2016 and the presence of a thunderstorm the day it was scheduled to be sampled in 2017.

The sites are within close proximity to each other. Hurricane Hole (HH) was used as the 'reference' due to its protected status and pristine nature. Great Lameshur Bay (GL) was greatly impacted by Hurricane Hugo, which wiped out a portion of the forest while Coral Bay (CB) is continually impacted by human activities (Figure 2).

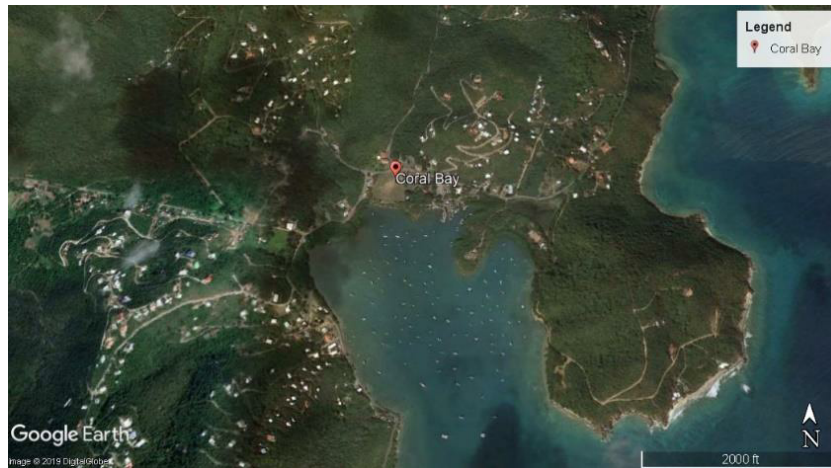


Figure 2. Satellite image of Coral Bay St. John, USVI

2.1 Hurricane Hole

Located on the island is a protected national monument and more importantly a natural and relatively untouched mangrove forest, protected from all human activities. The site is commonly called Hurricane Hole due to its topography and natural geography. It is recessed behind several mountainous regions shielding it from major storms from almost all directions. The site's unique natural shielding was recognized by the United States Government, which declared it a National Park to preserve the shielding and use it as a storm refuge site for boats during hurricanes (National Parks System).

This study site was used as the reference and basis for comparison against the other two locations because of its highly protected habitats. This site is minimally impacted by both natural and human activities.

2.2 Great Lameshur

Great Lameshur (GL) is located on the central southeast side of St. John. It is directly exposed on the south and open to destructive hurricane forces. When Hurricane Hugo (1989) impacted St. John, the storm created a sediment wall along the tidal entrance to Great Lameshur Bay mangrove forest. This tidal wall cut off tidal inflow, while also exposing it to extreme temperatures and salinities. The tidal recharge that was blocked caused catastrophic damage to the forest leading to the widespread

degradation and massive negative impacts to aquatic organism within (Bologna 2014). This created highly anoxic conditions in the forest, leading to a mass die off of mangroves and organisms within the tidal forest. While Hurricane Marilyn (1995) caused major damage to the island, it was also responsible for washing out some of the sediment wall retuning minimum tidal flow to the forest. This minimum flow allowed for an extremely slow recovery to begin. It was not until the hurricane season in 2010, including Hurricane Earl, that the sediment wall was fully demolished, retuning full flow to the forest.

2.3 Coral Bay

Coral Bay is a site heavily impacted by human infrastructure and tourism on a daily basis (Figure 2). Coral Bay is near a major tourist area and is frequently subject to human activities including dumping, boat repair, and fishing. With the frequency of potentially harmful runoff associated with human activities the more sensitive species may not be able to survive. Coral Bay does have some exposure from the south-east and has been negatively impacted by hurricanes in the past.

3.0 Research Objectives

The focus of this study has two objectives to assess the potential recovery of the mangrove forest in Great Lameshur Bay. By comparing the fouling communities found on the prop roots of *Rhizophora mangle* at the hurricane and human impacted sites against the pristine site. Secondly, an analysis of historical satellite images to measure the progression and recovery of the mangrove forest via tree top cover analysis.

4.0 Methodology

4.1 Fouling Community Assessment

Using underwater photographic images taken at each site, the species growing on the roots were identified to lowest possible taxon. A GoPro® hero 4 Plus was used in order to video the roots; screen shots were then taken from the video. Representative images are provided in Appendix A. Once the stills were taken the species were identified then compiled into a presence/absence species chart for each bay. This

shows the species richness across each of the three bays, how unique each site was, and the species that were common between sites.

A species accumulation curve was used on a site per year basis to determine species representation at the study sites. The photos were analyzed, and total species identified were summed. Using the Go Pro editing software, the stills were sharpened and touched up to allow for a better image quality and identification of the species in question. The species within an image were identified by using the most easily recognized subjects first, as well as previous root comparisons of the species to properly identify the subject. New species found in the image were first categorized into sponge, algae, coral or other, then guides like the Smithsonian species database, the Sponge Guide, and a number of taxa books were used to narrow down the species to the lowest possible taxa. Once a significant portion of the root images was sampled, they were plotted into a species accumulation curve. This was used to determine completeness of image analysis. Completion of species identification and image analysis occurred when no new species were being observed in the images and there was observed a plateau of the total number of species identified.

Once these curves were deemed complete, the species were compiled into a Venn diagram and given color codes. Each color represented a different taxa group:

Algae	Green
Arthropoda	Brown
Cnidarians	Red
Porifera	Yellow
Annelida	Blue
Mollusca	Purple
Chordata	Tan

To assess the temporal recovery of the GL fouling community, a cluster analysis (Bray Curtis Similarity) was conducted in Primer[®] and compared using the species

richness found between GL and HH among years. The results were then plotted to assess similarities in species richness and relatedness.

4.2 Mangrove Forest Recovery

To determine the progression of mangrove canopy changes occurring, image analysis was conducted using Google Earth Pro's image analysis function. Historical satellite images were obtained, and the spatial coverage of the mangrove calculated based on the presence of observable mangrove tree cover (Figure 3, Appendix B). 2002 was used as the baseline to evaluate initial unvegetated cover and determine the forest potential after the series of damaging hurricanes. This date was chosen because this was prior to some limited restoration efforts that took place (Devine and Blondeau 2004). Surrounding the unvegetated salt pan in the middle exist surviving mangrove trees including red, white, and black mangroves. Devine and Blondeau (2004) identified and plotted surviving trees and they found only 34 surviving red mangrove trees, but numerous black and white mangroves surviving in the periphery of the salt pan. Subsequent images were georeferenced and overlain on the base 2002 cover images. Images were collected from the available database and include November 2006, August 2009, February 2013, July 2014, January 2015, December 2016, and August 2017 (Figure 3).

Photo interpretation of each image was conducted, and the tree canopy cover was then delineated on the image. Delineated polygons of canopy cover were plotted and analyzed for area via the polygon function to show changes in canopy cover throughout the years. The polygons were converted to square meters and all polygons were summed to determine total area and the total perimeter of polygons. In this manner, data regarding both canopy cover and perimeter of the recovering patches were obtained for each image. Post image analysis also calculated the Perimeter to Area (P:A) ratio as a metric to evaluate patch coalescence from each image. It was expected that as patch forests sections grew, they would coalesce and expand, leading to an increase in area over perimeter, thus causing the P:A ratios to begin to decline. When the mangroves first began to grow the P:A ratio was increasing as many small

patch islands formed before eventually merging together to form a conglomerate with a lower P:A ratio than that of the patch islands. A regression analysis was conducted to assess the relationship and rate of recovery of canopy cover compared to time.

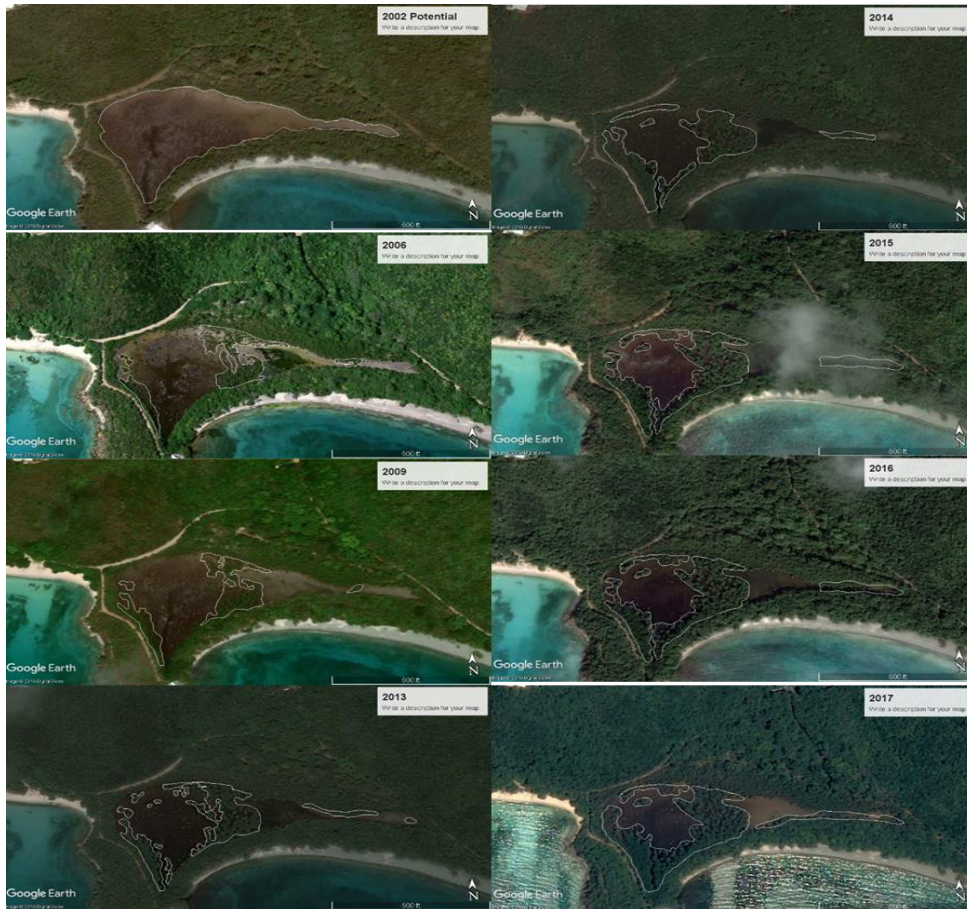


Figure 3. Changes in canopy cover of Great Lameshur Bay over time.

5.0 Results

All species that were identified from images are tabulated in Appendix C for reference. Each species was given a number designated and grouped by taxonomic phyla. Species that could not be identified due to image clarity or insufficient detail to specifically identify were grouped at the end of each section with species type (e.g. unidentified sponge) in the taxonomic grouping. A total of 60 taxa was identified from photographic images. The greatest number of taxa identified were observed in the

sponge group, with 29 individual taxa identified. The coral class was found to have 11 species and the algae class a total of 13 species. Two species of mollusks were identified as well as one species of Hydrozoa, Polychaeta, and Tunicata. The photoimagery was then used to create species-image curves (Figures 4, 5, 6). Images were analyzed for species present until a plateau was encountered where no new taxa were added to the site total. After the plateau, another 10-20 images were analyzed to ensure completeness of the data set. Great Lameshur species curves maxed out at about 50 images, but substantially more taxa were identified in 2016 and 2017 compared to 2015 (Figure 4). For Hurricane Hole, the species curve plateaued at about 70 images with similar taxa richness among all years ranging from 26-30 taxa identified (Figure 5). Coral Bay was only sampled in 2015 and it plateaued after 12 images with only 5 taxa identified (Figure 6).

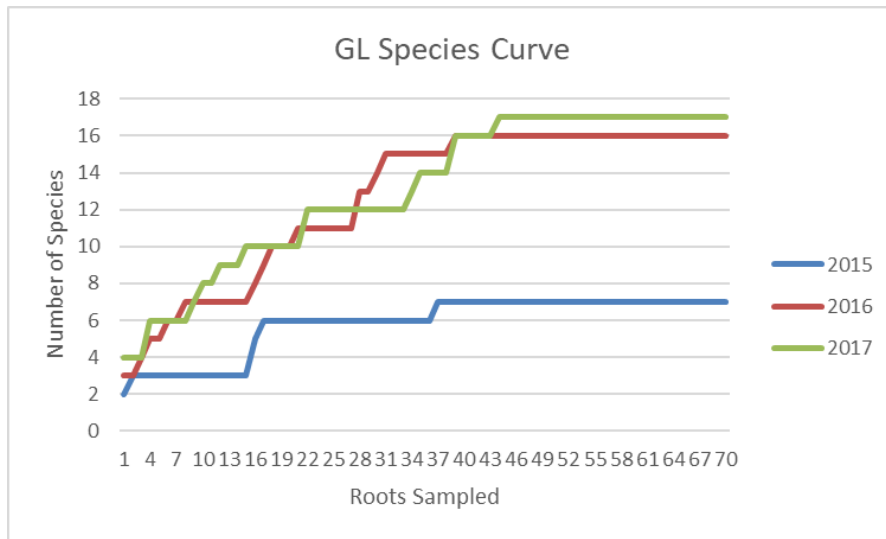


Figure 4. GL Species Accumulation Curve, all years. 7 species found in 2015. 16 found in 2016. 17 found in 2017.

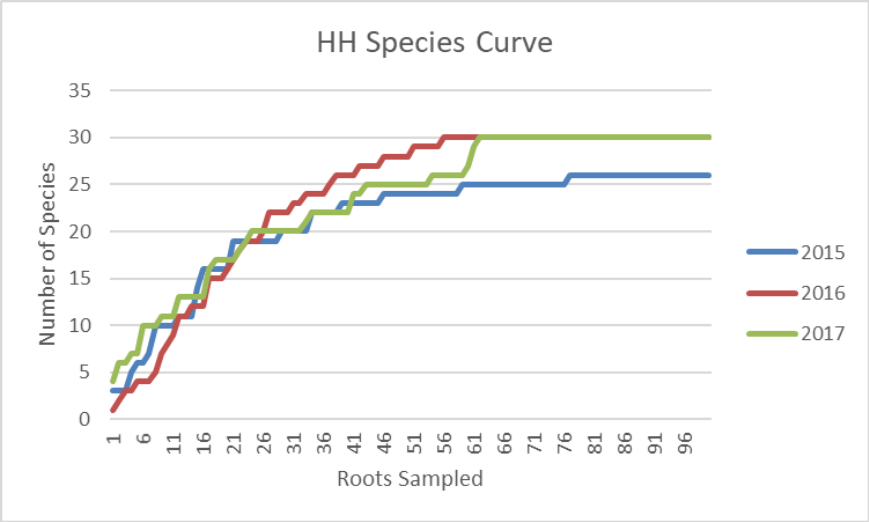


Figure 5. HH Species Accumulation Curve, all years. 29 species found in 2015. 31 species found in both 2016, 2017. All years sampled to 100 roots

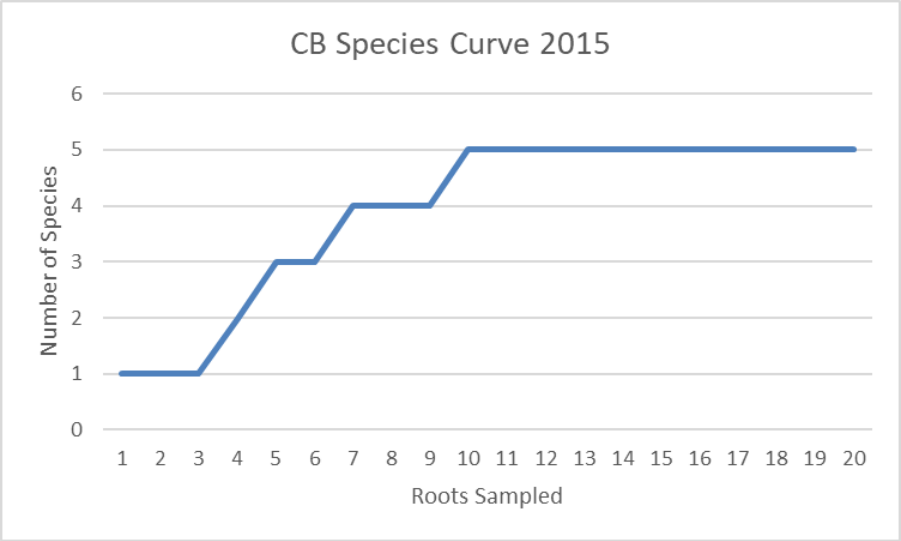


Figure 6. CB Species Accumulation, 2015. Only sampled once do to time constraints.

5.1 2015 Community Assessment

Within the first year of the study there was a total of 31 identifiable species, with only a single species of hydroid, *Sertularia cylindrica* (#26) found across all sites (Figure 7). Hurricane Hole and Coral Bay were found to share one species of brown algae, *Dictyota mertensii* (#6). Hurricane Hole had the most species observed with 23

individual taxa. The flat tree oyster, *Isognomon alatus* (#58) was shared between Hurricane Hole and Great Lameshur. Great Lameshur was found to have 3 species unique to its location including *Caulerpa racemosa* (#3), *Stelletta kallitetilla* (#30), and *Holopsamma helwigi* (#34). Coral Bay had the lowest number of species identified and observed in imagery. With only one species, an unidentified orange encrusting sponge, found to be unique to the site, two other species, *Bryopsis pennata* var. *secunda* and *Tedania ignis*, were shared with Great Lameshur, and one shared with Hurricane Hole, along with the hydroid found at all sites.

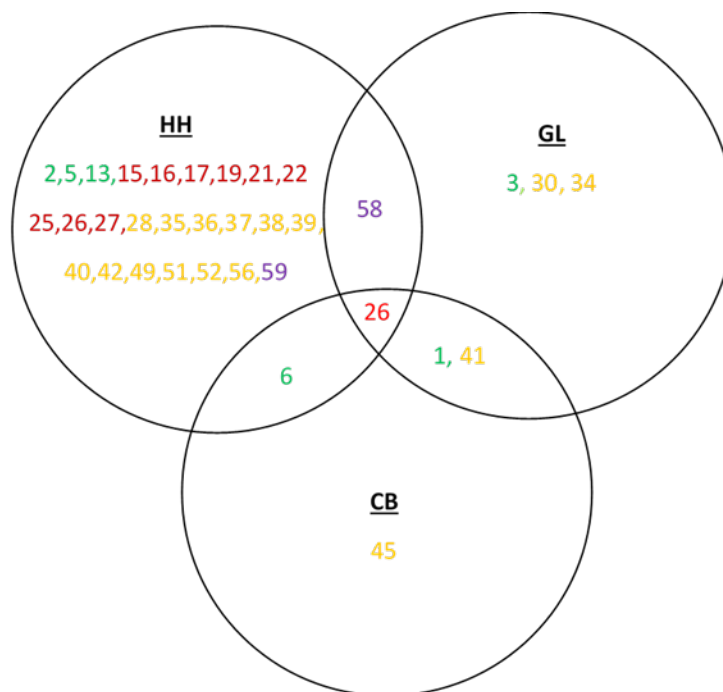


Figure 7. 2015 species comparison. Species 26 was found at all sites.

5.2 2016 Community Assessment

In the 2016 sampling year, 39 species were identified across all sites. Hurricane Hole was found to again hold the most species with 23 unique species and 7 shared with Great Lameshur. Great Lameshur was found to contain a total of 9 unique taxa. Of the 7 species shared, 3 were sponges, two algae, one coral, and one oyster. The same species of mollusk *I. alatus* (#58) was observed in both sites again.

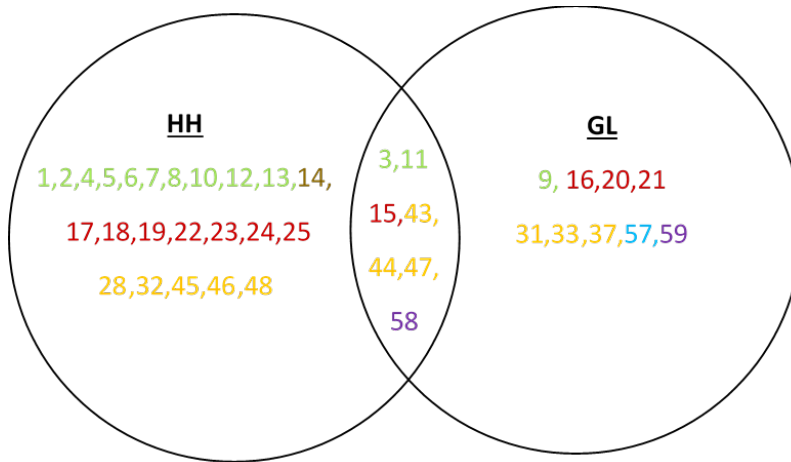


Figure 8. 2016 species comparison. Numbers 3,11,15,43,44,47,58 were shared at all sites. The majority of species were found at HH.

5.3 2017 Community Assessment

Thirty-eight species were found in the 2017 data, sponges were shown to be the most common species in all images taken. Hurricane Hole was observed to have 21 unique species and eight species were found to be unique to Great Lameshur, one less than the 2016 data set. The shared species count increased by two this year climbing from 7 to 9. Again *I. alatus* was shared between both sites, along with the additional green oyster, *Lophia frons* (#59).

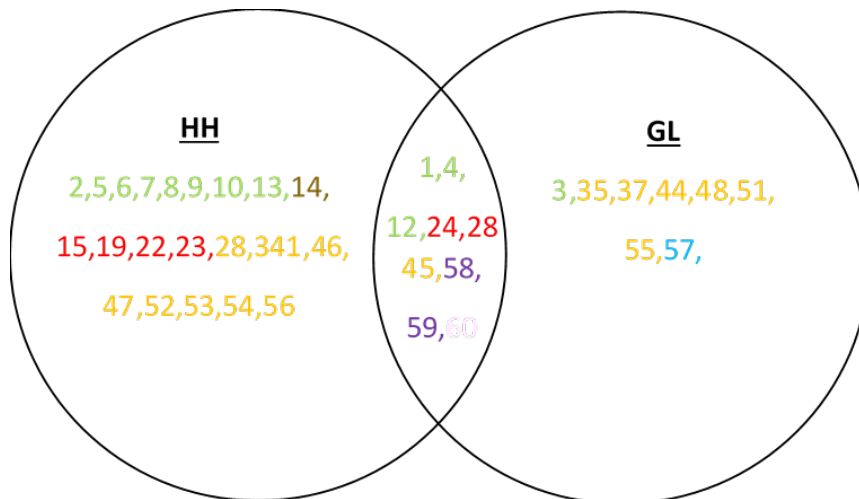


Figure 9. 2017 Species comparison Eight species shared, 3 algae, 1 coral, 1 sponge, 2 mollusks, 1 hydroid and 1 sea squirt

5.4 Hurricane Hole vs. Great Lameshur all years

All three study years for Hurricane Hole and Great Lameshur were compiled into a single analysis of all taxa identified (Figure 10). Hurricane Hole was found to have 28 unique taxa, but Great Lameshur only had 8 unique taxa. Twenty-two species were found to be shared across both sites, and the majority of these were sponges and algae with 8 and 7 individual species found respectively. Both species of mollusks were observed at the two sites during multiple years of the study. Corals were noticeably lacking in all three years with 3 shared between the two sites and only one found exclusively in Great Lameshur.

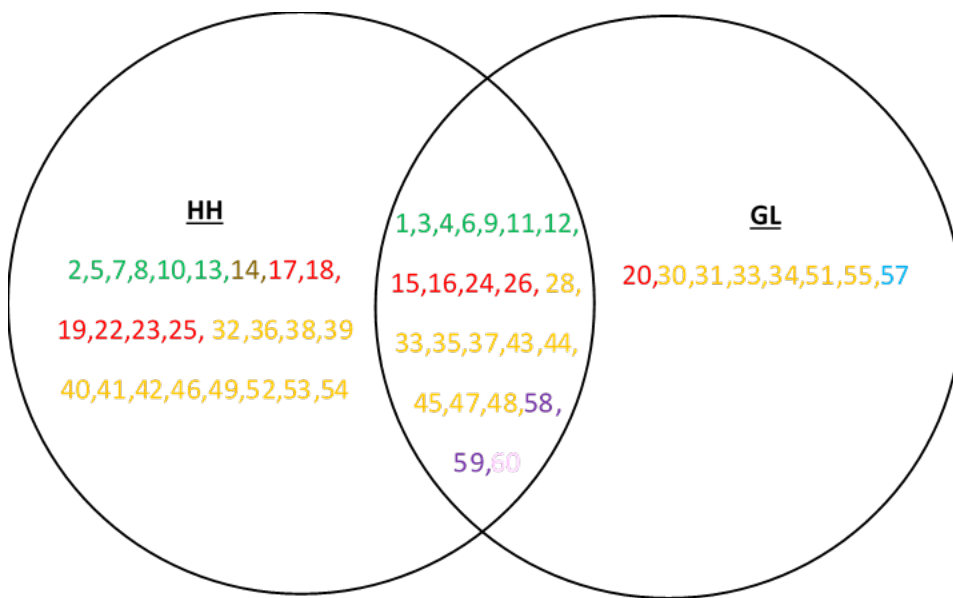


Figure 10. All years HH vs GL. 22 species were found to be shared. Algae and sponges made the majority of the shared species. Only three corals were shared.

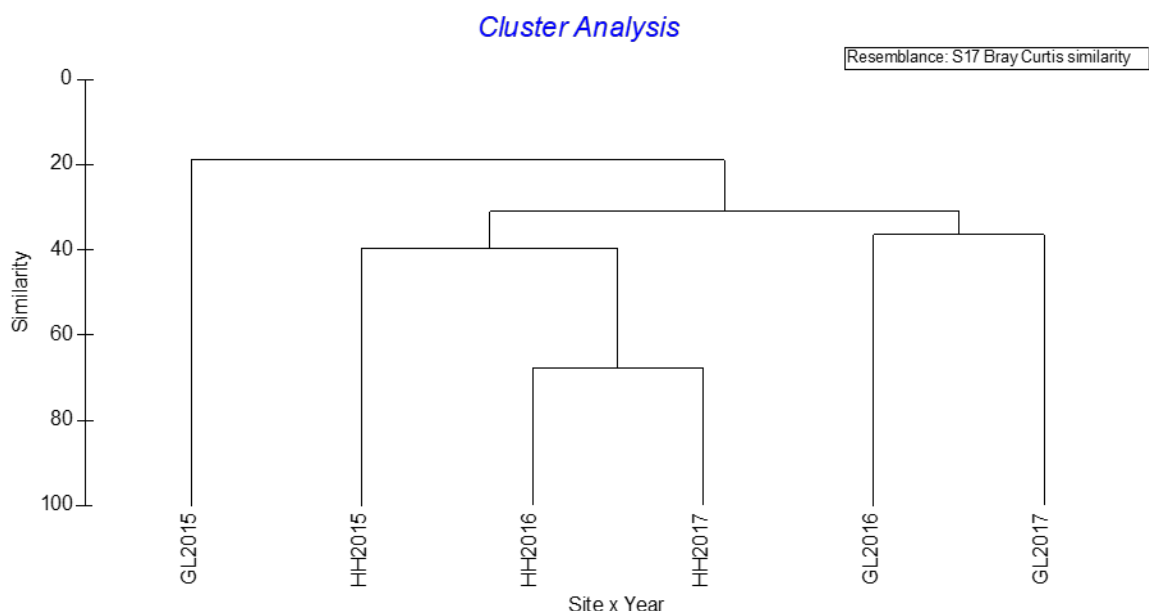


Figure 11. Cluster analysis of similarity between Great Lameshur and Hurricane Hole. The x-axis represents site-year. Y-axis represents level of similarity

5.5 Cluster Analysis

The cluster analysis shows the similarity of the various sites in relation to each other (Figure 11). What is evident in this analysis is the distinct differences the community structure of Great Lameshur 2015, as compared to the other sampling events. It is clear that the community structure of Hurricane Hole is similar among all years, but the high levels of shared similarities of Great Lameshur 2016 and 2017 show them clustering next to the Hurricane Hole communities. This indicates that as the recovery of the prop-root community progresses, it is looking more similar to the pristine mangrove community.

5.6 Mangrove Forest Recovery

The initial assessment of the potential for recovery indicated a total area of 24,324 square meters were unvegetated (Figure 3). In 2006, 6044 m² was calculated as growing within this unvegetated region (Figure 12; Table 1). In the following image year, there was a decrease in cover to 5651 m². However, in all subsequent years an increase in canopy cover occurred leading to a significant regression between year and canopy cover ($F_{1,5} = 26.8$, $P < 0.003$, $R^2 = 0.84$; Figure 12).

The forest recovery was assessed using the satellite images analyzed (Figure 3). The Perimeter to Area ratio started at 0.18, rose to 0.21, before beginning to decline and finally ending at 0.11 in 2017 (Figure 13). The initial increase in P:A ratio was the result of successful recruitment of new trees into the unvegetated region of the salt pan. This caused multiple independent “islands” of mangroves to begin to grow and expand. After February of 2013, the P:A ratio began to decrease as these “islands” began to coalesce into larger conglomerates of forest and finally into a singular unit in August of 2017. Starting in 2013, the average forest growth was between 1500-2000m² per year excluding the 2015-2016-time frame (Table 1). During this period, the average precipitation for the first half of 2015 was slightly lower than the normal expected (Figure 14). The rainfall peaks also were not to the extent that occurred in previous or post years following the 2015-2016 sample year.

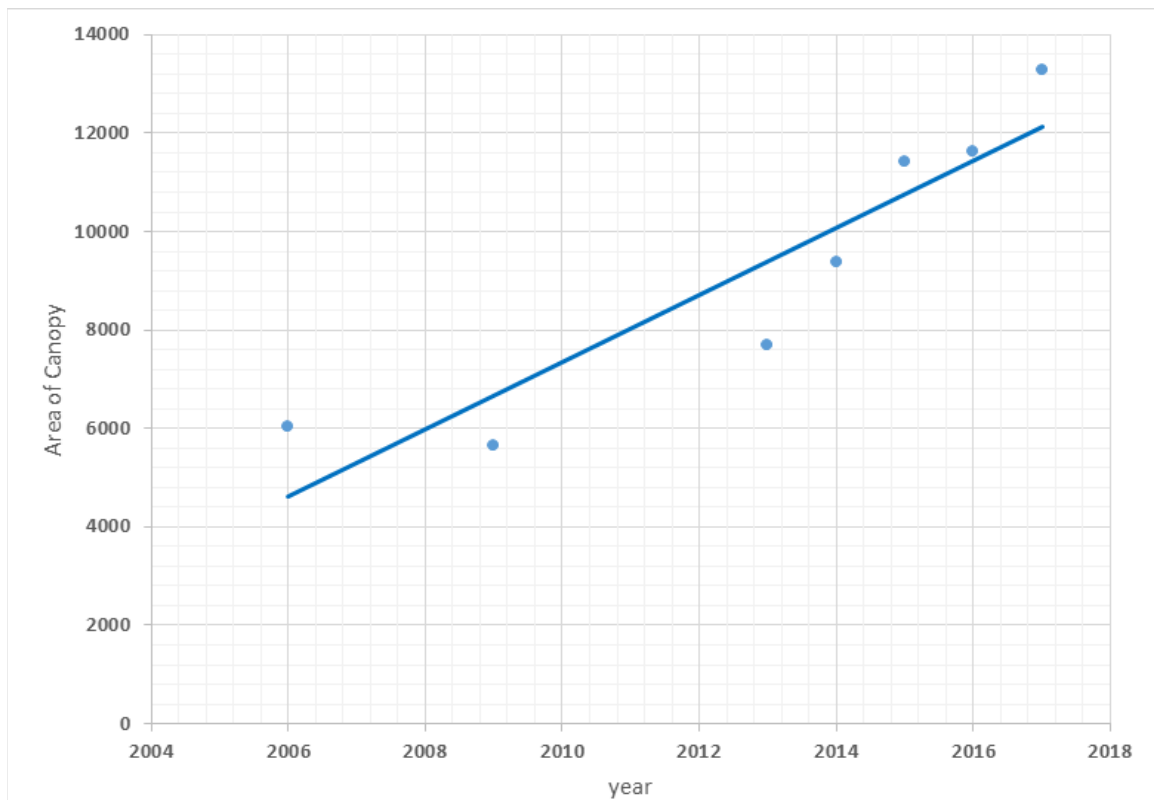


Figure 12. Linear regression between year of observation and canopy area

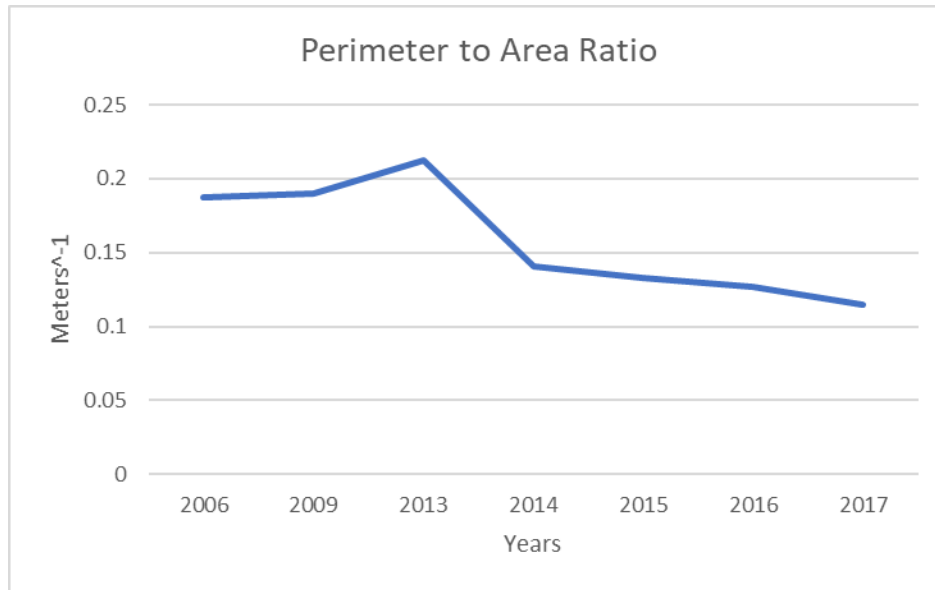
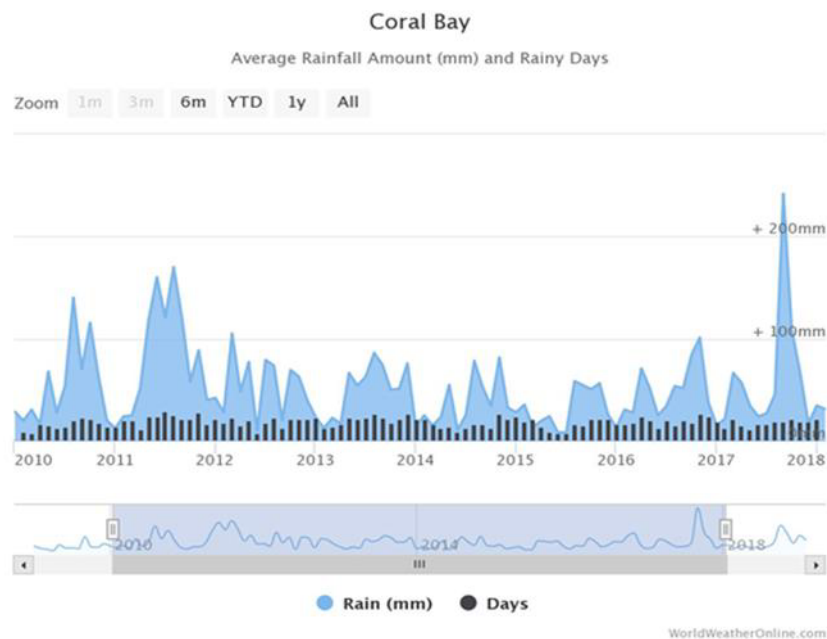


Figure 13. Perimeter to Area Ratios for sample collections. The initial rise in 2013 relates to new tree recruitment into the forest and the subsequent drop reflects coalescence



Weather data online: <https://www.worldweatheronline.com/coral-bay-weather-history/virgin-islands/us.aspx> Data provided by WorldWeatherOnline.com

. Figure 14. Coral Bay historical rain data July '14-July '17

Table 1. GL mangrove growth values

Date	Area (square meters)	Perimeter (meters)	P:A Ratio	Percent Potential
2002 (Potential)	24324	947		
Nov-06	6044.7	1132.6	0.187370755	24.85076468
Aug-09	5651	1071.5	0.189612458	23.23219865
Feb-13	7707.6	1639.2	0.212673206	31.6872225
Jul-14	9377	1321	0.140876613	38.55040289
Jan-15	11424	1516.6	0.132755602	46.96595955
Dec-16	11628	1471.6	0.126556588	47.8046374
Aug-17	13277	1517.7	0.114310462	54.58395001

6.0 Discussion

Hurricane Hole (HH) is a pristine environment and its high diversity of species could be attributed to the relatively untouched habitat, because it is a part of the National Parks System and a National Monument. With little societal impact, it can be reasonably inferred that there is little to no human disturbance or runoff from the surroundings into the site. Thus, allowing for more sensitive species to thrive. Hurricane Holes natural land formation also shields it from heavy wave and current movements allowing more physically sensitive epibiota to settle on the root structures. This is in line with Ellison et al. (1996) findings that the lower the water currents and turbidity, the higher the richness.

Great Lameshur (GL) was expected to have a lower species richness with the site being in a state of recovery, which is reflected in the cluster analysis where 2015 showed a high dissimilarity score (Figure 11). The waters remained highly turbid, with frequent flushing events related to tidal changes, limiting the ability of epibiota settlement onto the prop root structure reflecting the findings of Ellison et al. (1996). With the recovery of the forest, the turbidity should drop and allow the successful recruitment of more photosensitive species.

This was the case in 2015 since only 7 species were found with 3 of the species being unique. A noticeable difference was found in the 2016 and 2017 data, when the number of species found jumped considerably from 7 to 16 then 17 for the respective

years (Figure 3). This large jump indicates a very successful recruitment year following 2015 sampling period. With the site being a part of the National Park, the recovery began to show signs of similarity to Hurricane Hole. With the increase of only one additional species found in 2017 compared to 2016 it could indicate that the forest reached a temporary carrying capacity. As the forest continues recovering and tidal flow is restored, the number of species should increase as well, since more nutrients, resources, and larvae are brought into the system.

While outside the scope of the study, the various sponge species found in Great Lameshur indicates the recovery rates of the forest are potentially being supplemented by the sponge/mangrove mutualism Ellison et al. (1996) established. As the mangroves continue to recover, sponge species will continually grow onto the prop root structure. As these sponges cover the prop roots, the likelihood that microbranchlets will grow into the sponge to facilitate nutrient transport will also increase. Which will increase the overall health of the trees and forest. This positive feedback cycle should accelerate the growth of the mangroves, thus helping the forest to recover faster. This in turn will allow other species such as corals, oysters or other epibiota to settle sooner than if the forest's prop roots were spongeless.

Coralline algae often precede coral settlement and when found, indicates a successful recovery process for more sensitive species. Corals are naturally sensitive to water temperature and water quality. The presence of corals at Great Lameshur provides a greater insight that the location is in a much better state than during the 2015 sampling period. This is also reflected in the remote sensing data showing the presence of green space covering the southern half of the swampland (Figure 3).

Figure 9 portrays a more complete picture of the state of Great Lameshur. All the species found in the three-year study were compiled into one comparison which shows that Great Lameshur, while a long way away, is slowly becoming increasingly similar to Hurricane Hole. Both sites have a total of 22 species shared between them, which is greater than the unique species found at either of the two sites separately. With Great

Lameshur's relative isolation and difficulty in reaching the bay by land it should slowly take on more species found in Hurricane Hole. As the forest continues to recover, the unique species found in Hurricane Hole should start to dwindle and the number of shared species should start to increase.

The most surprising results were found during the remote sensing objective of this study. With the short term of the in-field study, the remote sensing data provided a viable back drop to show forest recovery at the community level. 2002 showed an almost 24500 square meter dead zone, however, 11 years later in 2013 the dead zone is seemingly diminished with 7706.6 square meters covered in trees which is roughly 32% of the total area. Then again in 2017 almost 55% of the initial 24324 square meters is covered in dense tree top cover. The northern part of the swampland still shows considerable unvegetated regions, but the southern section near the mouth of the inlet shows profound growth, with that alone being 10,449 square meters of treetop. The treetops, especially during the 2015 and onward, began to lose their definition and instead became a coalescence of green. The Devine and Blondeau (2004) study only found a total of 34 surviving red mangroves, but this number has greatly increased in the last 13 years. The noticeable outlier is the 2015-2016 growth period (Table 1), in which the forest only saw 204 m² of growth. This low growth could be attributed to the low rain levels seen during the typical wet season (April to October, Figure 14). *Rhizophora mangles*' peak growth is during the wet season, the low rain values during this time indicate that the mangroves have missed their yearly peak growth period, thus leading to a low growth rate. The rainfall during this time did not follow the standard peak previous years had and may have caused the growth of the mangroves to stunt during this drier time period.

The recovery of an ecosystem is always a complex and time-consuming action. Great Lameshur still has many years to go before it can be said to be recovered. This being said, in accordance with the finding of Baldwin et al. (2001), which found that the rate of recovery was related to the amount of free ground exposed to light for saplings recruitment. With a large amount of exposed surface still to be regrown, the forest

should see an increase in growth as more nutrients become available as the recovery process continues for the forest. The complexity of a mangrove swampland and its associated biotic and abiotic functions take time to properly equilibrate and recover. As the northern dead zone continues to shrink with the trees continual encroaching on the zone the water quality, temperature and available nutrients released into the habitat should also increase thus allowing for an increase in successful recruitment of new epibiont species. As the years progress there should be an ever-increasing success rate of recruitment and growth.

Great Lameshur as evidence by the 2017 satellite image still has room for the mangroves to grow into, this should thus lead to a faster and more successful recruitment of epibiota. With the similarity of GL 2016, 2017 to HH 2015-2017 it should be expected that the species found at Great Lameshur are also found at Hurricane Hole. As Great Lameshur continues to recovery and grow the similarity scores for future years should also be expected to increase. Great Lameshur is well on its way to become similar to the pristine Hurricane Hole site as Great Lameshur recovers do to its protect and isolated nature. The similarity jump between 2015 and 2016 along with the satellite images showing massive tree growth through the years since the sea wall broke bodes well for Great Lameshur's potential recovery and return to a productive and pristine ecosystem.

7.0 Literature Cited

- Alongi, D. E. 2002. Present state and future of the world's mangrove forests. *Environmental Conservation Journal* 29(3): 331-349.
- Baldwin, A., Egnotovich, M., Ford, M., and Platt, W. 2001. Regeneration in fringe mangrove forests damaged by Hurricane Andrew. *Plant Ecology* 157: 149-162.
- Bouillon, S., Koedam, N., Raman, A. V., and Dehairs, F. 2002. Primary producers sustaining macro-invertebrate communities in intertidal mangrove forests. *Oecologia* 130: 441-44
- Bologna, P. 2014. Mangrove loss leads to fish Hyperutilization of seagrass beds in UNESCO biosphere reserve. *Journal of Fish Biology* 84: 1620-1625.
- Carter, H., Schmidt, S., Hirons, A. 2015 An International Assessment of Mangrove Management: Incorporation in integrated Coastal Zone Management, *Diversity* 7 74-104.
- Coral Bay Historical Weather (2008) In World Weather Online Retrieved March 7, 2019 from <https://www.worldweatheronline.com/coral-bay-weather-history/virgin-islands/us.aspx>
- Devine, B., Blondeau, J. Restoration of wetlands at Lameshur Bay. 2004. Mapping, Assessment, Planting and Monitoring Report. Submitted to the Center for Marine and Environmental Sciences, University of the Virgin Islands and the Virgin Islands National Park. 32p.
- Díaz, M. C., Smith, K. P., and Rützler, Klaus. 2004. "Sponge species richness and abundance as indicators of mangrove epibenthic community health." *Atoll Research Bulletin*. 518:1-17. <https://doi.org/10.5479/si.00775630.518.1>
- Ellison, A.M., Farnsworth E.J., Twilley R. R. 1996. Facultative Mutualism between Red Mangroves and Root-Fouling sponges in Belizean Mangal *Ecological Society of America* 77(8): 2431-2444.
- Fourqurean, James et al. 2012. Seagrass ecosystems as a globally significant carbon stock, *Natural Geoscience*
- Google. (2019) Google Earth Pro (Version 7.3.2.5495) [Computer program] Available at <https://www.google.com/earth/versions/> (Accessed on December 11, 2018)
- Lavery PS, Mateo M-Á, Serrano O, Rozaimi M (2013) Variability in the Carbon Storage of Seagrass Habitats and Its Implications for Global Estimates of Blue Carbon Ecosystem Service. *PLoS ONE* 8(9): e73748. <https://doi.org/10.1371/journal.pone.0073748>
- Linton, Dulcie M., And Warner, George F., 2003. Biological indicators in the Caribbean Coastal zone and their role in integrated coastal management. *Ocean & Coastal Management* 46: 261-276
- Macdonald, J., and Weis, J. 2013. Fish community features correlate with prop root epibionts in Caribbean mangroves. *Journal of Experimental Marine Biology and Ecology* 441: 90-98.

- Mcleod, E. , Chmura, G. L., Bouillon, S. , Salm, R. , Björk, M. , Duarte, C. M., Lovelock, C. E., Schlesinger, W. H. and Silliman, B. R. (2011), A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO₂. *Frontiers in Ecology and the Environment*, 9: 552-560. doi:10.1890/110004
- Nanjo, K., Nakamura Y. Horinouchi M., Kohno, H. and Sano, M. 2011. Predation risks for juvenile fishes in a mangrove estuary: A comparison of vegetated and unvegetated microhabitats by tethering experiments. *Journal of Experimental Marine Biology and Ecology Journal* 450: 53-58.
- Perry, D. M. 1988. Effects of Associated Fauna on Growth and Productivity in the Red Mangrove. *Ecology Journal* 69(4): 1064-1075.
- Reef, R., Lovelock, C.E. Regulation of water balance in mangroves, *Annals of Botany*, Volume 115, Issue 3, February 2015, Pages 385–395, <https://doi.org/10.1093/aob/mcu174>
- Rogers, C. S., Miller, J. 2001 Coral bleaching, hurricane damage, and benthic cover on coral reefs in St. John, U.S. Virgin Islands: A comparison of surveys with the chain transect method and videography. *Ingenta Volume* 69, Pages 459-470.
- Sherman, R. E., Fahey, T. E., and Martinez, P. 2001. Hurricane Impacts on a Mangrove Forest in the Dominican Republic: Damage Patterns and Early Recovery. *Biotropica* 33(3): 393-408.
- Source: "Great Lameshur Bay." 18°19'11.16" N 64°43'27.86" W Google Earth September 10, 2002. February 29, 2019.
- Source: "Great Lameshur Bay." 18°19'11.16" N 64°43'27.86" W Google Earth November 29, 2006. February 29, 2019.
- Source: "Great Lameshur Bay." 18°19'11.16" N 64°43'27.86" W Google Earth August 13, 2009. February 29, 2019.
- Source: "Great Lameshur Bay." 18°19'11.16" N 64°43'27.86" W Google Earth February 12, 2013. February 29, 2019.
- Source: "Great Lameshur Bay." 18°19'11.16" N 64°43'27.86" W Google Earth July 1, 2014. February 29, 2019.
- Source: "Great Lameshur Bay." 18°19'11.16" N 64°43'27.86" W Google Earth January 7, 2015. February 29, 2019.
- Source: "Great Lameshur Bay." 18°19'11.16" N 64°43'27.86" W Google Earth December 10, 2016. February 29, 2019.
- Source: "Great Lameshur Bay." 18°19'11.16" N 64°43'27.86" W Google Earth August 10, 2017. February 29, 2019.

Valiela, I., Bowen, J. L., York, J. K. Mangrove Forests: One of the World's Threatened Major Tropical Environments:, *BioScience*, Volume 51, Issue 10, October 2001, Pages 807–815, [https://doi.org/10.1641/0006-3568\(2001\)051\[0807:MFOOTW\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0807:MFOOTW]2.0.CO;2)

8.0 Appendix A



9.0 Appendix B







10.0 Appendix C

ID#	Common name	Scientific name	Family
	Algae		
1	Green algae	<i>Bryopsis pennata</i> Var. <i>secunda</i>	Bryopsidaceae
2	Caulerpa mexicana	<i>Caulerpa mexicana</i>	Caulerpaceae
3	Green grape algae	<i>Caulerpa racemosa</i>	Caulerpaceae
4	Crustose Coraline	<i>Corallinaceae</i> spp.	Corallinaceae
5	Brown seaweed	<i>Dictyopteris justii</i>	Dictyotaceae
6	Brown algae	<i>Dictyota mertensii</i>	Dictyotaceae
7	Brown crusty algae	<i>Lubophora variegata</i>	Dictyotaceae
8	Spiny seaweed	<i>Acanthophora spicifera</i>	Rhodonelaceae
9	Dark red algae	<i>Bryothamnion triquetrum</i>	Rhodonelaceae
10	Sea pearl	<i>Ventricaria ventricosa</i>	Siphonocladaceae
11	Green ball algae	<i>Dictyosphaeria cavernosa</i>	Valoniaceae
12	Brown bushy algae	Unidentified	Algae
13	Brown fuzzy algae	Unidentified	Algae
	Arthropoda		
14	Sessile Barnacles	<i>Cirripeda</i> spp.	Thecostraca
	Cnidarians		
15	Yellow sheet Coral	<i>Agaricia grahvae</i>	Agariciidae
16	Lamarck's sheet Coral	<i>Agaricia lamarcki</i>	Agariciidae
17	Stony Coral	<i>Astrocoeniidae</i> spp.	Astrocoeniidae
18	Golfball Coral	<i>Favia fragum</i>	Faviidae
19	Encrusting Fire Coral	<i>Millepora alcicornis</i>	Milleporidae
20	Rose Coral	<i>Manicina areolate</i>	Mussidae
21	Red reed rod	<i>Alcyonacea holaxonia plexauridae</i>	Plexauridae
22	Mustard Coral	<i>Porites asteriodes</i>	Poritidae
23	Finger Coral	<i>Porites</i> spp.	Poritidae
24	Green encrusting Coral	Unidentified	Coral
25	Unidentified Red encrusting Coral	Unidentified	Coral
26	Hydroid	<i>Sertularia cylindrica</i>	Syntheciidae
27	Sea Anemone	<i>Lebrumia</i> sp	Aliciidae

	Porifera		
28	Brown/Orange Tublar Sponge	<i>Agelas schimdti</i>	Agelasidae
29	Purple tube Sponge	Unidentified	Agelasidae
30	<i>Stelletta kallitetilla</i>	<i>Stelletta kallitetilla</i>	Ancorninidae
31	<i>Chalinula molitba</i>	<i>Chalinula molitba</i>	Chalinidae
32	Yellow boring Sponge	<i>Clionadeiitrix sp</i>	Clionaodae
33	Red Boaring Sponge	<i>Clionadeiitrix sp</i>	Clionaodae
34	Purple lumpy Sponge	<i>Holopsamma helwigi</i>	Desmacididae
35	Yellow Tube Sponge	<i>Biemna tubulata</i>	Desmacellidae
36	<i>Scoplalina ruetzleri</i>	<i>Scoplalina ruetzleri</i>	Dictyonellidae
37	Heavenly Sponge	<i>Dysidea etheria</i>	Dysideidae
38	<i>Mycale microsigmatosa</i>	<i>Mycale microsigmatosa</i>	Mycalidae
39	Black ball Sponge	<i>Irania strobalina</i>	Irciniidae
40	Brown encrusting octopus Sponge	<i>Ectyoplasia ferox</i>	Raspailiidae
41	Fire/volcano Sponge	<i>Tedania ignis</i>	Tedaniidae
42	Blue encrusting Sponge	Unidentified	Sponge
43	Blue/green Sponge	Unidentified	Sponge
44	Light Blue/white Sponge	Unidentified	Sponge
45	Orange encrusting Sponge	Unidentified	Sponge
46	Purple encrusting Sponge	Unidentified	Sponge
47	Red encrusting Sponge	Unidentified	Sponge
48	Unidentified Yellow encrusting Sponge	Unidentified	Sponge
49	Shallow Water Strawberry Sponge	<i>Igernalla notabilis</i>	Sponge
50	<i>Wrighteilla blodgetti</i>	<i>Wrighteilla blodgetti</i>	Sponge
51	Unidentified White Sponge	Unidentified	Sponge
52	Unidentified Pink Sponge	<i>Unidentified</i>	Sponge
53	Blood red tube Sponge	<i>Unidentified</i>	Sponge

54	Green ball Sponge	<i>Unidentified</i>	Sponge
55	light green Sponge	<i>Unidentified</i>	Sponge
56	Blue Sponge	<i>Unidentified</i>	Sponge
	Annelida		
57	Feather duster	<i>Sabellidae spp.</i>	Sabllidae
	Mollusca		
58	Flat tree oyster	<i>Isognomon alatus</i>	Pteridae
59	Green oyster	<i>Lophia frons</i>	Ostereida
	Chordata		
60	Sea squirt	<i>Eudistoma grey</i>	Polycitoridae