Fish assemblages and benthic habitats of Buck Island Reef National Monument (St. Croix, U.S. Virgin Islands) and the surrounding seascape: A characterization of spatial and temporal patterns

A cooperative investigation between NOAA and the National Park Service

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Fish assemblages and benthic habitats of Buck Island Reef National Monument (St. Croix, U.S. Virgin Islands) and the surrounding seascape: A characterization of spatial and temporal patterns

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About this Document

The report provides a spatial and temporal characterization of the fish and benthic communities of Buck Island Reef National Monument and the surrounding seascapes of northeastern St. Croix, United States Virgin Islands. The project is a component of NOAA's Caribbean Coral Reef Ecosystem Monitoring (CREM) project of NOAA's Coral Reef Conservation Program (CRCP) and the National Park Service (NPS). The project integrates field data on coral condition, living marine resources and benthic habitats through an ongoing multi-agency collaboration between NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch (CCMA-BB), NPS, U.S. Geological Survey and the Virgin Islands Department of Planning and Natural Resources (VI-DPNR).

This Technical Memorandum is part one of a series of reports that focus on providing a quantitative spatial and temporal characterization of living marine resources and benthic communities associated with marine protected areas in the U.S. Caribbean. This project complements the National Coral Reef Ecosystem Monitoring Program's (NCREMP) Coral Reef Ecosystem Monitoring grants awarded to the VI-DPNR by CRCP. The integration of the NOAA/NPS lead efforts with data generated by VI-DPNR provides robust spatial and temporal data to characterize St. Croix coral reef ecosystems. This project was funded by NOAA's CRCP and National Centers for Coastal Ocean Science's CCMA and CSCOR, NPS's Natural Resource Preservation Program (NRPP) at Buck Island Reef National Monument and NPS's South Florida/ Caribbean Inventory and Monitoring Program.

Related projects include:

Caribbean Coral Reef Ecosystem Monitoring
http://ccmaserver.nos.noaa.gov/ecosystems/coralreef/reef_fish.html

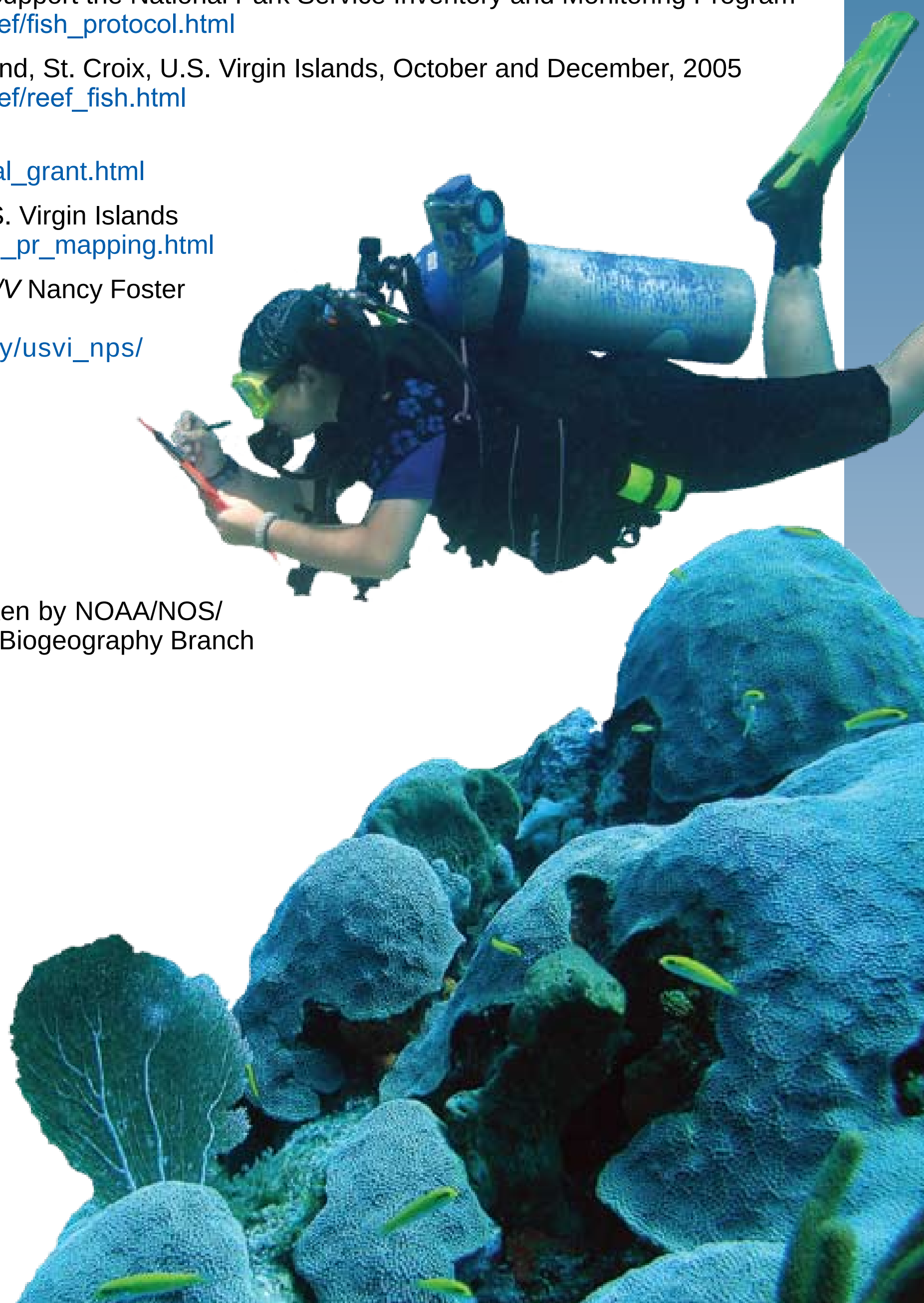
Development of Reef Fish Monitoring Protocols to Support the National Park Service Inventory and Monitoring Program
http://ccmaserver.nos.noaa.gov/ecosystems/coralreef/fish_protocol.html

Coral bleaching and recovery observed at Buck Island, St. Croix, U.S. Virgin Islands, October and December, 2005
http://ccmaserver.nos.noaa.gov/ecosystems/coralreef/reef_fish.html

National Coral Reef Ecosystem Montoring Program
http://ccma.nos.noaa.gov/ecosystems/coralreef/coral_grant.html

Benthic Habitat Mapping of Puerto Rico and the U.S. Virgin Islands
http://ccma.nos.noaa.gov/ecosystems/coralreef/usvi_pr_mapping.html

Seafloor Characterization of the U.S. Caribbean - *R/V* Nancy Foster Missions
http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/overview.html



All photographs provided in this document were taken by NOAA/NOS/NCCOS/Center for Coastal Monitoring Assessment Biogeography Branch in St. Croix, USVI unless otherwise indicated.

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Executive Summary

Since 1999, NOAA's Biogeography Branch of the Center for Coastal Monitoring and Assessment (CCMA-BB) has been working with federal and territorial partners to characterize, monitor, and assess the status of the marine environment around northeastern St. Croix, U.S. Virgin Islands. This effort is part of the broader NOAA Coral Reef Conservation Program's (CRCP) National Coral Reef Ecosystem Monitoring Program (NCREMP). With support from CRCP's NCREMP, CCMA conducts the "Caribbean Coral Reef Ecosystem Monitoring project" (CREM) with goals to: (1) spatially characterize and monitor the distribution, abundance, and size of marine fauna associated with shallow water coral reef seascapes (mosaics of coral reefs, seagrasses, sand and mangroves); (2) relate this information to in situ fine-scale habitat data and the spatial distribution and diversity of habitat types using benthic habitat maps; (3) use this information to establish the knowledge base necessary for enacting management decisions in a spatial setting; (4) establish the efficacy of those management decisions; and (5) develop data collection and data management protocols. The monitoring effort in northeastern St. Croix was conducted through partnerships with the National Park Service (NPS) and the Virgin Islands Department of Planning and Natural Resources (VI-DPNR). The geographical focal point of the research is Buck Island Reef National Monument (BIRNM), a protected area originally established in 1961 and greatly expanded in 2001; however, the work also encompassed a large portion of the recently created St. Croix East End Marine Park (EEMP). Project funding is primarily provided by NOAA CRCP, CCMA and NPS.

In recent decades, scientific and non-scientific observations have indicated that the structure and function of the coral reef ecosystem around northeastern St. Croix have been adversely impacted by a wide range of environmental stressors. The major stressors have included the mass *Diadema* die off in the early 1980s, a series of hurricanes beginning with Hurricane Hugo in 1989, overfishing, mass mortality of *Acropora* corals due to disease and several coral bleaching events, with the most severe mass bleaching episode in 2005. The area is also an important recreational resource supporting boating, snorkeling, diving and other water based activities. With so many potential threats to the marine ecosystem and a dramatic change in management strategy in 2003 when the park's Interim Regulations (Presidential Proclamation No. 7392) established BIRNM as one of the first fully protected marine areas in NPS system, it became critical to identify existing marine fauna and their spatial distributions and temporal dynamics. This provides ecologically meaningful data to assess ecosystem condition, support decision making in spatial planning (including the evaluation of efficacy of current management strategies) and determine future information needs. The ultimate goal of the work is to better understand the coral reef ecosystems and to provide information toward protecting and enhancing coral reef ecosystems for the benefit of the system itself and to sustain the many goods and services that it offers society. This Technical Memorandum contains analysis of the first six years of fish survey data (2001-2006) and associated characterization of the benthos (1999-2006). The primary objectives were to quantify changes in fish species and assemblage diversity, abundance, biomass and size structure and to provide spatially explicit information on the distribution of key species or groups of species and to compare community structure inside (protected) versus outside (fished) areas of BIRNM.

Methods:

For each biannual survey mission, selection of sample sites occurred via a stratified random design (2001-2006) using hard and soft bottom habitat types delineated in NOAA's benthic habitat map (Menza et al., 2006). In 2003, after implementation of the park's Interim Regulations, sampling was also stratified by whether or not the site was located inside or outside BIRNM to evaluate effect of the fishing closure (only 2003 to 2006). Fish were surveyed during daylight hours along 25 m long by 4 m wide belt-transects for a fixed duration of 15 minutes. All species observed were identified to the lowest possible taxonomic level and their abundance was counted and grouped by size class. To quantify benthic habitat, five 1 m^2 quadrats were randomly placed on the transect and used to examine the relatively fine-scale biotic and abiotic components of the seascape (e.g., coral cover, macroalgal cover, etc.). In addition, Geographical Information System (GIS) tools were used to quantify the seascape surrounding each transect using habitat distributions represented in NOAA's benthic habitat maps (e.g., amount of seagrass, number of habitat types, etc.).

Comparative analyses of biotic components inside versus outside BIRNM were conducted using a wide range of fish variables representing community, trophic, family and individual species level data incorporating measures of abundance, biomass and diversity. A total of 884 transects collected between 2003 and 2006 inclusively were used to examine differences in fish metrics inside versus outside BIRNM. Benthic comparisons used 716 benthic surveys on hardbottom habitat types conducted between 2001 and 2006. Abundance maps were used to examine species distributions for both juveniles and adults and interpolations of point data were used to examine broad-scale spatial patterns of fish and benthic habitat variables.

Major findings:

Diversity hotspots

- Despite heavy impacts from disease, bleaching and hurricanes, the area around the eastern tip of Buck Island remains ecologically distinctive having some of the highest live coral cover and rugosity in the mapped region, also with high calcareous coralline algal cover, high fish species richness, biomass of herbivorous fish and high abundance for many common fish species.

- The linear reef (i.e., barrier reefs) and adjacent colonized pavement that extends east-west from Teague Bay to Coakley Bay and now falls within the EEMP "no-take zone" and "recreation zone" was found to support high coral species richness and fish species richness.
- Extensive areas with high coral species richness, high live coral cover for *Montastraea cavernosa* and *M. annularis*, high fish species richness and high abundance for several fish species including coney (*Cephalopholis fulva*), rock beauty (*Holacanthus tricolor*) and queen triggerfish (*Balistes vetula*) occurred along the northernmost edge of the benthic habitat map. This indicates that important deeper water habitat is likely to exist beyond the scope of this report, requiring further benthic habitat mapping effort combined with visual census (diver/remotely operated vehicle [ROV]) to capture data on fish communities (see Foster Mission web site: http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/overview.htm).
- Many of the coral reefs with highest fish species richness were within 200 m of seagrass beds. Several other studies have demonstrated links between fish distribution on coral reefs and proximity to seagrass beds suggesting that many species may benefit from complementary resources provided by seagrasses in close proximity to coral reefs. This highlights the importance of considering mosaics of habitat types in resource management decision making.

Benthic habitat

- The benthic environment inside BIRNM was significantly different to the outside for 75% of fine-scale variables quantified within 1 m^2 quadrates and 78% of seascape variables quantified within 100 m^2 radius seascape units surrounding each transect.
- Seventy-eight percent of the mapped area inside BIRNM was hardbottom habitat dominated by colonized pavement and 22% was softbottom (sand and seagrasses); outside BIRNM, 46% was hardbottom and 54% softbottom. Seascapes inside BIRNM also had significantly higher mean habitat richness.
- Coral cover for all major scleractinian (hard coral) families was significantly higher inside BIRNM and coral reefs had a significantly higher ratio of live coral cover to macroalgal cover than outside BIRNM.
- Overall, hardbottom habitats of the study area were dominated by turf algae (37%) and macroalgae (11.4%), with mean scleractinian coral cover of only 5.6% ranging from 12.1% on patch reefs to 2% on the less rugose reef rubble.
- Across years (2003-2006), macroalgal cover showed some indication of decline both inside and outside BIRNM.
- Filamentous cyanobacteria/macroalgal blooms were detected in the fall sampling period with mean cover as high as 18% in October 2005; a year with anomalously high summer water temperatures that also resulted in a mass coral bleaching event.
- Peaks in mean algal turf cover (50-60%) were detected in the spring (2006) season following the mass coral bleaching event and mean live coral cover approximately one year after the event was the lowest since this study commenced.

Fish

- A total of 201 fish species/species groups were identified from 56 families. Nine of the 10 most frequently encountered species belonged to the families Labridae (wrasse), Acanthuridae (surgeonfish) and Scaridae (parrotfish).
- The majority of the most abundant fish across the study region were found in highest densities over hardbottom habitat types, yet most also utilized multiple habitat types including seagrasses and sand.
- Fish metrics significantly higher on hardbottom habitat inside BIRNM included fish biomass (all fish combined), herbivore biomass, parrotfish biomass, shark and ray biomass, coney (*C. fulva*) density and biomass, blue tang (*Acanthurus coeruleus*) density and biomass, and striped parrotfish (*Scarus iseri*) biomass.
- Fish metrics significantly higher outside BIRNM included ecologically important predator groups such as piscivore biomass (including sharks and rays), snapper (Lutjanidae) density, and grunt (Haemulidae) density and biomass.
- Red hind (*Epinephelus guttatus*) and coney (*C. fulva*) exhibited distinct patterns in spatial distributions, with high coney density mostly over the contiguous colonized hardbottom areas (much of which is inside BIRNM) and high densities of red hind found mostly to the south of Buck Island (many outside BIRNM).
- Very few of the largest (>35 cm) and very few of the smallest (<5 cm) size classes were observed for groupers (Serranidae) and snappers. Groupers and snappers in the largest size class (>35 cm) were recorded at <1% and 3%, of survey sites, respectively.
- Body lengths of the largest individuals of several common groupers, snappers and grunts were less than the maximum size recorded for the species. The largest yellowtail snapper (*Ocyurus chrysurus*) was approximately 70% of the maximum known adult size, schoolmaster snapper (*Lutjanus apodus*) 66%, bluestriped grunt (*Haemulon sciurus*) 65-76%, white grunt (*H. plumierii*) 56-66% and red hind (*E. guttatus*) 60% of known maximum size.
- Highest densities of threespot damselfish (*Stegastes planifrons*), a potential indicator of healthy reefs with high live coral cover, were found around the eastern tip of Buck Island within BIRNM and the fringing reef extending east-west along the northeast coast of St. Croix.

Historic and recent changes in fish populations

- Synoptic overview of inter-annual differences inside and outside BIRNM showed no consistent decline for any of the 39 fish metrics inside BIRNM, but instead showed increases every year between 2003 and 2006 for mean fish density (all species combined). Densities in 2005 and 2006 were significantly higher than 2003. It is not yet clear if this has resulted from initiation of NPS Interim Regulations and enforcement patrols.
- No such increases were recorded outside BIRNM, instead considerable and consecutive inter-annual decline was apparent for grunt biomass, especially bluestriped grunt (*H. sciurus*), and density and biomass of stripped parrotfish (*S. iseri*). Densities in 2005 and 2006 were significantly lower than 2003.
- Only three Nassau grouper (*Epinephelus striatus*), three yellowfin grouper (*Mycteroperca venenosa*) and one tiger grouper (*M. tigris*) were observed in the study region over the course of six years of monitoring using 1,275 samples. Notably, these three species were completely absent from the Buck Island nearshore areas in 2001-2006, but were present in low abundance in 1979. These grouper species are highly vulnerable to fishing due to their large body size and relatively slow maturity and this historical difference in abundance indicates that the grouper have been overfished.
- In contrast, coney (*C. fulva*) and red hind (*E. guttatus*) were more abundant around Buck Island between 2001 and 2006 than in 1979.
- Threespot damselfish (*S. planifrons*), a potential indicator of healthy reefs with high live coral cover, was more abundant around Buck Island in 1979 than in the 2001-2006 sampling period.

Macroinvertebrates

- Long-spined urchin densities (*Diadema antillarum*) around Buck Island have not recovered since the mass mortality in 1983. However, this study and the scientific literature indicate that some minor recovery may be occurring in lagoonal and back reef areas along the sheltered coastline of northeastern St. Croix. Long-spined urchins were once important ecosystem engineers controlling the abundance of algae in the region and little is known about the factors (e.g, limitations to recruitment) that are controlling population recovery.
- Coral reef ecosystems of the study region, particularly the large expanse of seagrasses between Buck Island and St. Croix support regionally important populations of adult and juvenile queen conch (*Strombus gigas*). This is important since queen conch is an important food resource in the Virgin Islands and according to NOAA's Office of Protected Species, queen conch is declining throughout the species' range.

Recommendations:

Additional mapping, inventory and monitoring efforts are required to explore the deeper water ecosystems within the BIRNM that exist outside NOAA's current benthic habitat map. In addition, acoustic tracking studies may reveal the mechanisms underlying some of the observed temporal changes in fish communities and will determine connectivity between lagoons and coral reefs offshore. Tracking will also provide important information on the time that individual fish spend inside and outside the boundaries of protected areas. Very little is known about the timing of movements during the daily home range, ontogenetic shifts and spawning migrations and spatial pathways for such movements for most species. Some targeted surveying for specific substrate types may be required to identify the extent of suitable settlement habitat for juvenile grouper in the study region or whether groupers are instead immigrating into the region from settlement habitat outside. Long-term monitoring is necessary to determine the magnitude of the apparent declines and to track the trajectory of recovery for species that exhibited an increase in density after several years of decline. Long-term monitoring effort may also reveal direction in the change for the many species that were too highly variable from year to year to provide such information over the four years of data used. Within the BIRNM-EEMP Marine Protected Area (MPA) complex, resource managers and stakeholders should examine the option of closing the gap between the southern boundary of BIRNM and the no-take zone of EEMP along the northeastern coast of St. Croix. An adjoining of the boundaries would incorporate an extensive area of seagrass habitat thus ensuring full protection of important complementary resources that provide food and habitat for many fish (both resident and transient species). These seagrass beds are also regionally important habitat for queen conch and may provide important resources for Caribbean spiny lobster. Further targeted surveys are required to assess and monitor the status of queen conch populations and to determine whether long-spined urchins are recovering. Such information will help to determine if management intervention is needed to assist recovery of sea urchin populations and to evaluate the conch fishery. Additional work to map the distribution of juvenile and adult Caribbean spiny lobster populations using existing survey data and to determine the factors that explain spatial distributions would be very valuable in supporting ecosystem-based management of marine resources in the region. Benthic habitat maps should be periodically updated due to the dynamic nature of coral reef ecosystems. This is particularly important when linking fish seascape structure and when assessing seascape change such as quantifying gain or loss of major habitat types.

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1. Introduction and Study Area

1.1 Background

Buck Island Reef National Monument (BIRNM) is located on the northeastern shelf of St. Croix, in the U.S. Virgin Islands (USVI; Figure 1) and encompasses an uninhabited island of approximately 712,000 m² and the surrounding mosaic of coral reefs, seagrasses and sand patches. The Monument is under the jurisdiction of the U.S. National Park Service (NPS) and was originally designated by the U.S. Department of Interior in 1961 according to Presidential Proclamation 3443, in order to preserve the island and the surrounding submerged lands which at that time included "one of the finest marine gardens in the Caribbean Sea". The original monument encompassed 880 acres (approximately 3.56 km^2) and marine areas were zoned to form a protected "Marine Garden" (259 acres or approximately 1.04 km^2), which included extensive stands of the now federally protected elkhorn coral (*Acropora palmata*) and an area with restricted fishing (445 acres or approximately 1.8 km^2; Figure 2a). The "Marine Garden" was one of the first "no-take" marine reserves in U.S. waters and in the Caribbean region. The boundaries were slightly modified in 1975 (Presidential Proclamation 4346), but it was not until 2001 that the monument was greatly expanded to 19,015 acres (approximately 77 km^2) under Presidential Proclamation 7392 (Figure 2b). At that time, new regulations were enacted making the entire monument a no-take and "restricted anchoring" zone. The BIRNM expansion was the first substantial no-take area established for the island of St. Croix and it now protects about 7.4 percent of the St. Croix shelf area. The expansion resulted in a 10-fold increase in protection of shallow water (<30 m) hardbottom and sand habitat types and a seven-fold increase for seagrasses when compared with the 1961 Monument (Kendall et al., 2004a). In January 2003, BIRNM became contiguous with the East End Marine Park (EEMP) through the adjoining of the southern boundary of BIRNM and northern boundary of EEMP. However, over 80% of EEMP is open to fishing including an area that extends between the southern boundary of BIRNM and the EEMP no-take coastal lagoon zone (see zoning map in Appendix A). In April 2003, NPS implemented the Interim Regulations (36 CFR Part 7.73; Federal Register Volume 68, No. 65) and begun work on the General Management Plans for BIRNM.

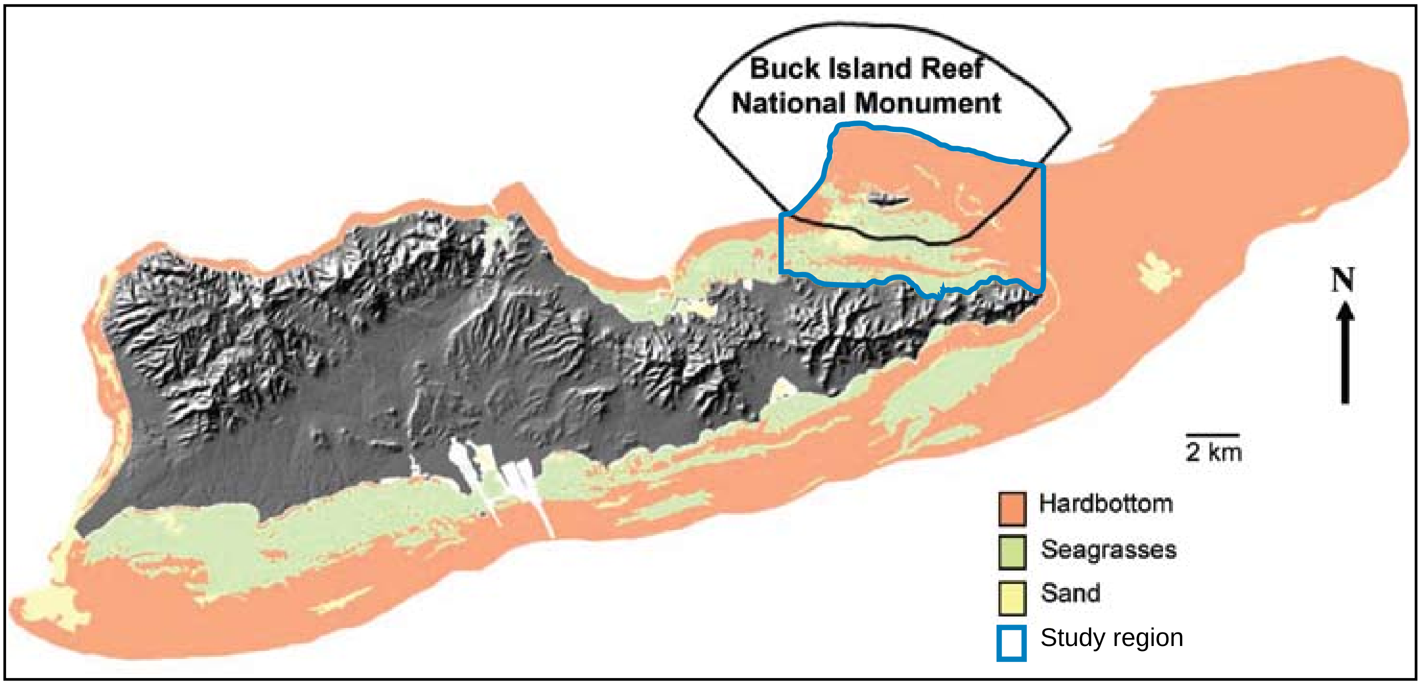


Figure 1. The island of St. Croix, USVI showing the distribution of surrounding nearshore habitat types using NOAA's benthic habitat map (Kendall et al., 2002) and the administrative boundary of BIRNM.

In recent decades, the ecological structure and function of coral reef ecosystems of the northeastern St. Croix study region have deteriorated dramatically due to a combination of stressors including fishing, anchor drops, excessive nutrient inputs, *Diadema* die-off, mass coral bleaching related to anomalous sea water temperatures, the emergence of widespread coral diseases and extensive hurricane damage (Bythell et al., 1993; Rogers and Beets, 2001). The enlarged monument now incorporates components of the marine ecosystem, which have been impacted by fishing of finfish, conch and lobster. Currently the expanded area is being illegally fished using hand and rod fishing, spear fishing, fish traps, gill or trammel nets, and long-lines in the deeper portions of the Monument. Law enforcement patrols have been active since 2003 and compliance is increasing. These deleterious environmental changes together with significant changes in management strategies, such as boundary expansion, require that the ecological patterns and processes characterizing the region be adequately inventoried, spatially characterized and continuously monitored to support the resource-management decision-making process. Knowledge of the current status of fish communities coupled with a spatially explicit understanding of the key resources and followed by a program of long term monitoring of fish and benthic communities will enable evaluation of management efficacy that is required to guide future management actions. In addition, comparison between managed versus unmanaged areas (e.g., inside and outside the protected area) allows managers to assess the impact, if any, of a

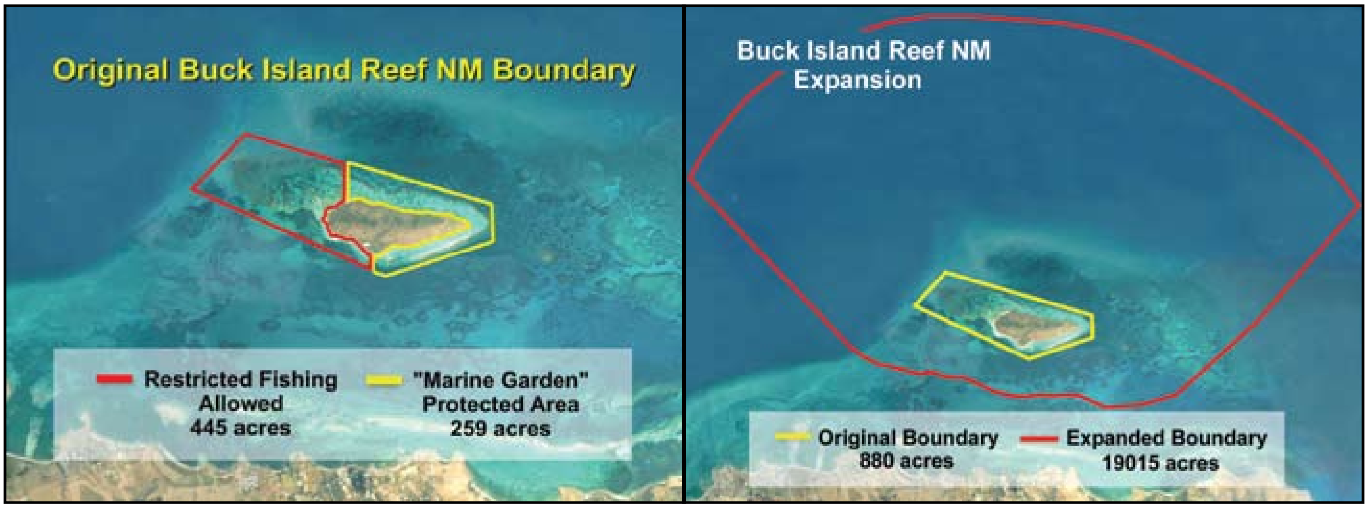


Figure 2. (a) The boundaries of the original Buck Island Reef National Monument established in 1961 and (b) the expanded boundary established in 2001. Source: National Park Service, St. Croix.

change in regulation and evaluate the resources that are included or excluded from protection. This report represents an evaluation and characterization of fish and their habitat both inside and outside BIRNM and summarizes the first six years of long-term monitoring data collected using consistent survey methods and a stratified-random sampling design.

Providing park managers with scientifically validated evidence of reserve effectiveness or ineffectiveness is not only essential to informing resource management, it is critical to building public support for management plans. In response, NPS in partnership with NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch (CCMA-BB) initiated their Caribbean Coral Reef Ecosystem Monitoring (CREM) project at BIRNM in February 2001. In 2003, the U.S. Virgin Islands Department of Planning and Natural Resources joined this collaborative effort to monitor the broader region including the East End Marine Park (EEMP). This effort supports objectives of the NPS Inventory and Monitoring Program with an objective to "improve park management through greater reliance on scientific knowledge", BIRNM is one of seven National Parks forming the NPS's South Florida/Caribbean Network (NPS-SFCN) with special requirements for producing natural resource inventories and conducting ecosystem monitoring. This project provides data and data interpretation to meet NPS BIRNM Government Performance Results Act Goals pertinent to Threatened and Endangered Species Ia2A, Natural Resource Data Sets IB01 and Visitor Understanding IIb1 by providing new information on the condition of the monuments marine resources.

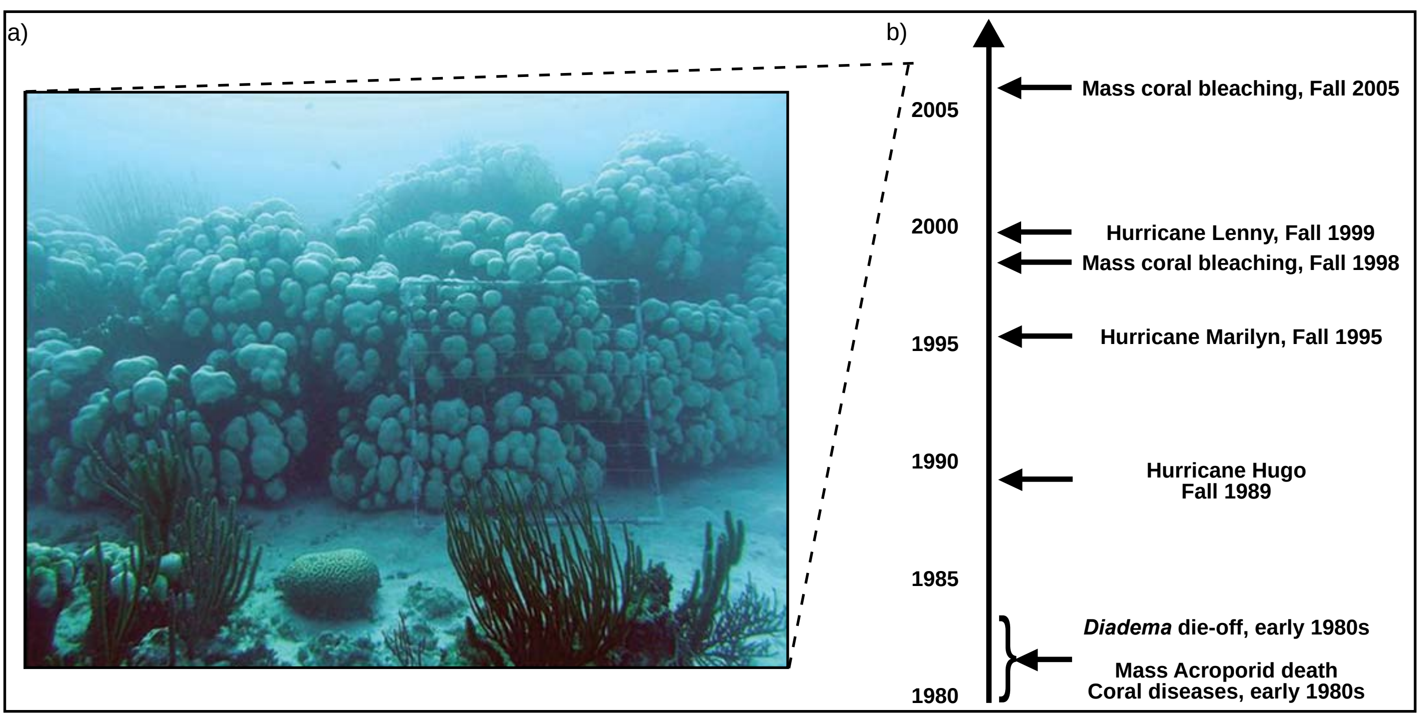
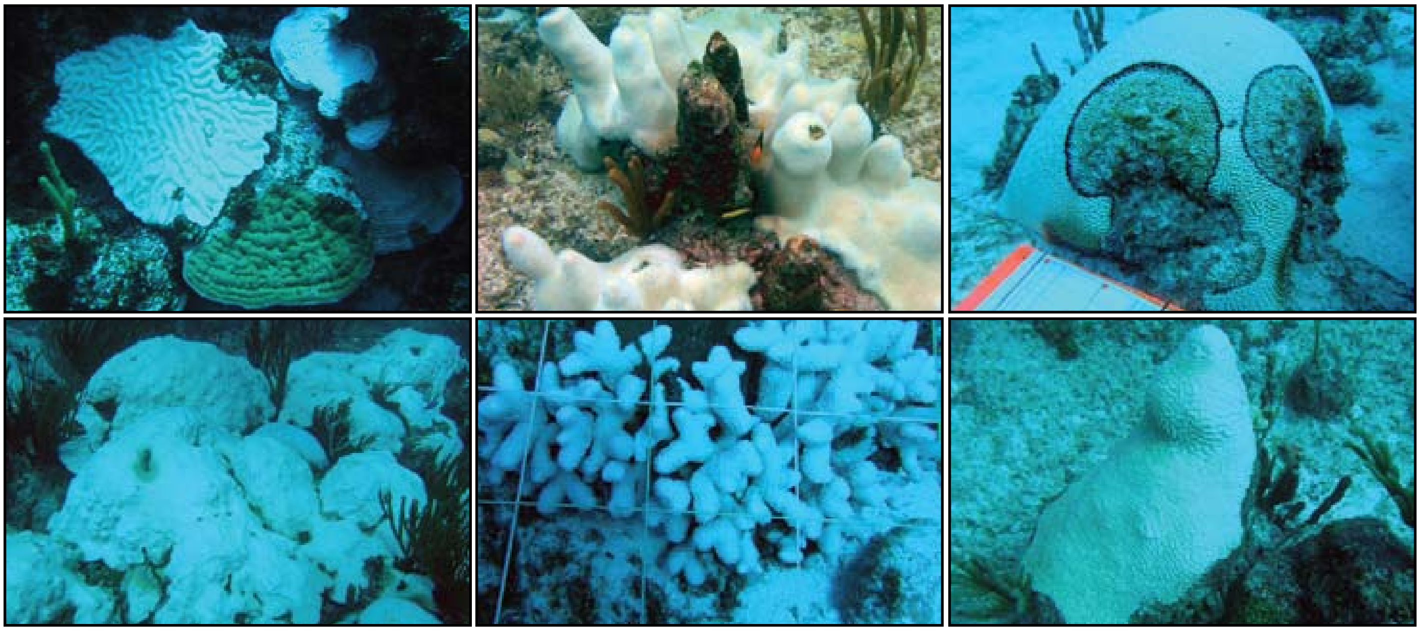


Figure 3. (a) Bleached coral at BIRNM (October 2005). A 1 m^2 quadrat is shown for a scaling reference. (b) Chronology of major broad-scale stressors to coral reef ecosystem structure and function in the Buck Island region, St. Croix since 1980.

1.2 Environmental monitoring and ecosystem changes around Buck Island

Many marine ecological studies have been carried out in the region with long-term monitoring studies first conducted by scientists at the West Indies Laboratory (WIL) in the 1970s and a series of permanently marked sites for long-term monitoring of coral reef community structure and function initiated by the NPS in the 1980s. Results of early monitoring efforts have revealed some major changes, primarily in live coral cover and structure that have occurred across the region. Gladfelter et al. (1977) reported greater than 50% *Acropora palmata* on the reef crest of the north and south bank-barrier reefs and the northern forereef around Buck Island, but by 1984 large areas of dead *A. palmata* colonies encrusted with algae and gorgonians and other dead *Acropora* species (including *A. cervicornis*) were reported and were thought to have resulted from a mass mortality event caused by coral diseases such as white-band disease (Anderson et al., 1986). At the same time, the widespread die-off of *Diadema antillarum* sea urchins in the early 1980s, a key algal grazer and ecosystem engineer, altered the ecosystem dynamics on many shallow-water coral reefs in the region (Lessons et al., 1984). In 1989, Hurricane Hugo passed directly over the region with reported wind speeds of 260 kph. Bythell et al. (1993) and Rogers et al. (1982) resurveyed permanent transects and reported extensive localized damage with the southeast reef front razed to substrate level between the surface and 7 m depth and the reef crest behind it smothered in a 1 m deep layer of broken coral rubble. Although some coral had recovered by 1991, the community composition remained altered. In the 1990s the region was again impacted by hurricanes with Hurricane Marilyn in 1995 and Hurricane Lenny in 1999.

Extensive bleaching was observed at BIRNM in the fall of 1998 when water temperature reached a maximum of 29.9^{o}C (Rogers and Beets, 2001). More recently, in 2005, CCMA-BB, NPS-SFCN and U.S. Geological Survey (USGS) scientists observed widespread coral bleaching around BIRNM, which was part of a mass bleaching event that occurred throughout the tropical western Atlantic (Clark et al., in press). During October 2005, over 90% of the coral was bleached at almost all NPS/USGS permanent monitoring sites (J. Miller, pers. comm.). Furthermore, bleaching was observed in 91 of 94 randomly selected survey sites, with an estimated 53% of the coral cover bleached (Clark et al., in press; Figure 3). In addition, changes in the amount and spatial arrangement of seagrasses and sand habitat types has occurred in the BIRNM region, and have been reported in neighboring islands, yet are largely unquantified (but see Rogers and Beets, 2001; Kendall et al., 2005). The chronology of major events resulting in deterioration of coral reef ecosystem structure and function in the St. Croix study region is depicted in Figure 4.



Various species of bleached coral. All photographs were taken during the October 2005 St. Croix mission.

Fish and fish communities respond to changes in their environment including habitat loss and extractive activities, such as fishing, but few historical monitoring surveys have focused on fish communities. Illegal commercial fishing has also been observed within BIRNM (NPS records). The Caribbean Fisheries Management Council (CFMC) reports that USVI fisheries target approximately 180 species of fish (64 species commonly caught), queen conch (*Strombus gigas*) and spiny lobster (*Panulirus argus*; CFMC, 1985; Appendix B).

1.3 Benthic habitat mapping in the region

In 1976, the first benthic habitat map was drawn by scientists at the WIL to depict the spatial distribution of marine habitat types around Buck Island using both quantitative and qualitative ground-truthing of aerial photographs (Gladfelter et al., 1977; Figure 4a). Almost a decade later, Anderson et al. (1986) updated the original benthic habitat map using 1984 ground-truthed aerial photographs (Figure 4b). In 1999, NOAA's National Ocean Service acquired aerial photographs in order to create benthic habitat maps in response to a need to identify Essential Fish Habitat (EFH) in the U.S. Caribbean. CCMA-BB digitized benthic habitat for a 490 km^2 area of nearshore coral reef ecosystems in the USVI using a 1 acre

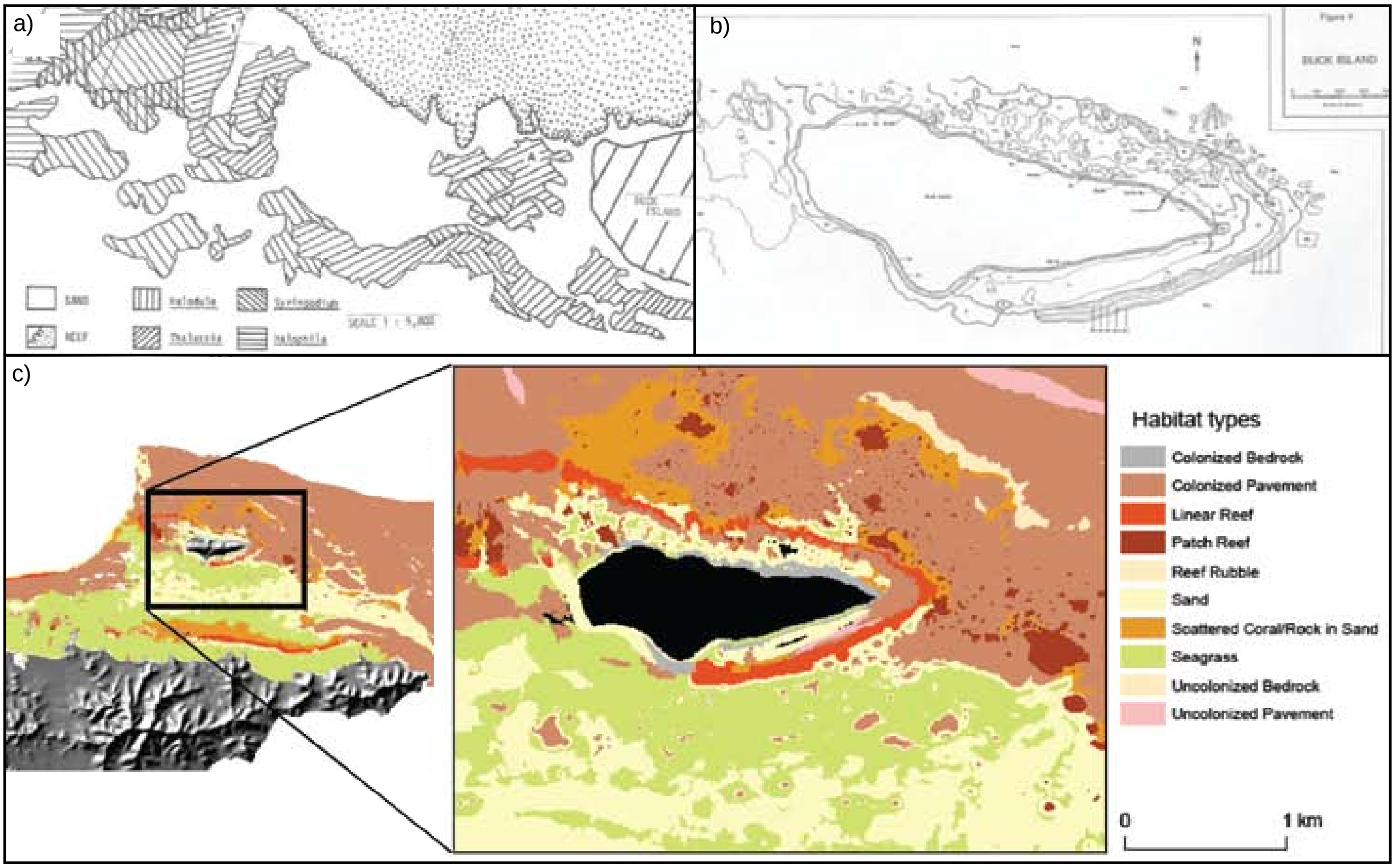


Figure 4. Benthic habitat maps constructed for Buck Island region since the 1960s. (a) Subset of Gladfelter et al. (1977); (b) Anderson et al. (1986); and (c) subset of CCMA-BB's digital map using a 100 m² MMU based on methods described by Kendall et al. (2002).

(approximately 4,047 m²) minimum mapping unit (MMU). Thematic accuracy around the test area of BIRNM was assessed using 120 stratified-random benthic surveys resulting in an overall map accuracy of 93.6%, with 100% users accuracy for submerged vegetation, 97.2% for hardbottom habitat types and 86.1% for sand (Kendall et al., 2002). Data and methods are available online: http://ccma.nos.noaa.gov/products/biogeography/benthic/htm/data.htm

In addition, with an objective to study fish-seascape relationships at a finer spatial scale, an area of approximately 50 km² around Buck Island was also digitized to a spatial resolution of 100 m² (Figure 4c).

In 2004, 2005 and 2006 CCMA-BB and NOAA's Office of Coast Survey, in collaboration with NPS, USVI Territory and private sector partners, used multibeam sonar and underwater video to map bottom features (>20 m depth) and characterize nearshore benthic structure around BIRNM (Figure 5). These data are a component of the Seafloor Characterization of the Caribbean project supported by NOAA's Coral Reef Conservation Program (CRCP) and are available online at http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/overview.html. Data includes 5 m point data files, digital terrain models and mosaics of the acoustic backscatter.

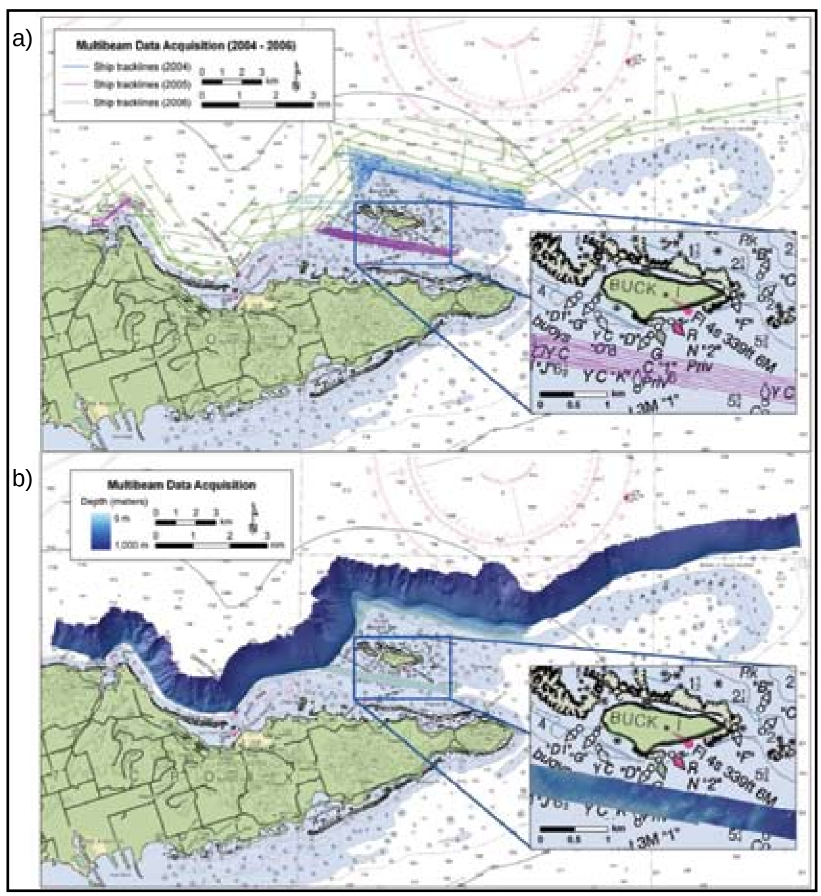


Figure 5. (a) Ship survey tracks and (b) bathymetric data from NOAA's acoustic multibeam seafloor mapping activities within and surrounding BIRNM.

2. Methods

To assist in monitoring coral reef ecosystem resources and to achieve a better understanding of fish-habitat relationships in the U.S. Caribbean, CCMA-BB developed a fish and macro-invertebrate monitoring protocol to provide precise, fishery-independent and size-structured survey data, needed to comprehensively assess faunal populations and communities (Menza et al., 2006). In addition, a complementary benthic composition survey was also developed to support studies of fish-habitat relationships. These data collection activities and analytical products are core components of NOAA's CRCP implemented through CCMA-BB's CREM project. CREM protocols were created primarily to quantify long-term changes in fish species and assemblage diversity, abundance, biomass and size structure and to compare these metrics between areas inside and outside of Marine Protected Areas (MPAs). A stratified random sampling design was used to optimize the allocation of samples and allow rigorous inferences to the entire study area, as well as, the selected management domains (e.g., inside and outside BIRNM). Two strata were selected based upon: 1) the study objectives; 2) parsimony in the approach; and 3) results from statistical analyses of variance (Menza et al., 2006). The "hard" stratum comprised bedrock, pavement, rubble and coral reefs. The "soft" stratum comprised sand, seagrasses and macroalgal beds. In 2003, NPS management domains were incorporated as a second level of spatial stratification and were designated as "inside" and "outside" BIRNM (Figure 6).

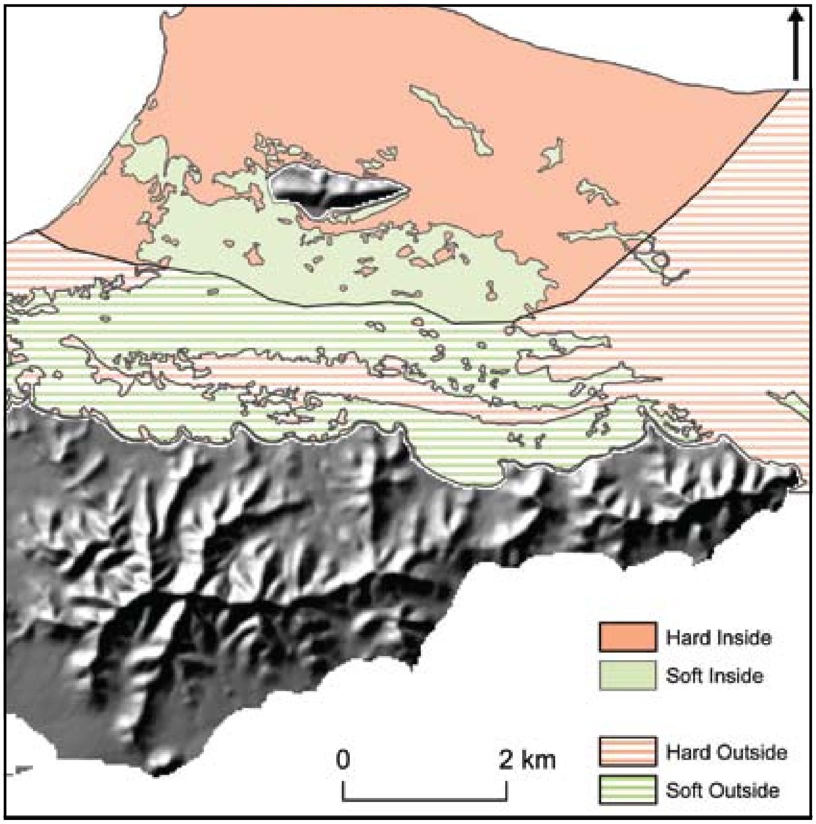


Figure 6. NOAA's benthic habitat map showing hard and softbottom habitat types both inside and outside BIRNM. Spatial information was used to identify strata within which to allocate random samples for CREM fish and benthic habitat composition surveys (figure adapted from Menza et al., 2006).

2.1 Field survey methods

This report uses underwater census data collected in March/April and October/November each year from 2003 to 2006. This data set is part of a broader ongoing monitoring study that began in year 2001, with over 1,300 transects surveyed thus far around BIRNM. There are two complementary components to the biological field methods: (1) benthic habitat composition surveys and (2) fish surveys.

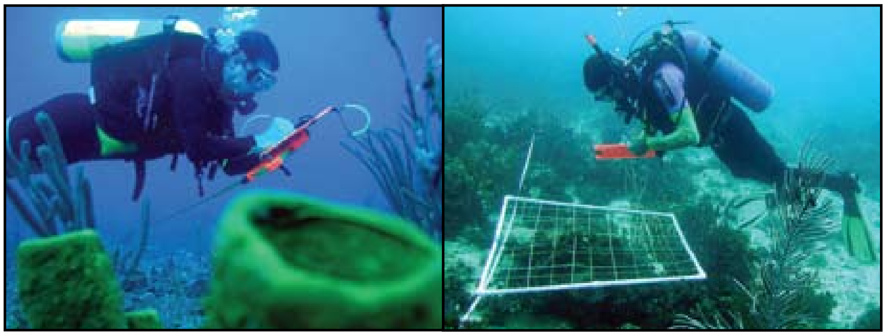


Figure 7. NOAA trained observers recording fish species abundance and body length along a 25 x 4 m timed 15 minute belt transect (left); and benthic habitat composition recorded within five randomly placed 1 m² quadrats along the belt transect (right).

2.1.1 Benthic habitat composition surveys

To conduct benthic habitat surveys, a second observer places a 1 m² quadrat divided into 100 (10 x 10 cm) smaller squares (1 square = 1% cover) at five randomly pre-selected locations along the transect, such that a quadrat is placed once somewhere within every 5 m interval along the transect (Figure 7). Percent cover is estimated within the quadrat in a two-dimensional plane perpendicular to the observer's line of vision.

Information recorded include:

1) *Habitat structure* (e.g., colonized hardbottom, spur and groove, patch reef, pavement) - based on the habitat types used in the benthic habitat maps (Kendall et al., 2002; Figure 8), until 2004, after which habitat structure was classified only to hard, soft and mangrove.

2) *Abiotic footprint* - defined as the percent cover (to the nearest 1%) of sand, rubble, hardbottom, fine sediments and other non-living bottom types within a 1 m² quadrat.

3) *Biotic footprint* - defined as the percent cover to the nearest 1% of algae, seagrass, upright sponges, gorgonians and other biota and to the nearest 0.1% for live, bleached and recently dead/diseased coral within a 1 m² quadrat.

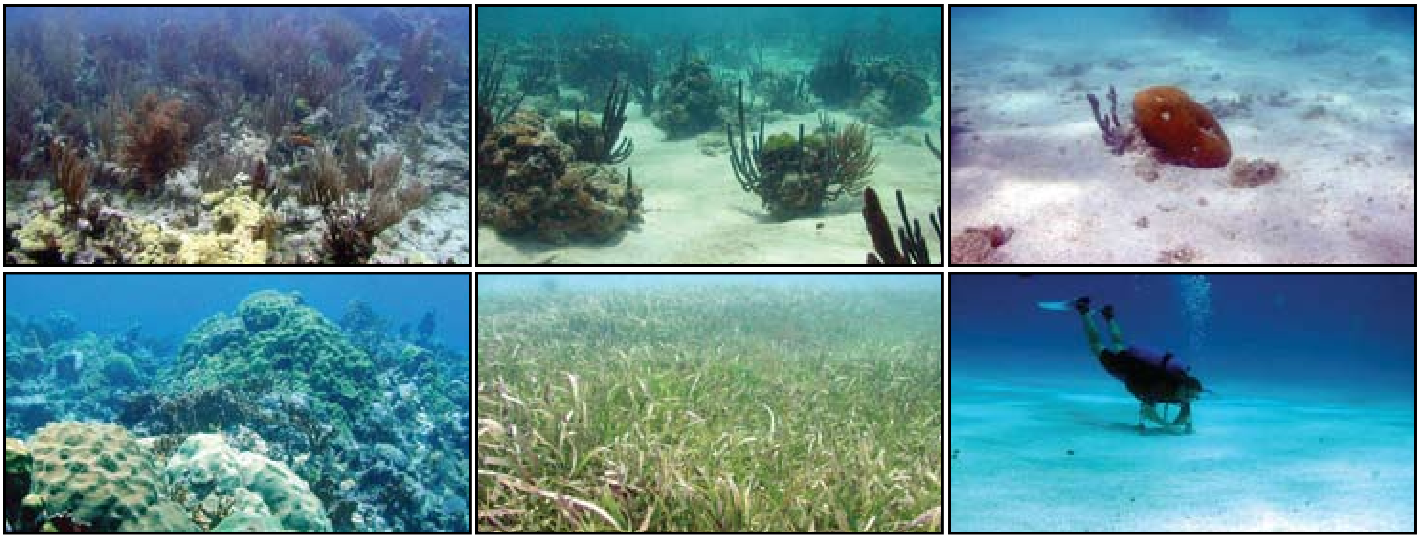


Figure 8. A selection of habitat types designated in the hierarchical classification scheme of NOAA's benthic habitat map (Kendall et al., 2002) for the U.S. Caribbean (clockwise from left to right): colonized pavement, patch reef, scattered coral and/or rock, linear reef, seagrass and sand.

4) *Transect depth profile* - the depth at each quadrat position. Depth is measured with a digital depth gauge and rounded up or down to the nearest foot.

5) *Maximum canopy height* - for each biota type, height of soft structure (e.g., gorgonians, upright sponges, seagrass, algae) structure is recorded to the nearest 1 cm.

6) *Hardbottom rugosity* - measured by placing a 6-m chain at two randomly selected start positions ensuring no overlap along the 25-m belt transect. The chain is placed such that it follows the relief along the centerline of the belt transect. Two divers measure the straight-line horizontal distance covered by the chain.

7) *Proximity of structure* - on seagrass and sand sites, the habitat diver records the absence or presence of reef or hard structure within 4 m of the belt transect.

Table 1 provides a list of measured variables. The habitat observer also counts queen conch (*Strombus gigas*), long-spined sea urchins (*Diadema antillarum*) and Caribbean spiny lobster (*Panulirus argus*) Further information about macroinvertebrate data collection is described in section 2.1.3. Conch were counted separately as mature and immature animals based on lip thickness and shell size.

2.1.2 Fish surveys

Fish surveys were conducted along a 25 m long by 4 m wide belt (100 m^2) using a fixed survey duration of 15 minutes (Figure 7). The fixed duration of 15 minutes standardizes the samples collected to facilitate between site comparisons. The number of individuals per species is recorded in 5 cm size class increments up to 35 cm using the visual estimation of fork length. Individuals greater than 35 cm are recorded as an estimate of the actual fork length to the nearest centimeter.

Table 1. Abiotic and biological variables measured to characterize benthic assemblages along fish transects in St. Croix.

Benthic Biota	Measurements		
	% Cover	**Height (cm)**	**Abund. (#)**
Abiotic			
Hardbottom	X	X	
Sand	X		
Rubble	X		
Fine sediment	X		
Rugosity			
Water depth			
Biotic			
Corals (by species)	X		
Macroalgae	X	X	
Seagrass (by species)	X	X	
Gorgonians			
Sea rods, whips and plumes	X	X	X
Sea fans	X	X	X
Encrusting form	X		
Sponges			
Barrel, tubes, vase morphology	X	X	X
Encrusting morphology	X		
Other benthic macrofauna			
Anemonies and hydroids	X		X
Tunicates and zoanthids	X		
Macro-invertebrates			
queen conch (by sexual maturity)			X
Spiny lobster			X
Long-spined urchin			X

2.1.3 Macroinvertebrates counts

Queen conch

The abundance of immature and mature queen conch (*Strombus gigas*) was assessed and quantified within the 25 x 4 m belt transects used for fish surveys. The maturity of each conch was determined by the presence (mature) or absence (immature) of a flared lip (Figure 9). Conch was included in the survey protocol from 2004 onward.

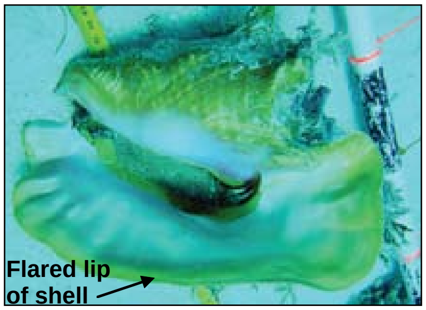
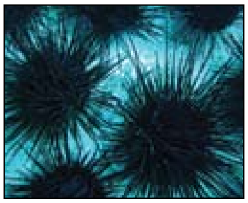


Figure 9. Image of queen conch and location of flared lip.

Caribbean spiny lobster

Abundance of Caribbean spiny lobsters (*Panulirus argus*) are reported for the period 2003 to 2006. Lobster sightings were recorded during fish and benthic composition surveys (i.e., within the 100 m^2 survey unit area). Lobsters were recorded if seen, but without active searches of holes or crevices.



Long-spined sea urchins

Long-spined sea urchins (*Diadema antillarum*) were also counted within the 25 x 4 m belt transect between 2004 and 2006. No measurements of size or estimates of maturity were collected.

2.1.4 Observer training

Observers were trained and tested in the identification of species/groups for both fish and habitat surveys by pairing inexperienced and experienced observers in the water and comparing data. Fish size estimation training was carried out *in situ* by estimating lengths of model fish of various shapes and sizes.

2.1.5 Data management

All fish and benthic habitat survey data were quality assessed before storage on an online relational database. All survey data were stored with a unique identification number and a geographical coordinate to facilitate spatial analyses. The database including metadata that provide detailed field methods are available at: http://ccmaserver.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html.

2.2 Analyses

2.2.1 Characterizing patterns of benthic habitat cover

The benthic habitat section of the report provides summary data from 716 benthic *in situ* surveys (approximately 3,580 quadrats) on hardbottom habitat types (e.g., linear reef, colonized pavement, patch reefs) around BIRNM and the northeastern shore of St. Croix between 2001 and 2006 (Tables 2 and 3). The number of surveys conducted during any single mission was relatively low for the least abundant hardbottom habitat types (i.e., reef rubble and bedrock), but high for

Table 2. The number of hardbottom benthic habitat sites surveyed by mapped habitat type for the St. Croix study region as a whole and inside and outside of BIRNM. Mapped habitat categories are from Kendall et al. (2002).

			Number of sites surveyed		
Mapped habitat types	**Area (km^2)**	**% Area**	**Inside**	**Outside**	**Total**
Bedrock	0.58	2%	13	14	27
Linear reef	1.56	5%	22	33	55
Patch reef	4.10	13%	98	4	102
Pavement	22.19	70%	274	199	473
Reef rubble / macroalgae	0.23	1%	2	4	6
Scattered coral and/or rock	3.22	10%	36	17	53
Total	31.88	100%	445	271	716

Table 3. Number of hardbottom benthic habitat sites surveyed by mission and mapped habitat type. Mapped habitat categories are from Kendall et al. (2002).

Sample period	Location	Bedrock	Linear reef	Patch reef	Pavement	Reef rubble/ Macroalgae	Scattered coral / rock	Total
2001 Spring	Inside	3	3	16	24		2	48
2001 Fall	Inside		1	10	13		2	26
2002 Spring	Inside		5	5	18	2	5	35
2002 Fall	Inside		2	16	12		3	33
2003 Spring	Inside	3		10	27		1	41
	Outside	1	5		29		2	37
2003 Fall	Inside	1	5	3	25		2	36
	Outside	1	9		24		1	35
2004 Spring	Inside			1	12		2	15
	Outside	1	2	1	6		2	12
2004 Fall	Inside			6	26		3	35
	Outside	3	5		19	1	2	30
2005 Spring	Inside	2	4	6	18		3	33
	Outside	4	5	1	20		1	31
2005 Fall	Inside			8	37		3	48
	Outside		3		36	1	6	46
2006 Spring	Inside			10	31		5	46
	Outside	1	2	1	30	2	2	38
2006 Fall	Inside	4	2	7	31		5	49
	Outside	3	2	1	35		1	42
Total		27	55	102	473	6	53	716

colonized pavement and patch reefs (Table 3). Although many benthic variables have been measured during the surveys, this report focuses primarily on the areal abundance (% cover) of the sessile biotic components (Table 1). In addition, we also compared habitat composition at a broader scale by quantifying the amount of each habitat type and the number of habitat types in the seascape surrounding each fish and benthic habitat survey site. These seascape variables were quantified within a 100 m radius buffer using a custom-built Geographical Information Systems (GIS) tool developed specifically for this project (Diversity Calculator for ArcGIS 9.2 is freely available at http://arcscripts.esri.com). Essentially, the buffer is analogous to a quadrat, but instead of quantifying percentage cover of fine-scale components such as coral cover we quantify the amount of habitat type from the benthic habitat map. The selection of a 100 m radial seascape sample unit was determined from a review of several studies that have identified the first 100 m surroundings as most influential in determining fish species distributions (Kendall et al., 2003; Pittman et al., 2007; Figure 10).

Differences in the abundance of individual components of the benthos inside versus outside BIRNM were tested using the parametric Tukey's HSD (Honestly Significant Difference) pairwise comparison for normally distributed data and the nonparametric Wilcoxon test for non-normally distributed data. Broad spatial patterns in the benthic variables were determined from visual interpretation of mapped values and simple deterministic interpolations. Interpolations were performed using the Inverse Distance Weighting (IDW) interpolator with a relatively small neighborhood of samples (n=5 points) to create spatial surfaces within a GIS. This technique makes few assumptions of the data and estimates cell values by averaging sample points within a neighborhood. The values are distance weighted such that points closer to the center of a cell are assigned more weight in the averaging process. All data were used to construct surfaces including samples where the measured variable was recorded as zero. For marine algae, the entire surface is shown (e.g., both hard and softbottom areas) since spatial variability of algae across seagrasses may also be informative. For other biotic components, such as corals, softbottom areas were masked out of the interpolated surface since few corals exist in sand and seagrass beds. The intent was not to create detailed and accurate spatial predictions, but instead to show a spatially continuous representation of fine-scale point data to aid in interpretation of broad-scale distribution patterns. The spatial extent of all analyses in this report is limited to the mapped portions of the study area.

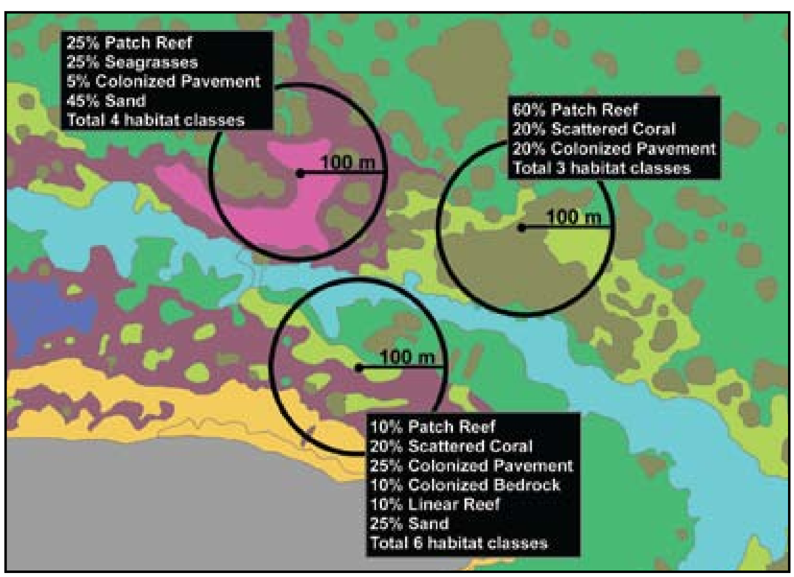


Figure 10. Seascape sample units of 100 m radius surrounding each fish transect were used in a GIS to quantify variability in seascape composition. In this example, it is clear that each seascape unit is characterized by very different patch type composition and patch richness.

2.2.2 Characterizing patterns in fish species and communities

Assessing differences in univariate metrics inside versus outside BIRNM
Differences in univariate community metrics as well as individual species/group metrics inside versus outside BIRNM were tested using parametric and nonparametric tests as appropriate. Only data for years 2003 to 2006 were examined because allocation of samples prior to 2003 occurred using different strata (n=431 inside BIRNM; 291 hardbottom and 140 softbottom; n=453 outside BIRNM; 303 hardbottom and 150 softbottom). Designations of habitat type (colonized hardbottom, seagrasses and unvegetated sediments) were collected by benthic habitat observers.

Diversity was measured using the Shannon Index (*H'*; Equation 1). In this way, the diversity measure incorporates richness, commonness and rarity. Although, the Shannon Index has been shown to be an effective discriminator of community structure it is not independent of sample size (Magurran, 1988). Taxonomic indices, on the other hand are considered to be significantly less influenced by sample size than the conventional species richness, evenness and diversity indices (Warwick and Clarke, 1995) and, therefore, more appropriate for any comparative studies with unbalanced sampling effort (Clarke and Warwick, 1998).

$$H' = - \sum_i p_i \, (\log_e p_i) \qquad \text{(Equation 1)}$$

Where *H'* is a weighted combination of: total number of species (richness) and the extent to which the total abundance is spread equally amongst the observed species (evenness). p_i is the proportion of the total count arising from the *i*th species.

Taxonomic indices
Samples may differ in the way assemblages are composed at the genus, family, order, class and phylum levels of the standard Linnean taxonomic hierarchy. For example, species diversity may be similar between two samples, yet one may support several species belonging to the same family, while the other may support several species, all belonging to different families and even different classes orders, etc. Quantitative taxonomic diversity indices therefore provide an additional dimension of information that is likely to be more closely linked to functional diversity (Clarke and Warwick, 1999). The importance of this measure of diversity is that families, orders, etc. as opposed to species, represent a greater variety of fundamentally different body plans and life histories.

As such Taxonomic diversity (Δ) (Warwick and Clarke, 1995; Equation 2) was measured for all samples. Fish were distinguished at four taxonomic levels: species, genus, family and class.

Samples were grouped by habitat type as determined by benthic habitat observers and by management domain as determined by the mapped strata (e.g., inside and outside BIRNM).

$$\Delta = \frac{\sum\sum_{i<j} W_{ij} X_i X_j + \sum_i 0.\, x_i (x_i - 1)/2}{\sum\sum_{i<j} x_i x_j + \sum_i x_i (x_i - 1)/2} \qquad \text{(Equation 2)}$$

Letting x_i denote the presence or absence of the *i*th species and the W_{ij} the "distinctness weight" given to the path length linking species i and j in the hierarchical classification, then taxonomic diversity (Δ) is defined simply as the average (weighted) path length between every pair of individuals. The null second term in the numerator has been included to emphasize that the weight for the path linking individuals of the same species is taken to be zero.

Assessing differences in community composition inside versus outside BIRNM
Differences and similarities in the species composition of communities between samples (often referred to as assemblage or community structure) were examined using a species biomass by site data matrix. Samples with zero fish were removed from the data matrix. Infrequently observed species, with extreme outlying biomass were removed, including small-bodied pelagic schooling fish (e.g., Clupeidae, Antherinidae, etc.) and large-bodied broad ranging species (e.g., sharks, rays, barracuda). Infrequently observed fish that were not identified to species level were also removed. The matrix was square-root transformed to ensure that intermediate biomass species, in addition to the high biomass species, played a significant role in determining patterns in community composition. The data was then used to construct a matrix of the percentage similarity in community composition between all pairs of sites using the Bray-Curtis Coefficient (Equation 3).

$$S'_{jk} = \left[1 - \frac{\sum_{i=1}^{n} X_{ij} - X_{ik}}{\sum_{i=1}^{n} X_{ij} + X_{ik}} \right] \qquad \text{(Equation 3)}$$

Where x_{ij} is the abundance of the *i*th species in the *j*th sample and where there are n species overall.

This algorithm is considered a robust estimator of ecological distance and has had widespread usage in ecology particularly for comparison of biological data on community structure (Faith et al., 1987). Its robustness is in part due to its exclusion of double zeros, that is, if two samples are missing the same species, they will not be regarded as similar based on the same absentees (Legendre and Legendre, 1998). This similarity coefficient reduces the comparison between all pairs of samples to single numerical values that are arranged in a secondary matrix from which pattern is examined. Sample sites were assigned a factor representing a dominant habitat type (e.g., either colonized hardbottom, seagrasses or sand) and a management domain (e.g., inside or outside BIRNM). Factors were used to identify pairs of treatments in order to test for significant differences using Analysis of Similarities (ANOSIM), a multivariate version of Analysis of Variance (ANOVA; Primer v5; Clarke and Warwick, 1994), and for visual examination of patterns of between site similarity using a non-metric dimensional scaling plot (nMDS). In addition, Similarity percentages (SIMPER) were calculated and used to identify the species which contributed most to the differences between treatments (Primer v5; Clarke and Warwick, 1994).

Where species groups were used, **herbivores** included all species that were important consumers of marine algae; **piscivores** included all fish that were important predators of fish; **snapper** included all Lutjanidae spp.; **groupers** included all commercially harvested Serranidae spp.; **grunts** included all Haemulidae. Juveniles/subadults were identified based on length at maturity information provided by García-Cagide et al. (1994) and FishBase (http://www.fishbase.org, version 11/2007), whereby, juveniles/subadults were fish with lengths less than the mean length at maturity and the remainder were considered as adults (Table 4). If the mean length at maturity was 14 cm then size classes <5 and 5-10 cm were considered juvenile/subadult. Where length at maturity was unknown, 1/3 of maximum adult size was used to segregate juveniles/subadults from adults. For mapping of juvenile and adult distribution all samples were used from 2001 to 2006.

Table 4. Length at first maturity estimates used to determine approximate size classes for juvenile/subadult and adult fish. Estimates are derived from data held by FishBase (http://www.fishbase.org, version 11/2007).

Species	Mean length at first maturity, L_m (cm)	Juvenile/subadult size class (cm)
Acanthurus bahianus	15.5	≤15
Acanthurus coeruleus	unknown	≤10
Balistes vetula	25	≤20
Cephalopholis fulva	16	≤15
Epinephelus guttatus	25	≤20
Halichoeres bivittatus	unknown	≤10
Haemulon flavolineatum	16	≤15
Haemulon plumierii	19	≤15
Haemulon sciurus	18.5	≤15
Holacanthus tricolor	17.4	≤15
Lutjanus apodus	25	≤20
Lutjanus griseus	31	≤20
Ocyurus chrysurus	24.5	≤20
Scarus iseri	unknown	≤10
Sparisoma aurofrenatum	unknown	≤10
Sparisoma viride	16.3	≤15
Thalassoma bifasciatum	unknown	0-5

2.2.3 Comparison of fish densities and species presence between 1979 and 2001-2006

Data on mean fish densities from visual surveys conducted between January and September 1979 (Gladfelter, 1980) were used for comparison with 2001-2006 data. The 1979 surveys were conducted during the day at five hardbottom sites (each one of 40 x 40 m^2) within 500 m of Buck Island. Each of the five sites received replicate surveys (North lagoon n= 30, SW lagoon n=30, NW leeward n=30, S forereef n=32, E forereef n=25) resulting in a total sample size of 147. These sites were not randomly located, but were selected to represent a variety of coral reef environments across a complexity gradient. Census involved swimming back and forth across the study site counting all fish observed. A mean density for each species of interest was calculated from pooled data on mean densities for each of the five plots and was standardized to 100 m^2 for comparative purposes. To provide a comparison with similar environments using CCMA-BB survey data from 2001-2006, only fish transects conducted over hardbottom habitat types within 500 m of Buck Island were used. This resulted in a sample size of 184 spatially random samples. Differences in technique were clearly evident resulting in limitations when attempting to undertake direct comparison, yet data can be usefully compared for presence and absence of species and any large differences in density between the two time periods.

2.2.4 Characterizing patterns in macroinvertebrate abundance

For *Diadema antillarum* (long-spined sea urchins) and *Strombus gigas* (queen conch) mean (±SE) density and summary statistics were calculated by habitat type using NOAA's benthic habitat map. To examine spatial distribution patterns, density data was overlayed on the benthic habitat map. In addition, for queen conch only, mean (±SE) abundance of juvenile and adults were determined for three Caribbean islands based on the area weighted abundance for each benthic habitat type in which queen conch surveys were conducted. Data collected between 2004 and 2006 were pooled to allow an adequate sample size (n≥2) with which to calculate means within each habitat type. The following equation was used to calculate total abundance estimates for each queen conch life stage:

$$\sum_{h=1}^{l} A_h \overline{X}_h$$

where A is the total area of each mapped habitat, $\overline{X}$ is the mean density (# of queen conch/m^2) in each habitat, and l is the total number of mapped habitats in each island. A sampling unit was a 25 x 4 m wide belt transect or a 100 m^2 area.

Mean densities were derived from multiple surveys that occurred within each habitat type. A range of the total abundance was calculated with the equation:

$$\sum_{h=1}^{l} A_h\left(\overline{X_h} \pm S.E\right)$$

where SE is the standard error of the mean queen conch density in each mapped habitat in each island.

3. Results

3.1 Benthic habitat cover

Colonized pavement was the most spatially extensive habitat type (70% of the study area) and was therefore most intensively surveyed, followed by patch reefs (13%) and linear reef (5%; Table 3). Hardbottom habitat types combined formed a larger proportion (78%) of BIRNM than did softbottom areas (22%). In contrast, outside BIRNM, softbottom habitat types formed a larger proportion (54%) of the total mapped area than hardbottom.

Estimates of percent cover (mean ± standard error [SE]) of selected benthic organisms are reported for: (1) the entire study area for all habitat types; and (2) inside and outside BIRNM using only three of the most abundant habitat types (colonized hardbottom, seagrasses, sand sites). These comparisons at broader thematic resolution are intended to highlight any major differences between inside and outside the protected area.

3.1.1 Characterization of colonized hardbottom types

Generally, colonized hardbottom habitat types were dominated by algae (36.7% ± 1.1% turf algae, 11.4% ± 0.5% macroalgae, and 1.8% ± 0.2% crustose coralline algae [CCA]; Figure 11). *Dictyota* spp., *Halimeda* spp. and *Sargassum* spp. were most abundant. Cyanobacteria and filamentous algae were grouped as a single component and had a mean cover of 4.3% ± 0.5%. Mean live scleractinian coral cover was 5.6% (± 0.5%) across the region. The mean percent cover of live scleractinian coral was highest on patch reefs (12.1% ± 1.3%; $p<0.05$) and lowest on reef rubble (2.0% ± 0.8%) and scattered coral and rock sites (3.4% ± 0.7%; Figure 12).

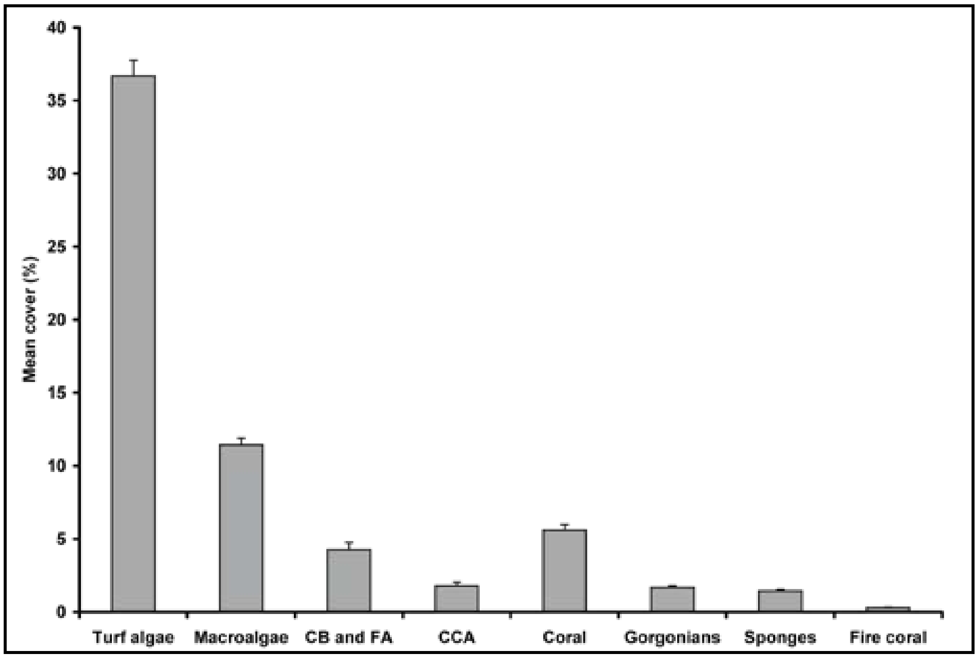


Figure 11. Percentage cover for key benthic components across hardbottom sites (n=716) in the study region (northeastern St. Croix) between 2001 and 2006. CCA= crustose coralline algae; CB and FA= cyanobacteria and filamentous algae.

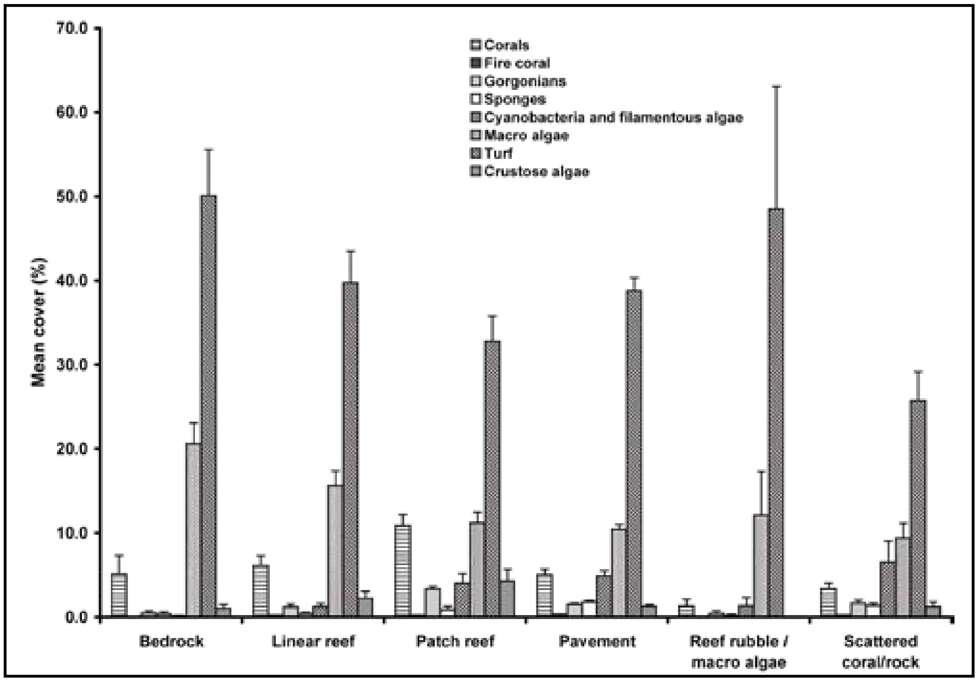


Figure 12. Percentage cover for key components of the benthic community across hardbottom habitat types (n=716) in the study region (northeastern St. Croix) between 2001 and 2006.

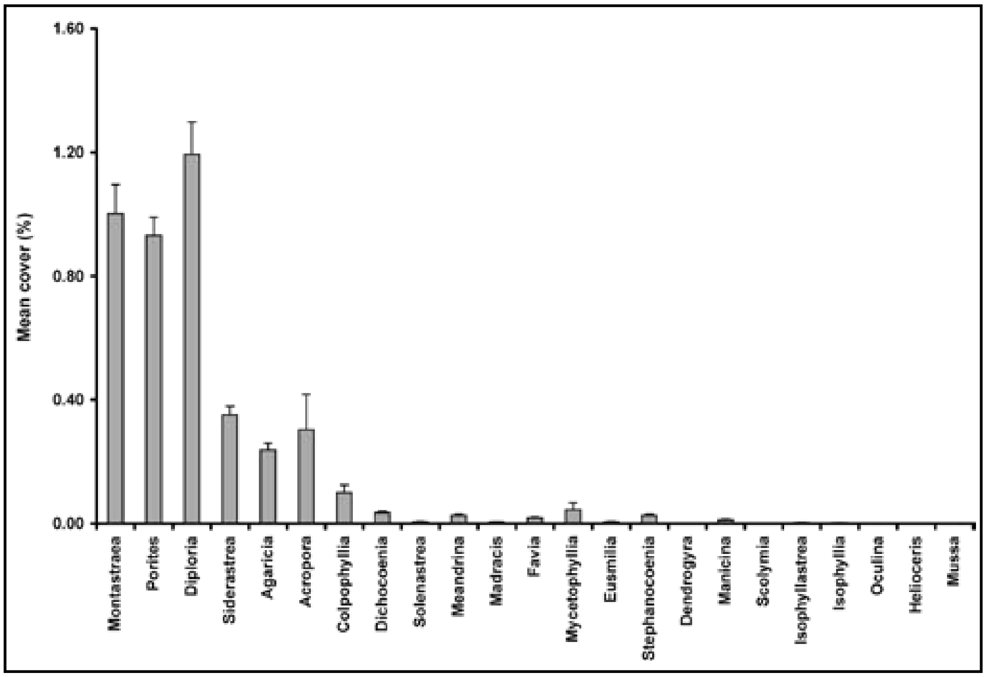


Figure 13. Abundance of coral genera found across hardbottom sites in the study region (northeastern St. Croix) between 2001 and 2006.

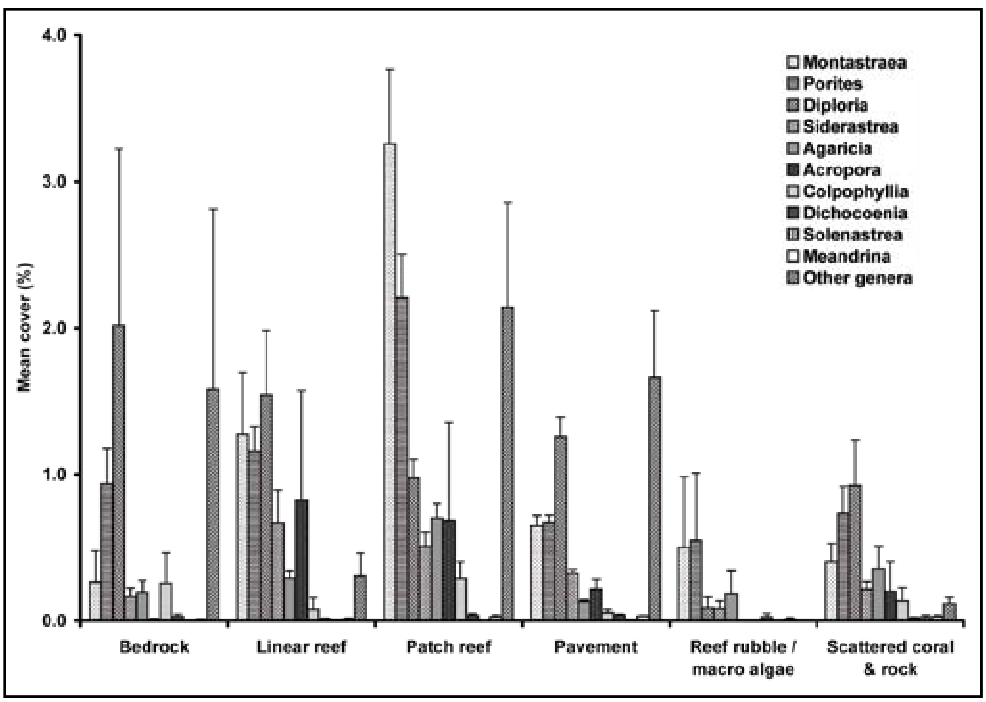


Figure 14. Abundance of coral genera by hardbottom habitat type in the study region (northeastern St. Croix) between 2001 and 2006.

Gorgonians were highest on colonized pavement and lowest on reef rubble sites. The percent cover of sponges and fire corals were similar among the habitat types surveyed (Figure 12).

Live scleractinian coral cover included at least 23 coral genera, but only nine with a mean cover greater than 0.01% (Figure 13). The three most abundant coral genus were *Diploria* spp. (1.2% ± 0.29%), *Montastraea* spp. (1.0% ± 0.09%) and *Porites* spp. (0.9% ± 0.06%). *Diploria* spp. cover was highest on colonized bedrock, linear reef and colonized pavement; *Montastraea* spp., *Porites* spp. and *Acropora* spp. was highest on patch reef and linear reef habitat types (Figure 14).

Table 5. Mean estimates of percent cover of selected benthic groups inside and outside BIRNM. Asterisks (*) indicate significant differences (p<0.05).

Habitat	Benthic Taxa	Mean percent cover (± SE)	
		Inside	Outside
Colonized hardbottom		*n = 310*	*n = 292*
	Live coral*	4.9 (0.3)	2.4 (0.2)
	*Acropora**	0.3 (0.1)	0.03 (0.02)
	*Montastraea**	1.0 (0.2)	0.5 (0.1)
	*Diploria**	1.8 (0.2)	0.6 (0.1)
	Agaricia	0.2 (0.02)	0.2 (0.03)
	Algae	51.9 (1.6)	53.6 (1.8)
	Macroalgae*	14.5 (0.9)	15.7 (0.8)
	Turf algae	35.7 (1.6)	36.8 (1.7)
	Crustose algae	1.8 (0.3)	1.6 (0.2)
	Gorgonians*	2.1 (0.2)	0.7 (0.08)
	Sponge*	1.4 (0.2)	1.7 (0.1)
	Seagrass*	0.3 (0.2)	1.4 (0.5)
Seagrass		*n = 55*	*n = 115*
	Live coral	0.5 (0.21)	0.19 (0.08)
	Acropora	0	0
	Montastraea	0.04 (0.03)	0.01 (0.01)
	Diploria	0.32 (0.1)	0.06 (0.03)
	Agaricia	0.01 (<0.01)	0.03 (0.02)
	Algae	14.89 (3.4)	9.46 (1.6)
	Macroalgae	6.92 (1.1)	5.73 (0.6)
	Turf algae	7.52 (2.9)	3.3 (1.4)
	Crustose algae*	0.45 (0.3)	0.44 (0.3)
	Gorgonians*	0.14 (0.06)	0.04 (0.03)
	Sponge*	0.07 (0.04)	0.26 (0.07)
	Seagrass*	19.84 (2.9)	40.32 (2.7)
Unvegetated sediments (sand)		*n = 67*	*n = 41*
	Live coral	0.2 (0.1)	0.01 (<0.01)
	Acropora	0	0
	Montastraea	0.02 (0.02)	0
	Diploria	0.12 (0.1)	0
	Agaricia	0.04 (0.04)	0
	Algae	4.1 (1.5)	2.1 (0.3)
	Macroalgae	2.7 (0.7)	2.0 (0.3)
	Turf algae	1.0 (0.5)	0.1 (0.1)
	Crustose algae	0.44 (0.4)	0
	Gorgonians	0.05 (0.05)	0
	Sponge*	0.001	0.1 (0.05)
	Seagrass	0.7 (0.16)	2.3 (1.7)

Table 6. Comparison of coral species richness and ratio of coral to macroalgae in major habitats inside and outside BIRNM. Asterisks (*) indicate significant differences (p<0.05).

Variable	Habitat type	Mean % cover (± SE)	
		Inside	Outside
		n = 310	n = 292
Number of coral species	Colonized hardbottom	5.3 (0.2)	5.2 (0.2)
	Seagrass	0.47 (0.16)	0.56 (0.13)
	Unvegetated sediments	0.3 (0.1)	0.1 (0.06)
Coral : Macro-algae ratio	Colonized hardbottom*	2.4 (0.5)	0.6 (0.1)
	Seagrass	0.04 (0.02)	0.04 (0.02)
	Unvegetated sediments	0.04 (0.03)	0.01 (0.01)

3.1.2 Benthic cover inside and outside BIRNM

Benthic composition of the major habitat types (hardbottom, seagrass and unvegetated sediments) occurring inside BIRNM was significantly different from those found outside. Colonized hardbottom inside BIRNM had significantly higher percent cover of live coral than colonized hardbottom sites outside and slightly lower macroalgal cover (Table 5). The cover of living *Acropora* was an order of magnitude greater inside compared with outside and percent cover of living *Montastraea* and *Diploria* was more than twice as high inside than outside (Table 5). Gorgonians and sponges also had higher mean percent cover inside BIRNM compared with outside.

Fewer significant differences were observed in seagrass and sand habitats. Percent cover of CCA and gorgonians in seagrass habitats were higher inside BIRNM compared with outside, whereas percent cover of sponges and seagrass in seagrass habitats were higher outside BIRNM than inside. In areas mapped as sand, only sponges and seagrass showed significant inside versus outside differences. Both had higher percent cover outside BIRNM than inside (Table 5).

Mean coral species richness inside BIRNM was slightly higher than outside, but not significantly different (Table 6). Colonized hardbottom habitat inside BIRNM had a significantly higher coral:macroalgal ratio compared with outside. This difference reflects the higher percent cover of coral and lower cover of macroalgae inside BIRNM relative to outside and suggests BIRNM may contain coral reefs in better condition than surrounding areas.

Furthermore, at a broader spatial scale of 100 m radius, benthic habitat composition surrounding survey transects were significantly different inside versus outside BIRNM for seven of 10 seascape variables (Table 7). The mean area of seagrass surrounding transects outside BIRNM was significantly higher than inside, while seascapes inside BIRNM had significantly higher habitat diversity, area of patch reefs, colonized pavement and area of sand.

3.1.3 Spatial patterns in benthic cover

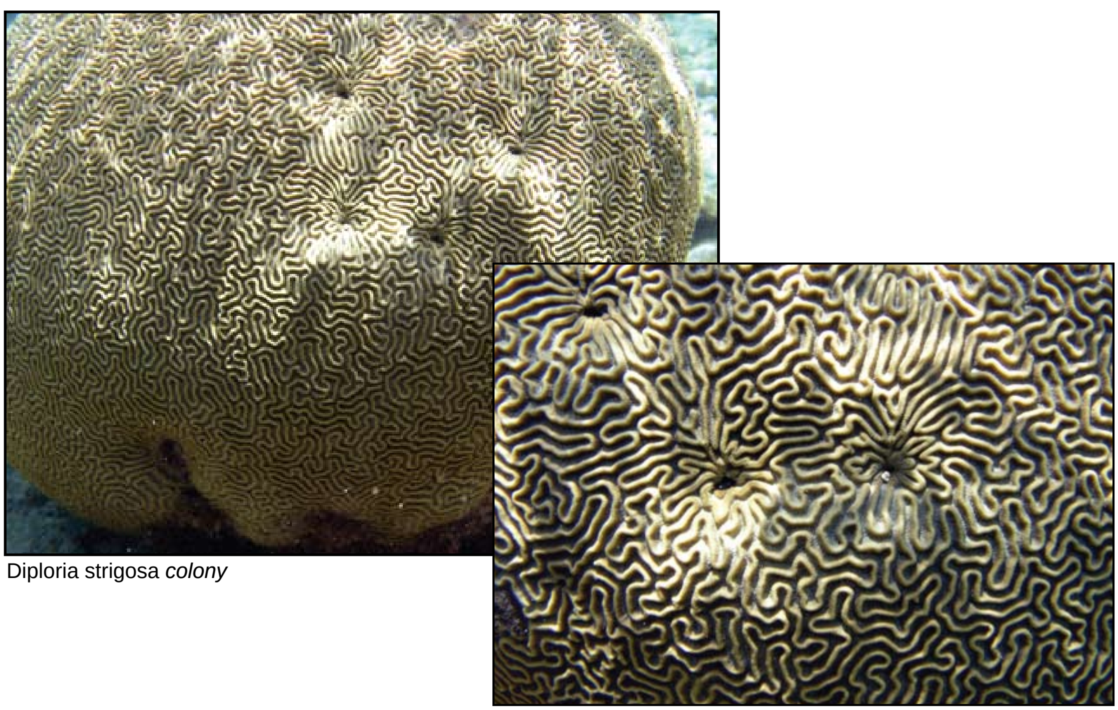
Visual examination of an interpolated surface of live coral cover indicated that areas with higher live coral cover were more extensive inside BIRNM than outside. For instance, live coral cover between 15-50% existed outside BIRNM in only one relatively small area (southeast of Buck Island along the north shore of St. Croix), whereas several areas inside BIRNM had live coral ranging from 15-50% (Figure 15a). The eastern tip and northwest end of Buck Island had the largest areas with live coral cover exceeding 15%. These two areas were also the most topographically rugose (Figure 15c) in the region forming a mosaic of branching coral dominated patch reefs interspersed among a matrix of massive coral dominated colonized pavement. Furthermore, two small areas inside the BIRNM had live coral cover exceeding 50% (Figure 15a). The number of hard coral species groups were relatively evenly distributed inside and outside BIRNM, with several areas in both domains having 9-14 coral species (Figure 15b). Overall, the existing boundary of BIRNM encompassed the majority of the most topographically complex hardbottom habitat types, with intermediate to high coral cover relative to that of the study region.

Intermediate to high levels of macroalgal cover (>20-95%) and algal turf was evident over a broad expanse of hardbottom area, both within and outside BIRNM (Figure 16a,b). Particularly high macroalgal cover was evident at deeper water sites along the northern boundary of the mapped/unmapped area and a large region along the eastern boundary of the study region (Figure 16a). Most of the hardbottom habitat inside BIRNM supported a high cover of algal turf (>30-96%; Figure 16b). In contrast, fewer areas had crustose coralline algae exceeding 30% cover (Figure 16c). These areas of high CCA cover were relatively localized and occurred mostly over colonized pavement within BIRNM north and east of Buck Island (Figure 16b). Given that CCA is known to facilitate settlement of coral larvae, the observed spatial distribution of CCA suggests that hardbottom areas inside BIRNM may have greater potential for coral settlement and recruitment than hardbottom areas outside BIRNM.

Table 7. Differences in seascape composition (amount and richness of habitat types) surrounding transects inside and outside BIRNM. Seascape composition was quantified within 100 m radius seascape units surrounding each fish transect using the NOAA benthic habitat map. Asterisks (*) indicate significant differences (p<0.05).

Habitat type	Mean area m² (± SE) Inside	Outside
Colonized hardbottom*	17232 (419)	15351 (576)
Colonized pavement*	11495 (394)	9910 (574)
Patch reef*	1341 (108)	395 (64)
Linear reef	1802 (147)	1650 (208)
Reef rubble	296 (70)	382 (82)
Scattered coral and/or rock*	1776 (136)	3015 (259)
Seagrass*	5812 (329)	10674 (556)
Sand*	6532 (284)	4061 (373)
Number of habitat types*	3.5 (0.06)	2.6 (0.06)

Although the study region had relatively low mean coral cover (approximately 5%; Table 2), interpolations of live cover for the five most abundant coral species show that several areas inside BIRNM had higher coral cover for some species in comparison with areas outside (Figures 17 and 18). Live cover of *Diploria strigosa* exceeded 5% in several areas inside BIRNM including two areas north of Buck Island which ranged between 10 and 26% (Figure 17a). Outside BIRNM, maximum live cover of *Diploria strigosa* was 10% in only one area along the eastern tip of St. Croix. The spatial distribution of *Montastraea annularis* was similar to that of *D. strigosa*. Three areas north and two areas east-southeast of Buck Island had live cover of *M. annularis* ranging from 15-33%, whereas live cover of *M. annularis* exceeded 15% in only one area outside BIRNM directly south of Buck Island (Figure 17b). Live cover of *Montastraea cavernosa* exceeded 5% in two areas inside BIRNM: (1) east of Buck Island and (2) north-northeast of Buck Island toward the edge of the study area; and one area outside BIRNM, southeast of Buck Island toward Point Udal on the island of St. Croix (Figure 17c). The highest cover of *Siderastrea siderea* ranged from 5.1-9.7% in two areas: (1) inside BIRNM north east of Buck Island and (2) outside BIRNM directly south of Buck Island close to St. Croix (Figure 18a). The highest cover of *Porites astreoides* ranged from 5-7% in two areas inside BIRNM (east of Buck Island) and one area outside BIRNM southeast of Buck Island (Figure 18b).



Diploria strigosa *colony*

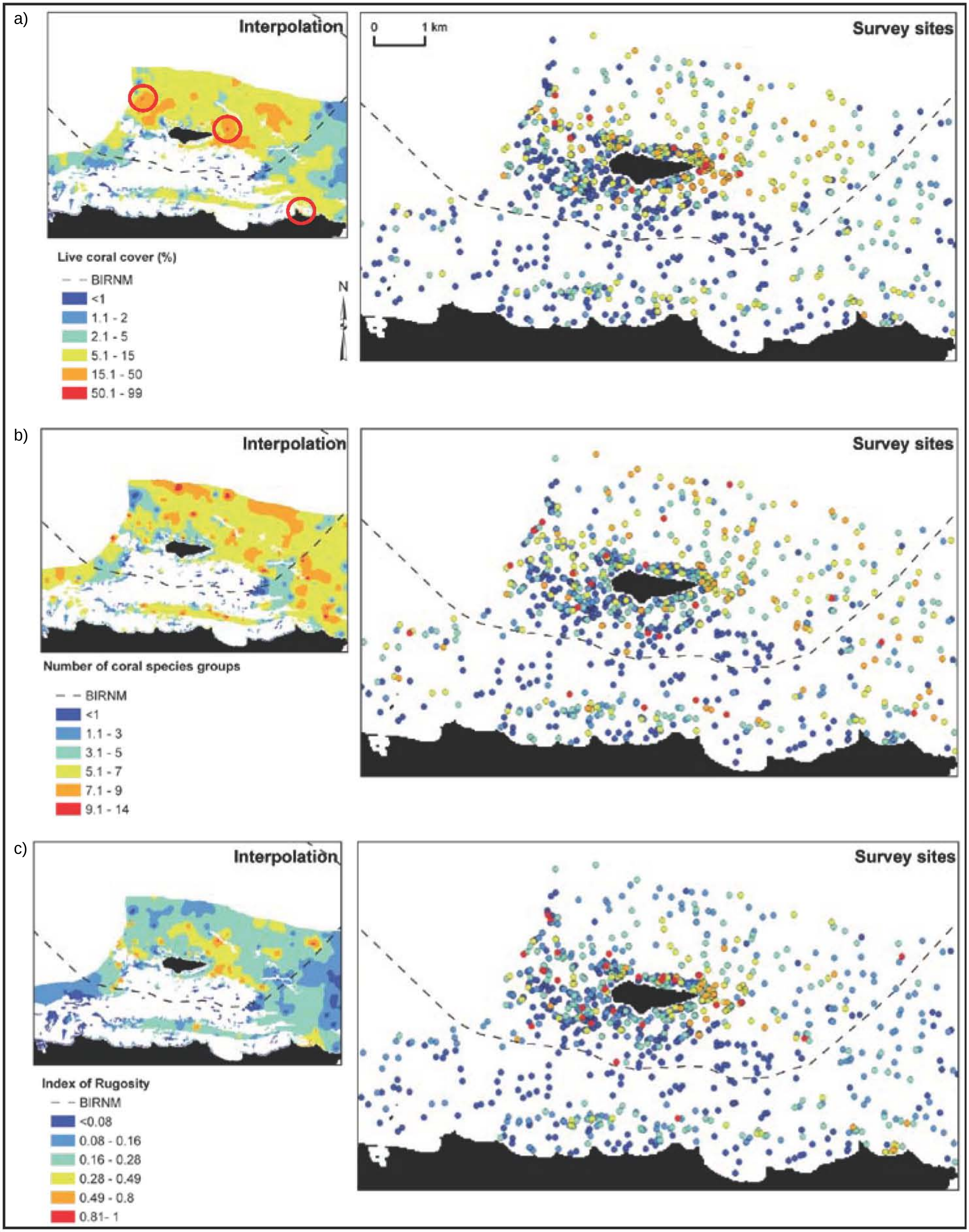


Figure 15. Spatial distributions of benthic components at all transects in the study region (northeastern St. Croix) between 2001 and 2006. (a) Percentage live coral cover (hard coral including fire coral); (b) number of coral species/groups; and (c) rugosity. White areas inside the mapped region denote softbottom habitats (sand and seagrasses). Small hotspots of high coral cover area are encircled.

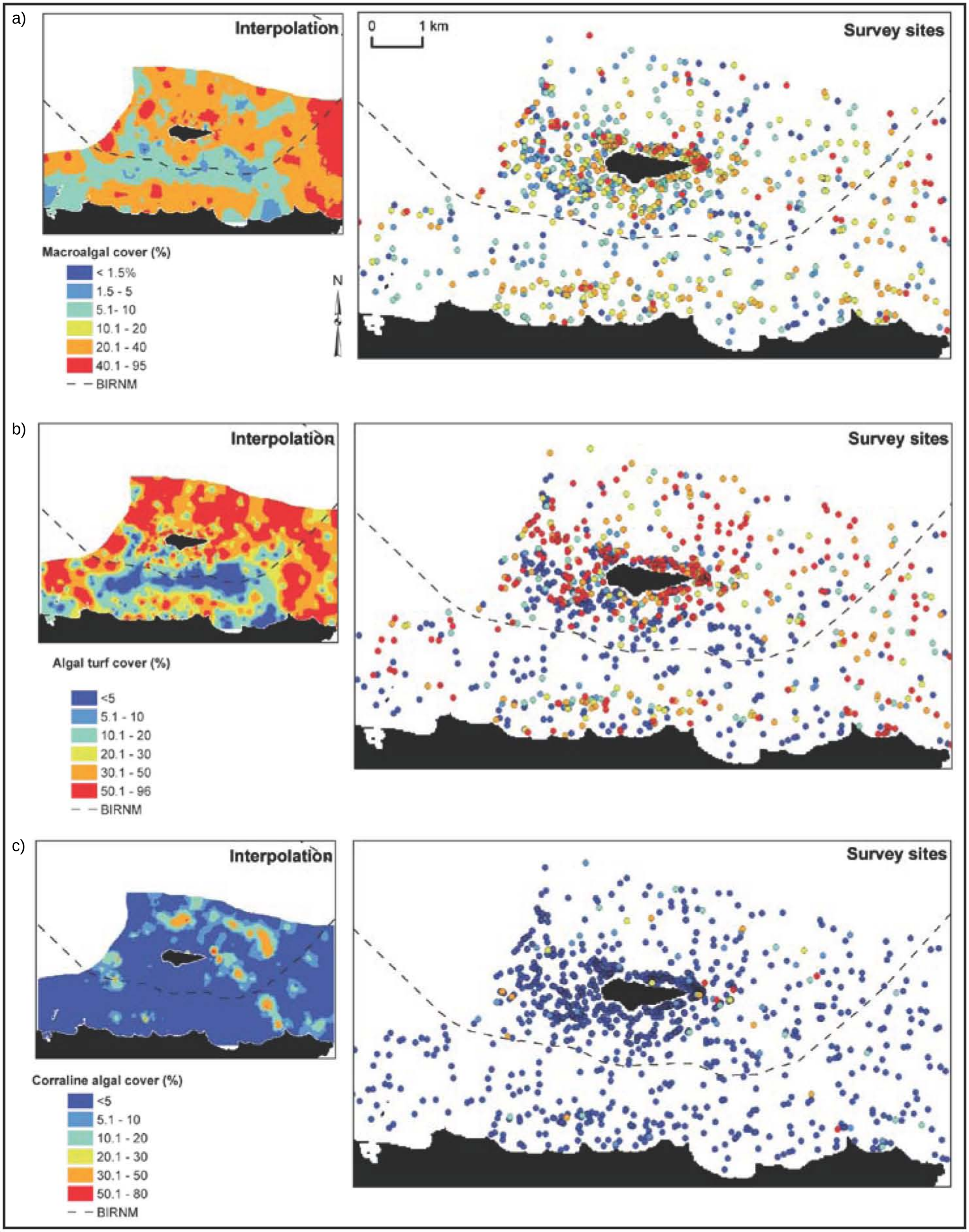


Figure 16. Spatial distributions of benthic components at all transects in the study region (northeastern St. Croix) between 2001 and 2006. (a) Macroalgal cover (including filamentous algae/cyanobacteria; (b) algal turf cover; and (c) crustose coralline algal cover.

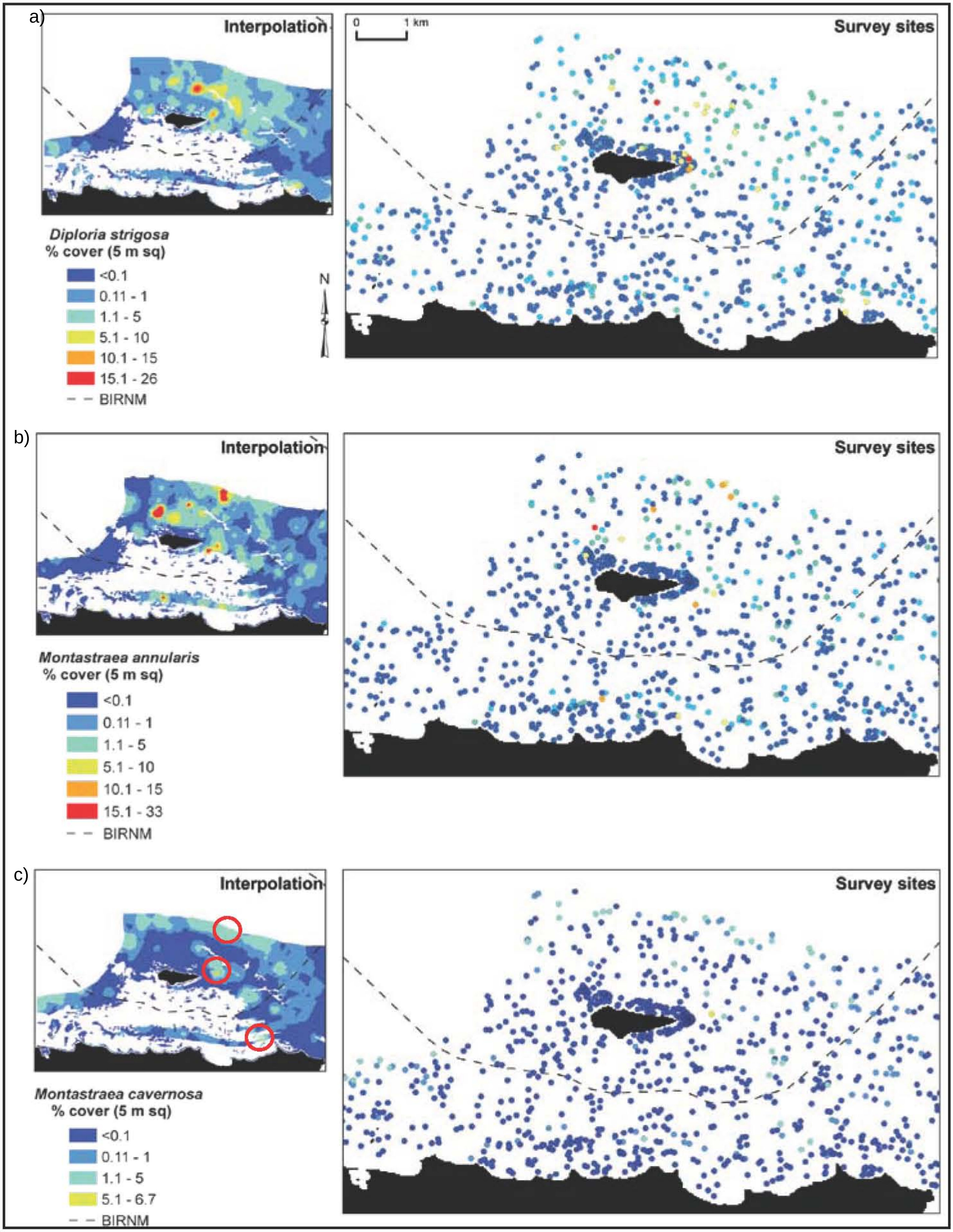


Figure 17. Spatial distributions of coral cover for individual coral species at all transects in the study region (northeastern St. Croix) between 2001 and 2006. (a) Diploria strigosa*, (b)* Montastraea annularis *and (c)* Montastraea cavernosa*. White areas inside the mapped region denote softbottom habitats (sand and seagrasses). Small hotspots of high coral cover are encircled.*

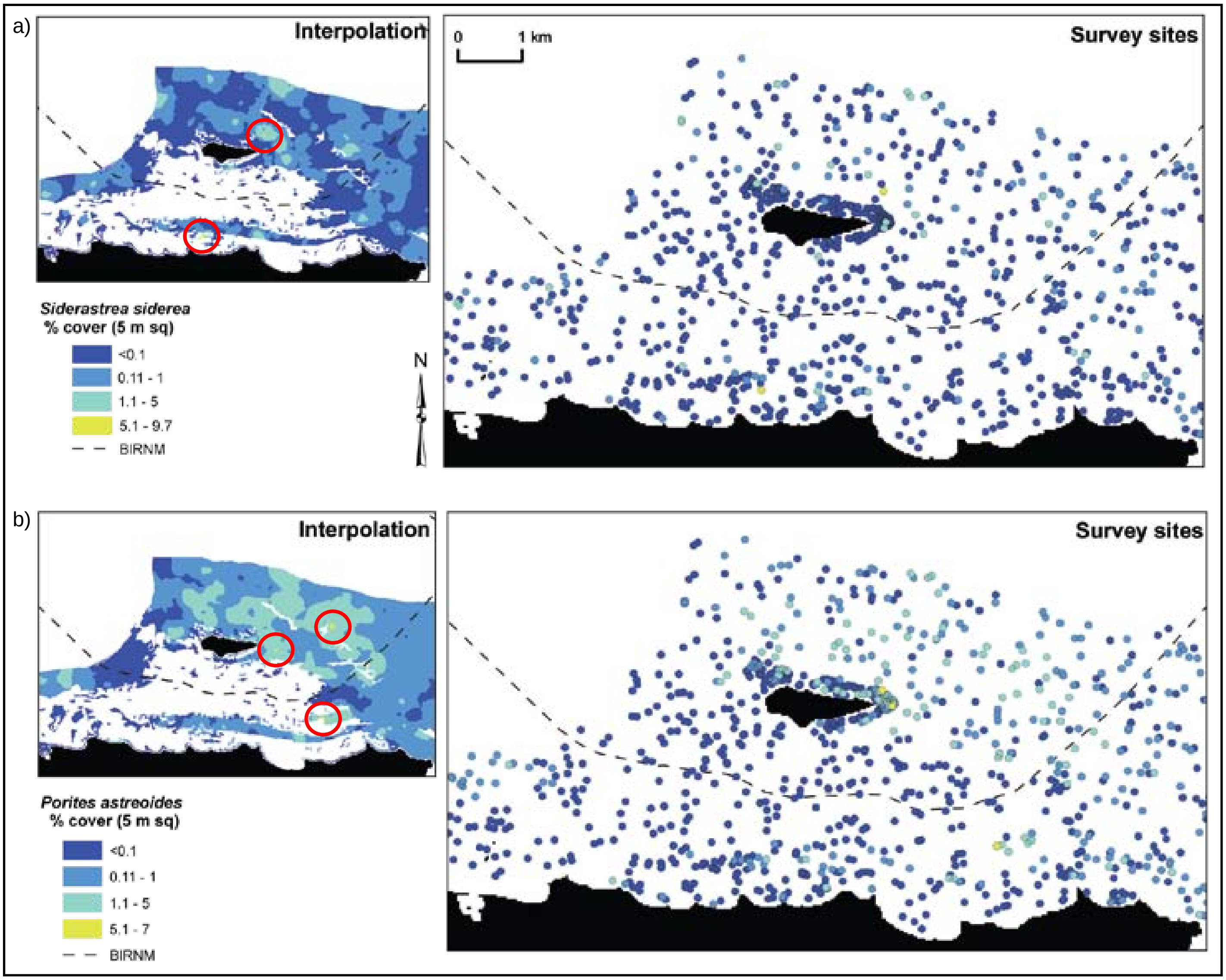


Figure 18. Spatial distributions of coral cover for individual coral species at all transects in the study region (northeastern St. Croix) between 2001 and 2006. (a) Siderastrea siderea *and (b)* Porites astreoides*. White areas inside the mapped region denote softbottom habitats (sand and seagrasses). Small hotspots of high coral cover are encircled.*

3.1.4 Temporal patterns in benthic cover

Mean live coral cover was higher inside than outside BIRNM for all sampling seasons and years (Figure 19). A dramatic decline in live coral cover due to a mass coral bleaching event in October 2005 was recorded outside BIRNM during the October 2005 sampling season and the subsequent April 2006 and October 2006 seasons. The decline inside BIRNM was not detected until the following year (October 2006).

Examination of differences in mean values for selected dominant plant biota inside and outside BIRNM over eight field missions from 2003 to 2006 (e.g., since the sampling design included the two management domains) also revealed some distinct temporal trends. Mean macroalgal cover was higher outside BIRNM for six of eight sampling periods (Figure 20). Spring macroalgal cover declined in abundance from 2003 to 2006 both inside and outside BIRNM, but exhibit higher cover in the fall. Algal turf cover was generally lower in the fall than spring, yet appeared similar in abundance inside and outside across seasons and years (Figure 20). In contrast, filamentous cyanobacterial/algal cover was markedly higher in the fall than in spring and was highly variable across years with greatest abundance observed in October 2005 (Figure 20).

Further more detailed examination of temporal trends in benthic components will be the focus of a separate future report.

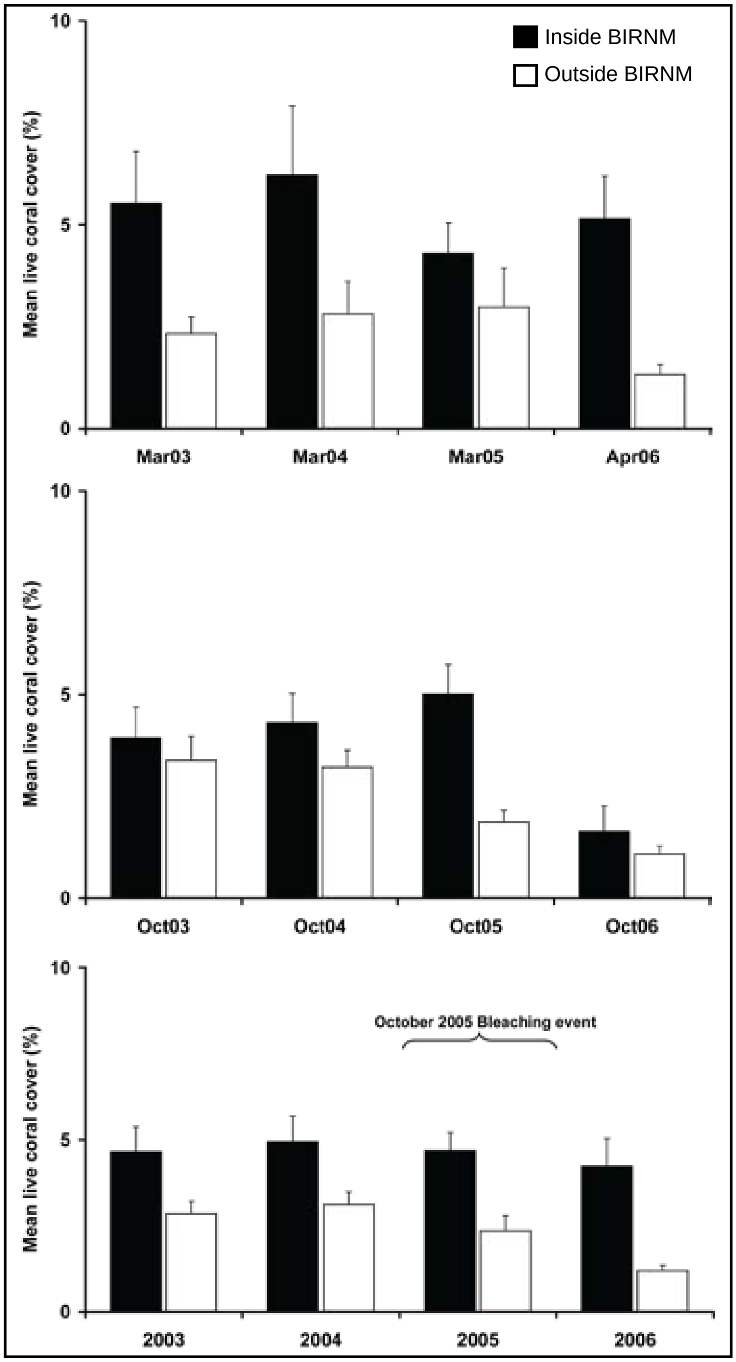
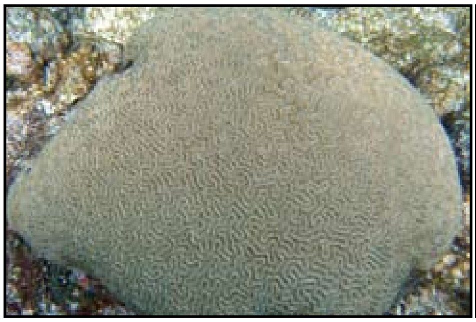
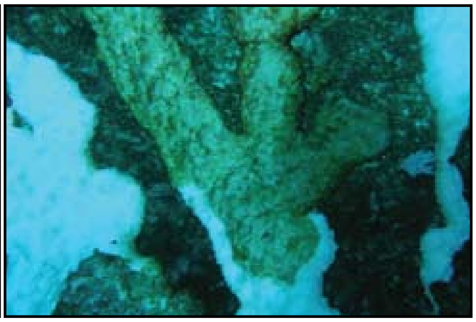


Figure 19. Seasonal and inter-annual patterns of live coral cover inside and outside BIRNM over a four year sampling period. Error bars indicate + SE.



Healthy coral

Recently bleached coral



Turf and filamentous algae over bleached coral

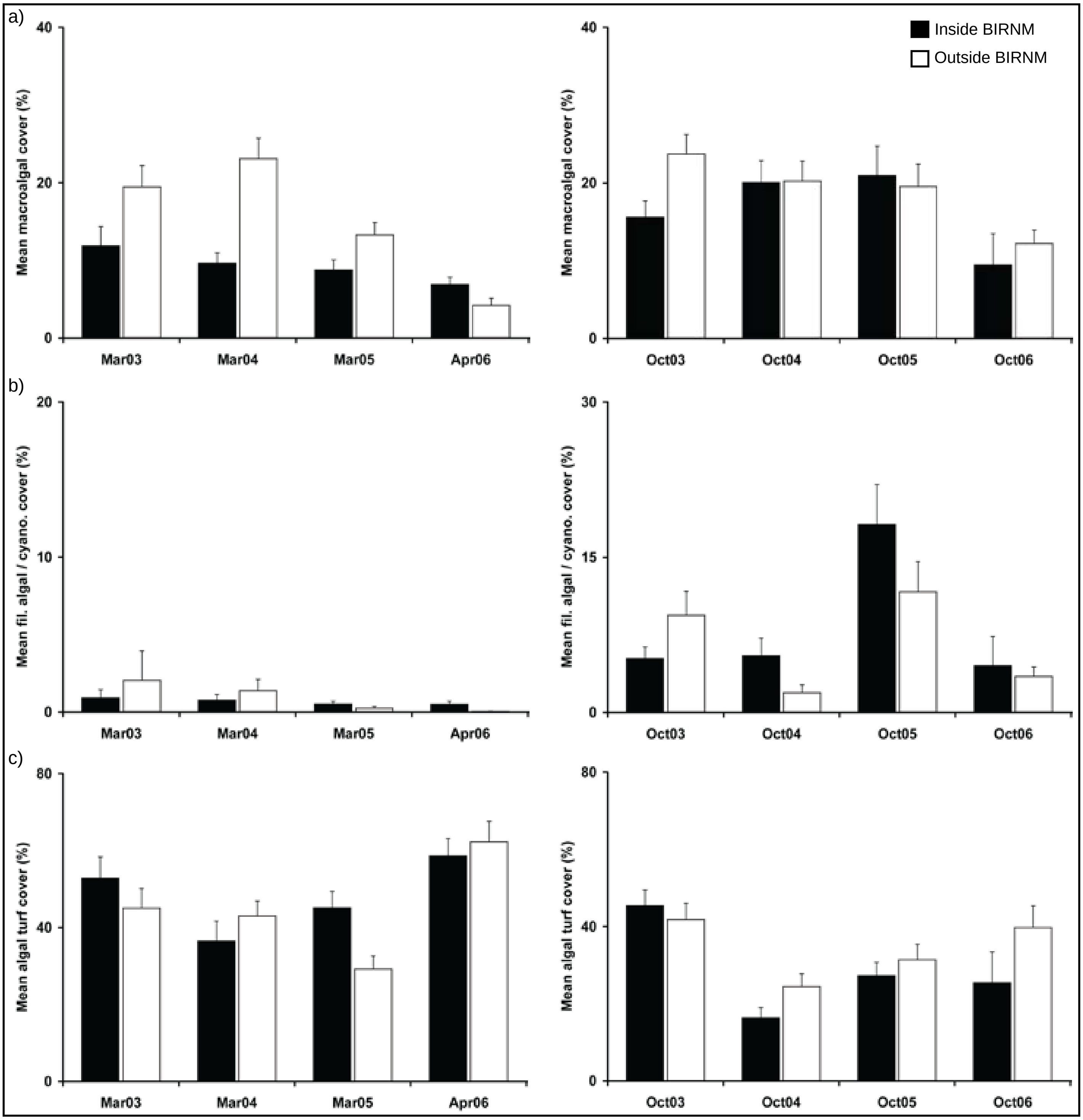


Figure 20. Seasonal and inter-annual patterns of marine plant cover inside and outside BIRNM over a four year sampling period: (a) macroalgae, (b) filamentous algae/cyanobacteria and (c) algal turf. Fil. algal/cyano.= filamentous algal/cyanobacterial. Error bars indicate + SE.

3.1.5 Mapping threatened Acropora species inside and outside BIRNM

Since 1980, populations of *Acropora cervicornis* (staghorn coral) and *A. palmata* (elkhorn coral) have declined by up to 98% throughout their range and localized extirpations have occurred due to combinations of stressors including disease, hurricanes and coral bleaching (Figure 21). In BIRNM, white-band disease and several major hurricanes have reduced live elkhorn coral cover by over 80 percent since the 1970s and 1980s. In 1999, NOAA National Marine Fisheries Service (NMFS) added elkhorn coral to the candidate species-list of the Endangered Species Act (ESA), but it was not until May 2006 that staghorn coral and elkhorn coral were formally listed as threatened species under the ESA. According to the Act, a species is considered endangered if it is in danger of extinction throughout all or a significant portion of its range or if it is likely to become an endangered species within the foreseeable future. In response to the designation, NMFS proposed in February 2008 to designate critical habitat areas for *Acropora* species throughout the U.S territories based on best available information on species distributions and habitat parameters (Federal Register 50 CFR Parts 223 and 226, February 6, 2008). Critical habitat was defined by Section 3 of the ESA (and further by 50 CFR 424.02(d)) and is paraphrased here as: (i) specific areas essential to the conservation of the species; and (ii) areas which may require special management considerations or protection; and (iii) specific areas outside the geographical area occupied by the species that are determined essential for the conservation of the species.

Within the BIRNM, NPS staff identified 2,492 *A. palmata* colonies greater than 1 m in size at 455 of 617 random survey sites (Mayor, 2005). In addition, CCMA-BB documented the presence of *A. palmata* at 32 of 815 hardbottom sites within the BIRNM and at 11 of 430 sites within the EEMP. The distribution of *A. palmata* is almost entirely confined to relatively shallow waters (<12 m or approximately 35 ft) with most colonies observed in waters less than 10 m on the exposed seaward side of Buck Island within BIRNM. The presence and absence of *A. palmata* in the study region of northeastern St. Croix is shown in Figure 22. *A. cervicornis* is considerably rarer in the study region than was *A. palmata*. CCMA-BB CREM surveys recorded the presence of *A. cervicornis* at 12 of 815 hardbottom sites within the BIRNM and at two of 430 sites within the EEMP, but they did not observe any colonies at 39 other sites visited in northeast St. Croix. In general, *A. cervicornis* has received much less attention by researchers than *A. palmata*, although for both species more data are required to adequately assess the distribution and occurrence of the species in the USVI. Due to the relatively well defined environmental conditions that support *A. palmata* establishment and growth (i.e., wave exposed shallow water hardbottom areas with good circulation and low exposure to sedimentation and fresh water incursions) it should be possible to develop predictive models that will help fill in the data gaps by providing species distribution maps.

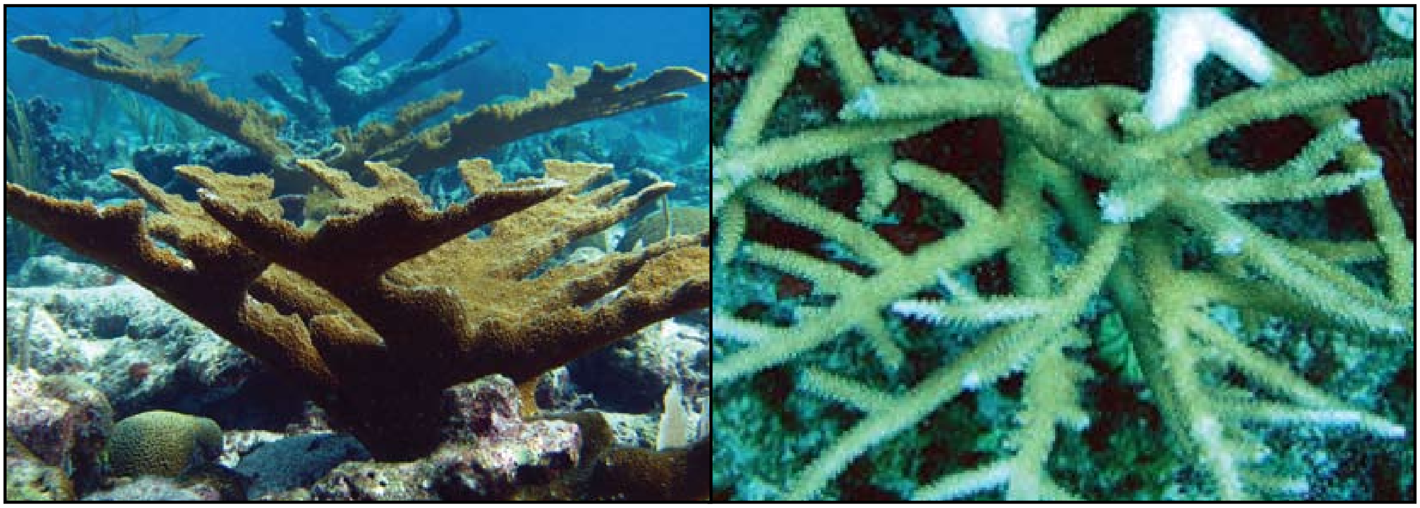


Figure 21. Two types of Acropora *species recorded in the study region (northeastern St. Croix):* Acropora palmata *(left) and* A. cervicornis *(right).*

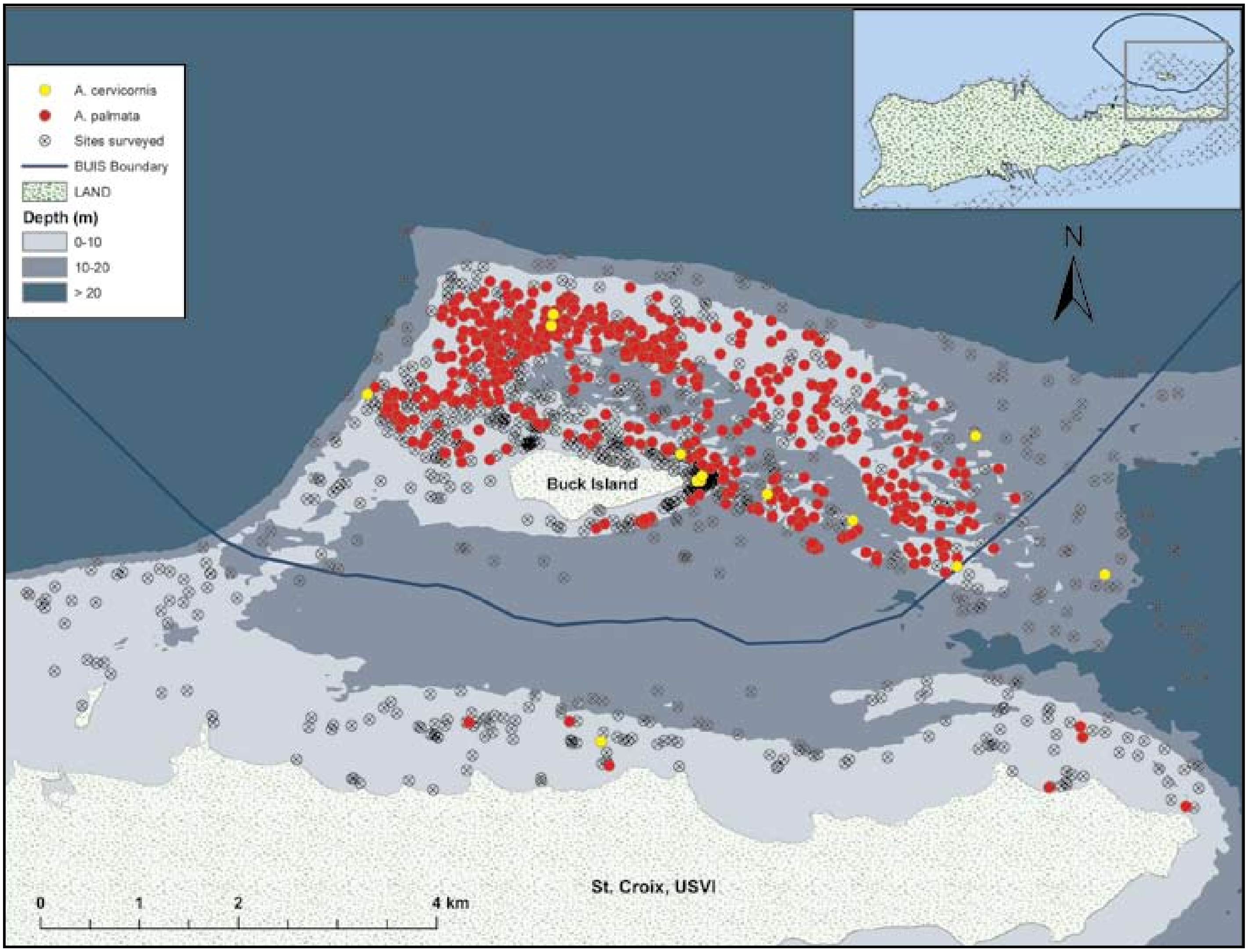


Figure 22. Spatial distribution of Acropora palmata *(red circles) and* A. cervicornis *(yellow circles) in St. Croix, U.S. Virgin Islands. Open circles indicate survey sites where* Acropora *corals were not observed. Source of Data: Mayor (2005) and NOAA Biogeography Branch database http://www8.nos.noaa.gov/biogeo_public/query_main.aspx*

*Blue tang (*A. coeruleus*) and* A. palmata

*Bar jacks (*C. ruber*)*

*Red hind (*E. guttatus*)*

3.2 Fish communities, groups and species

3.2.1 Fish community metrics

Fish biomass over colonized hardbottom habitat was significantly higher inside BIRNM for all (1) fish species combined and (2) all herbivorous fish (Figure 23). In contrast, mean biomass of piscivorous fish was lower inside BIRNM for all habitat types, although only significantly so over unvegetated sandy sediments (Figure 23). No significant difference was detected between inside and outside BIRNM for fish biomass over seagrasses.

Fish diversity (number of species, Shannon diversity and Taxonomic diversity) was highest over colonized hardbottom and lowest over unvegetated sediments and no differences were found between inside and outside BIRNM (Figure 24). In the study area overall, however, more fish species/species groups have been observed inside BIRNM than outside (201 inside and 182 outside).

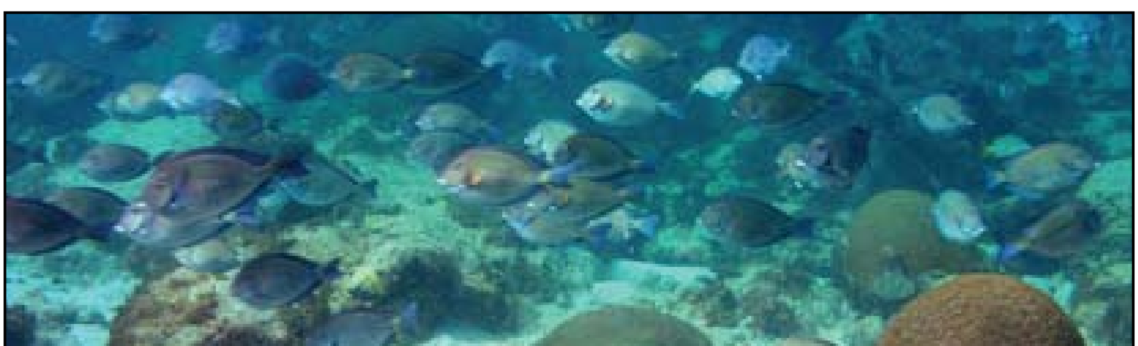
3.2.2 Fish community composition

nMDS plots and ANOSIM tests indicated that fish community composition between hard and soft habitat types was significantly different and well separated (Figure 25). Dissimilarities between sand and seagrasses were less distinct with considerable overlap (Table 8). Pairwise comparisons between the individual hardbottom habitat types revealed that fish communities were barely separable with substantial overlap. Highest dissimilarity existed between linear reefs and scattered coral. Fish community composition of aggregated patch reefs, linear reefs and colonized pavement were not significantly different (Table 8).

Much overlap was also found in fish community composition when also considering management domains. “R” values were very low (e.g., high similarity) when comparing the dominant softbottom habitat types inside versus outside BIRNM and even lower when comparing like hardbottom habitat types inside versus outside BIRNM (Figure 26 and Table 9). Although the null hypotheses of no difference was rejected (p=<0.05) for pairwise hardbottom habitat types, this is likely to be indicative of the high sample size rather than ecologically meaningful differences. The R value is a better relative indicator of the amount of dissimilarity between groups and is thus given greater emphasis here.

3.2.3 Fish groups

For all selected fish species groups and families (all Lutjanidae. [snapper], all Haemulidae. [grunts], all Scaridae [parrotfish], large-bodied Serranidae [groupers] species), mean density and biomass were highest on colonized hardbottom sites (Figure 26). Highest density and biomass were recorded for parrotfish. The most frequently observed species of parrotfish, with highest biomass were the redband parrotfish (*Sparisoma aurofrenatum*), the stoplight parrotfish (*Sparisoma viride*) and the striped parrotfish (*Scarus iseri*; Table 10). When management domains were considered, parrotfish exhibited significantly higher mean biomass inside BIRNM over colonized hardbottom.



Assemblage of Acanthuridae species

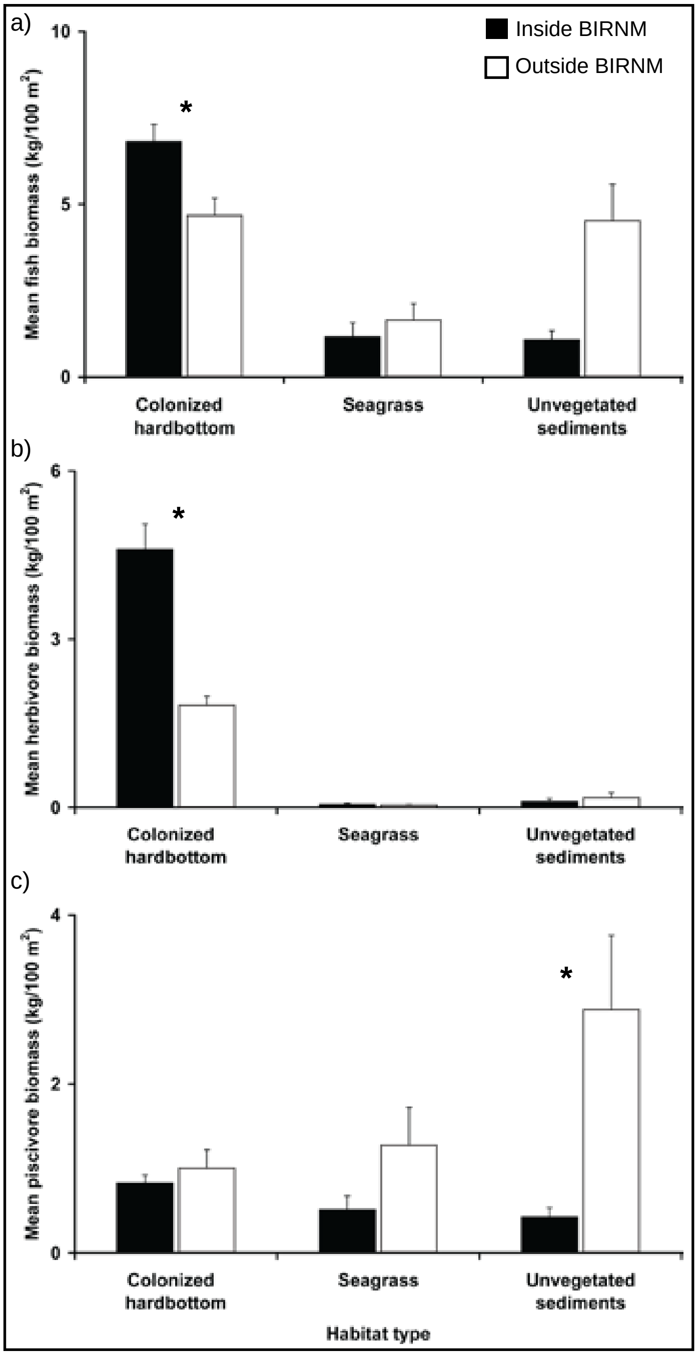


Figure 23. Comparison of mean (± SE) values inside versus outside BIRNM for: (a) biomass of all species; (b) biomass of all herbivores; and (c) biomass of all piscivores including sharks and rays. Asterisks (*) indicate a statistically significant difference between inside and outside.

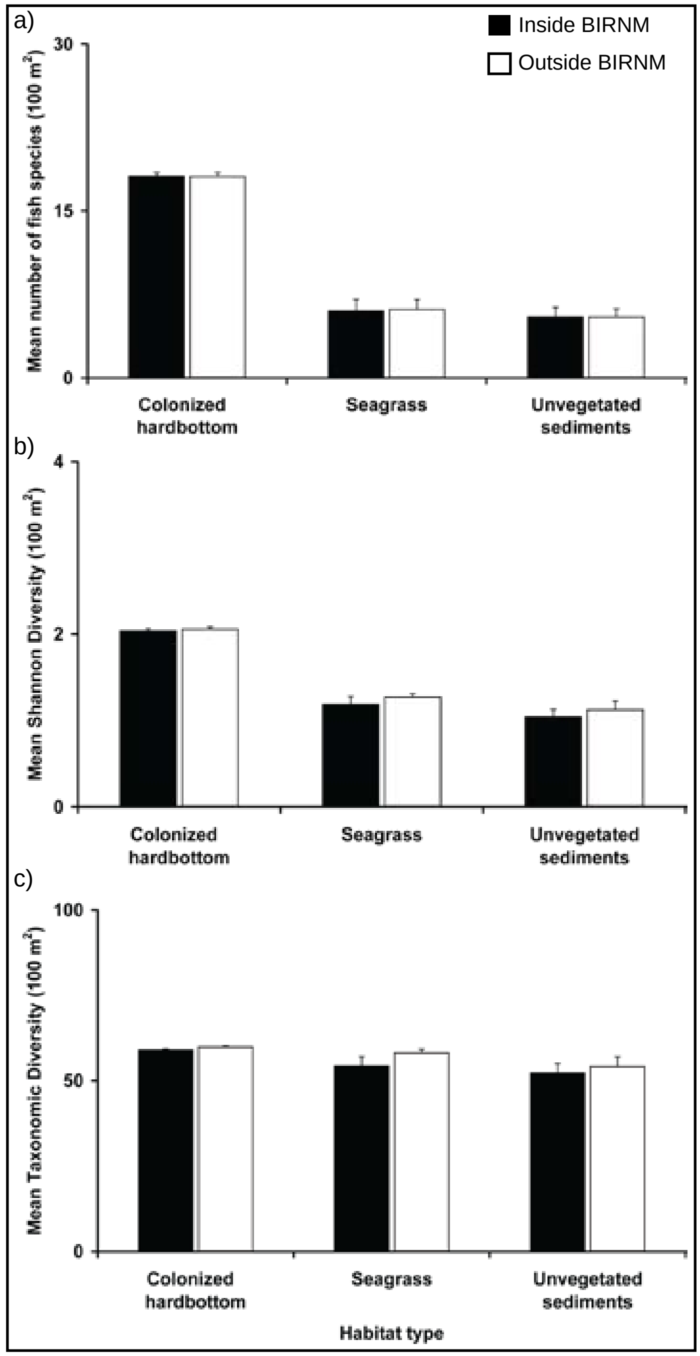


Figure 24. Comparison of mean (± SE) values inside versus outside BIRNM for: (a) number of fish species; (b) Shannon-Weiner diversity (H') using abundance data; and (c) taxonomic diversity using presence-absence data. Asterisks (*) indicates a statistically significant (p=<0.05) difference between inside and outside.

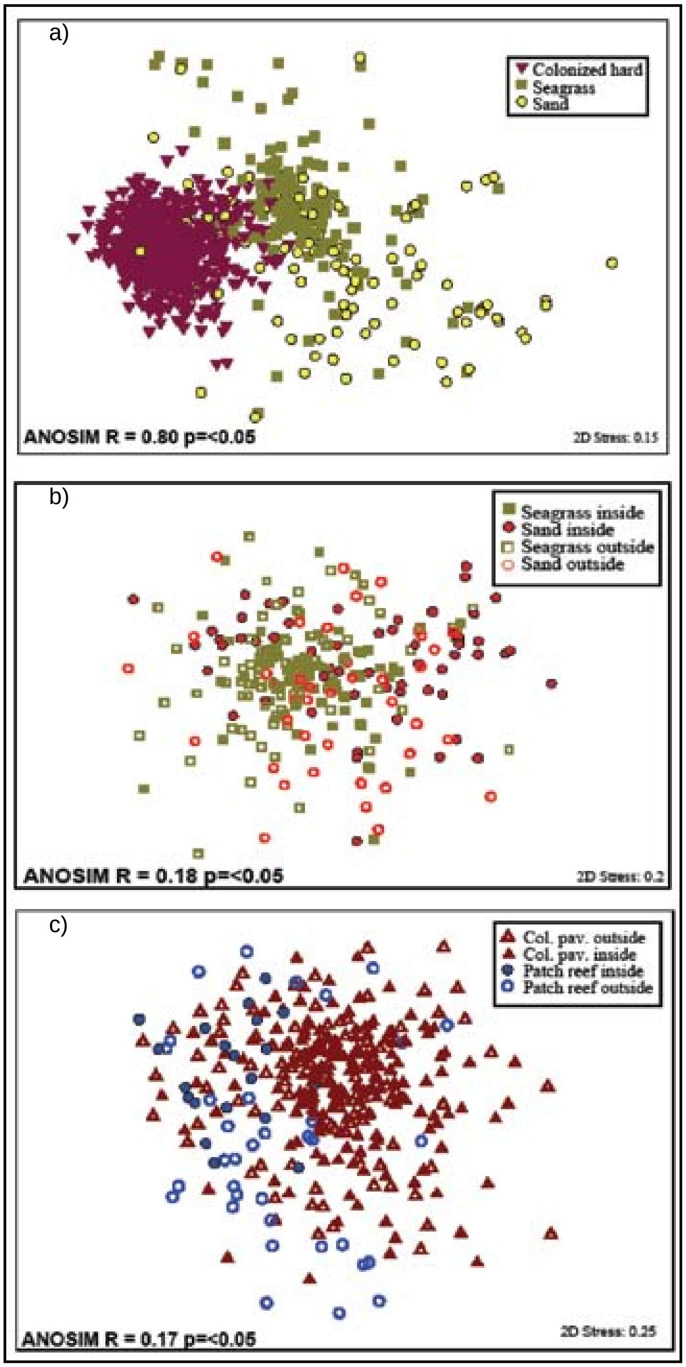


Figure 25. Non-metric multidimensional ordination based on between site similarity in fish community composition using species biomass data. (a) Community similarities by habitat structure; (b) community similarities by dominant softbottom habitat type inside versus outside BIRNM; and (c) community similarities by dominant hardbottom habitat types inside versus outside BIRNM.

Table 8. Results of ANOSIM test for significant difference in fish community composition using species biomass between samples grouped by habitat type. R<0.25 = barely separable; R<0.05 = overlapping, but clearly different. Asterisks (*) indicates null hypothesis of no difference rejected at p=<0.05. Agg= aggregated, Ind= individual.

Habitat pairs	ANOSIM *R*
Between major habitat types	
Global - all pairs*	0.80
Sand and Seagrass*	0.19
Sand and Colonized Hard*	0.83
Seagrass and Colonized Hard*	0.84
Amongst Colonized Hard	
Global - all pairs*	0.19
Linear reef and Scattered coral/rock*	0.31
Colonized pavement and Patch reef (Ind)*	0.29
Colonized pavement and Linear reef*	0.18
Colonized pavement and Scattered coral/rock*	0.28
Patch reef (Agg) and Linear reef	<0.01
Colonized pavement and Patch reef (Agg)*	0.13
Patch reef (Ind) and Linear reef*	0.14
Patch reef (Agg) and Scattered coral/rock*	0.17
Patch reef (Ind) and Scattered coral/rock*	0.11
Patch reef (Agg) and Patch reef (Ind)	0.04

Table 9. ANOSIM test for significant difference in fish community composition using species biomass between samples grouped by habitat type and management domain (inside/outside BIRNM). R<0.25 = barely separable; R<0.05 = overlapping, but clearly different. Asterisks (*) indicates null hypothesis of no difference rejected at p=<0.05.

Habitat pairs	**ANOSIM *R***
Sand Inside and Sand Outside	0.06
Seagrass Inside and Seagrass Outside	0.07
Col. pavement Inside and Col. pavement Outside*	0.04
Patch reef Inside and Patch reef Outside	0.05
All colonized hard Inside and All Colonized hard Outside*	0.04

Grouper were almost entirely found over colonized hardbottom, with very few individuals over seagrasses (Figure 26). Neither mean density nor mean biomass were significantly different inside versus outside BIRNM. The most frequently observed species of grouper were the coney (*Cephalopholis fulva*) at 32.4% of transects, red hind (*Epinephelus guttatus*) at 18.1% of transects and graysby (*Cephalopholis cruentata*) at 4.2% of transects (Appendix C). All other species of large-bodied serranids were relatively rare within the surveyed region. For example, only one tiger grouper (*Mycteroperca tigris*), three Nassau grouper (*Epinephelus striatus*) and three yellowfin grouper (*Mycteroperca venenosa*) were observed in 1,275 surveys over six years (Appendix C).

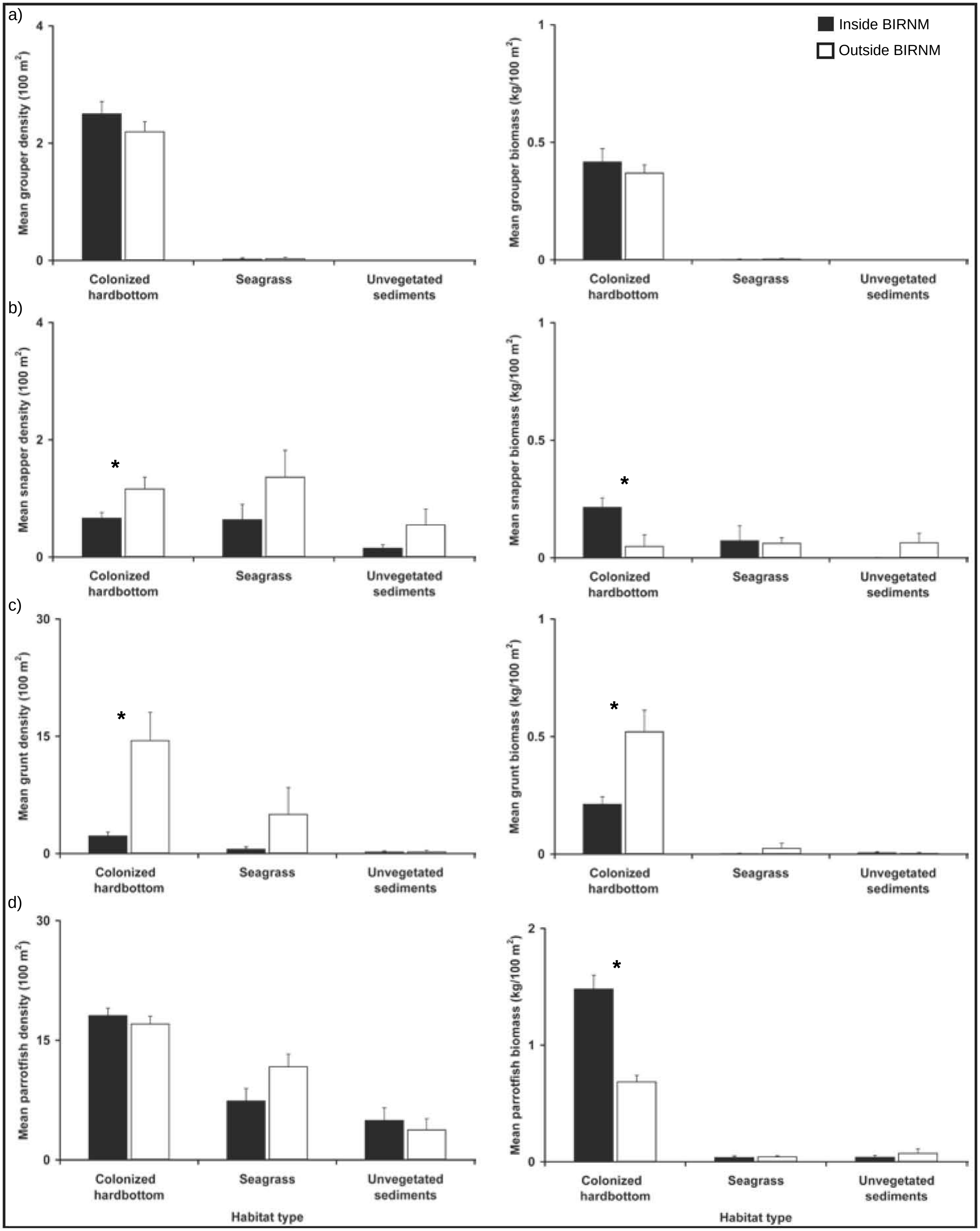


Figure 26. Comparison of mean (± SE) density and biomass inside versus outside BIRNM for: (a) grouper, (b) snapper, (c) grunt and (d) parrotfish. Asterisks (*) indicate a statistically significant difference between inside and outside.

Table 10. Twenty most frequently observed species in the CREM Buck Island survey area. For full species list see Appendix C. Fish surveys from http://ccmaserver.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html.

Species name	Common name	Total occurrence	% occurrence	Total abundance	Mean abundance (± SE)	Total biomass, kg	Mean biomass, kg (± SE)
Halichoeres bivittatus	Slippery dick	933	73.2	24752	19.4 (1.8)	97.96	0.08 (<0.01)
Thalassoma bifasciatum	Bluehead wrasse	777	60.9	32001	25.1 (1.2)	46.06	0.04 (<0.01)
Acanthurus bahianus	Ocean surgeonfish	762	59.8	8601	6.7 (0.36)	540.37	0.42 (0.04)
Sparisoma aurofrenatum	Redband parrotfish	669	52.5	4887	3.8 (0.18)	240.21	0.19 (0.01)
Stegastes partitus	Bicolor damelfish	624	48.9	10202	8.0 (0.44)	17.76	0.01 (<0.01)
Acanthurus coeruleus	Blue tang	595	46.7	8597	6.7 (0.65)	904.14	0.71 (0.08)
Halichoeres garnoti	Yellowhead wrasse	586	46.0	4658	3.7 (0.19)	34.69	0.03 (<0.01)
Sparisoma viride	Stoplight parrotfish	460	36.1	2456	1.9 (0.11)	331.90	0.26 (0.02)
Scarus iseri	Striped parrotfish	434	34.0	4761	3.7 (0.28)	74.27	0.06 (<0.01)
Halichoeres maculipinna	Clown wrasse	432	33.9	2176	1.7 (0.11)	10.19	0.01 (<0.01)
Cephalopholis fulva	Coney	413	32.4	1391	1.1 (0.07)	193.13	0.15 (0.01)
Stegastes leucostictus	Beaugregory	378	29.6	3991	3.1 (0.25)	12.88	0.01 (<0.01)
Carangoides ruber	Bar jack	364	28.5	1735	1.4 (0.17)	57.87	0.05 (<0.01)
Haemulon flavolineatum	French grunt	357	28.0	1944	1.5 (0.26)	107.19	0.08 (<0.01)
Serranus tigrinus	Harlequin bass	349	27.4	713	0.56 (0.03)	5.55	0.00 (<0.01)
Holocentrus rufus	Longspine squirrelfish	321	25.2	574	0.45 (0.03)	65.19	0.05 (<0.01)
Scarus taeniopterus	Princess parrotfish	318	24.9	1713	1.3 (0.10)	72.30	0.06 (<0.01)
Coryphopterus glaucofraenum	Bridled goby	302	23.7	1670	1.3 (0.11)	1.49	0.00 (<0.01)
Pseudupeneus maculatus	Spotted goatfish	297	23.3	915	0.72 (0.08)	72.22	0.06 (<0.01)
Microspathodon chrysurus	Yellowtail damselfish	272	21.3	1158	0.91 (0.08)	77.58	0.06 (<0.01)

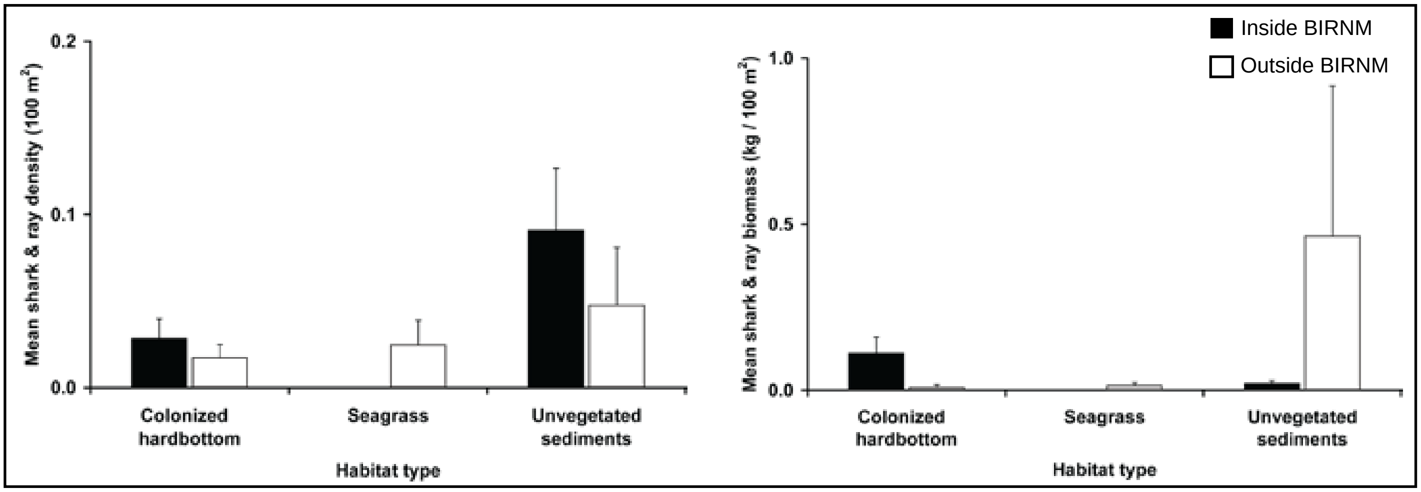


Figure 27. Comparison of mean (± SE) density and biomass inside versus outside BIRNM for sharks and rays. Asterisks (*) indicate a statistically significant difference between inside and outside.

Yellowtail snapper (*Ocyurus chrysurus*) was the most commonly observed lutjanid recorded at 20.4% of transects; mahogany snapper (*Lutjanus mahogoni*) at 3.4% and schoolmaster snapper (*Lutjanus apodus*) at 3.3% (Appendix C). Thirteen species of grunt (Haemulidae) were identified, with French grunt (*Haemulon flavolineatum*) the most commonly observed at 28% of transects followed by bluestriped grunt (*Haemulon sciurus*) at 4.3% of transects and tomtate (*Haemulon aurolineatum*) at 4.2% of transects (Appendix C).

Snapper and grunt density were higher outside BIRNM in all habitat types, although the difference was only statistically significant for colonized hardbottom. Mean biomass of snapper over colonized hardbottom and seagrasses was slightly higher inside BIRNM, but was not significantly different to the outside (Figure 26). Biomass of grunts, however, was significantly higher over colonized hardbottom outside BIRNM (Figure 26). Sharks and rays exhibited highest mean density and biomass over unvegetated sandy sediments (Figure 27). Although, only observed infrequently across the region, mean shark and ray density was higher over sand inside BIRNM than outside, but mean biomass was higher outside than inside BIRNM. None of the differences were significantly different. In total, 40 rays were recorded: three spotted eagle rays (*Aetobatus narinari*), 37 southern stingrays (*Dasyatis americana*), and nine nurse sharks (*Ginglymostoma cirratum*; Appendix C).

*Nurse shark (*Ginglymostoma cirratum*)*

3.2.4 Individual species

In the northeastern St. Croix study region, 201 fish species from 56 families have been positively identified using visual census and underwater photography. A further 26 fish types were identified to family only. Only selected species are examined at the individual species level herein, including species of special interest to NPS, those that were potentially threatened by overfishing and those that were dominant components of the fish community across the region.

Mean biomass for the two most abundant grouper species was higher inside BIRNM, with biomass and abundance of coney being significantly higher over colonized hardbottom habitat types inside (Figure 28).

None of the three most abundant snapper species were significantly different when comparing biomass and density inside versus outside BIRNM (Figure 29). Although not statistically significant, mean biomass of yellowtail snapper was markedly higher inside than outside, particularly over colonized hardbottom. Of note, was that yellowtail snapper were observed in all three major habitat types. In contrast, schoolmaster snapper and gray snapper (*Lutjanus griseus*) were found primarily over colonized hardbottom habitat types.

In general, French grunt and bluestriped grunt density and biomass were higher outside BIRNM (Figure 30). This was statistically significant for French grunt biomass and bluestriped grunt density. Assessment of differences for grunt, however, is hampered by the fact that 3,419 grunts were identified only to family; primarily small juveniles that can be very similar in appearance between species.

For abundant herbivore species, blue tang (*Acanthurus coeruleus*) and striped parrotfish biomass were significantly higher inside BIRNM over colonized hardbottom (Figure 31). Redband parrotfish density and biomass was very similar inside and outside BIRNM. Comparatively few individuals of the abundant herbivores were observed over seagrasses or sand.

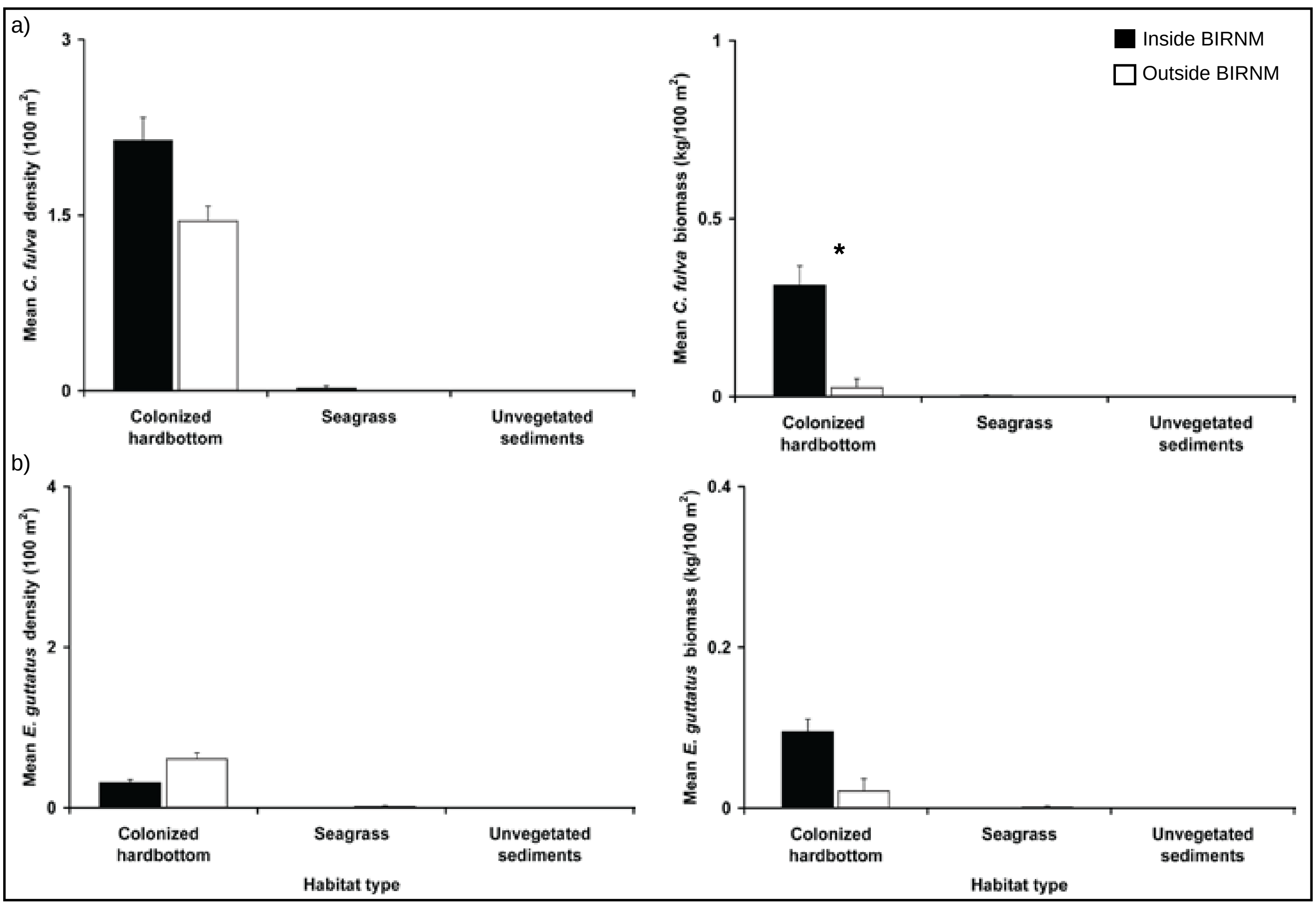


*Figure 28. Comparison of mean (± SE) density and biomass inside versus outside BIRNM for two grouper species: (a) coney (*C. fulva*) and (b) red hind (*E. guttatus*). Asterisks (*) indicate a statistically significant difference between inside and outside.*

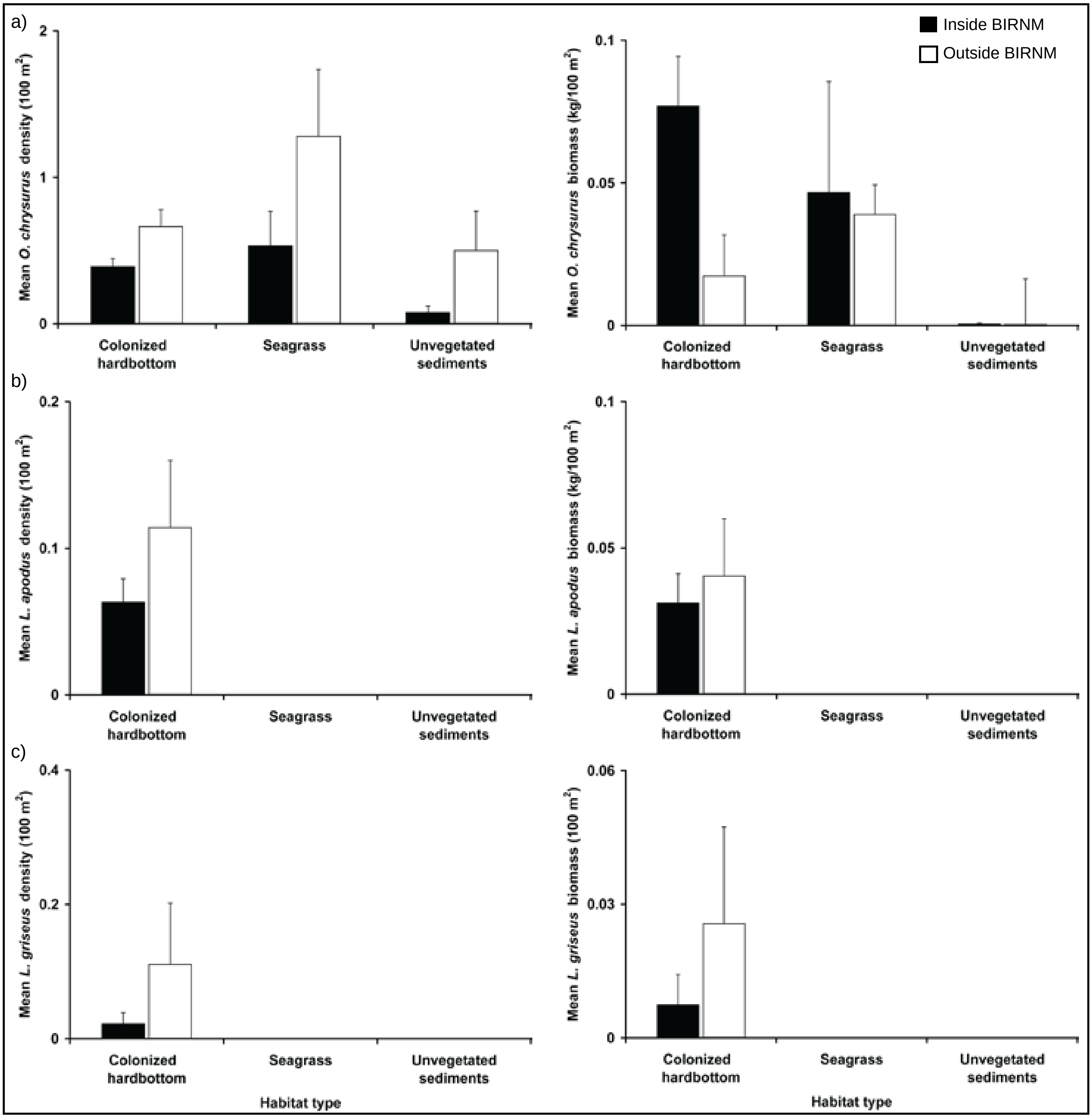


*Figure 29. Comparison of mean (± SE) density and biomass inside versus outside BIRNM for three snapper species: (a) yellowtail snapper (*O. chrysurus*), (b) schoolmaster (*L. apodus*) and (c) gray snapper (*L. griseus*). Asterisks (*) indicate a statistically significant difference between inside and outside.*

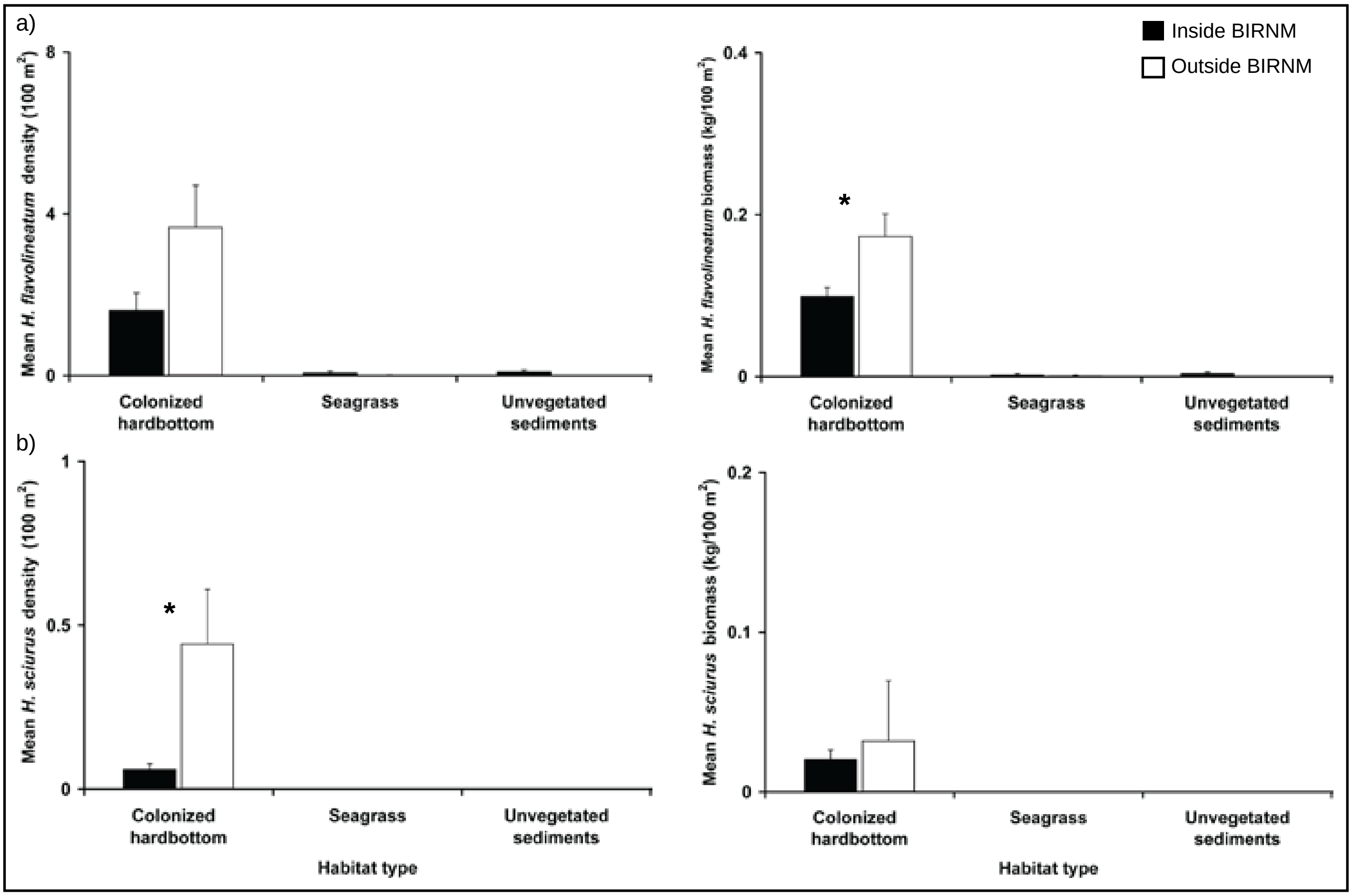


*Figure 30. Comparison of mean (± SE) density and biomass inside versus outside BIRNM for two grunt (Haemulidae) species: (a) French grunt (*H. flavolineatum*) and (b) bluestriped grunt (*H. sciurus*). Asterisks (*) indicate a statistically significant difference between inside and outside.*

*French grunts (*Haemulon flavolineatum*)*

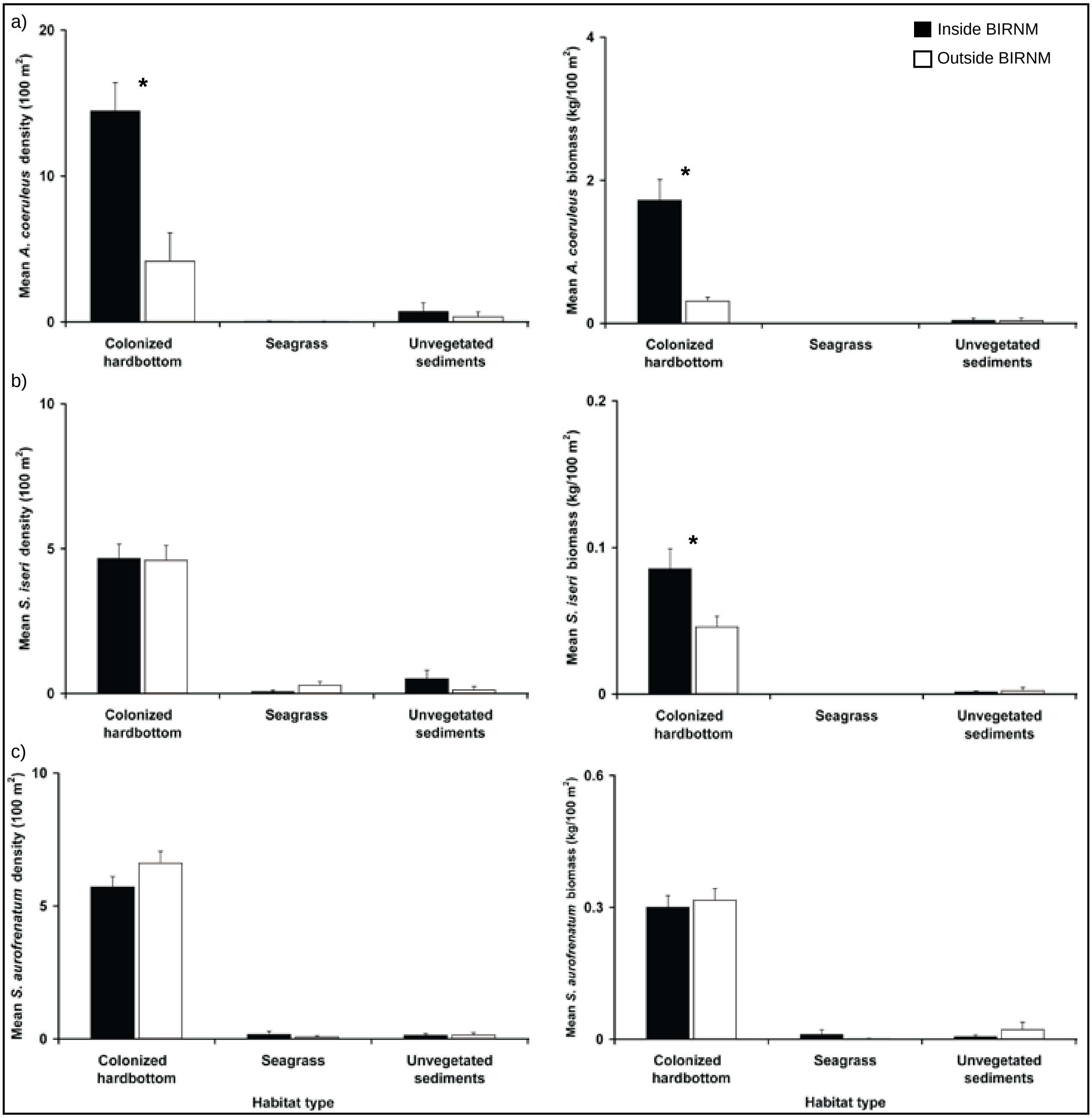


*Figure 31. Comparison of mean (± SE) density and biomass inside versus outside BIRNM for three numerically dominant herbivore species: (a) blue tang (*A. coeruleus*), (b) striped parrotfish (*S. iseri*) and (c) redband parrotfish (*S. aurofrenatum*). Asterisks (*) indicate a statistically significant difference between inside and outside.*

3.2.5 Spatial distribution patterns and species habitat associations

Twenty-five or more fish species were recorded at 100 sites, 62 of these high fish species richness sites were located within BIRNM and 38 were located outside BIRNM, but within 2 km of the current boundary. Fish species richness (number of species) hotspots were associated with shallow-water hardbottom habitat types and were located both within and outside BIRNM (Figure 32). The largest continuous area of high fish species richness existed around the eastern end of the Buck Island fringing reef comprising an interspersion of patches of linear reef, patch reef, colonized pavement and scattered coral. This included much of the area of the original "marine garden" zones. A second region of high fish species richness, however, also existed to the south of Buck Island immediately south of BIRNM, along the northern shore of St. Croix. This area comprised a similar range of hardbottom habitat types including linear reef, patch reef, colonized pavement and scattered coral, extending east to west alongside large expanses of seagrasses on both the north and south sides. Overlaying these high fish species richness sites on the NOAA benthic habitat map and measuring proximity

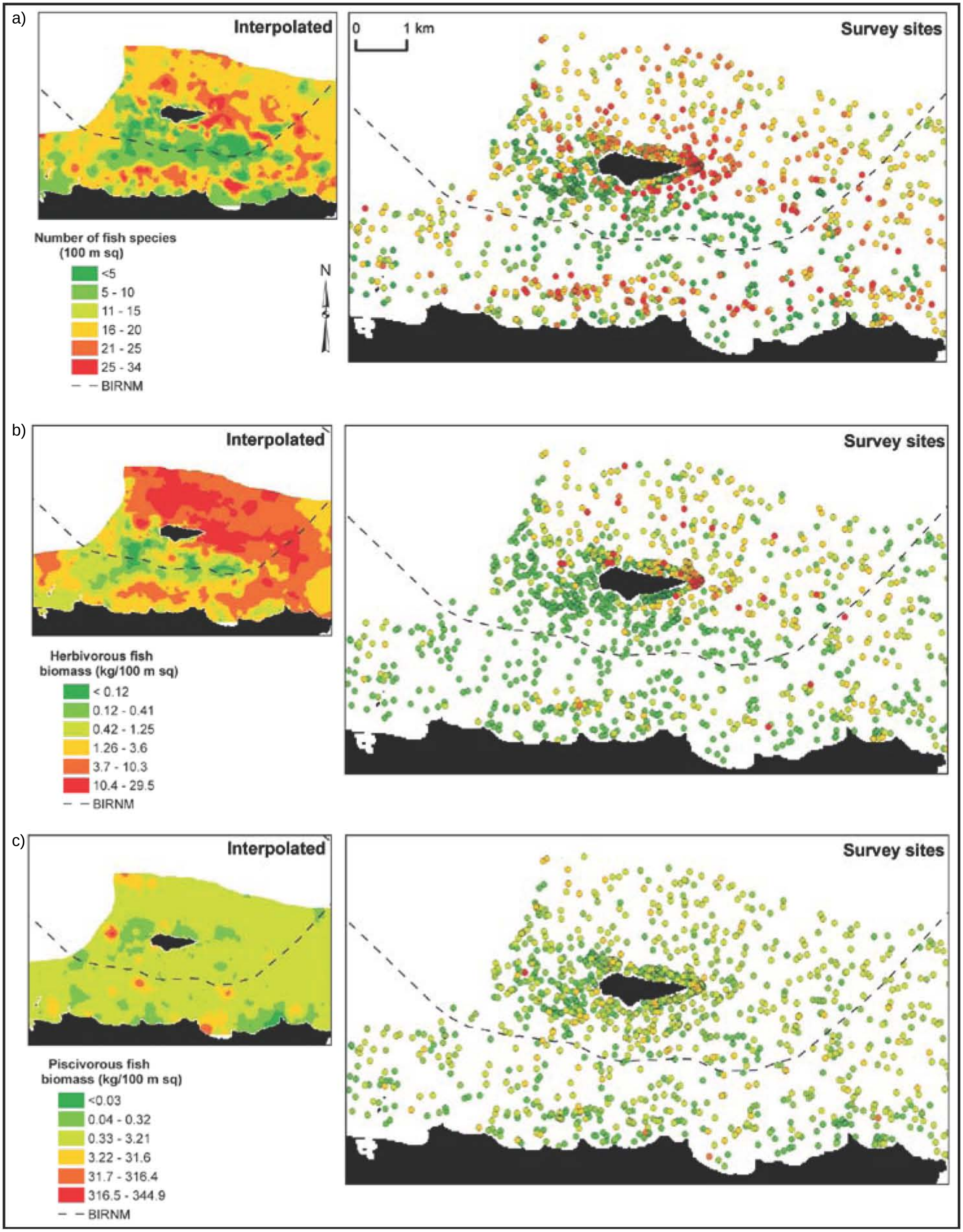


Figure 32. Interpolated spatial surfaces representing (a) number of fish species; (b) herbivorous fish biomass; and (c) piscivorous fish biomass using 1,275 samples.

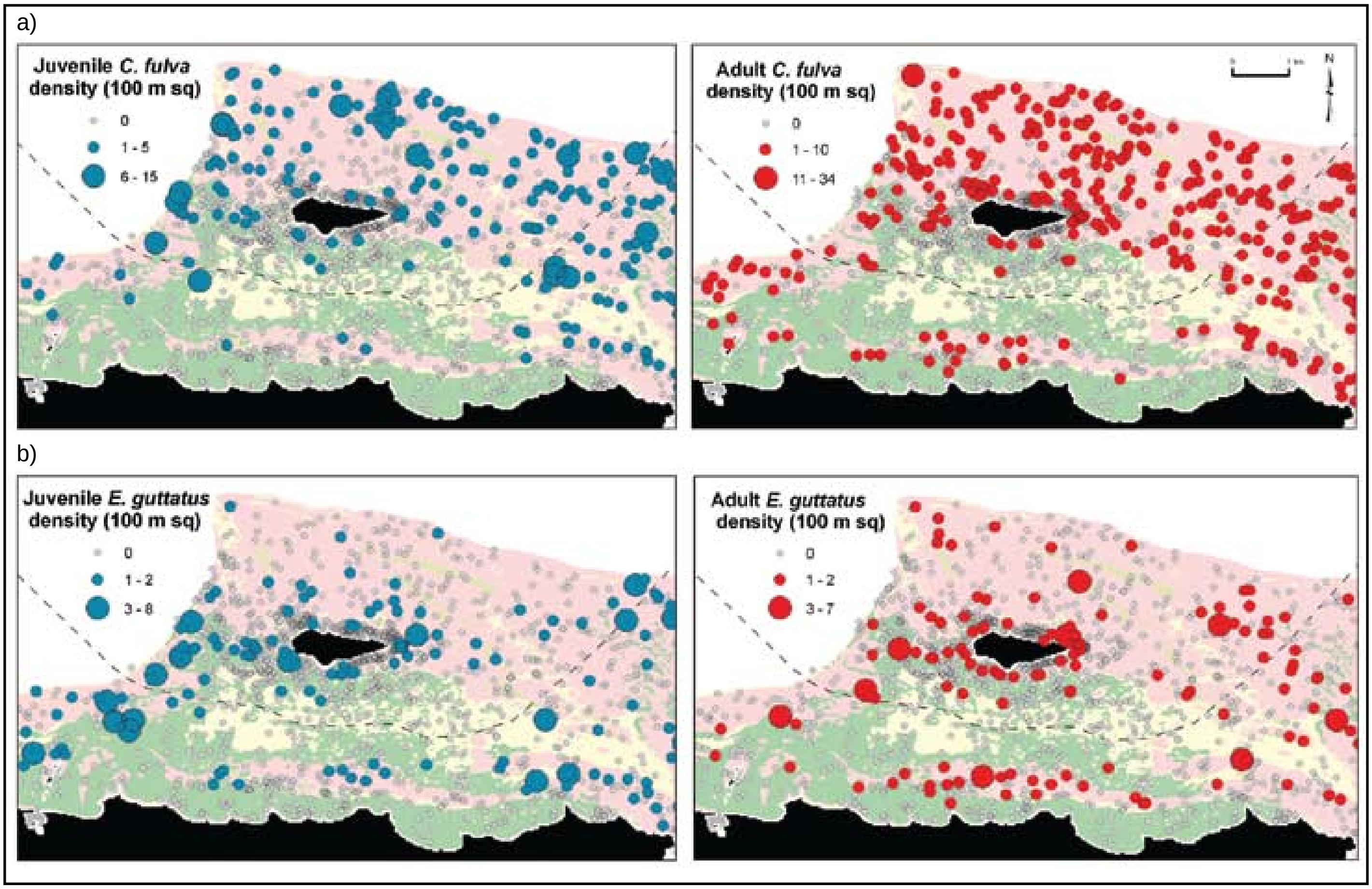


*Figure 33. Spatial distributions of juvenile and adult (a) coney (*C. fulva*) and (b) red hind (*E. guttatus*) in northeastern St. Croix.*

from sampling point to nearest seagrass beds revealed that approximately 80% of all high (=>30 species) fish species richness sites on coral reefs were within 200 m of seagrass beds.

The spatial distribution of herbivore biomass as represented by interpolation of transect data revealed a distinctive area of high herbivore biomass over much of the hardbottom habitat in the region, but especially high at the eastern end of the Buck Island fringing reef and to the north of Buck Island over scattered coral and branching coral dominated pavement (Figure 32). Lowest herbivore biomass was over sand and seagrasses farthest from hardbottom, creating an interior effect in the spatial surface of herbivore biomass over softbottom habitat types. High herbivore biomass was also estimated for the coral reefs along the northern shore of St. Croix, south of Buck Island.

Piscivore biomass was biased toward high biomass hotspots created by sharks (e.g. large-bodied fish predators). Otherwise, no distinctive hotspots were seen. Large areas of low piscivore biomass existed around the north shore of Buck Island and at several inshore locations along the north shore of St. Croix (Figure 32).

Spatial distributions for juveniles and adults of specific fish species show some individualistic species-specific and life-stage specific patterns. Coney juveniles and adults were widespread across hardbottom habitats, with both utilizing similar habitat types (Figure 33). Highest mean density for juveniles and adults was recorded for the most structurally complex coral reef habitat types including colonized pavement (0.75 and 1.83/100 m^2), linear reef (0.63 and 0.63/100 m^2) and aggregated patch reef (0.31 and 0.54/100 m^2; Figure 34). Juveniles and adults also were observed over less rugose reef rubble (0.52 and 0.61/100 m^2) and scattered coral and rock habitat types (0.45 and 0.53/100 m^2). Very few coney were observed over seagrasses and sand (0 and <0.01/100 m^2). Red hind were less abundant than coney over the large expanse of coral reef north of Buck Island, with distributions more closely associated with complex coral reef habitat types fringing Buck Island, and areas south and east of BIRNM (Figure 34). Highest mean density for adults was recorded for colonized pavement (0.31/100 m^2), patch reefs (0.23/100 m^2) and scattered coral and rock (0.19/100 m^2). Juvenile densities were highest for colonized pavement (0.36/100 m^2), scattered coral/rock (0.27/100 m^2) and reef rubble (0.23/100 m^2; Figure 34).

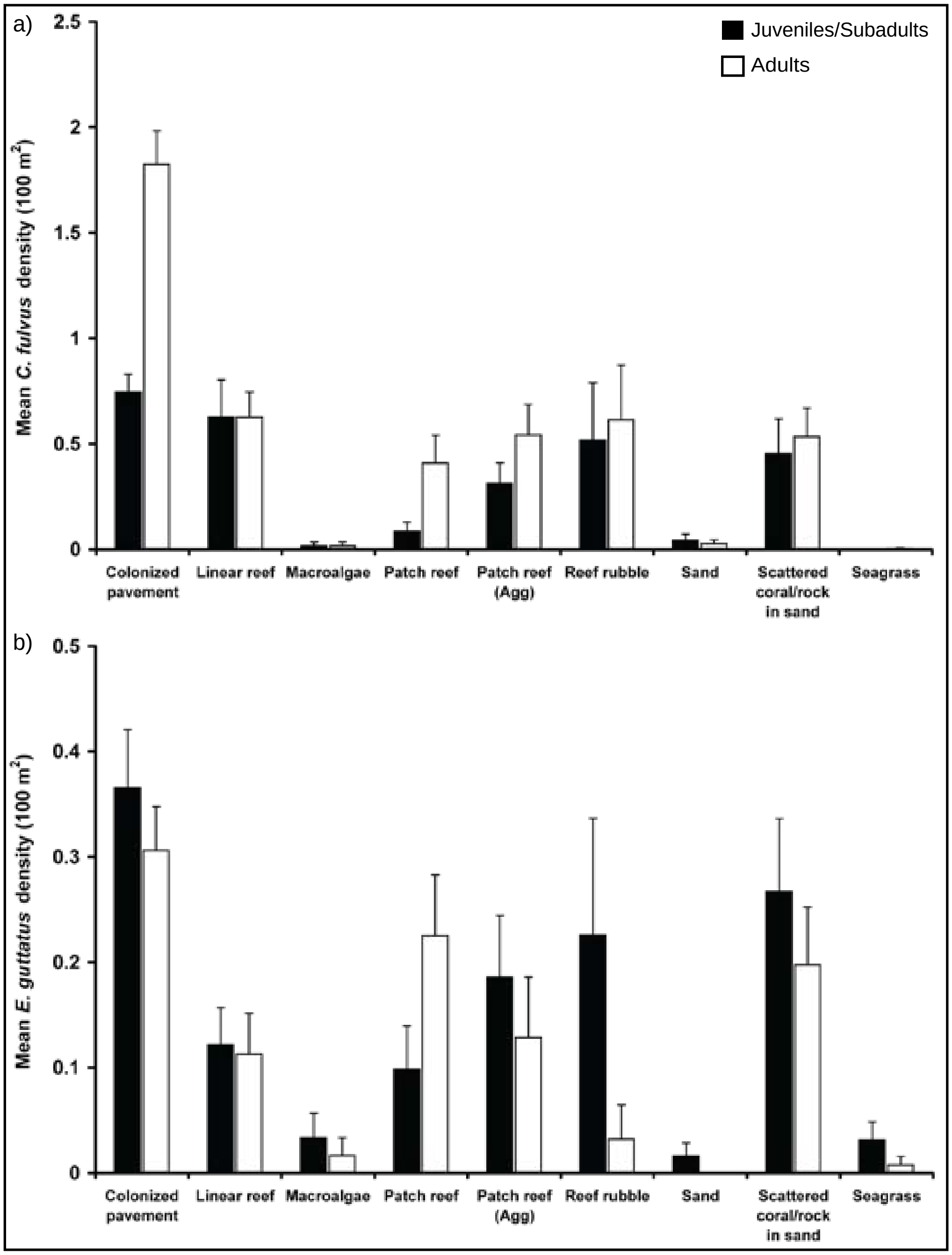


*Figure 34. Mean (± SE) density for juvenile/subadult and adult by observer habitat type for (a) coney (*C. fulva*) and (b) red hind (*E. guttatus*).*

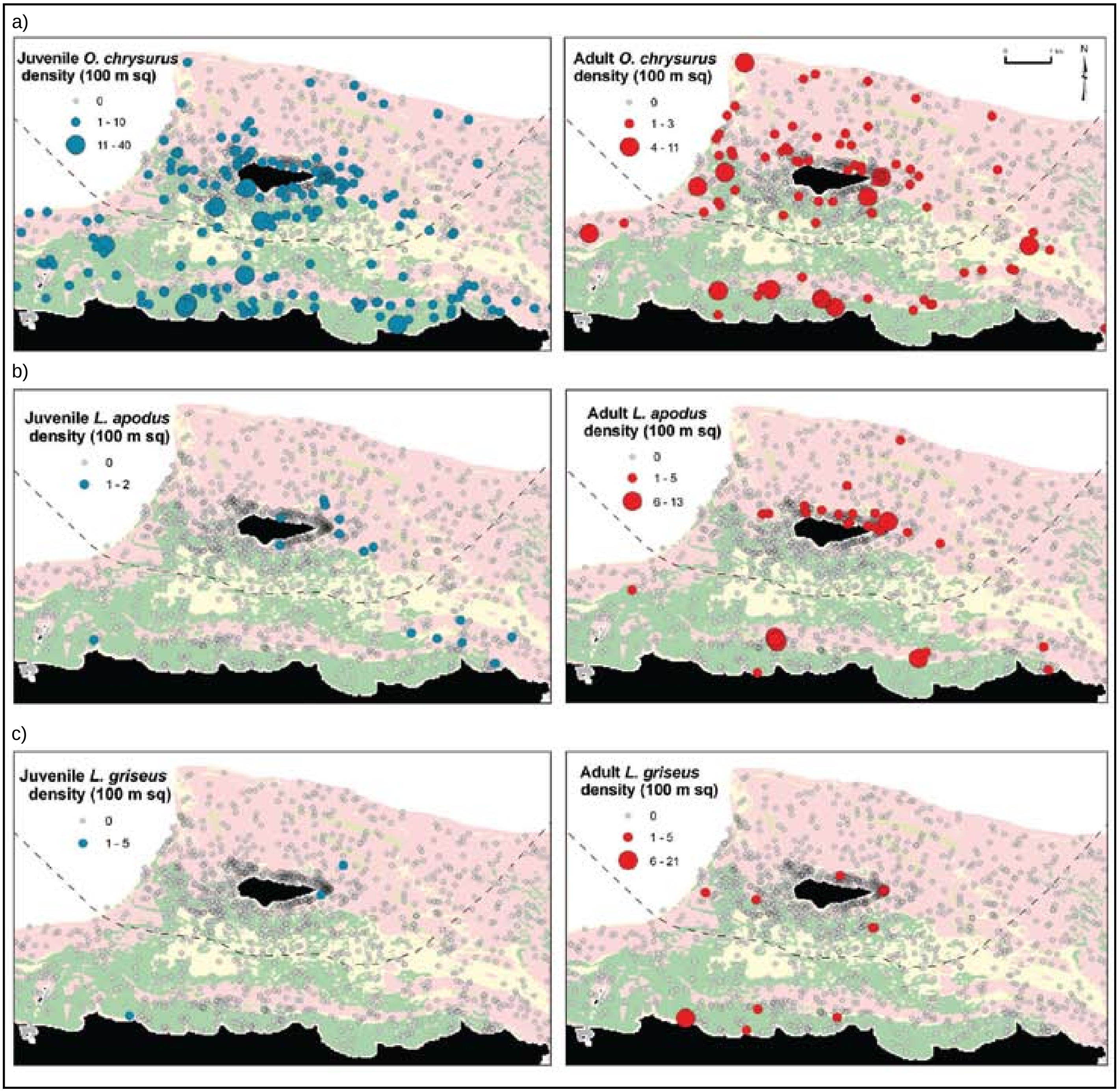


*Figure 35. Spatial distribution of juvenile and adult: (a) yellowtail snapper (*O. chrysurus*), (b) schoolmaster (*L. apodus*) and (c) gray snapper (*L. griseus*) in northeastern St. Croix.*

Juvenile yellowtail snapper were associated with all benthic habitat types, with highest mean density over patch reefs (0.94/100 m^2) and seagrasses (0.88/100 m^2). Spatially, juveniles were most abundant in shallow inshore waters around Buck Island and along the north coast of St. Croix outside BIRNM (Figure 35 and Figure 36). Adults used a similar range of habitat types, but were less frequently observed and occurred in lower densities. Highest adult densities were recorded for aggregated patch reefs (0.33/100 m^2). Juvenile schoolmaster snapper and gray snapper were infrequently observed in the study region (Figure 36 and Appendix C). Adults were slightly more abundant than juveniles, but relatively localized in distribution to the north shore of Buck Island and several locations along the St. Croix shoreline (Figure 35). Schoolmaster snapper adults were observed in all hardbottom habitat types, with highest density in aggregated patch reefs (0.29/100 m^2) and linear reefs (0.18/100 m^2; Figure 36). Mean density of adult gray snapper was highest in patch reefs (0.01/100 m^2).

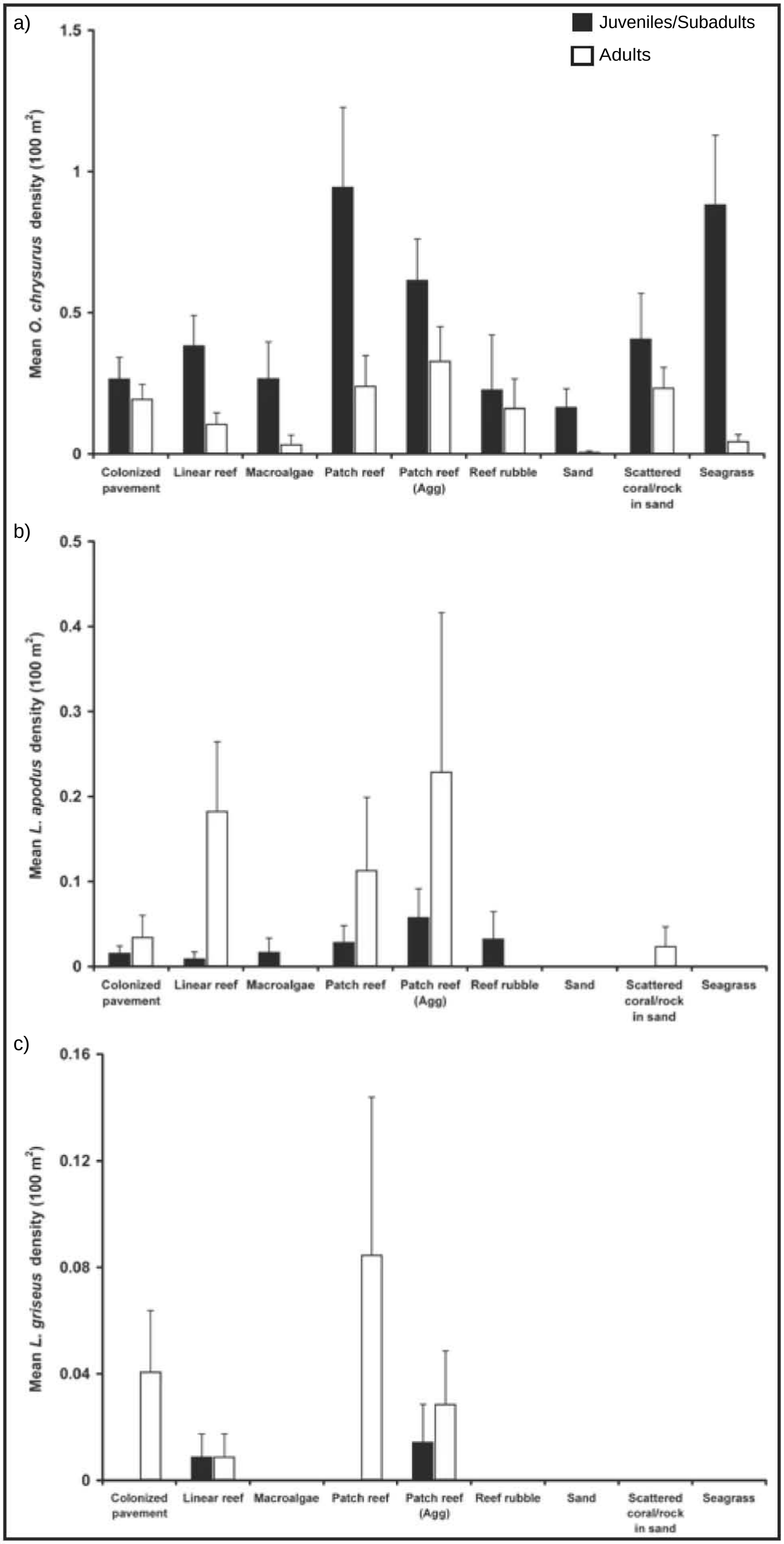


Figure 36. Mean (± SE) density for juvenile/subadult and adult by observer habitat type for: (a) yellowtail snapper (O. chrysurus), (b) schoolmaster (L. apodus) and (c) gray snapper (L. griseus).

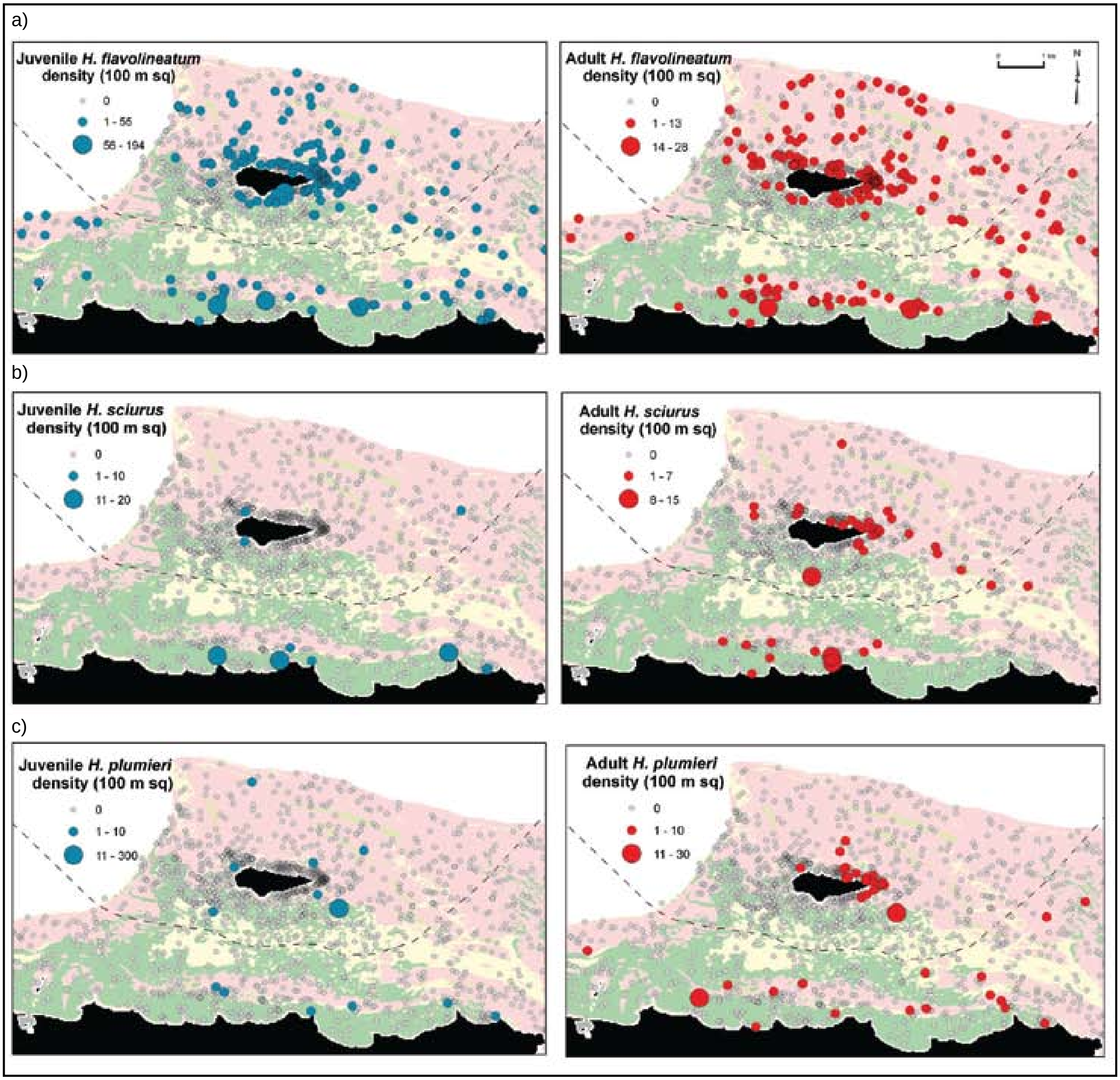


*Figure 37. Spatial distributions of juvenile and adult: (a) French grunt (*H. flavolineatum*), (b) bluestriped grunt (*H. sciurus*) and (c) white grunt (*H. plumierii*) in northeastern St. Croix.*

French grunt were the most widely distributed of the haemulids (Figure 37), found in all hardbottom habitat types (Figure 38). Similar habitat associations and spatial distributions were observed for both juveniles and adults, which exhibited highest densities over aggregated patch reefs (5.13 and 0.9/100 m^2), patch reefs (3.1 and 1.4/100 m^2), scattered coral/rock (2.67 and 0.57/100 m^2) and linear reef (2.60 and 1.08/100 m^2). Highest occurrence was recorded around the shallow fringing mosaic of habitats surrounding Buck Island (Figure 37). The majority of bluestriped grunt and white grunt (*Haemulon plumierii*) were found either in close proximity to Buck Island or to the south of Buck Island in shallow water hardbottom habitats that exist in close proximity to seagrasses. Very few individuals were found in the northern portion of the mapped BIRNM (Figure 37). Highest densities of juvenile and adult bluestriped grunt (0.60 and 0.67/100 m^2) and white grunt (4.35 and 0.51/100 m^2) were observed over patch reefs (Figure 38).

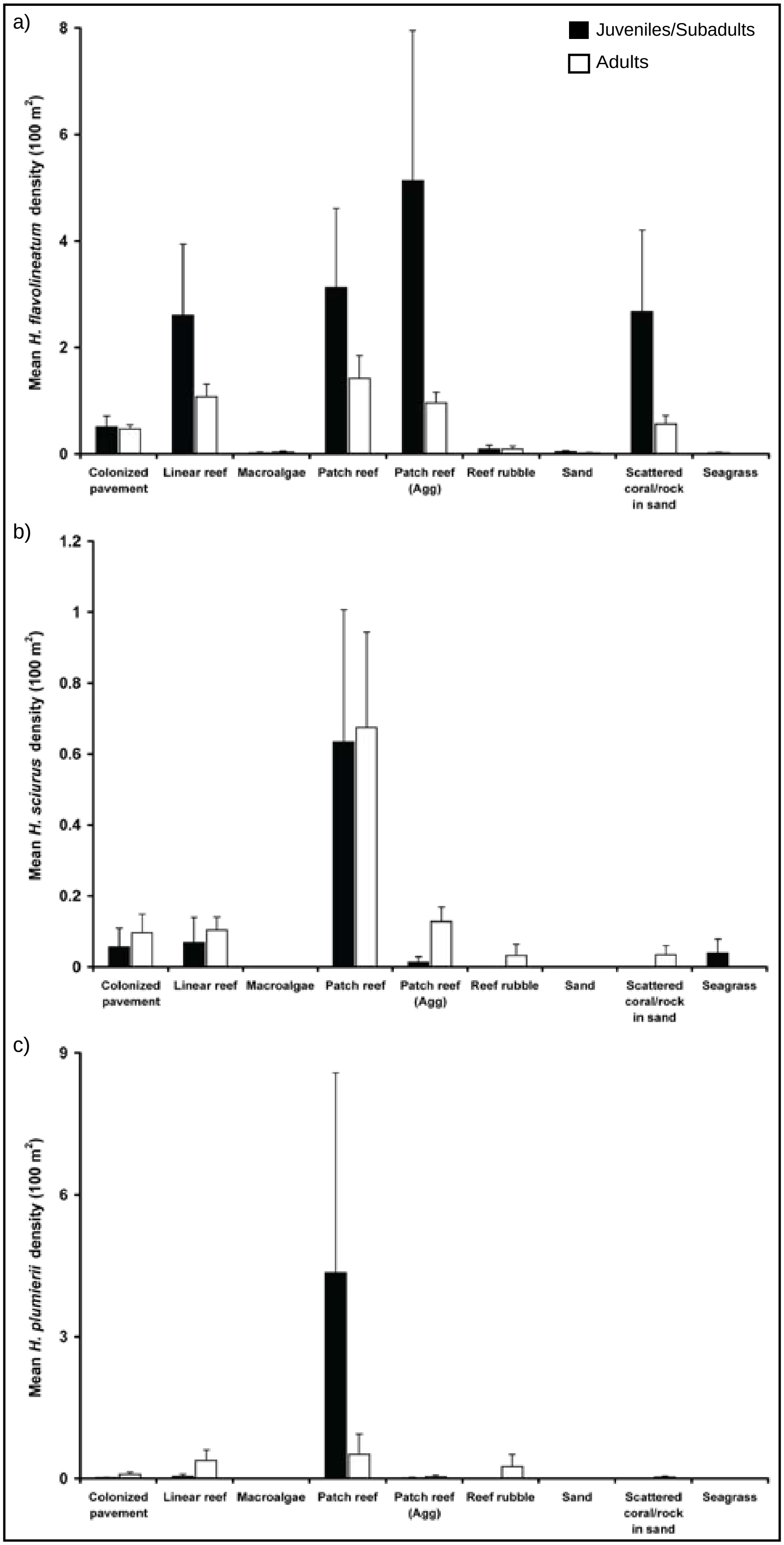


*Figure 38. Mean (± SE) density for juvenile/subadult and adult by observer habitat type for: (a) French grunt (*H. flavolineatum*), (b) bluestriped grunt (*H. sciurus*) and (c) white grunt (*H. plumierii*).*

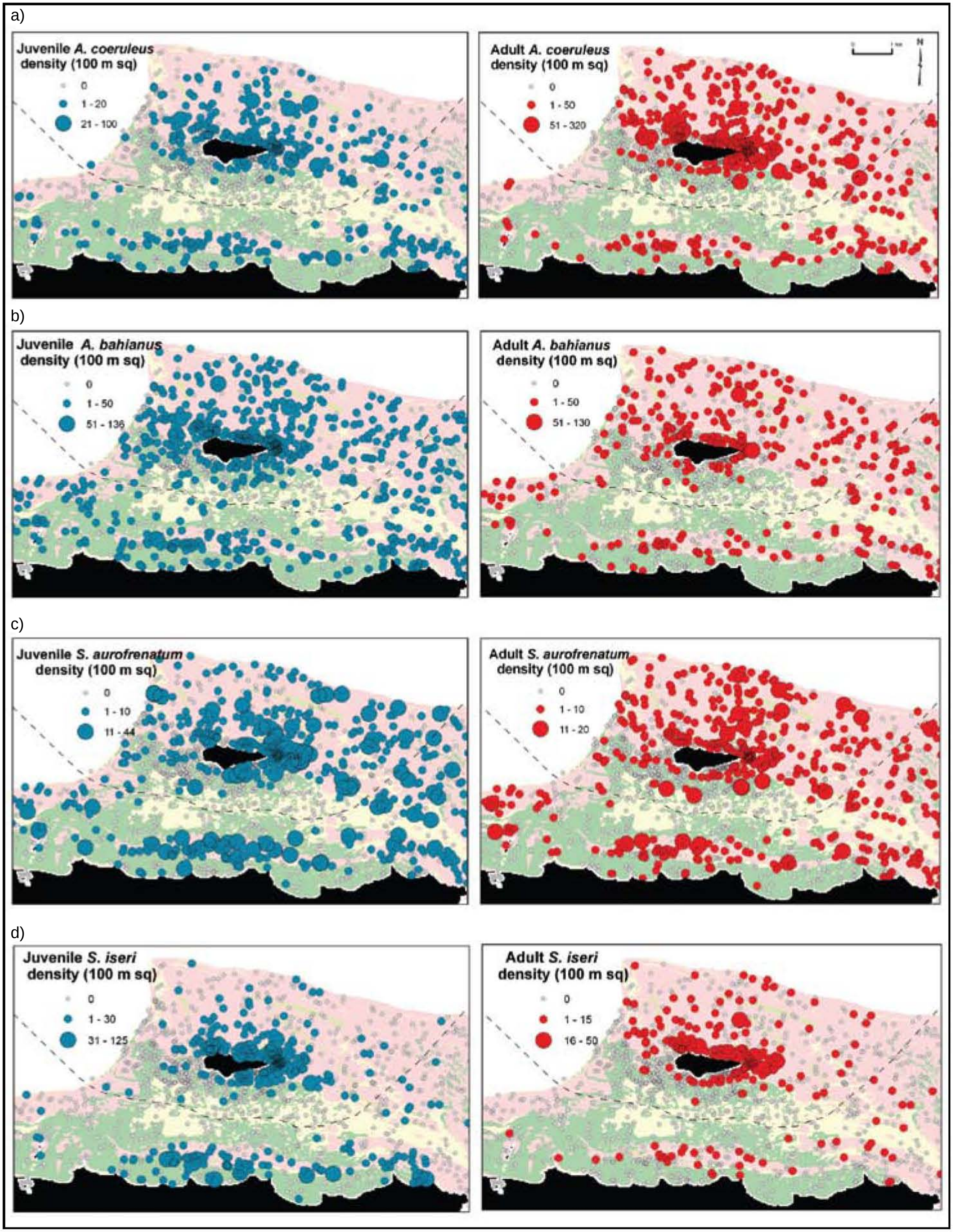


*Figure 39. Spatial distributions of juvenile and adult: (a) blue tang (*A. coeruleus*), (b) ocean surgeonfish (*A. bahianus*), (c) redband parrotfish (*S. aurofrenatum*) and (d) striped parrotfish (*S. iseri*) in northeastern St. Croix.*

Juvenile and adult blue tang, ocean surgeonfish (*Acanthurus bahianus*) and redband parrotfish were distributed widely across the study area, sharing the same habitat types (Figure 39 and Figure 40). Although present in all habitat types except macroalgal beds, highest densities of juvenile and adult blue tang were associated with structurally complex hardbottom habitats including aggregated patch reefs (4.08 and 17.88/100 m^2), linear reef (3.56 and 20.04/100 m^2) and patch reef (2.46 and 10.6/100 m^2). Adult and juvenile ocean surgeonfish were also very widespread across hardbottom habitat types, with highest density of adults recorded for colonized pavement (3.49/100 m^2) and aggregated patch reefs (3.3/100 m^2) and highest density of juveniles was recorded for linear reef (12.86/100 m^2), colonized pavement (7.79/100 m^2), aggregated patch reefs (5.21/100 m^2), reef rubble (7.2 /100 m^2) and scattered coral/rock (7.03/100 m^2; Figure 40). Visual comparison of adult to juvenile ratios for the two acanthurids revealed that adult blue tang were more abundant than juveniles, while juvenile ocean surgeonfish were more abundant than adult ocean surgeonfish.

Highest densities of juvenile and adult redband parrotfish were associated with aggregated patch reef (6.83 and 2.72/100 m^2), linear reef (3.70 and 2.12/100 m^2), patch reef (3.41 and 2.59/100 m^2) and colonized pavement (3.50 and 2.38/100 m^2; Figure 40). Juvenile and adult striped parrotfish were more restricted in distribution with highest densities of adults and juveniles close to Buck Island and also with high densities of juveniles along the nearshore fringing reef parallel to Teague Bay (Figure 39). Although observed in all habitat types, densities of juveniles and adults were highest over aggregated patch reef (11.64 and 3.06/100 m^2), linear reef (9.47 and 1.59/100 m^2) and patch reef (6.55 and 0.84/100 m^2; Figure 40).

Spatial distributions for other species are shown in Appendix D.

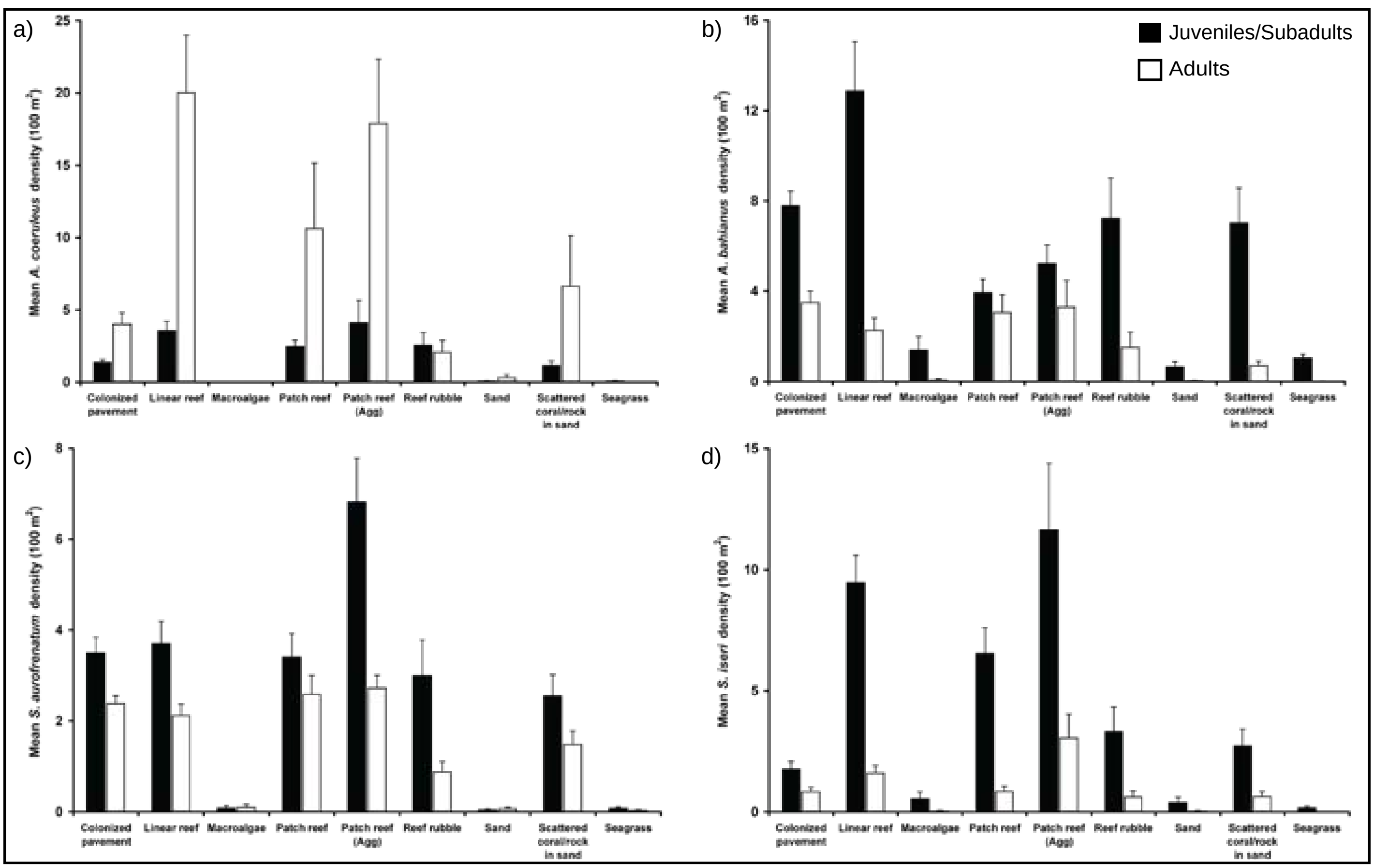


*Figure 40. Mean (± SE) density for juvenile/subadult and adult by observer habitat type for: (a) blue tang (*A. coeruleus*), (b) ocean surgeonfish (*A. bahianus*), (c) redband parrotfish (*S. aurofrenatum*) and (d) striped parrotfish (*S. iseri*).*

Table 11. Summary information on selected species from five key fish families showing maximum size observed in the study region (northeastern St. Croix) compared with maximum known size for the species and the proportion of juveniles found inside and outside BIRNM based on n=453 samples outside BIRNM and 431 inside BIRNM from 2003-2006. Maximum known fish size and size at first maturity are from FishBase (http://www.fishbase.org). TL= total length; FL= fork length

Species	Common name	Approx. size class at first maturity*	Max. known size, TL	Max. size observed St. Croix, FL	% juveniles	
					Inside BIRNM	Outside BIRNM
Serranidae						
C. fulva	Coney	15-20	41	30-35	35.1	35.2
E. guttatus	Red hind	20-25	76	45	47.4	61.2
Lutjanidae						
O. chrysurus	Yellowtail snapper	20-25	86.3	60	56.6	81.4
L. apodus	schoolmaster	20-25	67.2	45	35.3	22.9
Haemulidae						
H. flavolineatum	French grunt	15-20	30	30-35	65.7	73.4
H. plumierii	White grunt	15-20	53	30-35	12.0	20.5
H. sciurus	Bluestriped grunt	15-20	46	30-35	0.0	55.6
Acanthuridae						
A. bahianus	Ocean surgeonfish	15-20	38.1	30-35	73.8	77.8
A. chirurgus	Doctorfish	10-15	39	25-30	33.2	38.6
A. coeruleus	Blue tang	10-15	39	20-25	15.4	43.9
Scaridae						
S. iseri	Striped parrotfish	15-20	35	30-35	81.9	91.9
S. taeniopterus	Princess parrotfish	15-20	35	30-35	50.3	64.2
S. aurofrenatum	Redband parrotfish	15-20	28	30-35	64.7	63.9
S. viride	Stoplight parrotfish	15-20	64	50	74.7	87.4

3.2.6 Fish size class frequency distributions and maximum lengths

The body lengths of the largest individuals of several common groupers, snappers and grunts observed in the study region were less than the maximum size recorded for the species (Table 11). For example, the largest red hind was approximately 60% of the maximum known adult size for that species. The largest yellowtail snapper was approximately 70% of the maximum known, schoolmaster snapper 66%, white grunt 56-66%, and bluestriped grunt 65-76%. Even when factoring in the relatively small difference between fork length and total length these individuals were between 20-40% less than maximum size. In contrast, the longest parrotfish and surgeonfish were estimated at or near maximum size.

Size frequency distribution for all grouper species on hardbottom habitat types combined was approximately normal (e.g., a bell shaped distribution) both inside and outside BIRNM, with very few newly settled individuals (<5 cm FL) and very few large adults (>35 cm FL; Figure 41). Snappers exhibit a slightly flatter distribution slightly skewed towards a higher frequency of small and medium length fish. A higher frequency of large snapper were found inside BIRNM (Figure 41). Grunts and parrotfish exhibited a more strongly skewed size frequency distribution towards a higher frequency of the smallest size classes, this pattern was particularly strong for grunts outside BIRNM (Figure 41). Comparatively few large adults were observed either inside or outside BIRNM. Surgeonfish were more normally distributed inside BIRNM, with size frequency distribution outside skewed towards a higher frequency of smaller size classes.

At the species level, highest frequency of coney and red hind individuals occurred for subadults and small mature adults, with very few small juveniles or large adults. This pattern was similar to the size-frequency distribution for all grouper combined (Figure 42). Yellowtail snapper outside BIRNM showed a more skewed distribution than inside, with a higher frequency of juveniles and subadults and a greater decrease in frequency with larger size classes of subadults and adults (Figure 42). Schoolmaster snapper distribution was skewed in the opposite direction towards a higher frequency of small mature adults both inside and outside BIRNM. Very low frequency of the smallest juvenile (<5 cm) or largest adult (>35) schoolmaster snapper were recorded in the study area (Figure 42). French grunt and bluestriped grunt exhibited very different distributions inside versus outside BIRNM, with French grunt slightly skewed towards higher frequency of large juveniles and subadults inside BIRNM and towards higher frequency of small juveniles outside (Figure 42). Overall, blue tang and ocean surgeonfish showed similar near-normal size class distributions. Bluestriped grunt exhibited higher frequency of mature adults inside and higher frequency of juveniles and subadults outside.

Blue tang exhibit a peak in frequency for small adults and ocean surgeonfish exhibit a peak for subadults (Figure 43). In contrast, redband parrotfish and striped parrotfish showed a strongly skewed distribution, with high frequency of the smallest juveniles (<5 cm) and gradual decline with size with very few of the largest adults (Figure 43). Similar patterns existed for populations inside and outside BIRNM.

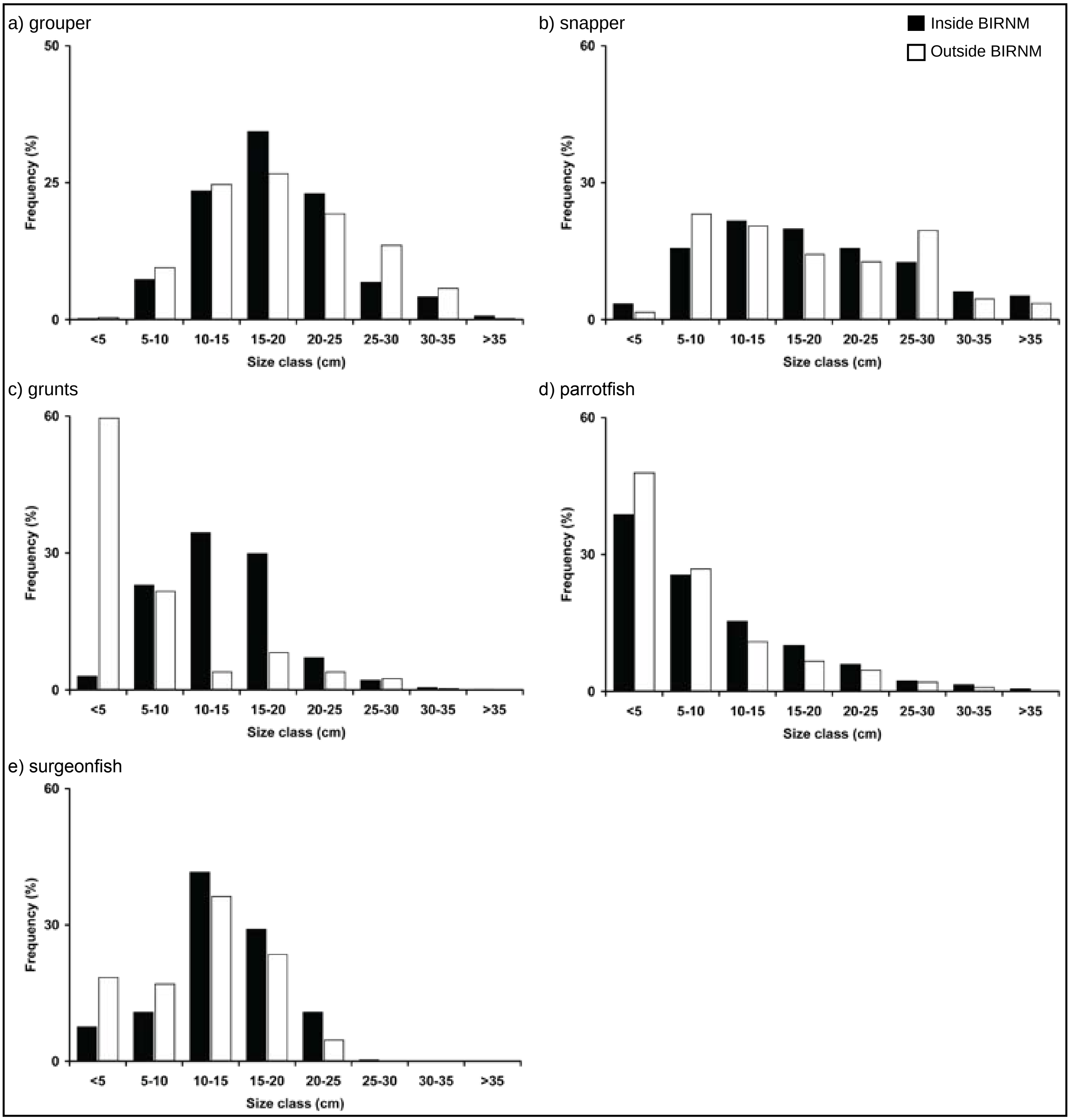


Figure 41. Length frequency histograms for key fish families over hardbottom sites inside and outside BIRNM: (a) grouper, (b) snapper, (c) grunts, (d) parrotfish and (e) surgeonfish.

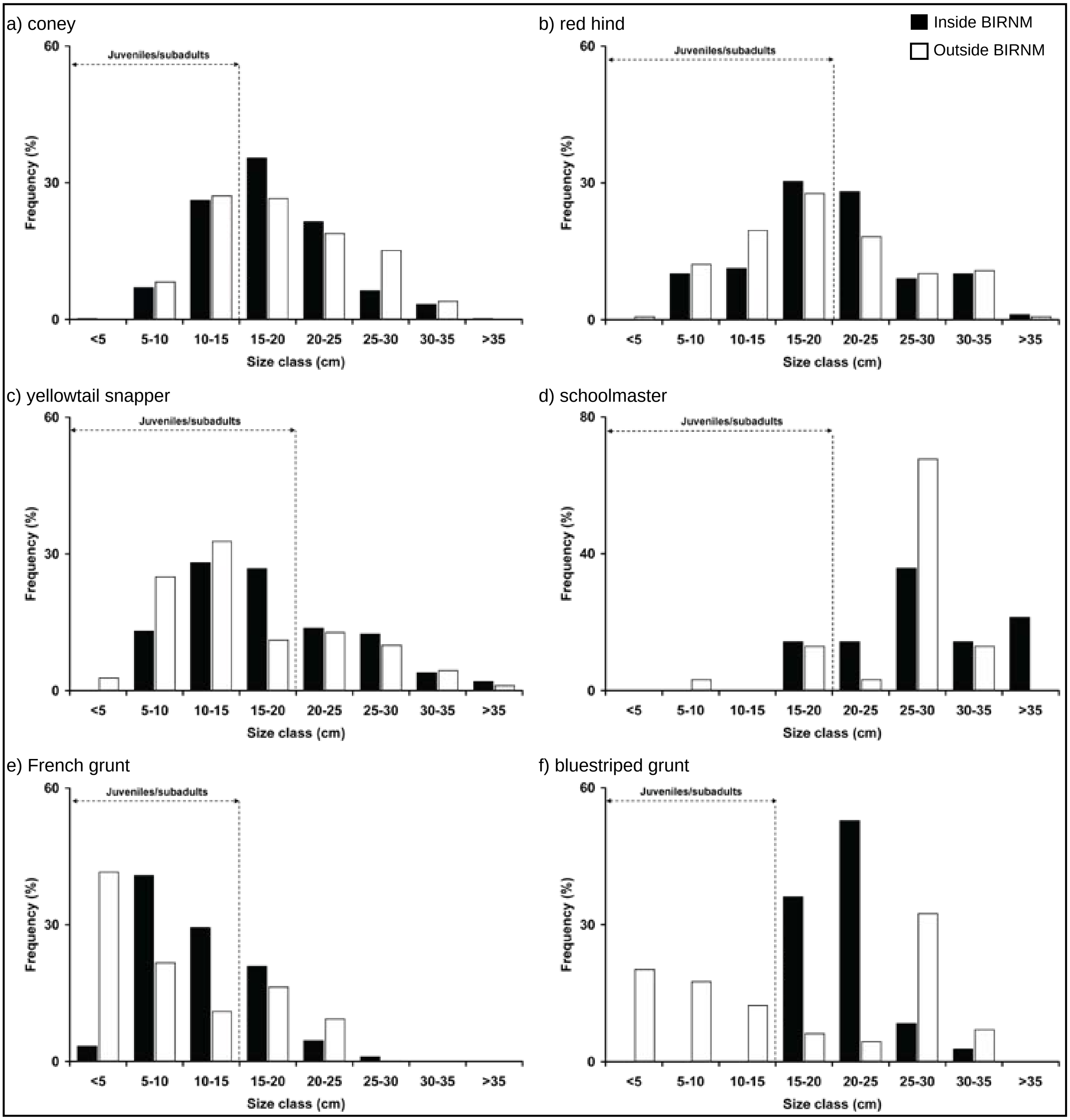


*Figure 42. Size class frequency histogram for selected fish species over hardbottom sites inside and outside BIRNM. (a) Coney (*C. fulva*), (b) red hind (*E. guttatus*), (c) yellowtail snapper (*O. chrysurus*), (d) schoolmaster (*L. apodus*), (e) French grunt (*H. flavolineatum*) and (f) bluestriped grunt (*H. sciurus*).*

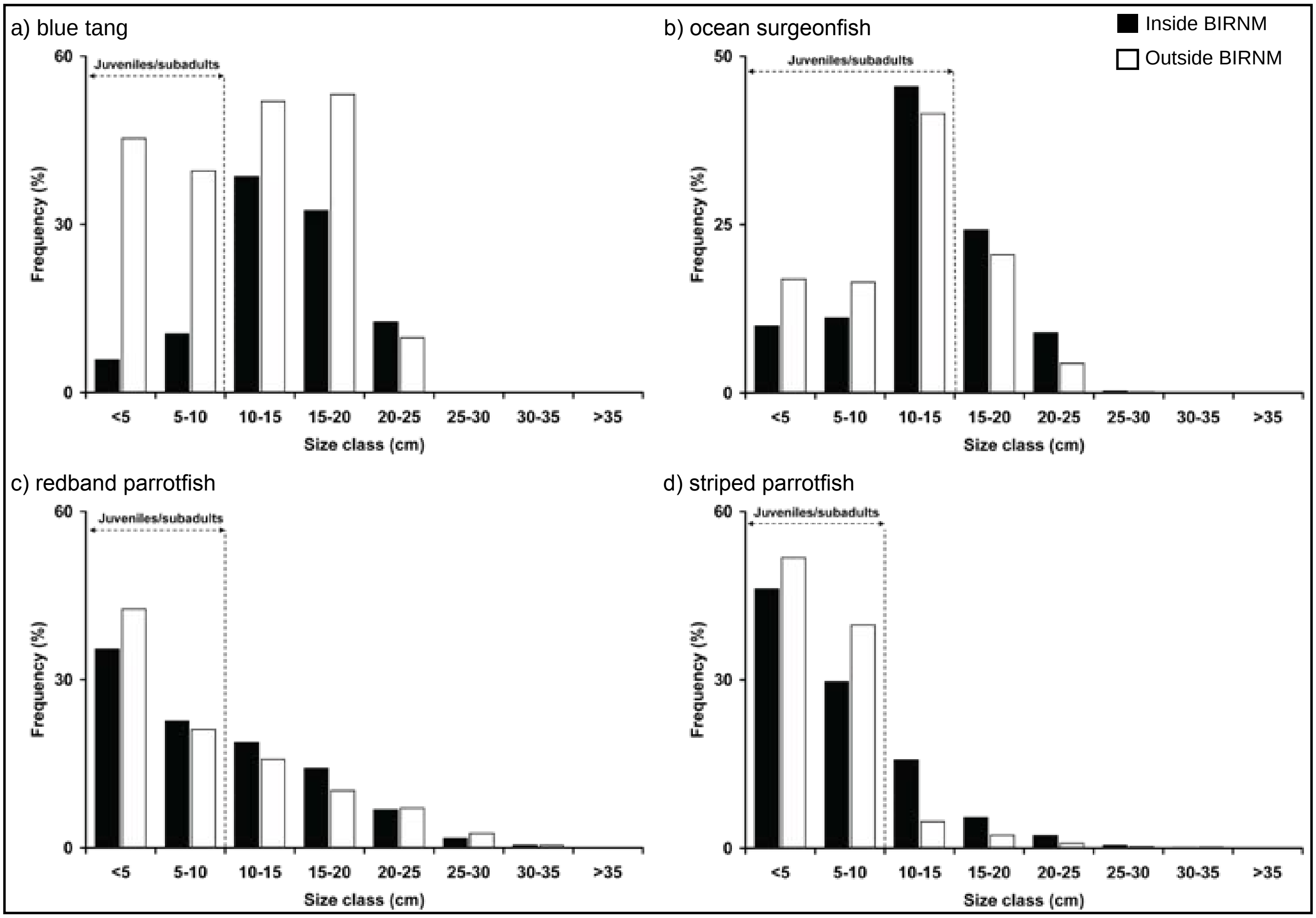


*Figure 43. Size class frequency histogram for selected fish species over hardbottom sites inside and outside BIRNM. (a) Blue tang (*A. coeruleus*), (b) ocean surgeonfish (*A. bahianus*), (c) redband parrotfish (*S. aurofrenatum*), and (d) striped parrotfish (*S. iseri*).*

3.2.7 Comparison of fish densities and species presence between 1979 and 2001-2006

The most conspicuous difference between fish surveyed in 1979 and those surveyed from the same general area (within 500 m of Buck Island) over two decades later was the absence of Nassau grouper (*E. striatus*), tiger grouper (*M. tigris*) and yellowfin grouper (*M. venenosa*) from the 2001-2006 data (Table 12). In contrast, smaller species of grouper such as red hind (*E. guttatus*) and coney (*C. fulva*) had increased in density since 1979. Overall, parrotfish also have increased in density since 1979 as have French grunt (Haemulon flavolineatum) and white grunt (*H. plumierii*), but not bluestriped grunt (*H. sciurus*). Snappers showed very mixed differences between the two survey periods, with a decrease in schoolmaster snapper (*L. apodus*) and mahogany snapper (*L. mahogoni*) and an increase in yellowtail snapper (*O. chrysurus*) and mutton snapper (*Lutjanus analis*; Table 12). Other commercially targeted species such as queen triggerfish (*Balistes vetula*), spotted goatfish (*Pseudupeneus maculatus*), yellow goatfish (*Mulloidichthys martinicus*) and bar jacks (*Carangoides ruber*) also increased since 1979. Threespot damselfish (*Stegastes planifrons*), a potential indicator of live coral cover, was substantially lower in 2001-2006 than in 1979.

Fish assemblages around dead Acropora palmata *and* Millepora *colony*

Table 12. Comparison of mean density for a range of key fish species from 1979 (n=147) and 2001-2006 (n=184) monitoring periods within 500 m surrounding Buck Island. Source: Gladfelter and Gladfelter, 1980; CCMA-BB reef fish database

Species	Mean density 1979 /100m²	Mean density 2001-2006 /100m²	Change
Serranidae			
Epinephelus striatus	0.01	**Absent**	-0.01
Epinephelus guttatus	0.08	0.18	+0.1
Mycteroperca venenosa	0.001	**Absent**	-0.001
Mycteroperca tigris	0.02	**Absent**	-0.02
Cephalopholis. fulva	0.01	0.30	+0.3
Lutjanidae			
Lutjanus apodus	0.28	0.16	-0.12
Lutjanus griseus	0.01	0.08	+0.07
Ocyurus chrysurus	0.17	0.24	+0.07
Lutjanus mahogoni	0.33	0.29	-0.04
Lutjanus analis	0.004	0.06	+0.06
Haemulidae			
Haemulon flavolineatum	2.49	2.89	+0.4
Haemulon sciurus	0.28	0.14	-0.14
Haemulon plumierii	0.21	0.22	+0.01
Scaridae			
Scarus vetula	0.38	1.21	+0.83
Sparisoma aurofrenatum	0.23	1.50	+1.27
Sparisoma viride	0.92	0.79	-0.13
Scarus guacamaia	0.01	0.07	+0.06
Sparisoma rubripinne	0.13	0.24	+0.11
Other			
Stegastes planifrons	4.09	2.18	-1.19
Balistes vetula	0.01	0.02	+0.01
Carangoides ruber	1.12	2.07	+0.95
Mulloidichthys martinicus	0.53	0.98	+0.45
Pseudupeneus maculatus	0.13	0.44	+0.31

3.2.8 Synoptic overview of inter-annual trends in mean fish metrics (2003-2006)

Presented here is a synoptic overview of inter-annual changes in summary statistics (mean and SE) for 39 fish metrics at the level of species, family, trophic group and community using data from both the whole study area and inside and outside BIRNM separately. The intention is to assist in highlighting potential trends that may be emerging even within the relatively short term monitoring data currently available. The synopsis is presented for: (1) the entire study area; (2) inside BIRNM; and (3) outside BIRNM.

Study area

Across the entire study area, mean biomass of bluestriped grunt, density of striped parrotfish and biomass of yellowtail snapper exhibited a year after year decline across three consecutive years (Table 13). Striped parrotfish density and bluestriped grunt biomass was significantly (p=<0.01) lower in 2003 than 2006. Although mean yellowtail snapper biomass declined over the study period too the difference was not significant. In contrast, mean herbivore density and biomass of redband parrotfish increased year after year across three consecutive years, with 2003 significantly higher than 2006. Other metrics were less consistent in the directionality of change. For instance, five metrics exhibited at least two consecutive years of increase, 15 exhibited at least two consecutive years of decrease and 19 showed no distinctive direction in inter-annual change (Table 13).

Inside BIRNM

Inside BIRNM, no metric exhibited three consecutive years of decline. Declines for at least two consecutive years, however, were documented for coney biomass, gray snapper density and biomass, all grunt density and biomass including French grunt density and biomass. In contrast, year after year increases for three consecutive years were documented for fish density (all species combined), with 2005 and 2006 density significantly higher than 2003 (Table 14 and Appendix E). Parrotfish biomass was also higher but not significantly (p=>0.05) different between years. In addition, increases inside BIRNM for at least two consecutive years were documented for herbivore density, parrotfish biomass, including redband parrotfish biomass and striped parrotfish biomass. Red hind density and all snapper density also increased. Overall, seven metrics exhibited at least two years of consecutive decline, seven exhibited increases and 25 showed no clear directionality (Table 14).

Table 13. Summary statistics (mean ± SE) for a range of fish variables grouped by year (2003-2006) for the study region (northeastern St. Croix). Blue arrow = two consecutive years of increase; Orange arrows = two consecutive years of decrease. Double arrows indicate three consecutive years. Multidirectional change is indicated by the label "variable".

	2003		2004		2005		2006		
Fish variable	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Change**
Community metrics									
Number of species	14.2	0.5	13.4	0.6	14.2	0.5	14.4	0.4	↑
Shannon diversity	1.8	0.04	1.7	0.05	1.8	0.04	1.8	0.0	Variable
Taxonomic diversity (pres/abs)	57.4	0.7	57.4	0.8	58.0	0.7	59.6	0.7	↑
Density (all species combined)	115.5	5.8	115.2	7.4	132.9	6.7	148.8	7.6	↑
Biomass	4371.1	497.8	5705.6	704.7	3444.7	273.1	5160.3	476.8	Variable
Herbivore density	44.8	2.6	45.1	3.7	53.7	3.3	56.2	3.6	↑↑
Herbivore biomass	1773.5	206.1	3156.7	582.7	1806.5	182.0	2326.6	358.7	Variable
Piscivore density	4.5	0.5	4.3	1.2	4.0	0.4	5.5	0.7	↓
Piscivore biomass	1015.9	162.7	1044.7	288.7	759.0	167.2	1173.5	231.9	Variable
Serranidae									
Grouper density	1.5	0.2	0.9	0.1	1.9	0.2	1.8	0.2	Variable
Grouper biomass	317.0	68.2	243.9	42.6	219.6	30.8	263.6	28.1	↓
Coney (*C. fulva*) density	1.2	0.2	0.7	0.1	1.5	0.2	1.4	0.1	Variable
Coney (*C. fulva*) biomass	231.3	63.3	173.8	35.4	131.0	20.5	175.3	22.3	↓
Red hind (*E. guttatus*) density	0.2	0.05	0.2	0.0	0.4	0.1	0.4	0.1	Variable
Red hind (*E. guttatus*) biomass	79.5	15.2	59.6	21.9	75.2	18.1	77.1	13.7	Variable
Lutjanidae									
Snapper density	0.9	0.2	0.7	0.1	0.6	0.1	1.2	0.3	↓
Snapper biomass	193.2	47.0	198.8	71.3	136.4	30.6	195.5	50.8	Variable
Yellowtail snapper (*O. chrysurus*) density	0.7	0.2	0.4	0.1	0.5	0.1	0.8	0.2	Variable
Yellowtail snapper (*O. chrysurus*) biomass	77.0	16.1	57.6	21.2	50.1	18.7	48.7	9.9	↓↓
Schoolmaster snapper (*L. apodus*) density	0.1	0.0	0.09	0.05	0.04	0.01	0.1	0.0	↓
Schoolmaster snapper (*L. apodus*) biomass	20.9	13.8	40.6	23.8	16.2	7.3	22.4	9.6	Variable
Gray snapper (*L. griseus*) density	0.04	0.03	0.01	0.01	0	0	0.1	0.1	Variable
Gray snapper (*L. griseus*) biomass	12.2	9.1	2.5	1.8	0	0	25.7	25.6	↓
Haemulidae									
Grunt density	10.3	2.9	8.1	3.8	2.1	0.6	4.5	1.9	↓
Grunt biomass	418.7	93.9	283.2	67.1	123.1	45.1	202.4	41.4	↓
French grunt (*H. flavolineatum*) density	2.7	0.9	1.1	0.3	1.0	0.3	2.0	0.9	↓
French grunt (*H. flavolineatum*) biomass	135.9	28.4	103.1	18.9	44.1	8.5	86.1	15.8	↓
Bluestriped grunt (*H. sciurus*) density	0.5	0.2	0.1	0.0	0.1	0.0	0.0	0.0	↓
Bluestriped grunt (*H. sciurus*) biomass	82.9	36.5	42.7	22.0	11.3	6.2	7.8	4.1	↓↓
Scaridae									
Parrotfish density	16.1	1.1	13.8	1.2	14.8	1.1	13.1	0.9	Variable
Parrotfish biomass	646.2	70.4	837.1	118.4	718.0	80.6	827.5	115.4	Variable
Redband parrotfish (*S. aurofrenatum*) density	3.7	0.4	2.4	0.3	5.4	0.5	4.7	0.4	Variable
Redband parrotfish (*S. aurofrenatum*) biomass	181.3	22.0	199.6	32.8	203.5	22.1	254.9	31.8	↑↑
Striped parrotfish (*S. iseri*) density	4.4	0.5	3.4	0.6	3.1	0.5	2.0	0.3	↓↓
Striped parrotfish (*S. iseri*) biomass	59.9	10.9	50.6	11.1	31.2	5.8	45.7	13.8	↓
Other species									
Blue tang (*A. coeruleus*) density	4.1	0.8	8.3	1.8	6.8	1.0	6.9	1.9	Variable
Blue tang (*A. coeruleus*) biomass	443.8	134.0	1199.5	308.5	483.9	106.0	788.5	248.8	Variable
Sharks and Rays density	0.03	0.01	0.01	0.01	0.03	0.01	0.05	0.02	Variable
Sharks and Rays biomass	435.9	381.9	41.2	39.6	43.4	31.4	148.6	88.3	Variable

Table 14. Summary statistics (mean ± SE) for a range of fish variables grouped by year (2003-2006) inside BIRNM, northeastern St. Croix. Blue arrow = two consecutive years of increase; Orange arrows = two consecutive years of decrease. Double arrows indicate three consecutive years. Multidirectional change is indicated by the label "variable".

	2003		2004		2005		2006		
Fish variable	**Mean ln**	**SE ln**	**Mean ln**	**SE ln**	**Mean ln**	**SE ln**	**Mean ln**	**SE ln**	**Change**
Community metrics									
Number of species	14.65	0.74	13.13	0.81	14.74	0.66	14.91	0.59	Variable
Shannon diversity	1.80	0.07	1.58	0.07	1.77	0.06	1.84	0.06	Variable
Taxonomic diversity (pres/abs)	55.91	1.27	55.35	1.53	57.14	1.16	60.00	0.84	Variable
Density (all species combined)	111.75	7.34	128.63	10.68	147.95	10.14	150.64	10.24	↑↑
Biomass	4520.20	542.35	6188.42	1261.80	4106.78	379.82	5985.86	773.23	Variable
Herbivore density	46.34	4.38	55.51	6.91	64.22	5.43	61.43	5.42	↑
Herbivore biomass	2567.12	390.94	4641.46	1177.32	2690.23	332.21	3520.99	697.34	Variable
Piscivore density	4.68	0.79	3.27	0.92	3.70	0.40	5.72	1.12	Variable
Piscivore biomass	970.10	201.34	479.55	102.22	594.25	105.95	831.62	141.42	Variable
Serranidae									
Grouper density	1.84	0.38	0.92	0.19	2.21	0.33	1.90	0.23	Variable
Grouper biomass	426.91	135.70	198.97	58.64	206.06	37.86	324.03	47.55	Variable
Coney (*C. fulva*) density	1.65	0.37	0.74	0.18	1.84	0.30	1.63	0.22	Variable
Coney (*C. fulva*) biomass	358.96	128.08	158.96	56.73	122.72	21.28	231.44	38.87	↓
Red hind (*E. guttatus*) density	0.15	0.04	0.18	0.06	0.31	0.07	0.24	0.04	↑
Red hind (*E. guttatus*) biomass	60.01	18.80	38.06	14.17	82.24	26.62	82.46	22.03	Variable
Lutjanidae									
Snapper density	0.56	0.10	0.27	0.07	0.58	0.14	0.75	0.21	↑
Snapper biomass	154.03	45.73	76.84	34.09	159.13	52.69	228.58	81.98	Variable
Yellowtail snapper (*O. chrysurus*) density	0.39	0.08	0.20	0.06	0.44	0.13	0.31	0.07	Variable
Yellowtail snapper (*O. chrysurus*) biomass	75.49	25.11	44.77	28.39	58.72	32.31	54.53	14.93	Variable
Schoolmaster snapper (*L. apodus*) density	0.03	0.02	0	0	0.08	0.03	0.05	0.02	Variable
Schoolmaster snapper (*L. apodus*) biomass	16.13	11.36	0	0	32.86	14.93	33.93	18.85	Variable
Gray snapper (*L. griseus*) density	0.04	0.04	0.01	0.01	0	0	0.01	0.01	↓
Gray snapper (*L. griseus*) biomass	18.00	18.00	1.89	1.89	0	0	0.26	0.26	↓
Haemulidae									
Grunt density	2.49	0.61	1.15	0.28	0.99	0.23	2.42	1.20	↓
Grunt biomass	180.51	53.39	119.77	31.46	77.53	21.42	221.49	58.89	↓
French grunt (*H. flavolineatum*) density	1.16	0.34	0.85	0.24	0.77	0.19	1.81	1.06	↓
French grunt (*H. flavolineatum*) biomass	63.91	10.93	57.58	15.05	44.39	10.61	114.66	23.44	↓
Bluestriped grunt (*H. sciurus*) density	0.06	0.02	0.04	0.02	0.05	0.03	0.02	0.01	Variable
Bluestriped grunt (*H. sciurus*) biomass	14.12	5.70	22.71	12.56	12.44	8.25	10.27	7.45	Variable
Scaridae									
Parrotfish density	13.73	1.39	11.54	1.37	16.55	1.83	15.44	1.35	Variable
Parrotfish biomass	909.42	125.44	997.91	214.23	1039.05	145.55	1261.63	225.00	↑↑
Redband parrotfish (*S. aurofrenatum*) density	3.24	0.50	1.67	0.28	5.22	0.73	5.61	0.58	Variable
Redband parrotfish (*S. aurofrenatum*) biomass	175.43	30.79	136.37	37.07	221.33	30.47	304.39	55.36	↑
Striped parrotfish (*S. iseri*) density	3.41	0.61	2.37	0.63	4.52	0.97	2.97	0.58	Variable
Striped parrotfish (*S. iseri*) biomass	72.06	19.86	38.14	14.57	42.93	10.05	83.89	27.88	↑
Other species									
Blue tang (*A. coeruleus*) density	6.29	1.57	13.65	3.60	11.18	1.99	10.92	3.76	Variable
Blue tang (*A. coeruleus*) biomass	818.37	272.97	2091.38	638.73	874.25	210.59	1305.35	504.49	Variable
Sharks and Rays density	0.03	0.02	0	0	0.03	0.02	0.07	0.03	Variable
Sharks and Rays biomass	100.50	71.75	0	0	84.21	64.25	126.96	85.60	Variable

Table 15. Summary statistics (mean ± SE) for a range of fish variables grouped by year (2003-2006) outside BIRNM, northeastern St. Croix. Blue arrow = two consecutive years of increase; Orange arrows = two consecutive years of decrease. Double arrows indicate three consecutive years. Multidirectional change is indicated by the label "variable".

Fish variable	2003 Mean Out	2003 SE Out	2004 Mean Out	2004 SE Out	2005 Mean Out	2005 SE Out	2006 Mean Out	2006 SE Out	Change
Community metrics									
Number of species	13.79	0.67	12.43	0.78	13.68	0.69	13.78	0.66	Variable
Shannon diversity	1.82	0.06	1.72	0.07	1.76	0.05	1.67	0.06	Variable
Taxonomic diversity (pres/abs)	58.79	0.83	58.51	0.93	58.70	0.79	59.31	1.03	Variable
Density (all species combined)	119.08	8.99	100.73	11.89	119.08	8.65	146.80	11.21	Variable
Biomass	3540.57	412.35	4918.35	806.26	2793.13	387.51	4284.39	561.44	Variable
Herbivore density	43.71	2.88	33.39	3.64	43.89	3.81	50.84	4.71	Variable
Herbivore biomass	1051.65	135.51	1607.58	307.11	961.77	124.16	1158.73	199.61	Variable
Piscivore density	4.25	0.74	5.40	2.38	4.33	0.62	5.34	0.79	Variable
Piscivore biomass	1070.27	256.58	1704.56	624.65	913.07	313.03	1503.03	431.69	Variable
Serranidae									↑
Grouper density	1.20	0.21	0.70	0.15	1.61	0.22	1.78	0.24	↓
Grouper biomass	213.22	36.57	297.83	71.38	224.39	47.82	207.83	31.45	↑
Coney (*C. fulva*) density	0.81	0.16	0.47	0.12	1.09	0.18	1.11	0.18	↓
Coney (*C. fulva*) biomass	110.21	24.02	194.08	51.59	140.02	34.87	125.58	23.13	↑
Red hind (*E. guttatus*) density	0.33	0.08	0.19	0.09	0.39	0.08	0.57	0.11	
Red hind (*E. guttatus*) biomass	98.15	23.84	91.41	46.23	67.08	24.99	69.78	16.88	Variable
Lutjanidae									
Snapper density	1.32	0.39	1.09	0.28	0.58	0.12	1.57	0.46	↓
Snapper biomass	233.31	81.46	181.72	64.75	105.80	31.36	156.75	62.33	↓
Yellowtail snapper (*O. chrysurus*) density	0.94	0.30	0.61	0.19	0.44	0.12	1.18	0.39	↓
Yellowtail snapper (*O. chrysurus*) biomass	79.74	21.03	49.39	28.51	32.34	17.57	37.97	12.03	↓
Schoolmaster snapper (*L. apodus*) density	0.07	0.06	0.18	0.11	0.01	0.01	0.06	0.02	Variable
Schoolmaster snapper (*L. apodus*) biomass	25.76	24.96	83.09	52.40	0.29	0.29	8.79	5.53	Variable
Gray snapper (*L. griseus*) density	0.04	0.03	0.01	0.01	0	0	0.21	0.21	↓
Gray snapper (*L. griseus*) biomass	6.82	5.62	3.53	3.53	0	0	49.88	49.88	↓
Haemulidae									
Grunt density	17.87	5.62	15.10	8.33	3.22	1.08	6.52	3.59	↓
Grunt biomass	650.30	174.85	354.92	96.83	166.04	86.32	156.63	51.25	↓ ↓
French grunt (*H. flavolineatum*) density	4.23	1.72	1.11	0.40	1.27	0.53	2.16	1.56	Variable
French grunt (*H. flavolineatum*) biomass	206.13	54.14	131.15	34.57	42.22	13.23	58.95	21.42	↓
Bluestriped grunt (*H. sciurus*) density	0.89	0.37	0.05	0.04	0.09	0.07	0.01	0.01	Variable
Bluestriped grunt (*H. sciurus*) biomass	149.13	70.93	27.31	20.55	10.28	9.23	1.99	1.99	↓ ↓
Scaridae									
Parrotfish density	18.58	1.61	14.40	2.09	13.25	1.22	10.82	1.19	↓
Parrotfish biomass	407.44	63.93	600.81	122.72	409.99	64.85	406.83	57.24	↓
Redband parrotfish (*S. aurofrenatum*) density	4.06	0.56	2.57	0.47	5.60	0.77	3.86	0.57	Variable
Redband parrotfish (*S. aurofrenatum*) biomass	189.60	31.85	213.25	51.02	184.58	32.24	212.55	33.74	Variable
Striped parrotfish (*S. iseri*) density	5.37	0.80	3.90	1.08	1.79	0.38	1.02	0.28	↓ ↓
Striped parrotfish (*S. iseri*) biomass	49.33	10.28	44.36	16.26	19.90	5.90	6.00	2.27	↓ ↓
Other species									
Blue tang (*A. coeruleus*) density	2.09	0.34	2.98	0.77	2.62	0.43	2.93	0.67	Variable
Blue tang (*A. coeruleus*) biomass	97.01	28.60	371.83	116.34	112.93	22.53	260.31	84.41	Variable
Sharks and Rays density	0.02	0.01	0.01	0.01	0.02	0.01	0.03	0.02	Variable
Sharks and Rays biomass	13.70	8.58	3.51	3.51	4.53	4.01	171.17	152.96	Variable

Outside BIRNM

Outside BIRNM, declines over three consecutive years were recorded for striped parrotfish and for grunt biomass including bluestriped grunt biomass, with 2005 and 2006 values significantly lower (p=<0.05) than 2003 (Table 15 and Appendix E). Unlike inside BIRNM, no metric exhibited three consecutive years of increase. Declines recorded for at least two consecutive years were considerably more widespread, with decreases in mean metric value for all major fish families, including: all grouper biomass; coney biomass; red hind density and biomass; all snapper density and biomass; yellowtail snapper density and biomass; gray snapper density and biomass; grunt density and biomass; French grunt and bluestriped grunt biomass; parrotfish density and biomass, including striped parrotfish density and biomass (Table 15). Overall, 17 metrics exhibited at least two consecutive years of decline, three metrics increased over two years, and 19 showed no clear directionality (Table 15). Interestingly, many of the fish metrics that showed a declining trend between 2003 and 2005, then showed a substantial increase in 2006.

3.2.9 Seasonal and inter-annual patterns in fish community metrics

Mean fish density was markedly lower over hardbottom habitat types during the spring sampling season than during the fall sampling season (Figure 44). Table 16 shows that all of the most abundant fish species in the study region were more abundant in fall than spring. Greatest differences were found for the three most abundant fish species bluehead wrasse (*Thalassoma bifasciatum*), slippery dick (*Halichoeres bivittatus*) and bicolor damselfish (*Stegastes partitus*).

As a result of this distinct seasonal difference, temporal change was examined separately for: (1) March/April; and (2) October sampling periods.

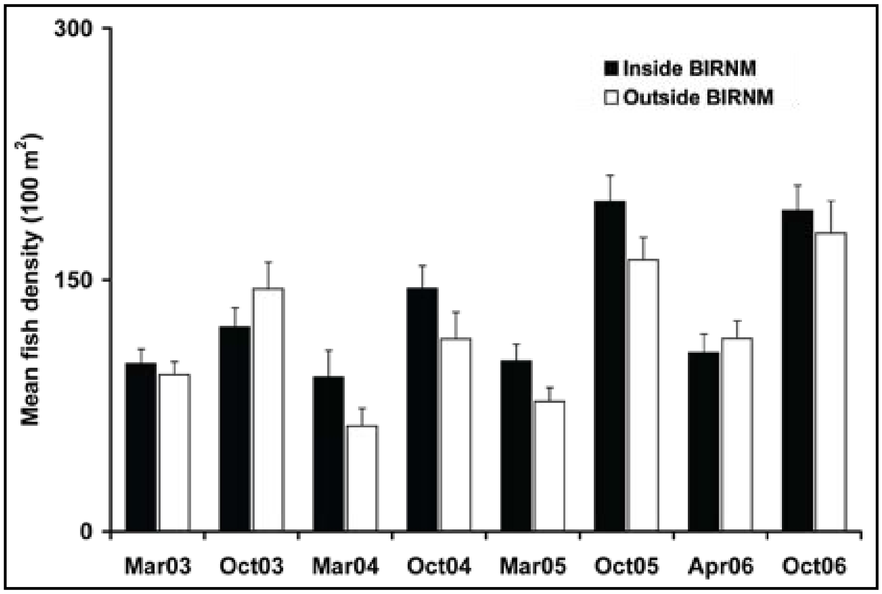


Figure 44. Mean (± SE) density for all species combined by sampling season for both inside and outside BIRNM.

Table 16. Spring and fall total abundance and mean (± SE) density for the 20 most abundant fish species across the study region (northeastern St. Croix).

Species	Common name	Spring total abundance	Spring mean density (±SE)	Fall total abundance	Fall mean density (±SE)
Thalassoma bifasciatum	Bluehead wrasse	9525	15.1 (0.9)	22476	34.9 (2.2)
Halichoeres bivittatus	Slippery dick	9710	15.4 (3.4)	15042	23.4 (1.3)
Stegastes partitus	Bicolor damselfish	3500	5.5 (0.5)	6702	10.4 (0.7)
Acanthurus bahianus	Ocean surgeonfish	3670	5.8 (0.4)	4931	7.7 (0.5)
Acanthurus coeruleus	Blue tang	3737	5.9 (0.8)	4860	7.5 (1.1)
Sparisoma aurofrenatum	Redband parrotfish	1820	2.9 (0.2)	3067	4.8 (0.3)
Scarus iseri	Striped parrotfish	2212	3.5 (0.3)	2549	4.0 (0.4)
Halichoeres garnoti	Yellowhead wrasse	1660	2.6 (0.2)	2998	4.7 (0.3)
Stegastes leucostictus	Beaugregory	1537	2.4 (0.3)	2454	3.8 (0.4)
Chromis cyanea	Blue chromis	1426	2.3 (0.4)	1895	2.9 (0.5)
Haemulon aurolineatum	Tomtate	1052	1.7 (0.9)	1581	2.5 (1.9)
Xyrichtys martinicensis	Rozy razorfish	1231	2.0 (0.6)	1351	2.1 (0.4)
Sparisoma viride	Stoplight parrotfish	968	1.5 (0.1)	1488	2.3 (0.2)
Decapterus macarellus	Mackerel scad	820	1.3 (0.5)	1499	2.3 (0.9)
Halichoeres maculipinna	Clown wrasse	743	1.2 (0.1)	1433	2.2 (0.2)
Clepticus parrae	Creole wrasse	827	1.3 (0.5)	1333	2.1 (1.2)
Haemulon flavolineatum	French grunt	687	1.1 (0.2)	1257	2.0 (0.5)
Stegastes diencaeus	Longfin damselfish	930	1.5 (0.2)	940	1.5 (0.2)
Scarus taeniopterus	Princess parrotfish	711	1.1 (0.1)	1002	1.6 (0.1)
Cephalopholis fulva	Coney	604	1.0 (0.1)	787	1.2 (0.1)

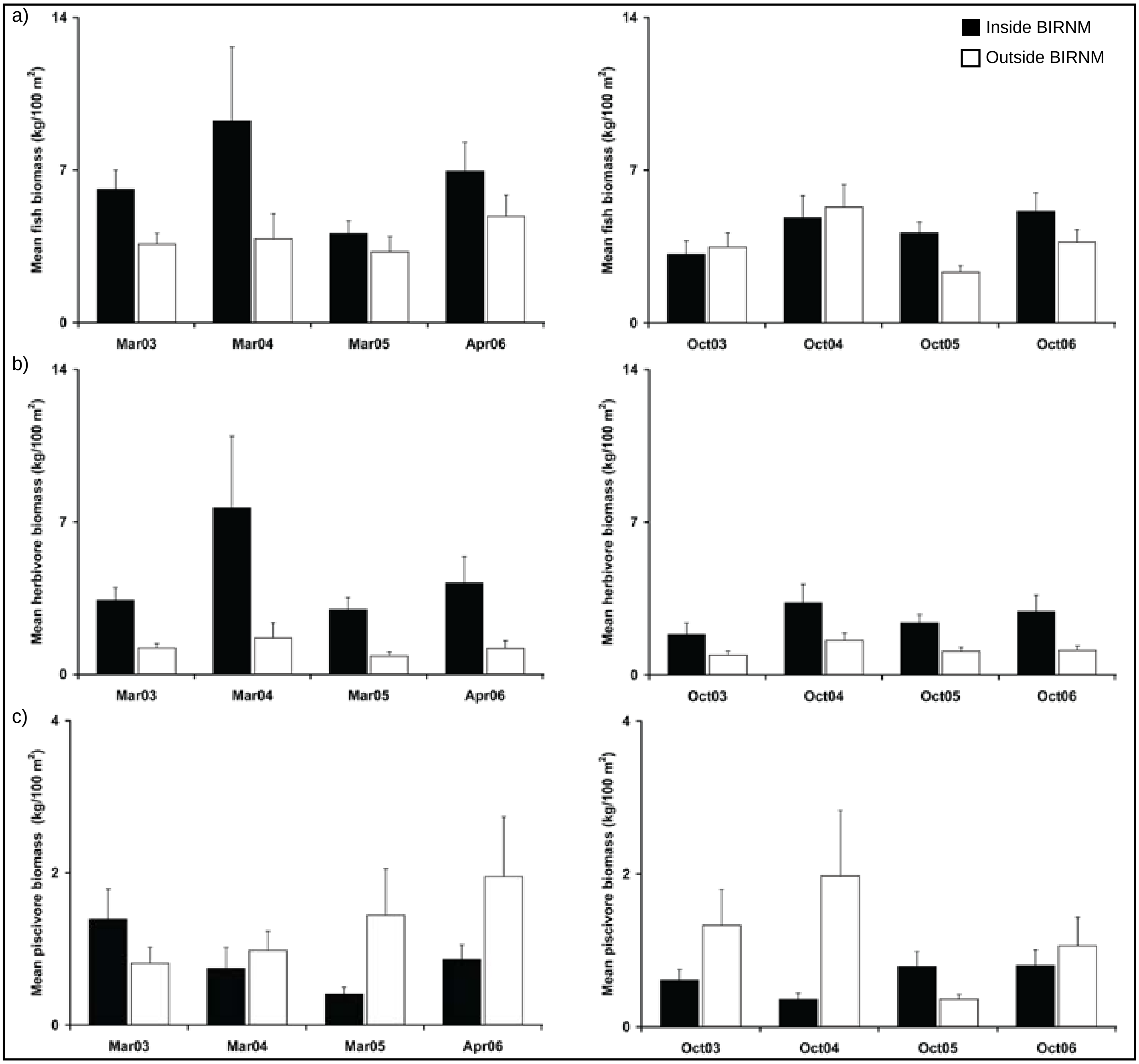


Figure 45. Seasonal and inter-annual (2003-2006) change in mean (± SE) fish biomass inside and outside BIRNM for: (a) all fish biomass; (b) herbivorous fish biomass; and (c) piscivorous fish biomass.

Between 2003 and 2006, mean density increased in both sampling seasons. Mean fish biomass was higher inside BIRNM for six of eight sampling seasons and mean herbivore biomass was higher inside BIRNM in all seasons and years. Piscivore biomass was higher outside in six out of eight sampling seasons (Figure 45). Furthermore, spring piscivore decreased inside, while increasing outside BIRNM between 2003 and 2006.

In contrast, the number of fish species and value of diversity indices varied very little across years except for a slight decrease during 2004, although mean values were marginally higher in fall 2005 and 2006 than fall 2003 and 2004 (Figure 46).

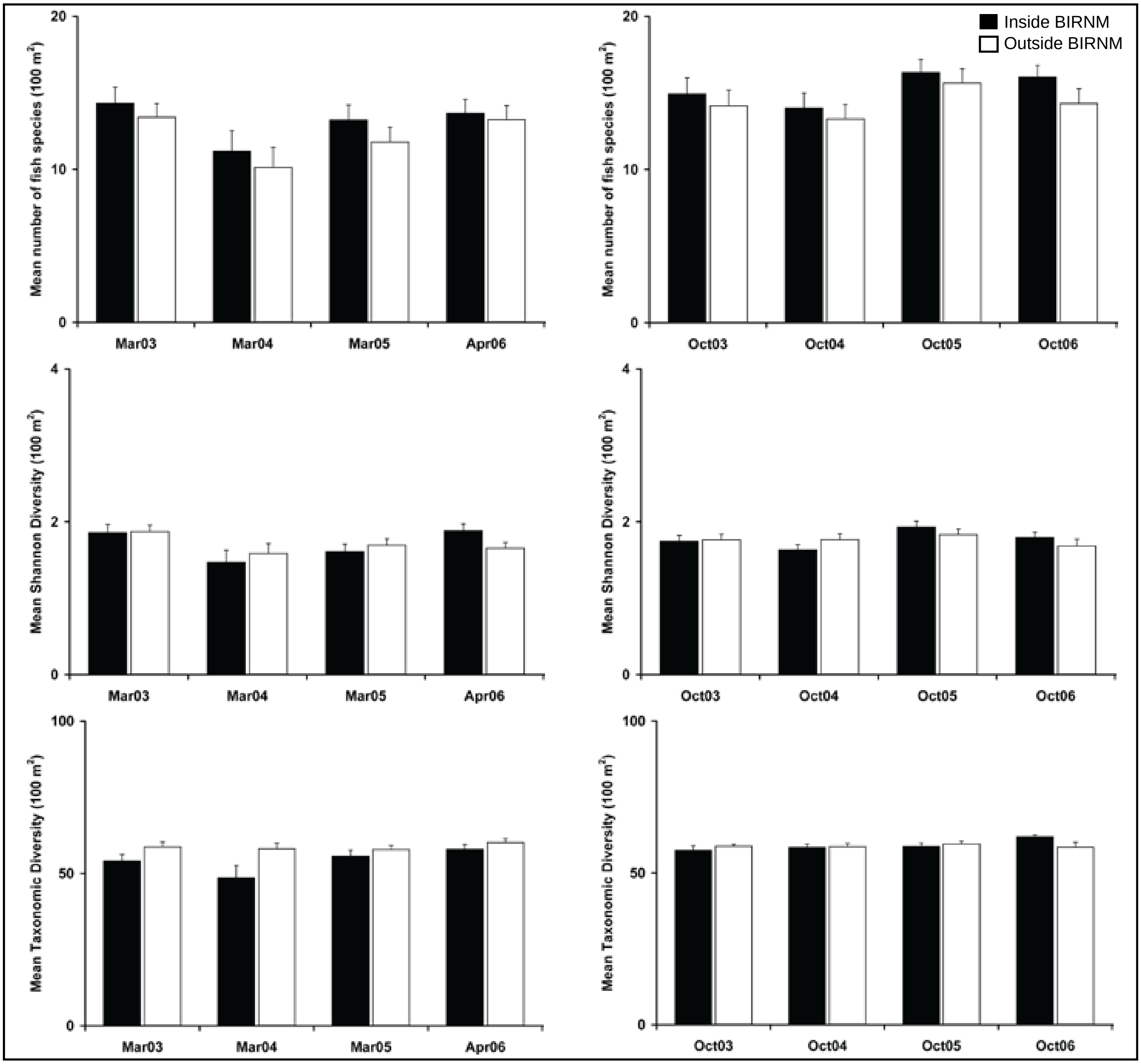


Figure 46. Seasonal and inter-annual (2003-2006) change in mean (± SE) fish diversity inside and outside BIRNM.

3.2.10 Seasonal and inter-annual patterns in fish groups and species

Mean grouper biomass was higher in spring than fall sampling seasons, particularly within BIRNM, although spring biomass declined inside BIRNM from 2003 to 2005 (Figure 47a). Spring snapper biomass also was greater than fall and increased gradually from 2003 to 2006 inside BIRNM, but appeared to decrease outside over the same time period (Figure 47b). Grunt and parrotfish biomass also was greater in spring than fall, but not for all years. In general, grunt biomass decreased outside BIRNM between 2003 and 2006 and remained relatively consistently low inside (Figure 47c). Parrotfish biomass was higher inside BIRNM for all sampling seasons and all years (Figure 47d). Spring biomass appeared fairly consistent across years, but fall biomass increased year upon year inside BIRNM.

Coney mean biomass was higher inside BIRNM for five of eight sampling seasons, but showed a dramatic decline from 2003 to 2005 in the spring sampling season (Figure 48a). Fall biomass was lower than spring and highly variable within season. Red hind biomass was lower than coney biomass and highly variable across seasons and years, with similar inside/outside biomass patterns (Figure 48b). Yellowtail snapper mean biomass in spring was higher inside than outside for all years (Figure 49a). Other snapper species were highly variable and not abundant enough to determine any meaningful temporal patterns between season and years (Figure 49).

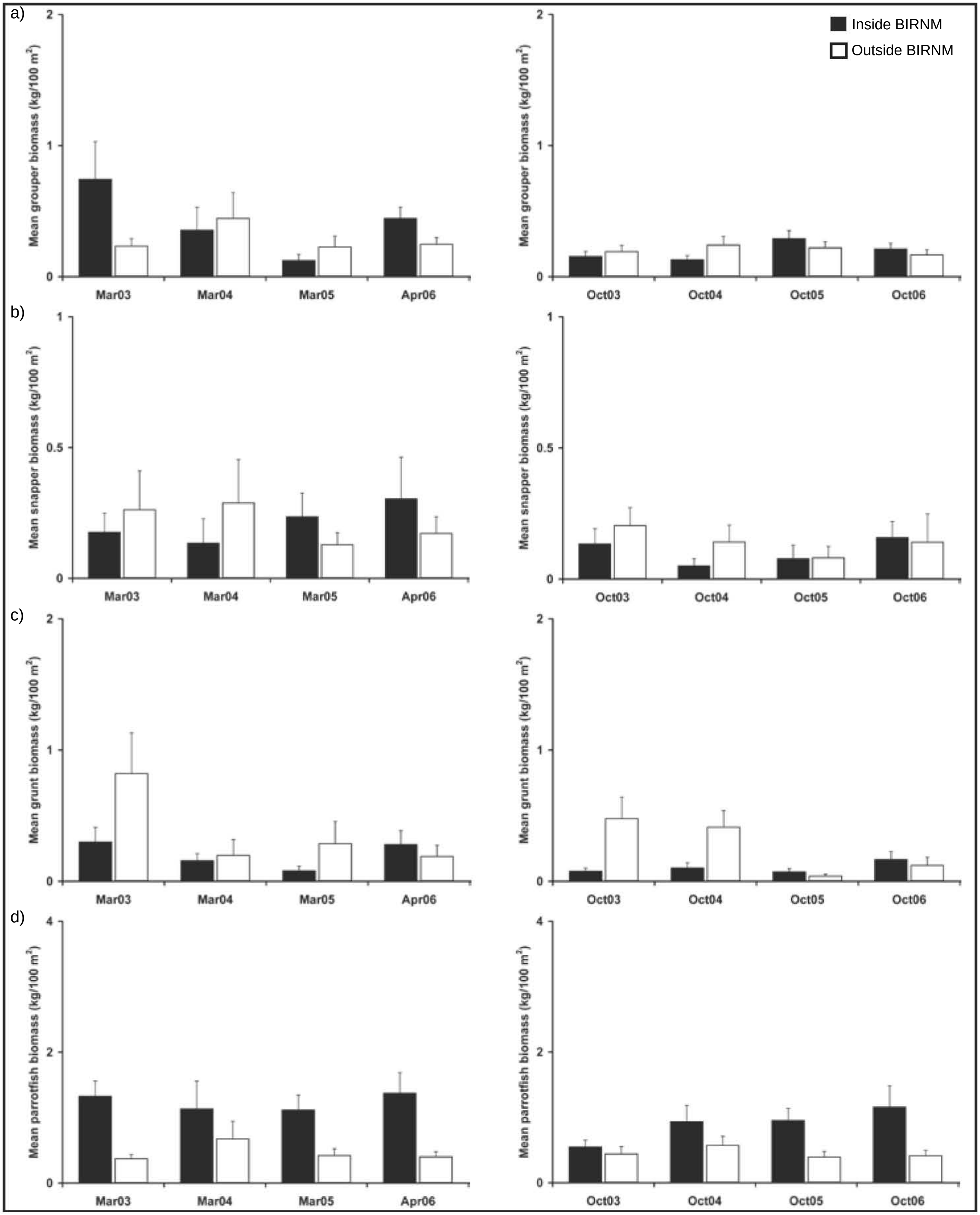


Figure 47. Seasonal and inter-annual (2003-2006) change in mean (± SE) fish biomass inside and outside BIRNM for: (a) groupers, (b) snappers, (c) grunts and (d) parrotfish.

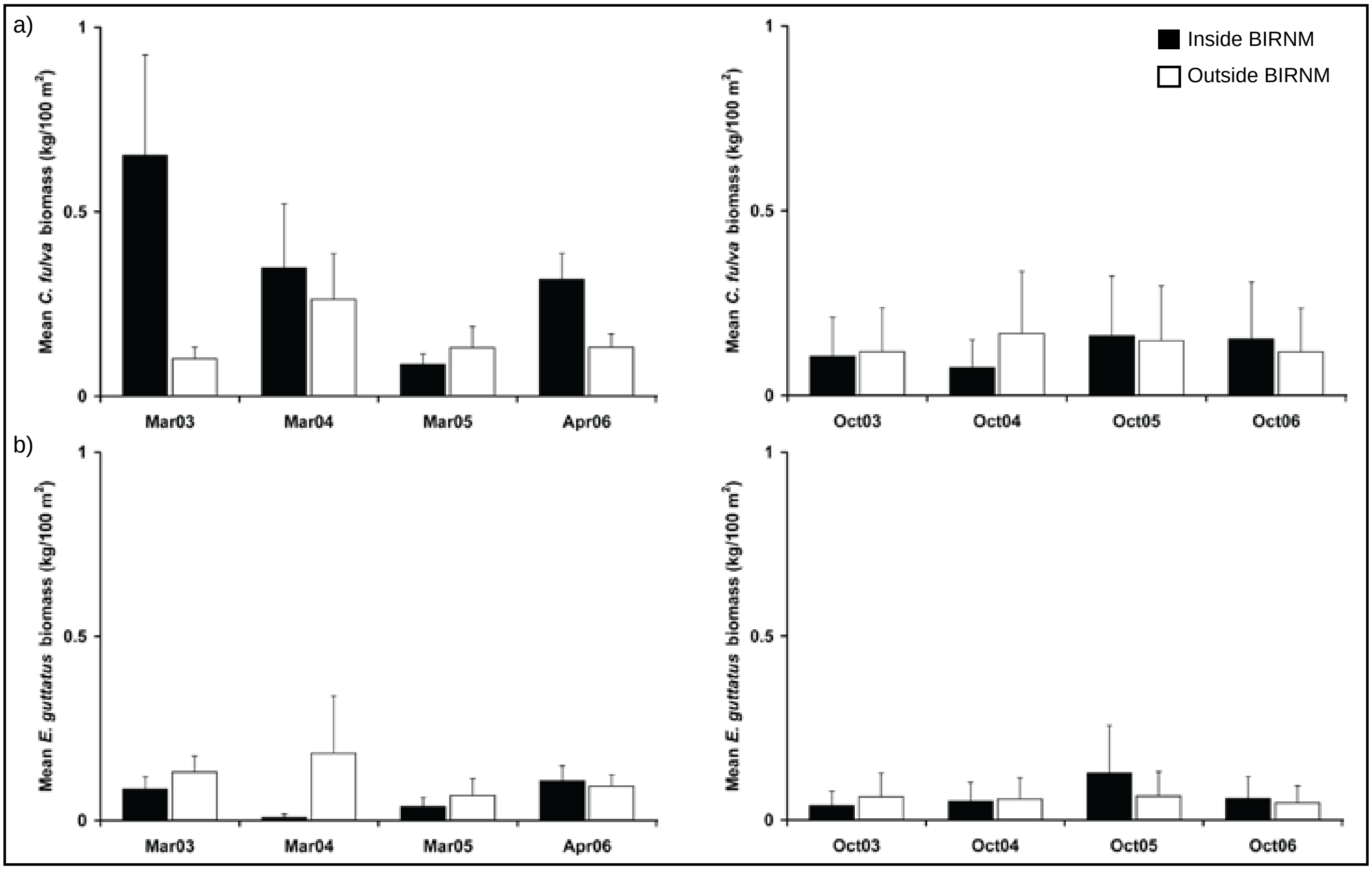
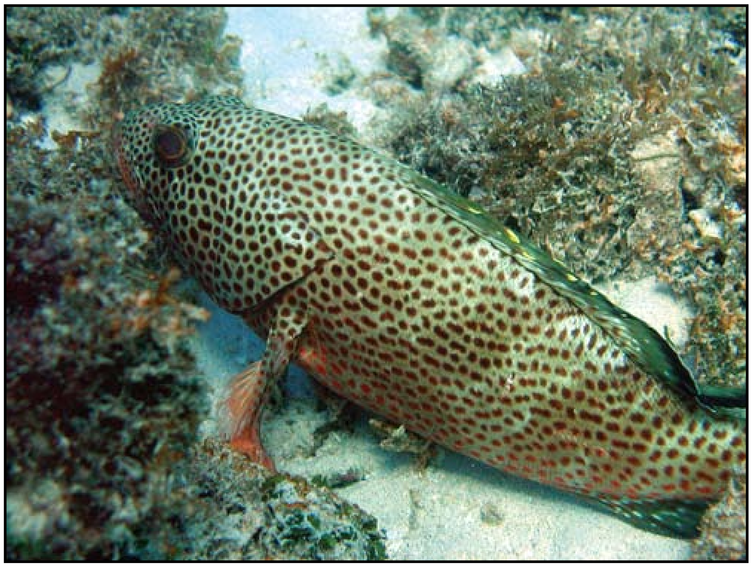


*Figure 48. Seasonal and inter-annual (2003-2006) change in mean (± SE) fish biomass inside and outside BIRNM for (a) coney (*C. fulva*) and (b) red hind (*E. guttatus*).*



*Red hind (*Epinephelus guttatus*)*

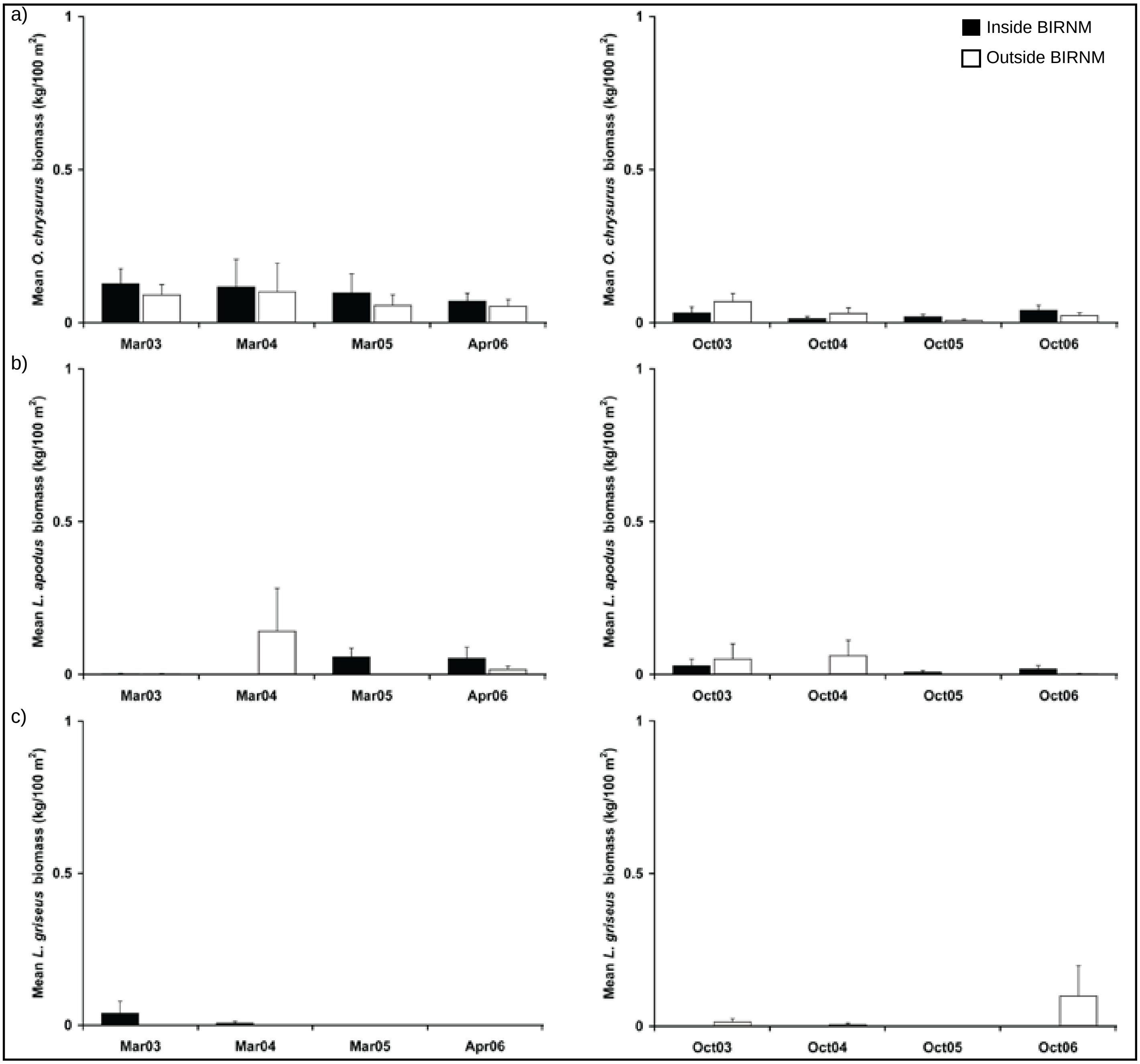


*Figure 49. Seasonal and inter-annual (2003-2006) change in mean (± SE) fish biomass inside and outside BIRNM for: (a) yellowtail snapper (*O. chrysurus*), (b) schoolmaster (*L. apodus*) and (c) gray snapper (*L. griseus*).*

*Yellowtail snapper (*Ocyurus chrysurus*)*

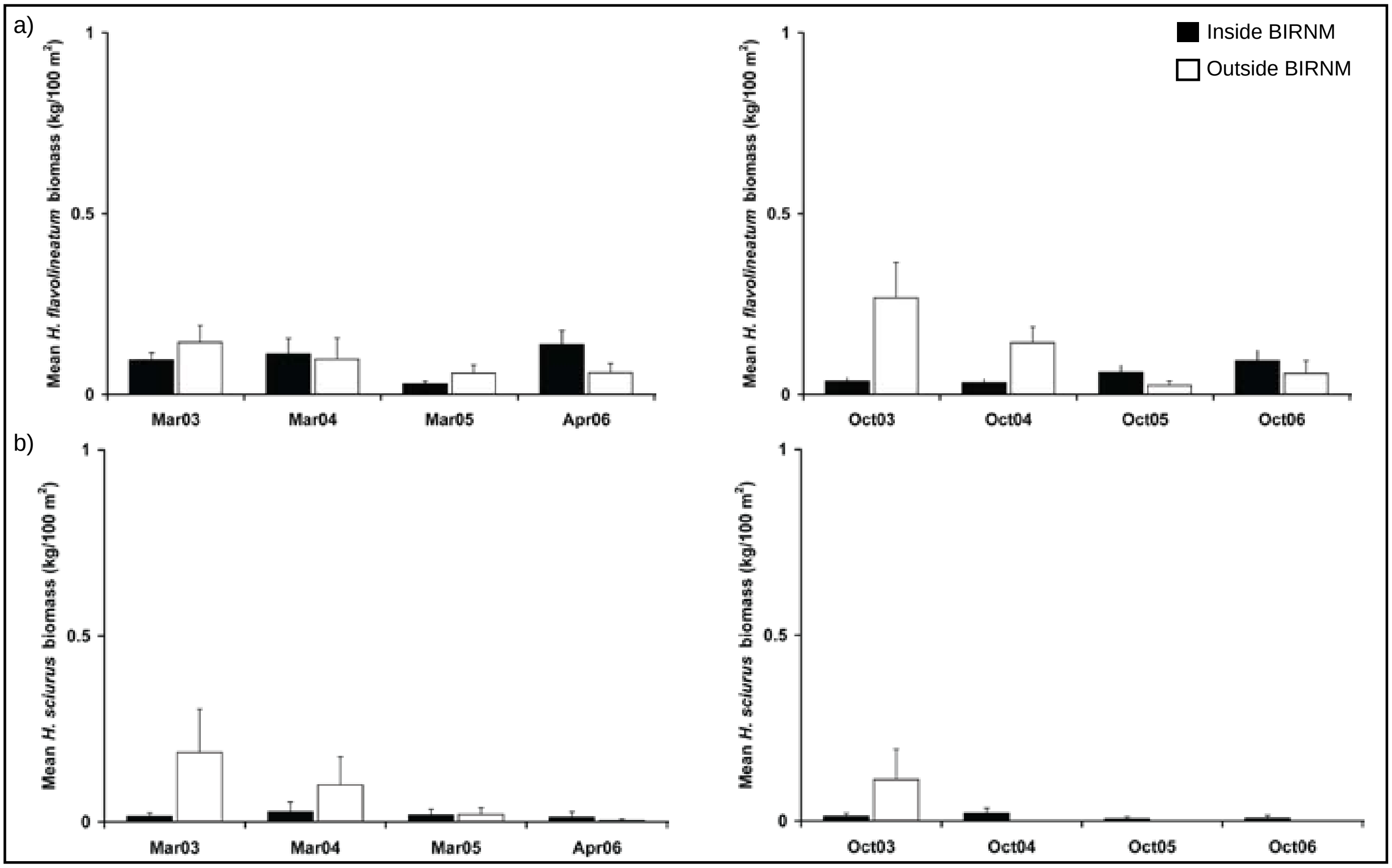


*Figure 50. Seasonal and inter-annual (2003-2006) change in mean (± SE) fish biomass inside and outside BIRNM for (a) French grunt (*H. flavolineatum*) and (b) bluestriped grunt (*H. sciurus*).*

Mean biomass of French grunts and bluestriped grunts outside BIRNM declined year after year from 2003 to very low levels in 2006 (Figure 50). Inside BIRNM, biomass increased for French grunt and varied little between years for bluestriped grunt.

Herbivore mean biomass in spring was higher inside BIRNM for all species (blue tang, striped parrotfish and redband parrotfish) and almost all years (Figure 51). In addition, spring biomass for all species examined was higher in spring than in fall. For both seasons biomass was highly variable among years and no obvious trend was observed.

Assemblage of juvenile, subadult and adult grunts (Haemulidae) on a patch reef.

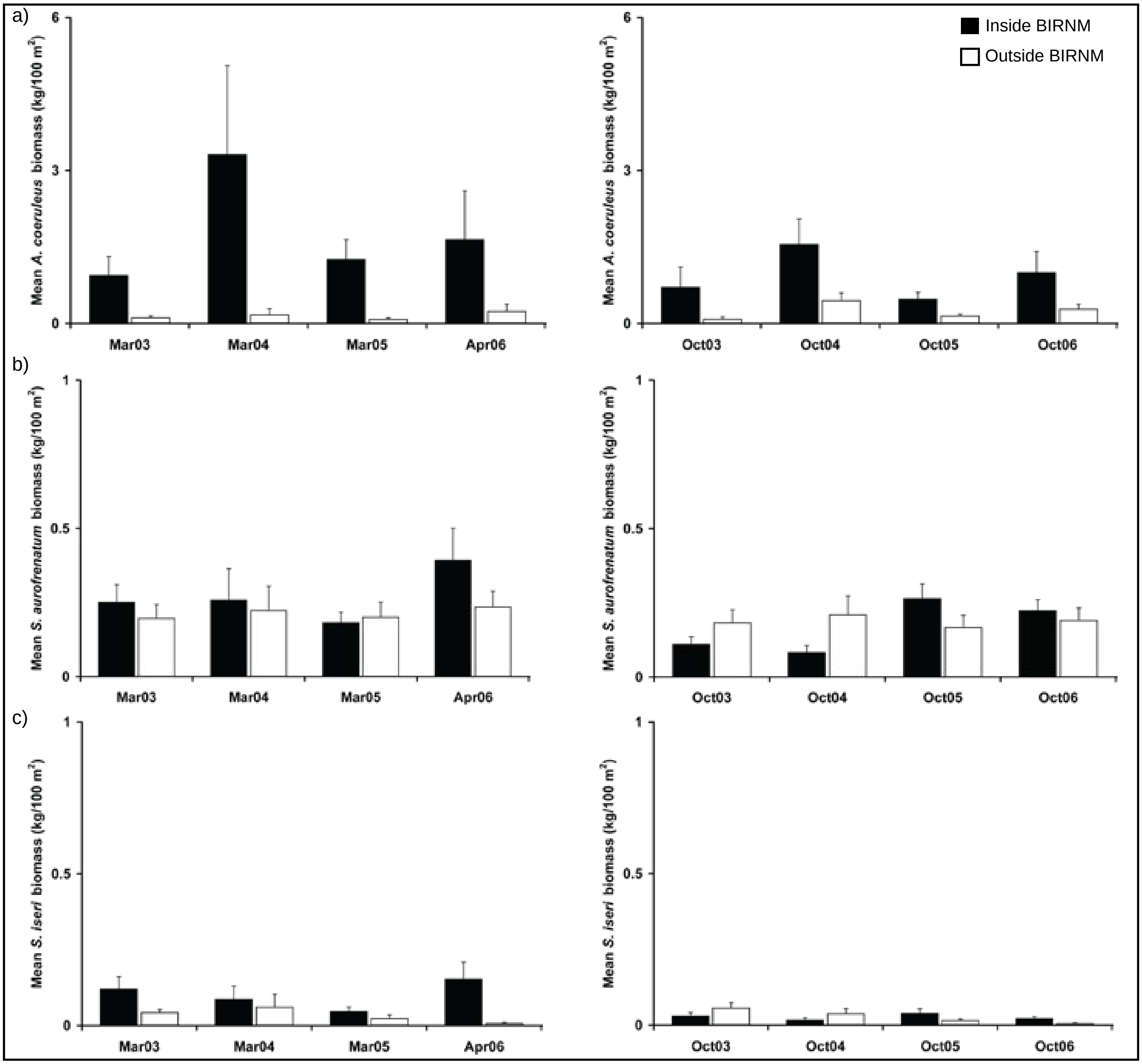


*Figure 51. Seasonal and inter-annual (2003-2006) change in mean (+ SE) fish biomass inside and outside BIRNM for: (a) blue tang (*A. coeruleus*), (b) redband parrotfish (*S. aurofrenatum*) and (c) striped parrotfish (*S. iseri*).*

3.3 Macroinvertebrate spatial distribution patterns and species-habitat associations

*3.3.1 queen conch (*Strombus gigas)

A total of 736 queen conch were observed in the study region (northeastern St. Croix) between 2004 and 2006, of which 72.3% were juveniles (i.e., no flared lip). Highest mean density of both juveniles and adults were recorded in seagrass beds inside BIRNM (Figure 52). The maximum number of individuals at any one survey site (100 m^2) was 59, recorded from a seagrass bed inside BIRNM. Overlay of distributions on the benthic habitat map showed a concentration of juveniles in seagrasses directly in the sheltered leeward side of Buck Island. Adults showed a similar distribution (Figure 53), albeit less concentrated and at lower densities revealing that adult and juvenile *S. gigas* were not spatially segregated. Sixty percent of sites with juveniles present also had adults present. Comparison of estimates of sighting frequency (Figure 54) show that *S.gigas* juveniles and adults were markedly more common in northeastern St. Croix than for St. John or southwestern Puerto Rico and comparison of area-weighted abundance for the three islands highlights the importance of the St. Croix seagrass beds in supporting a queen conch population of regional significance.

Comparison of estimates of sighting frequency (Figure 54) show that *S.gigas* juveniles and adults were markedly more common in northeastern St. Croix than for St. John or southwestern Puerto Rico and comparison of area-weighted abundance for the three islands highlights the importance of the St. Croix seagrass beds in supporting a queen conch population of regional significance (Table 17).

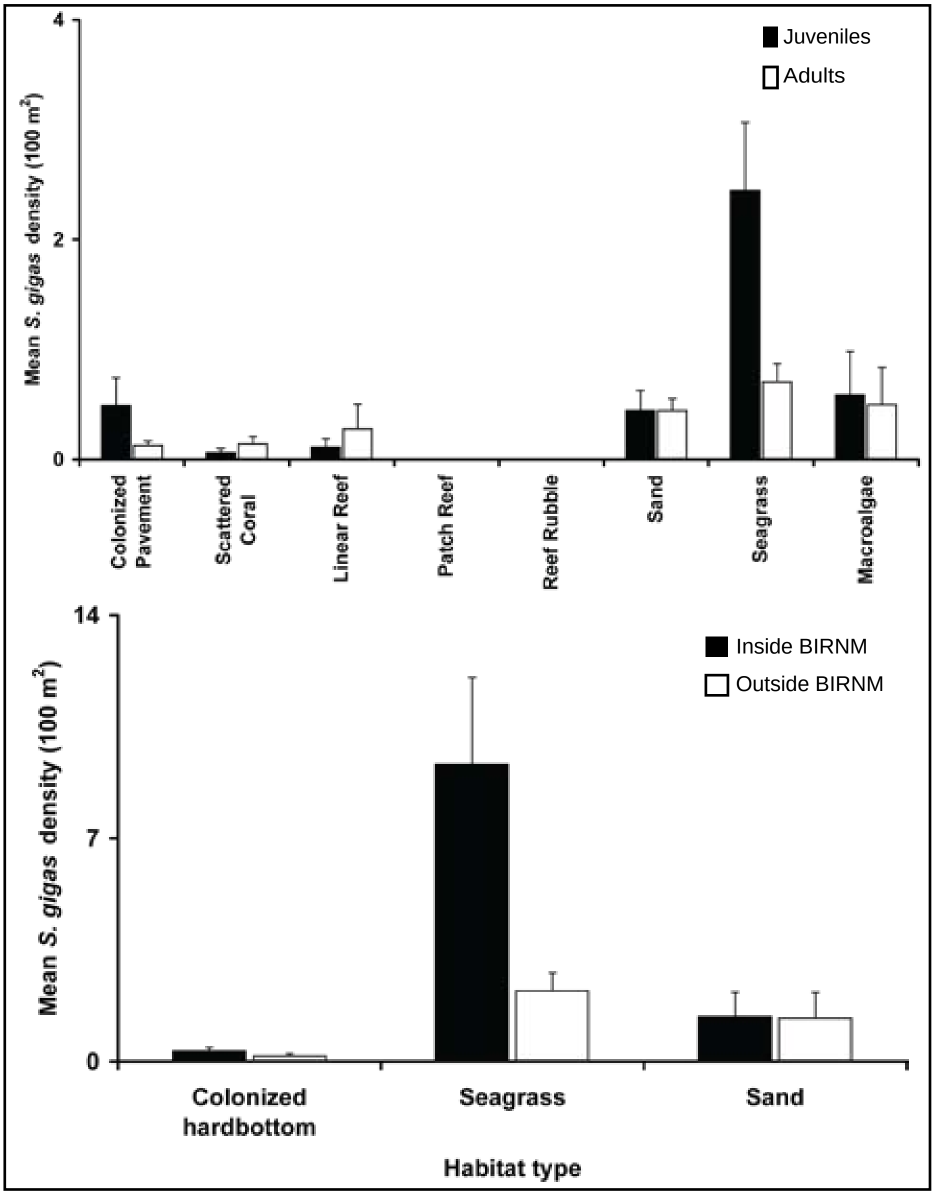


*Figure 52 Mean (± SE) density for (a) juvenile and adult queen conch (*S. gigas*) by habitat type, and (b) all queen conch inside and outside BIRNM by dominant habitat types in the study region (northeastern St. Croix) between 2004 and 2006.*

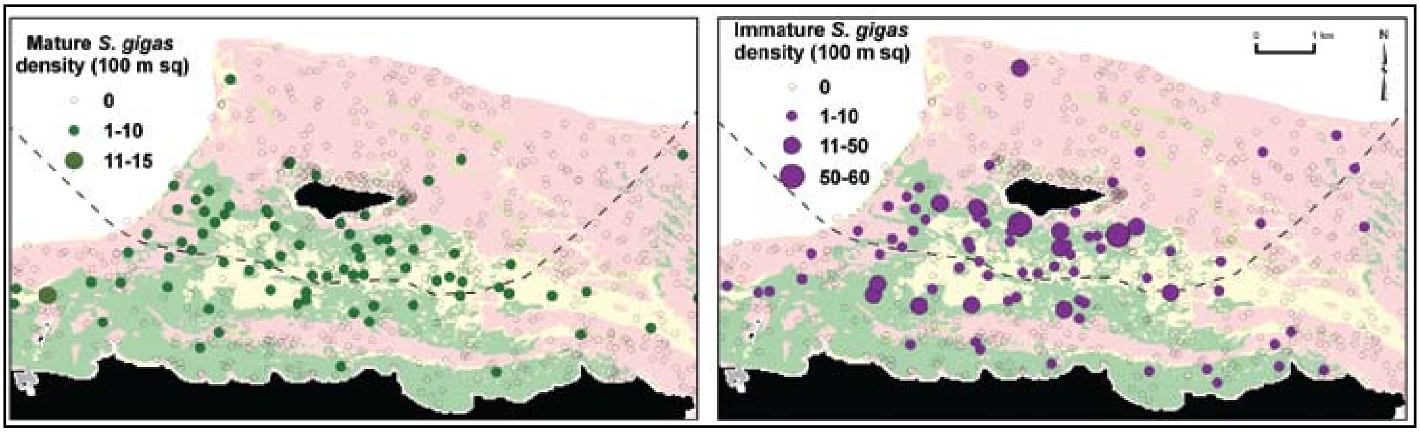


*Figure 53. Spatial distributions of (a) juvenile (immature) and (b) adult (mature) queen conch (*S. gigas*) density in the study region (northeastern St. Croix) between 2004 and 2006.*

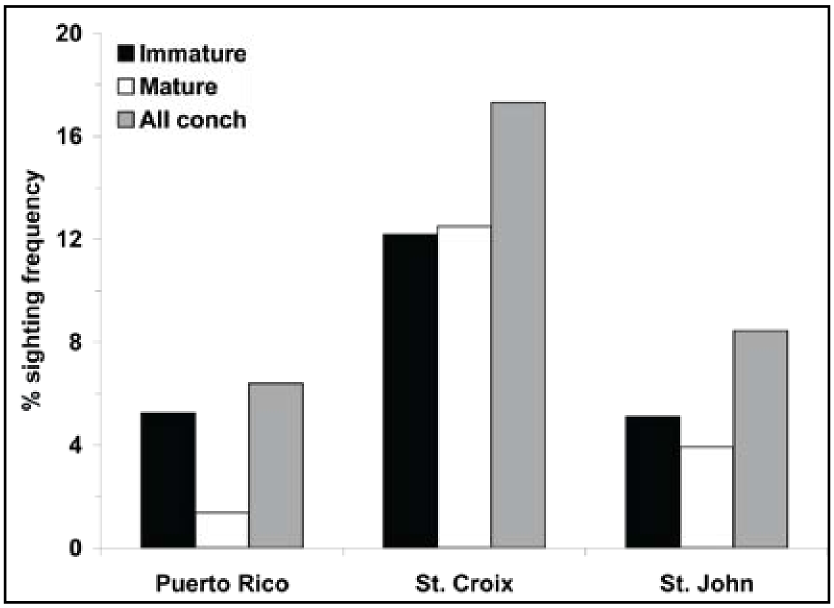


Figure 54. Sighting frequency of sexually immature (juvenile), mature (adult), and all queen conch from three study sites in the U.S. Caribbean: Southwest Puerto Rico; northeastern St. Croix and St. John. Sighting frequency was calculated as the percentage of sampled sites where at least one juvenile or adult conch was observed. Source: Jeffrey and Monaco, 2007.

Table 17. Estimates of total queen conch abundance (number of individuals) by life stage for three islands in the U.S. Caribbean (2004-2006). Source: Jeffrey and Monaco, 2007.

Island	Size of study area (ha)	% of area sampled	# of surveys	Life stage	Estimated abundance	Range of estimate
Puerto Rico	157,348	< 0.01	394	Immature	1,100,248	236,943 - 1,963,553
				Mature	204,645	34,698 - 374,591
				Total	**1,304,893**	**271,641 - 2,338,144**
St. Croix	32,014	0.02	624	Immature	1,933,950	1,025,084 - 2,842,815
				Mature	835,005	493,204 - 1,176,805
				Total	**2,768,954**	**1,518,288 - 4,019,620**
St. John	4,697	0.11	505	Immature	169,838	39,019 - 300,656
				Mature	72,832	26,576 - 119,087
				Total	**242,669**	**65,596 - 419,743**

*3.3.2 Long-spined sea urchin (*Diadema antillarum*)*

D. antillarum was observed at approximately 10% of sites (38 out of 364) surveyed between October 2005 and November 2006. Mean density across the study region was 0.03 (± 0.01 SE) per 1 m^2. Maximum density recorded at any individual site was 4.2 m^2. Visual assessment of spatial distributions of abundance revealed that very few *D. antillarum* were using the coral reef ecosystems around Buck Island between 2005 and 2006 (Figure 55) and *D. antillarum* densities were considerably higher on hardbottom habitat types outside BIRNM than inside (Figure 55). Highest densities were observed in the nearshore environments within the EEMP on colonized bedrock, colonized pavement and macroalgal beds in close proximity to extensive seagrass beds (Figure 56).

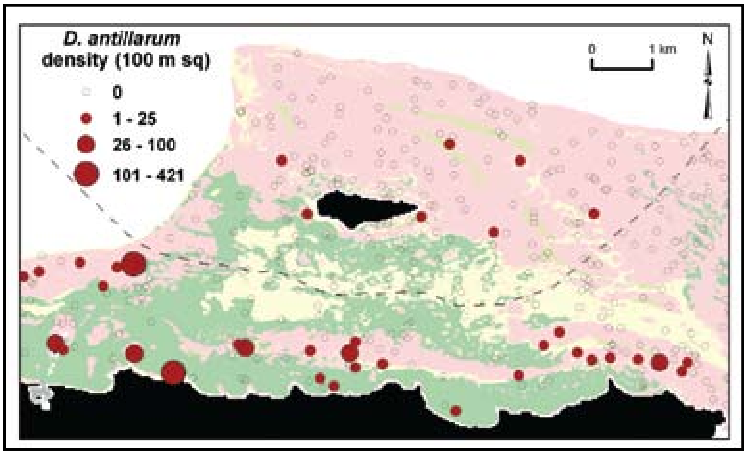


*Figure 55. Spatial distribution of long-spined urchins (*Diadema antillarum*) in the study region (northeastern St. Croix) between 2005 and 2006.*

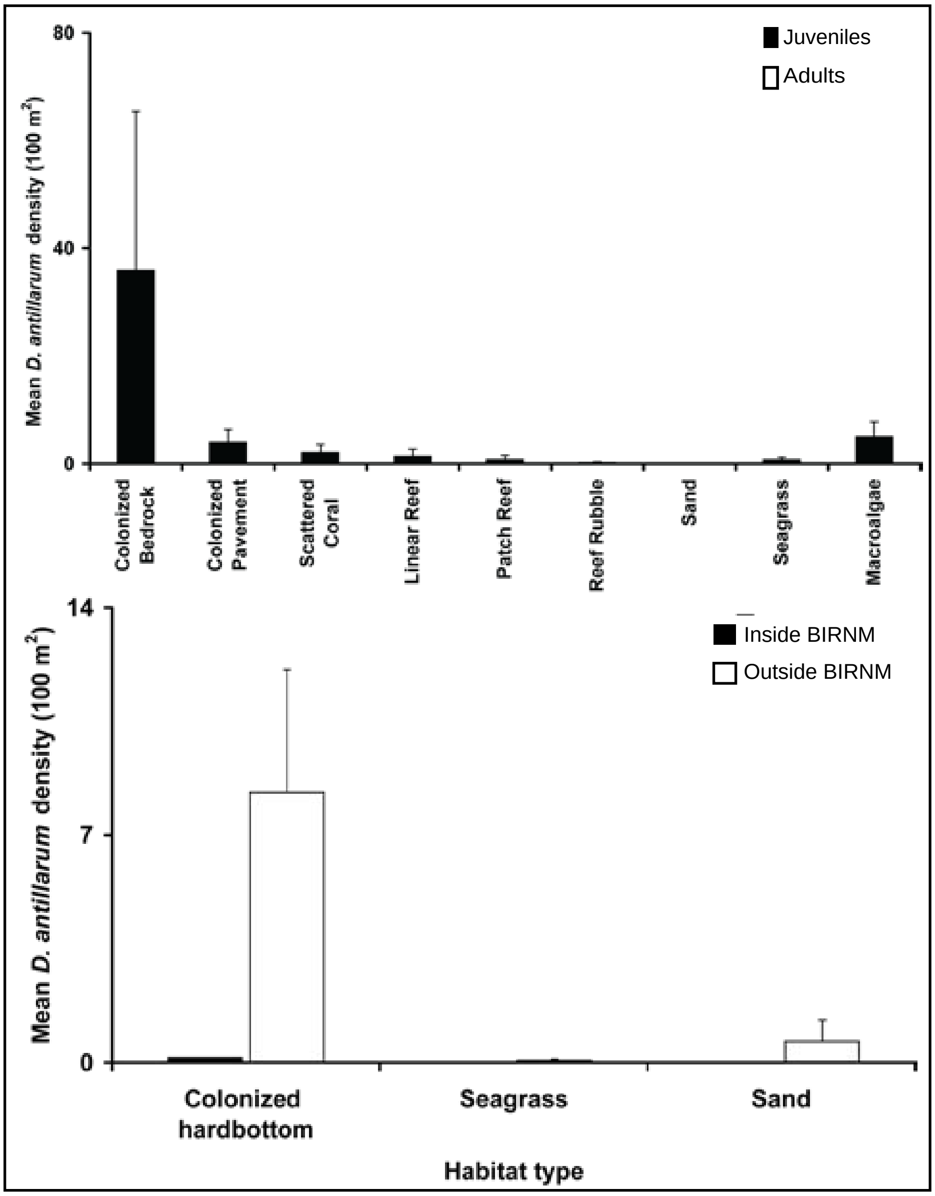


*Figure 56. Mean (± SE) density for long-spined sea urchin (*Diadema antillarum*) by (a) habitat type and (b) inside and outside BIRNM (northeastern St. Croix) between 2005 and 2006.*

3.3.3 Historical comparison of Diadema *abundance*

In 1979, Gladfelter (1980) carried out daytime surveys and recorded a peak density of 10.6 per m^2 on pavement areas at the northwest end of Buck Island ,between 5 and 10 per m^2 in the lagoonal patch reef south of island and 5-8.3 m^2 on the bank barrier reef at the eastern tip of the island. A few years earlier, Ogden et al. (1972) recorded mean *D. antillarum* densities of between 0.81 and 4.08 per m^2 on patch reefs in Teague Bay (Figure 57).

In contrast, between 2005 and 2006, mean density of *D. antillarum* was recorded at 0.03 m^2 across the study region and presence of *D. antillarum*. Of particular importance was the observation of only five *D. antillarum* individuals over hardbottom habitats in the lagoon and bank barrier reef areas (n=43 transects or 4,300 m^2 surveyed within 500 m of Buck Island) between October 2005 and November 2006. However, sea urchin densities were higher in lagoonal and back reef areas outside BIRNM along the northeastern coastline of St. Croix.

D. antillarum, *October 2005*

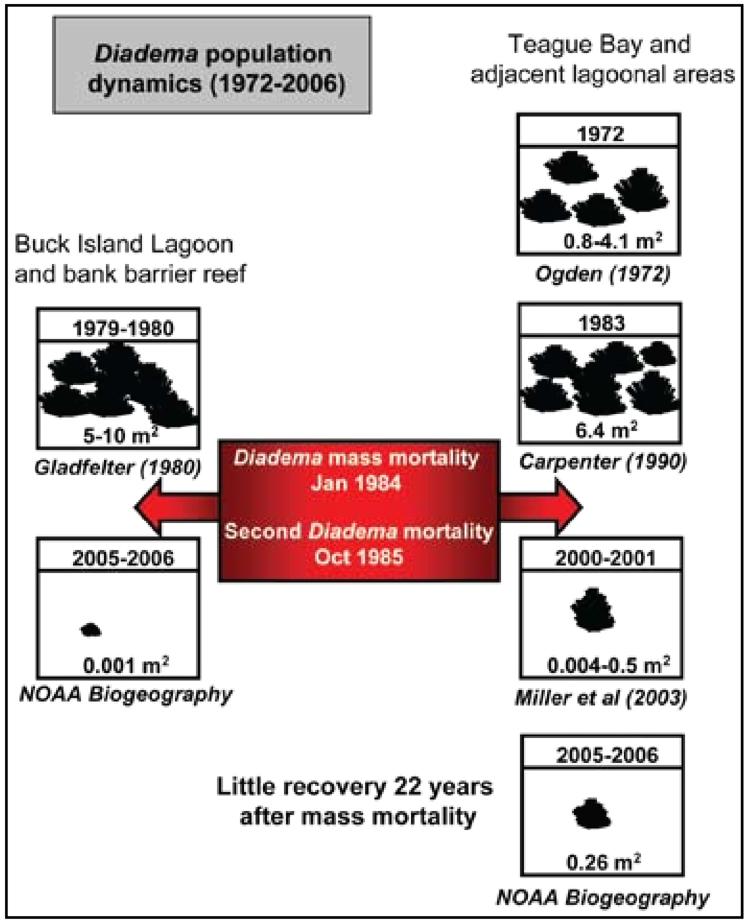
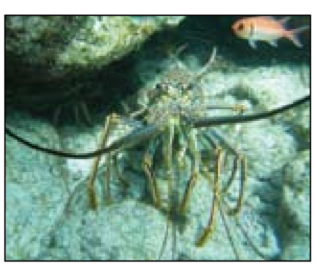


Figure 57. The changing abundance of Diadema antillarum *in (a) the lagoon and on bank barrier coral reefs within 500 m of Buck Island and (b) Teague Bay and adjacent nearshore lagoonal environments showing little to no recovery in over two decades since the mass mortality event. Source: Ogden, 1972; Gladfelter, 1980; CCMA-BB.*

3.3.4 Caribbean spiny lobster (Panulirus argus)

A total of 24 spiny lobster (*Panulirus argus*) were recorded over hardbottom areas from 2003 to 2006, including two in 2003 from two sites; eight in 2005 from six sites and 14 in 2006 from five sites (Table 18). There were no lobsters observed in 2004. Fifteen spiny lobsters were observed inside BIRNM and nine outside. The highest densities at individual sites were observed in patch reef and colonized pavement habitat types dominated by branching corals (three and nine lobsters respectively). Five lobsters were observed over scattered coral/rock in sand habitat type. No lobsters were observed on softbottom sites. However, the abundance of lobsters detected using existing techniques is very likely to be an underestimate of abundance. Lobsters are cryptic and crevice dwelling animals that are best surveyed using dedicated lobster census techniques and supplemented with night time surveys when some lobsters are more active and therefore more visible. These data should not be used to estimate spiny lobster populations in the study region.



P. argus, *March 2007*

*Table 18. Abundance of spiny lobster (*Panulirus argus*) in hard and soft habitats of the study region and inside and outside BIRNM (northeastern St. Croix) between 2003 and 2006.*

Year	Habitat Types	Location: Inside	Location: Outside	Total
2003	Hard	0	2	2
	Soft	0	0	0
	Overall	*0*	*2*	*2*
2004	Hard	0	0	0
	Soft	0	0	0
	Overall	*0*	*0*	*0*
2005	Hard	4	4	8
	Soft	0	0	0
	Overall	*4*	*4*	*8*
2006	Hard	11	3	14
	Soft	0	0	0
	Overall	*11*	*3*	*14*
Total		**15**	**9**	**24**

4. Discussion

This report demonstrates quantitatively and spatially that the benthic environment inside BIRNM was significantly different to the outside (Tables 5, 6 and 7). The results show conclusively that the abundance of key benthic components, at both the 1 m^2 spatial scale (quadrat sampling unit) and at the 100 m radius spatial scale (e.g., surrounding seascape unit), were significantly different inside. For instance, nine of 14 biotic variables measured within quadrats set over hardbottom habitat sites and seven of nine seascape metrics (amount and richness of habitat types) were significantly different inside versus outside BIRNM. Seascapes inside BIRNM were more diverse and had on average a higher area of colonized hardbottom and lower area of seagrasses surrounding transects. Furthermore, visual examination of interpolated distribution maps clearly showed that a greater spatially continuous area of high coral cover, coral species richness and rugosity was contained within the boundary of BIRNM consistent with objectives of the marine protected area designation. The existing BIRNM boundary broadly follows the boundary between medium-high coral cover and medium-low coral cover as depicted in the spatial interpolation. In addition, higher coral cover for all major scleractinian families was recorded inside BIRNM and coral reefs inside also had a higher ratio of live coral cover to macroalgal cover than coral reefs outside BIRNM. Such information may serve as a useful indicator for change detection, with the coral-macroalgal ratio being an important benthic relationship relevant to faunal communities and indicative of the functional status of the environment.


Crustose coralline algae

Although coral reef structure has been modified by several major events since the original National Monument designation and the special recognition of the “marine gardens” in 1961, the area around the eastern tip of Buck Island remains distinctive in both biological and geomorphological structure. The spatial data contained in the report characterizes this area as having high live coral cover, high rugosity, high coralline algal cover, high fish species richness, high biomass of herbivorous fish and high density for many fish species. The relevance of coralline algae is related to its function in providing an important food source for some fish including parrotfish and physical structure and chemical cues promoting the settlement and metamorphosis of many invertebrates including some coral larvae. The distinct biological features of the eastern tip of Buck Island suggest that the area could function as refugia for several benthic organisms. If true, then because of prevailing northeasterly winds and circulatory patterns, the area may be an important source of larvae for corals and other benthic organisms in down stream areas. Hardbottom areas inside BIRNM exhibited a significantly higher ratio of coral to macroalgae than did hardbottom areas outside. This may be indicative of greater top-down control of macroalgae due to grazing pressure since hardbottom areas inside BIRNM also have significantly higher herbivore biomass, particularly parrotfish and surgeonfish than similar outside areas.

In addition to the well-recognized and extensive hardbottom areas north and east of Buck Island within BIRNM, an additional area was found to support high coral species richness and fish species richness along the northeast coastline of St. Croix. The linear reef and adjacent colonized pavement extends east-west from Teague Bay to Coakley Bay and now falls within the EEMP no-take zone and recreation zone (Appendix A, Figure A1). This extensive fringing coral reef may also offer important habitat to fish moving from nearshore seagrass and patch reef environments to coral reefs as part of ontogenetic transitions in habitat use. More focused research including acoustic tracking may elucidate on the connectivity between nearshore lagoonal environments and coral reefs both inside and outside BIRNM. Very little is known about fish movement patterns in the study region and data from an acoustic tracking project would provide important information on connectivity. For example, is the reason for low abundance of the large size classes of grouper, snapper and grunt due to emmigration out from the study region to deeper waters or mortality? A multi-year broadscale acoustic tracking study has the capability to answer this question.

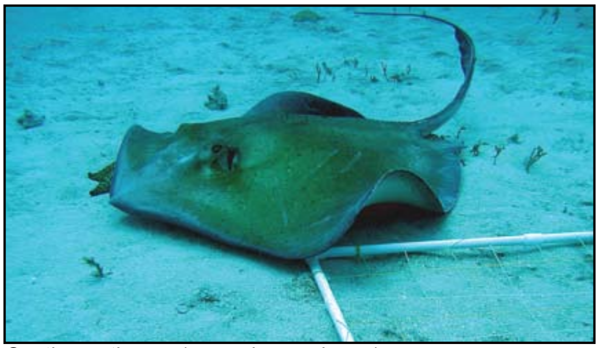
Extensive areas with high coral species richness, high cover for *Montastraea cavernosa* and *M. annularis*, high fish species richness and high abundance for several fish species including coney (*C. fulva*), rock beauty (*Holacanthus tricolor*) and queen triggerfish (*Balistes vetula*) occurred along the northernmost edge of the benthic habitat map. This indicates that important deeper water habitat is likely to exist beyond the scope of this report, requiring further benthic habitat mapping effort combined with deeper water visual census to capture data on fish communities.


*queen triggerfish (*Balistes vetula*)*

In comparative investigation of management domains for the purpose of evaluating efficacy (e.g., inside versus outside protected areas), caution is required since clear differences are evident in benthic habitat that will likely explain some of the patterns in faunal distributions independently of management practices. However, this does not obviate the usefulness of comparative analyses, since differences and similarities that exist within or between management domains provide valuable information in support of local decision-making processes for the selected regions of interest. Future assessments could, however, usefully attempt to partition out the relative influence of differences in habitat from the effects of management actions.

Fish species, family/trophic group and communities inside and outside BIRNM

As expected, fish community composition was most dissimilar between linear reefs and scattered coral or rock, habitat types that are known to differ markedly in structural complexity and areal extent. Unexpectedly, fish communities associated with aggregated patch reefs, linear reefs and colonized pavement were so similar as to be barely separable. These habitat types were considered distinct to the human observer when classifying the benthic structure, yet for the fish communities the differences were not significant. This may have implications for the level of thematic accuracy required when delineating benthic habitat in the construction of benthic maps for fish-habitat studies. Considerable cost savings may result from delineation of fewer classes of hardbottom. Further studies using high resolution Light Detection and Ranging (LiDAR) bathymetry should provide useful information on the structural variability within existing NOAA benthic habitat types and will help to understand the implications of benthic structural types for fish. Furthermore, fish communities associated with the same habitat types inside and outside BIRNM were very similar and indistinguishable. Examination of more subtle differences in community composition between strata may require additional multivariate analytical techniques.



*Southern stingray (*Dasyatis americana*)*

Several individual fish metrics were significantly higher on colonized hardbottom habitats inside than outside BIRNM including fish biomass (all fish combined), herbivore biomass, parrotfish biomass, shark and ray biomass, coney density and biomass, blue tang (*A. coeruleus*) density and biomass and striped parrotfish (*S. iseri*) biomass. Comparatively fewer fish metrics were significantly higher outside, but included ecologically important predator groups such as piscivore biomass, snapper density and grunt density and biomass. The greater biomass of piscivorous fish outside BIRNM probably relates more to habitat preferences of relatively infrequently occurring sharks and rays (over unvegetated sediments) than any indication of MPA performance. Similarly, higher grunt density and biomass outside BIRNM likely relates more to the abundance of shallow nearshore hardbottom environments in close proximity to seagrass beds than MPA performance. Interpretation of these patterns highlights the importance of using spatially explicit census data.

Size frequency histograms revealed some differences in size structure inside versus outside BIRNM for grunts and snapper, with: (1) a higher frequency of large bodied snapper inside BIRNM; (2) a greater decrease in frequency of large subadult and adult yellowtail snapper (*O. chrysurus*) with increasing size outside BIRNM; (3) a higher frequency of large juvenile and subadult French grunt inside BIRNM; and (4) higher frequency of small juveniles outside (Figures 42 and 43). These differences may reflect differences in environment or management/fishing pressure or both, but nevertheless data indicate that a larger proportion of the mature adult snapper and grunts are occurring inside the protected area than outside.

Interestingly, very few of the largest and very few of the smallest size classes were observed for grouper and snapper. For small juveniles, this suggests that either: (1) the study region is not a primary settlement area for groupers and snappers; or (2) newly settled juveniles exist, but are not being detected by the belt transect survey technique due to cryptic coloration or hiding behavior thus providing false absences. For large adults, this suggests that either: (1) large adults do not use the study area and may perhaps inhabit deeper unsurveyed waters by day; (2) large adults exist, but are not being detected by the belt transect survey technique due to avoidance behavior thus providing false absences; or (3) large adults are being removed from the system by fishing. Additional targeted survey work may be required to determine the locally important areas for both newly settled juveniles and large-bodied mature adults.

*Stoplight parrotfish (*Sparisoma viride*) and longfin damselfish (*Stegastes diencaeus*)*

Spatial distributions and fish-habitat associations

Although mean densities varied widely between habitat types, with many of the most abundant fish across the study region found in highest densities over hardbottom habitat types, most utilized multiple habitat types including seagrasses and sand. This has implications for the way species-habitat relationships are understood and managed and further study may provide insight into fish resource use patterns and predictions on resilience to change, with many species having evolved sufficient plasticity to exploit a diverse range of structurally distinct habitat types. In addition, many of the juveniles of the most abundant species used the same habitat types as adults and the two life-stages were often found to coexist in the same areas of the study area. This pattern is in contrast to results for the same species elsewhere (e.g., southwestern

Puerto Rico) that have shown a cross-shelf or water depth related size distribution or have reported juveniles using spatially discrete areas as nursery before undertaking ontogenetic habitat shifts to preferred adult habitat. This difference in pattern observed in northeastern St. Croix further highlights the flexibility or plasticity in resource utilization patterns for fish using heterogeneous coral reef ecosystems.

Visual assessment of density distributions for the two abundant species of grouper (red hind [*E. guttatus*] and coney) around northeastern St. Croix suggest different habitat use patterns, with high coney density being widespread over the contiguous colonized hardbottom areas (much of which is inside BIRNM) and high densities of red hind found mostly to the south of Buck Island (many outside BIRNM). These areas of highest red hind density are also close to the interface between seagrasses and extensive areas of colonized hardbottom which may relate to direct or indirect utilization of seagrasses presence of seagrasses or some other covarying environmental variable such as wave exposure (Kendall et al., 2004b). Almost all species examined here were found at higher densities on hardbottom habitat types than seagrasses or other softbottom, however, surveys were conducted during daylight hours and many of these species may use seagrasses during nocturnal foraging excursions. Thus, the low densities of fish associated with seagrasses should not be used in evaluation of relative habitat importance without complimentary information on resource use activity within the daily home range that includes examination of diel migrations. This is particularly relevant to many grunts which are known to make use of seagrasses adjacent to coral reefs as a nighttime feeding ground. Furthermore, most of the coral reefs with high species richness were within 200 meters of seagrass beds. Several studies have demonstrated links between fish distribution on coral reefs and proximity to seagrass beds suggesting that many species may benefit from complementary and supplementary resources provided by seagrasses in close proximity (Grober-Dunsmore, 2007; Pittman et al., 2007) to coral reefs. However, not all coral reef sites in close proximity to seagrasses supported high fish richness, thus it is likely that the interaction between multiple environmental variables including surface rugosity determine such complex spatial patterns.

Seagrasses and macroalgae habitat

Spatial distribution data on selected species may also provide valuable information that can be used as indicators for habitat structure, health, and in combination with temporal data, as a tool in change detection. For example, the threespot damselfish (*Stegastes planifrons*), which exhibits a strong preference for select taxa of live coral (e.g., *Agaricia* spp., *Acropora* spp. and *Montastraea* spp.) and through feeding promotes high algal diversity, may function as a useful indicator of healthy and structurally complex coral reefs. In the northeastern St. Croix study region, highest densities of threespot damselfish were found around the eastern tip of Buck Island within BIRNM and the fringing reef outside BIRNM extending east-west along the northeast coast of St. Croix (Appendix D).

Temporal trends in fish and benthic habitat

With respect to temporal trends, hardbottom benthic habitat exhibited a higher cover of filamentous algae/cyanobacteria and macroalgae, and lower turf algae in fall than in spring. A peak in filamentous cyanobacteria/algae was recorded for October 2005, a season with anomalously high water temperature that also resulted in a mass coral bleaching event. Highest algal turf was recorded for spring 2006, which may be linked to the algal colonization of dead coral colonies that is commonly observed after a bleaching event. Across years, macroalgae cover shows some indication of decline both inside and outside BIRNM between 2003 and 2006. This was especially evident for spring sampling seasons and may indicate increased grazing from a concurrent increase in density of herbivorous fish in the region as a whole and particularly larger (e.g. higher biomass) parrotfish inside BIRNM (see below). Another important observation that emerged from a seasonal comparison of fish density was the markedly higher abundance of fish in fall than in spring. This seasonal pattern was also noted by Simpson (1979) and attributed to the influence of summer recruitment. Still, little is known about the spatio-temporal characteristics of the life-history patterns for even the most common fish in the study region and Simpson's (1979) statement that "knowledge of spawning and recruitment of fishes is still rudimentary" is still pertinent today.

Bleached Diploria strigosa *with turf and cyanobacteria overgrowth.*

Synoptic overview of inter-annual differences in mean metric values both inside and outside BIRNM showed no consistent decline for any of the 39 fish metrics inside BIRNM, but increases every year between 2003 and 2006 were recorded for density of all fish and mean biomass of parrotfish. In contrast, increases for the entire sampling period were not evident outside BIRNM, instead considerable and consecutive decline was apparent for grunt biomass, especially bluestriped grunt (*H. sciurus*) and density and biomass of stripped parrotfish. Grunts and parrotfish are all readily captured in baited trap and net fisheries, and thus are highly susceptible to extraction from the ecosystem. Results here suggest that target species may receive some protection within BIRNM and that may account for the absence of continuous decline and the apparent increases during the sampling period between 2003 and 2006. If BIRNM retains fish species within its boundary and the existing legislated protection is enforced effectively, then biomass and abundance of fish would be expected to increase since the commencement of no-take regulations in 2003. Accumulation of biomass at detectable levels, however, may require longer term monitoring data. This is particularly likely for grouper since many grouper are comparatively slow growing and some such as the Nassau grouper are late maturing (i.e., approximately 50 cm length). This together with the fact that many grouper and snapper aggregate to spawn make them particularly vulnerable to fishing pressure and slower in recovery of viable populations.

Interestingly, many of the fish variables that showed a decline between 2003 and 2005 then showed an increase (sometimes substantial) in 2006, for example, coney biomass, piscivore density, grunt biomass and French grunt (*H. flavolineatum*) biomass inside BIRNM. This may be indicative of: (1) the beginning of a response to increased protection; (2) an artifact of random sampling; or (3) part of variable fluctuations driven by other ecological factors (e.g., predation pressure, changing habitat quality etc.). It is known that greater voluntary compliance began in 2003 and this was then supplemented with law enforcement patrols from 2004. Thus, if fishing pressure was an important determinant of fish abundance and biomass the recovery would not be expected to be detectable for several years after compliance. Further long term monitoring will be required to reveal the direction of apparent upturns reported in 2006 at the end of this portion of the monitoring data.

Diver collecting fish data

When comparing inside with outside BIRNM, neither groupers nor snappers exhibited any consistent increases or declines over the entire sampling period (2003-2006), yet at the scale of the entire study area, yellowtail snapper biomass declined year upon year. This trend warrants concern and requires further monitoring since yellowtail snapper mean is a highly valuable commercial species and important ecological component of the ecosystem, being found in all habitat types in the study region. Furthermore, breakout of data by spring season revealed apparent downward directional trends inside BIRNM for density of yellowtail snapper, coney, gray snapper (*L. griseus*) and piscivore biomass (2003-2005). No obvious trend for the same species existed during fall and this may relate to seasonal differences in the influx and outflow of fish to BIRNM. Acoustic tracking may provide useful information on the seasonal fish movement patterns.

The multi-level and multi-resolution analyses in this report showed that direction of trend and subsequent interpretation of results varied with temporal grouping or resolution. An apparent inter-annual trend for a single season and management domain may not be apparent when both seasons are combined, or when management domains are combined. In addition, density and biomass may exhibit different patterns over time. It is important, therefore, that future temporal characterizations using summary statistics be undertaken at multiple levels of temporal resolution (season, year), as well as biological resolution (species, family, trophic group, community) and management domain resolution (inside, outside, region).

Overall, the majority of fish biomass was highly variable between years and therefore long term monitoring is required to elucidate further on the direction of change and particularly to track the declining trends in several key fish species and groups.

Connection between life history and vulnerability to fishing

Fisheries management organizations and fishers themselves need to be more aware of the relationship between fish life history characteristics and vulnerability to fishing. The apparent decline of three species of large-bodied and late maturing grouper (tiger, yellowfin and Nassau grouper) in the study region highlights the vulnerability of some species that were once of significant commercial value to the local fishery. Species with larger body size, higher longevity, higher age at maturity, and lower growth rate are generally considered to have higher vulnerability to fishing (Jennings et al., 1999; Dulvy and Reynolds, 2002; Dulvy et al., 2003).

Evidence that fishing pressure may have been responsible for some observed declines in abundance comes from analytical methods used to estimate extinction vulnerability to fishing which have classified tiger grouper and Nassau grouper as having HIGH to VERY HIGH vulnerability and yellowfin grouper as MODERATE to HIGH vulnerability based on body size and other biological characteristics (FishBase: http://www.fishbase.org; Cheung et al., 2005; Table 19). These species are also thought to mature late, with tiger grouper estimated to mature at approximately half its maximum size at an age of between 6.5-9.5 years. As such all three species have low resilience to fishing with a minimum population doubling time calculated at between 4.5-14 years (Table 19). In contrast, the smaller-bodied grouper (red hind and coney)

E. striatus (*Nassau grouper*)

Table 19. Life history characteristics and vulnerability to fishing for three large-bodied species and two smaller-bodied species of grouper. Vulnerability is based on maximum size and the von Bertalanffy growth parameter (K) used by Cheung et al., 2005. Population doubling time is based on calculations by Musick et al., 2000 as reported in FishBase.

	M. tigris Tiger grouper	*M. venenosa* Yellowfin grouper	*E. striatus* Nassau grouper	*C. fulva* Coney	*E. guttatus* Red hind
Max. size (cm)	101 TL	100 TL	122 TL	41 TL	76 TL
Length first maturity (cm)	46 - 55 TL	51 FL	48 FL	16 FL	25 FL
Age first maturity (Y)	6.5-9.5	?	?	?	3
Pop. doubling time (Y)	4.5-14	4.5-14	4.5-14	1.4-4.4	1.4-4.4
Vulnerabilty (index)	High-Very High (74.9)	Mod.-High (49.7)	High-Very High (71.9)	Low-Mod. (32.5)	Moderate (41.5)

which are now more abundant in the study region have LOW to MODERATE vulnerability and medium resilience to fishing with an estimated population doubling time of between 1.4-4.4 years. For instance, the maximum body size for red hind is 76 cm TL, yet maturity has been recorded for fish at 25 cm FL (three years of age).

Distribution of macroinvertebrates

Long-spined sea urchins

Dramatic shifts in the distribution and abundance of the long-spined sea urchin (*Diadema antillarum*) were evident when comparing present day distributions (2005-2006) with historical distributions recorded in the 1970s. Comparison with historical density estimates indicated that 1970s/early 1980s densities were substantially higher than in 2005-2006. Gladfelter (1980) stated "*Diadema antillarum* is a conspicuous member of the Buck Island fauna" and Ogden et al. (1972) note that "on certain patch reefs in the vicinity of Teague Bay Reef, the grazing activities of this sea urchin have all but eliminated the growth of large benthic algae". Furthermore, high abundance of sea urchins was thought to have been responsible for the high abundance of sea urchin predators observed within the original BIRNM, including black margate (*Anisotremus surinamensis*), Spanish grunt (*Haemulon macrostomum*), caesar grunt (*Haemulon carbonarium*) and queen triggerfish; Gladfelter et al., 1977). In contrast, between 2001 and 2006, only two black margate were observed across the study region, however, caesar grunt, Spanish grunt and queen triggerfish were relatively abundant.

Even though differences occurred in the survey methods between studies in 1970s and 2005-2006, the evidence is clear that *D. antillarum* no longer plays such an important role as an "ecosystem engineer" in the coral reef ecosystems of northeastern St. Croix. This decline is likely to have contributed in part to the status of macroalgal/cyanobacterial/turf dominated coral reefs that currently exist over much of the study region. The likely cause of these changes was the reported sea urchin die-off that occurred in 1983 and 1984 throughout the Caribbean region resulting in an estimated 95-99% mortality rate (Lessios et al., 1984; Carpenter, 1988). Carpenter (1988) reported that five days after the mass mortality event in St. Croix, algal biomass increased by 20% and herbivorous removal of algal biomass decreased by 50%, although an increase in the rate of grazing by herbivorous fishes was also observed suggesting that exploitative competition for food was occurring between *D. antillarum* and some herbivorous fish species (Carpenter, 1988). In areas of the Caribbean where fishing had reduced the number of herbivorous fish, the growth and persistence of macroalgae increased (Lessios, 1988). It appears that recovery to pre-disease levels of density have not yet occurred in the BIRNM region even after more than two decades since the mass mortality event.

D. antillarum

In other areas of the Caribbean (e.g., Jamaica) populations of sea urchins appear to be showing signs of a recovery (Edmunds and Carpenter, 2001). In St. Croix, however, the high amounts of macroalgal cover on hardbottom areas and the small number of *D. antillarum* survivors (some of which may be relatively isolated from one another) may impede population recovery in the region. The ecological consequences of such low sea urchin abundance have not been evaluated for the coral reef ecosystems of BIRNM and surrounding areas. Furthermore, the dynamics of larval connectivity and other factors affecting recruitment are not well known for the region. However, at several shallow water sites (< 3 m) in Teague Bay lagoon, sea urchin densities were relatively high and this may be related to water depth and substratum type, with high densities observed at two colonized bedrock sites. Studies in St. Croix and elsewhere indicate that lagoonal and sheltered back reef areas may function to promote recovery in *D. antillarum* populations (Miller et al., 2003; Debrot and Nagelkerken, 2006) Further investigation is needed to determine the environmental factors that correlate with the observed spatial patterns in sea urchin occurrence and abundance and to determine if a recovery is occurring. Lessios (2005) recommended that assessment of sea urchin recovery should be are conducted using consistent survey methods that also include use of permanent transects due to the highly clustered distributions that are typically observed.

It is likely that 1970s populations were a result of explosive release due to predator removal by the fishery and were ecologically unsustainable thereby facilitating the exceptionally rapid spread of disease throughout the Caribbean.

Biological populations are naturally dynamic, yet questions regarding the optimum densities of sea urchin populations for a healthy coral reef ecosystem remain unanswered and future changes in sea urchin abundance must be monitored in order to determine if recovery is occurring and whether management intervention may be required.

Queen conch

Due to overfishing in many regions of the Caribbean and Florida, queen conch (*Strombus gigas*) has been listed in Annex II of the Cartagena Convention's Protocol Concerning Specially Protected Areas and Wildlife (SPAW Protocol) as a species that may be used on a rational and sustainable basis and that requires protective measures. Because of this recognition, the United States proposed queen conch for listing in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1992; this proposal was adopted, and queen conch became the first large-scale fisheries product to be regulated by CITES (see http://www.nmfs.noaa.gov/pr/species/invertebrates/queenconch.htm). In the U.S. Caribbean, the queen conch fishery is regulated under the auspices of the CFMC.

S. gigas *looking out of shell*

The coral reef ecosystems of BIRNM and adjacent seascapes support regionally significant populations of juvenile and adult queen conch (*S. gigas*). The large expanse of seagrasses between Buck Island and St. Croix coastline are key resources supporting conch populations. However, very little is known about the historical densities to determine if present day populations are relatively large or small. This is important since according to the NOAA Office of Protected Resources, queen conch abundance is declining throughout the species's range as a result of overfishing. Conch are an important food resource for the Virgin Islands and are known to be harvested from the Buck Island region, yet the extent and impact of the local conch fishery is undocumented. Infilling of this substantial knowledge gap may require collaboration with local fishers to ascertain levels of exploitation and to manage for ecologically sustainable levels of extraction.

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Appendix A

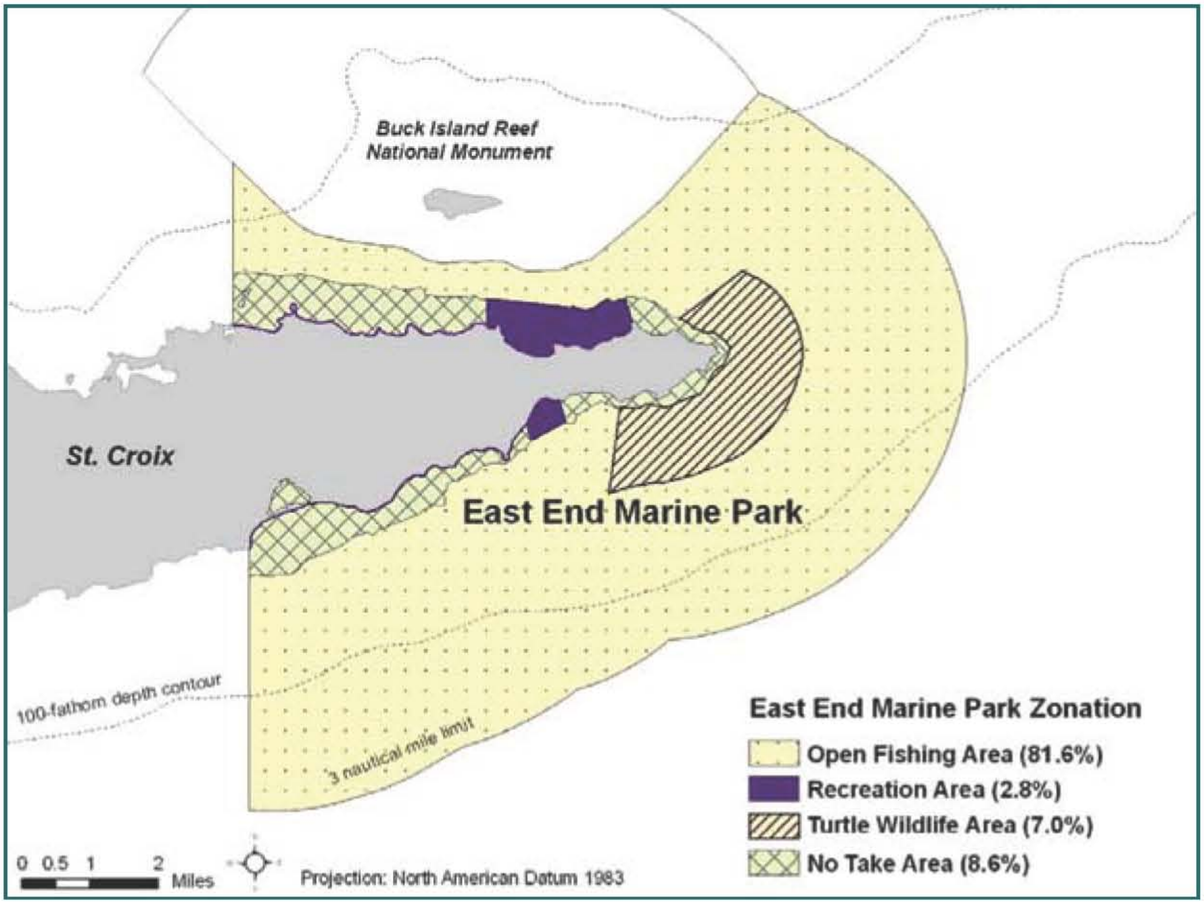

Figure A1. Map of the East End Marine Park and park zoning.
Source: http://www.stxeastendmarinepark.org/about.htm

Appendix B

Table B1. USVI finfish landings as a proportion of the total finfish landings reported for the U.S. Caribbean in 1980. Listed are the most commonly landed species and species groups. Data from the Caribbean Fisheries Management Council (CFMC, 1985).

Species/Species group	Fish Family	USVI % of total landings U.S. Caribbean
Grunts	Haemulidae	0.47
Groupers	Serranidae	13.91
Goatfish	Mullidae	0.99
Parrotfish	Scaridae	5.83
Lane snapper (*L. synagris*)	Lutjanidae	0.03
Yellowtail snapper (*O.chryusurus*)	Lutjanidae	2.89
Triggerfishes	Balistidae	29.68
Squirrelfishes	Holocentridae	4.84
Mutton snapper (*L. analis*)	Lutjanidae	0.13
Other snappers	Lutjanidae	1.04
Hogfish	Labridae	1.06
Trunkfish	Ostraciidae	0.08

Appendix C

Table C1. Fish species list and summary data on occurrence, abundance and biomass (2001-2006) for the study region (northeastern St. Croix).

Family / *Species name*	Common name	% occurrence	Total occurrence	Total abundance	Mean abundance (± SE)	Total biomass, g	Mean biomass, g (± SE)
Acanthuridae							
Acanthurus bahianus	Ocean surgeonfish	59.8	762	8601	6.7 (0.36)	540368.5	423.8 (37.0)
Acanthurus chirurgus	Doctorfish	11.8	150	652	0.51 (0.06)	48646.1	38.2 (5.7)
Acanthurus coeruleus	Blue tang	46.7	595	8597	6.7 (0.65)	904137.1	709.1 (83.8)
Acanthurus UNK	SURGEONFISH sp	0.1	1	1	<0.01 (<0.01)	0.8	<0.01 (<0.01)
Apogonidae							
Apogon binotatus	Barred cardinalfish	0.1	1	1	<0.01 (<0.01)	7.7	<0.01 (<0.01)
Apogon maculatus	Flamefish	0.2	2	2	<0.01 (<0.01)	8.1	<0.01 (<0.01)
Apogon quadrisquamatus	Sawcheek cardinalfish	0.5	6	22	0.02 (<0.01)	10.1	<0.01 (<0.01)
Apogon townsendi	Belted cardinalfish	0.5	7	16	0.01 (<0.01)	29.0	0.02 (0.02)
Apogon UNK	CARDINALFISH sp	0.3	4	7	<0.01 (<0.01)	46.8	0.04 (0.03)
Astrapogon puncticulatus	Blackfin cardinalfish	0.1	1	1	<0.01 (<0.01)	0.5	<0.01 (<0.01)
Astrapogon stellatus	Conchfish	0.2	3	4	<0.01 (<0.01)	2.0	<0.01 (<0.01)
Aulostomidae							
Aulostomus maculatus	Trumpetfish	6.3	80	107	0.08 (0.01)	9163.9	7.2 (1.0)
Balistidae							
Balistes vetula	Queen triggerfish	8.5	108	208	0.16 (0.02)	175978.6	138.0 (19.6)
Melichthys niger	Black durgon	4.4	56	158	0.12 (0.02)	118235.5	92.7 (21.4)
Belonidae							
Ablennes hians	Flat needlefish	0.2	2	51	0.04 (0.04)	1891.0	1.5 (1.5)
Blenniidae							
Ophioblennius macclurei	Redlip blenny	9.0	115	368	0.29 (0.04)	1442.1	1.1 (0.18)
Parablennius marmoreus	Seaweed blenny	0.1	1	4	<0.01 (<0.01)	1.2	<0.01 (<0.01)
Bothidae							
Bothus lunatus	Peacock flounder	2.3	29	32	0.03 (<0.01)	5391.4	4.2 (1.5)
Bothus ocellatus	Eyed flounder	0.6	8	9	<0.01 (<0.01)	224.7	0.18 (0.10)
Bothus UNK	FLOUNDER sp	0.5	6	6	<0.01 (<0.01)	13.4	0.01 (<0.01)
Callionymidae							
Paradiplogrammus bairdi	Lancer dragonet	1.1	14	20	0.02 (<0.01)	49.2	0.04 (0.02)
Carangidae							
Carangoides bartholomaei	Yellow jack	0.5	6	22	0.02 (<0.01)	33344.3	26.2 (17.8)
Caranx crysos	Blue runner	12.8	163	1064	0.83 (0.12)	369852.4	290.1 (53.4)
Caranx hippos	Crevalle jack	0.2	2	2	<0.01 (<0.01)	2218.8	1.7 (1.3)
Caranx latus	Horse-Eye jack	0.2	2	7	<0.01 (<0.01)	1822.9	1.4 (1.1)
Carangoides ruber	Bar jack	28.5	364	1735	1.4 (0.17)	57872.9	45.4 (8.6)
Caranx UNK	JACK sp	0.1	1	1	<0.01 (<0.01)	389.1	0.31 (0.31)
Decapterus macarellus	Mackerel scad	2.9	37	2319	1.8 (0.51)	136084.3	106.7 (30.6)
Decapterus UNK	SCAD sp	0.3	4	244	0.19 (0.13)	6799.1	5.3 (2.9)
Selar crumenophthalmus	Bigeye scad	0.1	1	24	0.02 (0.02)	2182.9	1.7 (1.7)
Chaenopsidae							
Acanthemblemaria aspera	Roughhead blenny	0.2	2	3	<0.01 (<0.01)	0.6	<0.01 (<0.01)
Acanthemblemaria maria	Secretary blenny	0.2	2	2	<0.01 (<0.01)	0.4	<0.01 (<0.01)
Acanthemblemaria spinosa	Spinyhead blenny	0.1	1	1	<0.01 (<0.01)	0.2	<0.01 (<0.01)
Acanthemblemaria UNK	TUBE BLENNY sp	0.1	1	6	<0.01 (<0.01)	1.2	<0.01 (<0.01)
Chaenopsis limbaughi	Yellowface pikeblenny	2.0	26	123	0.10 (0.03)	266.2	0.21 (0.09)
Chaenopsis ocellata	Bluethroat pikeblenny	2.0	26	54	0.04 (0.01)	241.0	0.19 (0.06)
Chaenopsis UNK	PIKEBLENNY sp	0.4	5	8	<0.01 (<0.01)	21.3	0.02 (<0.01)
Emblemaria pandionis	Sailfin blenny	0.3	4	7	<0.01 (<0.01)	1.4	<0.01 (<0.01)
Chaetodontidae							
Chaetodon capistratus	Foureye butterflyfish	15.4	196	385	0.30 (0.02)	9481.2	7.4 (1.2)
Chaetodon ocellatus	Spotfin butterflyfish	0.7	9	14	0.01 (<0.01)	283.1	0.22 (0.14)
Chaetodon sedentarius	Reef butterflyfish	1.2	15	22	0.02 (<0.01)	624.8	0.49 (0.17)
Chaetodon striatus	Banded butterflyfish	7.0	89	147	0.12 (0.01)	4940.0	3.9 (0.79)
Prognathodes aculeatus	Longsnout butterflyfish	0.5	7	9	<0.01 (<0.01)	151.4	0.12 (0.06)
Cirrhitidae							
Amblycirrhitus pinos	Redspotted hawkfish	1.3	17	22	0.02 (<0.01)	24.8	0.02 (<0.01)
Clupeidae							
Clupeidae UNK	HERRING sp	0.1	1	70	0.05 (0.05)	3.4	<0.01 (<0.01)
Jenkinsia UNK	HERRING sp	0.1	1	50	0.04 (0.04)	2.4	<0.01 (<0.01)

Table C1 cont...

Family *Species name*	Common Name	**% occurrence**	**Total occurrence**	**Total abundance**	**Mean abundance (± SE)**	**Total biomass, g**	**Mean biomass, g (± SE)**
Congridae							
Heteroconger longissimus	Brown garden eel	1.5	19	1711	1.3 (0.66)	46379.3	36.4 (18.8)
Dactylopteridae							
Dactylopterus volitans	Flying gurnard	0.1	1	3	<0.01 (<0.01)	330.6	0.26 (0.26)
Dasyatidae							
Dasyatis americana	Southern stingray	2.2	28	37	0.03 (<0.01)	10064.2	7.9 (2.3)
Diodontidae							
Chilomycterus antennatus	Bridled burrfish	0.1	1	1	<0.01 (<0.01)	395.5	0.31 (0.31)
Diodon holocanthus	Balloonfish	0.7	9	10	<0.01 (<0.01)	1196.3	0.94 (0.44)
Diodon hystrix	Porcupinefish	0.7	9	10	<0.01 (<0.01)	9898.9	7.8 (3.9)
Echeneidae							
Echeneis naucrates	Sharksucker	0.7	9	11	<0.01 (<0.01)	8529.7	6.7 (2.5)
Engraulidae							
Engraulidae UNK		0.1	1	1	<0.01 (<0.01)	0.2	<0.01 (<0.01)
Gerreidae							
Eucinostomus gula	Silver jenny	0.2	3	10	<0.01 (<0.01)	616.2	0.48 (0.32)
Eucinostomus melanopterus	Flagfin mojarra	0.2	2	6	<0.01 (<0.01)	115.1	0.09 (0.07)
Eucinostomus UNK	MOJARRA sp	0.1	1	13	0.01 (0.01)	668.4	0.52 (0.52)
Gerres cinereus	Yellowfin mojarra	6.9	88	162	0.13 (0.02)	7597.4	6.0 (1.1)
Ginglymostomatidae							
Ginglymostoma cirratum	Nurse shark	0.5	7	9	<0.01 (<0.01)	37663.9	29.5 (12.1)
Gobiidae							
Coryphopterus dicrus	Colon goby	1.3	16	19	0.01 (<0.01)	12.5	<0.01 (<0.01)
Coryphopterus eidolon	Pallid goby	0.1	1	1	<0.01 (<0.01)	0.7	<0.01 (<0.01)
Coryphopterus glaucofraenum	Bridled goby	23.7	302	1670	1.3 (0.11)	1490.4	1.2 (0.12)
Coryphopterus lipernes	Peppermint goby	0.2	2	5	<0.01 (<0.01)	3.3	<0.01 (<0.01)
Coryphopterus personatus/hyalinus	Masked/Glass goby	1.7	22	639	0.50 (0.28)	418.8	0.33 (0.19)
Ctenogobius saepepallens	Dash goby	1.1	14	68	0.05 (0.03)	44.6	0.03 (0.02)
Elacatinus chancei	Shortstripe goby	0.5	7	20	0.02 (<0.01)	5.0	<0.01 (<0.01)
Elacatinus evelynae	Sharknose goby	6.4	81	143	0.11 (0.02)	35.8	0.03 (<0.01)
Elacatinus multifasciatus	Greenbanded goby	0.1	1	1	<0.01 (<0.01)	0.3	<0.01 (<0.01)
Elacatinus prochilos	Broadstripe goby	1.8	23	45	0.04 (0.01)	11.3	<0.01 (<0.01)
Elacatinus saucrus	Leopard goby	0.1	1	1	<0.01 (<0.01)	0.3	<0.01 (<0.01)
Elacatinus UNK	GOBY sp	0.1	1	1	<0.01 (<0.01)	0.3	<0.01 (<0.01)
Gnatholepis thompsoni	Goldspot goby	14.6	186	690	0.54 (0.07)	298.7	0.23 (0.07)
Gobiidae UNK	GOBIES	0.2	2	2	<0.01 (<0.01)	1.3	<0.01 (<0.01)
Microgobius carri	Seminole goby	0.1	1	1	<0.01 (<0.01)	0.2	<0.01 (<0.01)
Nes longus	Orangespotted goby	0.4	5	8	<0.01 (<0.01)	68.9	0.05 (0.04)
Priolepis hipoliti	Rusty goby	0.1	1	1	<0.01 (<0.01)	0.4	<0.01 (<0.01)
Grammatidae							
Gramma loreto	Fairy basslet	4.0	51	154	0.12 (0.02)	131.7	0.10 (0.03)
Haemulidae							
Anisotremus surinamensis	Black margate	0.2	2	2	<0.01 (<0.01)	2048.1	1.6 (1.3)
Anisotremus virginicus	Porkfish	0.2	3	3	<0.01 (<0.01)	850.7	0.67 (0.38)
Haemulon album	White margate	0.2	2	5	<0.01 (<0.01)	2840.8	2.2 (2.1)
Haemulon aurolineatum	Tomtate	4.2	53	2633	2.1 (1.1)	109702.8	86.0 (32.2)
Haemulon carbonarium	Caesar grunt	1.8	23	130	0.10 (0.03)	22569.4	17.7 (6.5)
Haemulon chrysargyreum	Smallmouth grunt	1.2	15	201	0.16 (0.07)	5190.1	4.1 (2.1)
Haemulon flavolineatum	French grunt	28.0	357	1944	1.5 (0.26)	107188.4	84.1 (7.5)
Haemulon macrostomum	Spanish grunt	1.0	13	54	0.04 (0.02)	2954.0	2.3 (1.5)
Haemulon melanurum	Cottonwick	0.5	6	209	0.16 (0.16)	15919.8	12.5 (11.5)
Haemulon parra	Sailors choice	0.2	2	3	<0.01 (<0.01)	377.4	0.30 (0.27)
Haemulon plumierii	White grunt	3.5	45	468	0.37 (0.26)	64316.4	50.4 (17.7)
Haemulon sciurus	Bluestriped grunt	4.3	55	199	0.16 (0.04)	42646.6	33.4 (8.4)
Haemulon striatum	Striped grunt	0.1	1	1	<0.01 (<0.01)	43.9	0.03 (0.03)
Haemulon UNK	GRUNT sp	4.1	52	3419	2.7 (0.78)	9538.7	7.5 (3.8)
Holocentridae							
Holocentrus adscensionis	Squirrelfish	11.8	150	349	0.27 (0.05)	48639.6	38.1 (6.3)
Holocentrus rufus	Longspine squirrelfish	25.2	321	574	0.45 (0.03)	65191.6	51.1 (4.2)
Myripristis jacobus	Blackbar soldierfish	3.5	45	127	0.10 (0.04)	13899.2	10.9 (4.3)
Sargocentron vexillarium	Dusky squirrelfish	0.6	8	13	0.01 (<0.01)	448.2	0.35 (0.16)

Table C1 cont...

Family *Species name*	Common name	% occurrence	Total occurrence	Total abundance	Mean abundance (+ SE)	Total biomass, g	Mean biomass, g (+ SE)
Inermiidae							
Inermia vittata	Boga	0.5	7	490	0.38 (0.19)	6365.2	5.0 (2.9)
Kyphosidae							
Kyphosus sectator	Chub (Bermuda/Yellow)	0.5	6	20	0.02 (<0.01)	10739.8	8.4 (4.6)
Labridae							
Bodianus rufus	Spanish hogfish	6.4	81	149	0.12 (0.02)	14514.0	11.4 (2.1)
Clepticus parrae	Creole wrasse	3.5	45	2160	1.7 (0.67)	65470.5	51.3 (17.7)
Halichoeres bivittatus	Slippery dick	73.2	933	24752	19.4 (1.8)	97962.0	76.8 (5.8)
Halichoeres cyanocephalus	Yellowcheek wrasse	0.7	9	9	<0.01 (<0.01)	656.0	0.51 (0.29)
Halichoeres garnoti	Yellowhead wrasse	46.0	586	4658	3.7 (0.19)	34689.8	27.2 (1.8)
Halichoeres maculipinna	Clown wrasse	33.9	432	2176	1.7 (0.11)	10193.3	8.0 (0.78)
Halichoeres pictus	Rainbow wrasse	1.8	23	164	0.13 (0.04)	483.3	0.38 (0.12)
Halichoeres poeyi	Blackear wrasse	16.7	213	650	0.51 (0.05)	3592.1	2.8 (0.33)
Halichoeres radiatus	Puddingwife	21.1	269	503	0.39 (0.03)	5361.9	4.2 (1.2)
Lachnolaimus maximus	Hogfish	0.4	5	6	<0.01 (<0.01)	115.5	0.09 (0.05)
Thalassoma bifasciatum	Bluehead wrasse	60.9	777	32001	25.1 (1.2)	46055.3	36.1 (1.7)
Xyrichtys martinicensis	Rosy razorfish	13.6	174	2582	2.0 (0.34)	12572.0	9.9 (2.4)
Xyrichtys novacula	Pearly razorFish	0.3	4	6	<0.01 (<0.01)	40.6	0.03 (0.02)
Xyrichtys splendens	Green razorfish	11.8	150	598	0.47 (0.08)	3050.0	2.4 (0.54)
Xyrichtys UNK	RAZORFISH sp	0.2	3	23	0.02 (0.01)	6.2	<0.01 (<0.01)
Labrisomidae							
Malacoctenus aurolineatus	Goldline blenny	0.9	11	23	0.02 (<0.01)	15.6	0.01 (<0.01)
Malacoctenus boehlkei	Diamond blenny	0.1	1	1	<0.01 (<0.01)	0.2	<0.01 (<0.01)
Malacoctenus gilli	Dusky blenny	0.4	5	9	<0.01 (<0.01)	2.2	<0.01 (<0.01)
Malacoctenus macropus	Rosy blenny	4.7	60	129	0.10 (0.02)	87.4	0.07 (0.01)
Malacoctenus triangulatus	Saddled blenny	10.4	132	265	0.21 (0.02)	77.7	0.06 (0.01)
Malacoctenus UNK	LABRISOMIDS	0.5	6	8	<0.01 (<0.01)	2.9	<0.01 (<0.01)
Malacoctenus versicolor	Barfin blenny	1.1	14	14	0.01 (<0.01)	10.4	<0.01 (<0.01)
Lutjanidae							
Lutjanus analis	Mutton snapper	3.2	41	49	0.04 (<0.01)	81134.4	63.6 (15.1)
Lutjanus apodus	Schoolmaster	3.3	42	81	0.06 (0.02)	30045.2	23.6 (6.0)
Lutjanus buccanella	Blackfin snapper	0.1	1	1	<0.01 (<0.01)	1.5	<0.01 (<0.01)
Lutjanus griseus	Gray snapper	1.2	15	53	0.04 (0.02)	12823.5	10.1 (5.3)
Lutjanus jocu	Dog snapper	0.2	2	2	<0.01 (<0.01)	7404.6	5.8 (5.4)
Lutjanus mahogoni	Mahogany snapper	3.4	43	129	0.10 (0.03)	13467.7	10.6 (2.4)
Lutjanus synagris	Lane snapper	2.3	29	60	0.05 (0.01)	5485.8	4.3 (1.2)
Lutjanus UNK	SNAPPER sp	0.1	1	1	<0.01 (<0.01)	0.4	<0.01 (<0.01)
Ocyurus chrysurus	Yellowtail snapper	20.4	260	741	0.58 (0.06)	73934.6	58.0 (7.0)
Malacanthidae							
Malacanthus plumieri	Sand tilefish	10.7	137	232	0.18 (0.02)	66683.8	52.3 (6.3)
Megalopidae							
Megalops atlanticus	Tarpon	0.1	1	1	<0.01 (<0.01)	37379.9	29.3 (29.3)
Microdesmidae							
Ptereleotris helenae	Hovering goby	0.8	10	29	0.02 (0.01)	39.5	0.03 (0.02)
Monacanthidae							
Aluterus scriptus	Scrawled filefish	0.2	3	3	<0.01 (<0.01)	153.5	0.12 (0.11)
Cantherhines macrocerus	Whitespotted filefish	0.4	5	6	<0.01 (<0.01)	734.9	0.58 (0.35)
Cantherhines pullus	Orangespotted filefish	1.7	22	26	0.02 (<0.01)	1157.9	0.91 (0.36)
Monacanthus ciliatus	Fringed filefish	1.1	14	14	0.01 (<0.01)	23.2	0.02 (<0.01)
Monacanthus tuckeri	Slender filefish	1.5	19	24	0.02 (<0.01)	44.4	0.03 (0.01)
Monacanthus UNK	FILEFISH sp	0.2	3	3	<0.01 (<0.01)	1.5	<0.01 (<0.01)
Mullidae							
Mulloidichthys martinicus	Yellow goatfish	7.3	93	344	0.27 (0.05)	69054.0	54.2 (16.5)
Pseudupeneus maculatus	Spotted goatfish	23.3	297	915	0.72 (0.08)	72224.9	56.6 (6.8)
Muraenidae							
Enchelycore nigricans	Viper moray	0.1	1	1	<0.01 (<0.01)	253.1	0.20 (0.20)
Gymnothorax funebris	Green moray	0.1	1	1	<0.01 (<0.01)	52.9	0.04 (0.04)
Gymnothorax miliaris	Goldentail moray	0.2	2	2	<0.01 (<0.01)	6.7	<0.01 (<0.01)
Gymnothorax moringa	Spotted moray	0.2	3	3	<0.01 (<0.01)	2063.0	1.6 (1.2)
Gymnothorax UNK	MORAY EEL sp	0.1	1	1	<0.01 (<0.01)	0.6	<0.01 (<0.01)
Gymnothorax vicinus	Purplemouth moray	0.2	2	2	<0.01 (<0.01)	373.1	0.29 (0.22)
Muraenidae UNK		0.1	1	1	<0.01 (<0.01)	18.6	0.01 (0.01)

Table C1 cont...

Family *Species name*	Common name	% occurrence	Total occurrence	Total abundance	Mean abundance (± SE)	Total biomass, g	Mean biomass, g (± SE)
Myliobatidae							
Aetobatus narinari	Spotted eagle ray	0.2	3	3	<0.01 (<0.01)	26717.4	21.0 (16.1)
Ogcocephalidae							
Ogcocephalus nasutus	Shortnose batfish	0.1	1	1	<0.01 (<0.01)	0.5	<0.01 (<0.01)
Ophichthidae							
Myrichthys breviceps	Sharptail eel	0.1	1	1	<0.01 (<0.01)	1000.0	0.78 (0.78)
Myrichthys ocellatus	Goldspotted eel	0.3	4	4	<0.01 (<0.01)	130.5	0.10 (0.06)
Ophichthus ophis	Spotted Snake eel	0.1	1	2	<0.01 (<0.01)	42.4	0.03 (0.03)
Opistognathidae							
Opistognathus aurifrons	Yellowhead jawfish	3.5	44	145	0.11 (0.03)	710.6	0.56 (0.13)
Opistognathus macrognathus	Banded jawfish	0.3	4	7	<0.01 (<0.01)	16.2	0.01 (<0.01)
Ostraciidae							
Acanthostracion polygonius	Honeycomb cowfish	0.5	6	7	<0.01 (<0.01)	1620.8	1.3 (0.65)
Acanthostracion quadricornis	Scrawled cowfish	0.2	2	3	<0.01 (<0.01)	199.8	0.16 (0.14)
Lactophrys bicaudalis	Spotted trunkfish	0.5	7	7	<0.01 (<0.01)	1566.0	1.2 (0.62)
Lactophrys trigonus	Trunkfish	1.1	14	15	0.01 (<0.01)	4200.4	3.3 (1.2)
Lactophrys triqueter	Smooth trunkfish	4.1	52	55	0.04 (<0.01)	7529.1	5.9 (1.1)
Paralichthyidae							
Syacium UNK	SAND FLOUNDER sp	0.2	3	3	<0.01 (<0.01)	113.5	0.09 (0.08)
Pempheridae							
Pempheris schomburgkii	Glassy sweeper	0.3	4	40	0.03 (0.02)	609.0	0.48 (0.30)
Pomacanthidae							
Holacanthus ciliaris	queen angelfish	0.6	8	10	<0.01 (<0.01)	2662.5	2.1 (1.3)
Holacanthus tricolor	Rock beauty	6.0	76	94	0.07 (<0.01)	9185.6	7.2 (1.5)
Pomacanthus arcuatus	Gray angelfish	1.0	13	16	0.01 (<0.01)	8538.6	6.7 (4.5)
Pomacanthus paru	French angelfish	2.5	32	45	0.04 (<0.01)	15188.9	11.9 (3.9)
Pomacentridae							
Abudefduf saxatilis	Sergeant major	5.2	66	202	0.16 (0.03)	7497.3	5.9 (1.5)
Abudefduf taurus	Night sergeant	0.2	2	2	<0.01 (<0.01)	256.9	0.20 (0.14)
Chromis cyanea	Blue chromis	17.3	220	3321	2.6 (0.30)	18487.0	14.5 (2.0)
Chromis multilineata	Brown chromis	6.4	81	812	0.64 (0.11)	7800.1	6.1 (1.4)
Microspathodon chrysurus	Yellowtail damselfish	21.3	272	1158	0.91 (0.08)	77577.9	60.8 (6.8)
Stegastes adustus	Dusky damselfish	16.8	214	1544	1.2 (0.12)	11375.4	8.9 (1.1)
Stegastes diencaeus	Longfin damselfish	20.7	264	1870	1.5 (0.13)	18510.1	14.5 (1.8)
Stegastes leucostictus	Beaugregory	29.6	378	3991	3.1 (0.25)	12877.4	10.1 (0.86)
Stegastes partitus	Bicolor damselfish	48.9	624	10202	8.0 (0.44)	17761.2	13.9 (1.2)
Stegastes planifrons	Threespot damselfish	15.9	203	1221	0.96 (0.10)	12604.7	9.9 (1.1)
Stegastes variabilis	Cocoa damselfish	8.9	114	343	0.27 (0.04)	1788.7	1.4 (0.33)
Priacanthidae							
Heteropriacanthus cruentatus	Glasseye snapper	0.2	2	2	<0.01 (<0.01)	314.9	0.25 (0.19)
Scaridae							
Cryptotomus roseus	Bluelip parrotfish	18.1	231	1968	1.5 (0.17)	13233.5	10.4 (1.6)
Scarus guacamaia	Rainbow parrotfish	0.3	4	14	0.01 (<0.01)	3907.1	3.1 (1.8)
Scarus iseri	Striped parrotfish	34.0	434	4761	3.7 (0.28)	74268.8	58.3 (5.8)
Scarus taeniopterus	Princess parrotfish	24.9	318	1713	1.3 (0.10)	72301.0	56.7 (5.3)
Scarus UNK	PARROTFISH sp	0.5	6	103	0.08 (0.04)	466.9	0.37 (0.22)
Scarus vetula	Queen parrotfish	13.4	171	489	0.38 (0.04)	133281.4	104.5 (12.0)
Sparisoma atomarium	Greenblotch parrotfish	13.7	175	845	0.66 (0.08)	1900.2	1.5 (0.46)
Sparisoma aurofrenatum	Redband parrotfish	52.5	669	4887	3.8 (0.18)	240212.9	188.4 (10.0)
Sparisoma chrysopterum	Redtail parrotfish	5.5	70	118	0.09 (0.01)	16052.8	12.6 (2.6)
Sparisoma radians	Bucktooth parrotfish	17.5	223	1181	0.93 (0.11)	3764.1	3.0 (0.61)
Sparisoma rubripinne	Yellowtail parrotfish	6.8	87	198	0.16 (0.03)	36043.3	28.3 (6.1)
Sparisoma UNK	PARROTFISH Genus	0.4	5	7	<0.01 (<0.01)	9.9	<0.01 (<0.01)
Sparisoma viride	Stoplight parrotfish	36.1	460	2456	1.9 (0.11)	331900.0	260.3 (24.1)
Sciaenidae							
Equetus lanceolatus	Jackknife-fish	0.1	1	1	<0.01 (<0.01)	2.5	<0.01 (<0.01)
Equetus punctatus	Spotted drum	0.4	5	5	<0.01 (<0.01)	1078.1	0.85 (0.59)
Pareques acuminatus	Highhat	0.3	4	8	<0.01 (<0.01)	2.3	<0.01 (<0.01)
Scombridae							
Scomberomorus regalis	Cero	0.9	11	11	<0.01 (<0.01)	13666.4	10.7 (4.2)

Table C1 cont...

Family *Species name*	Common name	% occurrence	Total occurrence	Total abundance	Mean abundance (+ SE)	Total biomass, g	Mean biomass, g (+ SE)
Scorpaenidae							
Scorpaena plumieri	Spotted scorpionfish	0.3	4	4	<0.01 (<0.01)	1015.8	0.80 (0.44)
Scorpaena UNK	SCORPIONFISH sp	0.2	2	2	<0.01 (<0.01)	113.6	0.09 (0.09)
Serranidae							
Alphestes afer	Mutton hamlet	0.3	4	4	<0.01 (<0.01)	896.1	0.70 (0.50)
Cephalopholis cruentata	Graysby	4.2	53	81	0.06 (0.01)	9010.6	7.1 (1.3)
Cephalopholis fulva	Coney	32.4	413	1391	1.1 (0.07)	193131.3	151.5 (15.0)
Epinephelus adscensionis	Rock hind	0.4	5	7	<0.01 (<0.01)	6562.3	5.1 (4.2)
Epinephelus guttatus	Red hind	18.1	231	379	0.30 (0.02)	89106.8	69.9 (6.9)
Epinephelus striatus	Nassau grouper	0.2	2	3	<0.01 (<0.01)	1267.8	0.99 (0.81)
Hypoplectrus chlorurus	Yellowtail hamlet	1.2	15	19	0.01 (<0.01)	235.5	0.18 (0.06)
Hypoplectrus guttavarius	Shy hamlet	0.1	1	1	<0.01 (<0.01)	4.1	<0.01 (<0.01)
Hypoplectrus indigo	Indigo hamlet	0.1	1	1	<0.01 (<0.01)	19.5	0.02 (0.02)
Hypoplectrus nigricans	Black hamlet	1.1	14	16	0.01 (<0.01)	146.5	0.11 (0.05)
Hypoplectrus puella	Barred hamlet	1.4	18	31	0.02 (<0.01)	234.7	0.18 (0.06)
Hypoplectrus unicolor	Butter hamlet	0.7	9	12	<0.01 (<0.01)	88.7	0.07 (0.03)
Hypoplectrus UNK	HAMLET sp	0.4	5	5	<0.01 (<0.01)	43.5	0.03 (0.02)
Mycteroperca tigris	Tiger grouper	0.1	1	1	<0.01 (<0.01)	2200.4	1.7 (1.7)
Mycteroperca venenosa	Yellowfin grouper	0.1	1	3	<0.01 (<0.01)	684.7	0.54 (0.54)
Rypticus saponaceus	Greater soapfish	0.1	1	1	<0.01 (<0.01)	29.1	0.02 (0.02)
Serranus baldwini	Lantern bass	3.7	47	112	0.09 (0.02)	187.2	0.15 (0.04)
Serranus tabacarius	Tobaccofish	3.5	45	75	0.06 (0.01)	796.5	0.62 (0.20)
Serranus tigrinus	Harlequin bass	27.4	349	713	0.56 (0.03)	5553.1	4.4 (0.59)
Serranus tortugarum	Chalk bass	0.2	3	9	<0.01 (<0.01)	3.2	<0.01 (<0.01)
Sparidae							
Calamus calamus	Saucereye porgy	0.1	1	2	<0.01 (<0.01)	101.4	0.08 (0.08)
Sphyraenidae							
Sphyraena barracuda	Great barracuda	4.5	58	61	0.05 (<0.01)	263227.7	206.5 (37.9)
Sphyraena picudilla	Southern sennet	0.1	1	300	0.24 (0.24)	344915.6	270.5 (270.5)
Syngnathidae							
Acentronura dendritica	Pipehorse	0.1	1	1	<0.01 (<0.01)	0.2	<0.01 (<0.01)
Cosmocampus elucens	Shortfin pipefish	0.2	3	5	<0.01 (<0.01)	1.5	<0.01 (<0.01)
Hippocampus reidi	Longsnout seahorse	0.1	1	1	<0.01 (<0.01)	0.6	<0.01 (<0.01)
Hippocampus UNK	PIPEFISH sp	0.1	1	2	<0.01 (<0.01)	1.3	<0.01 (<0.01)
Synodontidae							
Synodus intermedius	Sand diver	2.9	37	41	0.03 (<0.01)	3906.8	3.1 (0.89)
Tetraodontidae							
Canthigaster rostrata	Sharpnose puffer	15.1	192	287	0.23 (0.02)	1059.6	0.83 (0.12)
Sphoeroides spengleri	Bandtail puffer	2.5	32	36	0.03 (<0.01)	181.3	0.14 (0.04)
Sphoeroides testudineus	Checkered puffer	0.2	2	5	<0.01 (<0.01)	70.4	0.06 (0.04)

Appendix D

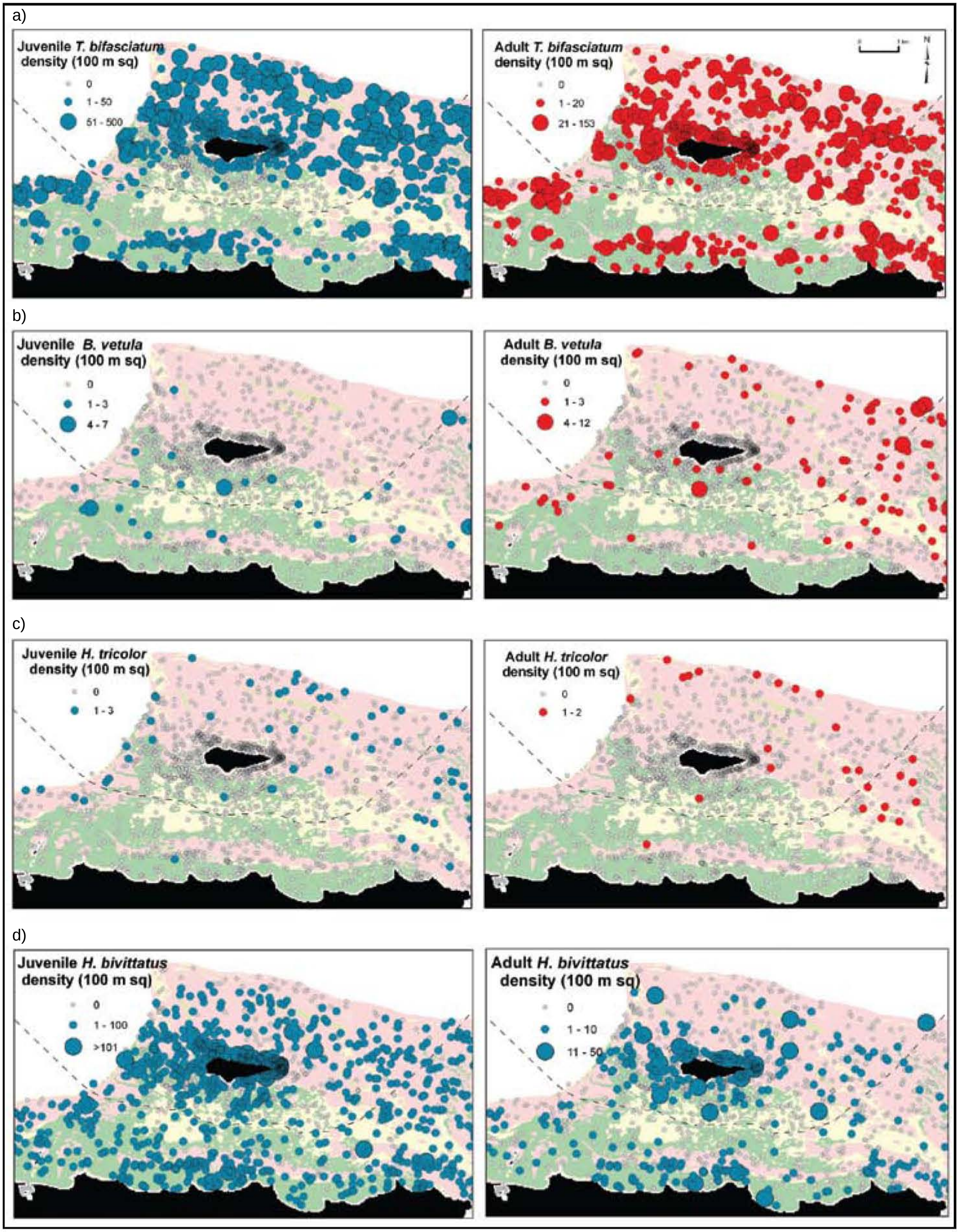

*Figure D1. Spatial distributions of juvenile and adult: (a) bluehead wrasse (*T. bifasciatum*), (b) queen triggerfish (*B. vetula*), (c) rock beauty (*H. tricolor*) and (d) slippery dick (*H. bivittatus*) in northeastern St. Croix.*

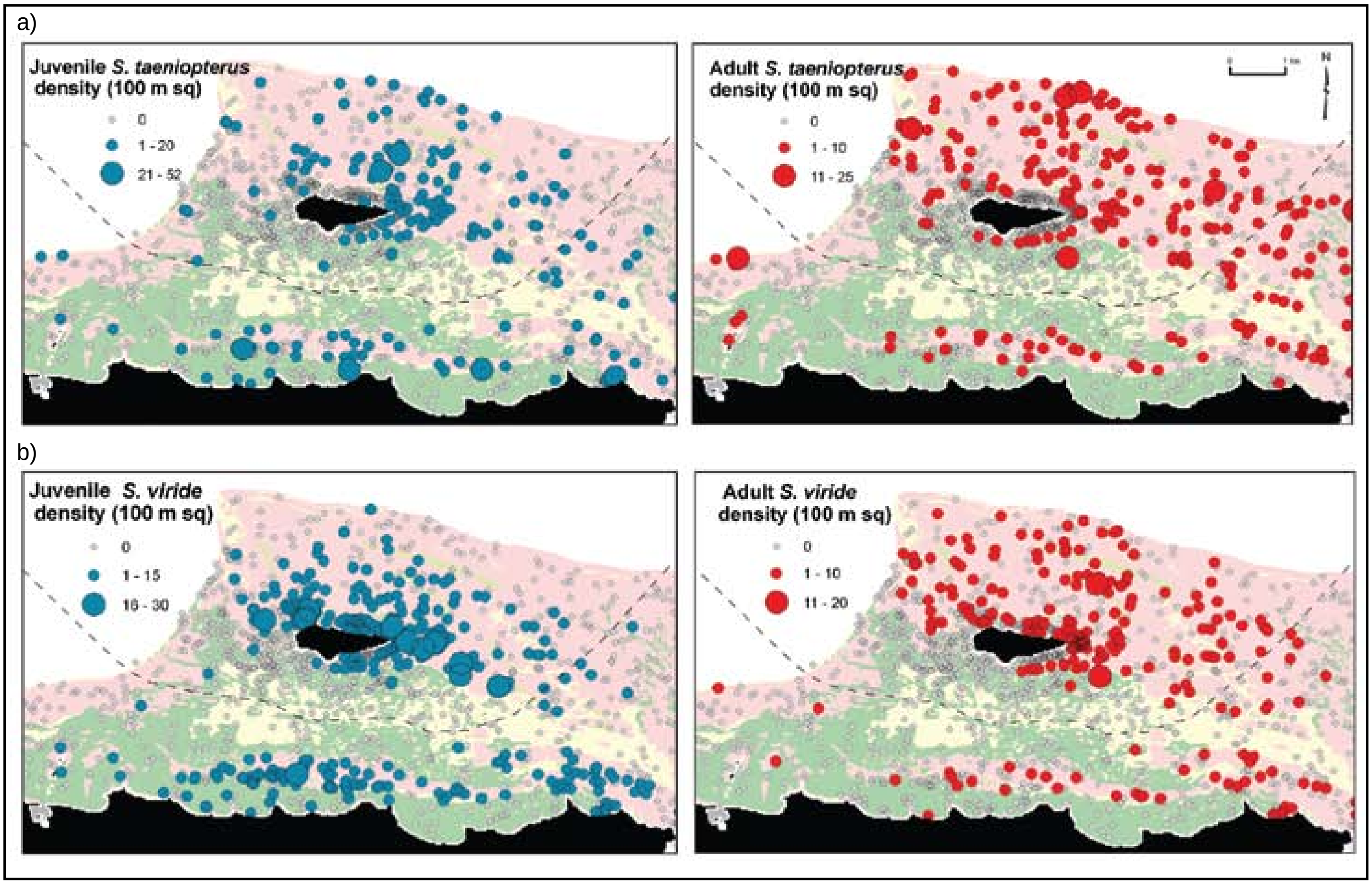

*Figure D2. Spatial distributions of juvenile and adult (a) princess parrotfish (*S. taeniopterus*) and (b) stoplight parrotfish (*S. viride*) in northeastern St. Croix.*

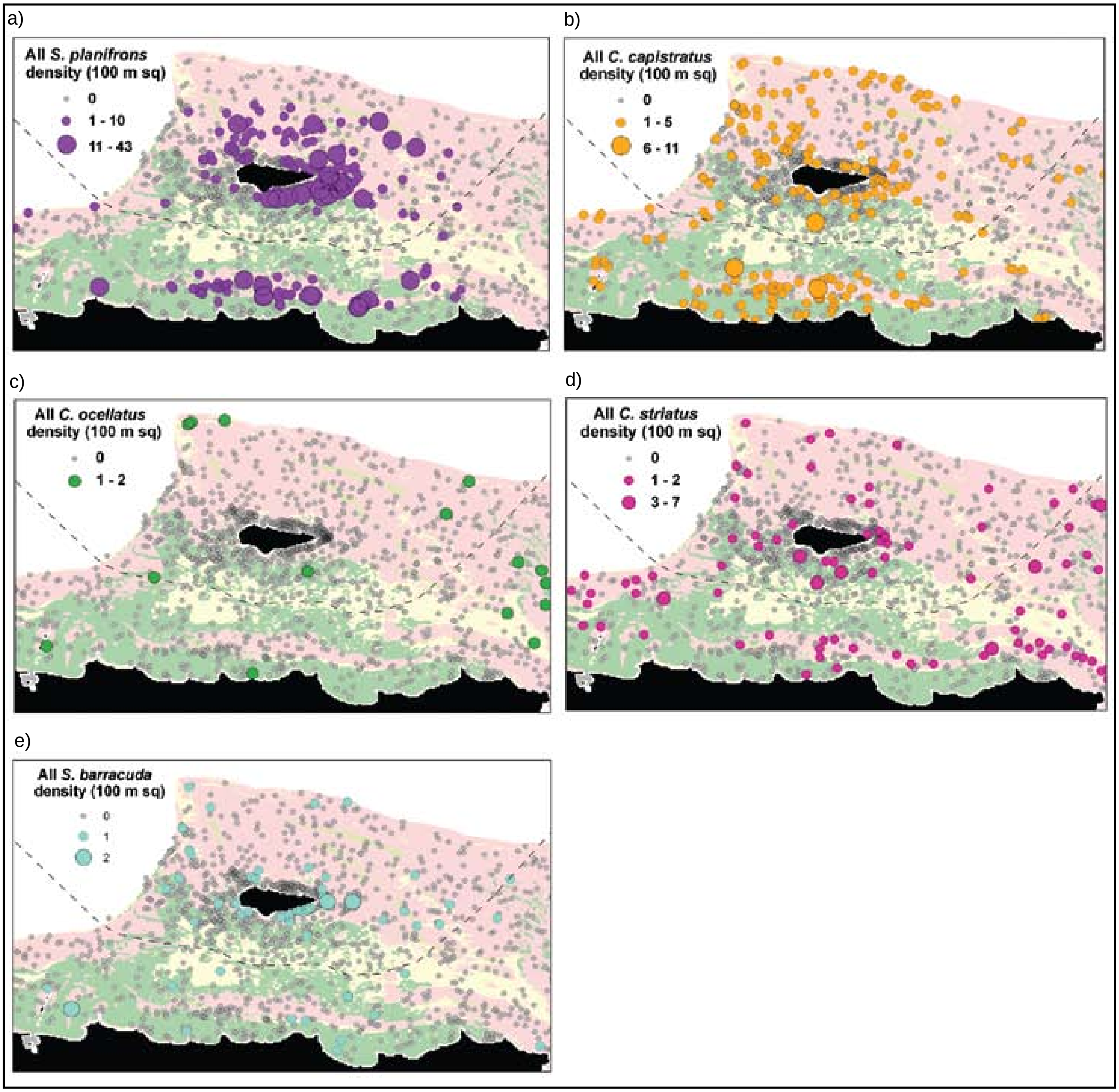

*Figure D3. Spatial distributions of juvenile and adult: (a) threespot damselfish (*Stegastes planifrons*), (b) foureye butterflyfish (*Chaetodon capistratus*), (c) spotfin butterflyfish (*Chaetodon ocellatus*), (d) banded butterflyfish (*Chaetodon striatus*) and (e) great barracuda (*Sphyraena barracuda*) in northeastern St. Croix.*

Appendix E

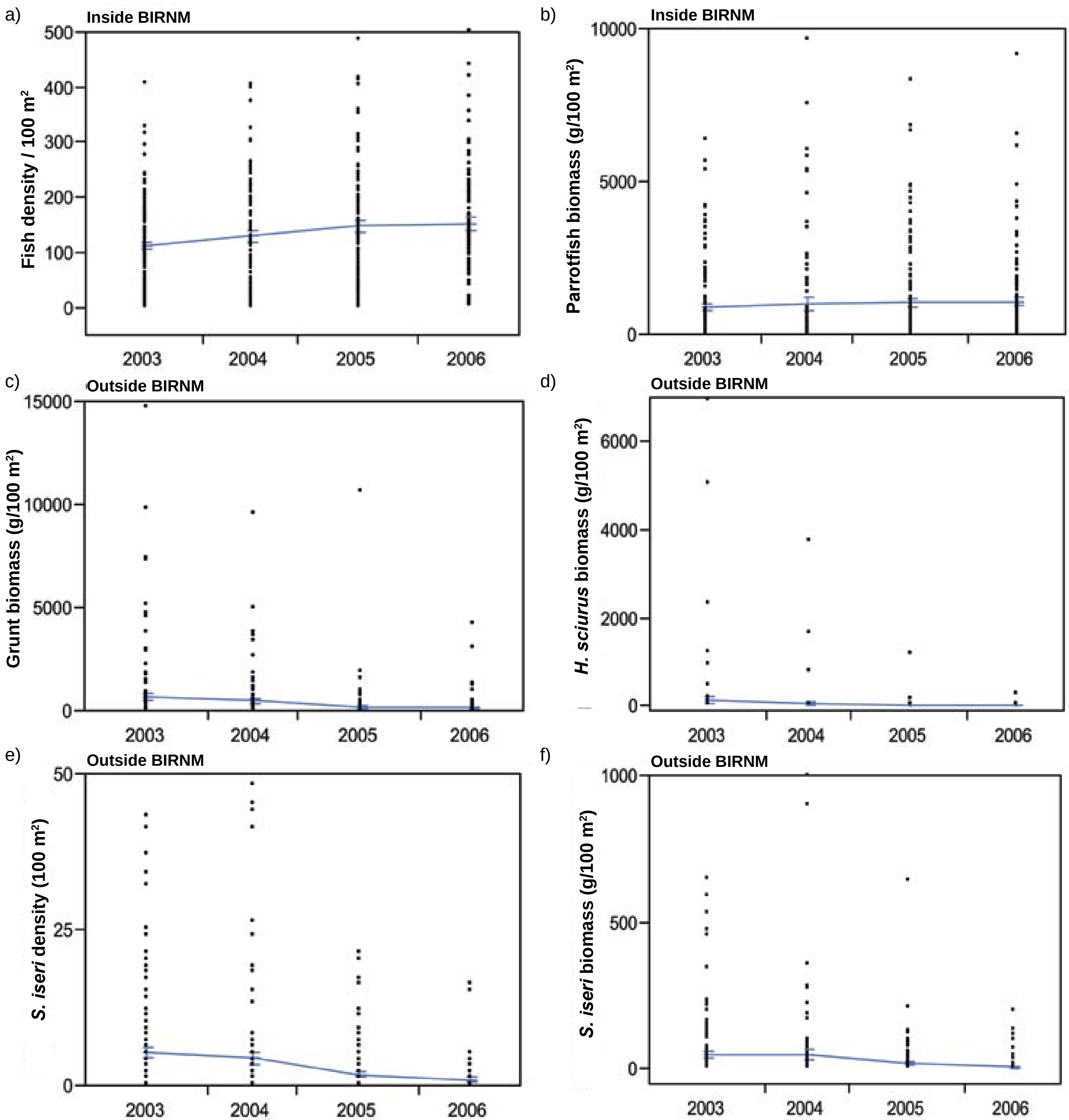

*Figure E1. Raw census data grouped by year of survey for fish metrics that exhibited an increase or decline every year over the study period (2003-2006). The horizontal blue line connects the mean (± SE) for each year. (a) Fish density (all species) increased gradually inside BIRNM, with 2005 and 2006 densities significantly higher than 2003; (b) Mean parrotfish biomass increased inside BIRNM from 2003 to 2006, but with no significant difference between years; (c) grunt biomass decreased each year outside BIRNM, with 2005 and 2006 biomass significantly lower than 2003; (d) bluestriped grunt (*H. sciurus*) biomass decreases each year outside BIRNM, with 2005 and 2006 biomass significantly lower than 2003; (e) striped parrotfish (*S. iseri*) density decreased each year outside BIRNM, with 2005 and 2006 biomass lower than 2003; and (f) striped parrotfish (*S. iseri*) biomass decreased each year outside BIRNM, with 2006 biomass significantly lower than 2003 and 2004.*

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