Temporal Analysis of Monitoring Data on Reef Fish Assemblages inside Virgin Islands National Park and around St. John, US Virgin Islands, 1988-2000

Jim Beets[1] and Alan Friedlander[2,3]

[1]Jacksonville University, Dept. of Biology and Marine Science, Jacksonville, Florida

[2]NOAA, National Ocean Service, National Centers for Coastal Ocean Science – Biogeography Program

[3]The Oceanic Institute, Makapu‘u Point/41-202 Kalanianaole Hwy, Waimanalo, Hawai‘i 96795

Submitted to:

U.S. Geological Survey
Caribbean Field Station
1300 Cruz Bay Creek
St. John, Virgin Islands 00830

June 2003

Table of Contents

EXECUTIVE SUMMARY

Reef fish monitoring data collected during 1988-2000 within Virgin Islands National Park (VINP for this report; NPS code: VIIS) and on adjacent reefs around St. John, U.S. Virgin Islands, were analyzed to provide information on the status of reef fishes during the monitoring period and for development of a reef fish monitoring protocol. Monitoring projects were initiated by the National Park Service in the 1980s to provide useful data for evaluation of resources and for development of a long-term monitoring program. Monitoring of reef fishes on selected reefs began in 1985. Monthly monitoring was conducted at two reef sites for 2+ years to document the monthly/seasonal variability in reef fish assemblages. An annual reef fish monitoring project was established in 1989 with 18-20 reef sites monitored until 1994. In 1995, a method change was adopted and annual monitoring was restricted to four reference sites. The difficulties associated with method changes are evident in analyses. A goal of the reef fish monitoring in VINP and of this analysis was to provide information for development of a reef fish monitoring protocol. With the establishment of the NPS Inventory and Monitoring Program and selection of VINP as a Prototype Park in 1995**,** greater emphasis was given to development of sound monitoring protocols. This need has grown with the establishment of Virgin Islands Coral Reef National Monument adjacent to Virgin Islands National Park, the expansion of Buck Island Coral Reef National Monument, and emphasis in monitoring within other NPS units.

This report provides 1) an evaluation of the spatial and temporal variability in reef fish assemblages at selected reef sites inside and outside of Virgin Islands National Park, 2) an evaluation of trends over 12 years of monitoring at the four reference sites, 3) an evaluation of sample sizes and methods used during the sampling period. Although the variability in reef fish abundance is quite large, general trends can be determined from annual samples taken at consistent time periods to avoid seasonal variability due to pulses of larval recruitment. These analyses demonstrated that most apparent factor influencing reef fish assemblages around St. John is large storm events. Storms had differential effects among reefs and species. It is imperative that these results be viewed with knowledge that the large predators in the system (e.g., groupers and snappers) are not in the abundances as documented in previous investigations. The decline of predators within the system can have profound cascade effects. Temporal analyses for determination of sample sizes and effort allocation for monitoring to answer specific resource management questions will prove challenging, and will probably require quite adaptive approaches, considering the strong influence of large storms on reef fish abundance among sites. Storm intensity and frequency varies temporally (among decades), negatively effects reef fish abundance and (to a lesser extent) species richness, and may require adjustment in sample size allocation.

The analysis of reef fish data included in this report provides evidence for two alarming conditions, both of which important for resource management in VINP. **1) Reef fish assemblages within Virgin Islands National Park are not significantly different than assemblages outside park boundaries. 2) Several species, including some of the most abundant species, demonstrated negative declines in abundance and frequency of occurrence over the past decade.** Some species, such as groupers and snappers preferred in the local fishery, have documented declines throughout the U.S. Virgin Islands and have fared no better within VINP. Other species may have declined due to the combined effects of habitat change, due to both natural and anthropogenic influences, and exploitation. Regardless of causes, we must conclude that the existing management strategies are not adequately protecting resources within the park and are in need of revision.

In this document, we provide recommendations for development of monitoring strategies, and emphasize the need for sound monitoring strategies and integrated analysis in order to develop defensible monitoring protocols.

INTRODUCTION

Reef fishes are challenging resources to sample because they are speciose, variable in size and behavior, occupy numerous habitat types, are frequently cryptic, and are used by humans for many reasons. Numerous species that are observed on coral reefs are transients, not residents, and may be numerous or few, frequent visitors or infrequent. Reef fish assemblages also exhibit high natural variability, in part due to recruitment variability. Therefore, a single method cannot be used to monitor all fishes which utilize reef habitat. Numerous reef fish sampling techniques and strategies have been developed to sample reef fishes, and many methods have been used around St. John to address several different management and scientific questions.

The National Park Service has supported reef fish research starting with the seminal work conducted by John Randall, 1958-1961. Several subsequent investigations of fish resources and fisheries investigations have been conducted around St. John (Idyll and Randall 1959, Beets et al. 1985, Boulon 1986a, 1986b, 1987, Boulon and Clavijo 1986, Boulon et al. 1986, Dammann 1986, Koester 1986, Beets and Friedlander 1990, Beets 1993, 1994, 1997, Beets et al. 1996, Garrison et al. 1998, Friedlander et al. 1999, Rogers and Beets 2001, Beets and Rogers 2002). These investigations have provided valuable information, including information on the changes in fish assemblages around St. John that have occurred over the past several decades. Large changes, especially declines in exploited species inside and outside of VINP, have been noted. Consistent monitoring efforts of reef fishes did not commence until 1988. An investigation to study the monthly variation in reef fish assemblages was initiated in November, 1988 and continued through May 1991 (Beets and Friedlander 1990, Beets 1993). It was conducted at two sites (Yawzi Point Reef and Cocoloba Reef, **Figure 1**) using the stationary visual census technique developed by Bohnsack and Bannerot (1986). This report is an analysis of reef fish data collected using visual census methods around St. John, U.S. Virgin Islands from 1988 to 2000.

One of the greatest justifications for consistent monitoring is to document the effects of natural events, such as the impact of hurricanes, and to attempt to differentiate natural fluctuations from human stresses. Storm events have devastating effects on reefs and their associated organisms. Storm intensity and frequency are quite variable, with low frequency of intense storms in some decades and several, intense storms in others. Numerous storms affected the community structure of reefs around St. John during the monitoring period covered in this report, with some storms having large effects (Rogers and Beets 2001). The two largest storms passing St. John, Hurricane Hugo (1989) and Hurricane Marilyn (1995), devastated some reefs and had less influence on others (Rogers et al. 1991, 1997). Monitoring data allow for more critical assessment of these large disturbances and the differential effects of storms.

Following Hurricane Hugo in September 1989, NPS initiated reef fish sampling at several reef sites (n = 18) around St. John in addition to the monthly sampling at the two sites in the southern portion of VINP. Jim Tilmant (NPS) and Dr. Joe Kimmel (previously with Florida Marine Research Institute) collaborated with Jim Beets and Alan Friedlander (U.S. Virgin Islands Division of Fish and Wildlife) on this project. The NPS decision was to use a modified visual census technique, which was developed and used in Dry Tortugas National Park in 1987 (Kimmel 1992). Monitoring at the sites established in 1989 (originally 18 reef sites were selected with a few omitted and added among years) continued once per year during June/July, using the modified method, until 1994. In 1995, the standard stationary visual census technique (Bohnsack and Bannerot 1986) was employed to continue long-term monitoring at four established monitoring sites (termed Reference Sites), which represented topographically complex, speciose sites including areas also selected for monitoring other resources (coral, macroalgae, water quality). The goals of this monitoring project were to 1) establish a baseline of information on reef fish assemblages around St. John, 2) conduct sustained monitoring on representative high-diversity reefs, 3) collect data on reefs with known and potential environmental degradation, 4) compare fish assemblages among selected reefs, and 5) determine trends in reef fish assemblages over time.

A methods comparison study was conducted at one site (Tektite reef) in 1992 to compare and calibrate data collected using the two visual census techniques employed. In 1999, a sample size study was conducted by sampling the continuous reef section of Tektite reef (Greater Lameshur Bay) using the stationary visual census technique. The primary purpose of this oversampling effort was to conduct a sample size analysis in order to evaluate sample size allocation (Friedlander et al. 1999). Results from these studies are summarized in this report.

The primary goals of this analysis and report were to 1) merge, verify and data check files, 2) evaluate the differences between sampling methods used during the period and evaluate the need for correction factors, and 3) conduct an analysis of reef fish data, especially for sites with adequate temporal coverage.

METHODS

Several fish sampling methods have been used for various investigations around St. John, however, this report covers data collected using visual census methods from 1988 to 2000. Due to limited resources, sampling was conducted only at reef sites with relatively high levels of live coral cover and topographic complexity (compared to reefs with low percent cover and relief) and depth range of 1-15 m.

Additional tasks were completed during the monitoring period. The variations of the visual census method used required a methods comparison study, conducted in July 1992 (described below). Although sample size analyses (based on the technique described by Bros and Cowell, 1987 – see Statistical Analysis below) had been conducted at the beginning of the project suggesting minimal sample size of 12-18, a sample size study, based on an oversampling of Tektite Reef, was conducted in 1999 (Friedlander et al. 1999).

Since sampling was initiated in 1988, a minimum of 18 samples were scheduled for each reef site during each sampling period, based on preliminary sample size analysis. Sampling was usually conducted by three divers (two divers were the same in all years, JB & AF), although as many as six divers collected data in some years.

A diversity of habitat types are found around St. John, and these have been classified, described and mapped (Beets et al. 1985, Kendall et al. 2001). Reef fish monitoring conducted between 1988 and 2000 in VINP was restricted to reef habitat (**Figure 1**). Monitoring sites were similar in live coral cover (usually 10-30%) and physical structure. Most sampling sites were located on lower forereef of fringing reefs, which gradually sloped to sand, and were dominated by *Montastrea annularis* or mixed corals. Following 'colonized pavement', which includes the ecologically important gorgonian-dominated pavement habitat type, lower forereef is a dominant reef habitat around St. John (**Figure 1**). Portions of this habitat are spatially complex with higher coral cover than surrounding colonized pavement and have the greatest species richness and numerical abundance of fishes of all habitats around the island. Our monitoring sites were located on these high-diversity portions of reef. Sampling was usually conducted from the reef-sand interface to the middle portion of the reef platform, which was normally dominated by *Montastrea annularis* on lower forereef sites. We stratified our sampling in the lower forereef zone between two subzones (edge - a steep slope which extends from the forereef-sand interface to change in slope; platform - the gradual slope from the edge or the sand interface to the next shallower zone, e.g., upper forereef [*Acropora* zone]).

Starting in November, 1988, two reef sites, Yawzi Point Reef and Cocoloba Reef, were sampled monthly until May, 1991 (**Figure 1**). The standard stationary point count census technique (Bohnsack and Bannerot 1986, described below) was the method used during this period. A primary goal of this sampling effort was to document the variability in reef fish assemblage characteristics based on monthly samples. The results of this monitoring were described in previous reports and are briefly discussed herein (Beets and Friedlander 1990, Beets 1993).

Following Hurricane Hugo in 1989, 18 reef sites were selected for monitoring, which included the two sites sampled monthly (**Figure 1**). Except for a few monitoring sites that were replaced with new sites, all sites were sampled annually through 1994. During 1989-1994, three sites in the upper fore reef zone, dominated by *Acropora palmata* (mostly dead colonies following the white-band disease event in the 1980s), were monitored to document the difference in reef fish assemblage structure between upper and lower forereef and to document variation in the upper forereef zone.

The four permanent **Reference Sites** (Yawzi Point Reef, Tektite Reef, Newfound Bay West Reef, and Haulover Bay West Reef) were monitored annually from 1989 to 2000 (except in 1990; Yawzi Point reef was a monitored monthly, 1988 - 1991) and were the focus of the analyses presented in this report. These monitoring sites were located on lower forereef habitat of these fringing reefs. (At Newfound Bay West Reef an additional zone, upper forereef – '*Acropora* zone', was also monitored. All four reefs are of similar percent coral cover (greatly altered by coral diseases and storm damage in recent years, as documented for Yawzi Point reef), physical structure, and reef morphology. All reefs have a gently sloping reef platform (1-15 m) and a 'wall-like' edge, which extends sharply from the platform break to the sand zone (15-20 m). The edge zone has high topographic complexity, with numerous small to large holes. Tektite Reef is the most developed and extensive of the four reefs, with spur and groove formations and impressive deeper forereef zone. Yawzi Point Reef has suffered the greatest impact from storm damage. Haulover Bay West Reef has a relatively narrow, but impressive, coral zone with a high density of large colonies of *Montastrea annularis*. Newfound Bay West Reef has a less developed reef platform, but well-developed edge structure. Haulover Bay Reef West and Newfound Bay Reef West had impressive upper forereef zones of *Acropora palmata*, which were devastated by the combination of white-band disease and storm damage in the 1970s and 1980s.

Visual census methods

The primary reef fish monitoring method used at Yawzi Point Reef and Coccoloba Reef, 1988-1991, and the four permanent monitoring reefs, 1995-2000, was the stationary visual census technique described by Bohnsack and Bannerot (1986). A single sample is conducted by a diver, who settles just above the reef substrate at a haphazardly selected point. During the point count, all fish species observed are listed within a 7.5 m radius cylinder (area: 176.7 m^2) for 5 min. Numbers and sizes of fishes of each species (estimated fork length placed in separate size classes) are added following the 5 min listing period. Habitat within the cylinder is briefly described, including substrate type, estimated coral cover, dominant benthic organisms, relative topographic complexity, depth and location on the reef.

The modified visual census technique, developed by J. Kimmel and J. Tilmant for fish monitoring in Dry Tortugas National Park (Kimmel 1992), was used in Virgin Islands National Park from 1989 to 1994. This modification used a 5-m radius cylinder (area: 78.5 m^2) and 15 min time interval with the last 5 min of the 15 min total used to search and enumerate species and individuals by swimming throughout the cylinder. Thus, this method was a 'plot count' instead of a 'point count', as described by Bohnsack and Bannerot (1986). The change back to the standard stationary visual census technique (Bohnsack and Bannerot 1986) in 1995 from the modified technique was to standardize with investigators working elsewhere in the Caribbean (especially, Jim Bohnsack and colleagues working in the Florida Keys National Marine Sanctuary and Dry Tortugas National Park).

For both methods, sampling was restricted to reef habitat. If a haphazard point count cylinder occupied less than 50% hard substrate and/or reef (greater than 50% sand), the diver moved to another haphazardly selected point on the reef.

Methods comparison study

As described above, two visual census methods were employed for reef fish sampling around St. John during the monitoring period covered in this report (1988-2000). In 1992, a study was conducted to analyze for differences between the two methods and to evaluate the need for correction factors. The methods comparison study was conducted on July 16, 1992 on Tektite Reef, the monitoring site with the consistently greatest species richness and fish abundance. Five plots on the reef of similar topographic complexity, coral cover, and depth were selected and marked for sampling. Each plot was located between 10-12 m water depth, approximately 25 m apart. Transect lines (15 m) were laid within each plot. Four experienced fish counters conducted one sample using each method within each plot. Method, site, and time were randomly assigned. This sampling design allowed for paired comparisons between methods for each diver at a given location. Although the samples taken on one section of a reef were potentially auto-correlated, the study was designed to detect differences between the two methods at a site with high species richness and abundance of reef fishes, therefore, the effects of auto-correlation for this analysis were not evaluated but should be evaluated in future studies.

Statistical analysis

Standard reef fish assemblage parameters were included in analyses: species richness (mean number of species per sample), abundance (mean number of individuals per sample), biomass (estimated live wet weight of individuals per sample), diversity (Shannon-Weiner H'), and evenness. Data presented in this report were means and standard errors, although error bars were not included in all figures to allow for better presentation. (Variance structures are available on request.) All analyses of numerical abundance and biomass excluded the masked goby (*Coryphopterus personatus)* because they were ubiquitous and their large numbers in samples (1000's) masked trends in the rest of the fish assemblage. The masked goby was included in calculations of species richness and diversity. Masked gobies are most abundant in reef structure with high topographic complexity and may be an important indicator of reef condition in the Virgin Islands, but this species contributes negligibly to biomass estimates because of its small size (< 3 cm). Trophic groups used in analyses were defined as benthic herbivores (dominated by damselfishes), mobile herbivores (dominated by parrotfishes and surgeonfishes), higher-order predators (dominated by groupers and snappers), and other predators (represented by numerous families). Biomass estimates for analysis were derived from calculated live wet weight. Live wet weight (W) was derived from the visually estimated mean fork length (FL) for each size class for each species using the relation $W = a(FL)^b$. Values of the fitting parameters a and b for each species were derived from Bohnsack et al. (1986) and the FishBase web site (http://fishbase.org/). For species not in these databases, estimates from available literature on the species or congeners were used. Biomass of all fishes recorded in all censuses was obtained by multiplying the mean live wet weight for each size class for each species by the total number of individuals observed in that size class.

A technique developed by Bros and Cowell (1987), which uses the standard error of the mean of samples and incorporates resolving power and expended effort, was used to estimate the number of samples needed to minimize variance estimates for species richness, abundance, and biomass. This method uses a Monte Carlo simulation procedure to generate estimates of standard error of the mean (SEM) and variation around the value over a range of sample sizes. The point at which the rate of change in the SEM or the variation around the SEM is sharply reduced, may be used as the minimum acceptable sample size. A Lotus macro program written by Doug Harper of the NMFS/SEFSC/ Miami Laboratory was used to conduct this analysis.

The relationship of sample size with accuracy of the mean was examined for assemblage characteristics using data from the sample size study conducted at Tektite Reef (n = 58 samples). Sample means were compared to a theoretical population mean using the t-distribution:

$$\text{t} - \text{value} = \frac{\text{sample mean} - \text{population mean}}{\sqrt{\text{sample variance / sample size}}}$$

(Eckblad 1991). The denominator of the above equation is the SEM. If the numerator is replaced with accuracy x sample mean, the equation can be rearranged to solve for sample size, for a specified relative accuracy in describing the theoretical population mean:

Sample size $\approx$ (t-value)^2 (sample variance)/(accuracy x sample mean)^2

A more liberal type-I error rate (concluding that there is an effect when in fact none exists) of 0.10 was chosen to be more responsive to changes that may be occurring in the system before more serious changes occurred. This is the precautionary approach to management as mandated by the Magnuson-Stevens Fishery Conservation and Management Act.

Parametric statistics (t-tests and ANOVA) were used to analyze for differences between sampling methods. Simple linear regression was used to determine corrections between sampling methods and to analyze for temporal trends. Detrended correspondence analysis (DCA), with rare species downweighted, was used to analyze the overlap in assemblage structure between sampling methods and between observers. Downweighting rare species can be useful in analyses with greater interest on common species, but still with a consideration of the effect of the rarer taxa. Those taxa that occurred in less than 20% of the number of samples than the most common taxon occurs were downweighted. The amount that the species was downweighted was inversely related to its frequency of occurrence. This ordination technique results in an arrangement of species samples in a low-dimensional space such that similar samples are in close proximity to one another.

We have provided analyses of species without Bonferroni corrections. The purpose of the Bonferroni correction is to control the probability of incorrectly rejecting one or more true null hypotheses. Bonferroni corrections are applied to control for group-wise type-I error rates. Since our analyses were not limited to a focal group, but rather independent analyses, we did not apply Bonferroni corrections. Bonferroni corrections would be necessary if specific trophic groups, families, or species groups were being analyzed.

RESULTS

Comparison of Visual Census Methods – Correction Factors

As previously stated, different methods may be used to answer different management questions. Methods will also be refined, modified, or changed as long-term monitoring progresses and as management questions change. Regardless, to ensure that long-term monitoring data are suitable for analysis of trend and change, methods must be consistently applied and compared. Method changes must be tested, validated, compared, and calibrated.

Visual census methods were selected by scientists for monitoring reef fishes in VINP. The change in methods used in VINP, from a 10 m/15 min count to a 15 m/5 min count (see Introduction/Methods), between 1994/1995 required a methods comparison. This comparison was conducted by four divers on Tektite Reef on July 16, 1992.

Results of the t-tests for the data obtained with the two methods for species richness, diversity, and evenness yielded probability values (p-values) < 0.1, whereas, abundance and biomass values did not **(Table 1A).** Analysis by trophic group resulted in 3 of 4 groups with p-values < 0.1 **(Table 1B).** The 'other carnivore' trophic group, which was comprised of the greatest number of species, was the only category of four analyzed with a probability value greater than 0.1. Only three of the eleven most abundant species were observed to have p-values less than 0.1 **(Table 1C).** Results of Detrended Correspondence Analysis did not show great differences between methods, but, interestingly, demonstrated considerable observer variation **(Figure 2).** Ranges of values among observers for some parameters were quite large (e.g., abundance, **Table 2**). These results would probably differ among different locations, reef types, habitats, etc., but demonstrated similarity in values for the parameters analyzed between variations of the method. Importantly, observer differences may account for more variation than differences in methods.

Since analysis of the two methods yielded differences in parameter values, application of **correction factors** for some parameters would be appropriate for analyzing trends, if a strong relationship exists between methods. Parameter values from samples at the same plot using both methods were regressed to obtain linear equations. Correlation coefficients were low for all assemblage parameters and trophic groups **(Table 3).** Regression analysis yielded p-values < 0.1 for only the derived parameters of diversity and evenness and the benthic herbivore trophic group. Therefore, analysis did not suggest strong relationships between the two methods.

This analysis differed from the analysis conducted by NMFS-SEFSC using data collected with both methods in Dry Tortugas National Park (unpubl. report). That comparison showed that ‘reef’ was the dominant signal, followed by ‘site within a reef’ and the ‘method’ was the least important. In the NMFS analysis, much greater correlation coefficients were calculated for assemblage characteristics with different and significant regressions. This is apparently due to analysis of a subset of species from the dataset. Only species with a total abundance greater than 10 individuals were used in their analysis (56 of 119 species, 7 sites). If a similar approach had been used in our analysis, we would have included 41 of 84 species from a single site and would have obtained similar results. Since assemblage characteristics are a primary focus of NPS monitoring and were the focus of our analysis (and not taxonomic groups), we suggest that data for the entire assemblage should be used. The result was that a poor relationship existed between the two methods for assemblage characteristics.

Since temporal trends were greatly influenced by storm effects (see below), which occurred at the beginning of the periods when the two different methods were implemented, it is very difficult to derive corrections based on trends. Both periods following implementation of each method were marked by recovery (e.g., increases in species richness and abundance; **Figure 3**). Since a period without storm influence is not present and the sequential impact of storms on the system confounded subsequent recoveries, corrections based trends would be misleading.

Based on the results provided above, we decided that the use of correction factors was inappropriate for our analyses. Our analyses were conducted using uncorrected data for separate time periods for assemblage characteristics and for the entire monitoring period for selected species, which showed no significant difference between methods.

Sample size analysis

Results of the Tektite Oversampling Project

Since 1995, the primary reef fish monitoring method used at the four permanent stations was the standard Bohnsack-Bannerot stationary visual census technique. Sample size had been set at a minimum of 18 samples per reef station per sampling date, based on earlier analysis of data collected using the modified method (10m/15min). In July 1999, an oversampling effort (n = 58 samples) was conducted on Tektite Reef (ca. 13,500 m^2) in order to 1) conduct a sample size analysis using the optimization technique and power analysis, 2) evaluate the advantages of random vs. haphazard sampling, and 3) provide a complete coverage for one reef among microhabitats and depths. Analyses of these data were previously reported (Friedlander et al. 1999).

A species cumulation curve of the samples collected at Tektite Reef in 1999 showed that the cumulative number of species reached an asymptote at 22 samples **(Figure 4;** Friedlander et al. 1999). The minimum sample size (n = 18) accounted for 96% of the total number of species sampled at Tektite Reef.

Optimization analysis of the Tektite Reef data suggested that approximately 11-16 samples were needed to sufficiently decrease the variation around the standard error of the mean (SEM; Bros and Cowell 1987) for number of species and number of individuals **(Figure 5**; Friedlander et al. 1999). Biomass had little variation in SEM but greater variation around the SEM, with greater sample size (n = 15-20) required to decrease variation around the SEM substantially. This suggested that biomass should be analyzed with caution when smaller sample sizes are used and when sampling designs require this data type.

Sample size analysis to determine detection levels of change provided greater differences among the fish assemblage parameters (**Figure 6**; Friedlander et al. 1999). At a Type I error rate of 0.1, less than two samples were required to detect a 20% change in number of species, whereas, 12.8 were required to detect a 20% change in number of individuals and approximately 140 samples needed to detect a 20% change for biomass.

Sample size analysis for other sites around St. John

For comparison, sample size optimization analyses were conducted on data for species richness, abundance, and biomass among the reference sites collected in 1999 **(Figures 7-9).** Sample sizes used for analysis were the same for all reefs (n = 18), except for Tektite reef (n = 58). Similar results were obtained among reefs for each parameter. For species richness, 5-11 samples were required to reduce standard error **(Figure 7).** Abundance required a greater number of samples among sites (7-14; **Figure 8**). Biomass required large sample size to adequately reduce standard error (11-22**; Figure 9**). Differences in estimated sample sizes were apparent among reef, with reefs with greater values generally requiring larger sample sizes.

For the four reference sites examined, two samples were needed to detect a 20% change in number of species at an alpha of 0.1 for any given site **(Figure 10).** The number of samples needed to detect a 20% change (at alpha = 0.1) in the number of individuals ranged from 8 samples at Haulover West Reef to 15 at Yawzi Point **(Figure 11)**. The high variance associated with total fish assemblage biomass resulted in sample sizes ranging from 41 at Newfound Bay to 140 at Tektite Reef in order to detect a 20% (alpha = 0.1**, Figure 12**).

Monthly Variation in Reef Fish Monitoring Data - Hurricane Hugo Impact, Nov 1988- May 1991

Understanding short-term temporal variability provides the critical context for interpreting the variability observed over longer time periods. Monthly sampling at two sites (Yawzi Point and Cocoloba reefs) for 2.5 years provided a valuable perspective at a smaller temporal scale **(Figure 13).** Sampling was conducted monthly to document the variability observed at that sampling frequency. Means for species richness and abundance varied differently between the two sampling sites, although the variability among samples were similar at both sites.

The most apparent effect was the impact of Hurricane Hugo in Sept. 1989. This large storm devastated local marine habitats, especially shallow coral reef and seagrass beds, and clearly influenced fish assemblages. Abundance was lower at both sites following the storm. However, the storm affected the two monitoring sites differently, with greater effects observed at Yawzi Point. The storm differentially affected species, with some showing only short term declines in abundance, and others, such as the blue chromis (*Chromis cyanea*), a planktivorous damselfish, exhibiting a longer recovery period **(Figure 13c).** The general increasing trends in most values prior to Hurricane Hugo was probably due to the impact of Hurricane Gilbert which passed south of the Virgin Islands in Sept.1988.

Trends in the Fish Assemblages at the Four Reference Sites

A total of 211 species from 55 families were observed during 1,764 visual census conducted at all sites from 1989 to 2000 (1989-1994:18-22 sites; 1995-2000: 4 Reference Sites) around the island of St. John. *Coryphopterus personatus* was numerically dominant accounting for over 64% of the total number of individuals but comprising less than one percent of the total biomass observed. Adult fishes were by far the most important component of the total assemblage by weight accounting for nearly 79 percent of the total biomass but only 18 percent of the total assemblage by number. When *C. personatus* was omitted, adults accounted for 49% of the total number of individuals observed.

Assemblage structure varied greatly among the 18 reef sites due to numerous factors, such as physical structure (topographic complexity, reef type, morphology), hydrodynamics, community dynamics, recruitment variability, connectivity with other habitats, etc. Analysis of monitoring data from the 18 reef sites around St. John, sampled 1989-1994, showed the variability in assemblage characteristics among reefs **(Figure 14).** Estimates from the **four Reference Sites** (four of the original 18 reefs sampled) were among the greatest values for assemblage characteristics among reef sites. The four Reference Sites were similar in physical structure, with generally greater topographic complexity and coral cover than most other reefs (although Yawzi Point Reef had lower coral cover than the other three reference sites due to damage during Hurricane Hugo).

Much temporal variation was observed for all assemblage characters among the four Reference Sites **(Figure 15).** As expected, variation in means for abundance and biomass was greater than for species richness. Generally, the sites with greater mean values (e.g., Tektite) showed greater temporal variation than the site with lowest mean values (Haulover West). Comparison of mean values of assemblage characteristics between all reef fishes (juveniles and adults) and adults demonstrated that the adult component of the assemblage had much lower temporal variability, particularly for abundance **(Figure 15b).** This was readily apparent in comparison of standard deviation estimates for assemblage characteristics between all reef fishes and adults for data from Tektite Reef (**Figure 16**). Standard deviation estimates were significantly smaller for adult fishes for all assemblage characteristics (t-tests values, $p < 0.05$). Since the adult components of the reef fish assemblages are less variable, they provide less ‘noise’ in analysis. Juveniles of many species are also more difficult to detect, especially from a stationary point, which is also a potential sources of variability.

The most apparent temporal signal was due to the influence of large storm events. The Virgin Islands have been greatly influenced by numerous large storms since 1988 **(Figure 17).** Data were separated into two periods (1989-1994 and 1996-2000), representing the post-storm recovery periods following the two major storms affecting St.

John during the period of analysis (Hurricane Hugo, Sept. 1989; Hurricane Marilyn, Sept. 1995). Since data for 1995 were collected just prior to Hurricane Marilyn, those data were excluded from analysis. Simple least-squares linear regressions were conducted on the five years of data following each storm event. All of the assemblage characteristics analyzed (species richness, abundance, and biomass) showed statistically significant increases during the five-year period following Hurricane Hugo (1989) **(Figure 18, Table 4).** While species, number of individuals, and biomass all trended upward following Hurricane Marilyn (1995), none of these trends were significant for the five year period following the storm **(Figure 18, Table 4).** Large storms, which passed near the Virgin Islands in 1998 and 1999, may have had a great negative impact on reef fish assemblage recovery, as lower values in assemblage characteristics were noted for 2000 **(Figures 15 & 18).**

Trophic group trends were similar to overall assemblage characteristic trends, with large differences in abundance among groups **(Figure 19).** Generally, no strong trends were apparent for any trophic group, although the influence of method change and large storm events were apparent. Trends within families presented a finer-scale perspective than did trophic groups. For example, surgeonfishes (Acanthuridae) and goatfishes (Mullidae) demonstrated no strong trends, although differences were apparent among reference sites **(Figure 20).** Abundance values of gobies (Gobiidae) and angelfishes (Pomacanthidae) were apparently influenced by method change, with lower abundance values in both taxa following method change. Abundance values of groupers (Serranidae) and parrotfishes (Scaridae) were apparently strongly influenced by both method change and storm events. Method change and storm events were clearly confounded and difficult to assess for many groups.

The most discernable trends in reef fish metrics (abundance, frequency of occurrence, average length) over time were apparent at the species level, however, most were not statistically significant. Numerous species showed significant declines for the entire period, whereas, others demonstrated a significant trend for only a portion of the period. A few examples of significant negative trends included three angelfishes, two groupers, and a squirrelfish for frequency of occurrence, abundance, or average length **(Table 5, Figures 21 & 22).** Some species, such as coney (*Epinephelus fulvus*), a mid-sized grouper, did not demonstrate a decline until after the second large storm (Hurricane Marilyn, 1995; **Figure 22**). Many fewer species, such as the tomtate (*Haemulon aurolineatum*) and bluestriped grunt (*H. sciurus*), demonstrated significant increases in abundance over the entire period **(Table 5, Figure 23).** Interestingly, butterflyfishes, which are considered by some investigators as indicator species, demonstrated no significant trends or large responses to storm events **(Table 5, Figure 23).** Most exploited species, in particular snappers and groupers, such as the historically-important Nassau grouper (*Epinephelus striatus*), showed no significant trends in this analysis. These species were in such low abundance in visual samples (e.g., *E. striatus*: number per sample: 0.04; frequency of occurrence: 0.03) both inside and outside the park that analysis for these groups proved impractical.

Sample size was adequate to discern significant trends for only a portion of the 211 species observed. Negative trends ($p < 0.1$; alpha = 0.05) were observed for 18 species for frequency of occurrence, 15 species for abundance, and 10 species for length. Importantly, for the 10 most abundant reef fishes in the data set, negative trends were observed for 6 species for frequency of occurrence, 2 species for abundance, and 2 for length **(Table 6)**.

Different zones may be affected differently by storm events and may have different recovery periods. Two zones, upper fore reef and lower fore reef, were monitored at one of the four reference sites (Newfound Bay West). The upper fore reef experienced greater effect than did the lower fore reef at this site **(Figure 24)**.

Finally, in order to have a comprehensive view on the community dynamics of the system, it is vital to compare data from reef fish assemblages with other assemblages at the same locations within Virgin Islands National Park. In comparison with coral and macroalgal assemblages monitored at the Yawzi Point site and with seagrasses adjacent to Yawzi Point Reef in Greater Lameshur Bay, reef fish abundance was clearly affected by the storm events, but showed relatively rapid recovery in comparison to other assemblages **(Figure 25)**. Coral cover declined significantly on Yawzi Point Reef following Hurricane Hugo in 1989 and has not demonstrated subsequent recovery. Macroalgae on reefs has generally showed an increase with in increase in available space with coral decline. In the adjacent seagrass community, we have observed a consistent decline in the late successional species, *Thalassia testudinum*, whereas, the earlier successional species, *Syringodium filiforme*, showed rapid responses following the two largest storm events (Muehlstein, unpubl. data). As we have presented with reef fishes, the effects within assemblages are more complex than the simpler view presented at the assemblage level.

Comparisons of Fish Assemblage Characteristics Inside and Outside of Virgin Islands National Park

To compare fish assemblage characteristics inside and outside Virgin Islands National Park, we analyzed data from the period during which numerous reef sites were monitored (n = 18, 1989-1994). These selected sites were in reef habitat with greater topographic complexity than surrounding colonized pavement. Sites that did not have an analog reef either inside or outside the park were excluded from this analysis. Reef sites located inside the park that were used in analyses included Hawksnest Bay Upper, Haulover Bay West, Fish Bay East, Yawzi Point Reef, and Tektite Reef (refer to Figure 1). Reef sites outside the park included Haulover Bay East, Newfound Bay West, Newfound Bay Upper, and Fish Bay West. There were no significant differences in number of species ($P > 0.05$) or fish biomass ($P > 0.05$) between sites inside and outside the park **(Table 7).** The total number of individuals was significantly greater ($P = 0.002$) at sites inside VINP compared with sites outside VINP likely owing to the greater proportion of 'edge habitat', with greater topographic complexity, sampled inside the park (Haulover West, Yawzi Point, and Tektite Reef) and the associated presence of large schools of planktivores at these sites.

DISCUSSION

This analysis of 12 years of reef fish monitoring data in Virgin Islands National Park at selected stations has provided a valuable view of reef fish assemblage structure, abundance, and variability. This was particularly true for the four Reference Sites, with similar reef topography, complexity, and community structure. Monitoring reef fishes in Virgin Islands National Park is a component of a monitoring program developed by USGS that is being implemented by NPS. This effort provides valuable information for development of strategies for long-term monitoring of coral reef fishes.

Temporal Variation and Trends in Reef Fishes

Although a large degree of variation in assemblage characteristics (species richness, abundance, biomass) was not apparent among reference sites, a large degree of variation was observed among years. The large temporal variation was attributed to 1) natural disturbance events (large storms), which greatly affect the living substrate and the associated fish assemblages, and to 2) the change in methods, which influenced some assemblage characteristics, species groups, and species. These events add much 'noise' to the time series and make determination of the 'normal' state much more difficult. It is important to note that determination of 'normal state' is relative, especially in consideration of longer temporal cycles which we are only beginning to understand. This emphasizes the need for maintaining consistent monitoring effort and awareness of the causes of the variation observed. High temporal variability in assemblage and taxonomic parameters is a characteristic of many ecological systems, and especially for reef fishes, which are highly mobile and exhibit complex behavior. Monitoring strategies must be designed with an understanding of the spatial and temporal variability. Obviously, more data in the time series (for example, monthly or quarterly samples) would allow for a greater determination of normal state, but would require a greater sampling effort. Since major storm events and other natural phenomena (coral diseases, coral bleaching) are not predictable, the effects of these stresses on the system are difficult to assess, especially when confounded by other influences, such as fishing, coastal development, etc. Regardless, these factors have large effects on coral reef communities of which we have an inadequate understanding. We also recommend analyzing reef fish data with and without juveniles. As shown in this report, the adult component of the reef fish assemblages are less variable, so consequently they provide less 'noise' in most analyses.

Beyond the view of assemblage-level variation, analyses at the trophic, family and species levels provide us with valuable trends and differences that may be more important for resource management. For example, numerous species show variation in abundance but no trend, whereas, some species show declining frequency, abundance, and/or average length over time. These declines, especially for species targeted in the fishery, suggest the need for additional management action. Visual data on single species collected at sufficient spatial scales can be used for fishery stock assessment (Ault et al. 2002). A combination of analyses is needed for comprehensive resource evaluation and compatible management actions.

This analysis underscores the value of establishing 'reference sites', with intensive sampling effort, so that the dynamics of selected reef sites can be assessed and potentially used as indicators of change. Different reefs, even of similar physical structure, have different fish assemblages. Numerous factors contribute to these differences. Since St. John is a small tropical island, with discrete and fragile communities within the different bays, there is a need to assess reefs and bays independently. Each has its own characteristics and influences. Unlike a large, continuous reef tract, small insular reefs are discrete units (which may be quite heterogeneous) with unique patch dynamics. We emphasize the importance of monitoring Reference Sites, which include those sites representing diversity 'hot spots' and areas of particular concern. This is in line with the key element of the establishment of permanent plots (versus 'representative sites') as described in 'Sampling Design Considerations', NPS Inventory and Monitoring, Monitoring Natural Resources in our National Parks. (http://www.nature.nps.gov/im/monitor/index.htm)

The Effect of Storm Events on Reef Fishes and Influence on Monitoring Design

The most apparent effect on reef fish assemblage structure in VINP over the 12-year monitoring period was the large impact of storms. Hurricanes have had great impacts on the shallow-water reef communities of St. John. If properly designed, monitoring programs allow for an evaluation of the effects of these events both spatially and temporally. Without long-term consistent data, the ability to evaluate such events is compromised.

In 1989, Hurricane Hugo greatly modified reef communities throughout the Virgin Islands by greatly altering the physical and biological structures (Rogers et al. 1991, Rogers and Beets 2002). The impact on the reef fish assemblage was apparent for both the monthly and annual monitoring periods. Although the monthly and seasonal variation was large, the greatest source of variation was the storm event. The subsequent recovery period was quite different among species. Interestingly, increases were observed for most parameters during the 10-month sampling period prior to Hurricane Hugo. We presume that this was a recovery trend following the large storms, which passed south of St. John in 1988, especially Hurricane Gilbert that created large storm waves on the south side of St. John. Hurricane Gilbert had the lowest sea level pressure (888 Mb) ever recorded in the Western Hemisphere. Hurricane Hugo ranked as the eleventh most intense hurricane at time of landfall to strike the U.S. in the 20th century and was rated as the second costliest hurricane with over $7 billion in damages. Hugo's storm surge was the highest ever recorded on the East Coast of the U.S. (Information from National Oceanic and Atmospheric Administration, National Ocean Service, Coastal Services Center).

Since Hurricane Hugo, several storms have affected marine communities in the Virgin Islands, especially in 1995 (Hurricane Marilyn). The fish assemblages were greatly affected by these large events and were differentially affected among reefs. The significant increase in assemblage characteristics following Hurricane Hugo reflected the recovery of the fish assemblages from this major disturbance event, whereas, the lack of significant trends following Hurricane Marilyn may be a response to a system that is still in a state of instability.

This period, characterized by higher storm frequency in the Virgin Islands compared to the lower storm frequency in previous decades (NOAA climatological data), has resulted in measurable changes in the marine communities, with large declines in densities of some reef fishes with subsequent increases during recovery periods. This dynamic condition results in large parameter estimate variation, which makes the calculation of sampling effort very difficult. This constitutes and also necessitates a greater time series to adequately understand the local dynamics.

Storm frequency and intensity clearly affect tropical systems (Rogers 1993). This requires a more critical consideration of monitoring design and effort estimates. Tropical communities within the hurricane belt may approach stable conditions during periods of low storm frequency, but this should not be viewed as 'normal' conditions. During periods of greater storm frequency and intensity, coral reef community dynamics may fluctuate greatly. The disturbance-induced dynamics are complicated by the general non-equilibrial nature of marine communities (but see Hixon and Webster 2002). Futhermore, most marine species, with open populations and bipartite life history characteristics, have extremely variable recruitment (Doherty 2002). This is certainly the case with the coral reef fishes of St. John (Miller et al. 2001, unpubl. data). Recruitment variability coupled with storm frequency/intensity greatly influences assemblage dynamics around the island.

The frequency of storm events and their effects on community dynamics must be considered during design and effort allocation for a monitoring program. Variance estimates in assemblage parameters greatly influences monitoring effort allocation. If sampling size estimation and allocation had been conducted during the period of relatively low storm frequency prior to Hurricane Hugo, sampling effort would probably have been established using lower variance values resulting in lower sampling effort. Assessment of change, and of the impacts which have occurred, may have been difficult since the sampling effort for established levels of detection may have been too low. Clearly, effort assessment must be an adaptive process.

Application of Conversion Factors for Analysis

We suggest caution when using correction factors/equations, since they vary among resources and locations. Our decision was to provide data analysis without corrections since most assemblage and trophic parameters showed no significant difference or strong relationship between methods. We conducted the methods assessment at a single location, and different correction factor values could be obtained at different locations. Specific assemblage characteristics, trophic groups, or species may require corrections for analysis, therefore, correction equations were provided. We also conducted analyses of species without Bonferroni corrections. Bonferroni corrections would be necessary based on the species group being considered for investigation and/or management action. Detrended correspondence analysis of the data from the methods comparison showed that observer differences may be greater than method differences. However, the observers in the study were experienced fish samplers and different results might be obtained with less experienced samplers (or a combination of experienced and less experienced observers).

We believe that management questions should drive the analyses. If a specific resource (e.g., trophic group, family, species or species complex) requires analysis, application of correction factors should be evaluated and applied as needed. For example, our analysis showed that large and significantly different abundance values existed for two benthic damselfishes (*Stegastes planifrons* and *S. variabilis*), but not for *S. partitus* **(Table 1C).** The difference is not surprising since one method was a 'point count' (where the diver made observations from a single point in a cylinder) and the other was a 'plot count' (where the diver made observations over the entire cylinder and would observe more cryptic and smaller species and individuals). We suggest that neither of these methods may be best for small benthic fishes. Application of correction factors could be applied in the future as more data allow for more robust analyses and should be applied for analysis of specific resources (e.g., benthic damselfishes). Regardless, correction factors and their application should be based on sound scientific assessment and analysis. As appropriately stated in an AIMS long-term monitoring status report:

> "For a correction factor to have generality, the relationship between abundance estimates [of different methodological approaches]… should not be influenced by density of fish and so should be linear over a broad range of densities" (AIMS, 1997).

Conditions Inside and Outside of Virgin Islands National Park

The analysis suggests that the park is not functioning effectively as a protected area for reef fish assemblages. The species richness of reef fishes and reef fish biomass was not significantly different between reefs located inside and outside of the park. Although reef fish abundance was significantly greater within the park, this was probably due to the greater number of reefs sampled within the park with sharp slopes and greater spatial complexity that support large numbers of planktivorous fishes. Numerous investigations have documented the negative status of the reef fish assemblages in the U.S. Virgin Islands, and specifically for VINP (Appeldoorn et al. 1992, Beets 1996, 1997, Rogers and Beets 2002, Beets and Rogers 2002). The results of this report provide additional evidence of the depressed condition of reef fishes in VINP. Similar conditions have been documented for queen conch (Friedlander 2003) and spiny lobster (Wolff 1998).

Conclusions and Recommendations

Although this report provides a valuable perspective on reef fish monitoring, we cannot over-emphasize that the period of analysis is a short-term view of fish assemblages that have changed greatly during the past several decades. Monitoring must be framed in the context of these changes. Several publications have presented information and data comparisons on the changes in reef fish populations and assemblages around St. John and throughout the Virgin Islands (Appeldoorn et al. 1992, Beets 1996, 1997, Beets and Rogers 2002). For several species, such as large groupers and snappers, we are currently monitoring variation in very low abundances relative to historical abundances. Some species, such as the well-documented case of Nassau grouper (*E. striatus*), are even approaching local extinction (Beets and Rogers 2002; unpubl. data). Many species declines are due to overfishing, which has great effects on reef fish assemblage and coral community structure (e.g., 'phase shifts', see Hughes 1994). Numerous species, especially large predators, are less abundant, less frequent in samples, and have lower average lengths than recorded in previous decades (Beets 1997). Spawning aggregations have been extirpated and herbivorous fishes have increased proportionally in samples as higher-order predators have declined. Much of this change is due to fishing effort, which has continued in Virgin Islands National Park, and is compounded by the increases in coastal development, storm damage, and other natural biological factors (coral diseases, coral bleaching).

Based on the results of this analysis, we offer several recommendations:

1) The point count method is a useful monitoring technique for reef fishes, but as with any method, there are limitations, which must be considered in development of a comprehensive monitoring program. Additional methods must be considered for specific resources. Transect sampling methods may be more appropriate for small benthic species and for larger, less common species and should be evaluated based on data needs for resource management.

2) Methodological changes are necessary, especially as new technologies are developed, but much consideration should be given to reasons for, and benefits of, change. Method change had a large effect on some parameters analyzed for this report, emphasizing the importance in methods comparison and calibration. Calibration of methods should be conducted over an extended period to ensure data comparisons and corrections are valid. The comparison of methods, use of correction factors, and community change, including disturbance regime, should be considered before methods are replaced.

3) Observer differences can be significant and should be minimized with careful training. Several training methods have been described and should be implemented. Data analysis should be incorporated into training assessment before samplers data are incorporated into monitoring databases.

4) Although correction factors were not applied in analyses for this report, correction factors may be needed for analysis of specific assemblage components, such as benthic damselfishes, which are usually underestimated by standard point counts.

5) Annual sampling of reef fishes should be considered the minimum sampling frequency for a monitoring program. Less frequent sampling would not allow for adequate trend analysis, detection of change, and management response. More frequent sampling would likely allow increased probability of change detection in shorter time periods. Future monitoring assessments should evaluate sampling frequency.

6) Increased sampling effort would provide data necessary for a more in-depth assessment of sampling effort and frequency, but must be allocated under personnel and fiscal constraints. Monitoring protocols should assist resource managers in making decisions for monitoring effort allocation. Monitoring at the four reference sites during 1995-2000 was conducted by three divers making two dives per site per year.

7) We highly recommend that monitoring, data entry, and analysis be designed for the easy extraction of juvenile fishes from the database. The greatest source of variability in reef fish assemblages is juvenile abundance, which can be particularly great following large episodic settlement events. The adult component of the reef fish assemblages is less variable and provides less 'noise' in analysis.

8) Powerful storms have large impacts on reef fish assemblages. Hurricanes cause large decreases in fish abundance followed by subsequent periods of recovery. Storm impact adds greatly to the natural variability in reef fish assemblage characteristics and must be taken into consideration when developing monitoring and management strategies.

9) The dataset analyzed for this report represents one of the longest, continuous datasets for coral reef fishes. The data collected in the last six years of the analysis (1995-2000) were collected by three samplers in four days per year, which is not a large level of effort. Many of the outstanding monitoring questions must be addressed from future studies with greater levels of effort and analysis. Some questions related to 'long-term monitoring' will require a greater time series.

10) This analysis provides additional support to the evidence that resource conditions inside VINP are similar to the degraded conditions outside of the park, which has been presented in previous publications. Overfishing has had obvious and documented effects on reef fishes. Although additional information is needed on the resources, and specifically on exploited species and the level of fishing effort in park waters, there is a great need for stricter management regulations within Virgin Islands National Park. The lack of evidence of protection of reef fishes suggests that conditions within the park are as poor as outside park boundaries and that stricter regulations are warranted.

Acknowledgements

We wish to acknowledge the continuing support from Dr. Caroline Rogers, especially her comments, patience, and long discussions on monitoring. Dr. Rogers has been instrumental in the development of the Inventory and Monitoring Program within the Virgin Islands National Park units and should be given much credit for her scientific contribution. Jeff Miller, Rob Waara, Rikki Grober-Dunsmore, Nick Wolff, Ginger Garrison, Ellen Link, and Gigi Berretta provided field support and comments on this report. NOAA-NOS Biogeography Team provided very valuable comments on the report. USGS-BRD provided funding for this report.

LITERATURE CITED

Appeldoorn, R., J. Beets, J. Bohnsack, S. Bolden, D. Matos, S. Meyers, A. Rosario, Y. Sadovy and W. Tobias. 1992. Shallow water reef fish stock assessment for the US Caribbean NOAA Tech. Memo. NMFS-SEFSC-304.

Ault, J.S., S.G. Smith, G.A. Meester, J. Luo, J.A. Bohnsack, S.L. Miller. 2002. Baseline multispecies coral reef fishe stock assessment for Dry Tortugas. NOAA Technical Memorandum NMFS-SEFSC-487. 117 pp.

Australian Institute of Marine Science (AIMS). 1997. Long-term monitoring of the Great Barrier Reef, Status Report Number 2. Queensland, Australia.

Beets, J. 1993. Long-term monitoring of fisheries in Virgin Islands National Park: Chapter I. Baseline data, 1988-1992, with emphasis on the impact of Hurricane Hugo. Virgin Islands National Park, Technical Report VINP 1/93.

Beets, J. 1996. The effects of fishing and fish traps on fish assemblages within Virgin Islands National Park and Buck Island National Monument. U.S. Virgin Islands National Park Technical Report 5/96. 44p.

Beets, J. 1997. Can coral reef fish assemblages be sustained as fishing intensity increases? Proceedings of the 8th International Coral Reef Symposium 2:2009-2014.

Beets, J., L. Lewand, and E.S. Zullo. 1985. Marine community descriptions and maps of bays within the Virgin Islands National Park/Biosphere Reserve. Biosphere Reserve Research Report No. 2. VIRMC/NPS, 118p.

Beets, J. and A. Friedlander. 1990. Long-term monitoring of fisheries in the Virgin Islands National Park: Impact of Hurricane Hugo. Annual Project Report to Virgin Islands National Park. 20p.

Beets, J., A. Friedlander, N. Wolff, and R. Waara. 1996. Evaluation of critical resources within Virgin Islands National Park: groupers, snappers, queen conch and spiny lobster. U.S. National Park Service Technical Report 8/96.

Beets, J. and C. Rogers. 2002. Decline of fishery resources in marine protected areas in the US Virgin Islands: the need for marine reserves. Proceedings of the 9th International Coral Reef Symposium: 449-454.

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41, 15 p.

Bohnsack, J.A., D.L. Sutherland, A. Brown, D.E. Harper, and D.B. McClellan. 1986. An analysis of the Caribbean biostatistical database for 1985. NOAA/NMFS/SEFSC/Miami Laboratory, Coastal Resources Division Contribution No. 86/87-10. 36 p.

Boulon, R. 1986a. Fisheries habitat of the Virgin Islands region of ecological importance to the fisheries resources of the Virgin Islands Biosphere Reserve. Biosphere Reserve Research Report No. 9. US National Park Service/VIRMC, 22 p.

Boulon, R. 1986b. Map of fishery habitats within the Virgin Islands Biosphere Reserve. Biosphere Reserve Research Report No. 8. US National Park Service/VIRMC, 70 p.

Boulon, R. 1987. Basis for long-term monitoring of fish and shellfish species in the Virgin Islands National Park. Biosphere Reserve Research Report No. 22. US National Park Service/VIRMC, 66 p.

Boulon, R., J. Beets, and E. Zullo. 1986. Long-term monitoring of fisheries in the Virgin Islands Biosphere Reserve. Biosphere Reserve Research Report No. 13. US National Park Service/VIRMC, 32 p.

Boulon, R. and I. Clavijo. 1986. Utilization of the Virgin Islands Biosphere Reserve (VIBR) by artisanal fishermen. Biosphere Reserve Research Report No. 13. US National Park Service/VIRMC, 37 p.

Bros, W.E. and B.C. Cowell. 1987. A technique for optimizing sample size (replication). Journal of Experimental Marine Biology and Ecology 114:63-71.

Dammann, A. 1986. Assessment of fish and shellfish stocks produced in the Biuosphere Reserve. U.S. National Park Service. Biosphere Reserve Research Report No. 10. US National Park Service/VIRMC, 30 p.

Doherty, P.J. 2002. Variable replenishment and the dynamics of reef fish populations. Chapter 15, Pages 327-358 *in:* P.F. Sale, ed. Coral Reef Fishes, Dynamics and Diversity in a Complex Ecosystem. Academic Press, San Diego, CA.

Eckblad, J.W. 1991. How many samples should be taken? BioScience 41: 346-348.

Friedlander, A.M. 2003. Temporal analysis of queen conch data collected around St. John, US Virgin Islands. Report to USGS, BRD, Virgin Islands National Park. 4pp.

Friedlander, A.M., J. Beets, and J. Miller. 1999. Evaluation of a Visual Census Method for Reef Fishes at Tektite Reef, Virgin Islands National Park, St. John, U.S. Virgin Islands: Determination of Optimal Sample Size. Report submitted to U.S. Geological Survey, Biological Resources Division. 23 p.

Garrison, V.H., C.S. Rogers, J. Beets. 1998. Of reef fishes, overfishing and in situ observations of fish traps in St. John, US Virgin Islands. Rev. Biol. Trop., 46 Supl. 5:41-59.

Hixon, M.A. and M.S. Webster. 2002. Density dependence in reef fish populations. Chapter 14, Pages 303-326 *in:* P.F. Sale, ed. Coral Reef Fishes, Dynamics and Diversity in a Complex Ecosystem. Academic Press, San Diego, CA.

Hughes, T.P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265:1547-1551.

Idyll, C. and J. Randall. 1959. Sport and commercial fisheries potential of St. John, V.I. 4th International Game Fish Conference, University of Miami, FL. 13p.

Kendall, M.S., M.E. Monaco, K.R. Buja, J.D. Christensen, C.R. Kruer, and M. Finkbeiner, R.A. Warner. 2001. (On-line). ***Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands*** URL: http://biogeo.nos.noaa.gov/projects/mapping/caribbean/startup.htm. Also available on U.S. National Oceanic and Atmospheric Administration. National Ocean Service, National Centers for Coastal Ocean Science Biogeography Program. 2001. (CD-ROM). ***Benthic Habitats of Puerto Rico and the U.S. Virgin Islands.*** Silver Spring, MD: National Oceanic and Atmospheric Administration.

Kimmel, J. 1992. NPS coral reef assessment program: preliminary assessment of fishes in the Dry Tortugas, Florida. Report to the National Park Service Coral Reef Assessment Program. 4 p.

Koester, S. 1986. Socioeconomic and cultural role of fishing and shellfishing in the VIBR. Biosphere Reserve Research Report No. 12. US National Park Service/VIRMC, 24 p.

Miller, J., J. Beets, and C. Rogers. 2001. Temporal patterns of fish recruitment on a fringing coral reef in Virgin Islands National Park, St. John, U.S. Virgin Islands. Bulletin of Marine Science 69:567-577.

Rogers, C.S. 1993. Hurricanes and coral reefs: the intermediate disturbance hypothesis revisited. Coral Reefs 12:127-137.

Rogers, C., V. Garrison, and, R. Grober-Dunsmore. 1997. A fishy story about hurricanes and herbivory: seven years of research on a reef in St John, US Virgin Islands. Proceedings of the 8th International Coral Reef Symposium 1: 555-560.

Rogers, C., L. McLain, and C. Tobias.1991. Effects of Hurricane Hugo (1989) on a coral reef in St John, USVI. Marine Ecology Progress Series **78**: 189-199.

Rogers, C. and J. Beets. 2001. Degradation of marine ecosystems and decline of fishery resources in marine protected areas in the US Virgin Islands. Environmental Conservation 28 (4): 312-322.

Wolff, N. 1998. Spiny lobster evaluation within Virgin Islands National Park (summer of 1996). Report to USGS, BRD. 16pp.

Table 1. Comparison of assemblage characteristics, trophic groups, and selected species between two visual census methods (15m/5 min and 10m/15 min) conducted at Tektite Reef, VINP, on 16 July 1992. The greatly abundant masked goby, *Coryphopterus personatus*, was not included in analysis.

A. Statistics for assemblage characteristics

Assemblage characteristics	15m	10m	Mean Difference	Std Error	Upper 95%	Lower 95%	N	Correlation	t-Ratio	DF	Prob > |t|	Prob > t	Prob < t
Species richness	22.35	28.90	-6.55	1.1573	8.9722	4.1277	20	-0.1072	-5.6597	19	<.0001	1	<.0001
Abundance	181.45	200	-18.55	20.33	24.0011	-61.101	20	-0.0750	-0.9124	19	0.373	0.8135	0.1865
Biomass (g)	6170.28	6930.84	-760.56	1381.95	2131.9	-3653	20	0.0587	-0.5503	19	0.588	0.7058	0.2942
Diversity	2.14	2.43	-0.29	0.0597	-0.1645	-0.4145	20	0.5831	-4.8494	19	0.0001	0.9999	<.0001
Evenness	0.700	0.733	-0.033	0.0175	0.0037	-0.0697	20	0.5530	-1.8821	19	0.0752	0.9624	0.0376

B. Statistics for trophic group numerical abundances. Data ln(x)-transformed.

Trophic group	15m	10m	Mean Difference	Std Error	Upper 95%	Lower 95%	N	Correlation	t-Ratio	DF	Prob > |t|	Prob > t	Prob < t
Benthic Herbivores	3.411	3.763	-0.352	0.1159	-0.1093	-0.5947	20	0.4633	-3.354	19	0.0068	0.9966	0.0034
Mobile Herbivores	2.635	3.037	-0.403	0.1497	-0.0897	-0.7163	20	0.3435	-2.692	19	0.0144	0.9928	0.0072
Higher-order Carnivores	1.096	1.465	-0.369	0.1839	0.0155	-0.7545	20	0.2197	-2.009	19	0.0590	0.9705	0.0295
Other Carnivores	4.719	4.759	-0.041	0.1501	0.2736	-0.3546	20	-0.0279	-0.270	19	0.7902	0.6049	0.3951

C. Statistics on abundance data for 11 numerically abundant species

Assemblage characteristics	Linear equation	R^2	Adj R^2	N	Df	F Ratio	Prob > F
Species	15m/5min = 24.952928 - 0.0900667 10m/15min	0.011486	-0.04343	20	1,18	0.2091	0.6529
Individuals	ln(15m/5min) = 5.6598039 - 0.1004952 ln(10m/15min)	0.004715	-0.05058	20	1,18	0.0853	0.7736
Biomass	ln(15m/5min) = 7.5809407 + 0.1049202 ln(10m/15min)	0.010778	-0.04418	20	1,18	0.1961	0.6631
Diversity	ln(15m/5min) = 0.4417896 + 0.6994288 ln(10m/15min)	0.340070	0.30341	20	1,18	9.2756	0.0070
Evenness	ln(15m/5min) = 0.2737132 + 0.5818497 ln(10m/15min)	0.305854	0.26729	20	1,18	7.9311	0.0114

Table 2. Sample means for assemblage characteristics for two variations of point count methods taken by different observers at Tektite Reef, VINP, 17 July 1992.

Observer	Species		Abundance		Biomass	
	15m/5min	10m/15min	15m/5min	10m/15min	15m/5min	10m/15min
AMF	24.0	28.2	168.2	212	4271.0	6457.1
GG	20.8	27.2	269.8	197.2	8527.8	4251.7
JJK	20.6	30.4	124.8	205.2	4153.0	6627.8
JPB	20.0	26.2	163.0	185.6	7729.4	10386.8
mean	21.4	28.0	181.5	200.0	6170.3	6930.9

Table 3. Results of regression analysis of assemblage characteristics and trophic groups between two visual census methods (15m/5 min and 10m/15 min) conducted at Tektite Reef, VINP, on 16 July 1992. The greatly abundant masked goby, *Coryphopterus personatus*, was not included in analysis.

Trophic Group	Linear equation	R^2	Adj R^2	N	Df	F Ratio	Prob > F
Benthic Herbivores	ln(15m/5min) = 1.3453655 + 0.5488729 ln(10m/15min)	0.214672	0.171043	20	1,18	4.9204	0.0396
Mobile Herbivores	ln(15m/5min) = 1.1522079 + 0.4879974 ln(10m/15min)	0.118027	0.069029	20	1,18	2.4088	0.1381
Higher-order Carnivores	ln(15m/5min) = 0.7139169 + 0.2607186 ln(10m/15min)	0.04826	-0.00461	20	1,18	0.9127	0.3520
Other Carnivores	ln(15m/5min) = 4.8756102 - 0.0330133 ln(10m/15min)	0.000776	-0.05474	20	1,18	0.0140	0.9072

Table 4. Results of least-squares linear regression analyses for fish assemblage characteristics for post Hurricane Hugo (1989-1994) and post Hurricane Marilyn (1996-2000) time periods. Number of individuals and biomass were ln(x) transformed for statistical analyses.

Assemblage characteristic	Time period	Least-squares regression model	R^2	F	P
Species	1989-1994	Species = -2032.193 + 1.0337838 (YR)	0.310	7.730	0.011
	1996-2000	Species = -496.3675 + 0.26025 (YR)	0.026	0.483	0.496
Individuals	1989-1994	ln (individuals) = -203.965 + 0.105 (YR)	0.337	9.136	0.007
	1996-2000	ln (individuals) = -104.2545 + 0.05475 (YR)	0.060	1.103	0.307
Biomass	1989-1994	ln (biomass) = -38.59824 + 0.0202027 (YR)	0.330	9.040	0.008
	1996-2000	ln (biomass) = -20.3435 + 0.011 (YR)	0.061	1.180	0.292

Table 5. Results of least-squares linear regression analyses of data for selected reef fish species for frequency of occurrence, abundance and length observed at the four reference sites, St. John, U.S. Virgin Islands. *1989 data excluded due to low abundance following storm.

Species	Frequency			Abundance			Length		
	R^2	F	P	R^2	F	P	R^2	F	P
Holacanthus ciliarus*	0.732	21.827	**0.002**	0.789	29.983	**0.001**	0.009	0.083	**0.780**
*Pomacanthus arcuatus**	0.536	9.250	**0.016**	0.647	14.656	**0.005**	0.065	0.626	**0.449**
P. paru	0.104	1.050	**0.332**	0.077	0.747	**0.410**	0.632	10.329	**0.018**
Epinephelus guttatus	0.362	5.110	**0.050**	0.267	3.285	**0.103**	0.000	0.000	**1.000**
E. fulvus	0.113	1.145	**0.312**	0.058	0.552	**0.477**	0.016	0.145	**0.712**
*Holocentrus rufus**	0.469	7.072	**0.029**	0.523	8.782	**0.018**	0.010	0.094	**0.766**
Haemulon sciurus	0.040	0.377	**0.554**	0.372	5.344	**0.046**	0.032	0.299	**0.598**
H. aurolineatum	0.102	1.023	**0.338**	0.640	15.979	**0.003**	0.007	0.067	**0.801**
Chaetodon capistratus	0.246	2.933	**0.121**	0.021	0.194	**0.194**	0.670	0.044	**0.044**
C. striatus	0.009	0.086	**0.776**	0.071	0.693	**0.427**	0.070	0.604	**0.454**

Table 6. Results of least-squares linear regression analyses of data for the 10 most abundant reef fish species for frequency of occurrence, abundance and length observed at the four reference sites, St. John, U.S. Virgin Islands. * indicates an increase in frequency of occurrence.

Species	Frequency			Abundance			Length		
	R^2	F	P	R^2	F	P	R^2	F	P
Chromis cyanea	0.320	4.240	**0.069**	0.063	0.603	**0.457**	0.041	0.388	**0.548**
Scarus croicensus	0.208	2.367	**0.158**	0.056	0.536	**0.483**	0.152	1.613	**0.236**
Thalassoma bifasciatum	0.069	0.666	**0.435**	0.245	2.917	**0.122**	0.005	0.048	**0.831**
Stegastes planifrons	0.122	1.255	**0.292**	0.198	2.230	**0.170**	0.600	11.434	**0.008**
Acanthurus bahianus	0.405	6.120	**0.035**	0.462	7.728	**0.021**	0.065	0.628	**0.448**
A. coeruleus	0.290	3.685	**0.087**	0.246	2.932	**0.121**	0.061	0.589	**0.462**
S. partitus	0.115	1.174	**0.307**	0.640	15.967	**0.003**	0.162	1.742	**0.220**
Sparisoma aurofrenatum	0.553	11.132	**0.009**	0.165	1.773	**0.216**	0.378	5.469	**0.044**
C. multilineatum *	0.301	3.877	**0.080**	0.222	2.575	**0.143**	0.029	0.274	**0.613**
S. viride	0.290	3.667	**0.088**	0.022	0.204	**0.663**	0.075	0.732	**0.414**

Table 7. Comparisons of fish assemblage characteristics inside and outside of Virgin Islands National Park using 15m/5min point count data from 1989 to 1994. Values in parentheses are standard error of the mean using pooled variances. Number of individuals did not meet the parametric assumption of homogeneity of variances and a Mann-Whitney Rank Sum Test was in place of the parametric Student's t-test. Statistical values of pooled data: t = Student's t-test, U = Mann-Whitney Rank Sum test.

Assemblage Characteristic	Inside VINP	Outside VINP	Statistical value	P
Species	30.9 (0.70)	30.2 (0.80)	t = 0.714	0.476
Number of individuals	228.6 (7.5)	188.2 (8.6)	U = 9.51	0.002
Biomass (kg)	9.2 (0.7)	8.1 (0.6)	t = 1.12	0.23

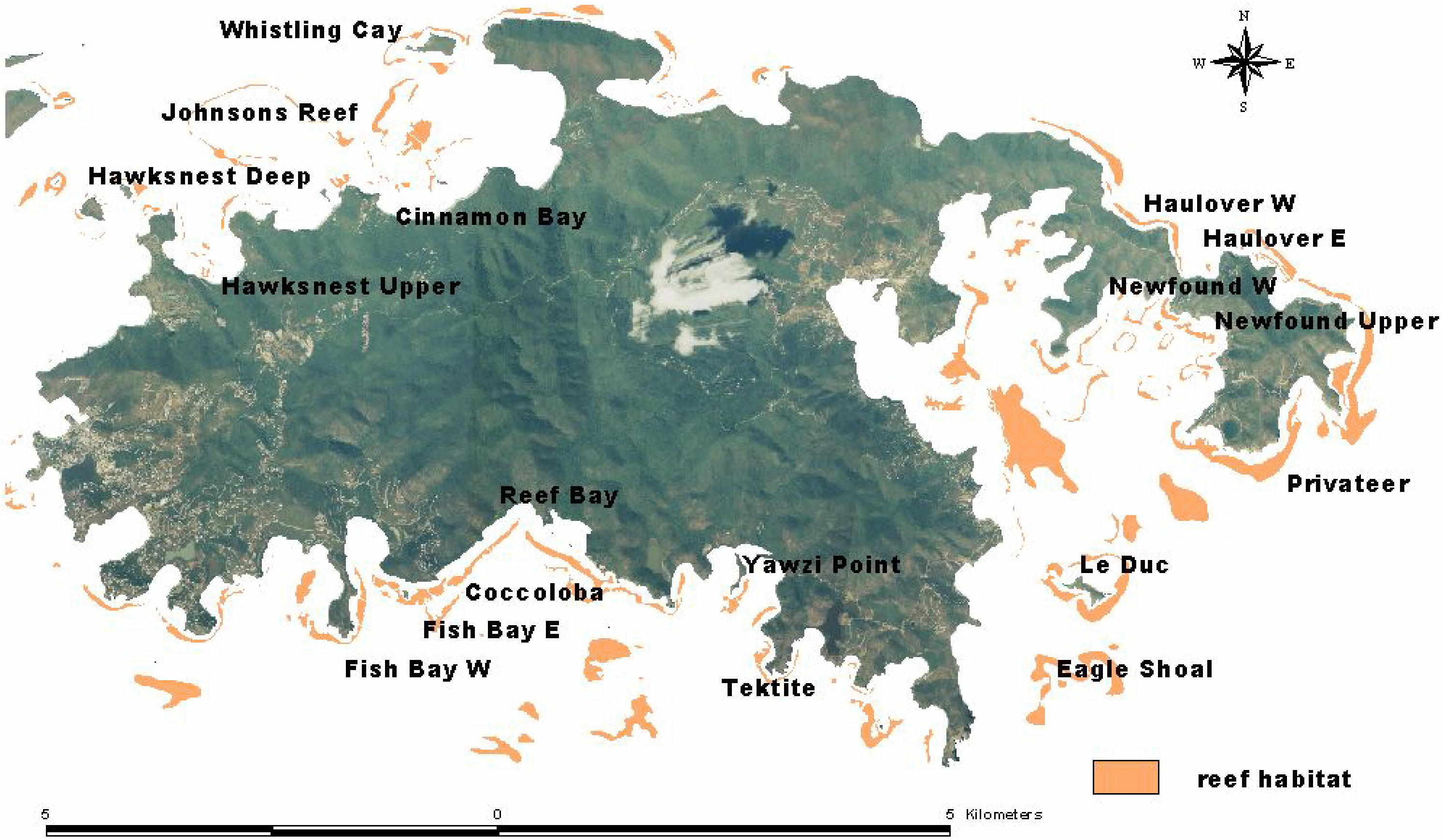

Figure 1. Map of St. John with reef habitat identified and monitoring sites labelled. Map created from NOAA/NOS data.

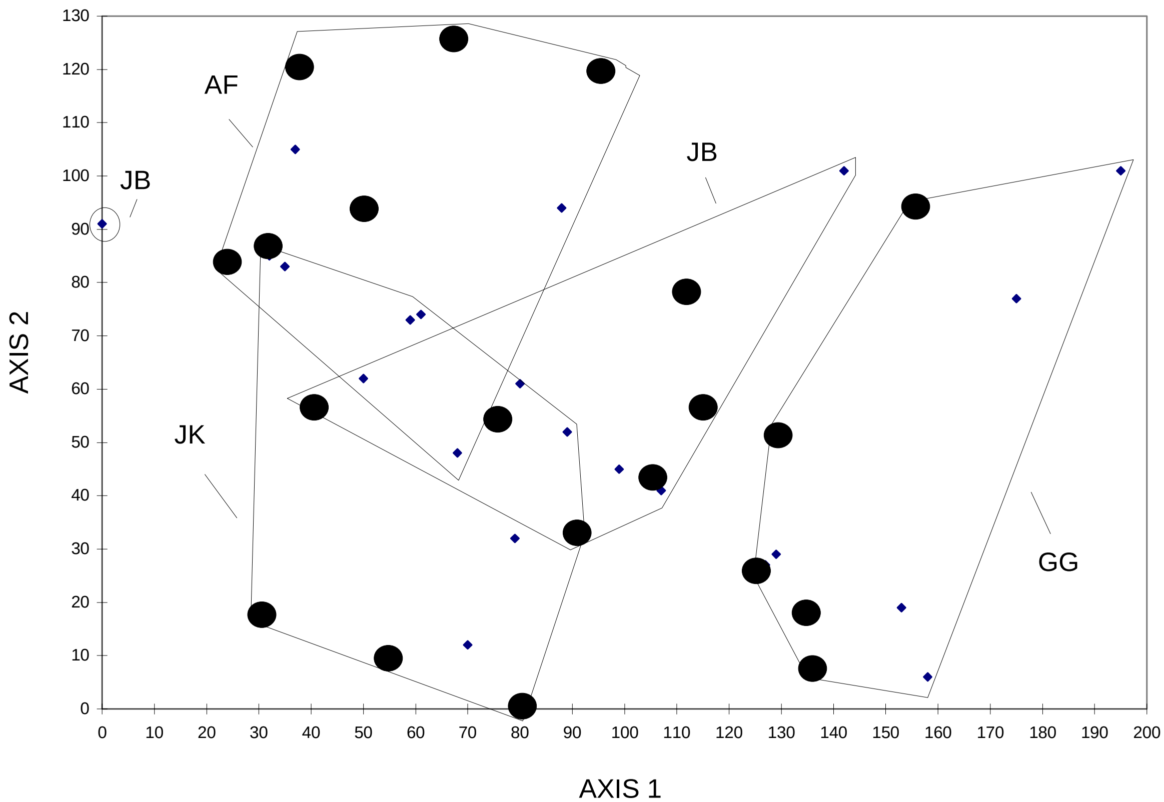

Figure 2. Results of detrended correspondence analysis of fish count data (4 observers; 40 samples) conducted at Tektite Reef for comparison of point count methods. Polygons denote each observer. Large circles are 10m/15min censuses; small circles represent 15m/5min censuses. Masked goby, *Coryphopterus personatus*, was not included in analysis.

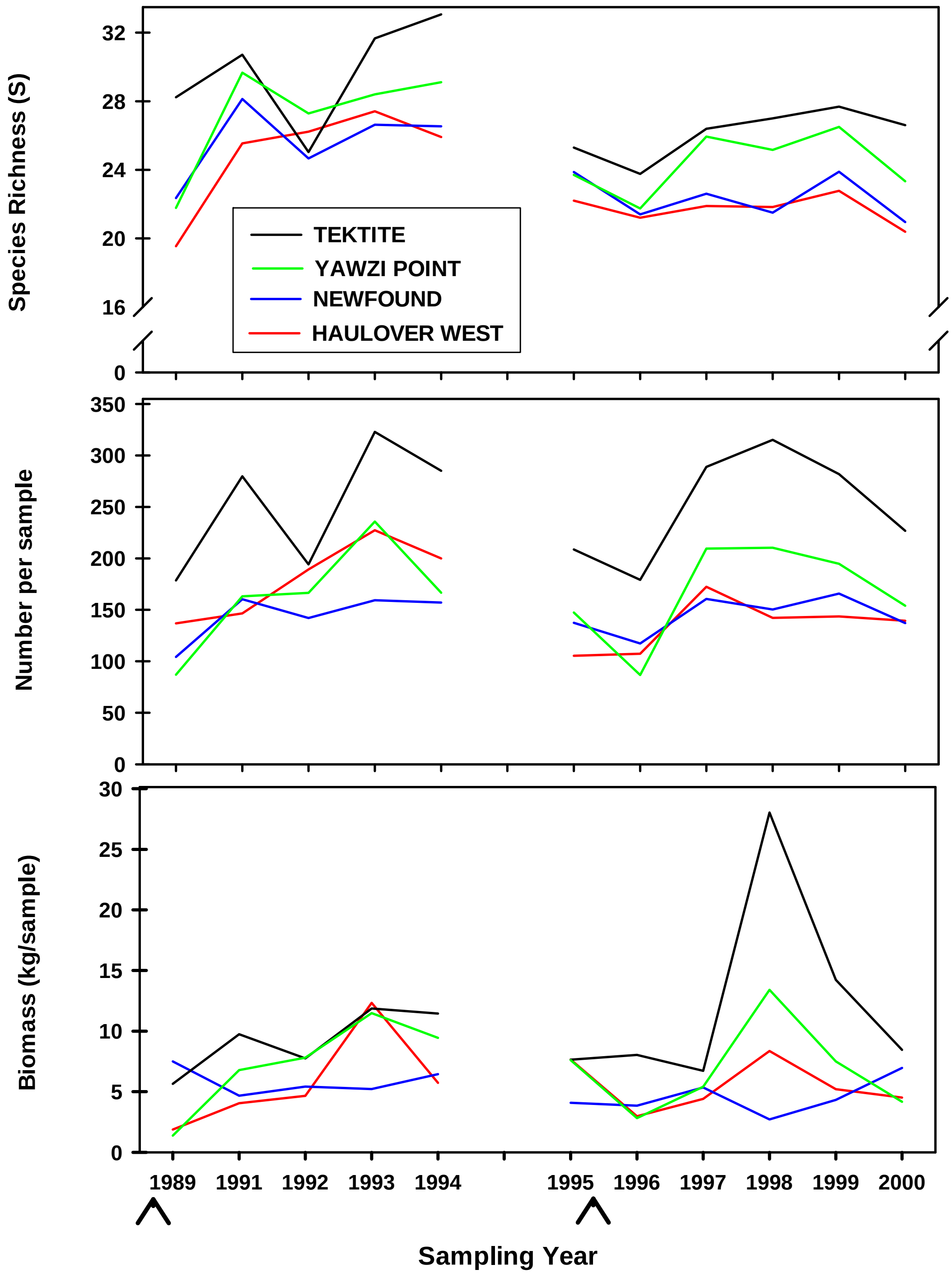

Figure 3. Comparison of fish assemblage characteristics among the four reference reefs sites around St. John, US Virgin Islands. The break between 1994 and 1995 marks methods change. Arrows mark two major hurricanes.

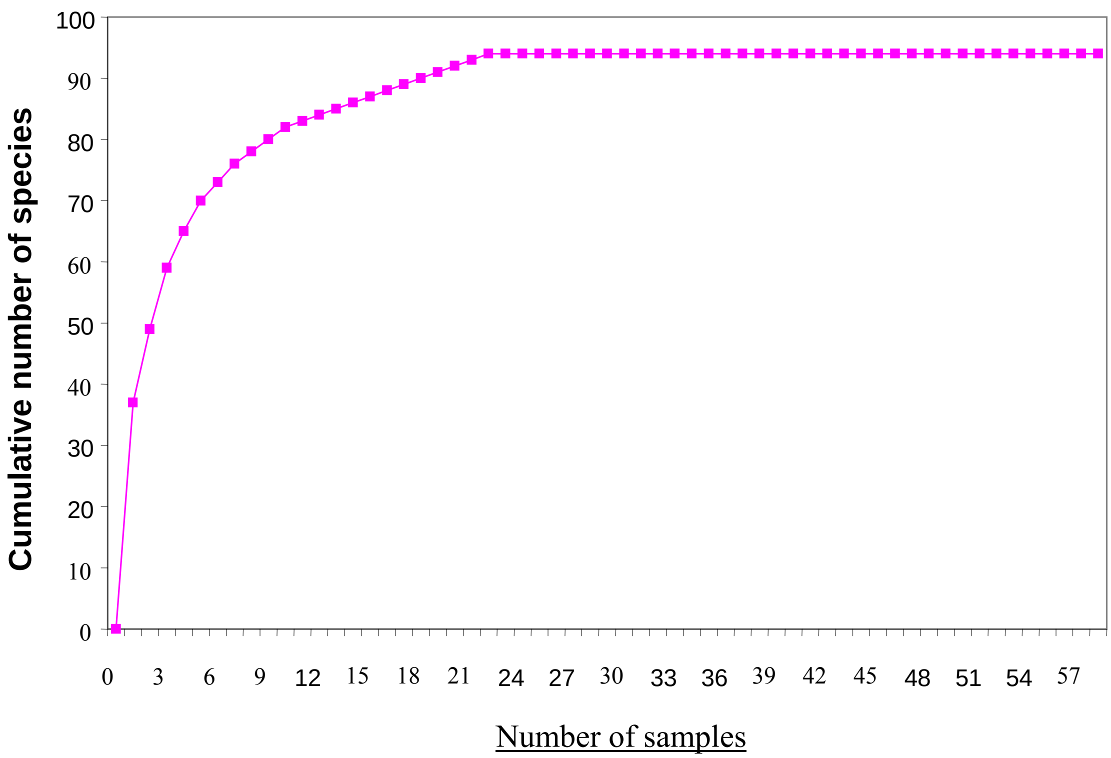

Figure 4. Cumulation curve showing the relationship between the cumulative number of species and the number of samples at Tektite Reef.

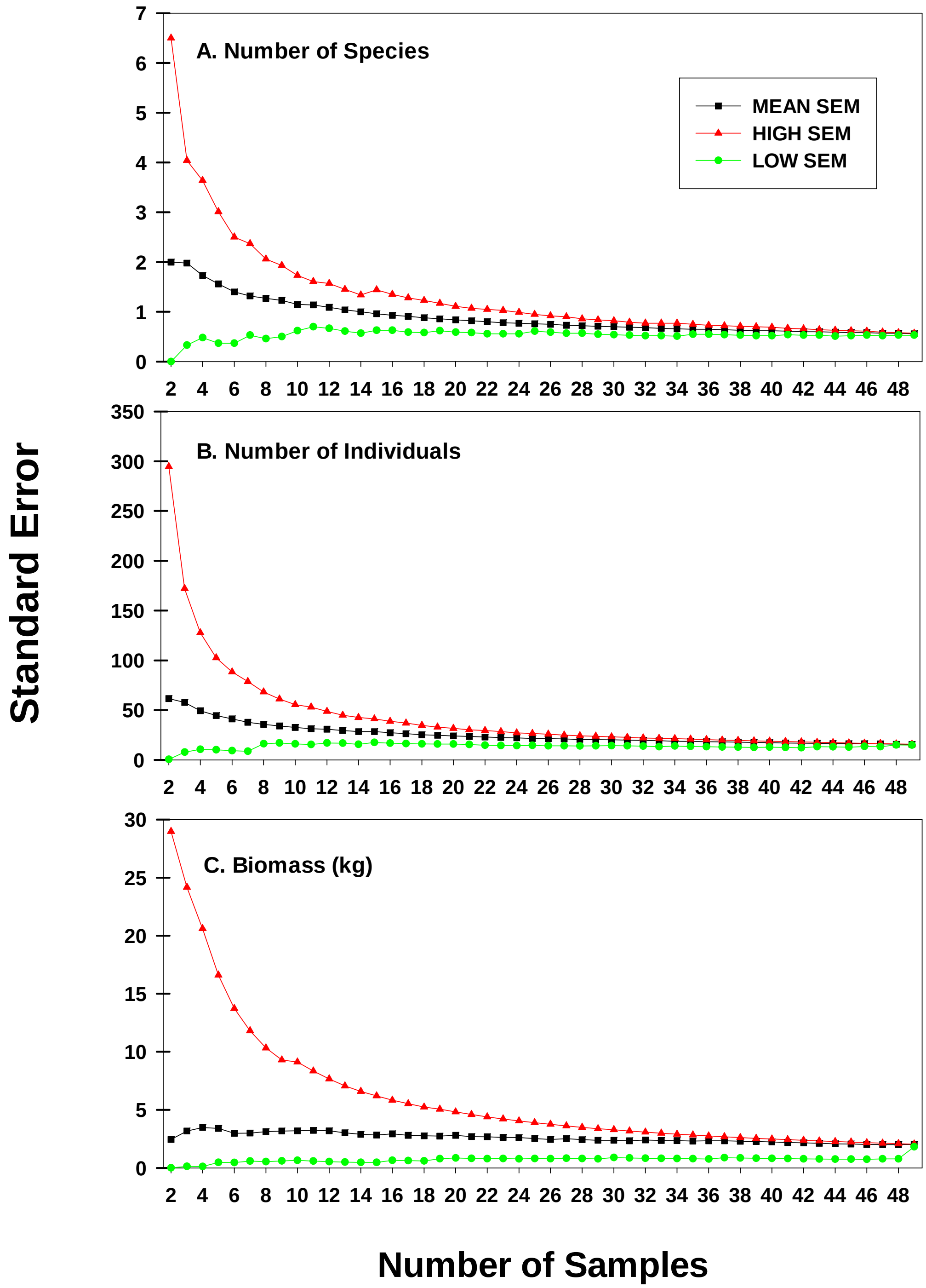

Figure 5. Sample size optimization of data from sample size analysis project at Tektite Reef, July 1999, for number of species, number of individuals, and biomass. Relationship between standard error of the mean (SEM) and sample size. Monte Carlo simulation procedure for sample size optimization described by Bros and Cowell (1987).

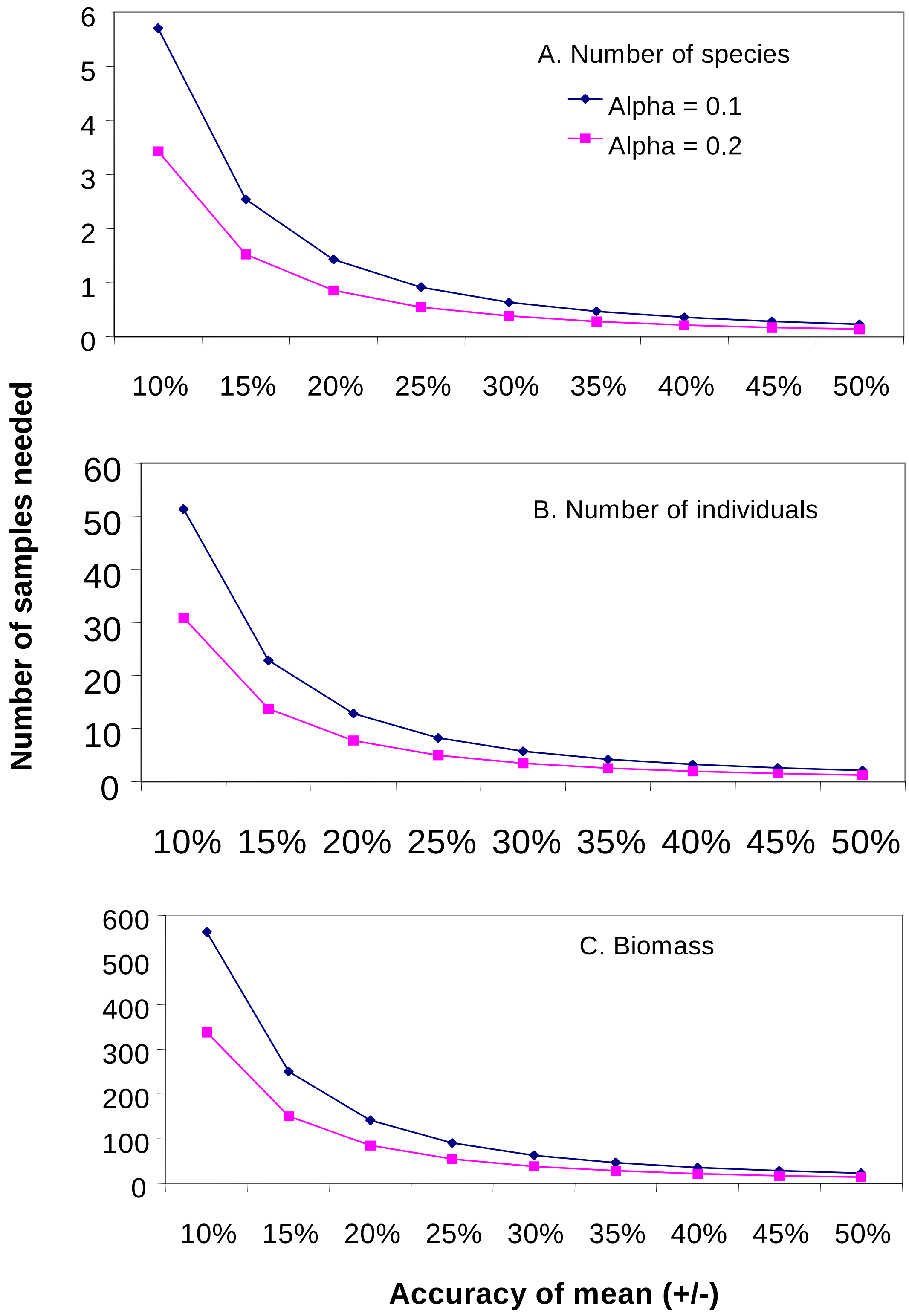

Figure 6. Estimated number of samples needed to detect changes in the mean of data from sample size analysis project at Tektite Reef, July 1999. A. number of species, B. number of individuals, and C. biomass. N = 58, α = 0.10 and 0.20.

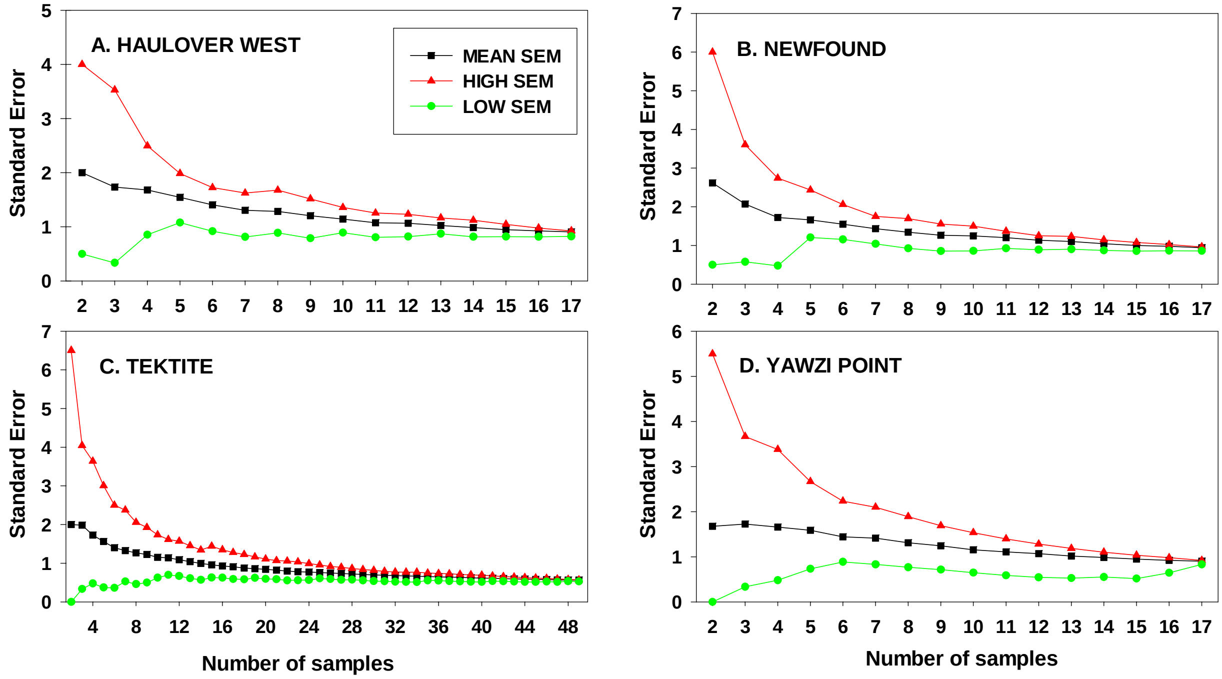

Figure 7. Results of sample size optimization for species richness among the four Reference Sites, St. John, U.S. Virgin Islands. Results based on data collected in 1999.

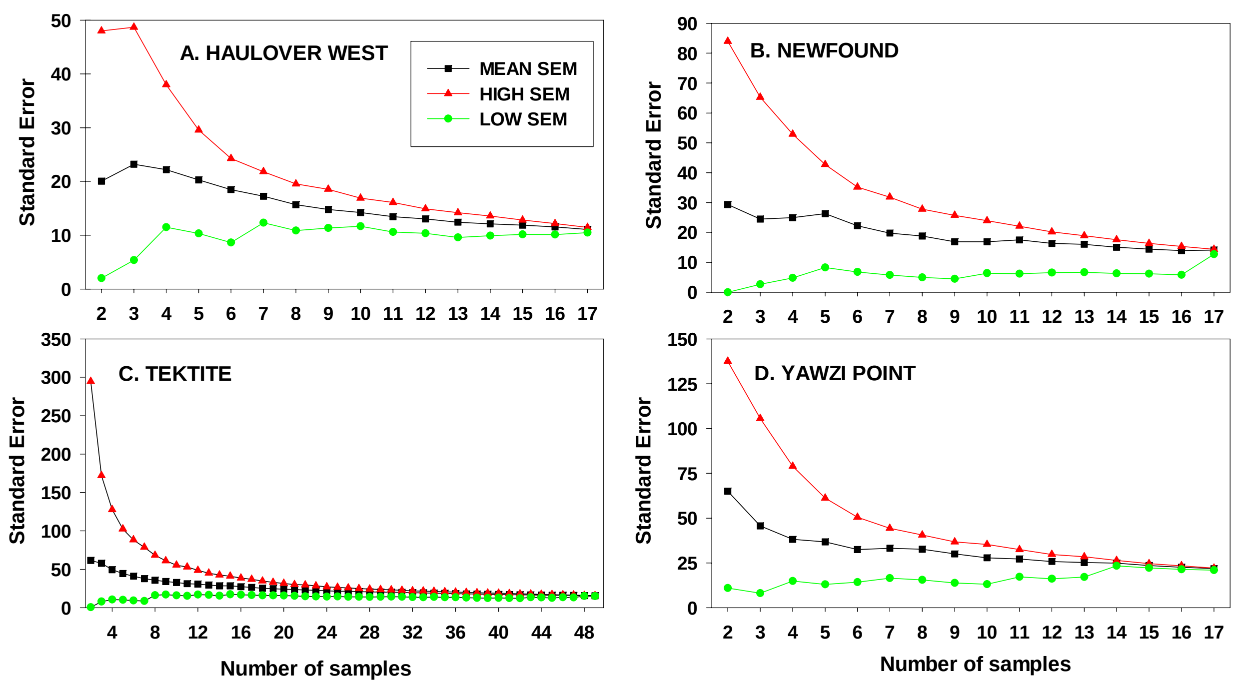

Figure 8. Results of sample size optimization for number of fishes among the four Reference Sites, St. John, U.S. Virgin Islands. Results based on data collected in 1999.

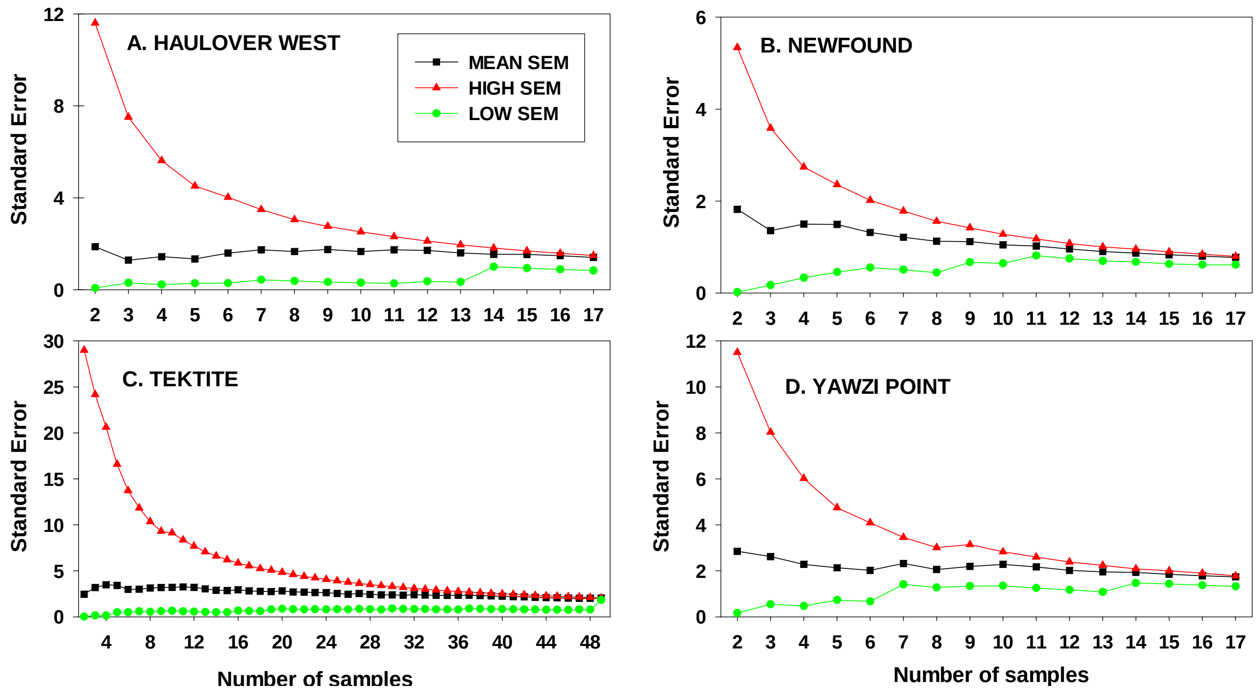

Figure 9. Results of sample size optimization for biomass (kg) among the four Reference Sites, St. John, U.S. Virgin Islands. Results based on data collected in 1999.

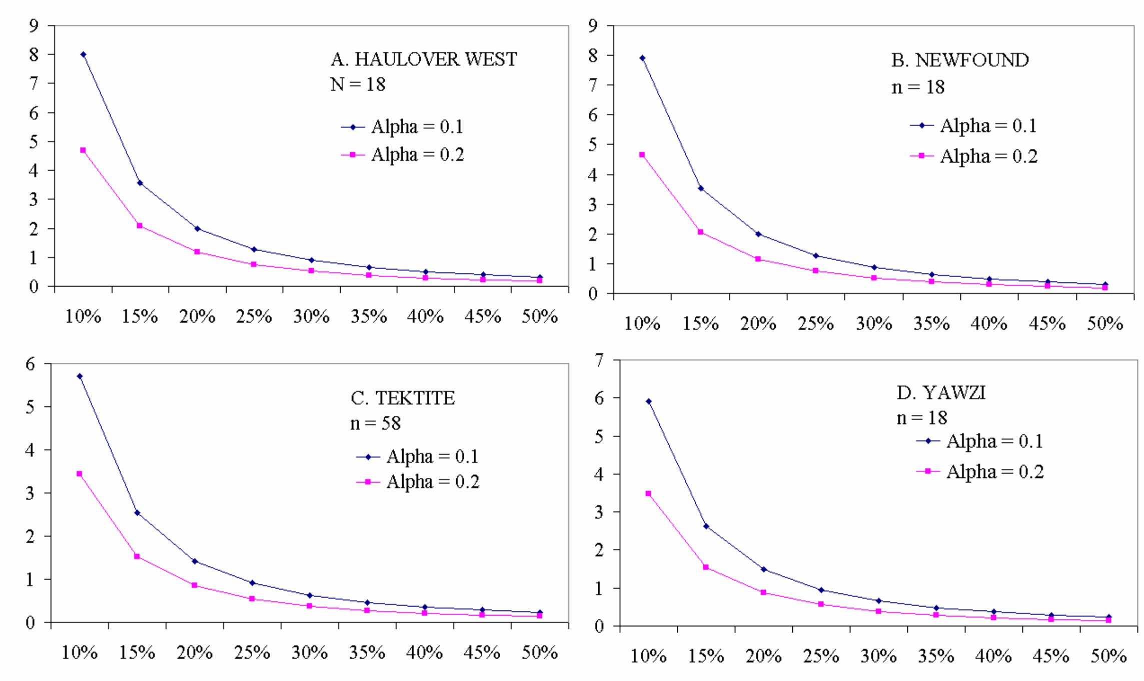

Figure 10. Estimated number of samples needed to detect changes in the mean for species richness among Reference Sites. N = 18 (except for Tektite: n = 58); α = 0.10 and 0.20.

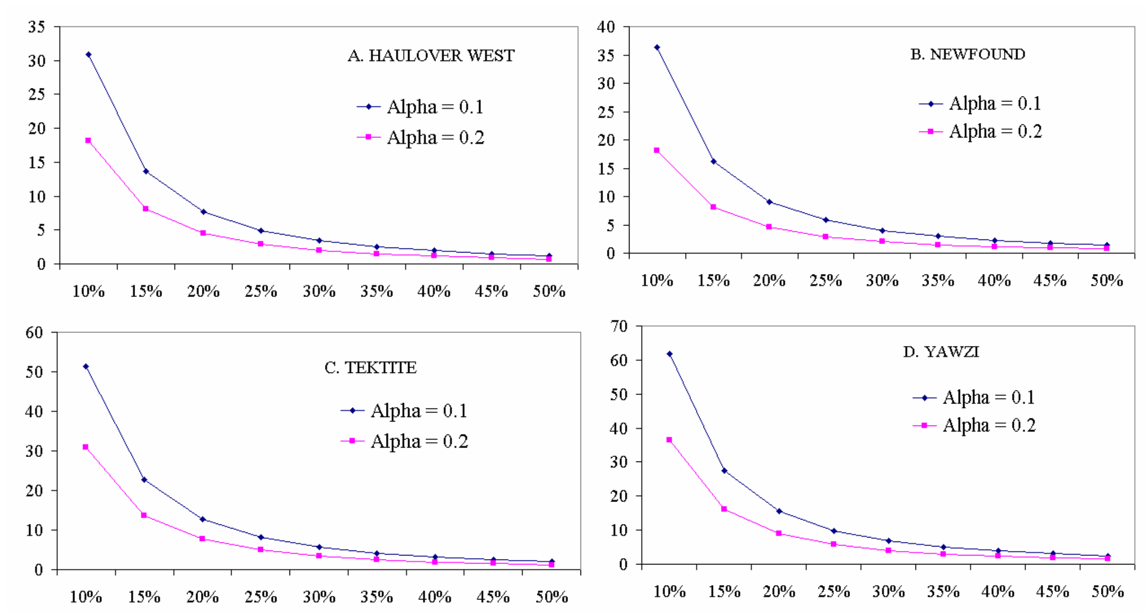

Figure 11. Estimated number of samples needed to detect changes in the mean for number of fishes among Reference Sites. N = 18 (except for Tektite: n = 58); α = 0.10 and 0.20.

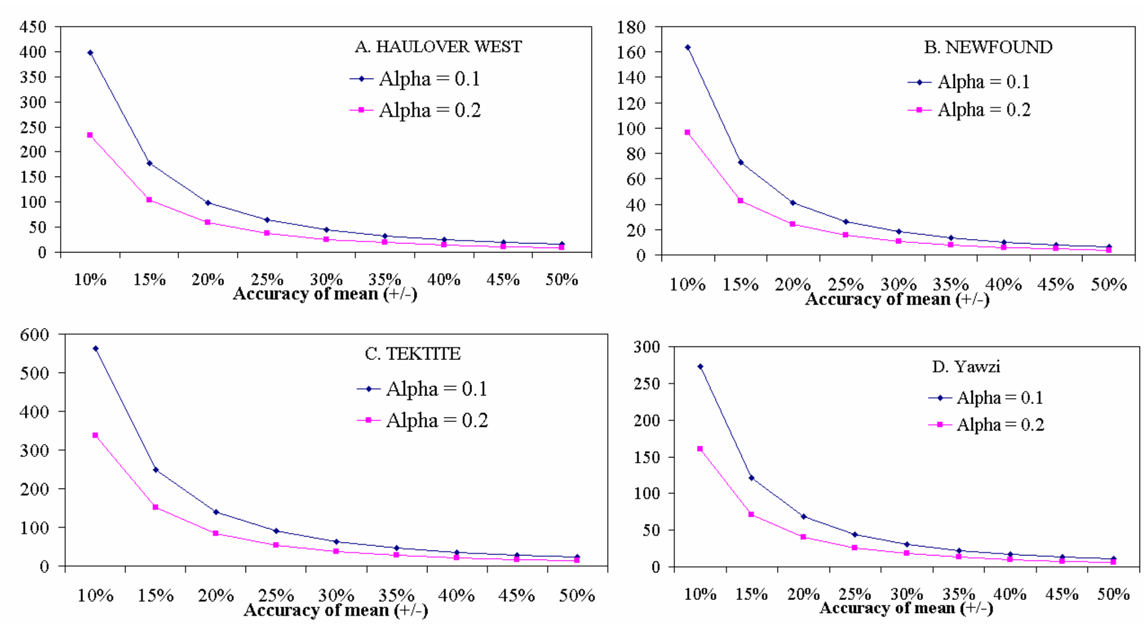

Figure 12. Estimated number of samples needed to detect changes in the mean for biomass among Reference Sites. N = 18 (except for Tektite: n = 58); $\alpha = 0.10$ and 0.20.

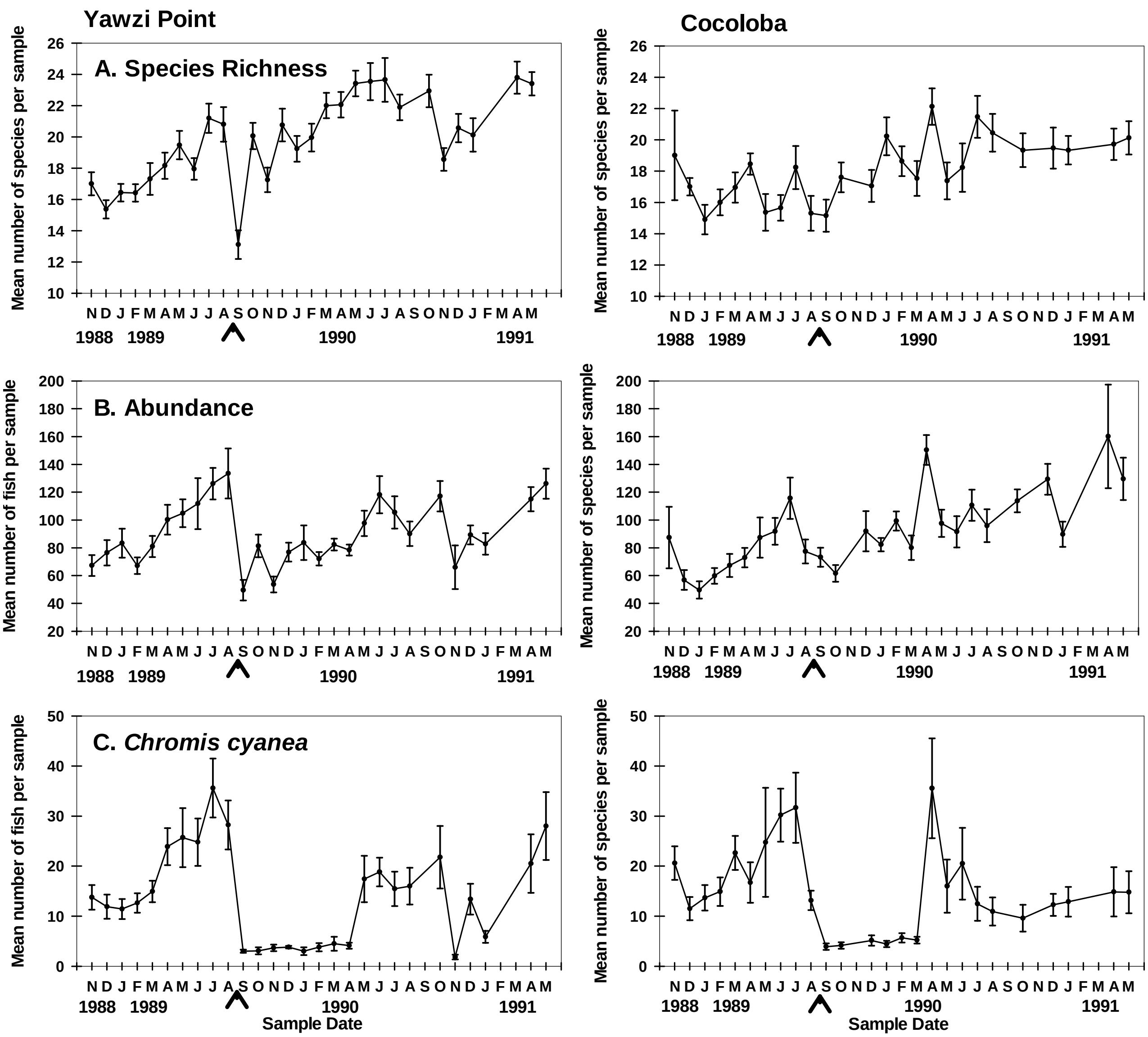

Figure 13. Mean monthly trends in A. Species richness, B. abundance, and C. abundance of *Chromis cyanea* at Yawzi Point and Cocoloba Cay monitoring sites, Nov 1988 – May 1991. Error bars are standard error (average sample size per month = 18). The arrow marks the passing of Hurricane Hugo, Sept. 1989.

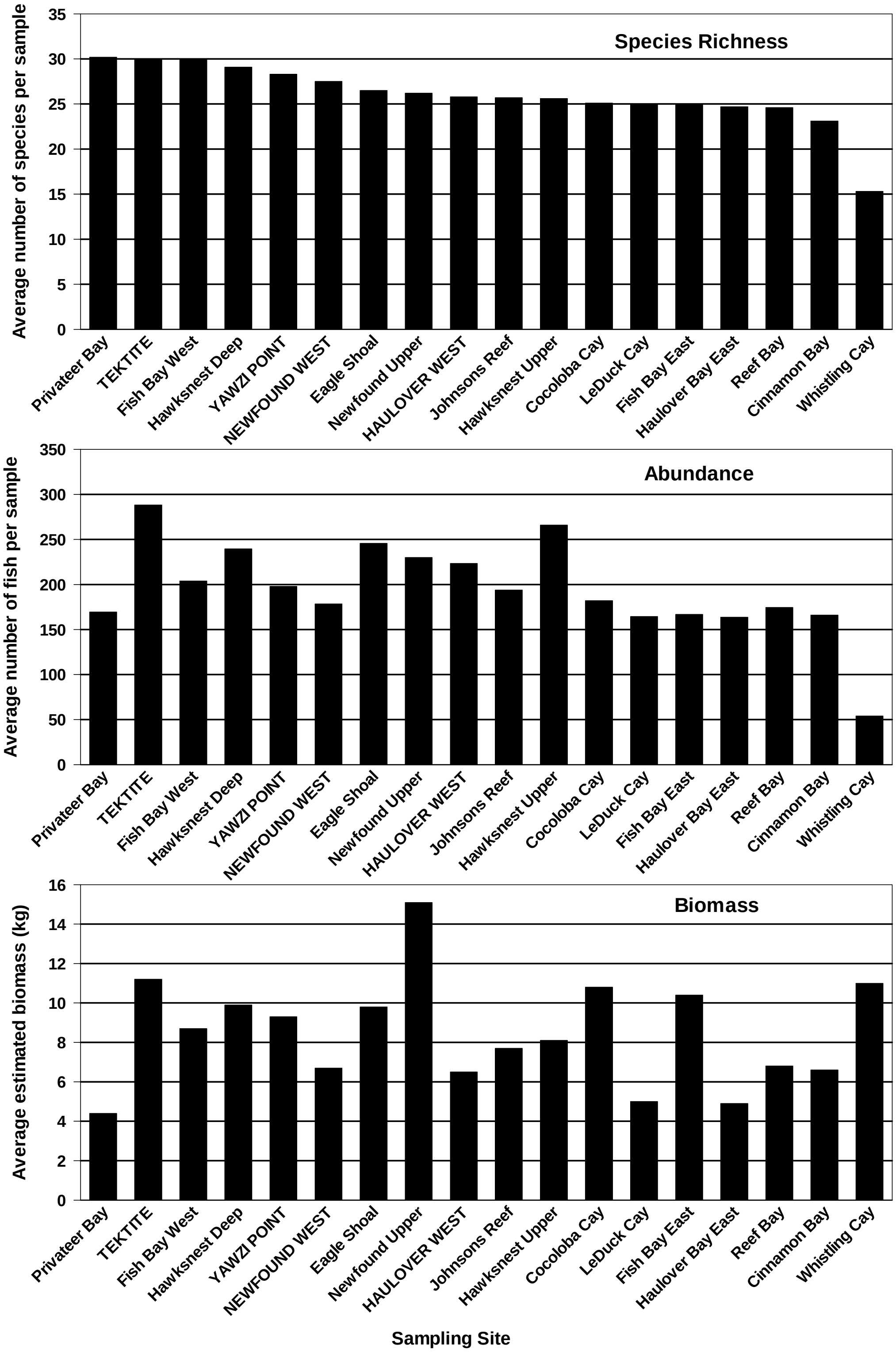

Figure 14. Comparison of fish assemblage characteristics among reefs sampled around St. John, US Virgin Islands, 1989-1994. Reference sites are bolded.

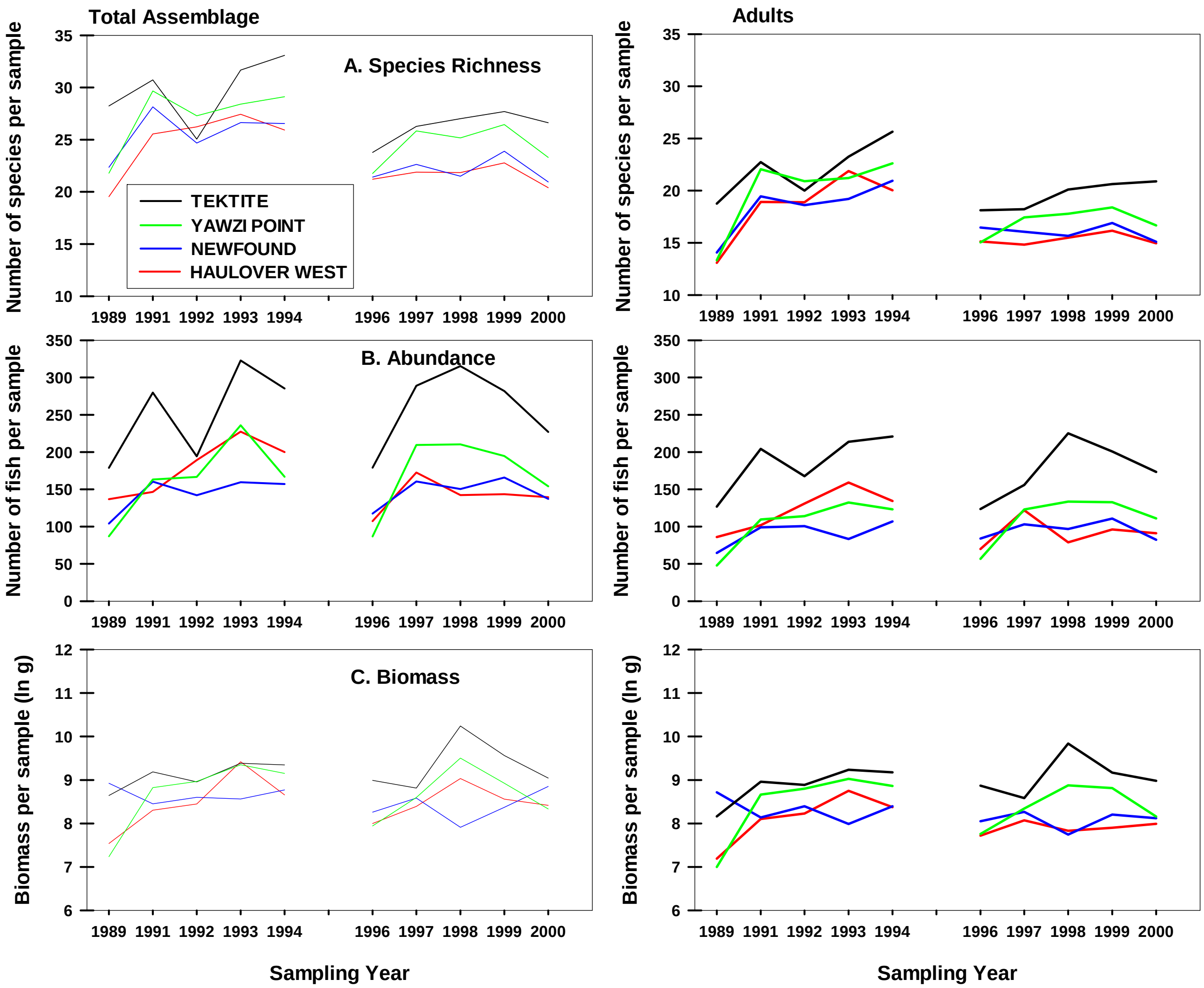

Figure 15. Comparison of trends of assemblage characteristic values (a. species richness, b. abundance, and c. biomass) between all reef fishes (Total Assemblage - juveniles and adults) and Adults (juveniles excluded) for the four reference sites, St. John, US Virgin Islands. Major storm events marked the beginning of each of the two periods shown in each graph (1989-Hurricane Hugo; 1995 – Hurricane Marilyn). The change in methods occurred in 1995 (data not presented for 1995).

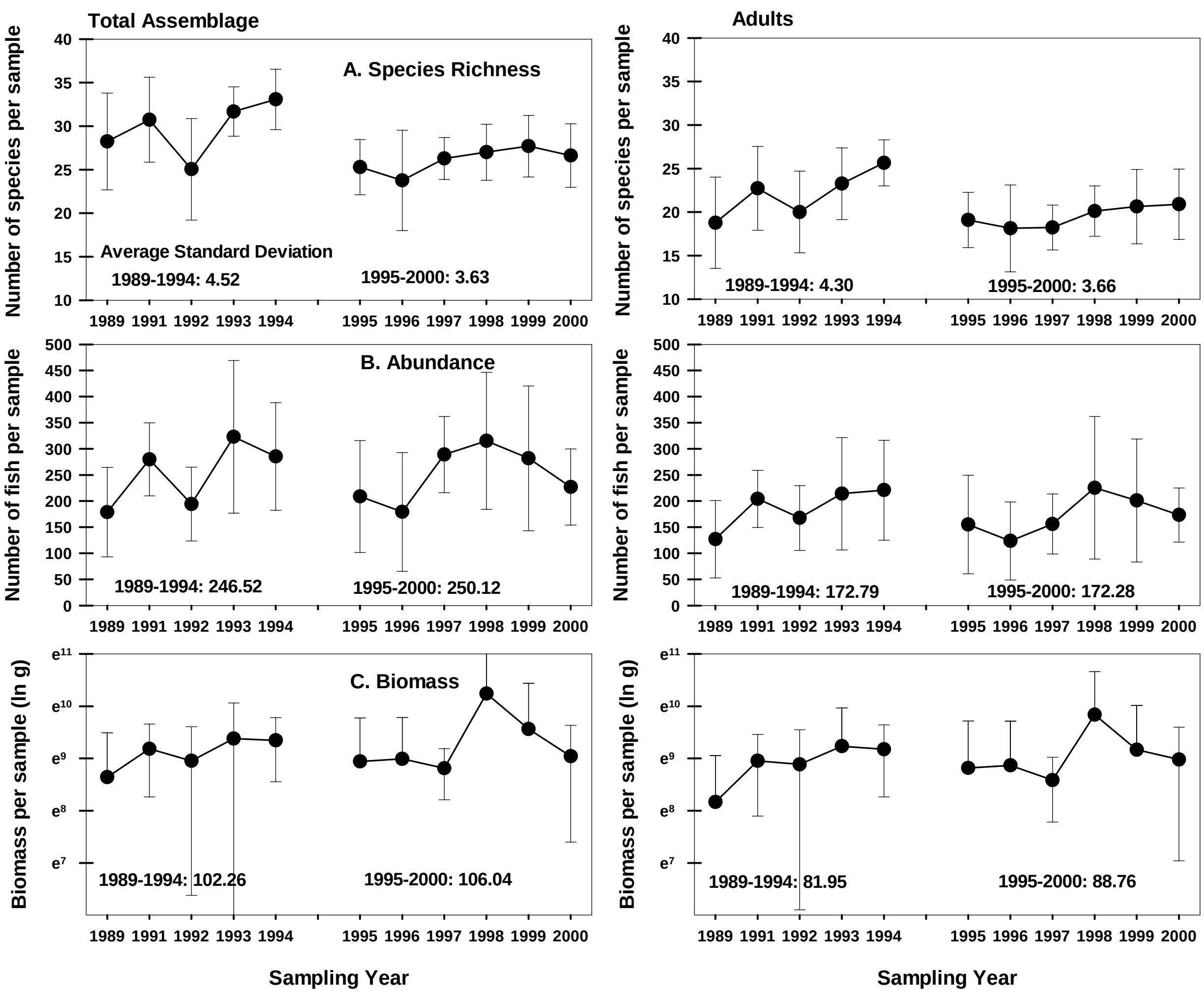

Figure 16. Comparison of variance estimates (standard deviation) of assemblage characteristics (a. species richness, b. abundance, and c. biomass) between all reef fishes (Total Assemblage - juveniles and adults) and Adults (juveniles excluded) for Tektite Reef, St. John, US Virgin Islands. Average standard deviation is presented for all reef fishes and adults for both sampling periods. The change in methods, which occurred in 1995, marked the separation in sampling periods.

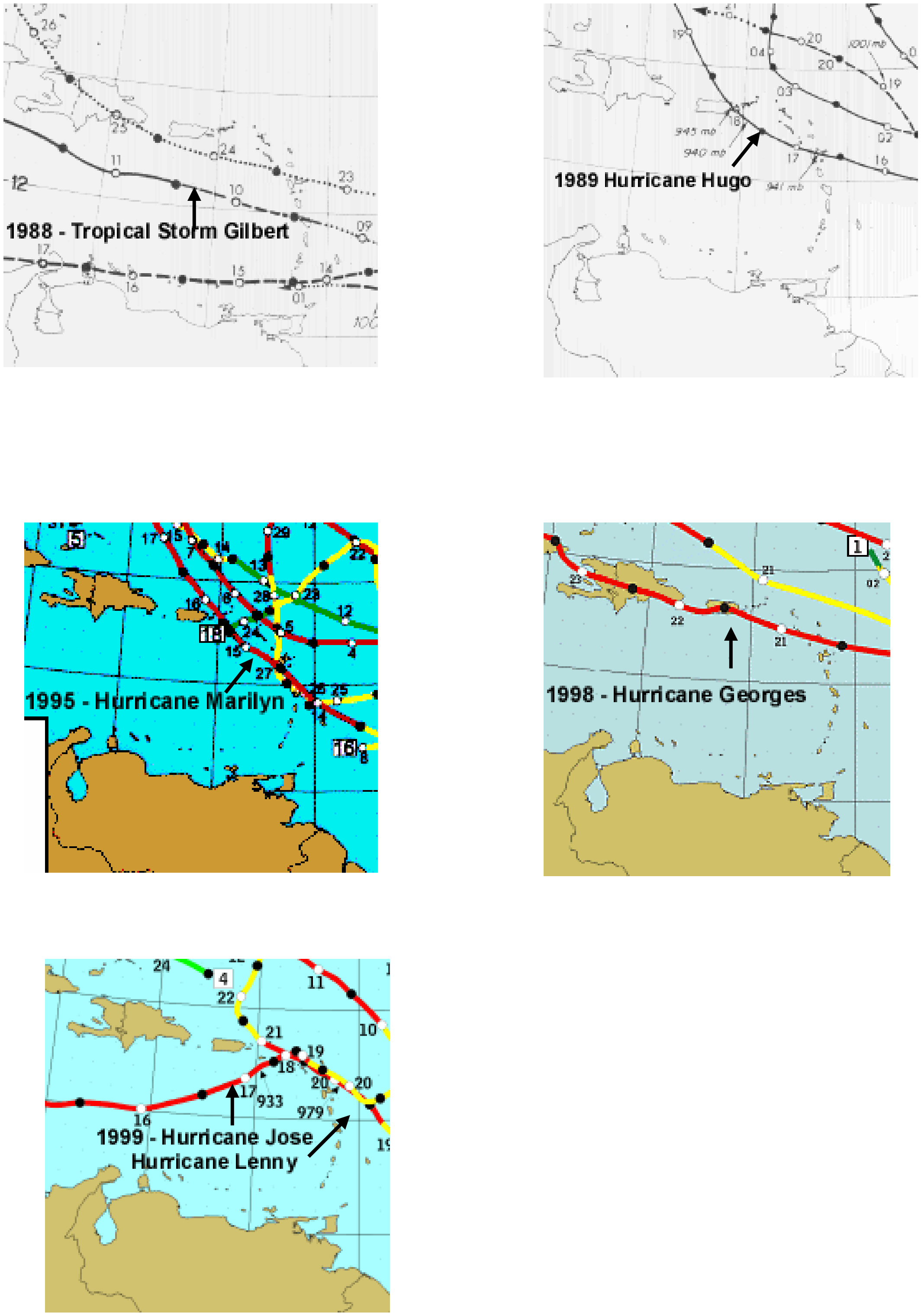

Figure 17. Tracks of major storms influencing marine habitats of St. John, U.S. Virgin Islands, 1988-2000.

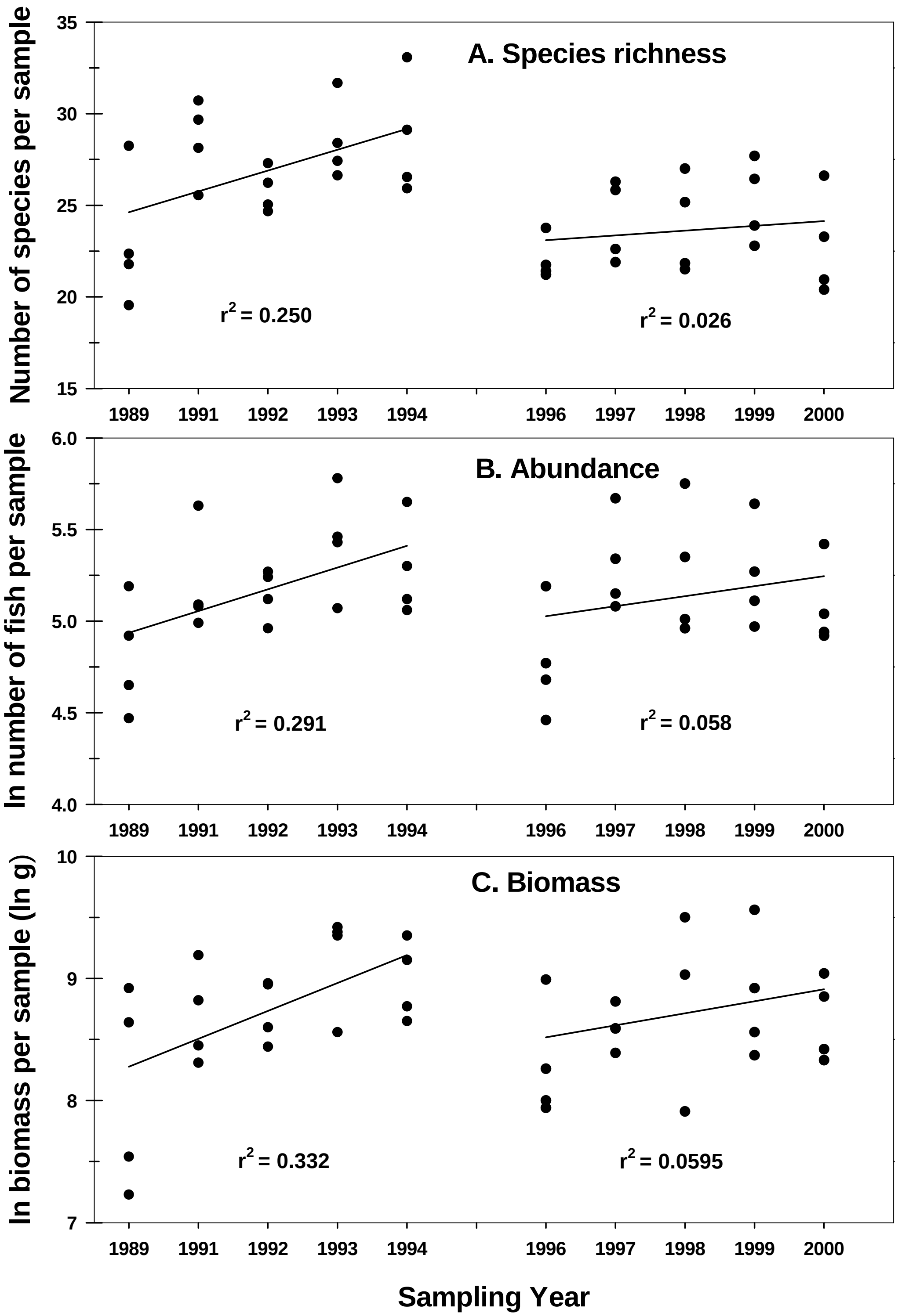

Figure 18. Trends in assemblage characteristics during the five-year periods following the two major storms which effected St. John (Hurricane Hugo, Sept. 1989; Hurricane Marilyn, Sept. 1995). Average values for each of the four reference sites are represented by circles for each year. Regression lines and coefficients were obtained from linear regression analysis. Data for 1995 was excluded from these analyses.

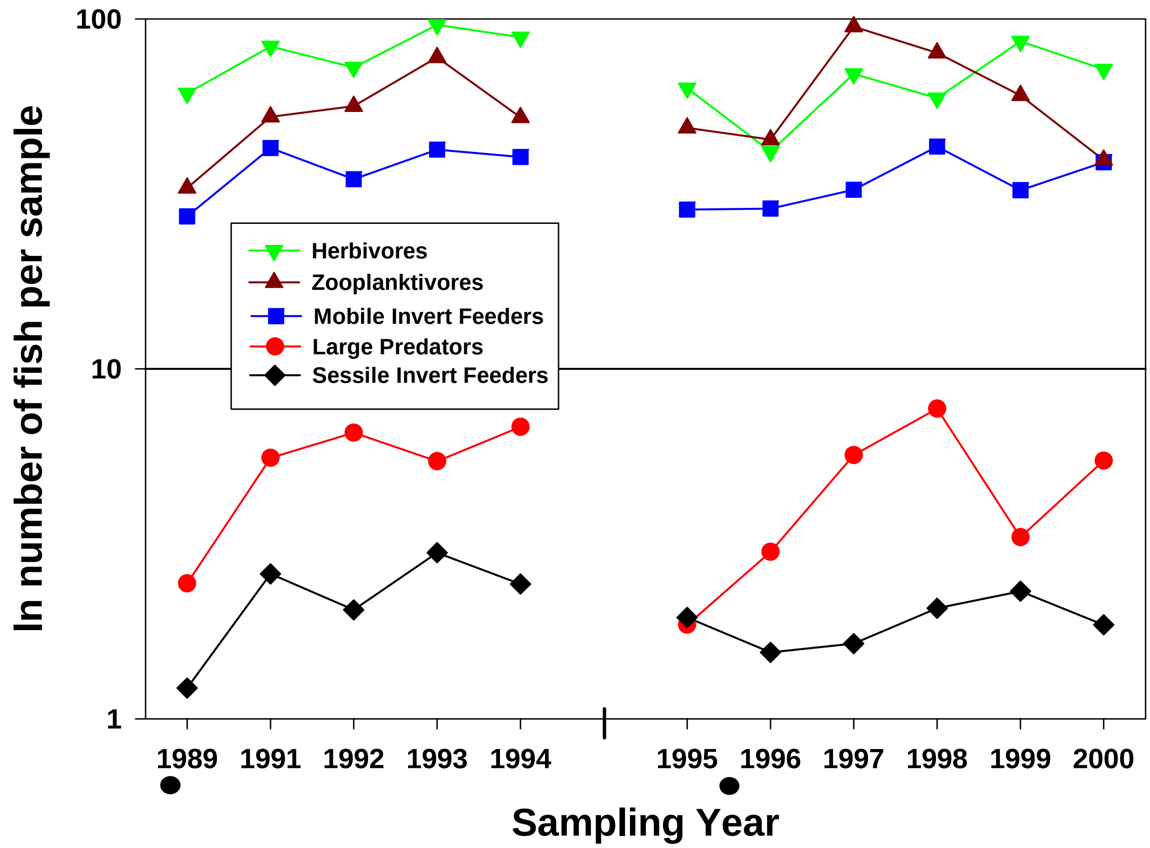

Figure 19. Abundance trends in trophic groups among the four Reference Sites around St. John, U.S. Virgin Islands, 1989-2000. Data were ln(x)-transformed. Method changed occurred in 1995. Black dots mark large hurricanes.

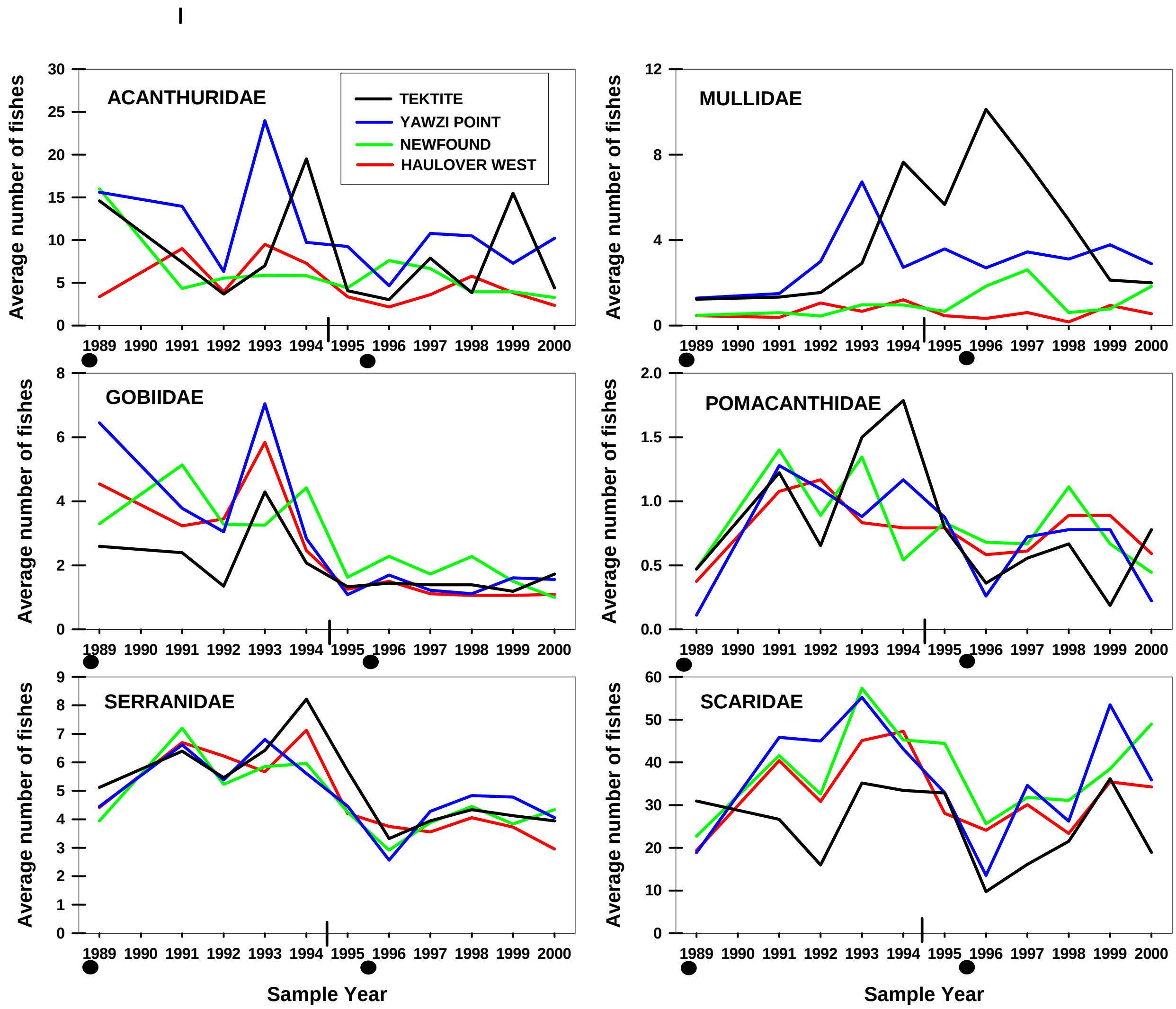

Figure 20. Abundance trends in selected fish families among the four Reference Sites around St. John, U.S. Virgin Islands, 1989-2000. Vertical bar on x-axis marks the method change; black dots mark large hurricanes.

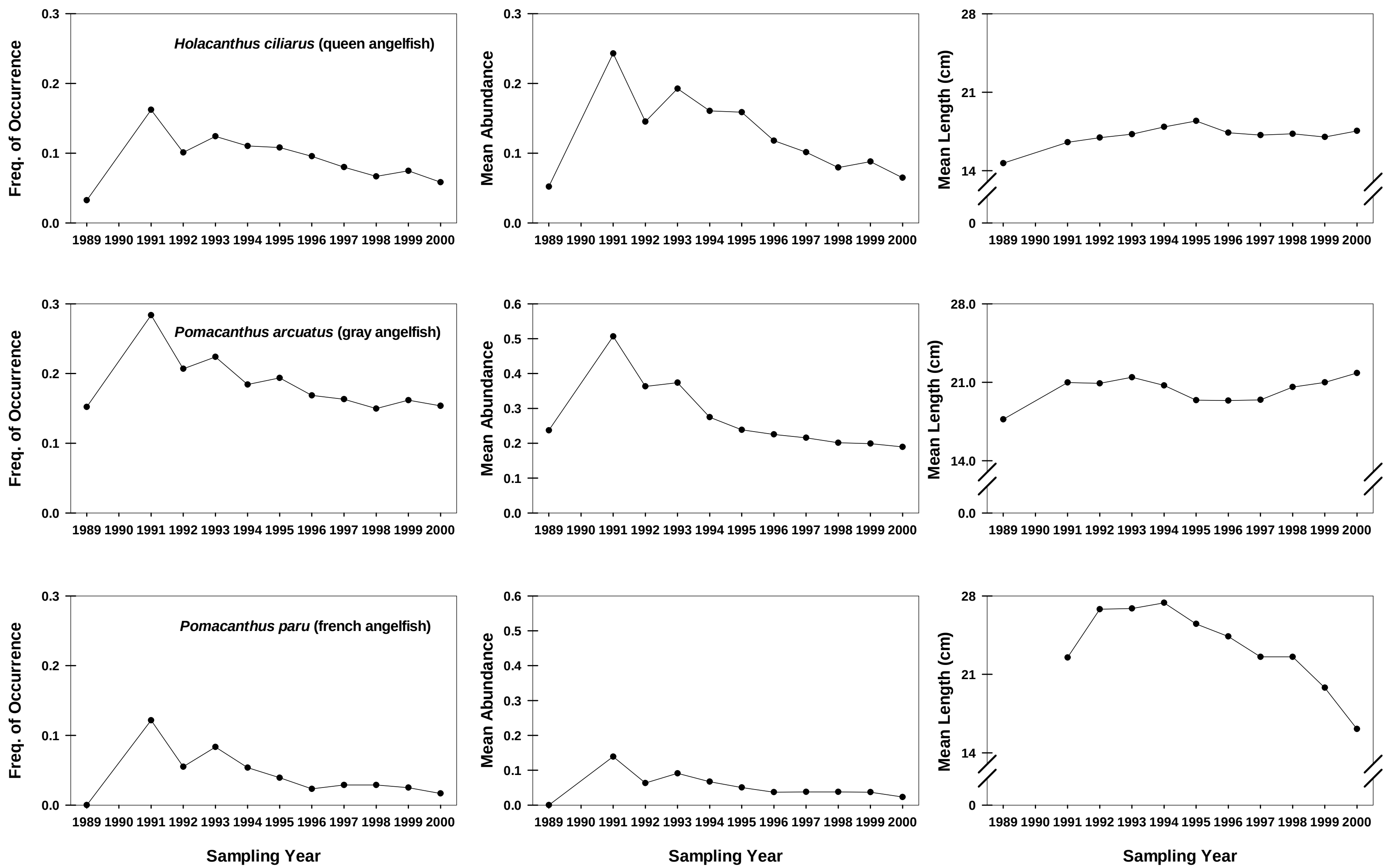

Figure 21. Trends in frequency of occurrence, abundance and length for three angelfish species sampled on the four reference sites, St. John, US Virgin Islands, 1989-2000. Data for graphs are 3-year running averages.

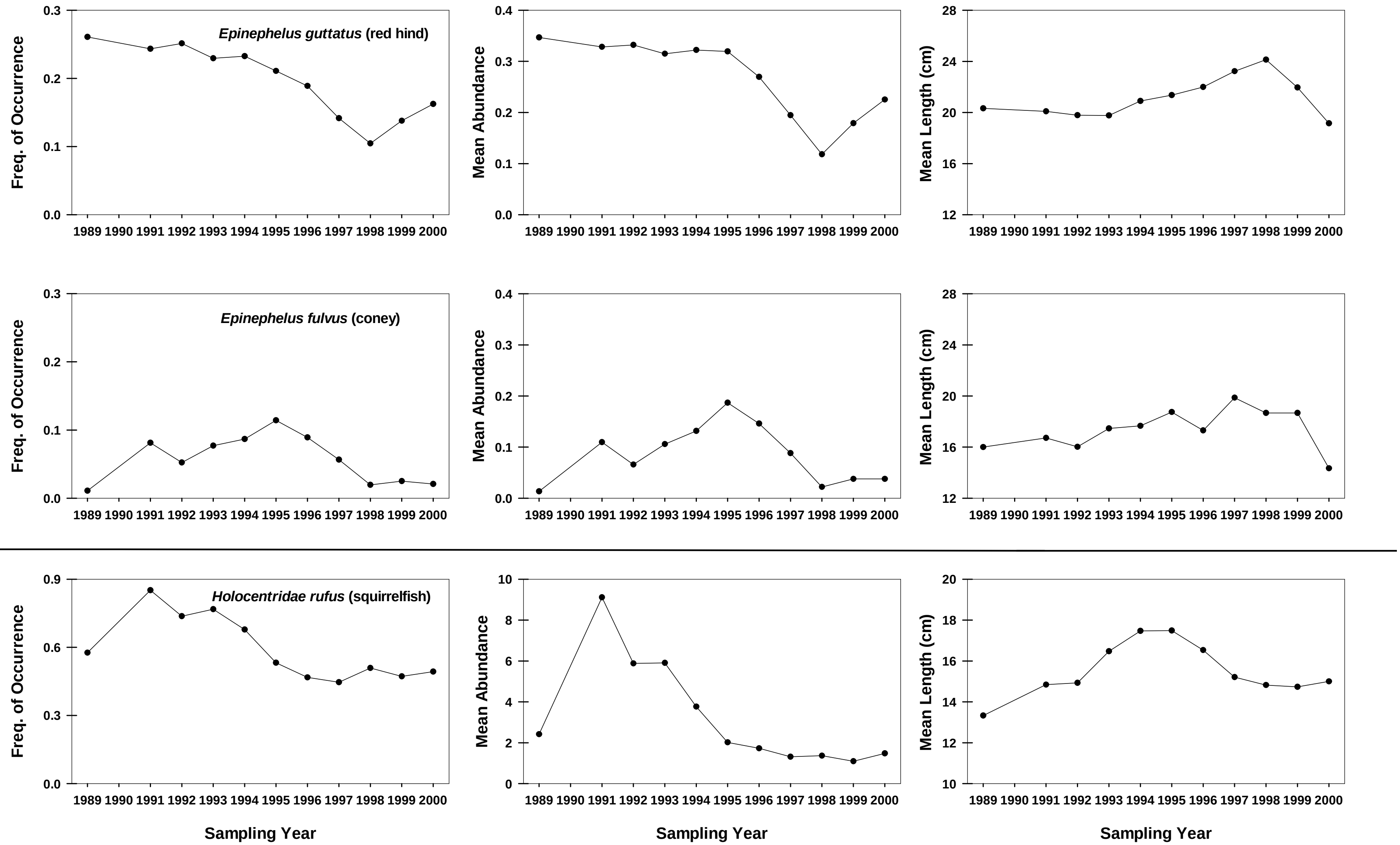

Figure 22. Trends in frequency of occurrence, abundance and length for two grouper and one squirrelfish species sampled on the four reference sites, St. John, US Virgin Islands, 1989-2000. Data for graphs are 3-year running averages.

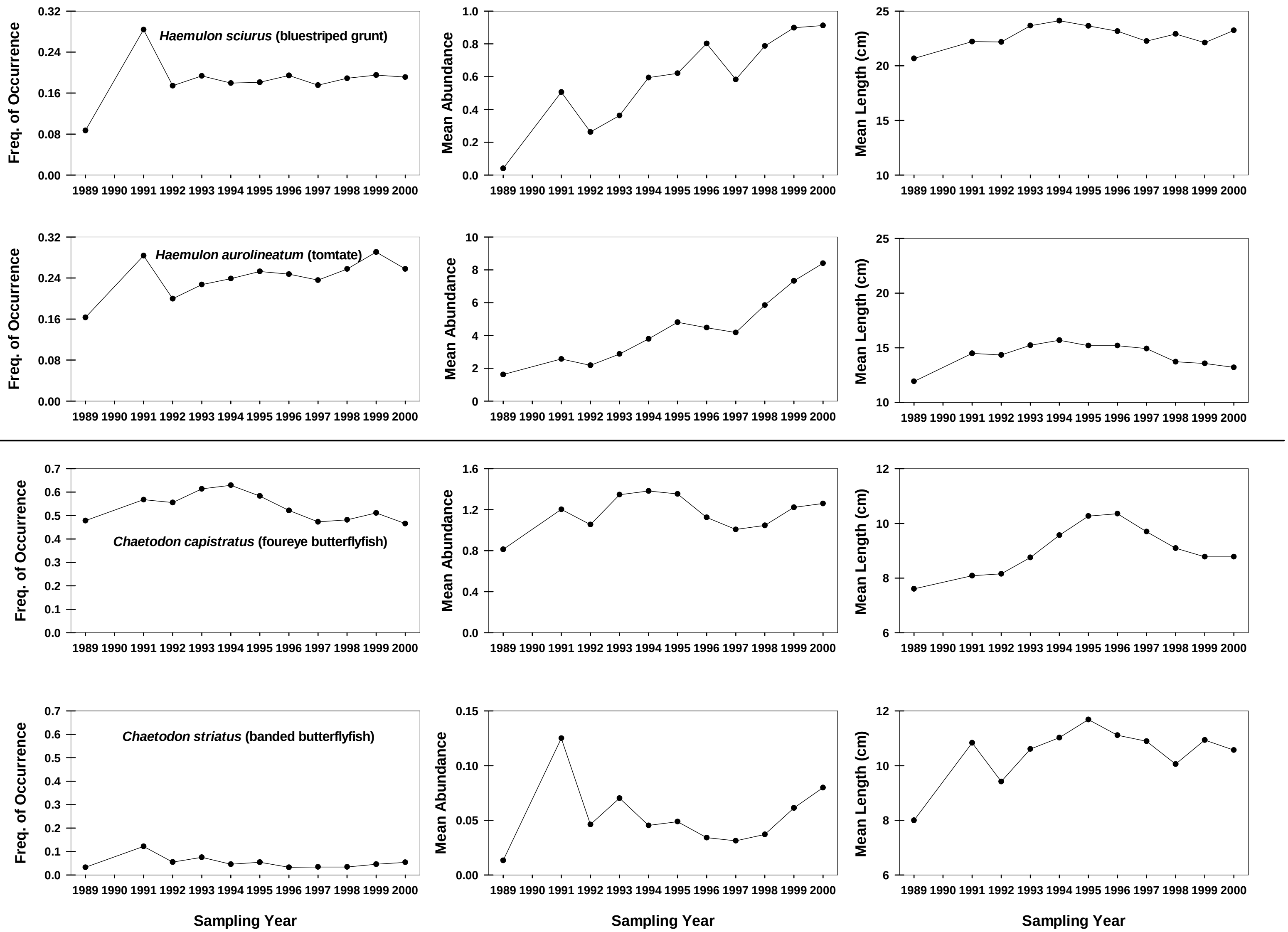

Figure 23. Trends in frequency of occurrence, abundance and length for two grunt and two butterflyfish species sampled on the four reference sites, St. John, US Virgin Islands, 1989-2000. Data for graphs are 3-year running averages.

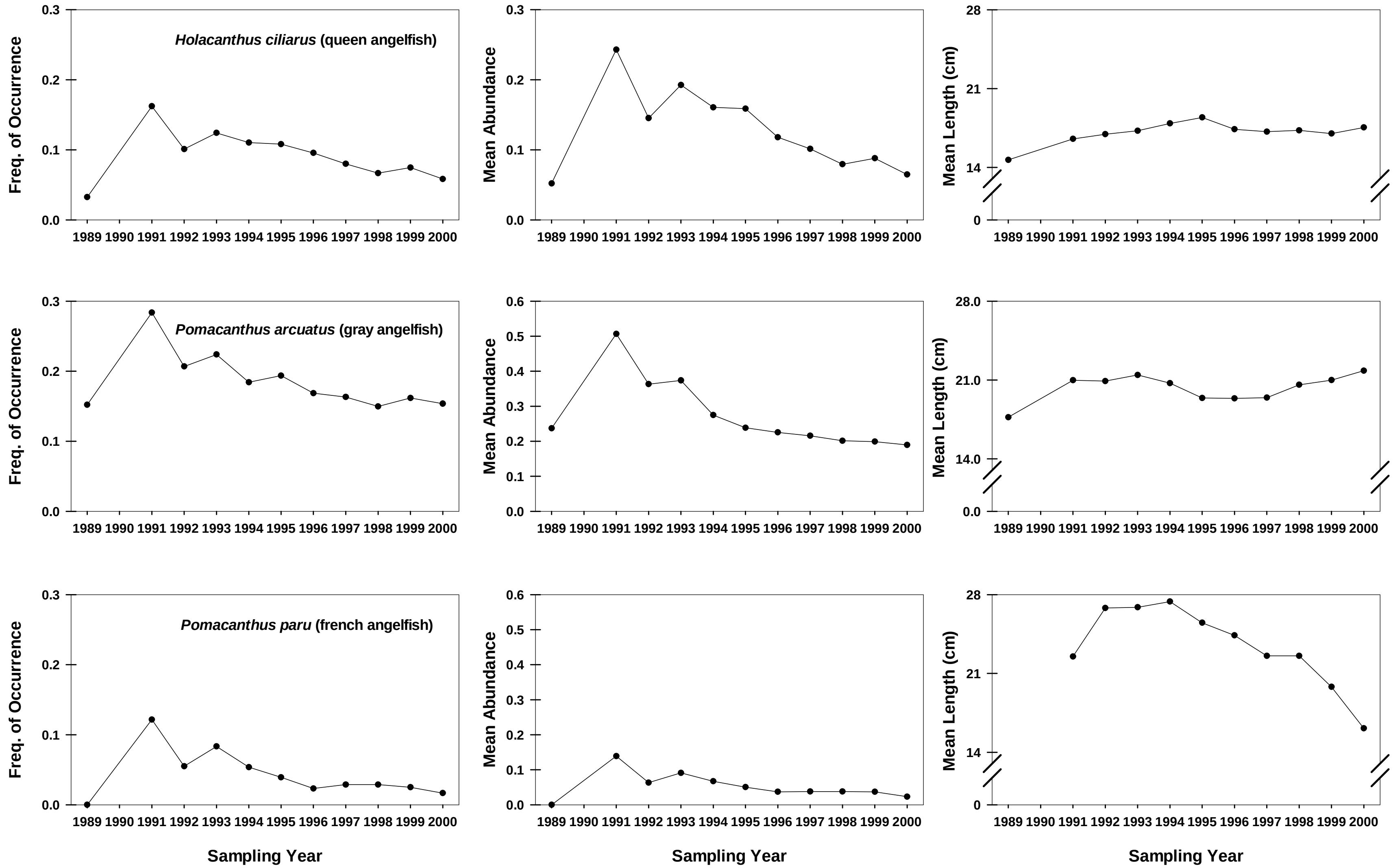

Figure 21. Trends in frequency of occurrence, abundance and length for three angelfish species sampled on the four reference sites, St. John, US Virgin Islands, 1989-2000. Data for graphs are 3-year running averages.

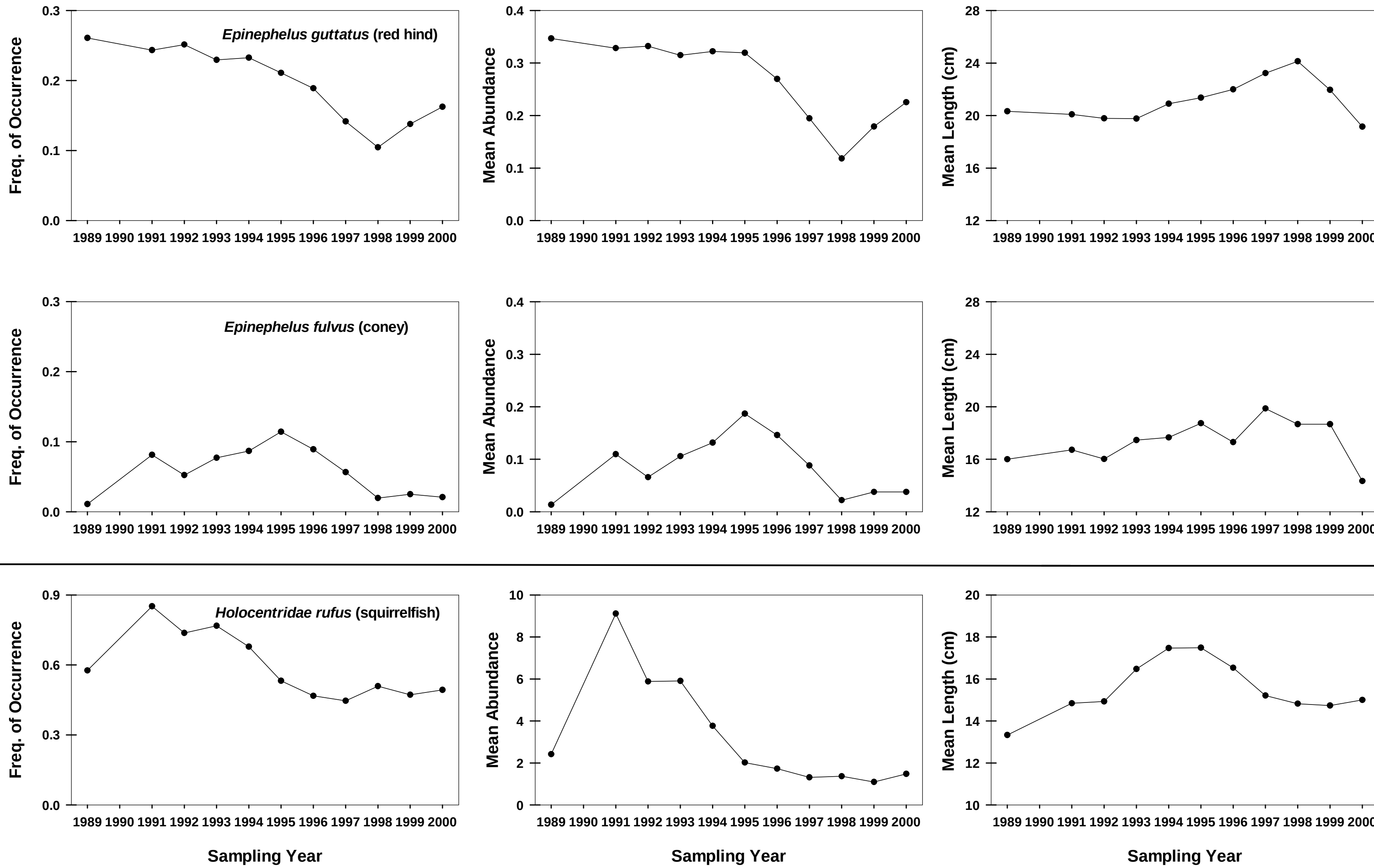

Figure 22. Trends in frequency of occurrence, abundance and length for two grouper and one squirrelfish species sampled on the four reference sites, St. John, US Virgin Islands, 1989-2000. Data for graphs are 3-year running averages.

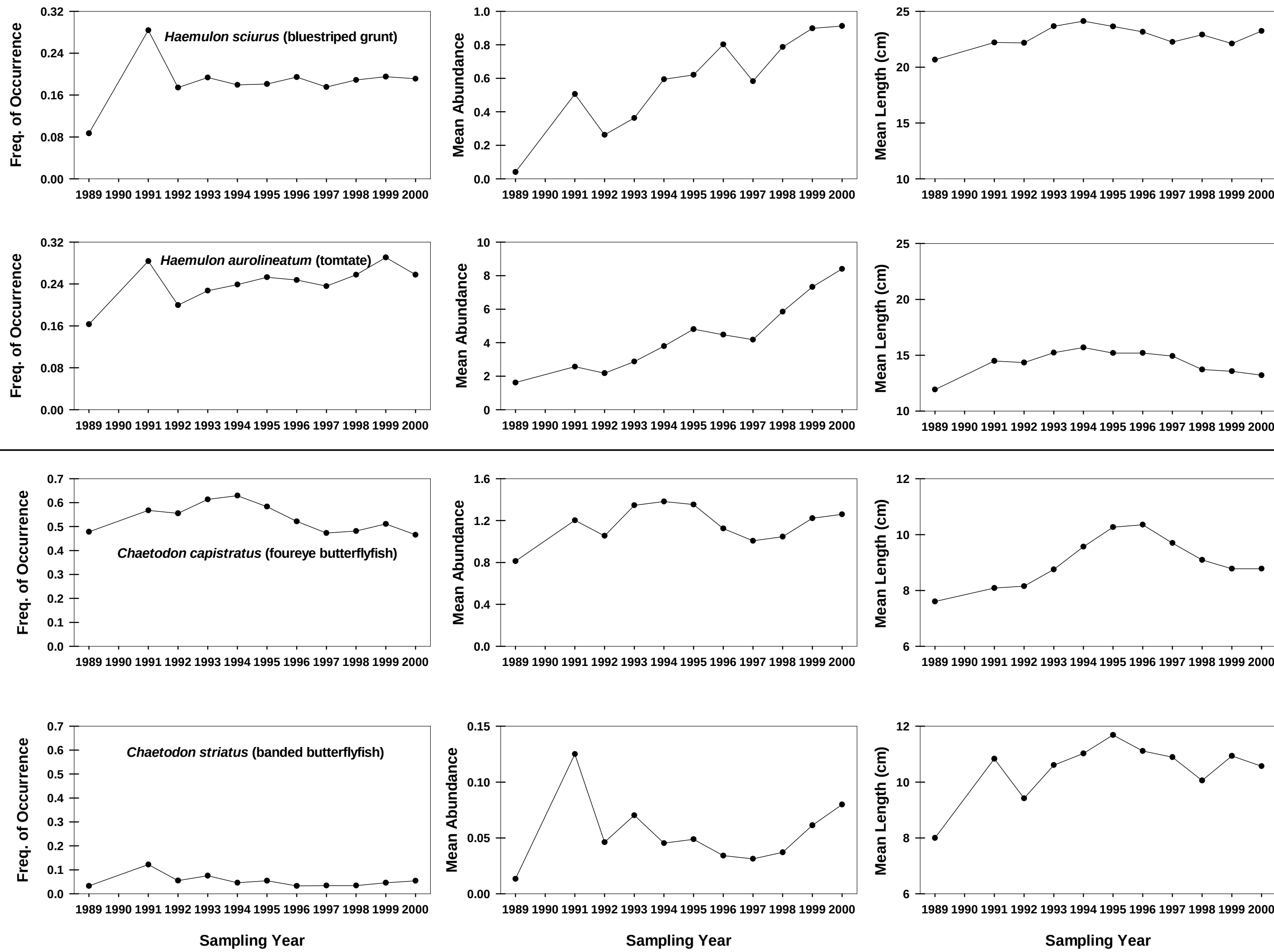

Figure 23. Trends in frequency of occurrence, abundance and length for two grunt and two butterflyfish species sampled on the four reference sites, St. John, US Virgin Islands, 1989-2000. Data for graphs are 3-year running averages.

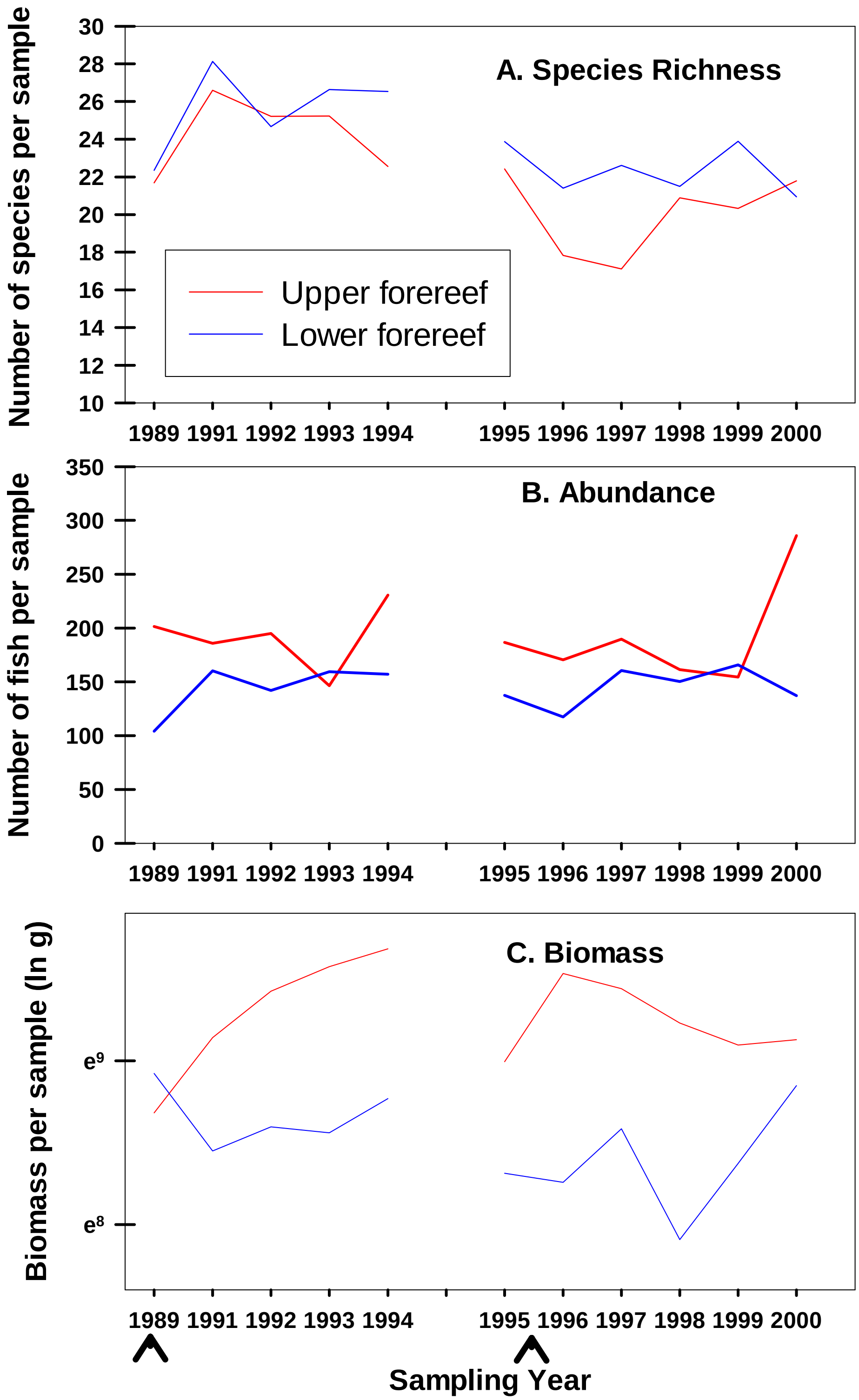

Figure 24. Comparison of trends of assemblage characteristic values (a. species richness, b. abundance, and c. biomass) between the upper and lower forereef zones at the Newfound Bay West reference site, St. John, US Virgin Islands. Major storm events are marked by arrows (1989-Hurricane Hugo; 1995 – Hurricane Marilyn). The change in methods occurred in 1995.

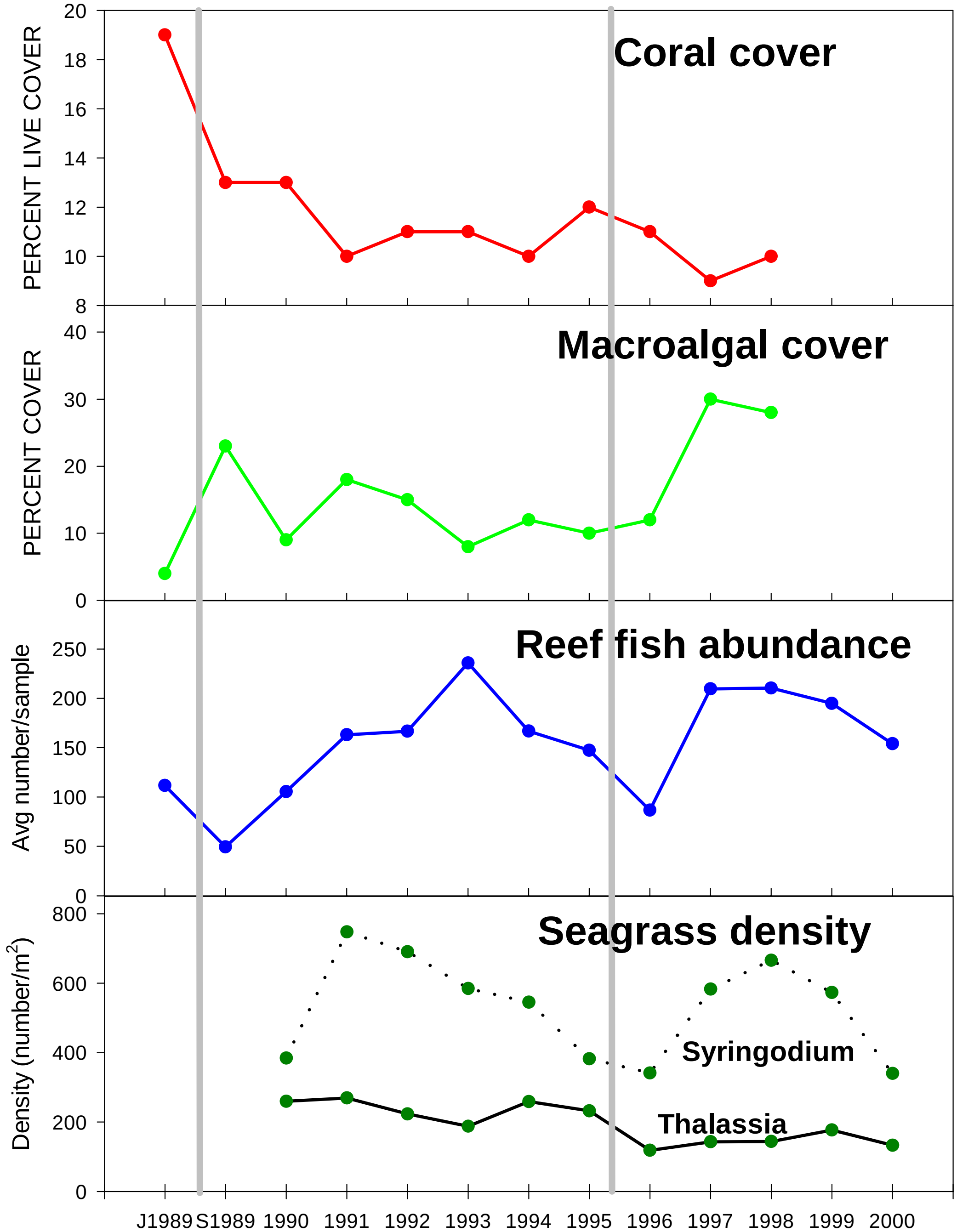

Figure 25. Trends in four assemblages monitored at Yawzi Point reef and Great Lameshur Bay, St. John, US Virgin Islands, 1988-2000. Gray lines represent two largest storm events (Hurricane Hugo, 1989; Hurricane Marilyn, 1995). Coral and macroalgal data provided by C. Rogers; seagrass data provided by L. Muehlstein.