Developing Surface Water GPS Digital Mapping Technology to Map the Spatial Distribution of Size Classes and Disease Prevalence of Elkhorn Coral in the Nearshore Waters of St. Thomas and St. Croix

Report to

The Nature Conservancy
Little Princesse, St. Croix, USVI
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Prepared By

Barry Devine, Ph.D., Chief Scientist
Pedro Nieves, Assistant Field and Data Manager
Conservation Data Center
University of the Virgin Islands

With assistance from

Mark Drew
Kim Ischida
Shona Patterson
Jeanne Brown
Lucy Mason
The Nature Conservancy

Christina Colletti
University of the Virgin Islands

Conestoga-Rovers and Associates
Ed Nesselbeck, Alek Hage and Michal Janyst

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Introduction

Much has been written about the species population status of the now ESA Listed Elkhorn (*Acropora palmata)* and Staghorn (*Acropora cervicornis)* corals throughout their range and the decline the two species have suffered over the past three decades from storms and disease. The University of the Virgin Islands Conservation Data Center in partnership with the Nature Conservancy, Eastern Caribbean Office created a pilot project to develop GIS/GPS digital technology to map the spatial extent of size classes and disease affecting the ESA Listed Species Elkhorn Coral (*Acropora palmata)* around St. Thomas and St. Croix, USVI as a population baseline. The project was submitted by The Nature Conservancy to the National Oceanic and Atmospheric Administration under a Coral Reef Conservation Program grant and received approval in 2006.

This Geographic Information Systems (GIS) pilot mapping project would have two goals; (1) to develop and use a new surface water Global Positioning System / Personal Data Assistant (GPS/PDA) to record data previously recorded and plotted by hand and (2) to map the spatial location and population patterns of these species in priority bays around St. Croix and St. Thomas as a foundation to broader mapping efforts and long term datasets on population recovery and decline. The sampling plan was to be completed twice, separated by a one year interval to possibly determine any recovery or decline within the surveyed population, but TNC staff and personnel issues, weather, site access, technical challenges and sampling plan adjustments caused that objective to be revised by the Principal Investigators.

Project Background

Mapping of Elkhorn Corals around the USVI has a brief but focused history that began with work by Rogers, Devine and Loomis (2002) and others. This team began the use of GPS units in Aquapacs mounted on kickboards to map the spatial location of elkhorn corals beginning with St. John bays. By 2004 the team had expanded to include Pedro Nieves who helped to increase efforts and refine the technical approaches to allow data collection for spatial location and population characteristics of size class, disease, predation, live cover, and physical health by digital methods, reducing transcription errors and adding tremendous efficiency to the data collection, databasing and mapping efforts. In 2004-5, 12 priority bays and more than 3300 corals were surveyed, GPS mapped and analyzed under a Disney Wildlife Conservation Grant (Rogers et al. 2005) In 2006 two of these priority bays were re-mapped and monitored on a monthly basis for a year to see the short term trends and patterns (Rogers et al. 2006). While St. John has had baseline mapping and these data were used to assist in the ESA Listing effort for the species, St. Thomas and St. Croix have had only sporadic reconnaissance mapping work accomplished. For this species. The distribution and health of populations around these islands are poorly understood. In order to address this gap the current project was begun.

The current project, " Mapping the Spatial Distribution of Size Classes and Disease Affecting Elkhorn Coral Around St. Thomas and St. Croix", began in late August 2006 with a meeting of the TNC and UVI research Teams including Mark Drew(PI) Shona Patterson and Kim Ischida from TNC along with Pedro Nieves and Barry Devine(PI). This was a training meeting for the TNC team based on the past experience of the UVI team to practice both in-water data collection and GPS/GIS data download training. The scope of this UVI/TNC contract included a training component of team meetings and group data collection at selected sites. Upon completion of training, the teams separated to conduct the research individually but working together as a team at specific locations on St. Croix. The TNC team would be primarily responsible for St. Croix sampling and conduct baseline research in selected St. Croix bays while the UVI team would complete work in St. Thomas bays. The UVI team under this contract would also store all data, train and assist in the field and provide GIS mapping and basic analysis of the data. The Project was to encompass ten sites on St. Thomas and St. Croix with a minimum sample of 100 corals as a baseline total of 1000 per island. The teams began research in fall 2006, however, delays at NOAA and in the negotiations of this contract between TNC and UVI delayed the signing of a contract for this work until April 30, 2007 and initial payment was not made until June 2007. This delay impacted the work schedule.

While the technical and mapping work had proceeded well on both islands, sampling work still took longer and more effort than anticipated as a result of weather, site access, and technical difficulties. Adjustments were made in the sampling schedule and number of sites based on the experience of the previous months. Inclement and stormy weather and conflicted work schedules caused progress to be slower than expected, however the technology was working well and good baseline was established at several sites. TNC staff required additional training and site visits by the St. Thomas team. Sampling volunteers changed and winter storms made sampling the shallow habitat impractical or dangerous on many scheduled field days. In spring and summer of 2007, the entire TNC monitoring team left their positions with TNC, creating an 8 month staffing void in the project and the uncertainty the project would continue. TNC staff was unable to give attention to this project again until the beginning of 2008 and while additional meetings of staff have occurred, no additional data has been received from the TNC-St. Croix team.

The UVI Team continued to gather data from the adjusted selection of St. Thomas sites and to complete a second sampling at the three original sites. In addition, data from the first season of both St. Thomas and St. Croix was processed, mapped and sampled for basic population characteristics. This established a limited but solid baseline for further study of these and other areas. This report is intended to compile the results of this work aimed at completing the two original goals.

Methods

Planning

Teams from UVI and TNC met to discuss known *Acropora* habitat locations around the islands of St. Thomas and St. Croix. This local knowledge, discussions with other scientists and previous sampling experience on both islands provided a list of 10-15 potential sampling locations for a targeted sampling approach on each island. A targeted sampling approach was planned and agreed upon by the two PI's, as this project was planned as an inventory/survey/census and not a random sample of the population. The objective was to inventory and assess the status of the resource island-wide at sites with the largest populations to understand recovery from increases in numbers, size as well as condition.

These sites and other potential locations were then field visited for initial review and selection. In the computer lab, GPS/PDA equipment was selected, programmed and tested to determine the use for faster and more accurate data collection and analysis.

Field and Computer Lab Methodology: A team of 2-3 persons would collect GPS position, data on size class and disease and a colony photograph for change detection and disease diagnosis.

- The specifications on technical equipment and software used are listed below.

1 TDS Recon 2000 PDA programmed to link Lat/long Coordinates with data collected
1 Garmin 12XL GPS unit
Garmin ique 3600
1 Olympus Stylus 710 7.1 megapixel camera and underwater housing
1 Sony 6.0 megapixel Digital Camera and Underwater Housing
Arcview 3.2 and ArcGis 9.2 as GIS platform software
OziExplorer GPS software
Pendragon Forms 5.0 Software
Microsoft Excel software
Aquapac Waterproof bags for GPS and PDA
Conestoga Rovers Associates (CRA) web design solutions and data server back-up
Wetsuits, snorkel gear

Field Methods: After selecting a sampling location, an in-water and map reconnaissance would help establish a sampling plan for the site based on the estimated number of colonies, size of the area, currents and other sampling issues. The team would then enter the water and using a methodical back and forth approach, attempt to census every colony, from small centimeter sized recruits to meter plus branching specimens. Approximately 100 colonies could be mapped and data recorded in a 3 hour sampling period. Initially, only 100 colonies/1000 total were to be counted at 10 sites, but after surveying Salt River (600+) and Green Cay (400+) on St. Croix and Flat Cay (600)+ on St. Thomas, it was decided by Devine(PI) and Drew(PI) that having more complete data on large populations was a better approach in light of the limited number of colonies in most populations. By attempting to census and sample every colony within large populations, a re-sampling of any sub-group could occur easily at some future date.

Team member 1, swimming on the surface, holds a GPS raft in front, floats directly over the colony being mapped and takes a GPS waypoint #1 location for the colony. The second research swimmer with the TDS Recon PDA studies the colony and then estimates the size class and whether the colony has some surface disease/anomaly. Additional data is also recorded on a number of other factors including live cover, predation, fragmentation and growth form. These data are recorded with waypoint #1 as the link to GPS data. The third research swimmer takes a photo of the coral in plan or profile and this photo is hot-linked to the database for review and comparison with later photos. The team then continues on to next coral, trying to follow a swimming pattern that will capture each and every colony for later baseline comparison.

Computer Lab Methods: In the Computer Lab, the GPS and PDA data are downloaded using active sync software. The GPS data is extracted using OziExplorer software and the datasets for Latitude/Longitude, size class, disease and photograph are rejoined and polished using Microsoft Excel. The database is then loaded to GIS platform for the creation of the layers. A hot-link in the GIS database was established for photographs, mapping and comparison.

Results

Technology Goal 1

Terrestrial landscape species population pattern analysis mapping using GIS/GPS has been fairly well developed for terrestrial ecology. The analysis of seascapes and seascape patterns lags far behind although the marine patterns have as much to do with biodiversity, ecosystem pattern, function and energy transfer as within terrestrial ecosystems. An equally important goal to mapping the spatial distribution patterns of marine life is the development of technological solutions for this field work that increases accuracy and efficiency. Our efforts in this regard have been to develop surface water GPS/PDA digital alternatives to hand written field data sheets requiring transcription and the time consuming and inefficient upload of the data into a statistical database. The introduction and development of this digital mapping approach provided for more accurate and rapid data collection in the field and more efficient incorporation of these data into the comprehensive database.

In the past, mapping of marine seascapes was done from black and white and color aerial photographs. Interpreting the biological patterns in these photographs was difficult and time consuming. As a result of scale issues and funding costs, mapping was done accurately for large habitat patches of a 0.4 hectare minimum. Smaller patch habitats, extremely important in creating the finer detail of ecosystem heterogeneity were neglected for time and funding constraints creating a duller picture of the diversity of the system. Individual species distribution in the marine environment has been infrequently mapped using expensive sonar systems tied to a known GPS location or by actually tape measuring the angle and distance to each colony from a known center point. This did not allow easy overlay on geo-referenced maps and photographs for graphic display, was prone to significant errors during field and transcription activities and was extremely time intensive to transcribe the data from field notes into a GIS compatible database.

Clearly, for large populations of marine organisms like corals, the sonar and the tape measure methods were too cumbersome to efficiently and accurately map these populations, especially if one were trying to map and re-map all colonies for baseline comparison over broad areas. By incorporating surface water GPS measurements of nearshore, shallow water organisms and digital data collection we feel we have created a mapping tool useful for mapping a diversity of marine species, both sessile and mobile to uncover spatial population characteristics.

Data Collection Development

Traditionally, Garmin GPS 12XL units were placed in Aquapac waterproof bags and these were carried into the sampling area. Placed on a raft or held above the water's surface, the units would quickly and easily record latitude –longitude waypoints for each colony marked when the unit on the surface was held over the colony below and a point recorded. Data about the individual colony was then recorded by another research swimmer on a complex 8 ½ x11 waterproof data sheet. Finally, a third swimmer would take a digital photograph of the colony.

Proceeding in the field through 1-100 colonies, a whole bay population or portion of the population was mapped and sampled. Our intent was to census the population of a bay and capture every coral, no matter the size and map them in a methodical manner. The results included a census of most bays and a large majority of species in other bays where we collected all corals within an area defined by placing a buffer around the pattern of points. While the GPS accuracy was generally 3-5 meters or better when tested against known locations, the importance was not high accuracy in exact locations, but accuracy in the overall population distribution patterns within the bay. GPS units suitable for marine work with differential and real time correction can bring this to sub-meter accuracy for those applications in future uses requiring it. Despite the normal positional error for these machines, the patterns plotted of locations gave a population pattern that had still retained significant geographical accuracy for disease and size class across gradients from east to west, north to south, inshore and offshore, shallow and deep. Additionally, the geographic location can be assessed against the back drop of adjacent terrestrial features like surface water drainage ghuts entering the coastal watershed impact area and specific upstream land use inputs and disturbances. This spatial mapping provides a fundamental means of linking landscape activities and seascape populations to observe patterns, processes and mechanisms.

The Lat/Long data from the Garmin GPS was downloaded via OziExplorer software and saved as a .dbf File. This coordinate file can be imported into ArcGIS or ArcView GIS as an event theme and overlayed on a geo-referenced aerial photograph producing a map of colony locations within the bay. Sampling data on hundreds of data points however, was time consuming to transcribe from data sheets to excel files and then join with the Lat/Long .dbf file. Each field sampling would typically last 2-3 hours while the data transcription in the lab consumed more than twice that amount of time. Additionally, the data recording and transfer is error prone. The traits or patterns common to the population could be represented in a GIS display to produce maps that depict the geographic distribution characteristics, if any. These distribution maps serve to exhibit patterns and trends in the seascape populations, tools unavailable a short time ago.

The Waterproof data sheet would need to be replaced in order to actually measure thousands of coral colonies. We initially chose a Garmin ique 3600 GPS/PDA and loaded Pendragon OS Palm Forms 5.0 Software. This allowed us to tie a GPS position together with a digital data form in the same machine. This worked well for terrestrial work because the screen was more easily seen, and a stylus could be used, but the unit proved impractical for surface water work. The small screen, glare of the water, stylus size and layers of Aquapac plastic and dive mask glass made the unit difficult to handle and see in surf conditions. Subsequently, this line of Garmin ique's developed battery issues and was discontinued by the company. After initial use and wear, our machine failed and was taken out of service.

Working with a software/hardware consultant Conestoga-Rovers & Associates (CRA), we settled on a replacement Trimble TDS Recon 2000 GPS/PDA. A data form was developed through collaboration with CRA to sample the corals and collect GPS location. The forms were written on a program that allowed a large touch screen. This machine proved reliable in tests and was selected for this project. Several machines were leased from CRA Associates, programmed and put into the field. The machines proved very efficient in data collection and data download. A data collection protocol was established and training was given to TNC staff. The Recon PDA was used to collect data only as the GPS function was eliminated when the unit was brought below the water's surface, an observation confirmed by the Garmin ique. The Garmin 12XL floating on a raft or hand carried, was used for GPS collected Lat/Long and the files were joined to the data files from the Trimble PDA.

In capturing data, the field method that worked best was to swim with the PDA 20cm below the surface in front of the swimmer and text-finger the touch screen to complete the sampling questions for each coral. A second swimmer using a separate GPS collected positional data. In total, more than 2100+ coral colonies were mapped and sampled around St. Thomas and St. Croix using this new technological approach. GIS maps of population distribution locations and characteristics were made and are provided on the following pages.

Currently we are advancing the technology for use with both terrestrial and marine populations by experimenting with additional equipment. We are currently testing Trimble Juno GPS/PDA's with Pendragon Forms 5.0 software and external antennas in trying to combine the GPS/PDA data collection activities under one collection method.

<u>Mapping Population Patterns Goal 2</u>

The mapping project for Elkhorn Coral completed six sampling sites on St. Croix and three sampling sites on St. Thomas. While the original plan was to assess and map approximately 10 sites around each island consisting of at least 100 colonies per site for a total of 1000 colonies per island, the actual in-field sampling indicated that many sites had fewer than 100 colonies while several other sites had many more than 100 colonies. In discussions between the PI's, it was decided that more information on the sites where large populations existed would have greater value statistically than smaller numbers of samples, especially since this was an initial pilot study to be supplemented by additional future site collection efforts. In this way, sites could be fully sampled and mapped for the total number of colonies increasing the sample size and adding power to the statistical comparisons completed now and done in the future as the database expanded in time and scope. This would make re-sampling more accurate and establish a solid foundation upon which to understand recovery or loss as data accumulated. This meant completing a more thorough examination of each site which would alter the number of sites but not the number of colonies. In the future this would serve as a solid baseline for each site and additional sites could then be brought on line, creating a larger and more comprehensive database. The total number mapped and sampled was 2130 colonies; 1418 colonies (10 sampling days x 2 teams) around St. Croix and 712 colonies (13 sampling days x 1 team) around St. Thomas. St. Thomas had fewer sites completed and corals, but assisted the TNC/St. Croix at 5 of the 6 sites and provided additional time for 3 in-water trainings and 2 GIS instructional trainings. The sites and the number of coral colonies sampled are listed below.

St. Thomas sites

5/10/07	Botany Bay	106 colonies	
5/22/08	Botany Bay	62 colonies	Re-sample
4/12/07	Sprat Bay	27 colonies	
6/17/08	Sprat Bay	36 colonies	Re-sample
11/16/06	Flat Cay	72 colonies	
12/19/06	Flat Cay	75 colonies	
2/1/07	Flat Cay	100 colonies	
2/15/07	Flat Cay	85 colonies	
3/1/07	Flat Cay	62 colonies	
3/22/07	Flat Cay	39 colonies	
3/29/07	Flat Cay	181 colonies	
5/15/08	Flat Cay	104 colonies	Re-sample
7/22/08	Flat Cay	79 colonies	Re-sample

St. Croix sites

12/07/06	Hams Bluff	62 colonies
12/08/06 3/1/07	Green Cay Green Cay	415 colonies
2/24-28/06	Salt River	659 colonies
3/13/07	East_ Northshore	135 colonies
3/15/07	West_Northshore	49 colonies

5/22/07 Point Udall 98 colonies

General: Size Classes/Disease

This project was primarily focused on mapping the number of coral colonies by size class and disease prevalence. Size classes were initially set and estimated at small (1-10cm), medium (11-50cm), large (51-100cm) and x-large (>1m).

Prevalence of disease among the colonies surveyed was categorized as yes, no and unknown. Disease recognition is a relatively new skill for coral research and a great deal of confusion still exists among researchers attempting to identify specific coral diseases. As the diseases occur on many coral species and can physically look very different, they are difficult to discern. As a result, we are reporting disease prevalence as yes/unknown and no. A positive answer of yes/unknown means that a specific disease was recognized or that the disease was not identified but coral polyp surface anomalies/lesions are found indicating some coral polyp loss not associated with predation. Colonies surveyed which had no surface anomalies/lesions were classified as no. In addition, the methodology allowed the capture of other colony characteristics including bleaching, % live coral cover, colony type, fragmentation and predation. These data are not analyzed but results are available in the digital appendix.

The sampling area has been delineated on all site maps. Density measures of coral colonies are a good statistic to consider for future analysis. However, the sampled areas in some cases may show large contiguous patches of corals as well as areas of no coral growth. A determination as to where to delineate the habitat must be standardized in order to get measurements that truly reflect the density of the colonies in actual habitat for comparison with other sites. This is important for future discussions and statistical treatment.

Note: Analyses of the coral colony characteristics are limited by the number of colonies surveyed and re-sampled and the number of sites. In most cases, these data establish a baseline of the bays completed which can be supplemented by additional field studies to complete the picture geographically around the island and at offshore locations. A comprehensive baseline of population characteristics and patterns if any, must be established over longer term sampling. However, three sites, Flat Cay, Green Cay and Salt River have large populations surveyed and are appropriate as solid long term monitoring sites.

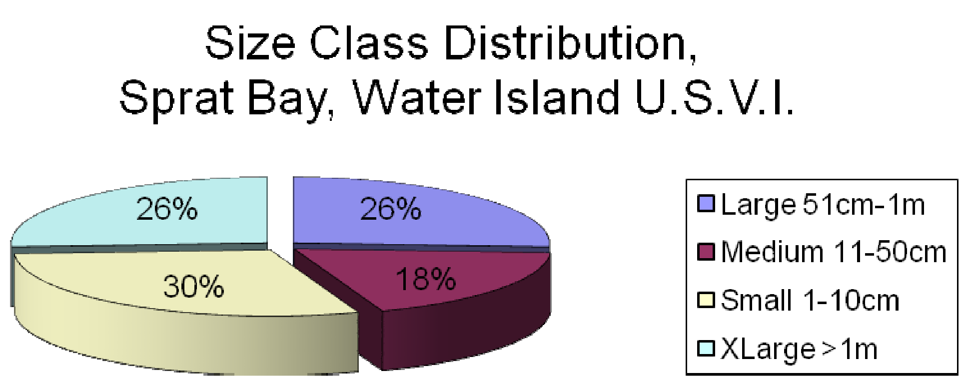
Map of St. Thomas *Acropora palmata* Sites

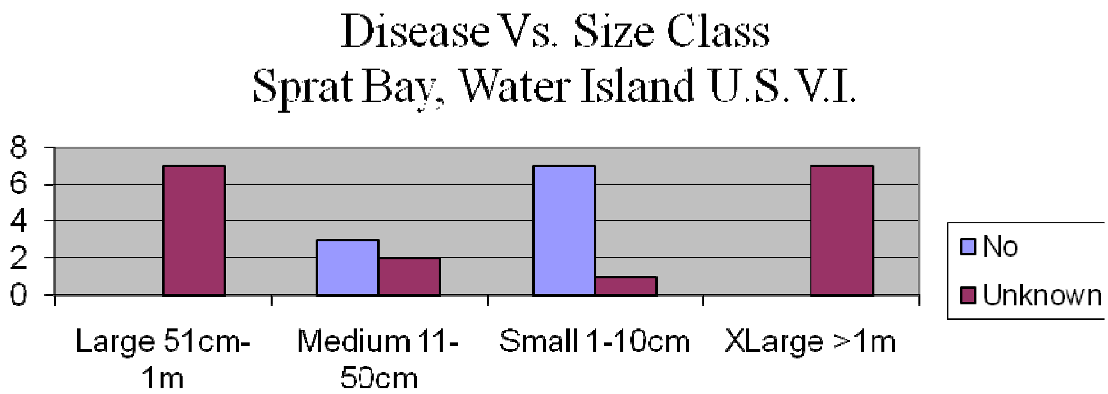
<u>1999 NOAA Aerial Photograph</u>

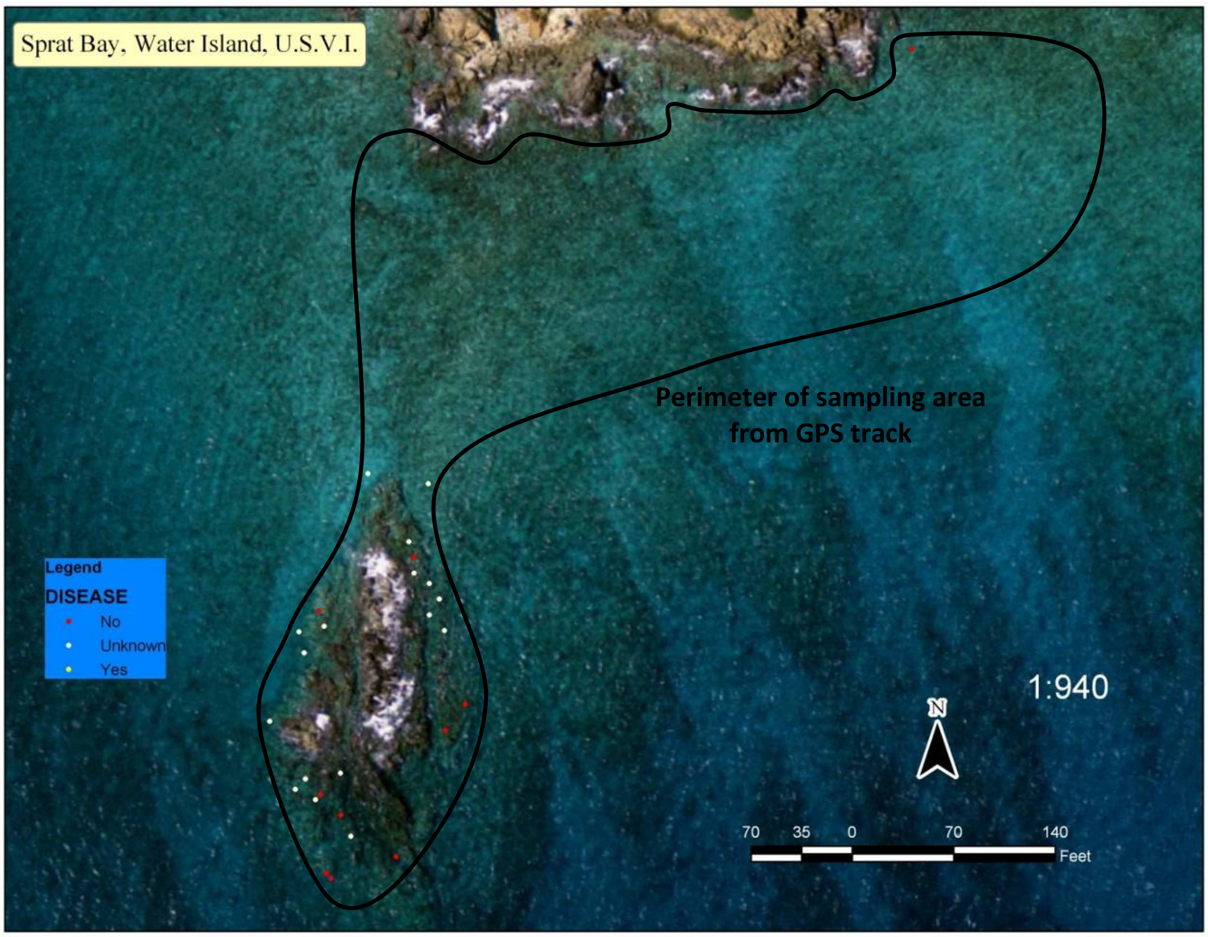
Population Characteristics – Year 1 **Sprat Bay, St Thomas** 4/12/07

SIZE_CLASS	Total
Large 51cm-1m	7
Medium 11-50cm	5
Small 1-10cm	8
XLarge >1m	7
Grand Total	27

DISEASE			
SIZE_CLASS	No	Unknown	Grand Total
Large 51cm-1m		7	7
Medium 11-50cm	3	2	5
Small 1-10cm	7	1	8
XLarge >1m		7	7
Grand Total	10	17	27







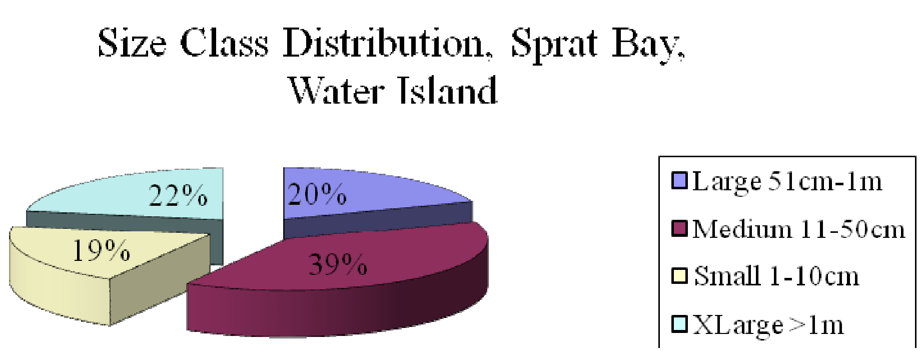
4/12/07 Aerial Map of Sprat Bay

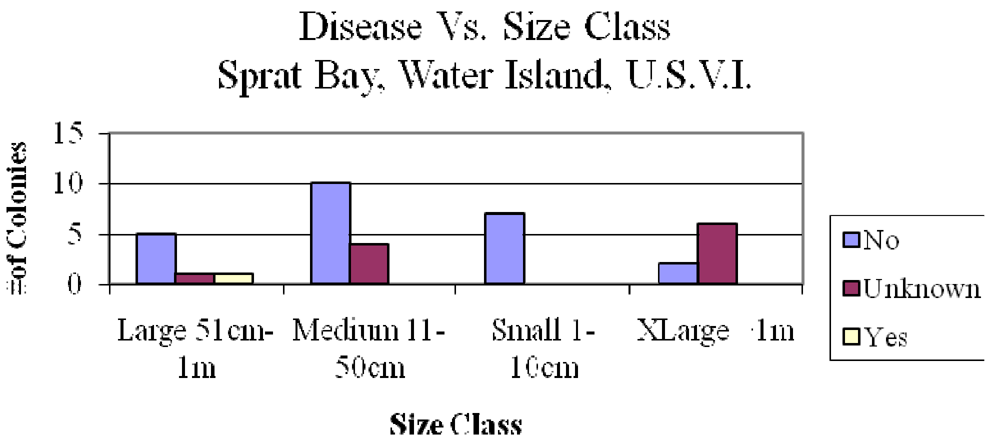
Within the larger Sprat Bay, we sampled the northern mainland shore and the area south to the rocky cay. Sprat Bay is located on the southeast side of Water Island, which lies in the greater Charlotte Amalie harbor island group along with Hassel Island. One elkhorn coral colony was found along the shore, the remainder in the shallows around the rock. The location along the shore and the cay was high energy swells and wind driven waves. The areas adjacent to the shore and cay were 3-8 meters deep hard pavement bottom type with low density coral outcroppings. Typical nearshore conditions of coastal bedrock, hard pavement, some reef areas but most coral growing on pavement and bedrock outcroppings.

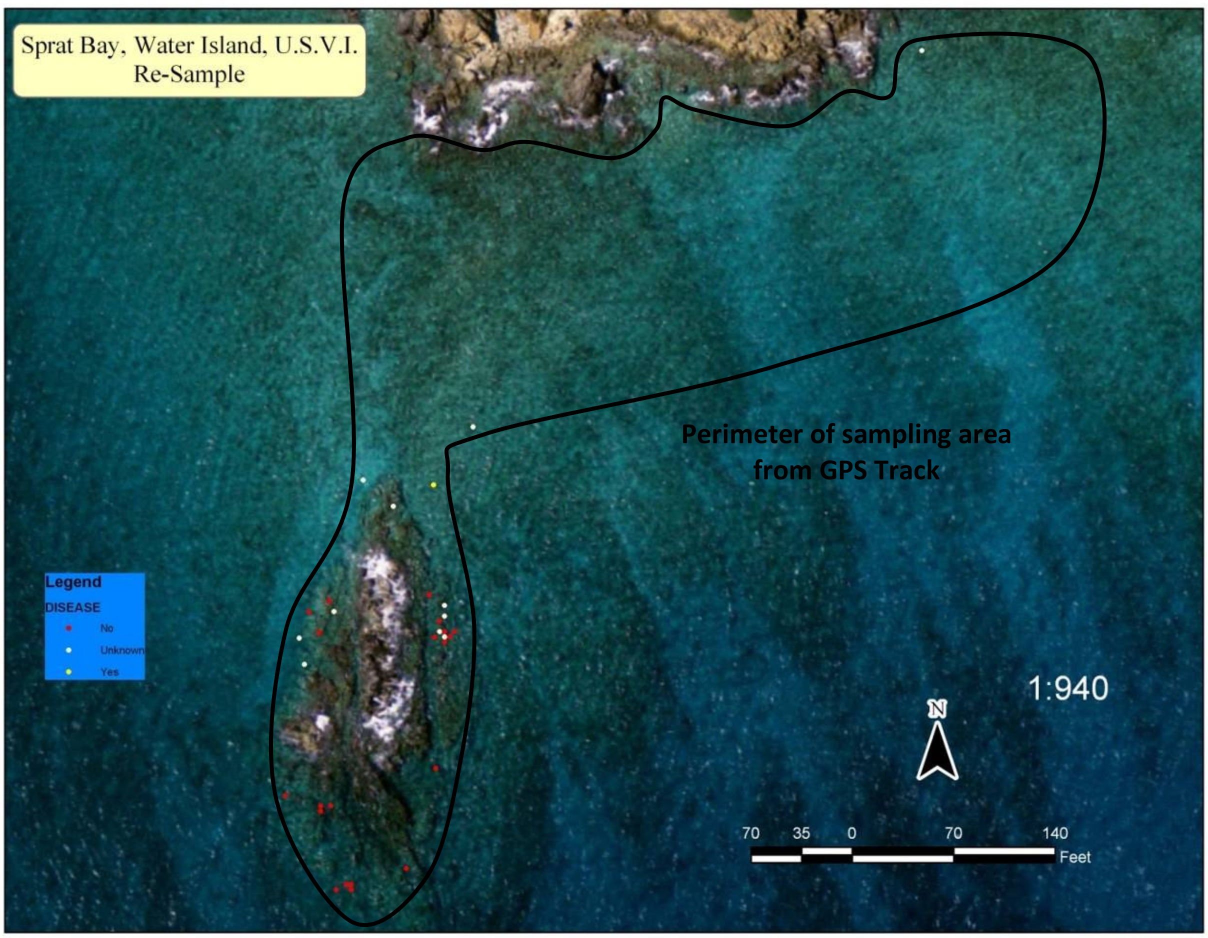
Population Characteristics Year 2 Re-Sample **Sprat Bay, St. Thomas** 6/17/08

SIZE CLASS	Total
Large 51cm-1m	7
Medium 11-50cm	14
Small 1-10cm	7
XLarge >1m	8
Grand Total	36

DISEASE				
Size Class	No	Unknown	Yes	Grand Total
Large 51cm-1m	5	1	1	7
Medium 11-50cm	10	4		14
Small 1-10cm	7			7
XLarge >1m	2	6		8
Grand Total	24	11	1	36

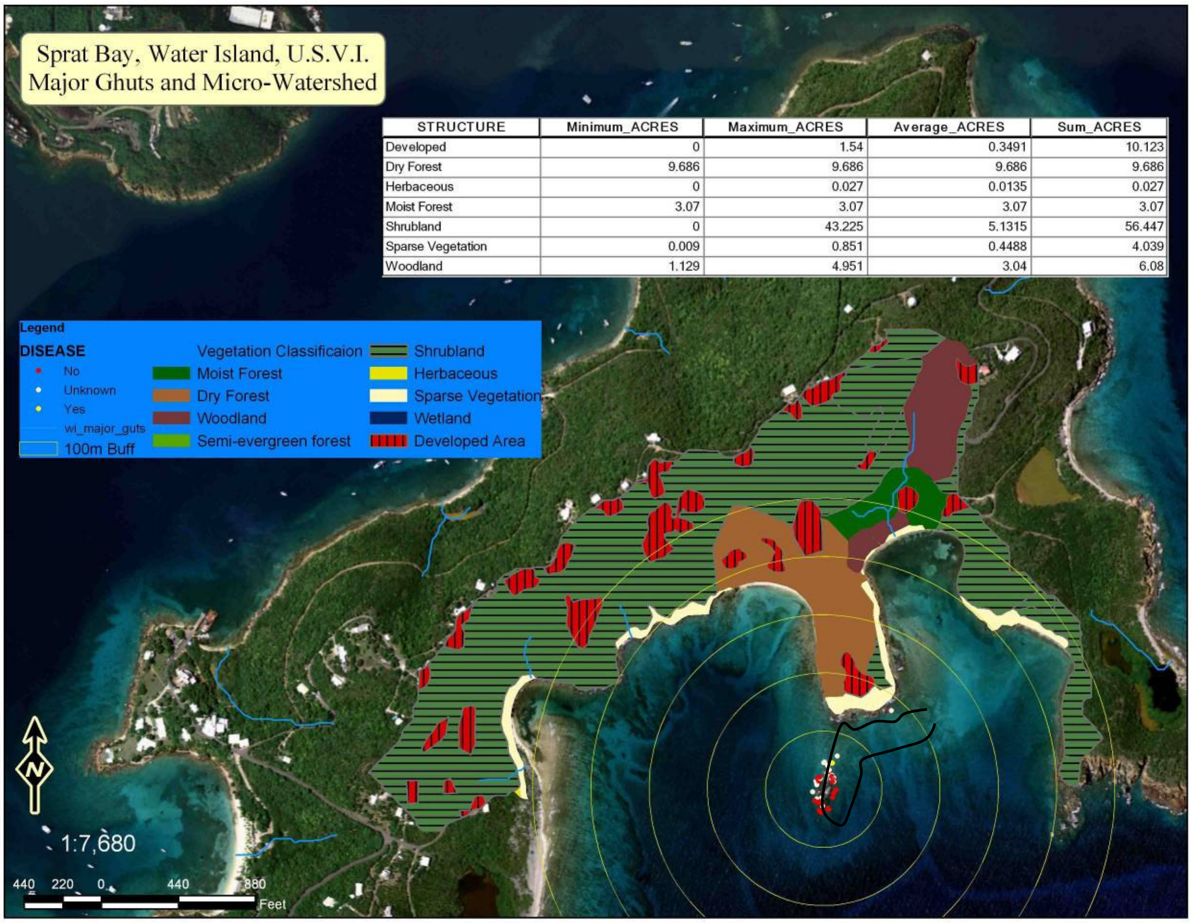






6/17/08 Aerial Map of Re-sample of Sprat Bay

An additional 9 colonies (36) were found one year later. From comparison of the plots, it is clear that some previous colonies are missing and it is suggested that many of the additional colonies seen may be the result of breakage, fragmentation and re-growth rather than reproduction.



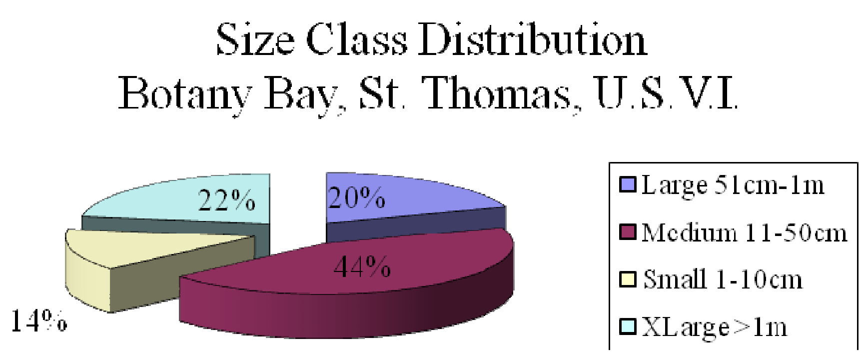
Watershed Characterization : Comprehensive foundation for initial assessment of the inter-dependence of land/sea ecosystems

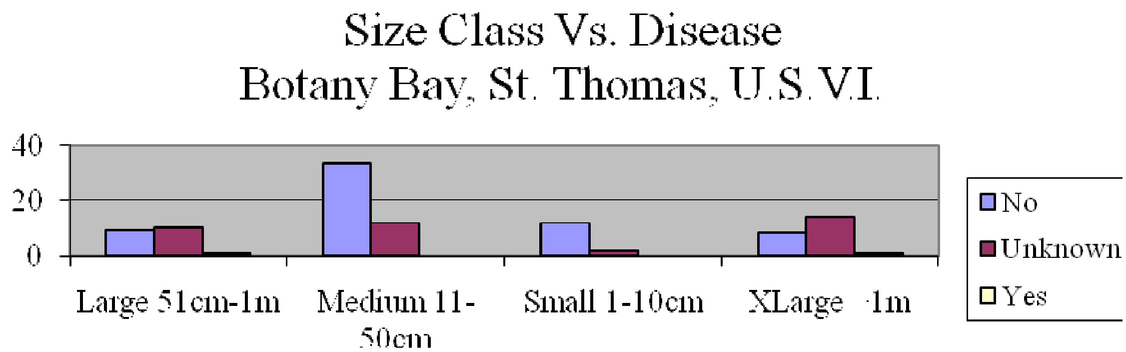
The map above presents basic physical characteristics of the sub-watershed immediately upland and contributing inputs and influences to Sprat Bay and its marine populations. Additional watersheds adjacent to the area can contribute significant influences also in an overlapping coastal watershed impact area. Bay currents and circulation, input locations, types of discharges, size of the contributing watershed and other issues can all affect resulting impacts. Marine population distribution is displayed in context with land use (developed) and land cover vegetation communities as well as major hydrologic drainage streams and ghuts carrying surface runoff to the bay. There are many other dataset overlays that could be added to the basic physical framework to further define the environment. These include disturbance metrics such as (1) % area of the watershed developed, % area developed on slopes >25%, (2) % land use in watershed change/decade, (3) length and areas of paved and unpaved roads, (4) number of times roads construction has crossed and altered natural drainage ghut flow and (5) % of the watershed runoff that is filtered by a coastal wetland and the % that drains directly into the bay. The type of pattern being investigated determines the data overlay sets for analysis.

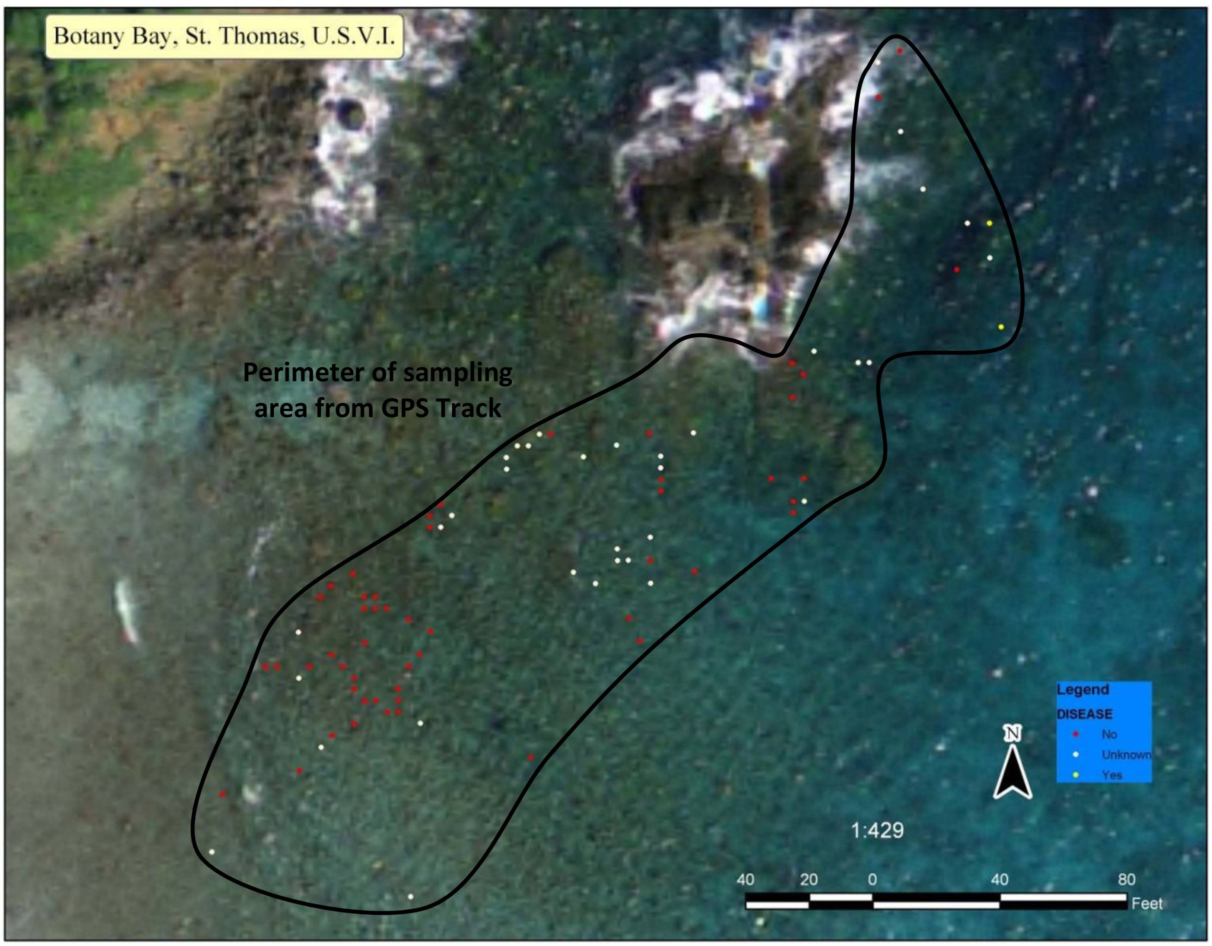
Botany Bay, St. Thomas 5/10/07

SIZE_CLASS	Total
Large 51cm-1m	20
Medium 11-50cm	45
Small 1-10cm	14
XLarge >1m	23
Grand Total	102

DISEASE				
SIZE_CLASS	No	Unknown	Yes	Grand Total
Large 51cm-1m	9	10	1	20
Medium 11-50cm	33	12		45
Small 1-10cm	12	2		14
XLarge >1m	8	14	1	23
Grand Total	62	38	2	102







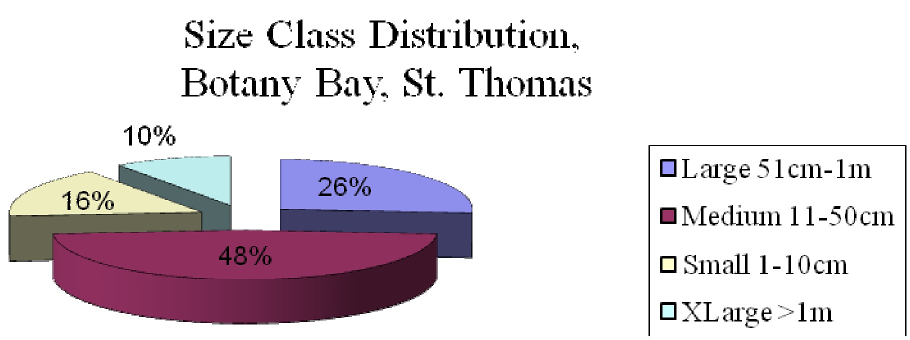
5/10/07 Aerial Map of Botany Bay

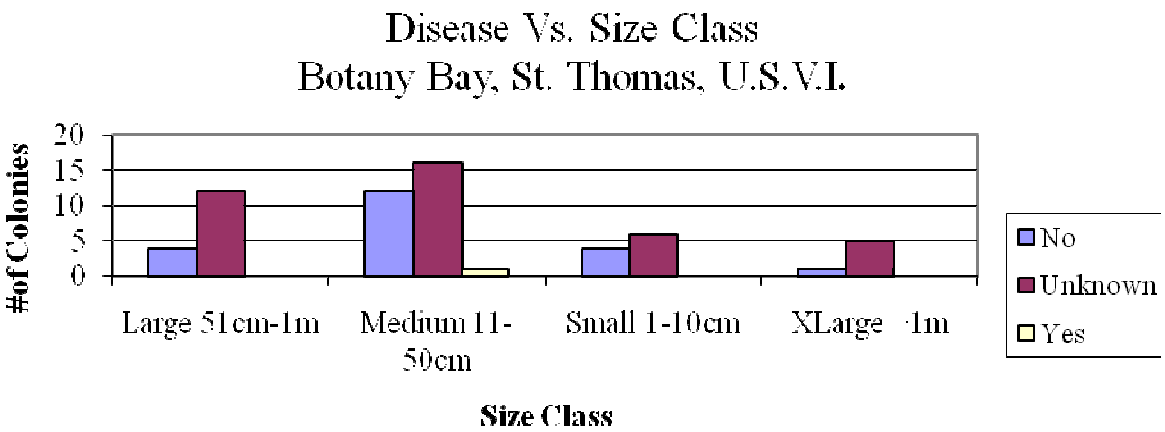
The Botany Bay location is a windward shore, high energy and exposed to large swells and storm conditions. We sampled the small southwest corner of the bay by Mermaid's Chair, a dead end sandspit and large headland that shallow near the shore and are pitted with large outcrop boulders. The inner area shallows to 1 meter for 50 meters out and then drops to sand and pavement surrounding large bedrock outcrops.

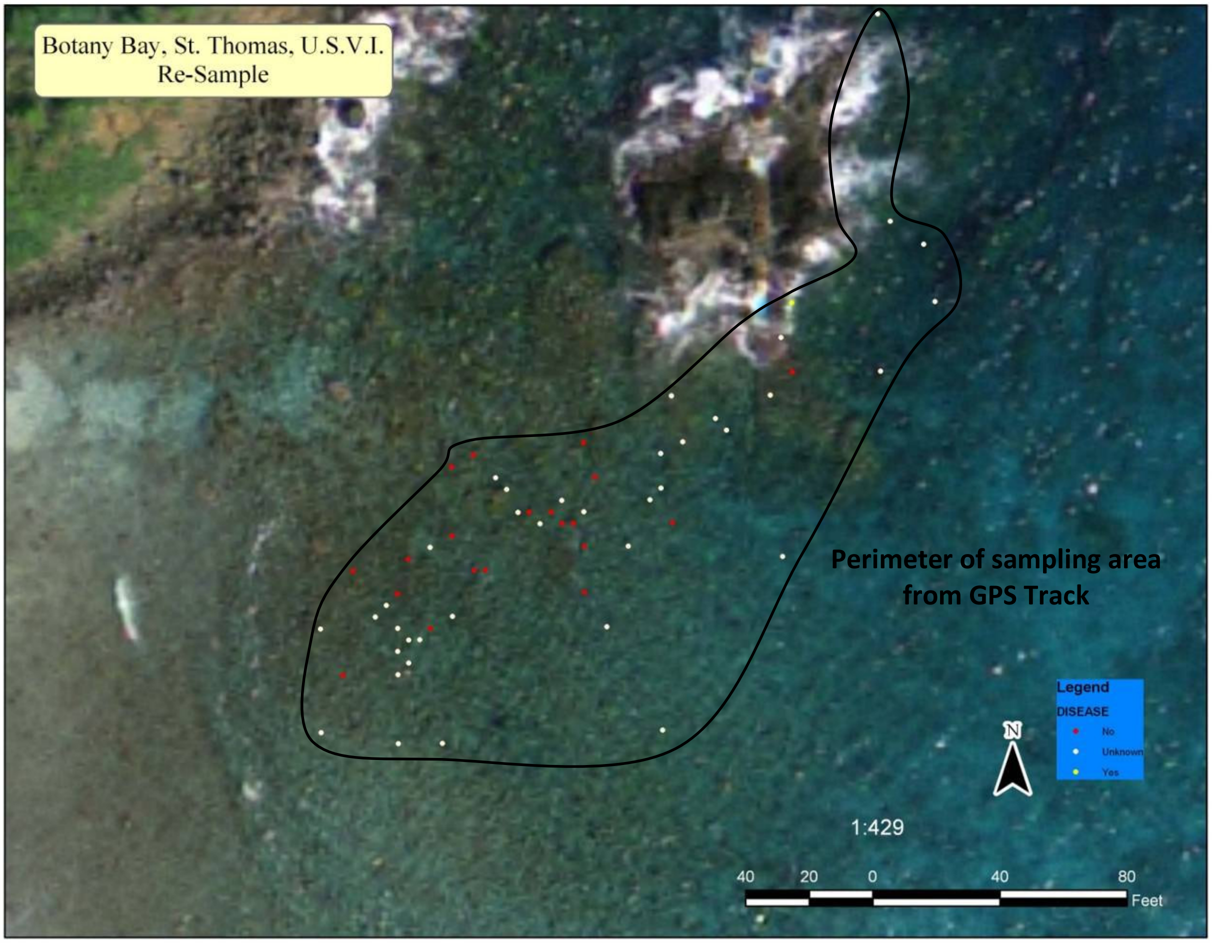
Population Characteristics Year 2 Re-Sample **Botany Bay, St. Thomas** 5/22/08

SIZE CLASS	Total
Large 51cm-1m	16
Medium 11-50cm	29
Small 1-10cm	10
XLarge >1m	6
Grand Total	61

DISEASE				
Size Class	No	Unknown	Yes	Grand Total
Large 51cm-1m	4	12		16
Medium 11-50cm	12	16	1	29
Small 1-10cm	4	6		10
XLarge >1m	1	5		6
Grand Total	21	39	1	61

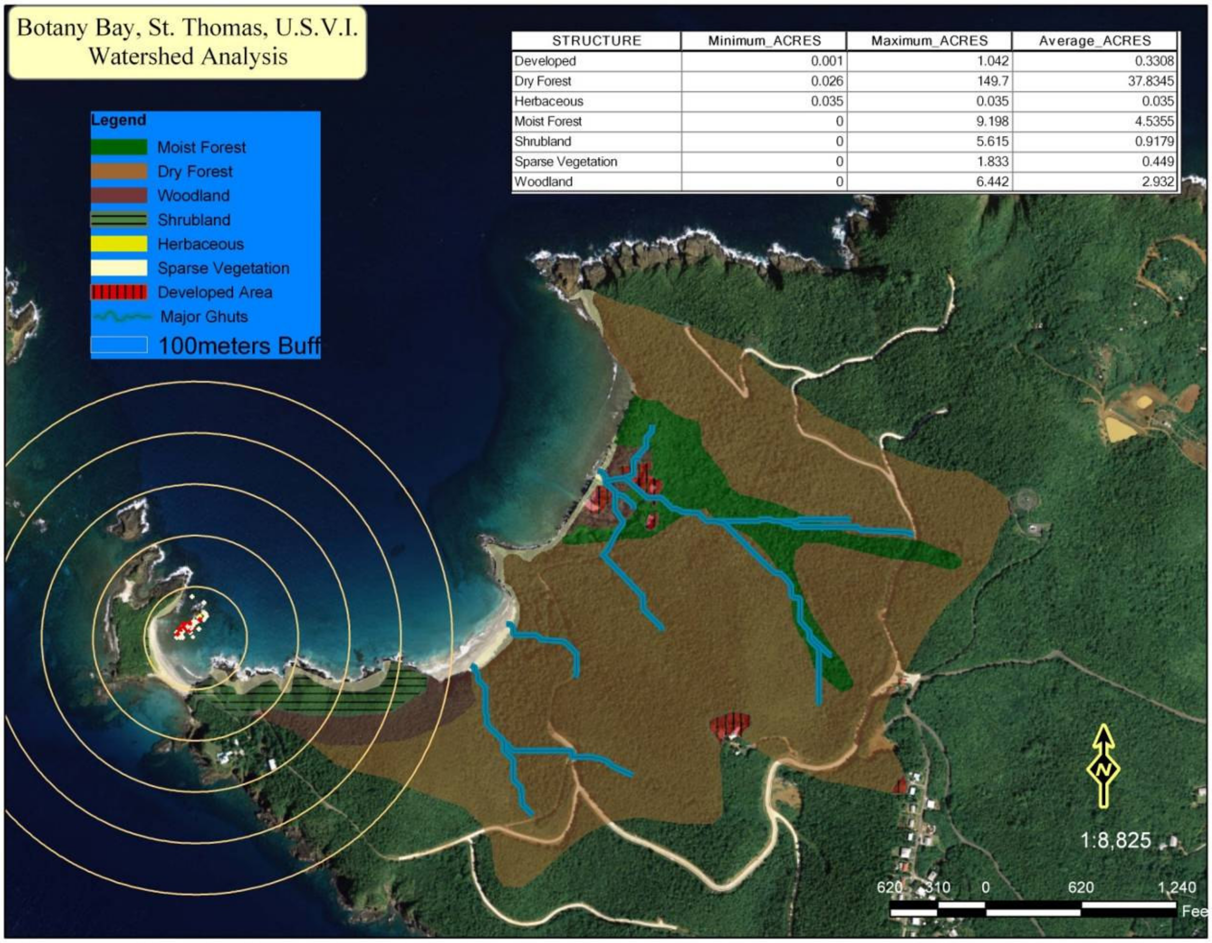



Disease Vs. Size Class
Botany Bay, St. Thomas, U.S.V.I.
#of Colonies
20
15
10
5
0
Large 51cm-1m
Medium 11-50cm
Small 1-10cm
XLarge 1m
Size Class
No
Unknown
Yes



5/22/08 Aerial Map of Botany Bay Re-sample

Comparing the original and resample, 61 of the 102 original colonies found in the area were re-sampled. Both the simple math and the visual pattern show that disease has increased, from 40% to 65% within the sample of the population. The map pattern shows many additional diseased colonies in the midst of areas where the first sampling showed healthy corals.



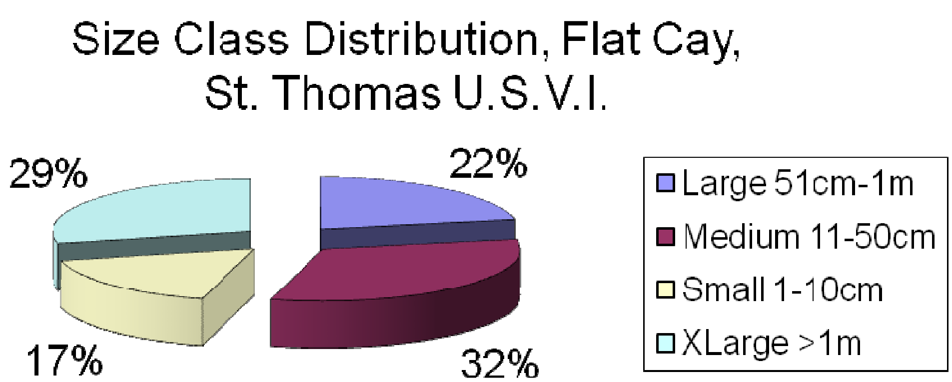
Watershed Characterization : Comprehensive foundation for initial assessment of the inter-dependence of land/sea ecosystems

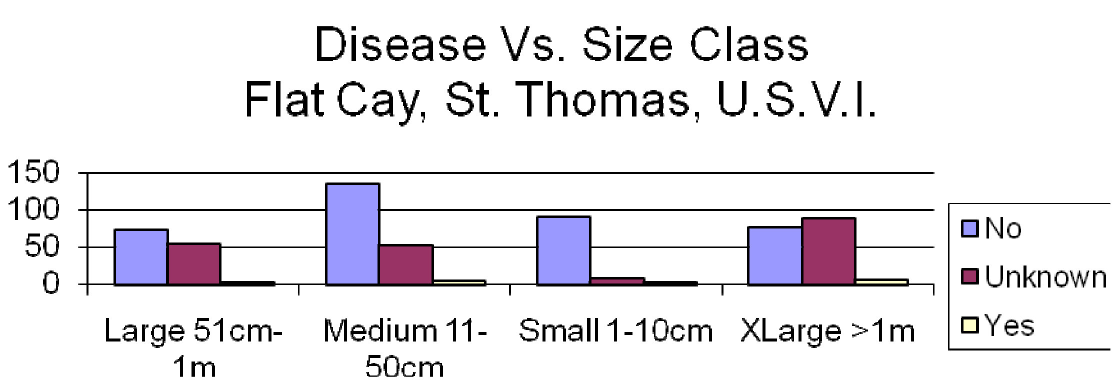
The map above presents basic physical characteristics of the sub-watershed immediately upland and contributing inputs and influences to Botany Bay and its marine populations. Additional watersheds adjacent to the area can contribute significant influences also in an overlapping coastal watershed impact area. Bay currents and circulation, input locations, types of discharges, size of the contributing watershed and other issues can all affect resulting impacts. Marine population distribution is displayed in context with land use (developed) and land cover vegetation communities as well as major hydrologic drainage streams and ghuts carrying surface runoff to the bay. There are many other dataset overlays that could be added to the basic physical framework to further define the environment. These include disturbance metrics such as (1) % area of the watershed developed, % area developed on slopes >25%, (2) % land use in watershed change/decade, (3) length and areas of paved and unpaved roads, (4) number of times roads construction has crossed and altered natural drainage ghut flow and (5) % of the watershed runoff that is filtered by a coastal wetland and the % that drains directly into the bay. The type of pattern being investigated determines the data overlay sets for analysis.

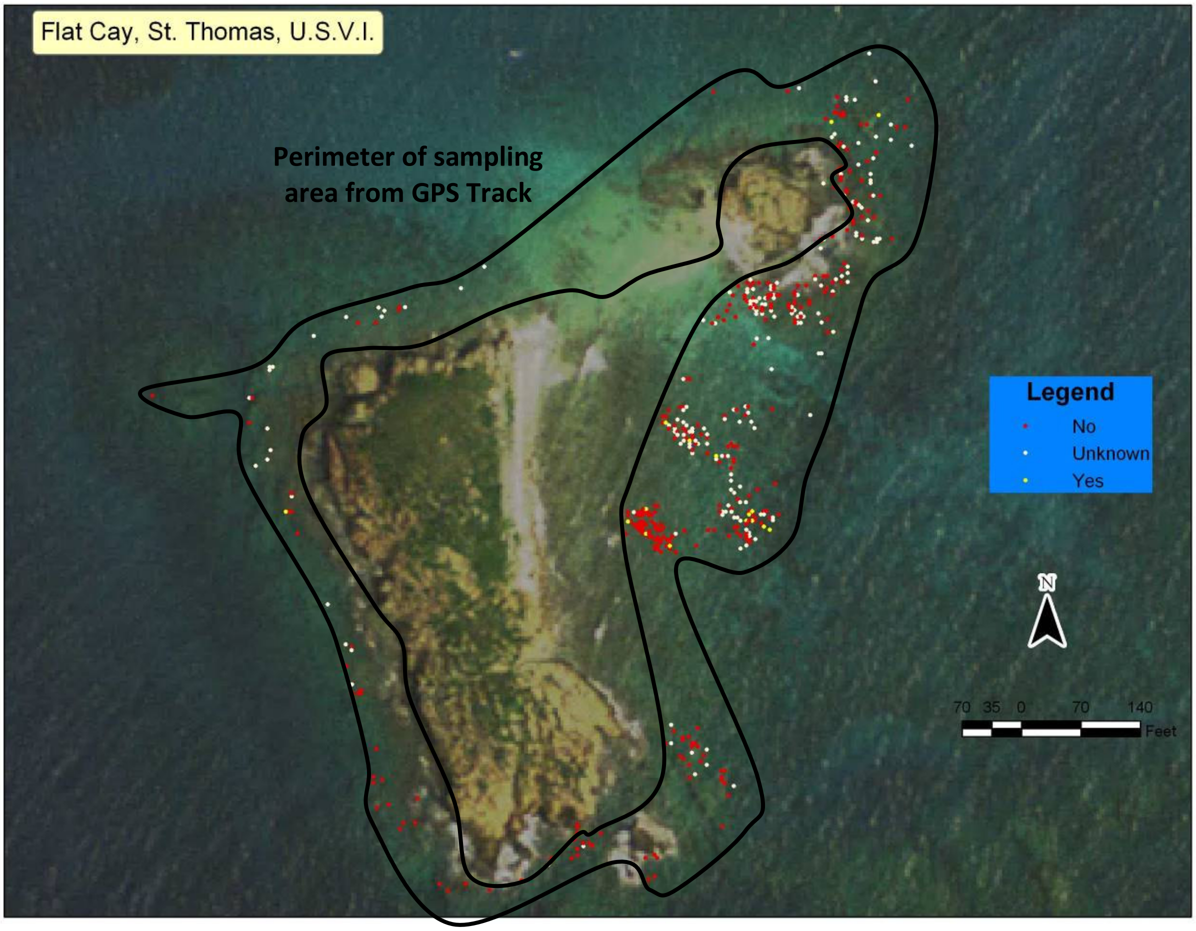
Flat Cay, St. Thomas (Multiple Dates)

SIZE_CLASS	Total
Large 51cm-1m	134
Medium 11-50cm	196
Small 1-10cm	104
XLarge >1m	175
Grand Total	609

DISEASE				
SIZE_CLASS	No	Unknown	Yes	Grand Total
Large 51cm-1m	74	56	4	134
Medium 11-50cm	137	54	5	196
Small 1-10cm	92	9	3	104
XLarge >1m	78	90	7	175
Grand Total	381	209	19	609





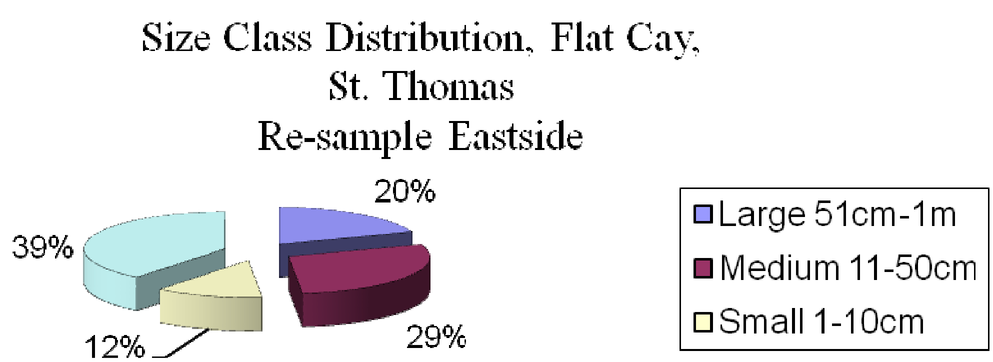


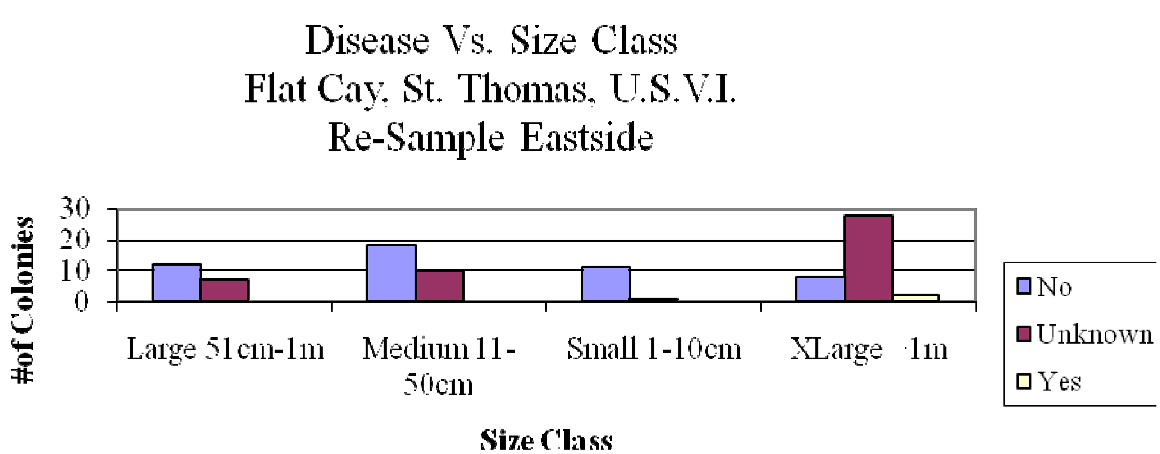
Multiple Sampling Dates: Aerial of Flat Cay site

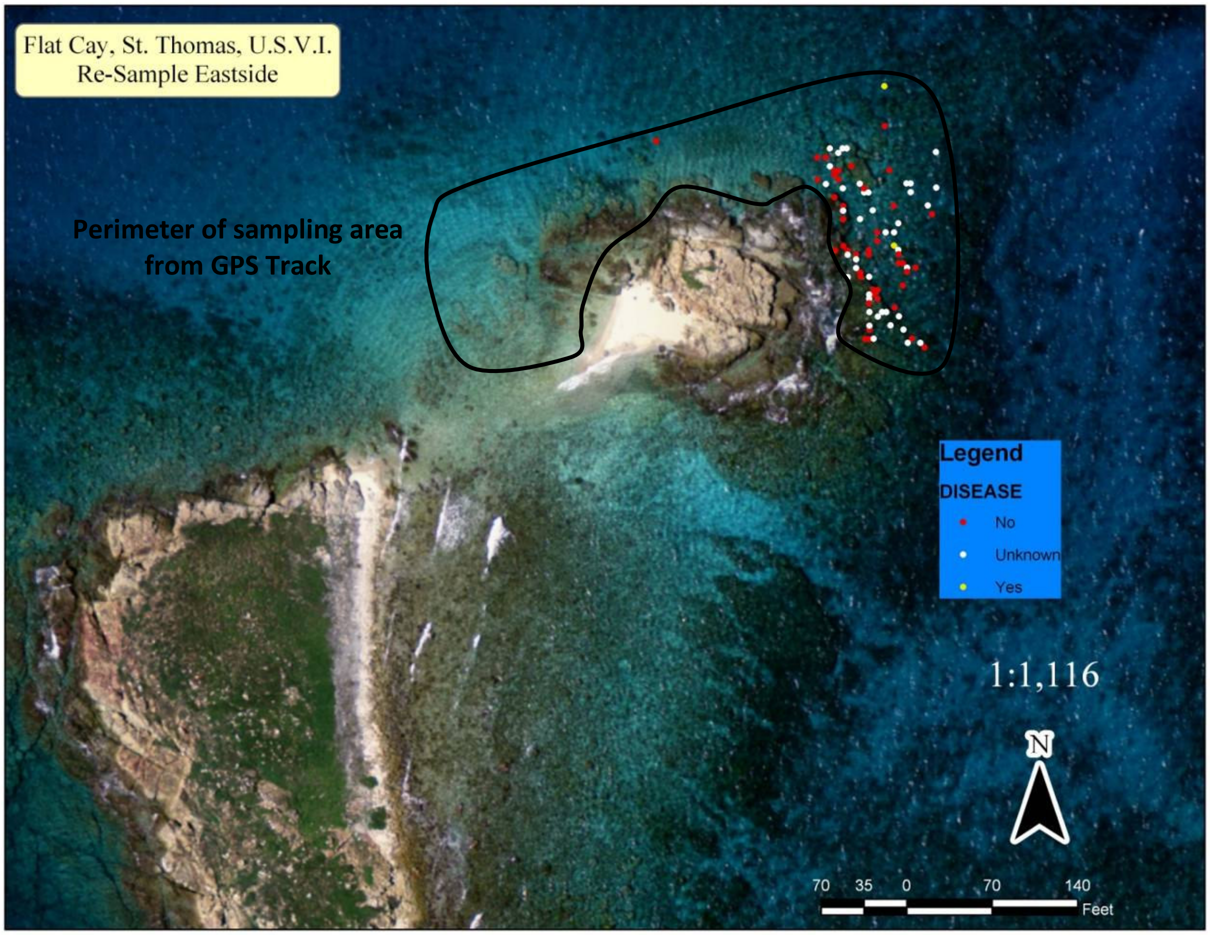
Re-Sample **Flat Cay, St. Thomas (Eastside)** 5/15/08

Size Class	Total
Large 51cm-1m	19
Medium 11-50cm	28
Small 1-10cm	12
XLarge >1m	38
Grand Total	97

DISEASE				
Size Class	No	Unknown	Yes	Grand Total
Large 51cm-1m	12	7		19
Medium 11-50cm	18	10		28
Small 1-10cm	11	1		12
XLarge >1m	8	28	2	38
Grand Total	49	46	2	97







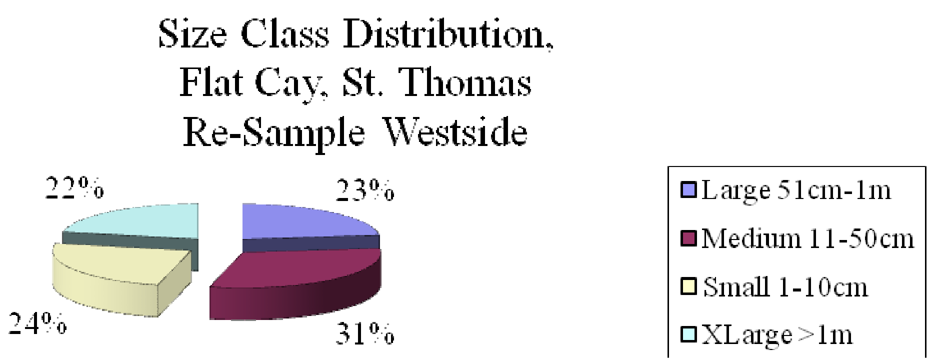
5/15/08 Aerial map of Flat Cay (Eastside)

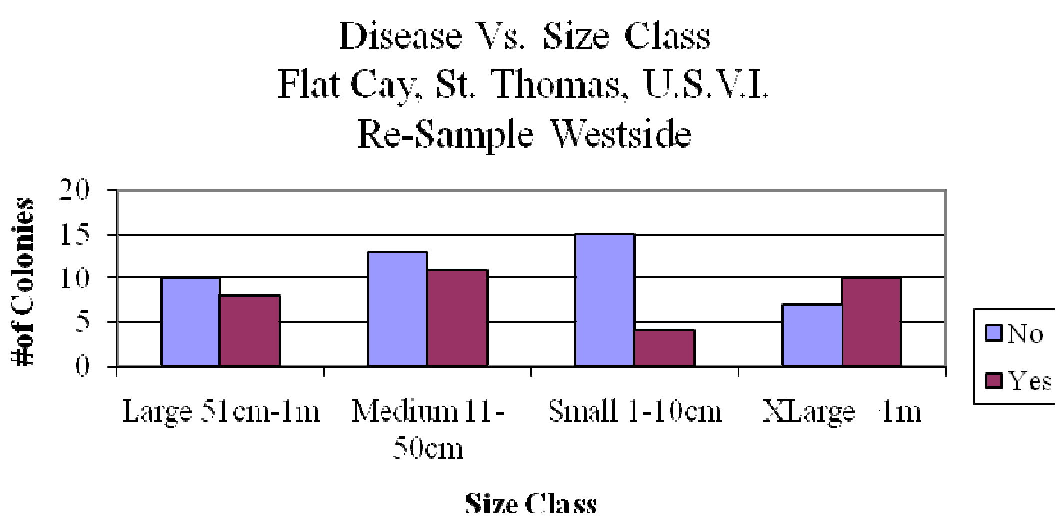
An eastside re-sample was chosen being inshore, north end of the island, exposed to high energy waves.

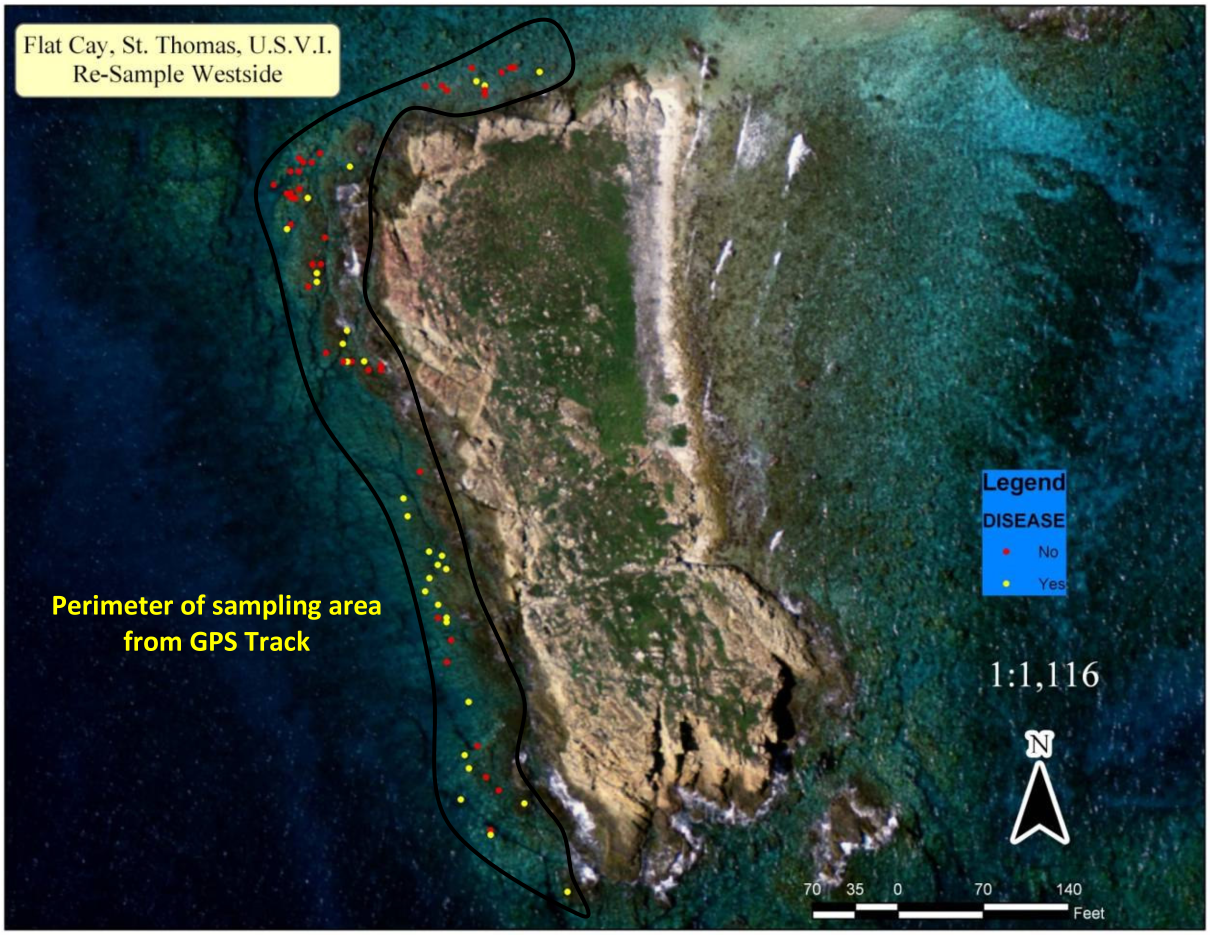
Re-Sample **Flat Cay, St. Thomas (Westside)** 5/15/08

Size Class	Total
Large 51cm-1m	18
Medium 11-50cm	24
Small 1-10cm	19
XLarge >1m	17
Grand Total	78

DISEASE			
Size Class	No	Yes	Grand Total
Large 51cm-1m	10	8	18
Medium 11-50cm	13	11	24
Small 1-10cm	15	4	19
XLarge >1m	7	10	17
Grand Total	45	33	78

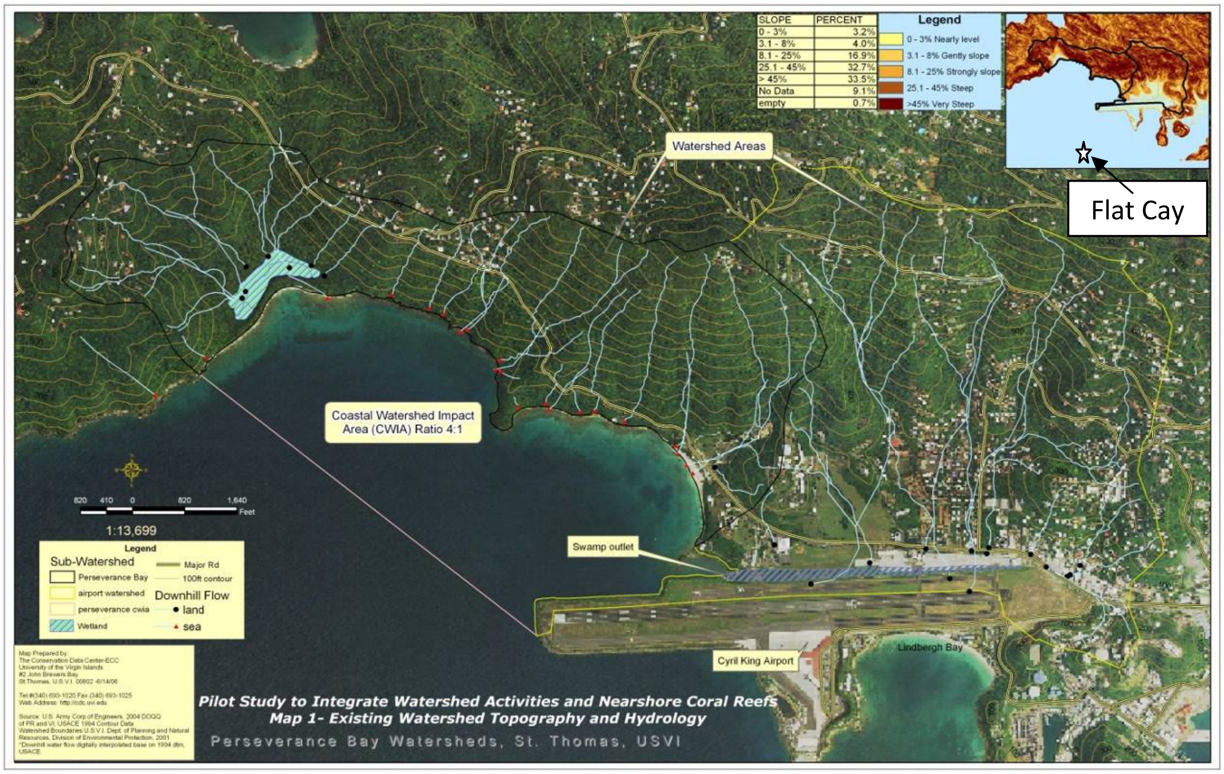






7/22/08 Aerial map of Flat Cay site (Westside)

A western lee shore was chosen as a geographical alternative to the eastside re-sampling.



Brewers Bay and Lindbergh Bay watershed characterization. The Brewers Bay watershed is located adjacent to and inshore of Flat Cay and is linked by hydrology to Lindbergh Bay watershed as a result of drainage alterations in the landscape causing surface water to drain north of the runway into Brewers Bay. Flat Cay is approximately 3000 meters SSE of the Cyril King Airport runway. Please see locus map upper right corner for location.

Brewers Bay – Existing Watershed Topography and Hydrology

This map introduces the main and contributing watershed study areas and the terrestrial factors (or features) that affect watershed drainage and the quality of stormwater delivered to embayments. This map product uses existing datasets to spatially and visually characterize the natural landscape. Geo-referenced aerial photographs (NOAA 2000 and 2004) and topographic contours are used to delineate the watershed and sub-watersheds, analyze watershed slope classifications, determine drainage system network/volume and locate wetland basin retention areas. As a result, the natural hydrologic drainage gutters and Coastal Watershed Impact Areas (CWIA) were identified.

<u>Topography and slope classifications</u>; The contour elevations are 100' intervals which are then divided into six slope classifications based on steepness. A review indicates the flatter areas < 8% grade represent a small percentage of the total watershed slope area.

<u>Drainage Network Complexity</u>; The path of runoff precipitation In evaluating the natural patterns represented on the map, several features are important in understanding the *symbology*. The areas where the drainage system shows net or ladder like *symbology,* are areas of significant volume collection or accumulation from the adjacent landscape by large area surface or sheet flow. These hillside slopes while steep, are still flat or planar and create numerous drainage sheet flows too small for measurement. Sheet flow on these planar sites gathers and concentrates in the main guts to

significantly increase volume. When these collection areas coincide with constrained soils, topographic alterations and septic installations, potential sediment and nutrient problems can be greatly exacerbated. While no standard applies to the increased collection volume, a close look at the map will qualitatively indicate that the network collection pattern can be larger (ladder-like) and longer in many places. This speaks to the complexity and volume gathering capacity of the gut. A greater number of individual guts, accumulation areas, main branches and load points multiply the complexity of the system but also spread the runoff load across the watershed and along the coastline. Brewers – Perseverance watershed drainage network is again, very complicated with many components, short steep guts and long shallower guts, accumulation areas and many load points.

Coastal Watershed Impact Area - protected and unprotected coastline

The watershed drainage network may drain into a wetland basin area or directly into the coastal waters creating areas of protected and unprotected coastline by basin wetlands. The ratio of the area of the watershed draining into a basin wetland versus the area draining directly into coastal waters is an important metric in characterizing the potential for protection or degradation of downstream communities. There are a number of sub-watersheds within the terrestrial lands draining into the CWIA all of which show separate drainage networks that sometimes join in the lower basin areas. Retention areas such as salt ponds and isolated wetlands at the base of large watersheds, act in both a sediment retention function and as a nutrient filter for runoff water eventually making its way to the sea.

The ratio of the percentage of the watershed that drains into retention ponds (protected) or directly (unprotected) into the CWIA is important and a good way to compare different watersheds from the perspective of threat or risk analysis. When roadways, residences and excavation of varying intensity create topographic change and disturbance, the problems can be magnified by whether the areas drain into protected coastline or unprotected coastal waters.

Additionally, the CWIA has been subjectively designated as the area of the bay from headland to headland which receives the terrestrial runoff. This measure has been used in the past by Hubbard (1987) to show the relationship of drainage area to receiving waters. The ratio of landscape area drained to area of the CWIA provides a metric which helps to characterize the size and potential impact of the watershed drainage on the water quality of the embayment. From a fundamental standpoint, the larger this ratio, the greater the potential impact of landscape on seascape. In this study, Brewers-Perseverance (4:1) have a landscape area 4-5 times as large as the smaller bay area it drains into. The potential for downstream impacts is magnified by the potential for disturbance or alteration of natural conditions. However, there are many other factors which increase or decrease this potential significantly including the open or closed geography of the bay and the bay currents that operate.

Watershed Boundary Alterations; combining watersheds

Brewers – Perseverance watershed exhibits an unusual characteristic of importance with regard to downstream impacts. Although no technical work has been done to recreate the original drainage, our assessment of existing conditions indicates that the area draining into the Brewers-Perseverance CWIA was once confined to the area above the bays. During the construction of the airport runway, some portion of the drainage from the sub-watershed to the east of the study site in Contant was diverted from Lindbergh Bay to the wetland channel north of the runway, feeding into Brewers-Perseverance Bays. This increases the size of the area, complexity of the drainage, and the quality and quantity of potential runoff into the study bay.

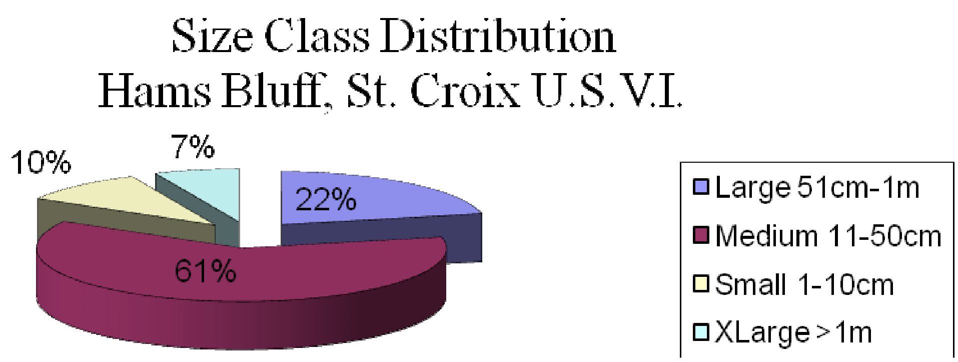
Map of St. Croix *Acropora palmata* Sites

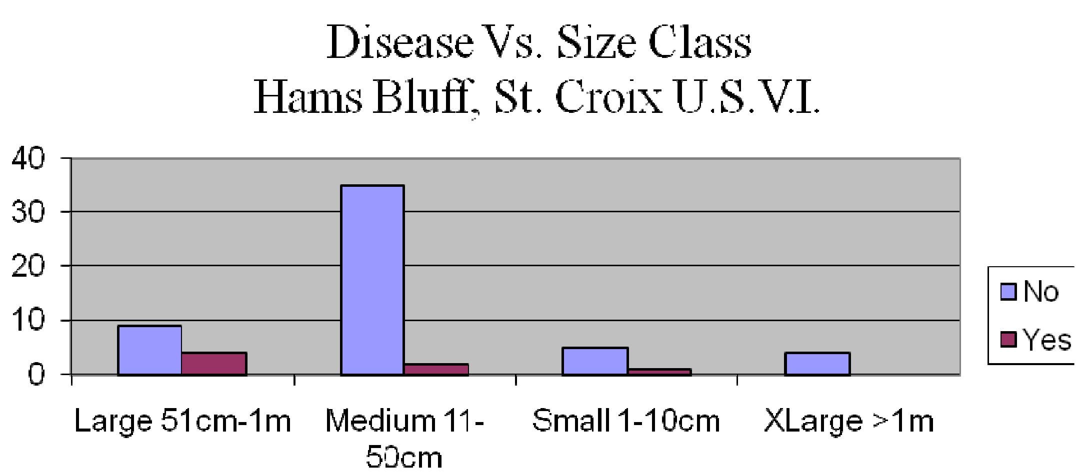
1999 NOAA SID Image

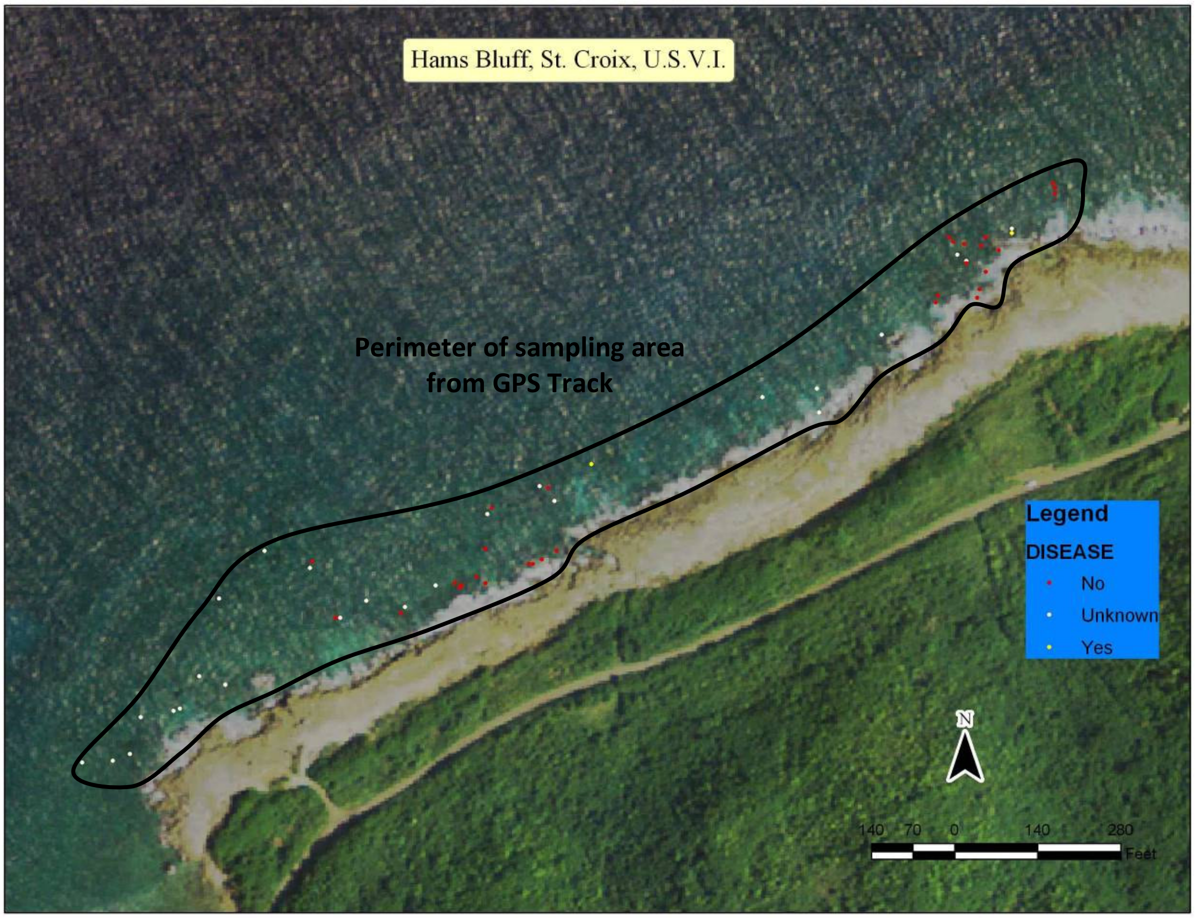
Population Characteristics Year 1 **Hams Bluff Bay, St. Croix** 12/7/06

SIZE_CLASS	Total
Large 51cm-1m	13
Medium 11-50cm	37
Small 1-10cm	6
XLarge >1m	4
Grand Total	60

DISEASE			
SIZE_CLASS	No	Yes	Grand Total
Large 51cm-1m	9	4	13
Medium 11-50cm	35	2	37
Small 1-10cm	5	1	6
XLarge >1m	4		4
Grand Total	53	7	60



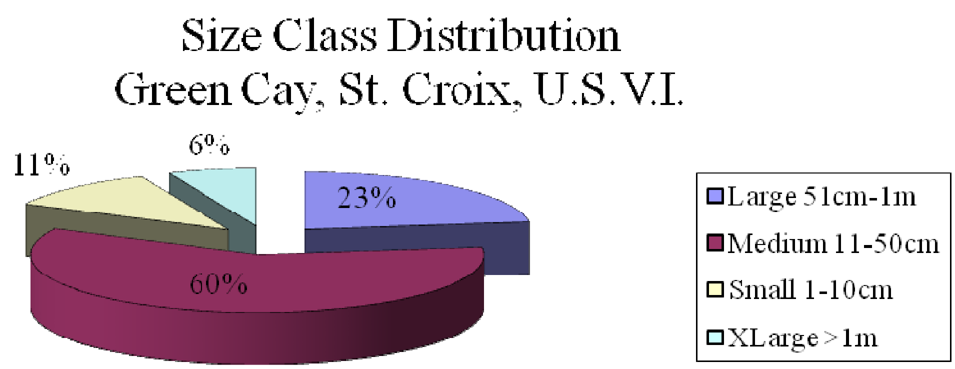


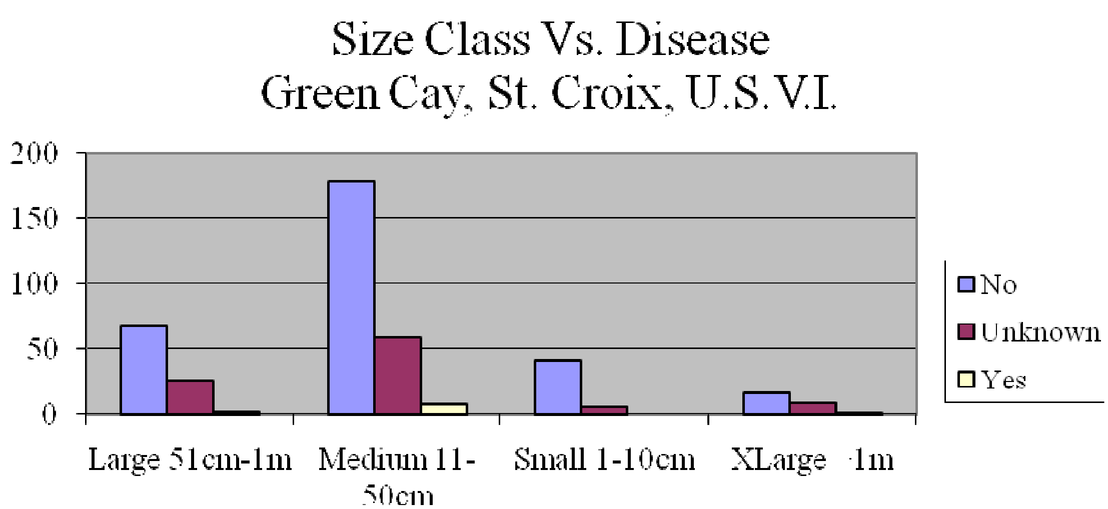


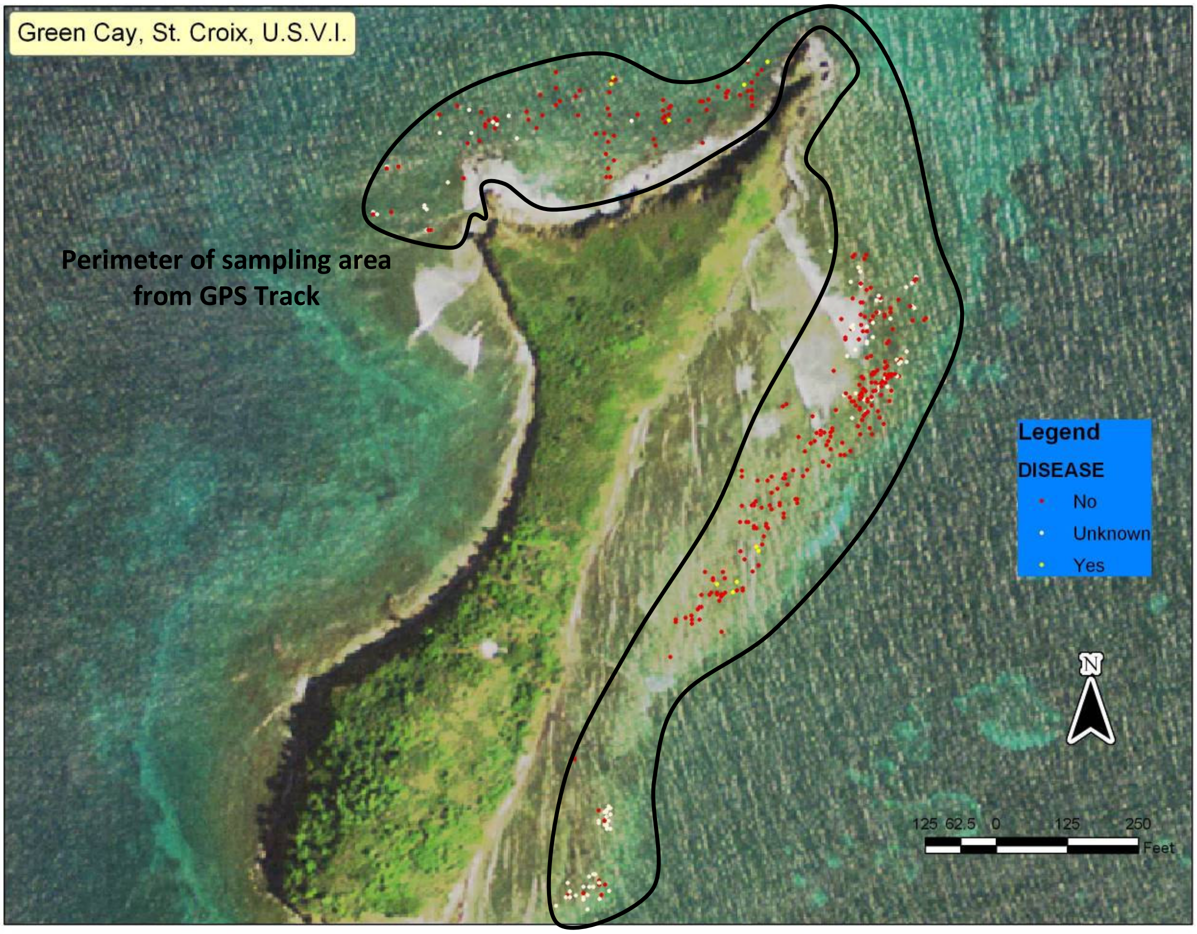
12/07/06 Aerial map of Hams Bluff site

Count of SIZE_CLASS	
SIZE_CLASS	Total
Large 51cm-1m	95
Medium 11-50cm	246
Small 1-10cm	47
XLarge >1m	26
Grand Total	414

Count of SIZE_CLASS	DISEASE			
SIZE_CLASS	No	Unknown	Yes	Grand Total
Large 51cm-1m	67	26	2	95
Medium 11-50cm	179	59	8	246
Small 1-10cm	41	6		47
XLarge >1m	16	9	1	26
Grand Total	303	100	11	414





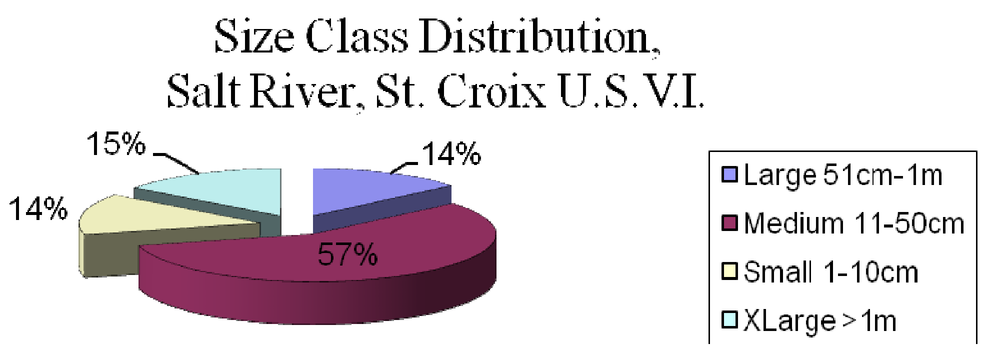


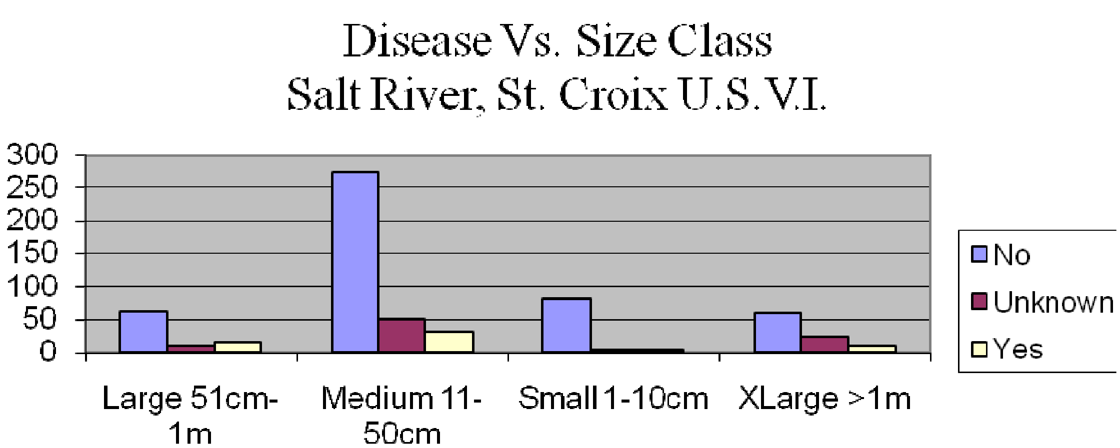
12/08/06 Aerial map of Green Cay site
3/01/07

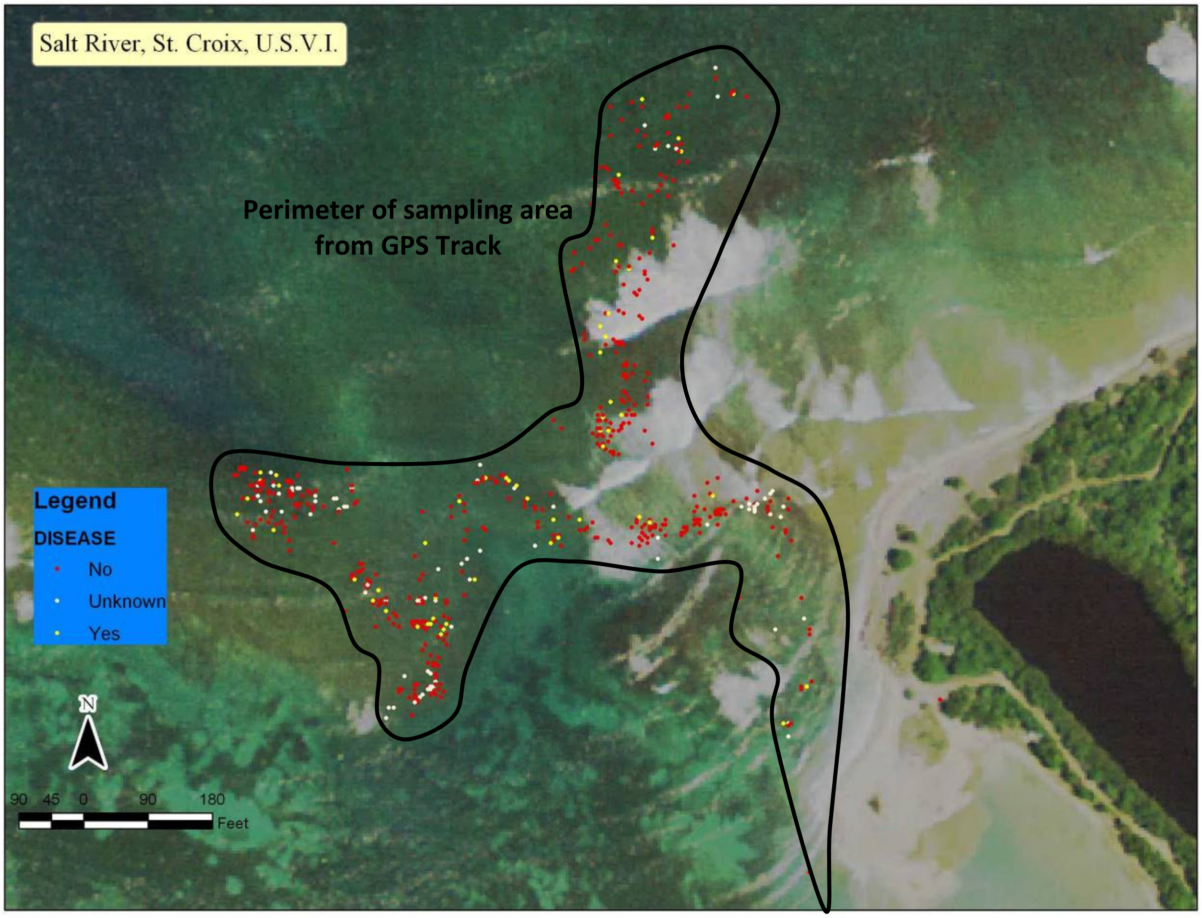
Salt River, St. Croix 2/24-28/07

SIZE_CLASS	Total
Large 51cm-1m	86
Medium 11-50cm	353
Small 1-10cm	87
XLarge >1m	92
Grand Total	618

DISEASE				
SIZE_CLASS	No	Unknown	Yes	Grand Total
Large 51cm-1m	61	9	16	86
Medium 11-50cm	274	49	30	353
Small 1-10cm	80	3	4	87
XLarge >1m	59	23	10	92
Grand Total	474	84	60	618





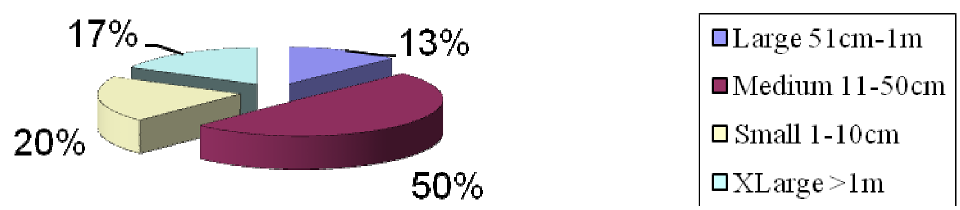


2/24-28/07 Aerial map of Salt River site

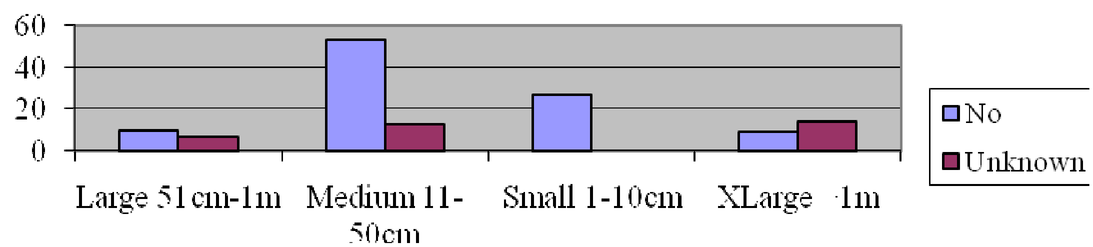
SIZE_CLASS	Total
Large 51cm-1m	17
Medium 11-50cm	66
Small 1-10cm	27
XLarge >1m	23
Grand Total	133

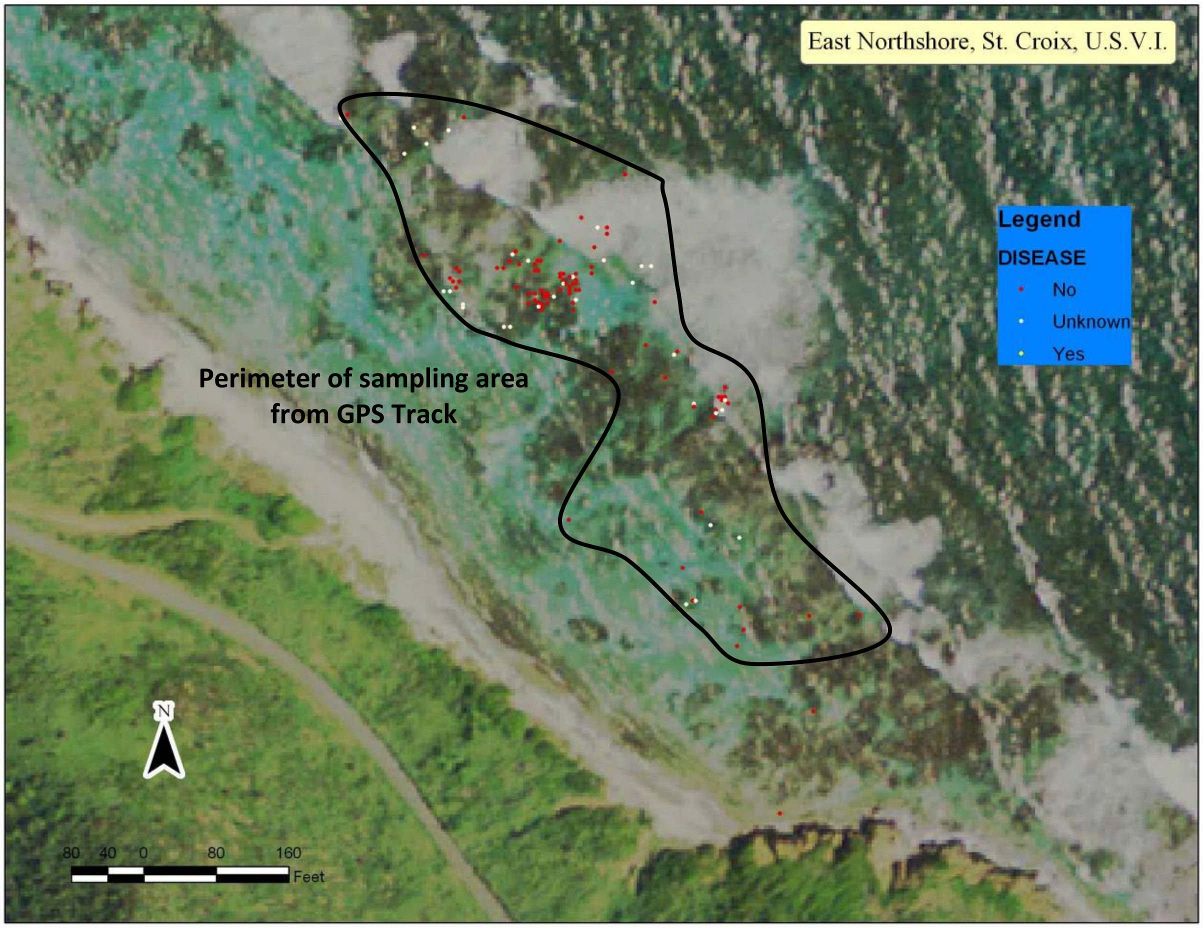
DISEASE			
SIZE_CLASS	No	Unknown	Grand Total
Large 51cm-1m	10	7	17
Medium 11-50cm	53	13	66
Small 1-10cm	27		27
XLarge >1m	9	14	23
Grand Total	99	34	133

Size Class Distribution,
East Northshore, St. Croix



Size Class Vs. Disease
East Northshore, St. Croix

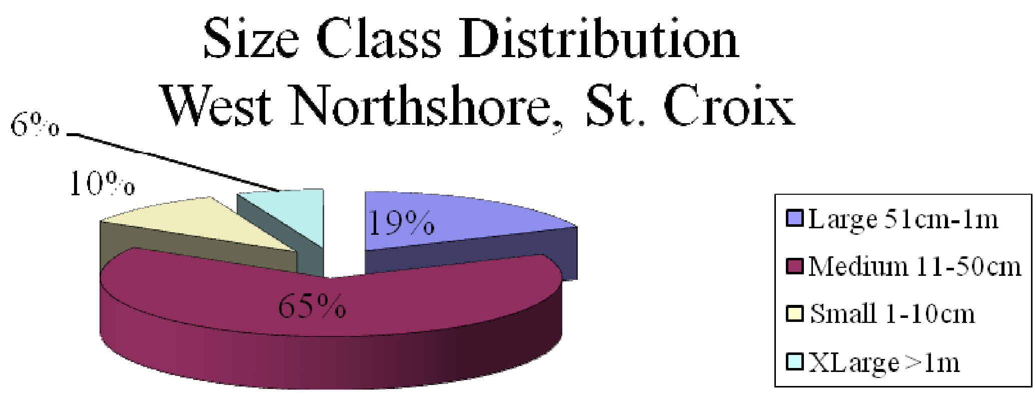


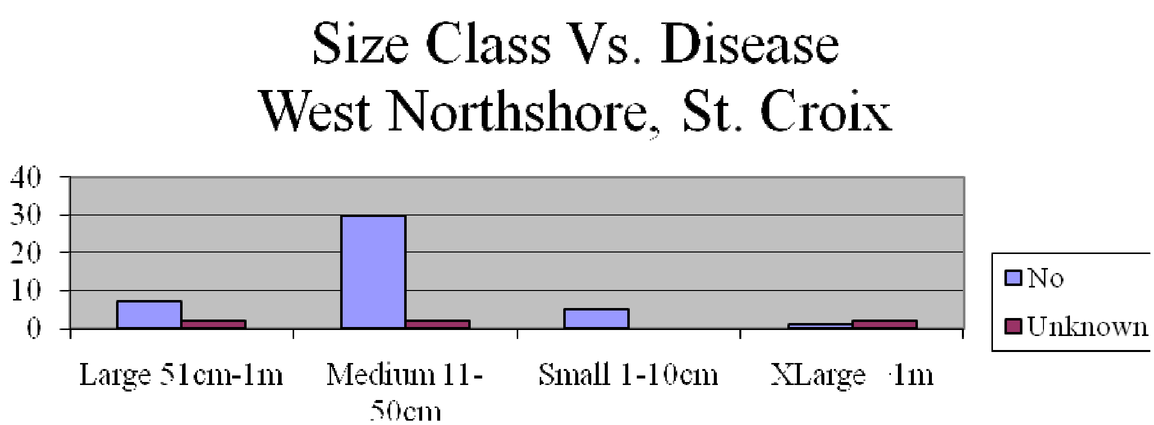


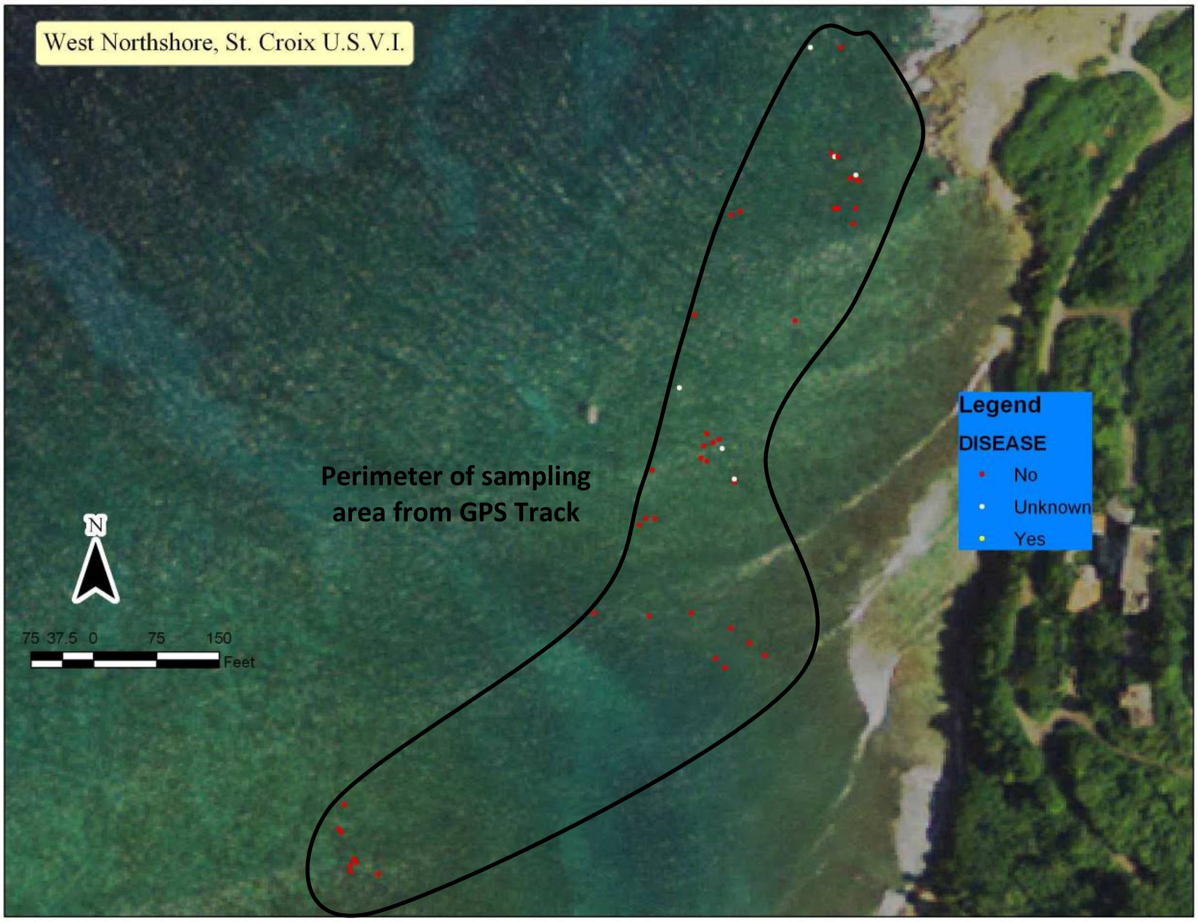
3/13/07 Aerial map of Eastern Northshore site

SIZE_CLASS	Total
Large 51cm-1m	9
Medium 11-50cm	32
Small 1-10cm	5
XLarge >1m	3
Grand Total	49

DISEASE			
SIZE_CLASS	No	Unknown	Grand Total
Large 51cm-1m	7	2	9
Medium 11-50cm	30	2	32
Small 1-10cm	5		5
XLarge >1m	1	2	3
Grand Total	43	6	49





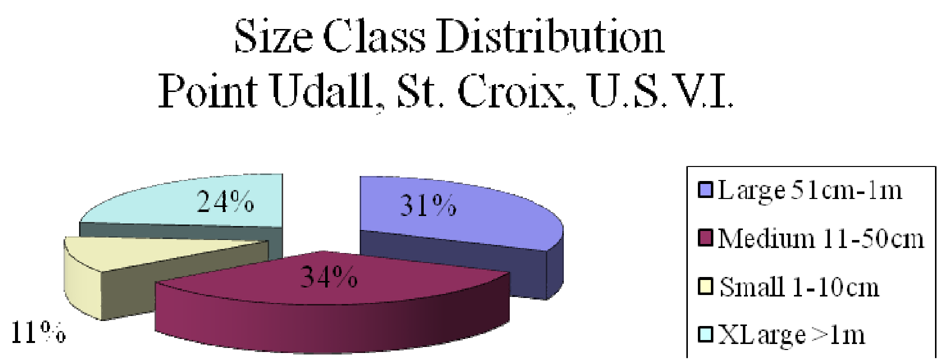


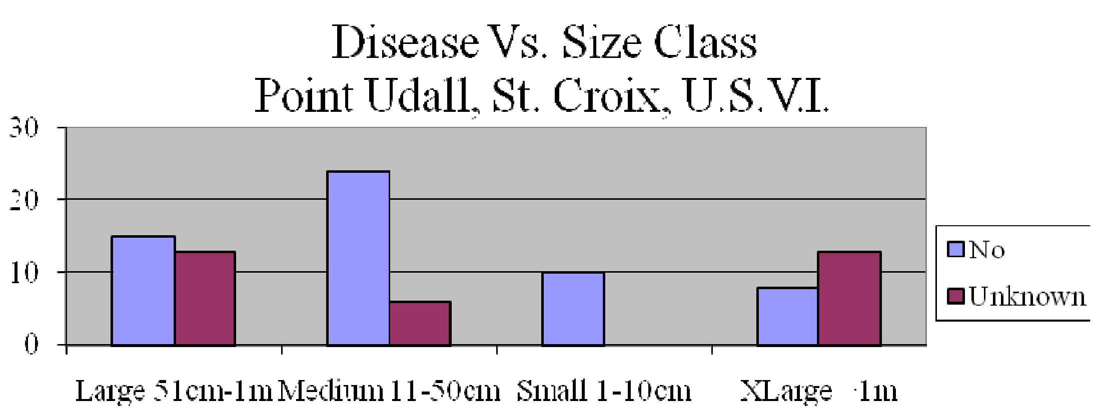
3/15/07 Aerial map of Western Northshore site

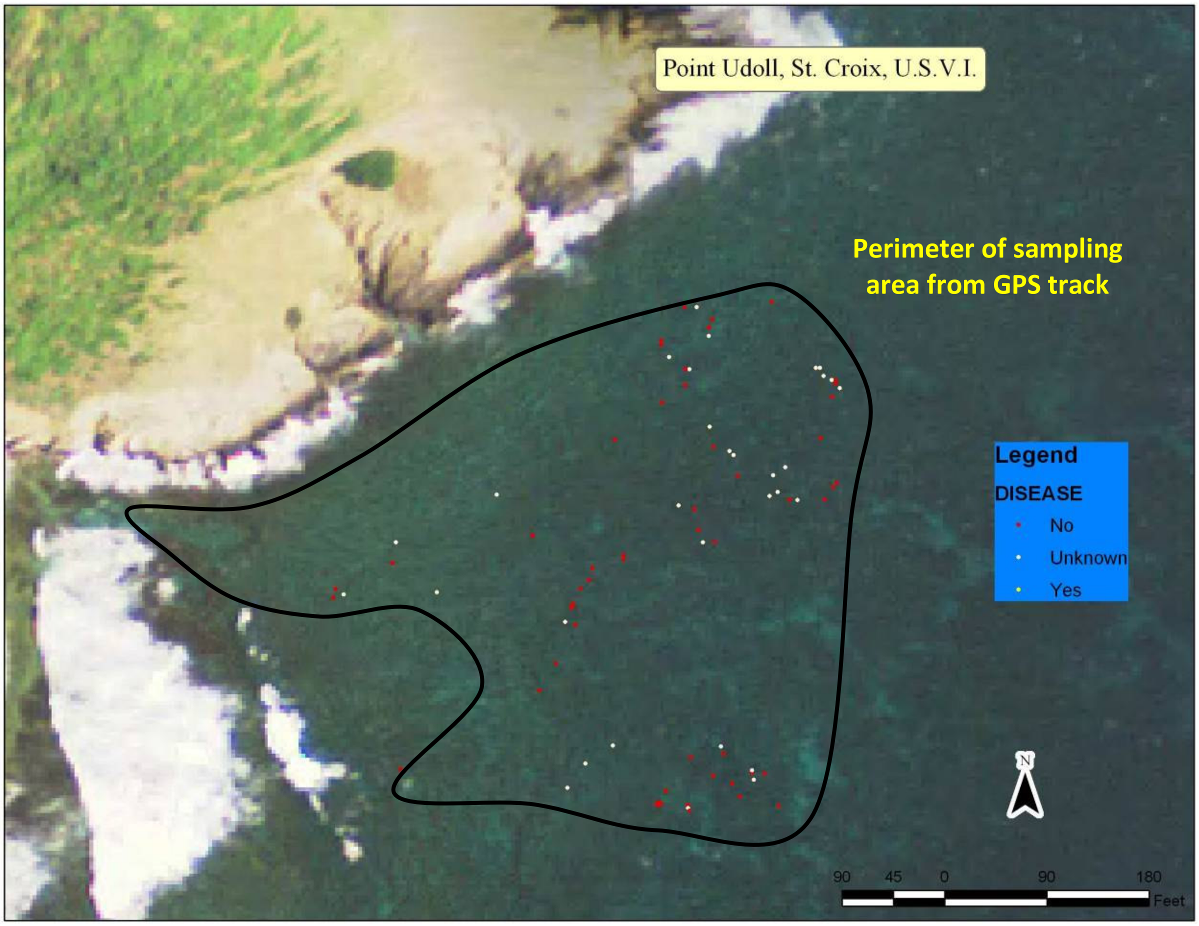
Point Udall, St. Croix 5/27/07

Size Class	Total
Large 51cm-1m	28
Medium 11-50cm	30
Small 1-10cm	10
XLarge >1m	21
Grand Total	89

DISEASE			
Size Class	No	Unknown	Grand Total
Large 51cm-1m	15	13	28
Medium 11-50cm	24	6	30
Small 1-10cm	10		10
XLarge >1m	8	13	21
Grand Total	57	32	89







5/27/07 Aerial map of Point Udall site

<u>Discussion</u>

<u>Technology</u> Goal 1

The mapping of marine populations using digital technology and Global Positioning Systems is a relatively new approach to the graphic display and databasing of marine geographic data. While landscape pattern analysis and its impact on ecosystem function and species distribution is fairly well developed, seascape pattern analysis is very much younger and presents different problems for the capture of and interpretation of these data. Landscape patterns are better understood scientifically as the science is stronger and better developed. The mechanisms controlling the distribution of habitat communities and terrestrial species have been the subject of decades of research and experimentation, especially when tied to Global Positioning Systems (GPS) which are easily utilized in landscape studies.

The application of landscape and pattern ecology measures to marine or aquatic systems is confounded by a number of issues. Both terrestrial and marine systems are impacted by GPS accuracy, especially in the tropics where satellite coverage is lower, there are a limited number of WAAS stations and base stations are few and far between. Standard GPS units provide 3-5 meter accuracy, but with differential and real time correction and better GPS receiver units, sub-meter accuracy can be achieved in those areas where satellites and stations are more numerous. Additionally, surface water GPS methodology is hampered by surface glare, GPS satellite reception, and vision through multiple layers of dive mask and waterproof Aquapacs. High intensity waves, turbulence and bottom visibility in high energy nearshore locations all hamper the effort to collect accurate data on bottom communities from surface collection methods. Still, the surface water GPS methodology offers significant advantages over more cumbersome and less efficient mapping approaches and many of the difficulties can be overcome with continued research and experimentation.

Our efforts to incorporate digital and GPS methodology to seascape pattern ecology have evolved during the course of these and previous efforts to introduce the new approach. While difficulties still exist and are being addressed, the digital method captures seascape patterns very accurately providing the first real ability to easily map marine populations from a geographic perspective. In addition, the method is easily learned, can be applied to numerous species and habitat types and reduces time for data collection, transcription, databasing and graphic display. Perhaps more importantly, the method reduces dramatically the errors which are common to typical marine data collection by eliminating most errors associated with the sample recording, transcription from data sheets and incorporation of these data into the database. Standard waterproof worksheet data collection is slow, highly inaccurate in high energy nearshore waters, error prone and time consuming to join data with GIS maps. Geographic location of populations of interest using these methods is inefficient also error prone and inaccurate from the standpoint of specific location. Joining questionable geographic locations with error prone data recording provides a very primitive approach to seascape pattern analysis and as a result of the inefficiencies and inaccuracies the field of seascape ecology, especially of nearshore waters is slowed.

As we have shown, collecting data digitally provides a single step method of combining many datasets with geographic coordinates and allows for very efficient graphic display and analysis of multiple parameters, providing the full range of GIS capability applied to seascape pattern research. The data collected provides a solid foundation for expanded work in population mapping of multiple species and communities and allows for relational development of these datasets with land based watershed issues. As a result, the GIS coverage layers allow for a comprehensive and permanent baseline upon which to assess influences, interactions and impacts between terrestrial and marine systems.

<u>Mapping Marine Populations</u> Goal 2

These data are presented as part of a baseline study of St. Thomas and St. Croix *Acropora palmata* populations and is intended to begin the long term monitoring of these important nearshore communities. During the conduct of these sampling activities the research teams continually adapted the mapping and data collection methodology as better and more efficient ideas were incorporated into the approach. Since the two goals for the project were linked, revisions in the scope, sites and size of samples were made to develop the method and to better depict and capture the existing conditions.

While the number of sites initially proposed was reduced because of weather and sea conditions, staffing difficulties, technical difficulties and sample size expansion for large populations; the number of sample days and number of colonies sampled was about what was initially determined. Rather than collecting smaller sample sizes at each site, it was determined early on in the process to sample each bay site thoroughly in order to establish a solid baseline for each location by collecting data on every coral colony located. This provided a better overall geographic picture of the population at each site, allowed for a more solid baseline and enabled added power to the establishment of a statistical foundation. Subsequent re-sampling completed on St. Thomas did not then require complete re-sampling of the populations but simply a re-sample of portions of the population. In this way, the re-sample can be overlayed on that portion of the colony, clipped and compared. This occurred at Sprat Bay, Botany Bay and Flat Cay, St. Thomas. The project team responsible for St. Croix sampling experienced staffing difficulties which did not allow for completion of the initial sampling or re-sampling as of this date. Still, the initial data collected represents a solid baseline to determine historical change and provides the graphic and database framework necessary as additional sampling is undertaken. As a result of the limitations of the data collected the analysis of the results will be confined to basic and general statements about the populations.

Additionally, data on size classes and disease prevalence were the main focus, but other data parameters were also collected on colony type, predation, and live cover and these are included in the digital appendix. Coral disease types are numerous and poorly differentiated especially by non-experts. In light of this identified diseased colonies and colonies with unidentified diseases but with some surface anomalies are treated as positive. Colonies with no disease or surface anomalies are treated as negative. St. Thomas data included some re-sampling which will be discussed while St. Croix data was not re-sampled. Discussions of these data are limited in scope because of the sample sizes. A fuller discussion of changes can take place only after subsequent projects provide more data over longer periods of time. However, the technology developed and the baseline established on the GIS platform provide a significant step forward in the mapping of these endangered marine species.

St. Thomas Sites

Sprat Bay – Developed, semi-urban site

Sprat Bay, on the south side of Water Island, adjacent to St. Thomas Harbor, appears as a site somewhat remote from mainland urban influences. However, taking a larger picture indicates that while the site is not flushed by a heavily developed watershed, its proximity to St. Thomas and Charlotte Harbor probably indicates a significant influence from the nearby highly disturbed landscape. The original sample at Sprat Bay found 27 colonies which were distributed fairly evenly across the four size classes. Disease was generally low in small size colonies and increased with size to a peak in large and x-large colonies. Of the 27 original colonies, 17 (63%) showed some sort of disease or surface lesions. Fourteen months later, 36 colonies were mapped and recorded. This increase in number (9) is likely made up of some new recruits to the population, growth of small into medium size class during this time, fragmentation and re-growth and colonies that may have been missed in the first survey. Turbulent conditions, limited visibility and cryptic locations all contribute to missed individuals. Only additional multiple re-samplings will allow differentiation between missed individuals and recruitment to be seen as an increase in the population. Disease in this re-sampling dropped to 33%, indicating a healthier population overall. This is possibly due to better growth conditions in the 18 months following the October 2005 bleaching event that affected 92% of the coral colonies (Miller et al. 2005) leaving many prone to disease syndromes and death. The map of the Sprat Bay watershed gives some indication of the land use and hydrology of the nearby contributing watershed.

Botany Bay – Undeveloped nearshore site

Botany Bay, at the westernmost end of St. Thomas, is a remote site with little impact from the impending development of the upper watershed. Flushed by strong currents and high energy waves, this site would seem to compare with other pristine areas along the coast. The sample of 102 colonies initially completed at Botany Bay on 5/10/07 was a sample of a much greater population spread across the bay and was comprised of a majority of medium size class corals (45), with an equal division of large(20) and x-large(23). The small size class (14) was considerably smaller, perhaps indicating that recruitment and reproduction was not significant. Disease or some type of surface lesions accounted for 40% of the sample at this site. In the re-sample on 5/22/08 only 61 colonies were sampled of the original 102, but the re-sample still indicated that the medium size class of 29 still dominated the population. Disease was found in 65% of this sample which may have been a result of the geographic inshore location of the re-sample or an indication of an increase in disease during this year long period. The single re-sample in all cases lacks power to substantiate the trend if there is a trend to be seen. Multiple re-samplings are necessary to increase the accuracy of the measurements.

<u>Flat Cay – Remote offshore site</u>

Flat Cay, located several kilometers south of the St. Thomas mainland and airport is considered a remote, pristine offshore location. Swept and nourished by constant waves and currents this site had a substantial population (609) of both *Acropora palmata* and thickets of ephemeral *A. cervicornis* . As a result of the large population proximate to the University, this site was selected by the project team as a long term monitoring site. The sampling here was intended to capture all, or nearly all of the colonies to serve as benchmark for future sampling. Over the course of multiple samplings at Flat Cay, the size class distribution included 32% or 196 medium size class corals. Both large (134) and x-large (175) colonies were abundant. The small size class (104) was again the smallest sample found perhaps indicating once again the lack of recruitment and/or reproduction. Approximately 37% of the corals were found to be diseased or impacted.

During re-sampling, two separate samples were taken, one on the east side of the island and one on the west side in order to look more closely at the influence of geographic location, if any. The re-sample on 5/15/08 captured 97 colonies for comparison. In this case, the x-large size class (38) was most abundant, followed by medium (28) and large (19). Again the small size class (12) was least abundant, following similar results found in Botany and Sprat Bays. Disease averaged 37% of all colonies surveyed with the largest percentage (31%) found in the x-large size class. Once again, disease was lowest (8%) in the smallest size class.

On the Westside, the 78 colonies were re-sampled on 7/22/08. The habitat here is a lee shore, rocky with a steep drop to deeper water compared to the eastside where the habitat shallows to a shelf and is generally windward of the island. Size classes were distributed fairly evenly here and the density of the population was significantly less than the west side where corals are spaced more evenly. The east side, windward to the waves and current, may also show greater density and clustering as a result of re-growth from fragmentation caused by wave breakage. Disease was found on 42% of the corals with the small size class (4) showing the least number of affected corals once again and fairly even distribution of disease among the three larger size classes. There seemed to be little to no difference between the geographic locations which could be a result of the time between surveys and low number of surveys.

<u>St. Croix Sites</u>

<u>Hams Bluff Bay – Pristine northshore site</u>

The Hams Bluff site on the northwestern shore of St. Croix is a shallow 5 meter deep slope off of a volcanic shelf shoreline. Access was extremely difficult as a result of the shoreline and wave energy. The bottom is generally a pavement substrate with some rubble, but mostly flat. The shelf continues north for several hundred yards until the wall drops more than 12,000 feet to the trench between St. Croix and St. Thomas. A sample of 60 corals was surveyed by two teams with the largest majority (37) in the medium size class. Large corals (13) were followed by small (6) and x-large (4). Only 12% of the corals were found to be diseased at this location spread across the three smaller size classes. The corals are distributed in a widely spaced array which is similar to many of the deeper, exposed locations. No re-sampling of the site had been completed by the TNC team as of this report.

Green Cay – North Coast Offshore island site

The Green Cay site encompasses and island environment ¼ mile off the north central coast of St. Croix. The windward side of the island has the majority of the colonies and these lie in hard pavement substrate in extremely shallow water, in many cases > 1m deep. The west side, in the lee of the island is generally formed of rocky outcrops of bedrock which dropped rapidly to 5-10m. Colonies on the windward side are dense while on the leeward side they are intermittently spaced and the density is lower. During two separate sampling events, with two research teams, a thorough survey of 414 individual coral colonies was completed and mapped. The distribution of size classes showed the largest majority were medium size (246) followed by large (95) and small (47). The x-large size class (26) was lower than for other sites and may be a result of the nature of this shallow, high energy location where breakage and fragmentation are common. Disease affected 27% of the colonies at this site and was common in all of the larger size classes ranging from 27% for the large and medium classes to 38% for the x-large class. The smallest size class again showed a low number and percentage of diseased colonies at 13%. No re-sampling of the site had been completed by the TNC team as of this report.

Salt River site – Developed watershed site (northshore)

The Salt River site lies outside Salt River Bay estuary, a submerged fault valley. The watershed is moderately developed and the sampling site lies outside of the bay entrance where the colonies are found at the shallow depths and the beginning of Salt River Canyon. A total of 5 sampling days surveyed 618 colonies. This site along with Green Cay was selected by the Project Team as a long term monitoring location on St. Croix. Every effort was made not only to survey and sample but actually perform a census, capturing all of the corals possible. The medium size class (353) was by far the largest percentage (57%) of the population. The small (87), large (86) and x-large size classes (92) were evenly distributed across the remaining 43%. A total of 23% of the colonies were impacted by disease, with the majority in the medium size class. No re-sampling of the site had been completed by the TNC team as of this report.

Eastern Northshore site – Low Development watershed site

A sample of 133 coral colonies were mapped and surveyed at this linear site by two field teams along the north coast on the descending shelf to the north drop. The site is exposed and high energy. The medium size class (66) was the largest though all size classes were represented in significant numbers. The small size class (27) was second in numbers indicating reasonable reproduction and recruitment to the population. The density of the site was strong, possibly indicating increases in abundance from fragmentation and re-growth during high energy storms and wave action. Disease or surface lesions were found in 27% of the colonies surveyed including 61% of the x-large colonies, 41% of the large size class, and 20% of the medium size group. No small size class corals were recorded with disease, again supporting the idea that disease attacks older, larger corals more commonly. No re-sampling of the site had been completed by the TNC team as of this report.

Western Northshore- Low Development watershed site

This site, west of the previous site had a lower density with corals spaced rather than clustered and a smaller overall population. Site conditions were somewhat different with less energy and wave action. A total of 49 colonies were surveyed with most (32) in the medium size class (65%). Very few small (5), large (9) and x-large (3) were found. This indicates recruitment and replacement is low, perhaps because the low energy of the site leads to fewer fragments and re-growth. Only 12% of the colonies exhibited any disease or surface lesions, high incidence of disease in the x-large and large size classes. The small size class (5) once again showed no signs of disease although the sample was very small. No re-sampling of the site had been completed by the TNC team as of this report.

Point Udall site- Undeveloped East End site (also called Death Bay for strong currents and poor access)

This site is an exposed east end location of intense energy and strong wave action. The watershed above is completely undeveloped except for the parking area and Millenium Monument on the bluff above. The bottom type is hard pavement which extends a number of miles east to Lang Bank as the domination coral community. Corals were scattered in low density across the area. Two sample teams collected data on 89 colonies which were distributed to small (10), medium (30), large (28) and x-large (21). More than 54% of the corals exhibited some form of disease or surface lesions, 61% of the x-large, 46% of the large and 20% of the medium size class. The small size class recorded no disease or surface lesions. No re-sampling of the site had been completed by the TNC team as of this report.

Conclusions

The technology development during the course of this study has been extremely successful and while only in a formative stage has proven its value in efficiency, economy and accuracy. The extension of this GPS mapping and PDA data collection effort has implications for many marine populations and can help to advance the digital collection of marine data and contribute greatly to our understanding of seascape ecology and the geographic distribution patterns and trends of marine populations. Additional effort should be continued to advance this technical approach and adapt it to other nearshore mapping and data collection efforts.

The data collected at the 9 sites, while representing a small fraction of the two island and multiple offshore cay populations, has established some important baseline work upon which to build. Much additional baseline workshould be completed under future contracts. Several locations like Salt River, Green Cay and Flat Cay provide large population samples that can be reliable indicators of the health of these populations. These sites should be considered long term monitoring datasets and the locations should be surveyed once again on a regular schedule to determine recovery or decline.

As a result of the limitations of the data; the sample size, locations and re-sampling efforts, additional analysis of these data is unreliable and speculative. More sites and larger populations should be added. Further work on the sites and surveys is needed to link this to watershed characteristics, and these watershed characteristics must be assessed for mapping. The contributing watersheds cross a gamut of differences from pristine to developed, small to large watershed size, the level and type of disturbance, bottom substrate, water quality and flushing ocean currents. As a result, sites are difficult to compare and geographic differences and similarities in pattern and trend are not able to be determined at this time.

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