A Summary of Biophysical Data Relevant to the Management of the East End Marine Park, St. Croix, US Virgin Islands

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Table of Contents

1. Introduction

The East End Marine Park (EEMP), located on St. Croix, US Virgin Islands (USVI), was enacted on January 9th, 2003, as the first in a system of Territorial marine parks, to protect territorially significant marine resources, promote sustainability of marine ecosystems, including coral reefs, sea grass beds, wildlife habitats, and other resources, and to conserve and preserve significant natural areas for the use and benefit of future generations. It encompass much of the extensive coral reefs found within the eastern end of St. Croix, a diverse assemblage of critical habitats. The law was a direct response to the US Coral Reef Task Force's National Action Plan to Conserve Coral Reefs, and the result of collaborative partnerships of several institutions and stakeholders in the USVI. The principal partners in this designation process included the Department of Planning and Natural Resources' Division of Coastal Zone Management (DPNR – CZM) and other divisions, The University of the Virgin Islands, The Ocean Conservancy (TOC), the Nature Conservancy, and the fishing community of St. Croix. The Ocean Conservancy played a critical role in brokering dialogue between the fishing community and CZM, and in helping to develop the location, zones and management plan for the EEMP, to ensure optimum success to conserve the coral reefs and associated systems on the eastern end of St. Croix. TOC remains involved in the implementation and management of the park as part of the EEMP advisory committee.

This report documents the results from TOC's project proposal to the National Oceanic and Atmospheric Administration (NOAA) titled "Enhancing the capacity to inform effective management decisions for the EEMP, St. Croix, USVI." The project's goal was to enhance effective management of the park, primarily through analysis, synthesis, and dissemination of both pre-existing and current data pertinent to the EEMP.

Chapter 2 describes the EEMP and illustrates the proposed zonation for the park. Chapter 3 analyzes available resource data for the EEMP. It is divided into two subchapters: *abiotic and biotic resources*. Chapter 4 summarizes management recommendations resulting from this project.

Data used for this project were derived from three sources: 1) peer-reviewed publications, 2) gray literature such as government agency reports and symposium proceedings and 3) raw data. A list of all publications and reports is given in the bibliography and was derived from a number of bibliographies and on-line search engines, including NOAA's Coral Health and Monitoring Program (CHAMP) gray literature database (www.coral.noaa.gov/cleo/literature.shtml), Google Scholar (http://scholar.google.com), Strombid Bibliography conch literature database (http://bellsouthpwp.net/c/u/culpsb/conchnews/bib/bib_start.html), Society for the Conservation of Reef Fish Aggregations (SCRFA) database (www.scrfa.org/server/educational/doc/publications.pdf), and DPNR – Division of Fish and Wildlife (DFW)'s in-house literature database (www.dpnr.gov.vi/dfw.htm).

Raw data were provided by NOAA/NOS/Biogeography (www8.nos.noaa.gov/biogeo_public), US Environmental Protection Agency (EPA) (www.epa.gov/STORET), National Climate Data Center (www.ncdc.noaa.gov/oa/ncdc.html), DPNR – Division of Environmental Protection

(DEP) (http://www.dpnr.gov.vi/dep/home.htm), and Craig Karnitz from the Maria Hill weather station.

2. Description of the East End Marine Park

The EEMP is located on St. Croix, the southern most island of the US Virgin Islands (USVI). St. Croix is located on its own island shelf, approximately 45 km to the south of the Puerto Rico/Virgin Islands shelf, and approximately 90 km to the northwest of Saba Bank (Figure 1).

The EEMP was enacted on January 9th, 2003, as a unit of the Territorial system of marine parks to protect territorially significant marine resources, promote sustainability of marine ecosystems, including coral reefs, sea grass beds, wildlife habitats, and other resources, and to conserve and preserve significant natural areas for the use and benefit of future generations (VI Code, Title 12, Chapter 1, §98). A management plan for the EEMP was developed by The Nature Conservancy (The Nature Conservancy 2002) and approved by the CZM Commission on July 19th, 2002. A management plan is a working document that needs to be updated periodically to allow for adaptive management. The EEMP management plan will be reviewed 7 years after initial adoption by the VI Legislature (2009), and afterward reviewed every 5 years.

The EEMP Rules and Regulations that include the zoning plan were approved by the CZM Commission on April 5, 2006. The proposed zonation is shown in Figure 2 and the marine habitats included in each zone are given in Table 1. The formal approval of the Governor is pending. The rules and regulations will have the force and effect of law, once they are approved by the Governor, endorsed by the Lieutenant Governor and the Lieutenant Government Secretary, the original and two duplicates are filed in the office of the Lieutenant Governor, published in the Virgin Islands Rules and Regulations, submitted to the Legislature, and published in at least one newspaper of general circulation. The enforcement provisions of these rules and regulations shall only go into effect once marker buoys are installed to delineate the boundaries of the park and the zones therein, and a 30-day public notice period has passed upon completion of the installation of the marker buoys. The CZM Commission will review the rules and regulations by the 5th anniversary of their enactment (2011).

Figure 1. Location of the US Virgin Islands (dark green) and the East End Marine Park (red) in relation to its neighboring islands (light green). The light blue areas indicate island shelves to depths of 100 fathoms. Distance rings of 10 km intervals are drawn around the St. Croix island shelf.

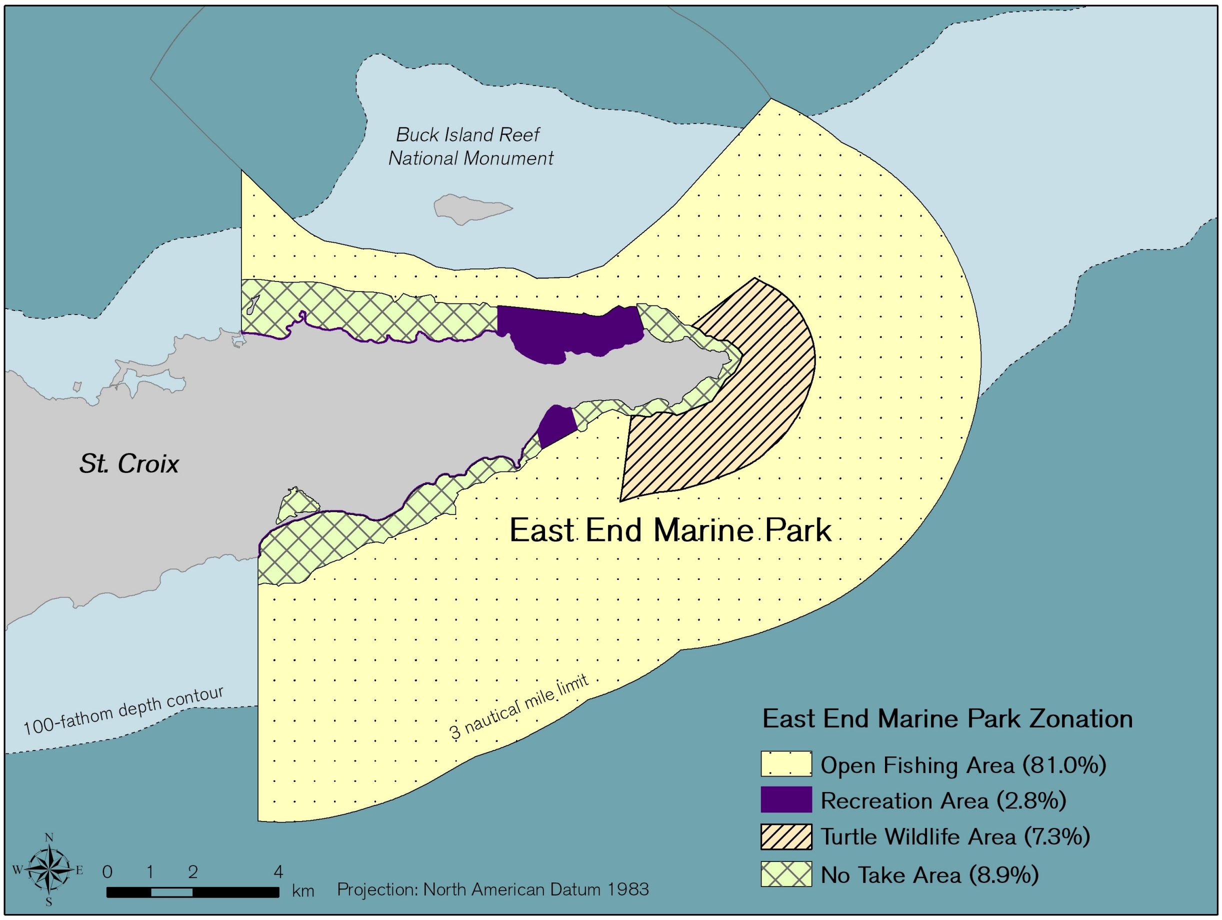

Figure 2. Proposed zonation map of the East End Marine Park. The light blue areas indicate the shelf area up to the 100 fathoms depth contour, the darker blue areas indicate deeper waters.

Table 1. The sizes of the four proposed management zones of the East End Marine Park and their respective habitats according to the NOAA habitat maps (Kendall et al. 2001)

			Area		
Management Zone	Shelf Location	Habitat	[acres]	[ha]	[%]
No Take Area	Bank	Hardbottom	1,075	435	
		Softbottom	553	224	
	Bank Total		1,627	659	
	Lagoon	Hardbottom	376	152	
		Softbottom	1,187	480	
	Lagoon Total		1,563	633	
	Pond	Mangrove	40	16	
		Softbottom	59	24	
	Pond Total		100	40	
	No Take Area Total		3,291	1,332	8.9%
Open Area	Bank	Hardbottom	15,712	6,359	
		Softbottom	3,593	1,454	
	Bank Total		19,305	7,813	
	Pelagic	Pelagic	10,673	4,320	
	Pelagic Total		10,673	4,320	
	Open Area Total		29,978	12,132	81.0%
Recreation Area	Bank	Hardbottom	237	96	
		Softbottom	93	38	
	Bank Total		330	134	
	Lagoon	Hardbottom	103	42	
		Softbottom	595	241	
	Lagoon Total		698	283	
	Recreation Area Total		1,028	416	2.8%
Turtle Wildlife Area	Bank	Hardbottom	2,289	926	
		Softbottom	429	174	
	Bank Total		2,719	1,100	
	Turtle Wildlife Area Total		2,719	1,100	7.3%
Grand Total			37,016	14,980	

3. Biophysical Data Summary

The EEMP's mission statement is to protect territorially significant marine resources, promote sustainability of marine ecosystems, and conserve and preserve significant natural areas for the use and benefit of future generations. Although the direct benefits of the EEMP will be first seen through the biophysical indicators such as 'focal species abundance', the indirect benefits are strongly socio-economical. As Pomeroy et al. (2004) stated: "an effectively managed marine protected area (MPA) is like a 'bank account' that preserves the natural 'capital' that society depends upon for the future. If this natural capital is left alone and allowed to grow over time, the 'income' generated from this 'principal' may be able to provide ecological goods and services that are of immediate use to people while also offering them future security. Without MPAs, too much of this natural capital may be 'spent' by society, draining away the 'principal' over time."

The potential local threats to the marine resources within the EEMP are input of nutrients, terrestrial sediments, anthropogenic pollutants, bacteria, and the take or physical damage of resources. Those threats can negatively impact the abiotic and biotic resources. The monitoring of biophysical variables (abiotic and biotic resources) assists park managers in determining the current health of the park's marine ecosystems and enables the evaluation of management effectiveness, therefore allowing for adaptive management. The monitoring of biophysical variables also may assist in identifying regional and global threats.

3.1. Abiotic Resources

3.1.1. Water Quality

Water quality is a key abiotic resource, and keeping water quality high is the foundation of a healthy marine ecosystem. The water quality of the USVI is negatively impacted by run-off from land, atmospheric deposition, and contamination (Garrison et al. 2003, Hubbard 1987, Nemeth and Sladek Nowlis 2001). Generally, the biological effects of poor water quality have been studied in coral reef systems (Kaczmarsky et al. 2005, Rogers 1983, Rogers 1990), since they are believed to be most sensitive (Hubbard 1987). However, poor water quality may affect a wide variety of marine organisms (Glazer and Quintero 1998). A survey of the USVI commercial fishers identified pollution and over-fishing to be the two major problems (Uwate et al. 2001).

In the USVI primarily two agencies collect water quality data: the US National Park Service (USNPS) and the DPNR – Division of Environmental Protection (DEP).

All data containing water quality information have been entered into two national data management systems maintained by the US Environmental Protection Agency (EPA): the Legacy Data Center (LDC) and STORET (STOrage and RETrieval). The LDC contains historical water quality data up to the end of 1998. Its database is static and of undocumented quality. STORET contains data collected beginning in 1999, along with older data that have been properly documented and migrated from the LDC.

Each sampling result in the LDC and in STORET is accompanied by information on where the sample was taken (latitude, longitude, state, county, Hydrologic Unit Code and a brief site identification), when the sample was gathered, the medium sampled (e.g. water, sediment, fish tissue), and the name of the organization that sponsored the monitoring. In addition, STORET contains information on why the data were gathered; sampling and analytical methods used; the laboratory used to analyze the samples; the quality control checks used when sampling, handling the samples, and analyzing the data; and the personnel responsible for the data.

The data in LDC and STORET are accessible to the public at www.epa.gov/STORET/. The data available for St. Croix are summarized in Tables 2 and 3 (accessed in October 2005).

Water quality standards for the Territorial waters vary depending on their water body class designation, and are defined in the Code of US Virgin Islands Rules (VIRR, Title 12, Chapter 12, Sub-chapter 186). Class A water bodies are designated for the preservation of natural phenomena requiring special conditions, such as the Natural Barrier Reef at Buck Island, St. Croix. Class B waters, in which all EEMP waters fall, are designated for maintenance and propagation of desirable species of aquatic life and for primary contact recreation. Class C water bodies, similar to class B, are designated for maintenance and propagation of desirable species of aquatic life and for primary contact recreation; however, the criteria are somewhat less stringent than for class B waters. Water quality criteria currently exist for classes B and C waters.

Table 2: Summary of data available at the Legacy Data Center for St. Croix. # Stns = number of sampling stations; # Obs = number of observations, meaning the number of data points collected during the sampling period (first date to last date).

Name	# Stns	# Obs	First Date	Last Date
Temperature, water (degrees centigrade)	62	4507	2/5/1968	3/29/1996
Turbidity, HACH Turbidimeter (Formazin turb unit)	4	134	2/5/1968	6/22/1983
Transparency, SECCHI disc (meters)	62	4335	2/1/1970	3/29/1996
Oxygen, dissolved (mg L^{-1})	62	4296	2/5/1968	3/29/1996
Oxygen, dissolved, (percent of saturation)	62	4125	2/5/1968	3/29/1996
pH (standard units)	53	2930	2/1/1970	12/8/1983
Salinity (parts per thousand)	83	4052	2/1/1970	3/29/1996
Residue, total nonfiltrable (mg L^{-1})	59	309	12/10/1982	5/9/1994
Nitrogen, ammonia, total (mg L^{-1} as N)	1	2	7/23/1986	9/23/1986
Nitrite nitrogen, total (mg L^{-1} as N)	54	241	12/10/1982	3/2/1989
Nitrate nitrogen, total (mg L^{-1} as N)	54	230	12/10/1982	5/6/1988
Nitrogen, Kjeldahl, total (mg L^{-1} as N)	2	5	5/30/1985	5/9/1994
Phosphate, total (mg L^{-1} as PO_4)	2	5	10/5/1984	8/4/1986
Phosphorus, total (mg L^{-1} as P)	47	221	12/10/1982	11/4/1987
Fecal coliform, membr filter, M-FC AGAR, 44.5 C, 24 hr	84	5057	1/9/1968	8/22/1990
Fecal coliform, membr filter, M-FC BROTH, 44.5 C	3	194	3/1/1975	3/29/1996
Fecal *Streptococci*, membr filter, KF AGAR, 35 C, 48 hr	28	1000	1/9/1968	9/14/1983
Nitrite nitrogen, total (mg L^{-1} as NO_2)	2	5	10/5/1984	8/4/1986
Ratio of fecal coliform to fecal *Streptococci* (CAL)	24	167	2/5/1968	9/14/1983
Turbidity, lab nephelometric turbidity units (NTU)	86	4342	2/3/1969	3/29/1996

Table 3: Summary of data available at STORET for St. Croix. # Stns = number of sampling stations; # Obs = number of observations, meaning the number of data points collected during the sampling period (first date to last date).

Name	# Stns	# Obs	First Date	Last Date
Depth, bottom	36	78	12/17/2003	3/25/2004
Dissolved oxygen (DO)	60	1628	1/1/1975	3/25/2004
Enterococcus Group Bacteria	66	453	9/14/2002	9/20/2004
Fecal Coliform	54	969	3/1/1975	3/25/2004
Nitrogen, Kjeldahl	35	60	5/30/1985	3/23/2004
Nitrogen, Nitrite (NO_2) as NO_2	2	5	10/5/1984	8/4/1986
pH	54	553	7/1/1975	3/25/2004
Phosphorus	33	55	3/25/2003	3/25/2004
Phosphorus, phosphate (PO_4) as PO_4	2	5	10/5/1984	8/4/1986
Salinity	54	397	7/1/1975	3/25/2004
Secchi disk depth	16	231	1/1/1975	3/25/2004
Temperature, water	54	1632	1/1/1975	3/25/2004
Total Suspended Solids (TSS)	54	351	5/30/1985	3/23/2004
Turbidity	54	1160	7/1/1975	3/25/2004

A set of the key abiotic variables for which data are regularly collected and single sample criteria exist were selected for analysis:

- Dissolved oxygen (DO): not less than 5.5 mg L^{-1} from other than natural conditions
- Bacteria: not to exceed a single sample maximum of 104 *Enterococcus* group bacteria per 100 mL at any time
- Turbidity: a maximum nephelometric turbidity unit (NTU) reading of three shall be permissible

DPNR - DEP's Water Pollution Control Program (WPC) is entrusted with the responsibility for implementing and enforcing water quality and pollution control laws in the USVI. Programs administered and managed under the WPC Program include but are not limited to the Ambient Monitoring Program and the VI Beach Monitoring Program (for more information on the programs visit: www.dpnr.gov.vi/dep/water_pollution.htm).

The Ambient Monitoring Program collects data at eight sites within the EEMP (Figure 3). The sites are accessed by boat four times per year. Dissolved oxygen (DO), temperature, salinity, pH, and turbidity are collected at the top and at the bottom of the water column with a 6600 YSI multi-parameter meter. Grab samples for the analysis of bacteria, turbidity, total suspended solids, and nutrients are collected at a depth of 4-6 in. Most recent data on DO, turbidity, and *Enterococcus* group bacteria levels are compiled in Tables 4 to 7 and Figures 4 to 7. The number of samples that did not meet VI water quality standards is given in Tables 8 to 10.

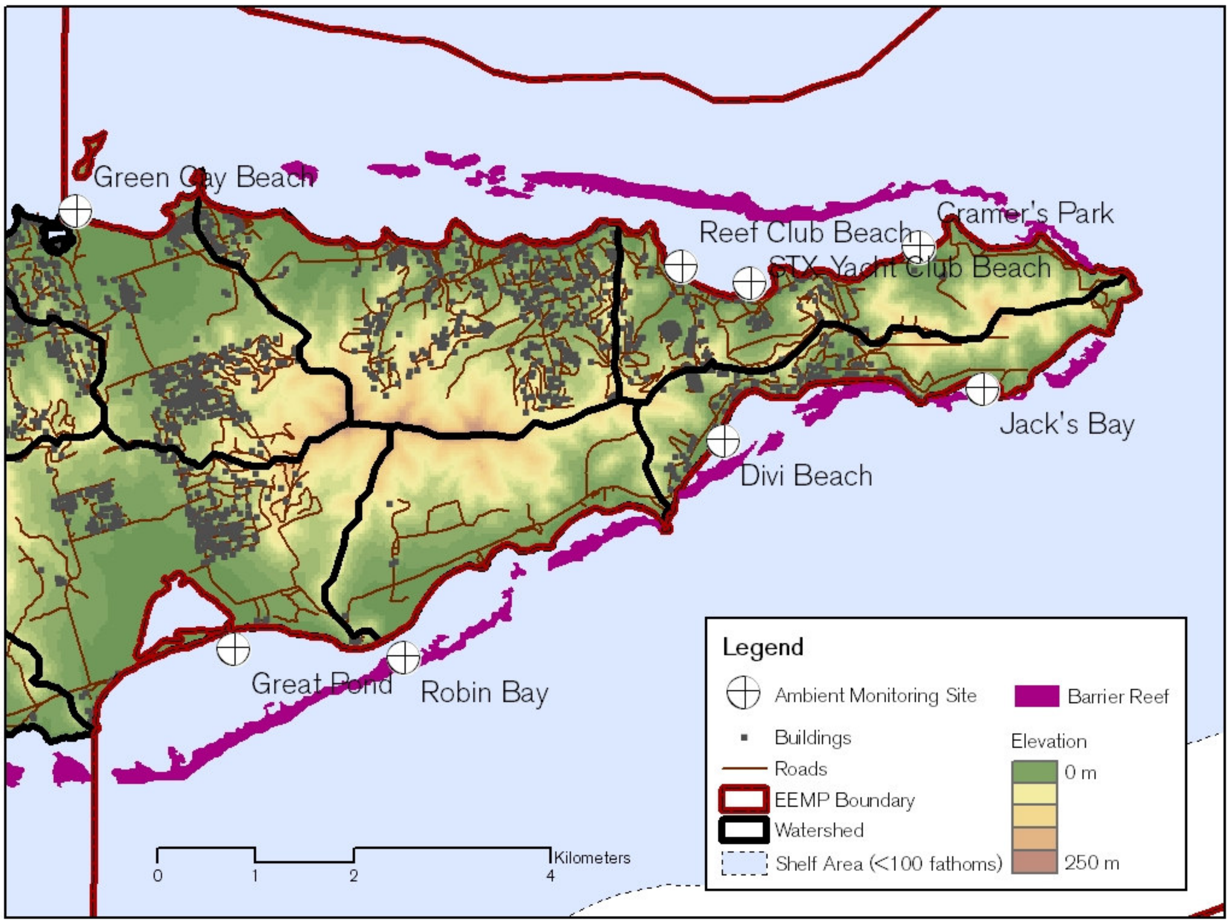

Figure 3. Ambient Monitoring Program collection sites within the East End Marine Park.

Table 4. Dissolved oxygen measurements at the bottom of the water column. Units in mg L^{-1}. Values below quality standards (5.5 mg L^{-1}) are in bold italics. Dashes indicate no data available.

Date	Green Cay Beach	Reef Club Beach	St. Croix Yacht Club Beach	Cramer's Park	Jack's Bay	Divi Beach	Robin Bay	Great Pond
Jun-00	6.30	6.51	6.22	6.22	-	-	5.51	***5.40***
Sep-00	***5.17***	6.45	***5.18***	6.53	***5.44***	***5.35***	5.57	5.89
Dec-00	6.84	7.00	6.53	6.53	-	-	6.47	5.85
Feb-01	6.80	7.20	6.56	6.54	-	-	6.49	6.33
Jun-01	6.86	7.15	5.86	5.89	6.43	6.56	6.30	-
Jul-01	7.37	6.17	5.70	5.51	***5.37***	5.61	5.59	5.87
Mar-02	5.72	6.55	6.20	6.37	6.56	6.69	6.29	7.01
Sep-02	6.63	6.71	6.24	6.58	7.09	6.27	6.62	6.04
Dec-02	-	-	-	6.22	-	-	-	-
Mar-03	5.52	7.40	7.54	7.63	6.77	7.04	6.89	5.98
Jun-03	5.74	6.56	5.53	5.91	5.86	6.04	5.85	6.40
Jul-03	8.06	8.43	7.92	9.20	9.97	7.20	6.88	6.96
Dec-03	6.76	6.95	7.02	6.96	8.35	8.59	7.31	6.71
Mar-04	13.06	12.26	10.42	11.13	10.03	13.79	14.64	14.09
Jun-04	7.49	7.74	7.03	7.31	11.94	7.91	8.89	8.33
Sep-04	***5.38***	6.15	***5.28***	***5.33***	8.23	8.71	8.72	6.17

Table 5. Dissolved oxygen measurements at the top of the water column. Units in mg L^{-1}. Values below quality standards (5.5 mg L^{-1}) are in bold italics. Dashes indicate no data available.

Date	Green Cay Beach	Reef Club Beach	St. Croix Yacht Club Beach	Cramer's Park	Jack's Bay	Divi Beach	Robin Bay	Great Pond
Jun-00	6.06	6.44	6.21	6.20	-	-	***5.47***	5.58
Sep-00	***4.52***	6.73	***5.23***	6.55	5.69	***5.26***	5.69	5.87
Dec-00	6.77	6.82	6.49	6.39	-	-	6.47	5.82
Feb-01	6.79	7.42	6.62	6.75	-	-	6.44	6.26
Jun-01	6.75	6.50	5.84	5.90	6.22	6.64	6.00	-
Jul-01	6.82	6.33	5.90	5.59	5.50	5.54	***5.13***	5.76
Mar-02	5.62	6.65	6.43	6.58	6.75	6.98	6.29	7.02
Sep-02	6.63	5.85	6.82	6.58	6.94	6.27	6.31	6.27
Dec-02	-	-	-	6.30	-	-	-	-
Mar-03	6.56	7.86	7.90	8.04	6.73	7.04	6.89	5.94
Jun-03	5.84	5.53	5.57	6.15	6.04	6.05	5.72	6.82
Jul-03	7.65	8.81	8.02	9.47	7.67	7.67	6.92	6.97
Dec-03	6.85	8.03	7.25	7.70	8.28	8.76	7.75	7.44
Mar-04	11.28	11.35	9.73	10.10	9.11	12.86	10.94	11.12
Jun-04	7.31	7.70	7.21	7.30	11.89	7.83	8.23	8.15
Sep-04	***5.17***	5.88	***5.20***	***5.47***	8.16	8.49	8.32	7.63

Table 6. Turbidity measurements at the top of the water column. Units in NTU. Values above quality standards (3 NTU) are in bold italics. Dashes indicate no data available.

Date	Green Cay Beach	Reef Club Beach	St. Croix Yacht Club Beach	Cramer's Park	Jack's Bay	Divi Beach	Robin Bay	Great Pond
Jun-00	0.31	0.38	0.35	0.37	-	-	0.95	0.24
Sep-00	0.52	0.56	0.75	0.40	1.21	1.02	0.49	0.76
Dec-00	1.42	0.76	0.87	0.86	0.42	1.08	0.48	0.54
Feb-01	0.37	1.60	1.10	0.30	-	-	0.31	0.69
Jun-01	0.37	0.49	0.65	0.30	0.16	0.04	0.04	-
Jul-01	0.48	0.35	0.99	0.24	0.53	0.18	0.31	0.32
Oct-01	0.59	0.11	0.28	0.31	-	-	0.07	1.30
Mar-02	0.78	0.94	1.20	0.86	0.58	0.29	0.38	0.56
Jun-02	0.59	1.04	0.80	0.66	2.02	0.50	0.55	-
Sep-02	0.89	0.58	1.16	1.41	0.56	0.48	0.74	0.47
Dec-02	0.60	1.23	1.09	1.41	1.49	1.14	0.43	0.53
Mar-03	***5.04***	0.71	1.60	1.60	0.81	0.60	0.35	0.67
Jun-03	1.07	0.50	0.76	0.99	1.73	1.07	0.55	0.88
Jul-03	0.67	0.66	1.14	0.70	0.87	0.42	0.40	0.32
Dec-03	2.58	***3.75***	***3.59***	1.57	1.24	2.28	1.04	1.35
Mar-04	***7.90***	1.44	2.01	1.28	0.52	0.84	0.73	0.86
Jun-04	0.70	0.99	1.45	0.79	0.41	0.54	0.66	1.26
Sep-04	1.71	2.07	2.37	***3.19***	0.63	0.96	0.95	0.78

Table 7. *Enterococcus* group bacteria measurements at the top of the water column. Units in count/100 mL. Values above quality standards (104/100 mL) are in bold italics. Dashes indicate no data available.

Date	Green Cay Beach	Reef Club Beach	St. Croix Yacht Club Beach	Cramer's Park	Jack's Bay	Divi Beach	Robin Bay	Great Pond
Sep-02	0	0	0	0	0	0	0	0
Dec-02	0	0	0	0	0	0	0	0
Mar-03	20	0	0	0	0	***128***	0	***356***
Jun-03	0	0	0	0	0	0	0	0
Jul-03	0	0	0	0	0	0	2	0
Dec-03	0	0	1	0	0	0	0	0
Mar-04	0	0	0	0	0	0	0	0
Jun-04	0	0	4	0	0	1	1	4
Sep-04	0	0	0	0	83	1	6	0

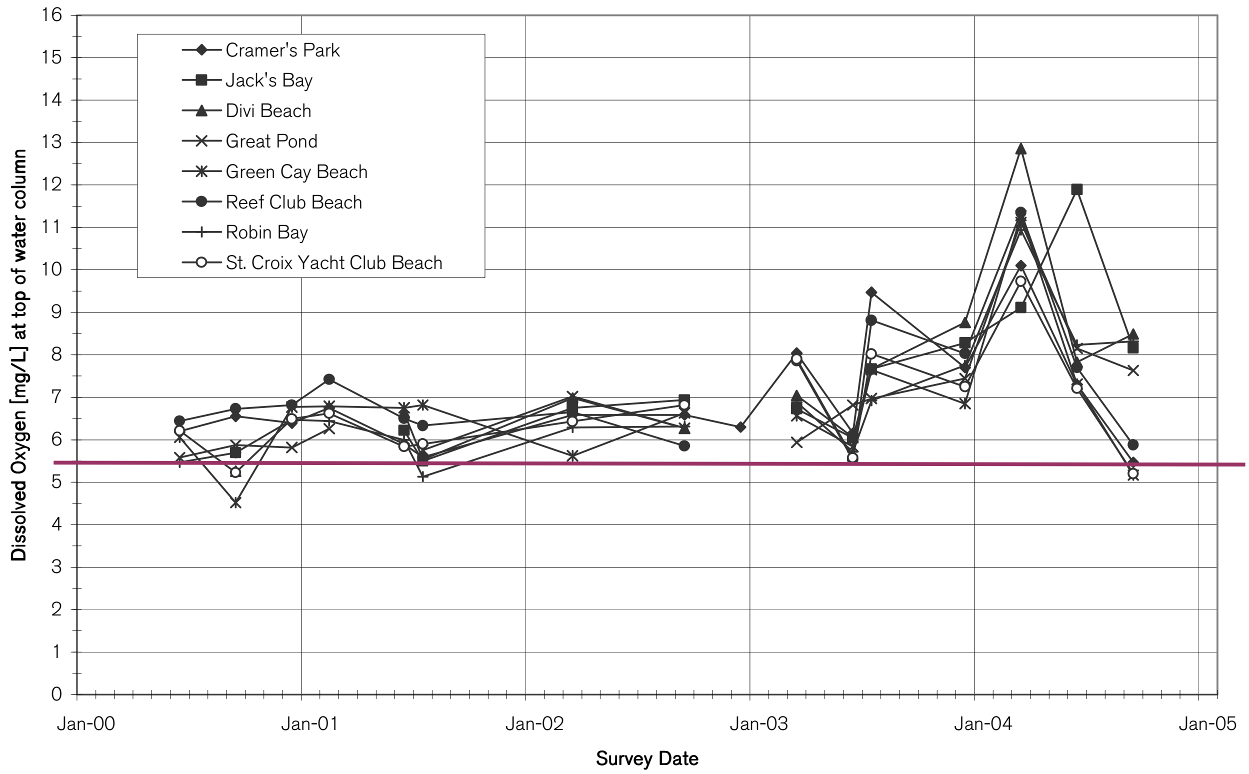

Figure 4. Dissolved oxygen measurements at the top of the water column. The quality standard (5.5 mg L^{-1}) is indicated by the horizontal line.

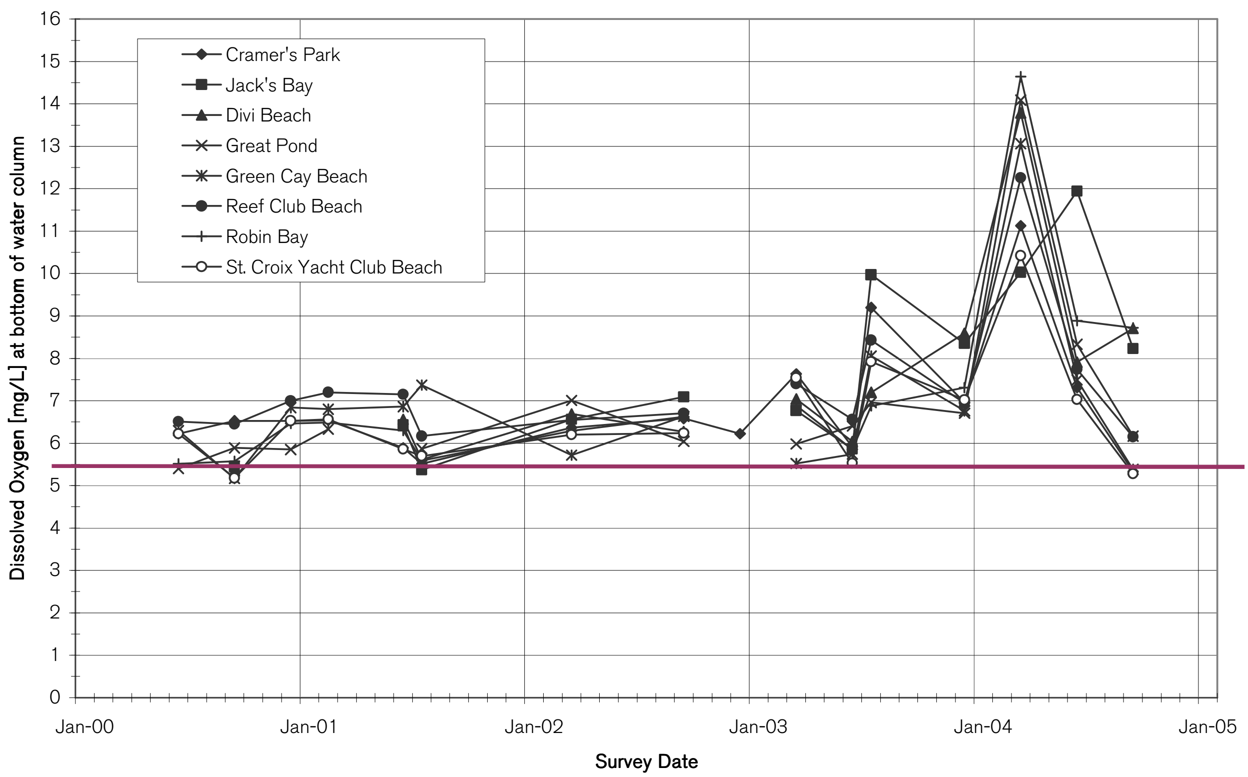

Figure 5. Dissolved oxygen measurements at the bottom of the water column. The quality standard (5.5 mg L^{-1}) is indicated by the horizontal line.

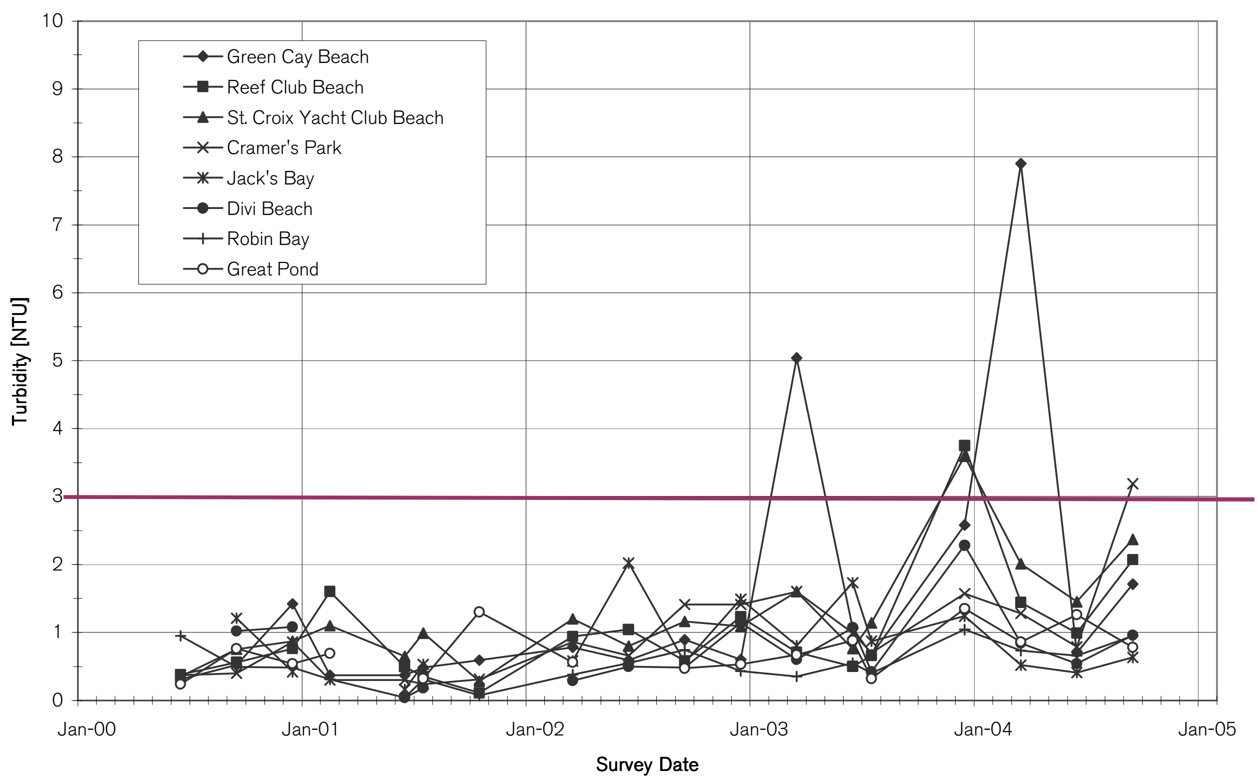

Figure 6. Turbidity measurements the top of the water column. The quality standard (3 NTU) is indicated by the horizontal line.

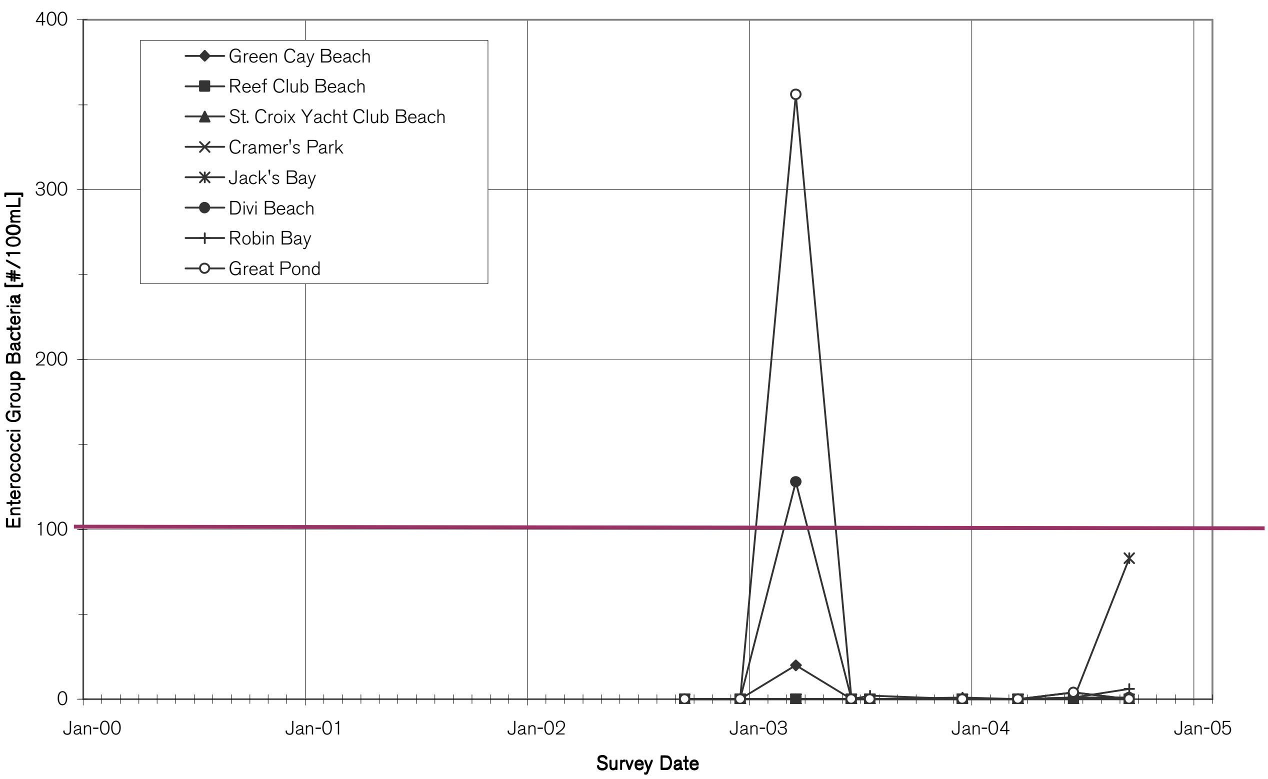

Figure 7. *Enterococcus* group bacteria measurements at the top of the water column. The quality standard (104 bacteria per 100 mL) is indicated by the horizontal line.

Table 8. The number of samples that do not meet VI water quality standards for dissolved oxygen from June 2000 to September 2004.

Station Name	n	# of samples with values <5.5 mg/L	Percent	Min value
Cramer's Park	32	2	6%	5.33
Jack's Bay	24	2	8%	5.37
Divi Beach	24	2	8%	5.26
Great Pond	28	1	4%	5.40
Robin Bay	30	2	7%	5.13
Green Cay Beach	30	4	13%	4.52
Reef Club Beach	30	0	0%	5.53
St. Croix Yacht Club Beach	30	4	13%	5.18

Table 9. The number of samples that do not meet VI water quality standards for turbidity from June 2000 to September 2004.

Station Name	n	# of samples with values >3 NTU	Percent	Max value
Cramer's Park	18	1	6%	3.2
Jack's Bay	15	0	0%	2.0
Divi Beach	15	0	0%	2.3
Great Pond	16	0	0%	1.4
Robin Bay	18	0	0%	1.0
Green Cay Beach	18	2	11%	7.9
Reef Club Beach	18	1	6%	3.8
St. Croix Yacht Club Beach	18	1	6%	3.6

Table 10. The number of samples that do not meet VI water quality standards for *Enterococcus* group bacteria from September 2002 to September 2004.

Station Name	n	# of samples with counts >104/100mL	Percent	Max value
Cramer's Park	9	0	0%	0
Jack's Bay	9	0	0%	83
Divi Beach	9	1	11%	128
Great Pond	9	1	11%	356
Robin Bay	9	0	0%	6
Green Cay Beach	9	0	0%	20
Reef Club Beach	9	0	0%	0
St. Croix Yacht Club Beach	9	0	0%	4

All sites, except Reef Club Beach, have had DO values below the water quality standard level of 5.5 mg L^{-1} within the period of June 2000 to September 2004. The number of samples that did not meet VI water quality standards per site ranged from 0-13% (mean = 7%, or 17 out of 228 samples), Green Cay Beach and St. Croix Yacht Club Beach having the highest percentages. Most of the low DO values occurred in September, coinciding with the beginning of the peak rainy season (Figure 8). The lowest DO values were 4.5 mg L^{-1}. It is to be noted, however, that samples were usually taken between 9:30 and 14:00 h and that the levels of DO change considerably during the course of a day, from a low point just before sunrise to the high point sometime in the midday. This is due to the oxygen production during the day and oxygen consumption during the night. Maximum DO values were measured up to 14.6 mg L^{-1}. However, maximum DO concentrations vary inversely with temperature and range from 7 to 9 mg L^{-1} for temperatures ranging from 20-34 °C in freshwater. At higher levels, oxygen bubbles form and escape the water column. Those maximum DO values are even lower in saltwater, since the amount of dissolved oxygen decreases as the amount of salt increases. The high DO values started to occur in July 2003 and did not appear in the previous three years. What caused those high DO values? In rough sea conditions with whitecaps super-saturation may occur, allowing for values above saturation. But why was super-saturation not encountered in earlier years? And why were higher super-saturation values recorded at the bottom and not at the top of the water column? Clearly, further investigation needs to be conducted to answer these questions. From a regulatory point of view, we recommend correcting DO values depending on their time of collection to obtain an estimated DO value at its low point just before sunrise. This would require the regulatory agents to understand the local daily DO fluctuations depending on weather conditions and

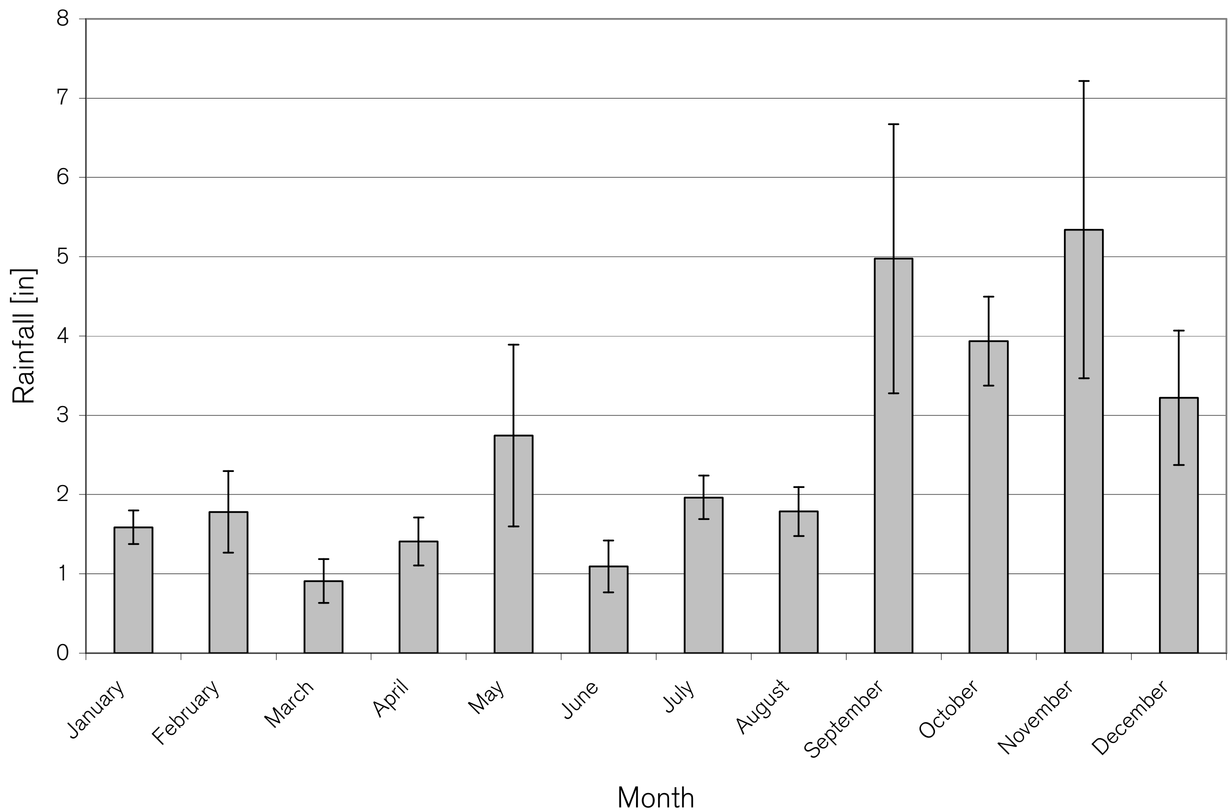

Figure 8. Average rainfall at Maria Hill, St. Croix from 1997 to 2004 (data from Craig Karnitz). Error bars represent one standard error.

habitat types (for example seagrass versus coral reefs). Additionally, limiting the data collection to early mornings would reduce the variance in the DO readings and more likely identify impaired water bodies in respect to DO. Attention also needs to be placed on adequate equipment maintenance and daily probe calibration and on understanding the probe's accuracy and precision. In the field, the samplers need to be able to recognize uncharacteristically high or low DO values and try to identify the reasons in situ.

Half of all sites had turbidity values above the acceptable level of 3 NTU within the period of June 2000 to September 2004. The number of samples that did not meet VI water quality standards per site ranged from 0-11% (mean = 4%, or 5 out of 136 samples), Green Cay Beach having the highest percentages. Although rain will transport nutrients and terrigenous sediments into the waters, which could cause turbid waters, there was a low correlation between turbidity and amount of rainfall. The best correlation occurred between turbidity and accumulated rainfall within 24 h ($R^2 = 0.29$) and decreased with increasing rain accumulation times, indicating that there is a short time lag between rain events and the surface water reaching the ocean. The data however do not reflect the full picture, since none of the samples were taken after heavy rain events. The amounts of rainfall were less than 0.1 inches within 24 hours prior to turbidity sampling and less than 0.7 inches within 6 days prior to turbidity sampling. In order to better understand the correlation between turbidity and rainfall, we recommend to conduct turbidity readings shortly after heavy rainfall events. It is also crucial to understand what is causing the turbidity: high nutrient levels causing plankton blooms, resuspended solids from surge, terrigenous sediments from surface run-off, or other? Thus, we recommend simultaneously collecting data from sediment traps, conducting nutrient and chlorophyll measurements, and continuing the turbidity measurements. Similar to the DO probe, attention also needs to be placed on adequate equipment maintenance and daily probe calibration and on understanding the probe's accuracy and precision.

Divi (Grapetree Bay) Beach and Great Pond Bay were the only two sites that had bacteria levels above the acceptable level of 104 *Enterococcus* bacteria per 100 mL within the period of September 2002 to September 2004. The number of samples that did not meet VI water quality standards per site ranged from 0-11% (mean = 3%, or 2 out of 72 samples). The two sample incidents occurred on March 25, 2003 and may have been linked to 0.26 in of rain two nights prior to sampling. However, sampling in December 2002, which did not encounter any *Enterococcus* group bacteria, occurred about 48 hours after 0.5 in of rain, and the relative high values at Jack's Bay in September 2004 occurred with virtually no rain up to three days prior to sampling. An increase in sampling frequency and an investigation of the correlation of bacteria levels and rain events may aid to answer similar questions in the future.

Additional *Enterococcus* group bacteria monitoring has been conducted by DEP's Beach Monitoring Program, which collects grab samples at four sites within the EEMP on a weekly basis (Figure 9). Monitoring sites are accessed by vehicle from land and samples are taken at depth of 4-6 inches in two feet of water. Most recent data on *Enterococcus* group bacteria levels from this program are compiled in Figure 10. The samples that did not meet VI water quality standards are given in Table 11.

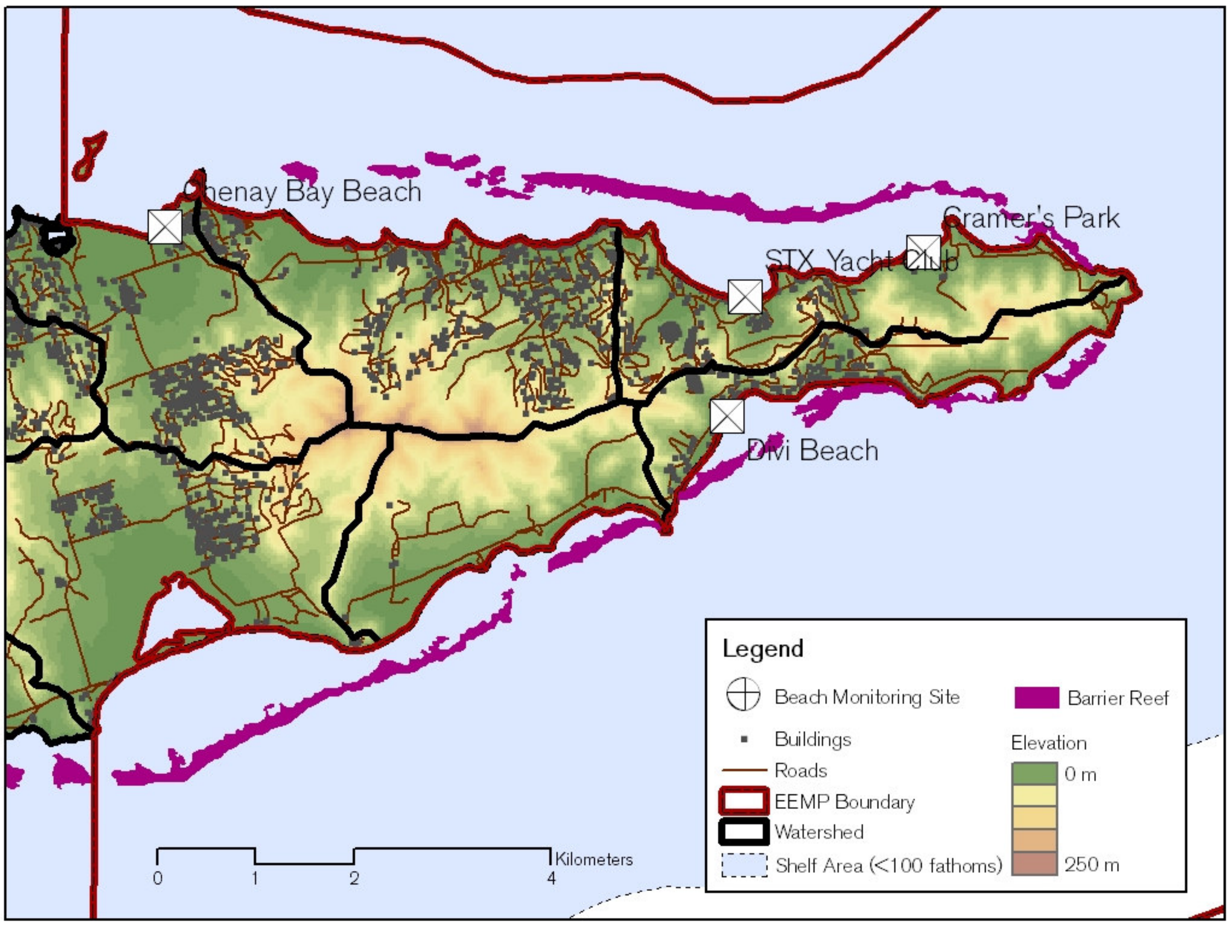

Figure 9. Beach Monitoring Program collection sites within the East End Marine Park.

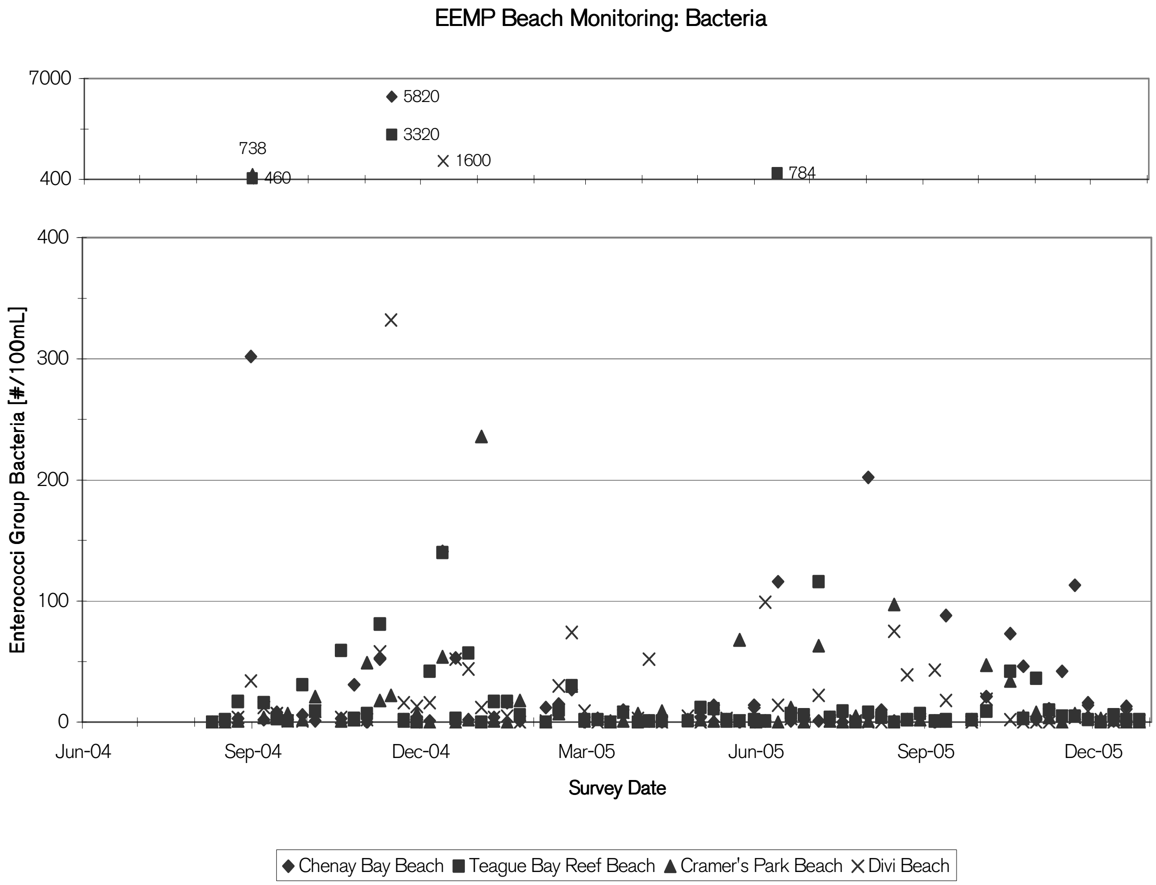

Figure 10. *Enterococcus* group bacteria measurements at the top of the water column collected through the Beach Monitoring Program. The quality standard is 104 bacteria per 100 mL.

Table 11. The Beach Monitoring Program samples that did not meet VI water quality standards for *Enterococcus* group bacteria from August 2004 to November 2005.

Date	Chenay Bay Beach	Teague Bay Reef Beach	Cramer's Park Beach	Divi Beach
8/31/2004	***302***	***460***	***738***	34
11/15/2004	***5820***	***3320***	22	***332***
12/13/2004	***141***	***140***	54	***1600***
1/3/2005	0	0	***236***	12
6/13/2005	***116***	***784***	0	14
7/5/2005	1	***116***	63	22
8/1/2005	***202***	8	1	0
11/21/2005	***113***	5	7	4
Over 104/100mL	6 (8.8%)	5 (7.4%)	2 (2.9%)	2 (2.9%)

All beach monitoring sites had bacteria levels above the acceptable level within the period of August 2004 to December 2005. The number of samples that did not meet VI water quality standards per site ranged from 3-9% (mean = 6%, or 15 out of 272 samples). Although the highest values occurred after a storm event, rainfall was poorly correlated to bacteria levels, with the majority of high bacteria levels occurring after periods with practically no rain (Figure 11). *Enterococcus* bacteria are correlated to feces of warm-blooded animals and humans. The low correlation to the amount of rain may indicate that some of the sources are within the water, such as illegal sewage dumping from boats, or there may be infiltrations from privately owned waste-water treatment facilities. Surveys with high bacteria levels received a follow-up measurement usually two days after the initial measurement. In all but one occasion those follow-up measurements were below 104/100 mL. High bacteria incidences seem to last for short periods and it is not clear from the data what triggers them.

The analysis of available data of some of the key abiotic variables monitored by DEP, highlighted the complexity of monitoring water quality. The reasons why some of the water quality samples violated VI water quality standards remain unclear. For example, the poor correlation between *Enterococcus* group bacteria levels and rain events raises the question of what causes high bacteria peaks during no-rain periods? What are the bacteria sources? On St. Croix bacteria counts are often related to releases from sewage outflows (Kaczmarsky et al. 2005). However, within the EEMP there is no public sewage system and therefore the most likely sources seem to be illegal sewage dumping from boats and excrements from dogs and other animals into the water. In addition to those sources, heavy rain events transport accumulated bacteria and most likely other contaminants and terrigenous

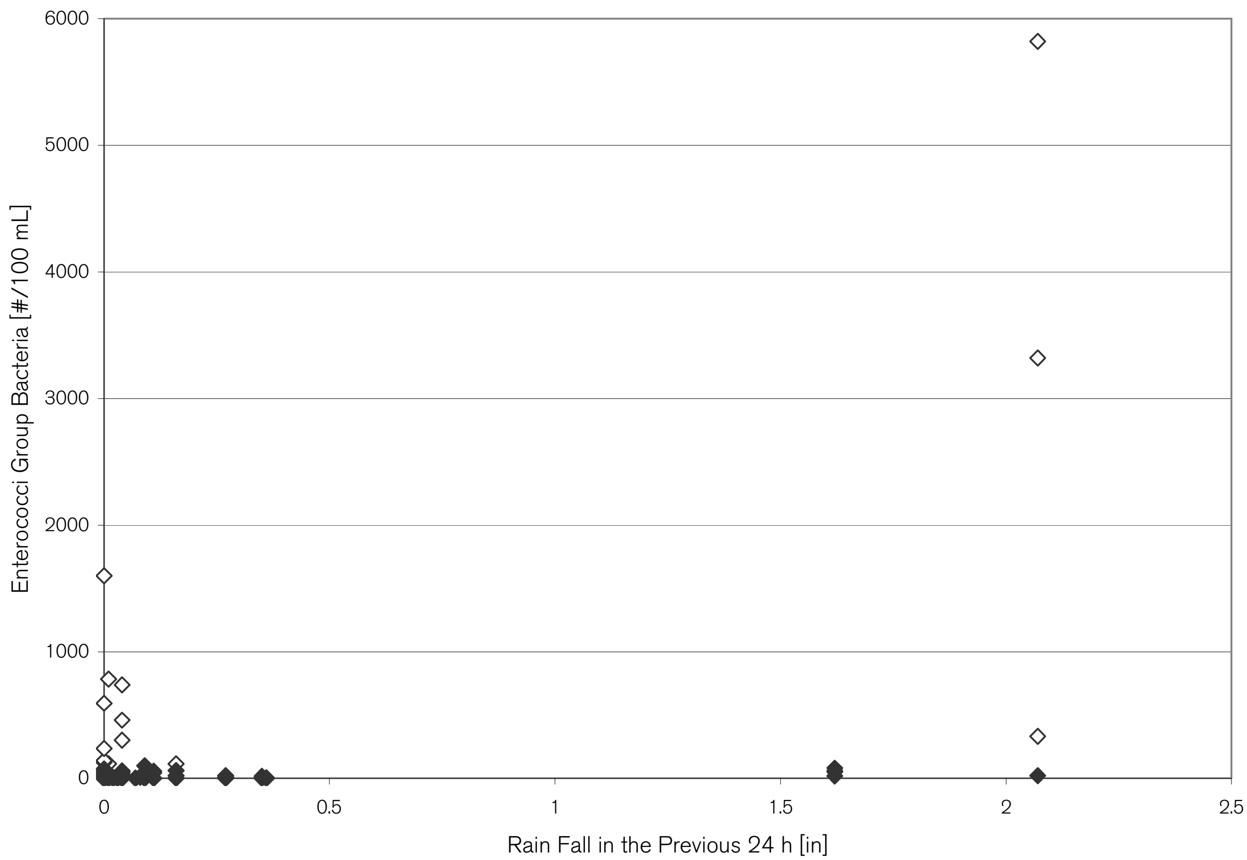

Figure 11. *Enterococcus* group bacteria measurements at the top of the water column collected through the Beach Monitoring Program and their corresponding amounts of rainfall within the previous 24 hours. Bacteria levels above 104 bacteria per 100 mL are marked in white.

sediments into the water. Poor water quality not only affects the marine environment and its inhabitants, but also affects human health. In 5.5% of the samples taken at the EEMP bacteria levels were above acceptable levels. This could be interpreted as it being unsafe to swim at the EEMP in 20 days out of the year. The Beach Monitoring Program monitors its beaches once a week, unless a sample tests above quality standards, in which case it gets resampled within two days. In 77% of the times, the resampled values were reduced to acceptable levels. This raises another question: if bacteria levels change so drastically, is monitoring the beaches once a week sufficient?

As per EPA's guidance, water quality standards are not attained when a "shall not exceed" parameter is exceeded in more than 10% of the total number of samples that are taken over a two or three year time period (DEP 2004). The water quality data analyzed above indicated that several of the sampling sites were close to not meeting those standards or did not meet those standards, depending on the period for which the data were taken. However, only Teague Bay (Reef Club Beach and St. Croix Yacht Club Beach) and Teague Bay Backreef (Cramer's Park) were placed on the 2004 303(d) Total Maximum Daily Load List (TMDL) due to impaired pH values. Priority was set to low and the tentative year of TMDL completion was 2017 (DEP 2004). Since several water quality standards were not met in close to 10% of the times, we recommend that park managers additionally take actions to investigate and mitigate threats to the park's water quality. Those actions could focus on 1) educating beach users and boaters in regards to for example dog feces in the water and illegal sewage dumping, 2) providing a sewage pump station for boaters, 3) educating private home owners to regularly maintain their septic systems and 4) assisting DEP and CZM in identifying inadequately installed silt curtains at construction and earth change sites in vicinity of the EEMP. We recommend that DEP continue conducting the water quality monitoring within the EEMP. Close coordination and communication between park staff and DEP should allow for an improved monitoring design within the EEMP that can answer park-specific water quality questions. Discussion points may include 1) the evaluation of additional water quality parameters for which water quality standards could be developed, such as terrigenous sediments, 2) the spatial and temporal representation and sampling frequency of monitored variables, and 3) the assessment of water quality during storm events.

3.2. Biotic Resources

The biotic resources are directly coupled to the abiotic resources and therefore both influenced by direct threats, such as the take and physical damage of resources, and the indirect threats from water pollution. For that reason the monitoring of biotic resources is crucial to park managers and should include the quantification of the commercial and recreational take and the fishery-independent evaluation of the status of biotic resources. Since the evaluation of all marine resources is virtually impossible, resource managers need to focus on a set of key resources that are indicative of the health of the ecosystem and in addition select management effectiveness indicators by which management objectives can be measured.

3.2.1. Quantification of Commercial and Recreational Take

The reporting of total landings by gear type by the commercial fishery was made mandatory in the US Virgin Islands in 1974. In 1983, DPNR - DFW entered into a cooperative agreement with the National Marine Fisheries Service (NMFS) to obtain more detailed data on the commercial fisheries of the USVI. A revised catch report form that provided landings by family or species groups and gear type became standard on St. Croix in 1996-1997 and on St. Thomas/St. John in 1998-1999 (Tobias et al. 2000b).

Although those revisions to the reporting of the commercial fishery landings are a significant improvement, three problems remain: 1) the accuracy of those reports is difficult to quantify, 2) they do not offer information at the species level, and 3) the exact catch locations are not provided. Nevertheless, the information collected can provide resource managers of the

EEMP with some important estimates on the amount of fish, lobster, and conch extracted from the park on an annual basis.

The annual mean total commercial landings on St. Croix for the period between July 1996 and June 1999 were 164 ± 23 tons of finfish, 21 ± 7 tons of lobster, and 19 ± 1 tons of conch (Table 12) (Tobias et al. 2000b). Finfish landings within the EEMP accounted for approximately a quarter and lobster and conch landings for about a third of the total landings of St. Croix. The average catch densities for finfish, lobster, and conch were 4.28 kg ha^{-1}, 0.54 kg ha^{-1}, and 0.49 kg ha^{-1}, respectively (Figure 12). Catch densities of finfish were lowest within the Lang Bank area and highest along the north and west coast of St. Croix, yet Lang Bank and the southwest shore made up the largest quantities of finfish landings due to their large areas. Lobster catch densities were lowest in the northwest and highest in the center (north and south). Conch catch densities were lowest in the northwest and similar high throughout the remaining areas.

In order to provide park and fisheries managers with the necessary data to manage for sustainable harvests, both commercial and recreational harvests need to be recorded accurately and at species level. Furthermore, the catch report zones need to be adjusted to include the newly added management zones within the EEMP. Currently, the only recreational fishing activities recorded are fishing tournaments. Recreational fishing may have a significant impact on the natural resources and should at least be quantified.

Commercial fisheries data at the species level have been collected through the voluntary biostatistical port-sampling program that was initiated by DPNR - DFW in 1983 and expanded in 1995 as part of the cooperative agreement with NMFS. The program has examined entire landings of volunteer fishermen and recorded species, size and weight of each animal caught. The data are confidential and entered into the Trip Interview Program (TIP) of the Southeast Fisheries Science Center (SEFSC) (www.sefsc.noaa.gov/tip.jsp) and were not available for analysis. The analysis of these data and the continuation of this program can fill in several of the data gaps.

Table 12. Mean total landings of finfish (caught by pot, hook, net, and spear), lobster, and conch within the six fishery management zones (C-1 to C-6) on St. Croix for the period from July 1996 to June 1999 (Landings from Tobias et al. 2000b). The EEMP encompasses 53.8% of C-3, 45.1% of C-4, and 27.7% of C-5 (see also following figure). The area of each zone is given in ha and in percent of total area, the mean landings are given in kg ± one standard error and in percent of total landings.

Zone	Area [ha] (%)	Finfish [kg] (%)	Lobster [kg] (%)	Conch [kg] (%)
C-1	1,100	7,897 ± 2,107	118 ± 66	189 ± 121
	(2.9)	(4.8 ± 1.3)	(0.6 ± 0.3)	(1.0 ± 0.6)
C-2	9,589	47,980 ± 6,544	4,400 ± 1,717	4,234 ± 30
	(25.1)	(29.3 ± 4.0)	(21.2 ± 8.3)	(22.6 ± 0.2)
C-3	6,292	28,385 ± 8,678	6,476 ± 2,077	4,210 ± 387
	(16.5)	(17.3 ± 5.3)	(31.1 ± 10.0)	(22.4 ± 2.1)
C-4	15,225	38,425 ± 6,406	3,682 ± 431	7,494 ± 607
	(39.8)	(23.5 ± 3.9)	(17.7 ± 2.1)	(39.9 ± 3.2)
C-5	5,086	35,054 ± 4,093	6,058 ± 2,932	2,519 ± 115
	(13.3)	(21.4 ± 2.5)	(29.1 ± 14.1)	(13.4 ± 0.6)
C-6	944	5,980 ± 2,224	56 ± 21	126 ± 65
	(2.5)	(3.7 ± 1.4)	(0.3 ± 0.1)	(0.7 ± 0.3)
Total	38,236	163,721 ± 23,022	20,791 ± 6,804	18,772 ± 1,024
	(100)	(100)	(100)	(100)
EEMP	11,653	42,292 ± 8,480	6,821 ± 1,972	6,339 ± 513
	(30.5)	(25.8 ± 5.2)	(32.8 ± 9.5)	(33.8 ± 2.7)

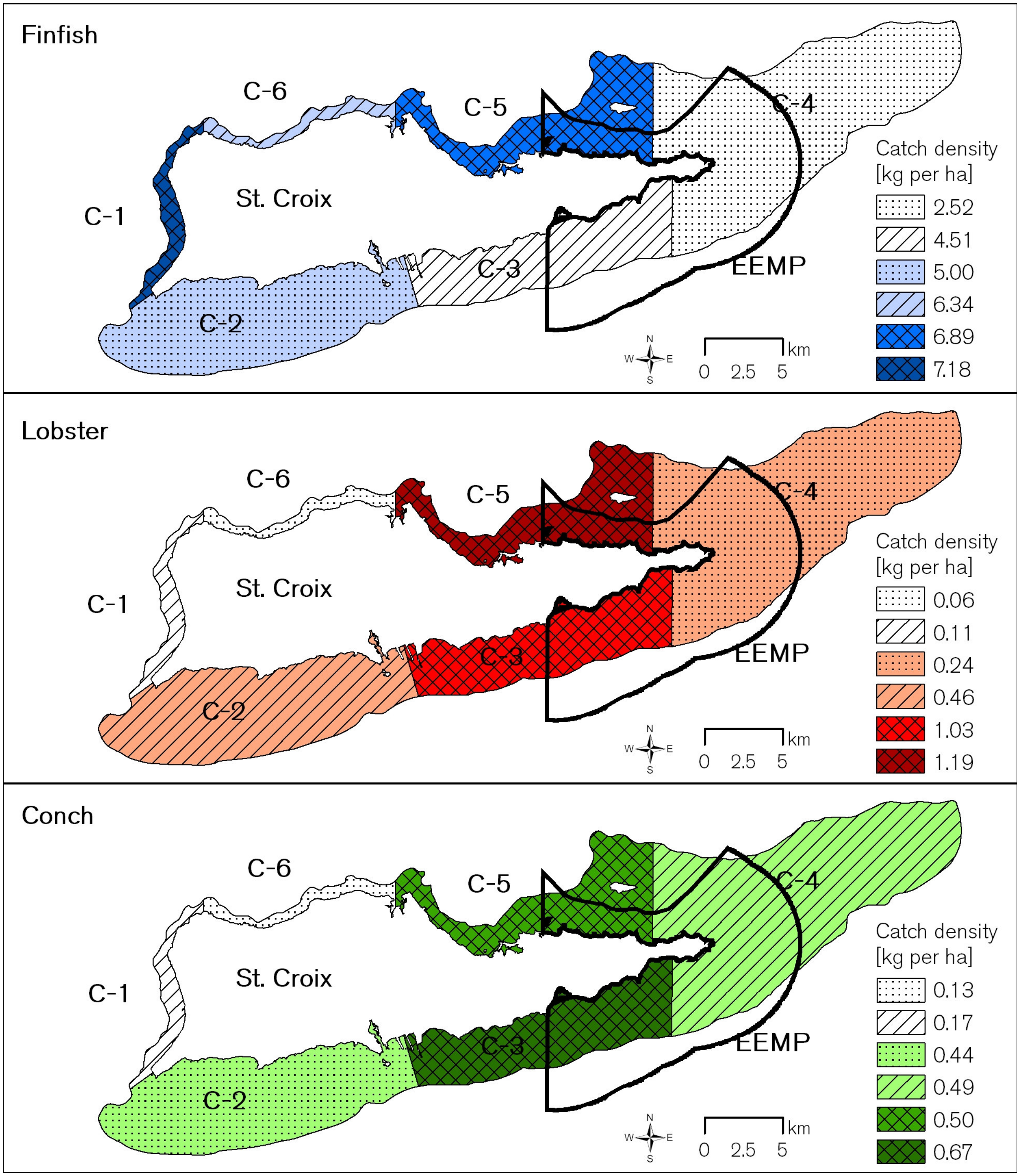

Figure 12. Catch density of finfish, lobster, and conch at the six fishery zones on St. Croix for the period from July 1996 to June 1999 (Data derived from Tobias et al. 2000b). Mean catch densities were 4.28 ± 0.60 kg ha^{-1}, 0.54 ± 0.18 kg ha^{-1}, and 0.49 ± 0.03 kg ha^{-1}, respectively.

3.2.2. Status of Key Marine Resources

Historically, one of the biggest challenges in quantifying marine resources has been to maximize the spatial extent for which the data are representative. Managers of the EEMP need to know the status of key resources within each of their management zones, as well as the status of resources outside of the park. Unfortunately, many of the earlier research studies concentrated on evaluating small areas, patch reefs, and sites of particular interest. Those data only represent those specific areas and do not provide an overall understanding of the status of those resources within the park. However, they do provide important data on long-term trends, thus it would be of great value to repeat some of the early studies within the EEMP applying the same methodologies.

First quantitative studies for finfish within the East End of St. Croix and Buck Island Reef National Monument (BIRNM) were carried out in the late 1970s. An assessment of 24 patch reefs was conducted at Tague Bay in 1976 (Gladfelter and Gladfelter 1978). Over a period of two months the presence or absence of reef fish were documented at each of the 24 patch reefs. A total of 92 species were encountered and although the numbers of fish were not quantified, the number of patch reefs at which they were present is indicative of its abundance. Fish counts conducted within 25 by 4 m transects at 47 hardbottom sites within the same area of Tague Bay by NOAA from 2003 to 2005 (derived from NOAA unpublished raw data) documented 66 of the 92 species found in 1976. Table 13 lists the 26 species found at the 24 patch reefs in 1976, but not recorded within the NOAA surveys from 2003-2005. The difference in number of species may be partly due to the difference in methodology, in which for example rare species may not have been easily detected with the

Table 13. Comparison between the 1976 study at Tague Bay (24 patch reefs) and NOAA surveys over hardbottom habitats within the same area of Tague Bay (47 sites) (derived from NOAA unpublished raw data), showing the species that were found in 1976 but not during 2003-2005.

Common Name	Scientific Name	Number of patch reefs with species present
Porcupinefish	*Diodon hystrix*	15
Blue parrotfish	*Scarus coeruleus*	15
Highhat	*Equetus acuminatus*	10
Longjaw squirrelfish	*Holocentrus marianus*	7
Mutton hamlet	*Alphestes afer*	6
Mutton snapper	*Lutjanus analis*	5
Porgy	*Calamus sp.*	4
Slender filefish	*Monocanthus tuckeri*	4
Rainbow parrotfish	*Scarus guacamaia*	4
Balloonfish	*Diodon holocanthus*	3
Rock hind	*Epinephelus adscensionis*	3
Bermuda chub	*Kyphosus sectatrix*	3
Greater soapfish	*Rypticus saponaceus*	3
Great barracuda	*Sphyraena barracuda*	3
Queen triggerfish	*Balistes vetula*	2
Sailors choice	*Haemulon parra*	2
Tiger grouper	*Mycteroperca tigris*	2
Lantern bass	*Serranus baldwini*	2
Black margate	*Anisotremus surinamensis*	1
Reef butterflyfish	*Chaetodon sedentarius*	1
Blue chromis	*Chromis cyanea*	1
Jacknife fish	*Equetus lanceolatus*	1
Bluespotted cornetfish	*Fistulatia tabacaria*	1
Honeycomb cowfish	*Lactophrys polygonia*	1
Southern sennet	*Sphyraena picudilla*	1
Permit	*Trachinotus falcatus*	1

NOAA survey transects, but detected within the sweeping search patterns during the 1976 surveys. However, the fact that species that are currently very rare on St. Croix, such as blue and rainbow parrotfish were documented relatively frequently at Tague Bay in 1976, supports the common opinion that several near-shore reef fish populations have declined (de Graaf and Moore 1987, Drayton et al. 2005).

In 1979 the West Indies Laboratory conducted a more extensive study of fish abundance within the old boundaries of BIRNM (prior to its expansion in 2001) (Gladfelter and Gladfelter 1980). Five sites were selected that represented a diversity of reef environments, each approximately 1,600 m^2 in size. A total of 100 species of adult fish were documented, excluding gobies, blennies, herrings, sardines, and razorfishes. NOAA fish counts that were conducted at 118 randomly selected hardbottom sites within the old boundaries of BIRNM during 2002-2005 (derived from NOAA unpublished raw data) found only 76 species with adults (Table 14), despite the spatially more representative method. This species richness reduction of 24% was due to declines among the piscivores, invertebrate feeders, and planktivores, whereas the number of herbivore species remained the same. Similarly, the Simpson's index of diversity reduced from 0.931 to 0.876 (SE = 0.019), showing the heaviest diversity reduction in the invertebrate feeders and planktivores (Table 14). Looking at the adult density estimates of several of the commercially and recreationally important fish species, a general decline can be noted among the groupers, snappers, jacks, grunts, angelfish, and triggerfish, and a steady-state or increase of parrotfish, surgeonfish, and small grouper species (Table 15). Error calculations for the 1979 surveys could not be extracted from the report. Also, it was not clear at what size individual species were considered to be

Table 14. Comparison of finfish species richness and diversity between a study by Gladfelter and Gladfelter (1980) and NOAA fish surveys conducted at BIRNM from 2002-2005 (Source: NOAA unpublished raw data). For the NOAA surveys the diversity index is given with one standard error (SE).

		Species Richness		Diversity ± SE	
Foraging Guilds	Examples	1979	2002-05	1979	2002-05
Piscivores	Red hind; Nassau grouper	18	14	0.745	0.755 ± 0.035
Herbivores	Stoplight parrotfish; ccean surgeonfish	21	21	0.866	0.800 ± 0.007
Invertebrate feeders	French angelfish; queen triggerfish	54	37	0.715	0.556 ± 0.055
Planktivores	Yellowtail snapper; black durgon	7	4	0.710	0.243 ± 0.073
Total		100	76	0.931	0.876 ± 0.019

Table 15. Comparison of adult fish density between a study by Gladfelter and Gladfelter (1980) and NOAA fish surveys conducted at BIRNM from 2002-2005 (derived from NOAA unpublished raw data). Gray shaded areas indicate a decline in abundance and white areas an increase. Data were sorted by foraging guild and current fish density. Density units are in fish per hectare. For the NOAA survey data the mean density is given with one standard error (SE).

			Abundance (ha^{-1}) ± SE	
Foraging Guild	Common Name	Scientific Name	1979	2002-05
Piscivores	Yellowfin grouper	*Mycteroperca venenosa*	0.4	0.0
Piscivores	Nassau grouper	*Epinephelus striatus*	0.6	0.0
Piscivores	Tiger grouper	*Mycteroperca tigris*	2.0	0.0
Piscivores	Mahogany snapper	*Lutjanus mahogoni*	32.9	3.4 ± 1.7
Piscivores	Red hind	*Epinephelus guttatus*	7.9	5.9 ± 2.2
Piscivores	Schoolmaster	*Lutjanus apodus*	27.8	7.6 ± 3.8
Piscivores	Bar jack	*Caranx ruber*	111.8	55.1 ± 19.0
Piscivores	Coney	*Cephalopholis fulvus*	1.1	33.1 ± 10.4
Herbivores	Midnight parrotfish	*Scarus coelestinus*	1.1	0.0
Herbivores	Bermuda chub	*Kyphosus sectatrix*	69.4	2.5 ± 2.5
Herbivores	Stoplight parrotfish	*Sparisoma viride*	91.6	77.1 ± 14.5
Herbivores	Rainbow parrotfish	*Scarus guacamaia*	1.4	1.7 ± 1.2
Herbivores	Yellowtail parrotfish	*Sparisoma rubripinne*	12.8	22.0 ± 6.8
Herbivores	Redband parrotfish	*Sparisoma aurofrenatum*	22.9	55.9 ± 9.3
Herbivores	Queen parrotfish	*Scarus vetula*	37.5	103.4 ± 19.2
Herbivores	Ocean surgeonfish	*Acanthurus bahianus*	170.4	287.3 ± 114.5
Herbivores	Blue tang	*Acanthurus coeruleus*	446.1	922.9 ± 215.2
Invertebrate feeders	Gray triggerfish	*Balistes capriscus*	0.1	0.0
Invertebrate feeders	Gray angelfish	*Pomacanthus arcuatus*	0.4	0.0
Invertebrate feeders	Spotfin butterflyfish	*Chaetodon ocellatus*	0.6	0.0
Invertebrate feeders	Ocean triggerfish	*Canthidermis sufflamen*	0.8	0.0
Invertebrate feeders	Queen angelfish	*Holacanthus ciliaris*	1.5	0.0
Invertebrate feeders	Rock beauty	*Holacanthus tricolor*	3.8	0.0
Invertebrate feeders	French angelfish	*Pomacanthus paru*	5.8	0.0
Invertebrate feeders	Queen triggerfish	*Balistes vetula*	1.3	0.8 ± 0.8
Invertebrate feeders	Foureye butterflyfish	*Chaetodon capistratus*	21.8	2.5 ± 2.5
Invertebrate feeders	Bluestriped grunt	*Haemulon sciurus*	27.6	9.3 ± 2.9
Invertebrate feeders	White grunt	*Haemulon plumierii*	21.4	16.9 ± 7.9
Invertebrate feeders	French grunt	*Haemulon flavolineatum*	248.5	49.2 ± 8.1
Invertebrate feeders	Banded butterflyfish	*Chaetodon striatus*	0.8	2.5 ± 1.9
Invertebrate feeders	Mutton snapper	*Lutjanus analis*	0.1	3.4 ± 1.7
Planktivores	Black durgon	*Melichthys niger*	2.9	0.0
Planktivores	Yellowtail snapper	*Ocyurus chrysurus*	17.1	3.4 ± 2.1

adults, adding an error to this comparison that could not be quantified. Despite those uncertainties, the data provided a first quantitative understanding of the general trend fish populations have undergone at BIRNM over the past 25 years. It is important to note that no quantitative data were available prior to 1979, thus making it difficult to understand what changes already had occurred by 1979.

It is clear that over the past decades and even centuries, St. Croix's marine ecosystems have undergone dramatic changes. Yet, we are missing a comprehensive baseline data set for the fish and invertebrate communities of St. Croix. For BIRNM, the NOAA Biogeography Program has undertaken this task in 2001, and provided the first spatially extensive assessment of fish densities and habitat types (Kendall et al. 2004). Starting in 2003, the assessment was expanded to include an additional 26 km^2 outside of BIRNM, principally located within the EEMP. Beginning in 2004, conch was added to the species monitored. Although the main focus of the NOAA study was to compare the resources at BIRNM to adjacent waters, this represented the most comprehensive and spatially extensive data set for fish and conch for the EEMP and set the standard for evaluating the remaining parts of the EEMP and ultimately the entire shelf of St. Croix.

Besides the need for a baseline data set of the entire EEMP and ultimately all of St. Croix, park managers need to focus on a set of indicators that can be used to evaluate the park's management effectiveness. These indicators may be of biological, physical, and socio-economical nature (Pomeroy et al. 2004) and can be specific for each management zone.

The Ocean Conservancy, in collaboration with partners and stakeholders, will conduct two workshops in 2007 to define these indicators.

The following subchapters summarize the abundance and distribution of four focal species that were selected from species that have Federal or Territorial regulations in place in the USVI regarding commercial or recreational take, and for which spatially extensive data were available for the EEMP. The four species were:

- Queen conch, *Strombus gigas* (species with harvest quota, size limit, and closed season within the Territory)
- Red hind grouper, *Epinephelus guttatus* (species with a seasonally closed spawning aggregation area on St. Croix)
- Nassau grouper, *Epinephelus striatus* (endangered species that is fully protected in Federal waters)
- Yellowtail snapper, *Ocyurus chrysurus* (species with a size limit in Federal waters)

The mean adult and juvenile population densities of additional 65 finfish species of commercial and recreational importance that were collected by the NOAA Biogeography Program were summarized in the Appendix. Adult sizes were estimated based on the lowest 50% maturity sizes compiled in www.fishbase.com and rounded to the nearest 5 cm. If no data on maturity sizes were available, adult sizes were estimated based on Humann (1997).

The data used for this analysis were collected by the NOAA Biogeography Program from October 2002 to March 2005 and were made available to the public through their website.

The NOAA Biogeography Program has been collecting biennial data on size and number of finfish and conch within 25 by 4 m (100 m^2) transects within all marine habitat types shallower than 30 m, found at BIRNM and the northwestern part of EEMP. The study area (4,982 ha) was stratified by park (BIRNM and outside of BIRNM), zone (lagoon and bank), and habitat type (hardbottom and softbottom) (Figure 13). BIRNM was made up of primarily hardbottom bank (55%) and softbottom bank (40%), whereas the area outside of BIRNM (EEMP) was made up of primarily softbottom bank (48%), hardbottom bank (29%) and softbottom lagoon (21%) (Figure 14).

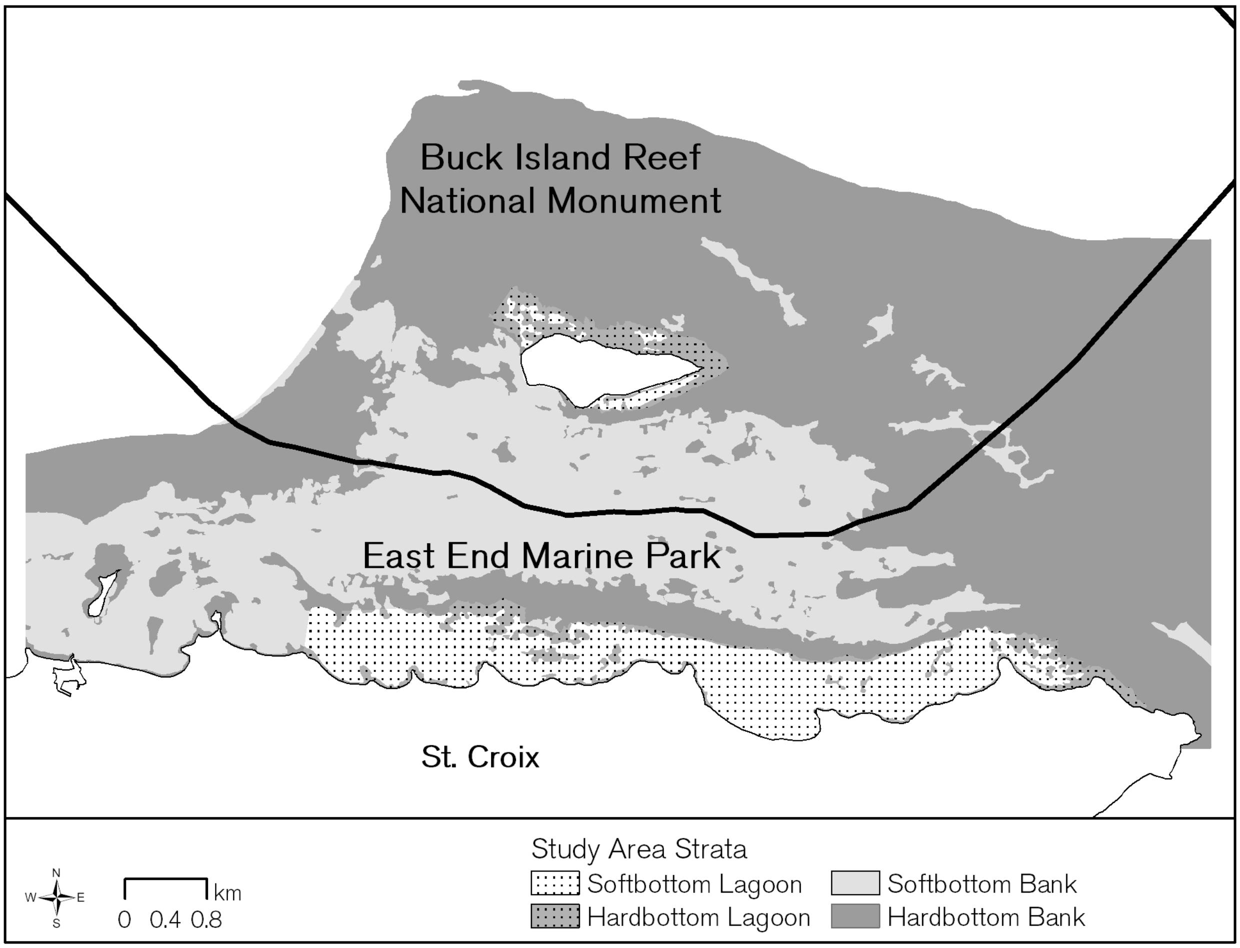

Figure 13. The NOAA Biogeography Program's study area stratified by park (inside BIRNM and outside), zone (bank and lagoon), and habitat type (hardbottom and softbottom).

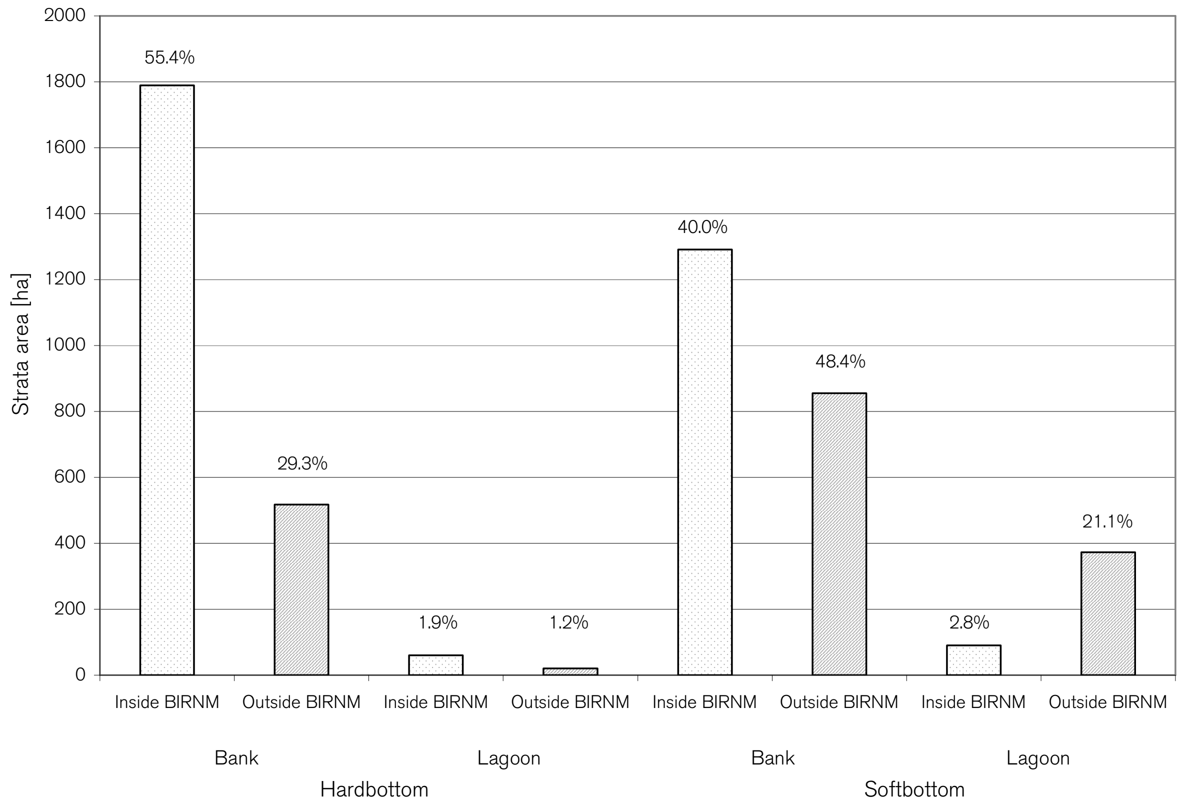

Figure 14. Comparison of stratum sizes within the NOAA Biogeography Program's study area on St. Croix. Percentage of total area are given for the strata inside and outside BIRNM.

Queen Conch

Current management regulations

Queen conch, *Strombus gigas*, is protected under the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) since 1992 (Appendix II, which includes species that, although currently not threatened with extinction, may become threatened without trade controls). Federal law prohibits import of conch unless: (1) the conch is accompanied by a CITES export permit from the appropriate regulatory authority of the exporting country, and (2) it is imported through a federally designated port of entry. The US is the largest conch importer in the world. Seventy-eight percent of all queen conch meat in international trade was imported by the US (including Puerto Rico and the US Virgin Islands), followed by France (including Guadeloupe and Martinique), which imported 19% of all meat reported in international trade between 1992 and 2001 (www.cites.org). Approximately 14 tons of conch meat per year is being legally imported to the USVI from St. Kitts (E. Monje, US Fish and Wildlife (USFW), Puerto Rico, personal communication). However, large quantities of illegal conch are being seized regularly by USFW (C. Lombard and M. Evans, USFW, USVI, personal communication).

The VI Rules and Regulations establish a closed season, harvest quotas, and size and landing restrictions for queen conch (VIRR, Title 12, Chapter 9A, Subchapters 301 to 307, 316, and 325). It is illegal to harvest queen conch from July 1 to September 30 and illegal to sell it from July 9 to September 30 each year. The harvest quotas are 6 conch per day per recreational (personal use) fisher, not to exceed 24 per boat per day and 150 conch per day per permitted commercial fisher. It is illegal to harvest queen conch that has a shell length smaller than 9 inches (23 cm), measured from the spire to the distal end, or has a shell lip thickness smaller than 3/8^{ths} of an inch (10 mm) lip thickness (Figure 15). In other words, to be legal a conch has to have a shell equal or larger than 9 inches AND a lip thickness equal or thicker than 3/8^{ths} of an inch. The lip thickness can only be measured correctly with a small caliper. All conch must be landed alive and whole in the shell at final landing sites. Transport of conch meat out of shell over open water is prohibited. The regulation of landing conch whole in the shell is currently not enforced. This makes the enforcement of conch size restrictions impossible. A challenge coupled with the enforcement of landing conch whole in the shell, is the disposal of accumulated shells on land.

In addition to a closed season, the harvest of conch has been prohibited within Salt River Bay Marine Reserve and Wildlife Sanctuary (SRB-MRWS) since 2002 and within BIRNM since July 2003. Furthermore, the proposed rules and regulations of the EEMP prohibit the harvest of conch within its No-Take and Recreation areas.

Summary of queen conch biology

The queen conch belongs to the class Gastropoda (snails) and is found throughout the Caribbean, however it has become uncommon in many areas because of over-harvesting. Queen conch inhabits seagrass beds, sand flats, rubble, and reefs to depths of up to 200 ft, but is most commonly found in seagrass beds where it feeds on algae.

The snail's soft body is mostly hidden within its cone-shaped shell. The shell is like a tubular whorl that is enlarged as the animal grows. The shell is made of calcium carbonate and is

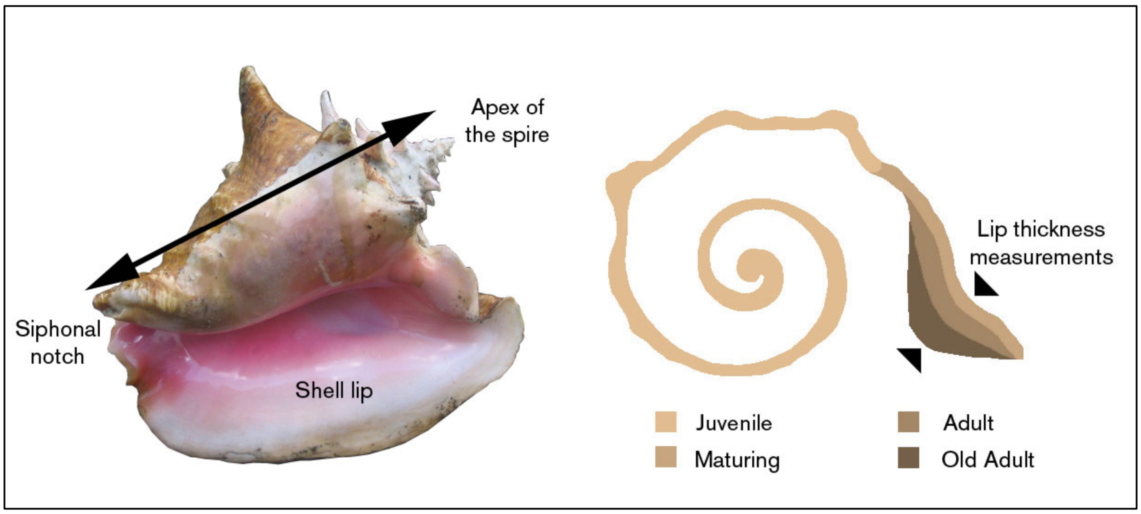

Figure 15. Queen conch are measured from the apex of the spire to the end of the siphonal notch. Lip thickness of adult conch is measured in the mid-lateral region of the shell with a caliper.

secreted from a specialized layer of the animals' outer tissue, called the mantle. The maximum shell length is obtained at or before sexual maturity, and growth energy is then devoted to the formation of a flaring shell lip and its subsequent thickening.

Berg (1976) estimated that 1, 2, and 3 year-old juvenile queen conch were 10.8, 17.0, and 20.5 cm in maximum shell length, respectively. Adult conch with newly formed lips were found to range in length from 14.3 to 26.4 cm (Randall 1964). Those numbers overlap substantially, thus, the presence of a flared shell lip is a more reliable way to tell if a queen conch has reached adulthood. Based on the lip thickness, the maturity level can be categorized into four adult stages (Table 16). Queen conch reach the flaring-lip stage after 3 years (Berg 1976). Sexual maturity however may not be reached for another year, at which point the conch are young adults with a lip thickness of up to 15 mm (Appeldoorn 1988). To date, conch cannot be aged directly, and growth appears to vary from area to area and probably also varies with density. Conch longevity is estimated at 20-30 years (Appeldoorn 1994).

Reproduction occurs during spawning aggregations from March to November (Randall 1964). Egg production peaks typically from July to September (Weil and Laughlin 1984). Because physical contact between males and females is necessary for copulation and because conch are slow moving, the maintenance of populations at high density is necessary for successful reproduction. At low densities, reproductive opportunities are lost to the time searching for mates. A minimum mating density is important for successful reproduction in queen conch

Table 16. Conch maturity categories modified from Appeldoorn (1992) and CFMC/CFRAMP (1999).

Stage	Category	Lip thickness	Description
0	Juvenile	No lip	Any conch without flared lip
1	Maturing	1-5 mm	Flared lip starting to grow or very thin. Periostrocum tan and clean. Often the lip is thin enough to allow the periostrocum to give color to the underside of the lip.
2	Young adult	6-15 mm	Flared lip is fully formed, with minimal to moderate erosion. Periostrocum tan, but may be sand covered or with some algal growth. Lip underside generally white with pink interior.
3	Old adult	16-33 mm	Outer lip starting to erode (as viewed from bottom). Top of shell still well formed, but periostrocum is lost and spines have rounded, with moderate erosion and fouling on the outside shell. Lip underside may have platinum color, with darker pink interior.
4	Very old adult	34-59 mm	Lip is very thick and flared portion may be completely eroded away. Outer shell is highly fouled and eroded, often resulting in a short total length. Viewed from the underside, the lip is squared off, the white portion is often completely eroded and the interior is a dark pink.

(Appeldoorn 1988). This minimal density may be around 50 conch ha^{-1} (Stoner 1997a), however, in relative natural populations of adults, such as Exuma Cays Land and Sea Park, Bahamas (320 km^2 reserve), adult abundances reach 270 conch ha^{-1} at depths of just 10-15 m (Stoner and Ray 1996). Glazer et al. (2003) found densities of 540 conch ha^{-1} and 290 conch ha^{-1} in two spawning aggregations in Florida. Based on acoustic telemetry the two aggregation home ranges were 72.9 ha and 22.5 ha, respectively, which would equal circles of 482 m and 268 m radii. Mean individual home range was 6.0 ha, ranging from 0.5 ha to 59.6 ha (138 m, 40 m - 436 m radii, respectively). Most conch aggregations in Florida have high densities but the overall abundance is low, which is an important fact to consider when estimating total conch populations.

Female queen conch place their egg strands into sand (Randall 1964). The demersal eggs hatch in approximately 5 days, releasing planktonic veliger larvae. The larvae are transported by surface currents from spawning grounds onto shallow banks where they settle. Metamorphosis of queen conch can occur in periods as short as 14 days (Davis et al. 1996), but larvae are also capable of remaining in the water column for long periods (perhaps 2 months). The average development period for queen conch larvae is 3 to 4 weeks (Davis et al. 1993). The larvae require a cue to initiate settlement and metamorphosis, and are capable of undergoing metamorphosis during a short competence period of 6 days (Davis 1994). Once settled, juvenile conch remain buried during their first year. The most productive nurseries for queen conch tend to occur in shallow (less than 6 m deep) sand to moderate density seagrass flats (Sandt and Stoner 1993). Aggregations of juveniles seem to occur in the same locations year after year within specific locations within those seagrass flats, leaving seemingly appropriate areas unoccupied by conch (Stoner 1997a). These critical nursery habitats need to be identified, understood, and protected to insure queen conch population stability.

Correlations between larval supply and juvenile population size over both spatial and temporal scales, along with data from transplant experiments, suggest that populations of queen conch are often recruitment limited, not habitat limited. Populations of queen conch are dependent upon upstream sources (Stoner el al. 1997). Sources of larvae may be local if retention mechanisms are strong. In the eastern Caribbean, populations of queen conch and other species with pelagic larvae must be maintained by local recirculation patterns. Position within the metapopulation structure can have important management consequences. For example, a source population will be highly vulnerable to recruitment overfishing, and emphasis must be placed on maintaining an effective and sustainable reproductive stock quality. It is still to be determined if St. Croix's conch populations are maintained by local recruitment or if they depend on recruitment from islands up current.

Queen conch are preyed upon by other gastropod species, the hermit crab, the spiny lobster, the spotted eagle ray, permit, hogfish, queen triggerfish, porcupine fish, and the loggerhead sea turtle (which is found rarely in the waters of the USVI). Due to many predators during the early juvenile phase the initial juvenile mortality is high, but rates rapidly decrease with age, largely due to increases in size and shell thickness. Natural mortality rates for adult conch are likely to be very low.

Queen conch data from the EEMP and adjacent areas

The NOAA/Biogeography Program data from October 2004 to March 2005 (NOAA unpublished raw data) are summarized in Table 17 and Figure 16 and the transect locations with the actual conch counts per transect are illustrated in Figures 17 and 18. Both juvenile and adult queen conch densities were highest in softbottom habitats within the bank of BIRNM and EEMP. These areas accounted for 75% of the total conch estimated within the study area. The remaining bank areas (hardbottom) accounted for 23% of the total estimated conch, leaving less than 2% within the lagoon areas (softbottom and hardbottom). The reason such low numbers were found in the shallow lagoon areas is because they are easily accessible by recreational and commercial conch fishers and therefore have been heavily targeted. As many of the older local residents of St. Croix can verify, queen conch used to be common in shallow seagrass beds of St. Croix, but have been fished out (de Graaf and Moore 1987, Drayton et al. 2005). It is interesting to note that even though size limits have been in place for over a decade, juvenile conch are not abundant in the lagoons either. This may primarily be explained by the lack of compliance with the existing laws.

To estimate conch densities within the proposed EEMP management zones, which consisted of up to four NOAA strata within one management zone, the conch densities of each of those strata had to be considered proportional to their respective size within that particular management zone (Table 18). Highest densities were recorded within softbottom habitats of the proposed Open and Turtle Wildlife areas. Current Territorial fishing regulations will remain governing those areas. The No-Take and Recreation areas on the other hand, will provide year-round protection to queen conch. Once the EEMP's rules and regulations are enacted

Table 17. Mean population densities of queen conch within the eight strata. Values are given with one standard error. HB = hardbottom; sb = softbottom. Conch length at legal harvest size is equal or greater than 23 cm. Data source: NOAA unpublished raw data.

Habitat	Zone	Park	n	Total [conch per ha]	Conch smaller than legal harvest size	Conch at legal harvest size	Area [ha]
HB	Bank	BIRNM	42	85.7 ± 39.5	52.4 ± 29.4	33.3 ± 12.6	1789.9
		EEMP	39	15.4 ± 13.0	2.6 ± 2.6	12.8 ± 10.5	1291.7
	Lagoon	BIRNM	50	12.0 ± 6.8	2.0 ± 2.0	10.0 ± 6.5	60.7
		EEMP	27	0 ± 0	0 ± 0	0 ± 0	90.1
SB	Bank	BIRNM	29	441.4 ± 216.2	362.1 ± 212.3	79.3 ± 29.9	517.5
		EEMP	33	400.0 ± 123.3	281.8 ± 102.9	118.2 ± 42.3	855.4
	Lagoon	BIRNM	8	0 ± 0	0 ± 0	0 ± 0	20.3
		EEMP	31	32.3 ± 13.4	19.4 ± 8.6	12.9 ± 7.7	372.7

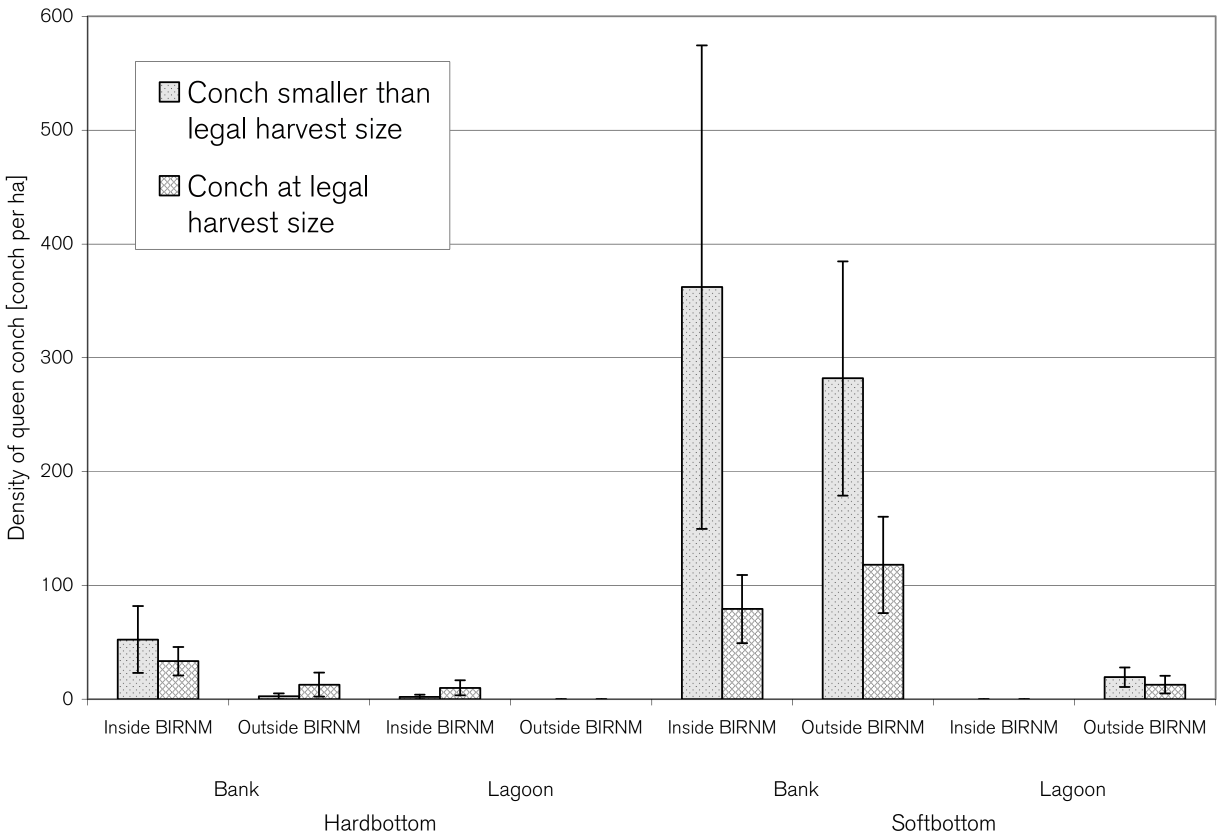

Figure 16. Mean population densities of queen conch within the eight strata. Conch length at legal harvest size is equal or greater than 23 cm. The error bars represent one standard error. Data source: NOAA unpublished raw data.

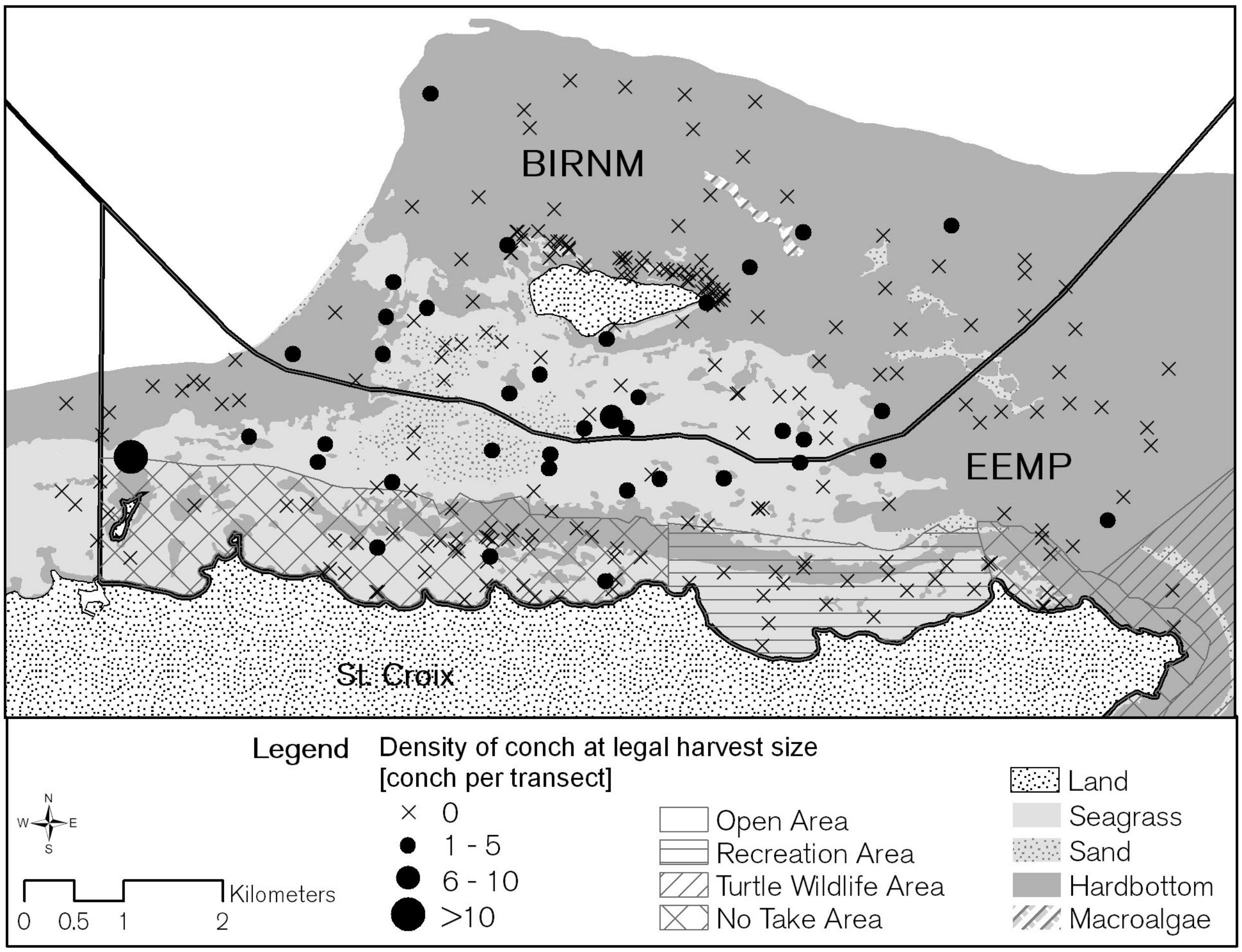

Figure 17. Number of adult queen conch per survey transect. Transects with no conch present are marked with an x. A total of 259 transects were conducted from October 2004 to March 2005. Data source: NOAA unpublished raw data.

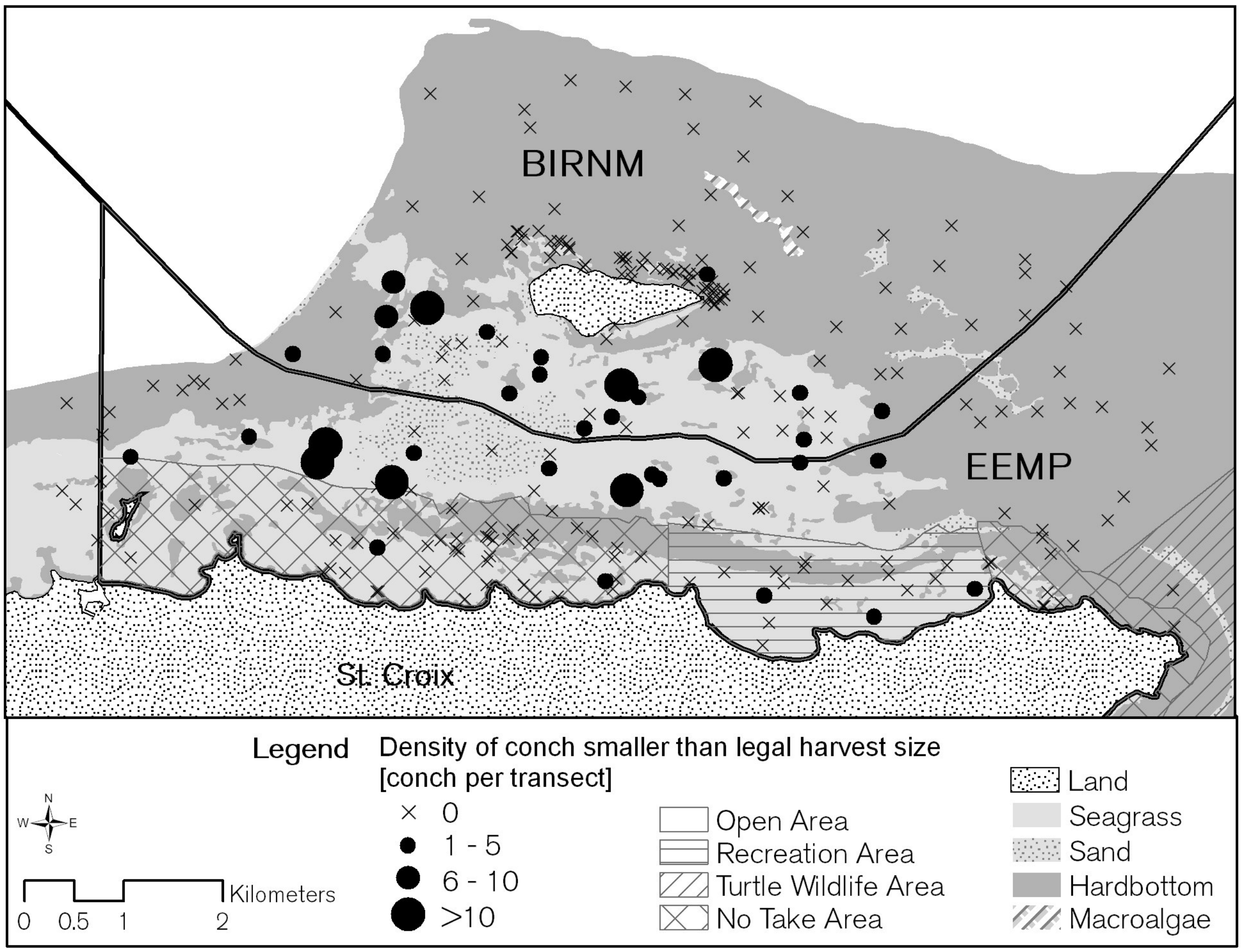

Figure 18. Number of juvenile queen conch per survey transect. Transects with no conch present are marked with an x. A total of 259 transects were conducted from October 2004 to March 2005. Data source: NOAA unpublished raw data.

Table 18. Mean population densities estimates of queen conch by habitat type within the four proposed management zones of the EEMP. Values are given with one standard error. HB = hardbottom, SB = softbottom. Data source: NOAA unpublished raw data.

Management Zone	Habitat	Area	Total [conch per ha]	Conch smaller than legal harvest size	Conch at legal harvest size
No-Take	HB	260.3	11.7 ± 9.9	2 ± 2	9.8 ± 8
	SB	402.8	236 ± 74.3	164.8 ± 60.9	71.2 ± 26.9
Recreation	HB	103.0	11.2 ± 9.5	1.9 ± 1.9	9.4 ± 7.7
	SB	230.9	92.5 ± 31.4	62.3 ± 24	30.1 ± 13.3
Turtle Wildlife	HB	55.1	15.4 ± 13	2.6 ± 2.6	12.8 ± 10.5
	SB	7.1	400 ± 123.3	281.8 ± 102.9	118.2 ± 42.3
Open	HB	926.8	15.4 ± 13	2.6 ± 2.6	12.8 ± 10.5
	SB	525.8	400 ± 123.3	281.8 ± 102.9	118.2 ± 42.3

and complied by, the conch densities within the No-Take and Recreation areas are expected to increase significantly within just a few years, primarily due to the expected population increases within the shallow lagoon areas. The No-Take and Recreation areas make up 8.9% and 3.9% of the EEMP, respectively (Table 1), and assuming similar conch densities as calculated from the NOAA data, those areas are projected to harbor approximately 11.5% and 2.6% of the EEMP's adult conch population, respectively. However, an increase of the adult conch densities within the lagoon softbottom habitats to densities similar to what currently exists in the bank softbottom habitats could increase the number of adults harbored within the No-Take and Recreation areas to over 30% of the EEMP's total, thereby increasing the total conch population by over 23%. This in turn would increase recruitment and ultimately increase St. Croix's queen conch population.

Berg (1976) estimated that queen conch reach an acceptable market size at 17.8 cm (7.0 inches) or at an age of about 2.5 years. Marketable size is reached well in advance of sexual maturity. Therefore, enforcement of conch harvest sizes is a critical step in conserving this species. Unfortunately, those harvest size limits are not enforceable, because the law requiring that queen conch are landed alive and whole in the shell is not being enforced.

The consequences of not enforcing size limits for queen conch can be shown with Figure 19. The total shell length and the lip thickness were measured from a total of 318 conch found at random sites within BIRNM and EEMP from October 2004 to March 2005 (NOAA unpublished raw data). Using Berg's (1976) acceptable market size of 17.8 cm, 49% of the

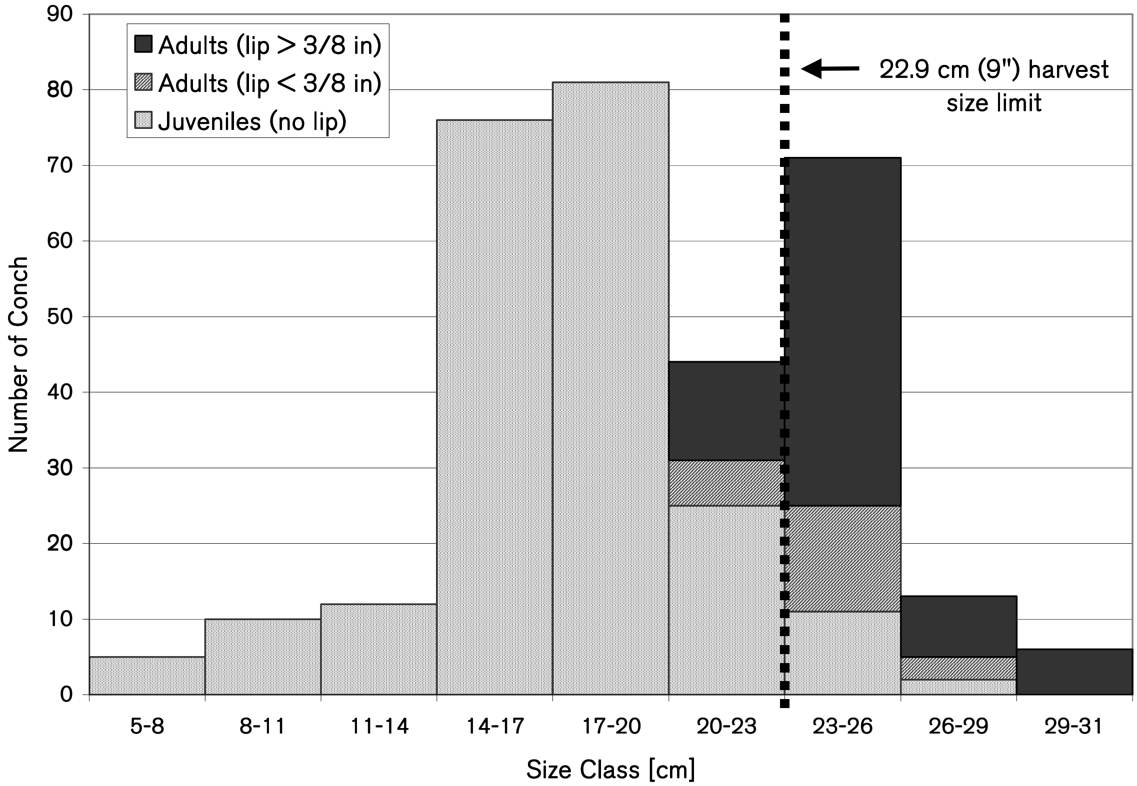

Figure 19. Queen conch size-class distribution from conch located within BIRNM and EEMP. A total of 222 juvenile and 96 adult conch were measured from October 2004 to march 2005. Data source: NOAA unpublished raw data.

measured conch would be marketable, including all adults and 19% of the juveniles without a flaring shell lip. The smaller juveniles, making up 51% of the conch, would be somewhat protected. If the law were to allow only the harvest of queen conch with flaring shell lips, then all juvenile conch would be protected, which equals to 70% of all conch. If in addition to having a shell lip, a minimum shell length of 9 in were required, then all juveniles, 26% of the maturing adults, and 18% of the adults would be protected, which equals to 76% of all conch. If as stated in the VI Code, a minimum shell length of 9 in and a minimum lip thickness of 3/8th of an inch were required, all juveniles and maturing adults, and 18% of the adults would be protected, totaling 81% of all conch. This illustrates the importance of enforcing the conch harvest size limits established within the VI Code as a critical step in conserving this species.

As illustrated in Table 17, adult queen conch densities within the softbottom habitats of the bank areas within the EEMP were above minimal densities of 50 conch ha^{-1}, which according to Stoner (1997) are needed for successful reproduction. The softbottom lagoon areas on the other hand were below that minimal threshold. The standard errors of the estimated mean density values were relatively large, though, providing low statistical power to the above statements. Nevertheless, we believe those minimal density estimates should be incorporated in habitat and zone specific management objectives within the management plan. We recommend setting the following two management objectives:

- To restore adult queen conch densities in softbottom habitats within the lagoon areas of the EEMP to a level safely above 50 conch ha^{-1}
- To maintain adult queen conch densities in softbottom habitats within the bank areas of the EEMP safely above 50 conch ha^{-1}

Furthermore, we urge park managers to assess queen conch population densities throughout all habitats of the EEMP on a quarterly basis (March, June, September, and December), in order to evaluate the spatial population distribution during different times of reproductive activity. Besides the need for baseline studies, specific research needs to be focused on determining larval settlement areas, spawning aggregation sites, migratory distances of conch participating in spawning aggregations, home range, and effects of water quality on reproduction and development. We believe the proposed management zones will benefit the EEMP's queen conch population and recommend to use queen conch density as a key management effectiveness indicator. Furthermore, queen conch has a strong cultural and commercial significance in the USVI, and the monitoring of queen conch can be easily and accurately conducted due to the species' low mobility.

Red Hind Grouper

Current management regulations

The red hind grouper, *Epinephelus guttatus*, is not regulated within Territorial waters. In Federal waters an area of approximately 9 km^2 at the tip of Lang Bank, northeast of the EEMP, is seasonally closed to all fishing from December 1 to February 28.

Summary of red hind grouper biology

The carnivorous red hind grouper is found in shallow reefs and rocky bottoms and is usually solitary and territorial. Sadovy et al. (1994) found that red hinds collected off Puerto Rico were protogynous, meaning that they start out as females and then change to males. Females became sexually mature at 21.5 cm total length, the size at 50% maturity was 28.5 cm, and they ranged in size from 11.0 to 48.0 cm. Males ranged in size from 27.3 to 51.0 cm. Since fishermen naturally prefer to catch the larger fish, this may have an impact on the size at which the sex change occurs. In an earlier study Sadovy et al. (1994) determined a maximum age of 18 years, thus this species is relatively long-lived.

Red hind groupers aggregate in large numbers during their spawning season (Coleman et al. 2000, Sadovy et al. 1994). A number of spawning aggregation sites have been documented in the Caribbean, one of which is located in Federal waters at the tip of Lang Bank, St. Croix. The timing of aggregations is somewhat variable, but in the USVI usually occur from December through March in association with the full moon.

Red hind grouper data from the EEMP and adjacent areas

The NOAA/Biogeography Program data from October 2002 to March 2005 (NOAA unpublished raw data) are summarized in Table 19 and Figure 20 and the transect locations with the actual fish counts per transect are illustrated in Figure 21. As expected, red hind groupers were primarily found in hardbottom habitats. They were more numerous within the bank than lagoon areas. Adult and intermediate size grouper densities were highest within bank hardbottom areas of the EEMP. Almost no juvenile red hinds smaller than 5 cm were found, except for a few within the BIRNM bank, raising the question of where they were hiding. The bank hardbottom areas harbored 92% of all adult and intermediate size red hind groupers within the study area, of which 52% were within the EEMP and 40% within BIRNM. The lagoon hardbottom areas harbored only 2% of the red hinds.

To estimate red hind densities within the proposed EEMP management zones, which consisted of up to four NOAA strata within one management zone, the grouper densities of each of those strata had to be considered proportional to their respective size within that particular management zone (Table 20). Densities were highest within hardbottom habitats and similar among the proposed management zones. Within the EEMP the Open Fishing and the Turtle Wildlife areas will be unrestricted in regards to the red hind grouper fishery and make up 88.3% of the area (Table 1). On the other hand, the Recreation areas (2.8% of the EEMP) will only allow for recreational hook and line fishing and in the No-Take areas (8.9%) all fishing will be prohibited. Once the EEMP's rules and regulations are enacted and enforced, the red hind grouper densities within the Recreational areas may experience a population change, depending on the impacts from the recreational hook and line fishery. The adult red hind population densities within the No-Take areas are likely to increase, primarily due to a probable population increase within the hardbottom lagoon areas. However, even with an increase of the population to densities found in bank hardbottom areas, and assuming similar red hind densities throughout the areas of the EEMP for which no data were available, the No-Take areas would only harbor about 8% of all adult red hinds within the EEMP. Nonetheless, marine reserves may especially be effective for the conservation of groupers because groupers are rather sedentary, long-lived, and only temporarily leave an area once they are sexually mature to participate in spawning aggregations. This in turn links the sustainable management of red hinds to the successful protection of spawning aggregation sites. Without their full protection any other conservation measure will fail. In summary, the proposed zonation of the EEMP may allow for an effective management of the red hind grouper and we recommended using red hind grouper as an indicator species to evaluate management effectiveness.

Table 19. Mean population densities of red hind grouper by size classes within the eight strata. Values are given with one standard error. HB = hardbottom; SB = softbottom. Data source: NOAA unpublished raw data.

Habitat	Zone	Park	n	Total [fish per ha]	Juvenile 0-5 cm	Intermediate 5-25 cm	Adult >25 cm	Area [ha]
HB	Bank	BIRNM	137	34.3 ± 6.0	0.7 ± 0.7	22.6 ± 4.7	10.9 ± 2.9	1789.9
		EEMP	89	60.7 ± 14.1	0 ± 0	34.8 ± 10.6	25.8 ± 9	1291.7
	Lagoon	BIRNM	104	13.5 ± 4.1	0 ± 0	9.6 ± 3.2	3.8 ± 1.9	60.7
		EEMP	63	12.7 ± 5.3	0 ± 0	6.3 ± 3.1	6.3 ± 4.5	90.1
SB	Bank	BIRNM	94	0 ± 0	0 ± 0	0 ± 0	0 ± 0	517.5
		EEMP	56	8.9 ± 5.3	0 ± 0	7.1 ± 4.3	1.8 ± 1.8	855.4
	Lagoon	BIRNM	40	0 ± 0	0 ± 0	0 ± 0	0 ± 0	20.3
		EEMP	58	5.2 ± 2.9	0 ± 0	1.7 ± 1.7	3.4 ± 2.4	372.7

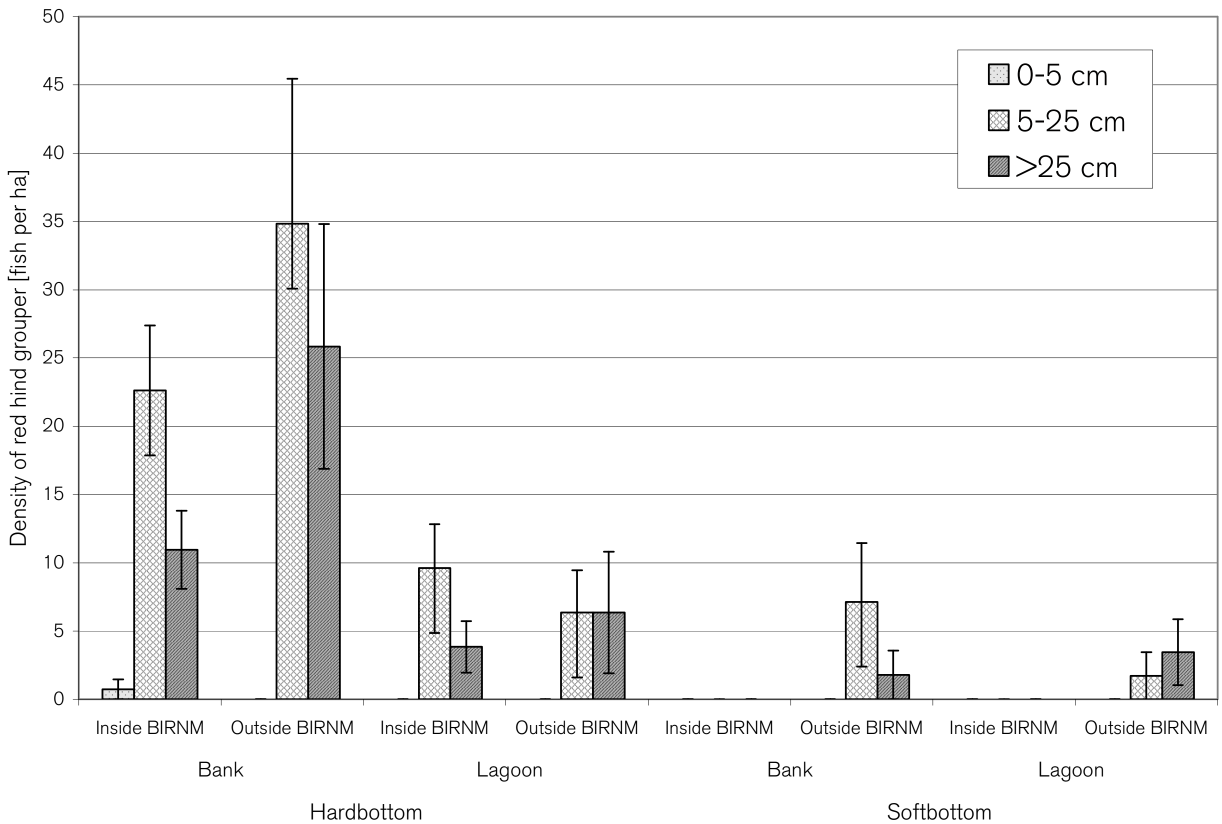

Figure 20. Mean population densities of red hind groupers within the eight strata. Sizes are given in cm total length. The error bars represent one standard error. Data source: NOAA unpublished raw data.

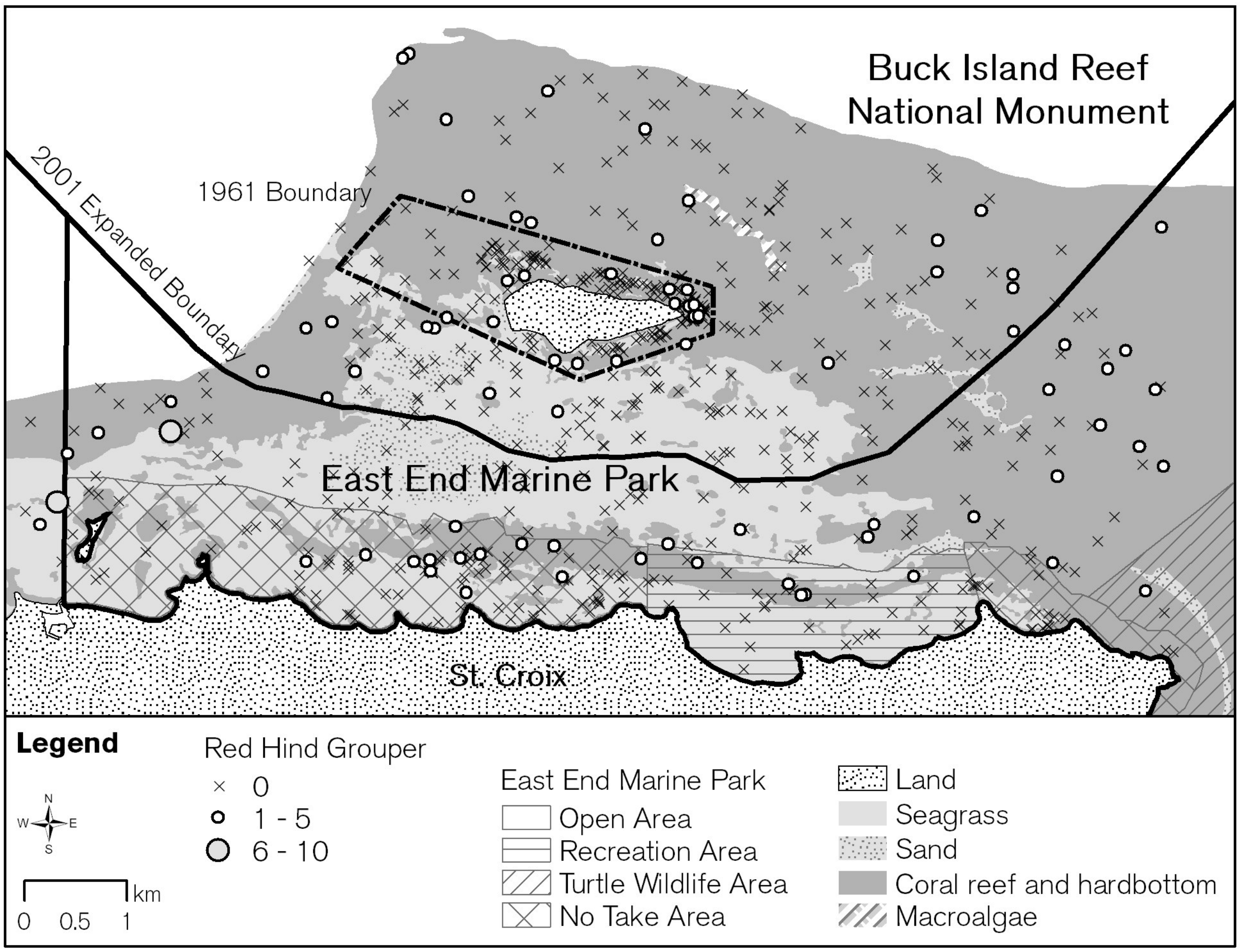

Figure 21. Number of red hind groupers per survey transect. Transects with no red hinds present are marked with an x. A total of 641 transects were conducted from October 2002 to March 2005. Data source: NOAA unpublished raw data.

Table 20. Mean population densities estimates of red hind grouper by habitat type and size class within the four proposed management zones of the EEMP. Values are given with one standard error. Data source: NOAA unpublished raw data.

Management Zone	Habitat Type	Area [ha]	Red Hind Density by Size Class [fish ha^{-1}] Total	5-25 cm	> 25 cm
No-Take	Hardbottom	260.3	49.2 ± 12.0	28.0 ± 8.8	21.2 ± 7.9
	Softbottom	402.8	7.3 ± 4.2	4.7 ± 3.2	2.5 ± 2.1
Recreation	Hardbottom	103.0	47.7 ± 11.7	27.2 ± 8.6	20.6 ± 7.8
	Softbottom	230.9	5.8 ± 3.3	2.6 ± 2.1	3.2 ± 2.3
Turtle Wildlife	Hardbottom	55.1	60.7 ± 14.1	34.8 ± 10.6	25.8 ± 9.0
	Softbottom	7.1	8.9 ± 5.3	7.1 ± 4.3	1.8 ± 1.8
Open	Hardbottom	926.8	60.7 ± 14.1	34.8 ± 10.6	25.8 ± 9.0
	Softbottom	525.8	8.9 ± 5.3	7.1 ± 4.3	1.8 ± 1.8

Nassau Grouper

Current management regulations

The Nassau grouper, *Epinephelus striatus*, has been designated as endangered (Baillie and Groombridge 1996), and its harvest or possession is prohibited in Federal waters (outside the three nautical mile limit). However, Territorial laws have not adapted those standards.

Summary of Nassau grouper biology

The carnivorous Nassau grouper is sedentary and usually associated with reefs, although juveniles are common in seagrass beds (Heemstra and Randall 1993). Unlike most other serranids, in which females become males, the Nassau grouper is primarily a gonochoristic species (no sex changes) (Sadovy and Colin 1995). Sadovy and Colin (1995) determined that male and female Nassau grouper matured between 40–50 cm and 4-8 years of age. Sadovy and Eklund (1999) reported a maximum size of 122 cm total length (male) and 23-27 kg, and maximum age of 29 years, thus substantially longer lived than the red hind grouper.

Adults lead solitary lives, except when they aggregate to spawn (Sadovy and Eklund 1999). The spawning season is brief and correlated with water temperature and the moon phase. At lower latitudes, reproductive activity lasts for about one week per month during December-February. Spawning aggregations in the Caribbean occur at depths of 20-40 m on the outer reef shelf edge, in December and January around the time of the full moon in waters of 25-26° C (Sadovy and Eklund 1999).

Nassau grouper data from the EEMP and adjacent areas

The NOAA/Biogeography Program data from October 2002 to March 2005 are summarized in a nutshell: only one Nassau grouper was recorded within all 641 survey transects. It measured 29 cm in total length and therefore was not considered to be an adult. The actual location of the sighting was within the hardbottom habitat of the lagoon area outside of BIRNM.

The decline of the Nassau grouper in the US Virgin Islands was attributed primarily to the over-fishing of the spawning aggregations. Since the ban on fishing of Nassau grouper in Federal waters since 1990 and closures of critical spawning aggregation sites in Federal waters (Red Hind Marine Conservation District since 1990 and Grammanik Bank since 2006), an increase in Nassau grouper juveniles have been documented in several of the bays of St. Thomas and St. John (R. Nemeth, personal communication). However, no such positive trends have been documented for St. Croix. This most likely is due to the fact that St. Croix sits on its own island shelf and is isolated from other islands by deep waters, thereby primarily relying on self-recruitment. Also, St. Croix only has a small area of Federal waters, therefore the fishing ban on Nassau grouper has only been providing limited protection. A recovery of the St. Croix Nassau grouper population will take a long time and require full protection in all Territorial waters. In regards to the EEMP rules and regulations, we recommend to prohibit any take of Nassau groupers within any of its zones. Due to the current low numbers of Nassau groupers and the uncertainty of recovery we do not recommended to use Nassau grouper as an indicator species to evaluate management effectiveness of the EEMP.

Yellowtail Snapper

Current management regulations

The yellowtail snapper, *Ocyurus chrysurus*, is not protected in Territorial waters. Federal waters the take of yellowtail snapper is restricted to individuals larger than 12 in (30 cm) total length.

Summary of yellowtail snapper biology

Yellowtail snappers are nocturnal predators that feed on a combination of planktonic, pelagic, and benthic organisms (Thompson and Munro 1974, Allen 1985, Bortone and Williams 1986). Adults typically inhabit sandy areas near offshore reefs (Muller et al. 2003). Juveniles are usually found over back reefs and seagrass beds (Thompson and Munro1974, Muller et al. 2003). Spawning occurs in offshore waters during February to October, with a peak from April to July (Figuerola et al. 1997).

The yellowtail snapper is a gonochoristic species (no sex changes). The size at 50% maturity was estimated for females at 24.8 cm and males at 22.4 cm fork length (Figuerola et al. 1997). The maximum reported size was 86.3 cm total length (male) and 4.1 kg (Allen 1985). Maximum age is estimated at 17 years (Manooch and Drennon 1987).

Yellowtail snapper data from the EEMP and adjacent areas

The NOAA/Biogeography Program data from October 2002 to March 2005 (NOAA unpublished raw data) are summarized in Table 21 and Figure 22 and the transect locations with the actual fish counts per transect are illustrated in Figure 23. Yellowtail snapper adults were almost exclusively found in hardbottom habitats, whereas juveniles smaller than 5 cm almost exclusively in softbottom habitats. Intermediate size snappers were found in all habitat strata. Juvenile and intermediate size snappers were more numerous within the lagoon softbottom habitat of the EEMP than the rest of the strata. The lagoon softbottom habitat of the EEMP harbored over 27% of the juvenile and intermediate size snappers, whereas the bank hardbottom areas, due to their large areas, harbored approximately 52% of the juvenile and intermediate and 90% of all adult snappers.

To estimate yellow tail snapper densities within the proposed EEMP management zones, which consisted of up to four NOAA strata within one management zone, the snapper densities of each of those strata had to be considered proportional to their respective size within that particular management zone (Table 22). Adult densities were highest within hardbottom habitats and similar among the proposed management zones. Juvenile densities were highest within softbottom habitats, in particular the proposed No-Take and Recreation areas due to the high densities within the lagoon softbottom areas. Currently, no Territorial fishing regulations exist for the yellowtail snapper, and although about 10% of the adults were estimated to be located within the proposed No-Take areas of the EEMP, the effective protection would be a lot smaller due to the daily feeding migrations and seasonal spawning migrations in and out of protected areas. As a first step in managing this species, we recommend adapting Federal size restriction to all Territorial waters. The proposed No-Take areas of the EEMP harbor approximately 30% of the juvenile and intermediate size yellowtail snappers, assuming similar densities for the areas of the EEMP where no data were available. Once the EEMP's rules and regulations are enacted and enforced, yellowtail snapper populations may increase within the park, however, the zonation design and rules and regulations may not be tailored for the management of the yellowtail snapper population. Therefore, we do not recommend using yellowtail snapper densities as a management effectiveness indicator for the EEMP. However, the monitoring of this species within the EEMP is critical and additional research is needed to understand their home range, their spawning aggregation sites, and their nocturnal feeding areas.

Table 21. Mean population densities of yellow tail snapper by size classes within the eight strata. Values are given with one standard error. HB = hardbottom; SB = softbottom. Data source: NOAA unpublished raw data.

Habitat	Zone	Park	n	Total [fish per ha]	Juvenile 0-5 cm	Intermediate 5-25 cm	Adult >25 cm	Area [ha]
HB	Bank	BIRNM	137	71.5 ± 17.3	0 ± 0	55.5 ± 14.5	16.1 ± 6.7	1789.9
		EEMP	89	40.4 ± 12.1	0 ± 0	24.7 ± 7.2	15.7 ± 7.8	1291.7
	Lagoon	BIRNM	104	42.3 ± 8.3	0 ± 0	25.0 ± 4.9	17.3 ± 6.6	60.7
		EEMP	63	81.0 ± 20.7	1.6 ± 1.6	65.1 ± 20.1	14.3 ± 7.5	90.1
SB	Bank	BIRNM	94	57.4 ± 31.1	7.4 ± 3.5	50.0 ± 30.9	0 ± 0	517.5
		EEMP	56	17.9 ± 8.1	12.5 ± 6.8	5.4 ± 3.0	0 ± 0	855.4
	Lagoon	BIRNM	40	10.0 ± 6.0	2.5 ± 2.5	7.5 ± 4.2	0 ± 0	20.3
		EEMP	58	194.8 ± 66.4	46.6 ± 21.5	139.7 ± 48.1	8.6 ± 8.6	372.7

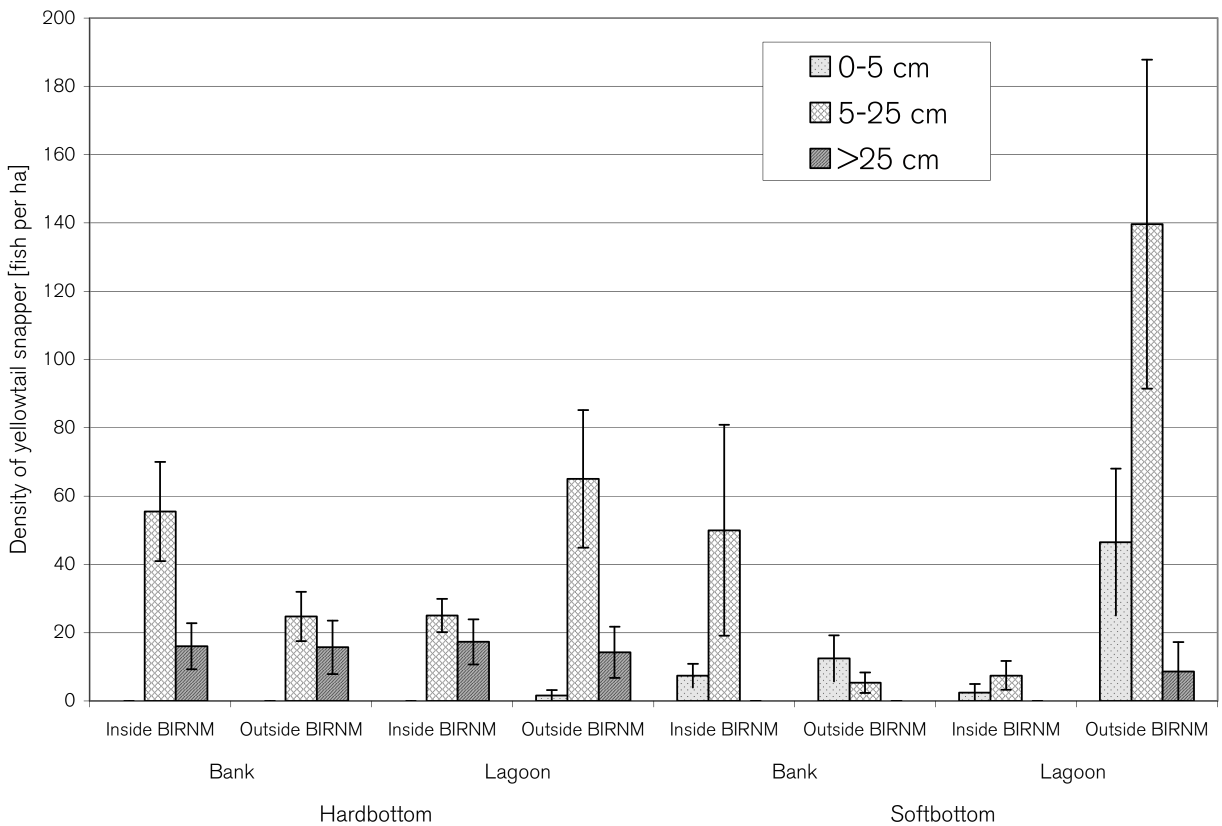

Figure 22. Mean population densities of yellow tail snapper within the eight strata. Sizes are given in cm total length. The error bars represent one standard error. Data source: NOAA unpublished raw data.

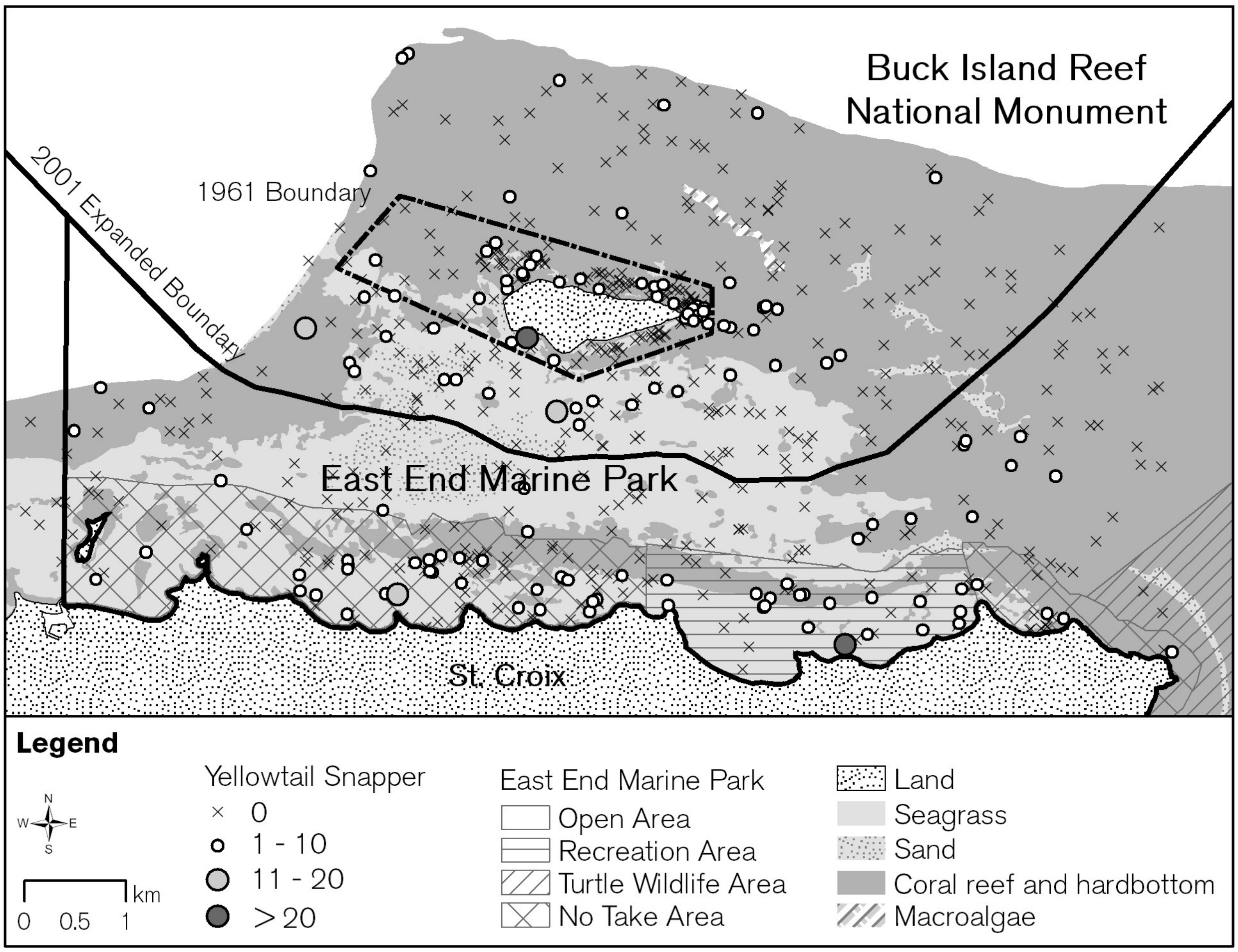

Figure 21. Number of yellowtail snappers per survey transect. Transects with no yellowtail snappers present are marked with an x. A total of 641 transects were conducted from October 2002 to March 2005. Data source: NOAA unpublished raw data.

Table 22. Mean population densities estimates of yellow tail snapper by habitat type (HB = hardbottom, SB = softbottom) and size class within the four proposed management zones of the EEMP. Values are given with one standard error. Data source: NOAA unpublished raw data.

Management Zone	Habitat Type	Area [ha]	Yellow Tail Snapper Density by Size Class [fish ha^{-1}] Total	0-5 cm	5-25 cm	> 25 cm
No-Take	HB	260.3	50.1 ± 14.2	0.4 ± 0.4	34.4 ± 10.3	15.4 ± 7.7
	SB	402.8	96.8 ± 34.1	27.7 ± 13.3	65.2 ± 23.1	3.8 ± 3.8
Recreation	HB	103.0	51.4 ± 14.5	0.4 ± 0.4	35.6 ± 10.7	15.3 ± 7.7
	SB	230.9	165.9 ± 56.9	41.0 ± 19.1	117.7 ± 40.7	7.2 ± 7.2
Turtle Wildlife	HB	55.1	40.4 ± 12.1	0 ± 0	24.7 ± 7.2	15.7 ± 7.8
	SB	7.1	17.9 ± 8.1	12.5 ± 6.8	5.4 ± 3.0	0 ± 0
Open	HB	926.8	40.4 ± 12.1	0 ± 0	24.7 ± 7.2	15.7 ± 7.8
	SB	525.8	17.9 ± 8.1	12.5 ± 6.8	5.4 ± 3.0	0 ± 0

4. Management Recommendations

The EEMP has a clear mission statement to protect territorially significant marine resources, promote sustainability of marine ecosystems, and conserve and preserve significant natural areas for the use and benefit of future generations (The Nature Conservancy 2002). The management plan also identifies a number of goals and objectives that are of biological, physical, and socio-economical nature. We recommend that once the proposed EEMP rules and regulations are enacted, park managers focus on identifying and monitoring biological, physical, and socio-economical indicators to evaluate park management effectiveness in achieving the objectives, goals, and overall mission statement.

It is important to realize that the EEMP is not a closed system: the protection of marine resources may be jeopardized by threats outside of the park. The EEMP has to be looked at in the context of the Territory's overall mission to protect its biodiversity and promote the sustainable use of marine resources. This overall mission can be achieved only if high water quality is ensured, and if a functional network of No-Take reserves is combined with management tools such as seasonal closures, size restrictions, gear restrictions, and species harvest bans. We recommend that, similar to the EEMP, Territorial rules and regulations be evaluated for effectiveness.

In the Territory there is a lack of spatially extensive baseline-data on key biotic resources that are indicative of the status of the USVI's coral reef and associated ecosystems, with the exception of what has been recently collected by the NOAA Biogeography Team and its partners in some of the Federal waters and a portion of the EEMP. However, these data are critically needed to allow for adaptive resource management. We recommend that this baseline assessment be expanded to the entire EEMP and ultimately to all Territorial and Federal waters.

The success of the EEMP relies heavily on the adequate enforcement of Territorial and Federal fishing, land-management, and waste-management regulations, which currently is deficient (Jeffrey et al. 2005). The establishment of MPAs is meaningless unless the compliance with its rules and regulations can be ensured. We recommend developing methods to assess compliance with the EEMP's rules and regulations and including compliance indicators as part of the management effectiveness evaluation.

Several water quality standards have not been met at DPNR - DEP's monitoring sites within the EEMP, but the reasons for that remain unclear. Illegal sewage dumping from boats, runoff from faulty private septic systems, excessive sediment runoff, and inadequate herbicide and pesticide usage are believed to be possible causes of water quality degradation within the EEMP, but studies still need to be undertaken to verify those hypothesis. Some of the assumed water quality issues could be addressed by having EEMP staff 1) educate boaters in regards to illegal sewage dumping, 2) provide a sewage pump station for boaters, 3) encourage private home owners to regularly maintain their septic systems, and 4) promote best-management practices to prevent erosion. We recommend that DEP continue to conduct water quality monitoring within the EEMP, but that park managers work closely with DEP to help identify the threats to the water quality of the EEMP and to modify the monitoring design to fit park managers' needs. We suggest to focus on 1) improving the spatial and temporal representation and sampling frequency of monitored variables, 2) developing additional water quality standards for parameters such as terrigenous sediments, and 3) assessing water quality during storm events.

The proposed No-Take and Recreation areas encompass 69% and 31% (total 100%) of all lagoon areas, and 7% and 1% (total 8%) of all bank areas of the park, respectively. When looking at habitat types, they encompass 27% and 11% (total 37%) of all softbottom habitats, and 7% and 2% (total 9%) of all hardbottom habitats of the park, respectively. Therefore, the EEMP is designed to primarily provide protection to the lagoon areas, thereby providing proportionally more protection to softbottom than hardbottom areas. Nevertheless, the No-Take and Recreation areas include the ecologically highly important barrier reef and lagoon patch reef systems within its boundaries. We believe that the success of the EEMP to protect territorially significant marine resources may be limited to species or their ontogenetic phases that occur primarily within the barrier reef and lagoon systems. From the four species that were summarized in this document, we believe that queen conch and red hind groupers will benefit the most from the proposed management zones, and could serve as good indicator species for the management effectiveness of the EEMP.

The proposed No-Take and Recreation areas may ensure a recovery of the once abundant near-shore queen conch populations, which in turn would increase reproduction and, therefore, provide a positive feedback. The current laws defining harvest quotas, size limits, and a closed harvest season, and the existence of other No-Take reserves, such as BIRNM and SRB-MRWS, provide a basis that may ensure sustainable queen conch harvests on St.

Croix. However, there is a pressing need to ensure compliance with these laws and to find ways to dispose of queen conch shells after they are landed. In future revisions of the management plan, we recommend to set specific management objectives for queen conch. Since minimal adult densities of 50 conch ha^{-1} are needed for successful reproduction, we recommend that a management objective be to restore and maintain adult queen conch population densities safely above 50 conch ha^{-1} in soft bottom habitats of the EEMP. Furthermore, we urge park managers to 1) increase queen conch monitoring frequency to evaluate the spatial population distribution during different times of reproductive activity, and 2) focus research on determining larval settlement areas, spawning aggregation sites, migratory distances of individuals participating in spawning aggregations, home range, and effects of water quality on reproduction and development.

The proposed No-Take areas of the EEMP are also likely to benefit the mostly sedentary groupers in general, and the red hind grouper in particular. Approximately 8% of the adult red hinds of the EEMP were located within proposed No-Take areas. The EEMP's No-Take areas will be an addition to the current marine reserves on St. Croix, BIRNM and SRB-MRWS, and increase long-term protection to St. Croix's red hind populations. However, the success of any marine reserve to protect red hind groupers depends on the protection of the red hind spawning aggregations. We recommend that the seasonal closed spawning aggregation site at Lang Bank be monitored for compliance.

The Nassau grouper populations are currently so low, that we recommend an immediate harvest ban within the entire EEMP. It may even be necessary to ban harvests throughout the entire St. Croix shelf. Due to the uncertainty of the recovery of Nassau groupers on St. Croix, we do not recommend using it as an indicator species for the management effectiveness of the proposed rules and regulations of the EEMP. However, we recommend monitoring this species.

The yellowtail snapper populations appear to be declining and large schools of adults are rarely seen. We recommend that Federal size restrictions be adapted in Territorial waters and that the yellowtail snapper population status be monitored. We also encourage additional research to understand their home range, their spawning aggregation sites, and their nocturnal feeding areas. We are uncertain if the current proposed rules and regulations may significantly contribute to a recovery of this species and at this point do not recommend using yellowtail snapper densities as a management effectiveness indicator for the EEMP.

As can be seen from this summary of some of the biophysical data relevant to the EEMP, the coral reef and associated ecosystems are highly complex and it takes considerable knowledge of the biology and behavior of each species to conduct effective resource management. Each species within the park, as well as each of their life-stages, may respond differently to the management measures proposed in the rules and regulations. Even for species that are relatively well understood, such as the queen conch, several critical questions still need to be researched for answers. Resource management often tends to be a trial and error experiment rather than exact science. However, with the alarming rate of decline of our marine resources, far-reaching changes need to occur within the VI Government and within the people of the Virgin Islands. It is critical that we thereby apply a cautionary approach to resource management.

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6. Appendix

Table A1. Mean adult population densities of commercially and recreationally important finfish species within a 26 km^2 section of the EEMP. Adult sizes were estimated based on the lowest 50% maturity sizes compiled in www.fishbase.com and rounded to the nearest 5 cm. If no data on maturity sizes were available, adult sizes were estimated based on Human (1997) and marked with an asterisk. Density values are given with one standard error. Source: NOAA unpublished raw data.

Common Name	Scientific Name	Adult Size [cm]	Density of Adults [fish ha^{-1}] Hardbottom Bank	Hardbottom Lagoon	Softbottom Bank	Softbottom Lagoon
Yellowfin grouper	*Mycteroperca venenosa*	50	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Yellowmouth grouper	*Mycteroperca interstitialis*	40*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Black grouper	*Mycteroperca bonaci*	70	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Tiger grouper	*Mycteroperca tigris*	45	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Goliath grouper	*Epinephelus itajara*	110	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Nassau grouper	*Epinephelus striatus*	40	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Rock hind	*Epinephelus adscensionis*	25	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Red hind	*Epinephelus guttatus*	25	25.8 ± 9.0	6.3 ± 4.5	1.8 ± 1.8	3.4 ± 2.4
Graysby	*Cephalopholis cruentatus*	15	11.2 ± 6.3	4.8 ± 2.7	3.6 ± 3.6	1.7 ± 1.7
Coney	*Cephalopholis fulvus*	15	139.3 ± 21.0	20.6 ± 8.2	1.8 ± 1.8	20.7 ± 11.5
Yellowtail snapper	*Ocyurus chrysurus*	25	15.7 ± 7.8	14.3 ± 7.5	0 ± 0	8.6 ± 8.6
Cubera snapper	*Lutjanus cyanopterus*	45*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Dog snapper	*Lutjanus jocu*	50	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Mutton snapper	*Lutjanus analis*	50	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Gray snapper	*Lutjanus griseus*	25	0 ± 0	1.6 ± 1.6	0 ± 0	0 ± 0
Schoolmaster	*Lutjanus apodus*	25	2.2 ± 1.6	36.5 ± 20.0	0 ± 0	0 ± 0
Lane snapper	*Lutjanus synagris*	20	1.1 ± 1.1	1.6 ± 1.6	0 ± 0	1.7 ± 1.7
Mahogany snapper	*Lutjanus mahogoni*	15*	3.4 ± 1.9	12.7 ± 6.2	0 ± 0	8.6 ± 7.1
Bar jack	*Caranx ruber*	25	119.1 ± 112.3	185.7 ± 91.0	55.4 ± 36.8	10.3 ± 5.9
Blue runner	*Caranx crysos*	25	142.7 ± 113.1	201.6 ± 159.6	42.9 ± 37.8	234.5 ± 99.5
Yellow jack	*Caranx bartholomaei*	45	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Horse-eye jack	*Caranx latus*	35	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Permit	*Trachinotus falcatus*	45	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Palometa	*Trachinotus goodei*	20*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Margate	*Haemulon album*	25	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Bluestriped grunt	*Haemulon sciurus*	20	2.2 ± 1.6	76.2 ± 32.8	0 ± 0	1.7 ± 1.7
White grunt	*Haemulon plumierii*	15	4.5 ± 2.2	46.0 ± 23.9	0 ± 0	46.6 ± 43.1
Cottonwick	*Haemulon melanurum*	20	0 ± 0	1.6 ± 1.6	0 ± 0	0 ± 0
French grunt	*Haemulon flavolineatum*	15	69.7 ± 14.8	196.8 ± 44.1	1.8 ± 1.8	100.0 ± 53.8
Tomtate	*Haemulon aurolineatum*	15	14.6 ± 8.5	182.5 ± 73.3	0 ± 0	0 ± 0
Spanish grunt	*Haemulon macrostomum*	25*	0 ± 0	6.3 ± 6.3	0 ± 0	0 ± 0
Caesar grunt	*Haemulon carbonarium*	15*	2.2 ± 1.6	61.9 ± 29.3	0 ± 0	0 ± 0
Smallmouth grunt	*Haemulon chrysargyreum*	15*	0 ± 0	33.3 ± 31.8	0 ± 0	1.7 ± 1.7
Sailors choice	*Haemulon parra*	20*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Porkfish	*Anisotremus virginicus*	15*	1.1 ± 1.1	0 ± 0	0 ± 0	0 ± 0
Black margate	*Anisotremus surinamensis*	30*	0 ± 0	0 ± 0	0 ± 0	0 ± 0

Table A1. Continued.

		Adult	Density of Adults [fish ha^{-1}]			
		Size	Hardbottom		Softbottom	
Common Name	Scientific Name	[cm]	Bank	Lagoon	Bank	Lagoon
Blue parrotfish	*Scarus coeruleus*	25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Midnight parrotfish	*Scarus coelestinus*	25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Rainbow parrotfish	*Scarus guacamaia*	25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Queen parrotfish	*Scarus vetula*	15*	7.9 ± 4.3	30.2 ± 11.0	1.8 ± 1.8	0 ± 0
Princess parrotfish	*Scarus taeniopterus*	15*	42.7 ± 11.4	3.2 ± 2.2	3.6 ± 3.6	0 ± 0
Striped parrotfish	*Scarus iseri*	15*	23.6 ± 9.2	20.6 ± 8.5	8.9 ± 8.9	0 ± 0
Stoplight parrotfish	*Sparisoma viride*	15	33.7 ± 8.3	42.9 ± 12.3	0 ± 0	1.7 ± 1.7
Redband parrotfish	*Sparisoma aurofrenatum*	15*	148.3 ± 21.4	101.6 ± 19.7	26.8 ± 18.8	25.9 ± 11.4
Yellowtail parrotfish	*Sparisoma rubripinne*	20*	7.9 ± 4.9	19.0 ± 11.5	0 ± 0	3.4 ± 2.4
Redtail parrotfish	*Sparisoma chrysopterum*	20*	0 ± 0	4.8 ± 2.7	0 ± 0	1.7 ± 1.7
Ocean surgeonfish	*Acanthurus bahianus*	15	394.4 ± 82.7	188.9 ± 34.7	25.0 ± 17.7	82.8 ± 39.5
Blue tang	*Acanthurus coeruleus*	15*	71.9 ± 28.0	238.1 ± 86.7	7.1 ± 7.1	62.1 ± 41.4
Doctorfish	*Acanthurus chirurgus*	15*	18.0 ± 11.6	79.4 ± 42.1	0 ± 0	25.9 ± 16.2
Hogfish	*Lachnolaimus maximus*	25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Spanish hogfish	*Bodianus rufus*	20*	7.9 ± 2.9	4.8 ± 3.5	0 ± 0	1.7 ± 1.7
Puddingwife	*Halichoeres radiatus*	15*	1.1 ± 1.1	4.8 ± 4.8	0 ± 0	0 ± 0
Gray angelfish	*Pomacanthus arcuatus*	25	0 ± 0	0 ± 0	0 ± 0	0 ± 0
French angelfish	*Pomacanthus paru*	25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Queen angelfish	*Holacanthus ciliaris*	20	1.1 ± 1.1	0 ± 0	0 ± 0	0 ± 0
Rock beauty	*Holacanthus tricolor*	15	9.0 ± 3.4	0 ± 0	0 ± 0	0 ± 0
Spotfin butterflyfish	*Chaetodon ocellatus*	10	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Foureye butterflyfish	*Chaetodon capistratus*	10	10.1 ± 4.2	4.8 ± 2.7	3.6 ± 3.6	1.7 ± 1.7
Banded butterflyfish	*Chaetodon striatus*	10	12.4 ± 4.7	3.2 ± 3.2	0 ± 0	0 ± 0
Reef butterflyfish	*Chaetodon sedentarius*	10*	1.1 ± 1.1	0 ± 0	0 ± 0	0 ± 0
Ocean triggerfish	*Canthidermis sufflamen*	25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Queen triggerfish	*Balistes vetula*	25	20.2 ± 5.8	0 ± 0	0 ± 0	0 ± 0
Gray triggerfish	*Balistes capriscus*	15	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Black durgon	*Melichthys niger*	15*	16.9 ± 7.2	0 ± 0	0 ± 0	0 ± 0
Cero	*Scomberomorus regalis*	35	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Atlantic spadefish	*Chaetodipterus faber*	30*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Bermuda chub	*Kyphosus sectatrix*	25*	0 ± 0	11.1 ± 11.1	0 ± 0	0 ± 0
Saucereye porgy	*Calamus calamus*	20*	0 ± 0	0 ± 0	0 ± 0	0 ± 0

Table A2. Mean juvenile population densities of commercially and recreationally important finfish species within a 26 km^2 section of the EEMP. Juvenile sizes were estimated to be smaller than the lowest 50% maturity sizes compiled in www.fishbase.com and rounded to the nearest 5 cm. If no data on maturity sizes were available, juvenile sizes were estimated based on Humann (1997) and marked with an asterisk. Density values are given with the standard error. Source: NOAA unpublished raw data.

			Density of Juveniles [fish ha^{-1}]			
		Size	Hardbottom		Softbottom	
Common Name	Scientific Name	[cm]	Bank	Lagoon	Bank	Lagoon
Yellowfin grouper	*Mycteroperca venenosa*	<50	3.4 ± 3.4	0 ± 0	0 ± 0	0 ± 0
Yellowmouth grouper	*Mycteroperca interstitialis*	<40*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Black grouper	*Mycteroperca bonaci*	<70	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Tiger grouper	*Mycteroperca tigris*	<45	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Goliath grouper	*Epinephelus itajara*	<110	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Nassau grouper	*Epinephelus striatus*	<40	0 ± 0	1.6 ± 1.6	0 ± 0	0 ± 0
Rock hind	*Epinephelus adscensionis*	<25	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Red hind	*Epinephelus guttatus*	<25	34.8 ± 10.6	6.3 ± 3.1	7.1 ± 4.3	1.7 ± 1.7
Graysby	*Cephalopholis cruentatus*	<15	5.6 ± 2.5	0 ± 0	0 ± 0	0 ± 0
Coney	*Cephalopholis fulvus*	<15	53.9 ± 15.3	0 ± 0	0 ± 0	0 ± 0
Yellowtail snapper	*Ocyurus chrysurus*	<25	24.7 ± 7.2	66.7 ± 20.1	17.9 ± 8.1	186.2 ± 66.3
Cubera snapper	*Lutjanus cyanopterus*	<45*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Dog snapper	*Lutjanus jocu*	<50	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Mutton snapper	*Lutjanus analis*	<50	6.7 ± 2.7	9.5 ± 3.7	10.7 ± 7.5	12.1 ± 7.4
Gray snapper	*Lutjanus griseus*	<25	0 ± 0	7.9 ± 6.5	0 ± 0	0 ± 0
Schoolmaster	*Lutjanus apodus*	<25	0 ± 0	3.2 ± 2.2	0 ± 0	0 ± 0
Lane snapper	*Lutjanus synagris*	<20	0 ± 0	7.9 ± 4.7	0 ± 0	1.7 ± 1.7
Mahogany snapper	*Lutjanus mahogoni*	<15*	0 ± 0	33.3 ± 33.3	0 ± 0	19 ± 19
Bar jack	*Caranx ruber*	<25	37.1 ± 16.7	3.2 ± 2.2	101.8 ± 77.3	15.5 ± 9.1
Blue runner	*Caranx crysos*	<25	9.0 ± 7.1	12.7 ± 10.0	17.9 ± 9.2	144.8 ± 34.8
Yellow jack	*Caranx bartholomaei*	<45	0 ± 0	15.9 ± 15.9	0 ± 0	3.4 ± 2.4
Horse-eye jack	*Caranx latus*	<35	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Permit	*Trachinotus falcatus*	<45	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Palometa	*Trachinotus goodei*	<20*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Margate	*Haemulon album*	<25	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Bluestriped grunt	*Haemulon sciurus*	<20	0 ± 0	52.4 ± 30.7	0 ± 0	82.8 ± 54.8
White grunt	*Haemulon plumierii*	<15	0 ± 0	15.9 ± 8.8	0 ± 0	12.1 ± 12.1
Cottonwick	*Haemulon melanurum*	<20	0 ± 0	0 ± 0	0 ± 0	0 ± 0
French grunt	*Haemulon flavolineatum*	<15	25.8 ± 7.6	634.9 ± 273.3	0 ± 0	184.5 ± 164.0
Tomtate	*Haemulon aurolineatum*	<15	2.2 ± 1.6	11.1 ± 8.5	23.2 ± 13.5	0 ± 0
Spanish grunt	*Haemulon macrostomum*	<25*	0 ± 0	3.2 ± 3.2	0 ± 0	0 ± 0
Caesar grunt	*Haemulon carbonarium*	<15*	0 ± 0	14.3 ± 12.8	0 ± 0	0 ± 0
Smallmouth grunt	*Haemulon chrysargyreum*	<15*	0 ± 0	38.1 ± 32.0	0 ± 0	101.7 ± 101.7
Sailors choice	*Haemulon parra*	<20*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Porkfish	*Anisotremus virginicus*	<15*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Black margate	*Anisotremus surinamensis*	<30*	0 ± 0	1.6 ± 1.6	0 ± 0	0 ± 0

Table A2. Continued.

			Density of Juveniles [fish ha^{-1}]			
		Size	Hardbottom		Softbottom	
Common Name	Scientific Name	[cm]	Bank	Lagoon	Bank	Lagoon
Blue parrotfish	*Scarus coeruleus*	<25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Midnight parrotfish	*Scarus coelestinus*	<25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Rainbow parrotfish	*Scarus guacamaia*	<25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Queen parrotfish	*Scarus vetula*	<15*	3.4 ± 2.5	3.2 ± 2.2	0 ± 0	0 ± 0
Princess parrotfish	*Scarus taeniopterus*	<15*	74.2 ± 21.6	352.4 ± 112.9	23.2 ± 17.5	58.6 ± 28.0
Striped parrotfish	*Scarus iseri*	<15*	177.5 ± 36.2	1088.9 ± 145.1	3.6 ± 3.6	589.7 ± 151.1
Stoplight parrotfish	*Sparisoma viride*	<15	87.6 ± 22.0	334.9 ± 43.7	1.8 ± 1.8	127.6 ± 37.4
Redband parrotfish	*Sparisoma aurofrenatum*	<15*	528.1 ± 72.0	306.3 ± 37.2	64.3 ± 43.9	98.3 ± 32.9
Yellowtail parrotfish	*Sparisoma rubripinne*	<20*	2.2 ± 2.2	58.7 ± 30.7	0 ± 0	15.5 ± 7.7
Redtail parrotfish	*Sparisoma chrysopterum*	<20*	1.1 ± 1.1	7.9 ± 4.1	0 ± 0	13.8 ± 9.0
Ocean surgeonfish	*Acanthurus bahianus*	<15	703.4 ± 103.2	338.1 ± 43.9	78.6 ± 30.0	272.4 ± 54.0
Blue tang	*Acanthurus coeruleus*	<15*	221.3 ± 37.9	233.3 ± 31.6	1.8 ± 1.8	81.0 ± 20.2
Doctorfish	*Acanthurus chirurgus*	<15*	16.9 ± 8.0	42.9 ± 16.1	21.4 ± 11.0	13.8 ± 6.7
Hogfish	*Lachnolaimus maximus*	<25*	1.1 ± 1.1	1.6 ± 1.6	0 ± 0	0 ± 0
Spanish hogfish	*Bodianus rufus*	<20*	3.4 ± 1.9	7.9 ± 5.2	0 ± 0	8.6 ± 5.1
Puddingwife	*Halichoeres radiatus*	<15*	53.9 ± 12.6	95.2 ± 13.8	0 ± 0	34.5 ± 16.4
Gray angelfish	*Pomacanthus arcuatus*	<25	1.1 ± 1.1	1.6 ± 1.6	1.8 ± 1.8	0 ± 0
French angelfish	*Pomacanthus paru*	<25*	0 ± 0	1.6 ± 1.6	0 ± 0	0 ± 0
Queen angelfish	*Holacanthus ciliaris*	<20	1.1 ± 1.1	3.2 ± 2.2	0 ± 0	3.4 ± 3.4
Rock beauty	*Holacanthus tricolor*	<15	9.0 ± 3.8	1.6 ± 1.6	0 ± 0	0 ± 0
Spotfin butterflyfish	*Chaetodon ocellatus*	<10	0 ± 0	1.6 ± 1.6	0 ± 0	0 ± 0
Foureye butterflyfish	*Chaetodon capistratus*	<10	20.2 ± 6.6	49.2 ± 10.1	19.6 ± 16.2	36.2 ± 10.9
Banded butterflyfish	*Chaetodon striatus*	<10	16.9 ± 5.6	3.2 ± 2.2	1.8 ± 1.8	1.7 ± 1.7
Reef butterflyfish	*Chaetodon sedentarius*	<10*	2.2 ± 2.2	0 ± 0	0 ± 0	0 ± 0
Ocean triggerfish	*Canthidermis sufflamen*	<25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Queen triggerfish	*Balistes vetula*	<25	10.1 ± 4.8	0 ± 0	3.6 ± 2.5	0 ± 0
Gray triggerfish	*Balistes capriscus*	<15	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Black durgon	*Melichthys niger*	<15*	3.4 ± 3.4	0 ± 0	0 ± 0	0 ± 0
Cero	*Scomberomorus regalis*	<35	2.2 ± 1.6	0 ± 0	0 ± 0	0 ± 0
Atlantic spadefish	*Chaetodipterus faber*	<30*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Bermuda chub	*Kyphosus sectatrix*	<25*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Saucereye porgy	*Calamus calamus*	<20*	0 ± 0	0 ± 0	0 ± 0	0 ± 0