The Frederiksted Reef System of Western St. Croix: A Survey of Inshore Habitats with Observations on Cross-Shelf Distribution Patterns of Fishes

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ABSTRACT

Coral reefs and inshore areas that comprise the Frederiksted Reef System of western St. Croix, U.S. Virgin Islands, are threatened by a number of anthropogenic impacts. This reef system has previously received little study. Without baseline information it is difficult to assess changes in fish and benthic communities that may result from anthropogenic activities. The objective of this study was to gather descriptive information on the cross-shelf distribution of hard bottom habitats and to examine differences in associated fish assemblages. Along inshore-offshore transects, divers identified four distinct habitat zones: intertidal and shallow subtidal (zone I), inshore low relief (zone II), patch or transitional reef (zone III) and reef crest (zone IV). Fishes were surveyed within each of the four zones using a Roving Diver Survey (RDS) methodology to determine relative abundance, sighting frequency, and species composition of assemblages. Results from comparisons among zones indicate that fish assemblage structure changes markedly across the shelf. Average species richness was significantly different among zones and increased with depth and distance from shore. Cumulative species richness generally increased with depth and distance from shore and was highest in zone IV. More species were observed in zone II than zone III. Assemblage composition also differed substantially among zones, and the cross-shelf distribution pattern was highly variable. It is suggested that for some species these cross-shelf distribution patterns are indicative of important fish-habitat associations occurring within the Frederiksted Reef system.

KEY WORDS: Cross-shelf distribution, reef fish, U.S. Virgin Islands

El Sistema Arrecifal de Frederiksted al Occidente de St. Croix: Un Estudio de Habitats Mar Adentro con Observaciones sobre los Patrones de Distribución Cruzada de Peces en la Plataforma

Los arrecifes coralinos y las áreas de mar adentro que comprenden el sistema arrecifal de Frederiksted en el occidente de St. Croix (Islas Vírgenes Americanas), están amenazados por cierto número de factores antropogénicos. Este sistema arrecifal ha sido motivo de pocos estudios en el pasado. Sin información de línea base, se dificulta evaluar cambios en las comunidades bénticas y de peces como consecuencia de actividades antropogénicas. El objetivo de este estudio fue la recopilación de información descriptiva sobre la distribución cruzada de habitats de fondos duros en la plataforma, y examinar la diferencia en ensamblajes de peces asociados. A lo largo de transectos mar adentro-mar afuera, buzos identificaron 4 diferentes habitats (zonas): intermareal y submareal poco profunda (zona I), bajo relieve mar adentro (zona II), parches o arrecife transicional (zona III), y cresta arrecifal (zona IV). Los peces fueron evaluados dentro de cada una de las 4 zonas usando la metodología *Roving Diver Survey* (RDS) para determinar la abundancia relativa, la frecuencia de avistamientos y la composición de especies. Los resultados de la comparación entre zonas indicaron que la estructura en las asociaciones de peces cambia notoriamente a lo largo de la plataforma. El promedio en la riqueza de especies fue significativamente diferente entre zonas, y aumentó con la profundidad y distancia a la costa. La riqueza cumulativa de especies aumentó, en la mayoria de los casos, con la profundidad y la distancia a la costa, y fue mas alta en la zona IV. En la zona II se observaron más especies que en la zona III. La composición de especies varió sustancialmente entre las zonas. El patrón de distribución cruzada en la plataforma fue altamente variado entre las diferentes especies. Se sugiere que para algunas especies los patrones de distribución cruzada son indicadores de habitats importantes de asociaciones de peces dentro del sistema arrecifal de Frederiksted.

PALABRAS CLAVES: Patrones de Distribucion, peces de arrecifes, Islas Vírgenes Americanas

INTRODUCTION

Coral reefs are productive, dynamic, and fragile ecosystems which provide food and numerous other resources of nearly inestimable value to over 100 countries from tropical regions (Birkeland 1997). Globally, concern has grown regarding the health and continued productivity of coral reef ecosystems in the face of anthropogenic impacts (Wilkinson 2000). In the United States Virgin Islands (USVI), coral reefs are threatened by a number of human activities (Jeffrey *et al.* 2005). Among these, the physical destruction of coral reefs by ship groundings and anchoring is a considered a high priority threat (Evans *et al*. 2002). Some USVI reefs that have been obliterated by anchoring show no signs of recovery after more than a decade (Rogers and Garrison 2001), suggesting that habitat destruction from anchoring is long term if not permanent.

An extensive but poorly studied coral reef occurs in the coastal waters of western St. Croix, USVI, along the seaward margin of the insular shelf near the port city of Frederiksted (Toller In preparation, also see Kendall *et al.* 2001). Among the various anthropogenic activities that impact the Frederiksted Reef System (Island Resources Foundation 1993a, Kaczmarsky *et al*. 2005), anchoring may be the most destructive. Portions of the Frederiksted Reef System have been chronically impacted by anchoring of large commercial vessels (Island Resources Foundation 1993b), however the extent of damage is unknown. A study of anchor damage was initiated by the Division of Fish and Wildlife (DFW) and results will be reported elsewhere (Toller In preparation).

A review of previous descriptions of the Frederiksted Reef System showed that existing information was incomplete, inconsistent or erroneous (e.g. Adey *et al.* 1977, Hubbard 1989, Goenaga and Boulon 1992). Although the reef is important to the local fishery (Island Resources Foundation 1977), only limited data were available for fish assemblages associated with it (Toller 2002) or nearby areas (Adams 2001). Therefore, descriptive information was collected to enable an evaluation of anchoring impacts to the Frederiksted Reef System. The specific objectives of this study were:

i) To provide a preliminary survey of the cross-shelf distribution of near shore, hard-bottom habitats, and
ii) To characterize the fish assemblages associated with those habitats.

MATERIALS AND METHODS

Study Site

The study area is located on western St. Croix, USVI, near the town of Frederiksted (Figure 1). This relatively open coastline lies in the lee of the island and is generally protected from prevailing easterly trade winds and ocean swells (Burns 1977). The shallow insular shelf extends ≤ 1 km offshore. Benthic habitat maps (Kendall *et al.* 2001) show a substantial "linear reef" that occupies the offshore margin of the bank/shelf zone and bank/shelf escarpment zone (Figure 1a). The semi-contiguous reef system extends more than 6.5 km from WSW of Butler Bay to an area north of Sandy Point. It is wider north of the Frederiksted pier and considerably narrower in its southern extension towards Sandy Point. The reef falls entirely within the "fetch-limited area" of western St. Croix (Burns 1977).

The northern portion of the Frederiksted Reef System was selected for study because anchor damage was reportedly more extensive there. The study area encompassed near shore waters from the northern end of Fort Frederik Beach to the Underwater Tracking Facility (UTR) located about 2.2 km to the north (Figure 1a). Maximally, the study area incorporated about 2.2 km^2, or about 2,200 hectares.

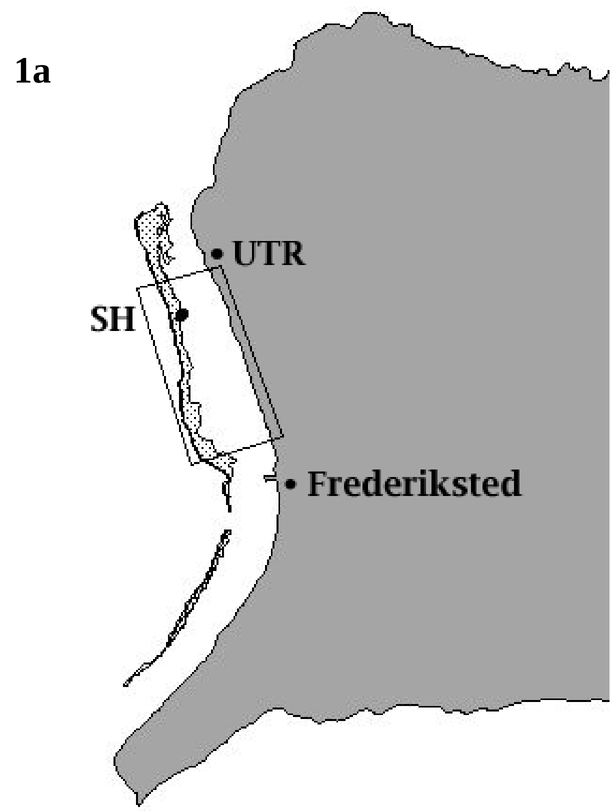
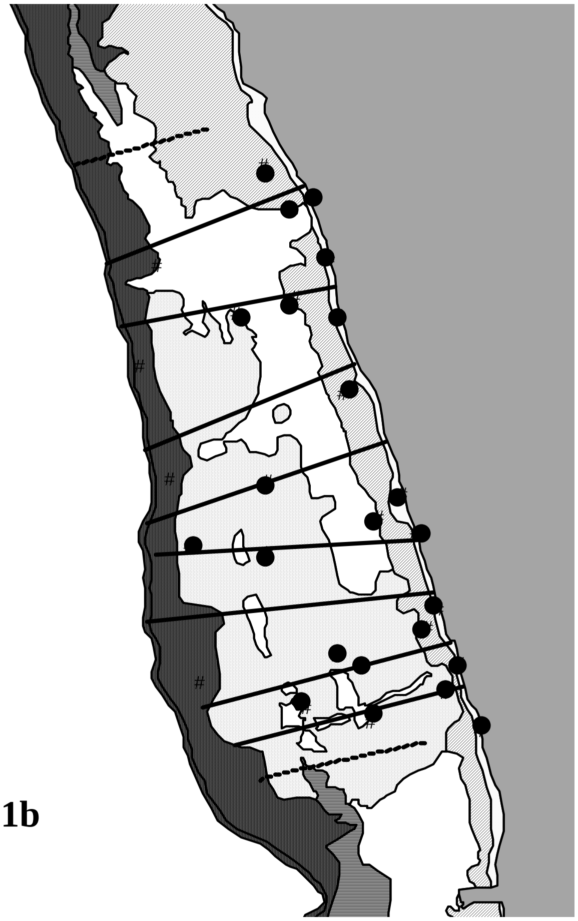


Figure 1a: Map of western St. Croix showing the Frederiksted Reef System and study area (rectangle). The map is re-drawn from Kendall et al. (2001) to show linear reef (stippled polygons). SH = Spat Hole, UTR = Underwater Tracking Range. On right, detail of study area showing location of cross-shelf, towed diver transects (straight lines) and sites of fish surveys (black circles). Polygons show habitat categories derived from aerial photos (Kendall *et al*. 2001).



1b

Figure 1b: Detail of study area showing location of cross-shelf, towed diver transects (straight lines) and sites of fish surveys (black circles). Polygons show habitat categories derived from aerial photos (Kendall *et al.* 2001).

Habitat Surveys

The motivation for this study derived from a need to evaluate impacts of anchoring to the Frederiksted Reef (Toller In preparation). A means of identifying damaged areas was required. The otherwise excellent habitat maps of Kendall *et al.* (2001) were not useful for this purpose nor were alternative survey methods (e.g. side scan sonar) immediately available. Instead, a towed-diver survey method was chosen as the most expedient way to examine shallow habitats across the insular shelf.

Cross-shelf surveys were conducted by towing an observer on snorkel behind a small boat. Divers examined bottom topography and coral coverage while searching for evidence of physical damage caused by anchoring. When necessary, divers released the tow line and free dived to examine habitat features in greater detail. Conspicuous habitat transition points were identified and the information conveyed to a shipboard observer. Onboard, an observer recorded GPS location using a handheld Garmin GPS Map 76 with WAAS correction (observed accuracy of 5 - 15 m during studies). Depth was recorded on a Furuno FMV-605 video depth sounder equipped with a 50/200 kHz dual frequency transducer. Depth recordings (and GPS position) were made at each habitat feature and at regular intervals along transects. Positional information was downloaded directly from the handheld unit to computer using MapSource version 4.08 (Garmin, Corp.) software or imported into ArcView GIS 3.2a (Environmental Systems Research Institute, Inc.) using DNR Garmin 4.3 software developed by Minnesota Department of Natural Resources.

Eight towed-diver transects were run perpendicular to shore along east-northeast to west-southwest lines (~ bearing 255º), with transects roughly evenly spaced from south to north across the study area (Figure 1b). They ran from shore to the 60-foot depth contour, at which point the bottom profile dropped rather sharply and surface based observations became impractical. The shoreward-most segments of transects were too shallow to negotiate by boat and observations here were completed by a snorkeler assisted with kayak. Surveys were conducted between January and July of 2004.

Cross-shelf zonation of habitat structure and benthic communities was readily apparent in transects (Table 1). To understand how fish assemblages changed in concert, fish surveys were performed within discrete habitat zones along a cross-shelf transect, an approach similar to the "physiographic zones" of Williams (1991). In the present study, four habitat zones were discerned: habitat zone I - intertidal/shallow subtidal, habitat zone II - inshore low relief, habitat zone III - transitional/patch reef, and habitat zone IV- reef crest (see Table 1). Fish surveys were not conducted in sand habitats or in the damaged reef habitats of zone IV.

Fish Assemblages

Fish assemblages were characterized using a Roving Diver Survey (RDS) method. Compared to other visual fish census methods, RDS provides more complete information on species richness (Rogers *et al.* 1994). A primary limitation of RDS is that it yields relative estimates of fish abundance rather than quantitative estimates of fish density. A second limitation is that RDS does not include information on the size structure of fish populations.

All fish surveys were conducted between January and March of 2005. Divers swam a haphazard circuit through specified habitat zones recording fish counts on a logarithmic scale as follow: I = 1 individual, II = 2 - 10 individuals, III = 11 - 100 individuals, IIII = 101 - 1,000 individuals, or IIIII = > 1,000 individuals. Each survey was 1.0 hour in duration. Divers also recorded general habitat features (topographic relief, substrate composition, predominant coral and algal species, and other related observations). Surveys were conducted on snorkel (zones I and II) or on Scuba (zones III and IV). Individual replicates generally fell along the cross-shelf transects described above. From these data average abundance index (AI) and percent sighting frequency (SF) were computed. Eight RDS replicates were completed within each habitat zone for a total of 32 surveys. Surveys were conducted at 27 sites (Figure 1), with duplicate surveys performed at 5 of these.

Fish were identified to species using standard field references (Randall 1968, Lieske and Myers 2002). In instances where species-level identification was uncertain, photos were taken with digital camera (Canon PowerShot A70). In practice, most taxa were adequately diagnosed in the field. The following fish were exceptions. Very small scarids (juvenile *Sparisoma* sp.) were commonly observed as mixed-species groups hiding in shallow macroalgal beds. These groups were thought to be comprised primarily of *Sparisoma radians*, *S. chryospterum*, and *S. rubripinne* although their similar appearance, cryptic behavior and small size precluded reliable identifications. Similarly, the large and often mixed-species schools of recently recruited grunts (juvenile *Haemulon* sp.) which occurred in zones I and II were not identified to species. Jawfish species (*Opistognathus macrognathus*, *O. maxillosus*, and *O. whitehurstii*) were lumped together exclusive of *O. aurifrons*. Two species of chubs (*Kyphosus sectatrix* and *K. incisor*) reportedly occur in the area but were not distinguished in the field, nor were two similar appearing gobies (*Coryphopterus personatus* and *C. hyalinus*). Some inter-observer discrepancies arose in distinguishing adult *Stegastes diencaeus* from *S. dorsopunicans* although juveniles were readily separable.

During fish surveys, it was apparent that juvenile and adult stages of some species were unequally distributed among habitat zones. When recruits or juvenile stages were judged to be more abundant than adults within a given survey, abundance estimates were annotated with an asterisk.

Table 1. Habitat zones identified in this study.

	Habitat Zone		
	I **intertidal/shallow subtidal**	**II** **inshore low relief**	**III** **transitional/patch reef**
cross-shelf location	shoreline	inshore	midshelf
approx. depth range (m)	0 - 1	1 - 7	6 - 11
predominant substrate	limestone bedrock, rubble, beachrock or sand	limestone pavements, rubble, sand	limestone ridges, wide sand/rubble channels
substrate configuration oriented	limestone spurs at shoreline, pavement, sand/cobble either continuous reef or beaches	low relief pavements with seams or holes and rubble/sand areas	moderate relief patches or ridges with grooves offshore
approx. coral cover	low (< 5%)	low (< 5%)	intermediate (5 to 15%)
coral community	low coral cover, shallow water forms	low coral cover, sediment tolerant forms,	abundant head corals, some branching and
characteristic hard corals	*Diploria clivosa* *Siderastrea radians* *A. palmata* (occasional)	*Diploria strigosa* *Dichocoenia stokesi* *Siderastrea siderea* *Solenastrea bournoni*	*M. faveolata* *M. cavernosa* *A. cervicornis* (occasional)
characteristic algae	*Laurencia papillosa* *Sargassum polyceratium* *Padina* sp. encrusting red corallines	*Dictyota* sp. *Bryothamnion triquetum* dense algal turfs	*Lobophora variegata* *Dictyota* sp. algal turfs
other characteristic	vermetid worms	*Psudopterogorgia* sp.	*Xestospongia muta*

Data Analysis

To examine differences in species richness among habitats, replicated observations (total number of species observed per survey) were tested with one-way ANOVA using Statistica (Statsoft, Inc., Tulsa, OK). A community coefficient was used to compare fish assemblages among habitat zones. Jaccard's coefficient (JC) - a similarity index commonly used by terrestrial ecologists to compare communities (Barbour et al. 1987) - was calculated using species presence/absence data according to the following formula:

$$JC = C / (A + B - C)$$

Where:

A = total number of species in habitat zone A,
B = total number of species in habitat zone B, and
C = total number of species in both habitat zones A and B.

JC was calculated utilizing either all observations or after excluding those species which were only observed in a single survey within a habitat zone.

Data from towed-diver surveys were converted into GIS files and examined further using ArcView GIS 3.2a (Environmental Systems Research Institute, Inc.). Transect information was first assembled using depth data and plotted GPS positions. Depth profiles were then prepared by plotting segment distance against depth for each point.

To determine the width of habitat zones, the GPS data (above) were filtered to retain only "transition points" between adjacent zones along each transect. In addition to the aforementioned habitat zones (i.e. zones I –IV), transition points included sand and damaged reef categories. Thus, a transition was considered to have occurred whenever the observer moved between any of the six categories (e.g. from sand to zone III, from zone IV to damaged reef, etc). Cumulative width of each habitat zone was calculated along each cross-shelf transect by measuring segment distance between pairs of transition points.

RESULTS

Habitat Surveys

The average cross-shelf width of the insular platform (to the 60 foot depth contour) was 851 m within the study area (Table 2). Sand, or soft bottom substrate, was the largest habitat zone observed (33.8%) and was highly variable among transects (range 124 - 444 m). Reef crest (habitat zone IV) was the largest hard-bottom habitat zone (27.1%). Almost half of the reef crest zone was observed to be damaged, with large areas reduced to rubble (Toller In preparation). Damage was particularly evident in southern transects. Zone II also accounted for a substantial portion of shelf habitat (21.9%). Habitat zone III formed 15.4% of habitat. Intertidal/shallow subtidal (zone I) was the narrowest zone and contributed least to observed habitats along transects (1.6%).

Table 2. Size of habitat zones based upon linear distances recorded during cross-shelf transects.

	Cumulative Segment Length (m)			
Habitat Zone	**Average**	**St.Dev.**	**Range**	**% of Total**
Zone I	13.5	6.4	4.8 - 24.7	1.6%
Zone II	180.2	78.3	78.3 - 307.9	21.2%
Zone III	137.9	105.2	0 - 282.6	16.2%
Zone IV*	231.4	68.7	142.5 - 367.5	27.2%
Unimpacted	120.1	96.6	0 - 271.2	14.1%
Damaged	111.3	116.2	0 - 256.1	13.1%
Sand	288.3	124.5	123.6 - 444.2	33.9%
Transect Total	851.4	-	-	100%

* Unimpacted and damaged habitats within habitat zone IV were quantified separately.

Cross-shelf depth profiles (Figure 2) were somewhat variable among transects. A generalized profile is as follows. An abrupt limestone step (0.5 to 1 m) occurred at the shoreline forming a rocky intertidal habitat. Beaches were interspersed among rocky areas and also abruptly stepped to ~ 0.5 m depth with sand usually being replaced by beach rock and rubble subtidally. The shallow subtidal area extended only a short distance offshore (< 25 m). Seaward of this, habitat zone II (usually) or sand (rarely) extended 150 - 200 m offshore as a moderate, uniform slope. Along most transects, the substrate was a smooth carbonate pavement. Farther offshore, the slope was more gradual and usually coincident with wide areas of sand. Within ~ 300 m of the shelf edge (habitat zones III and IV), depth profiles became quite irregular and variable among transects. At ~ 800 m offshore a rather abrupt drop off occurred at 10 - 12 m depths.

Fish Assemblages

In total, 176 fish taxa were observed representing 50 fish families (Table 3). When analyzed collectively (data from all zones combined), six species were highly abundant with an average AI ≥ 3.0. They were *T. bifasciatum* (SF=100%), *Acanthurus bahianus* (SF=100%), *Stegastes partitus* (SF=75.0%), *Haemulon flavolineatum* (SF=100%), *Halichoeres bivittatus* (SF=78.1%) and *A. coeruleus* (SF 100%). Forty species were moderately abundant (average AI between 1.0 and 3.0). The majority of species (130) were less abundant (average AI < 1.0). Twenty-eight species were observed in only one replicate survey and 17 of these were represented by observation of a single individual.

There were clear differences in the diversity of fish assemblages among habitat zones. Comparisons among zones showed that average species richness (number of species observed per survey) increased from inshore to offshore (Figure 3). Average richness was significantly different among habitats (one-way ANOVA, $F_{31} = 17.47$, $p < 0.001$). Rare species (species observed in a single survey within a zone) were excluded and the analysis repeated. A similar result was obtained after their removal (one-way ANOVA, $F_{31} = 16.33$, $p < 0.001$, Figure 3).

Cumulative number of species was least in zone I (86 species) and greatest in zone IV (110 species; Figure 3). Examination of species-area curves indicated that > 90% of the fish assemblages had been sampled (not shown) and confirmed a trend towards increased fish diversity with distance from shore. Zone II was somewhat exceptional in that cumulative species richness was high (106 species) and the species-area curve suggested that less of the fish assemblage had been sampled. When data for zone II were re-evaluated after excluding rare species, this pattern was not seen.

Similarity of fish assemblages from different habitat zones was calculated using Jaccard's Community coefficient (JC). Fish assemblages from zone III and IV were most similar to one another (JC = 0.68). The fish assemblage of zone I was least similar to that of zone III and IV (JC = 0.30, 0.31) and more similar to the assemblage of zone II (JC = 0.45). Zone II was slightly more similar to zone III (JC = 0.53) than it was to zone I (JC = 0.45). When rare species were excluded from calculations, JC values were lower but the rank order of similarity observed between habitat zones was qualitatively unchanged (not shown).

Further examination of cross-shelf distributions for individual species suggested that distribution patterns are distinct and non-random. Four types of cross-shelf distribution pattern were distinguished: broad, wide, restricted, and narrow (Table 4). Although approximately equal numbers of species were classified within each distribution category, the species were not evenly distributed among habitat zones. For example, species with narrow distributions were generally found in zone I or zone IV but not zones II and III. Species with wide distributions were generally found in zones II, III and IV but were absent from zone I. Those fish with restricted distributions were most commonly found in zones III and IV.

Cross-shelf distribution patterns were often quite variable among species (Table 3). Within families, closely related species frequently showed different distribution patterns. Examples are shown for the family Scaridae (Figure 4), and for select serranids, lutjanids, and haemulids (Figure 5).

For 14 species, juvenile fish stages were more abundant than adults in RDS surveys. Juveniles were unequally distributed among habitat zones and predominated in observations of 13 species in zone I, 10 species in zone II, 2 species in zone III, and 1 species in zone IV. Fishes were *Acanthurus bahianus* (zone I and II) *A. chirurgus* (zone I and II), *A. coeruleus* (zone I and II), *Chaetodon striatus* (zone I and II), *Haemulon carbonarium* (zone I and II), *Lutjanus apodus* (zone I), *L. mahogoni* (zone I and II), *Ocyurus chrysurus* (zone I and II), *Mulloidichthys martinicus* (zone I), *Psuedupeneus maculatus* (zone I and II), *Pomacanthus paru* (all zones), *Holacanthus ciliaris* (zone II and III), *Abudefduf saxatilis* (zone I), and *Sparisoma rubripinne* (zone I). In addition, juvenile *Sparisoma* sp. and juvenile *Haemulon* sp. were recorded only from zones I and II.

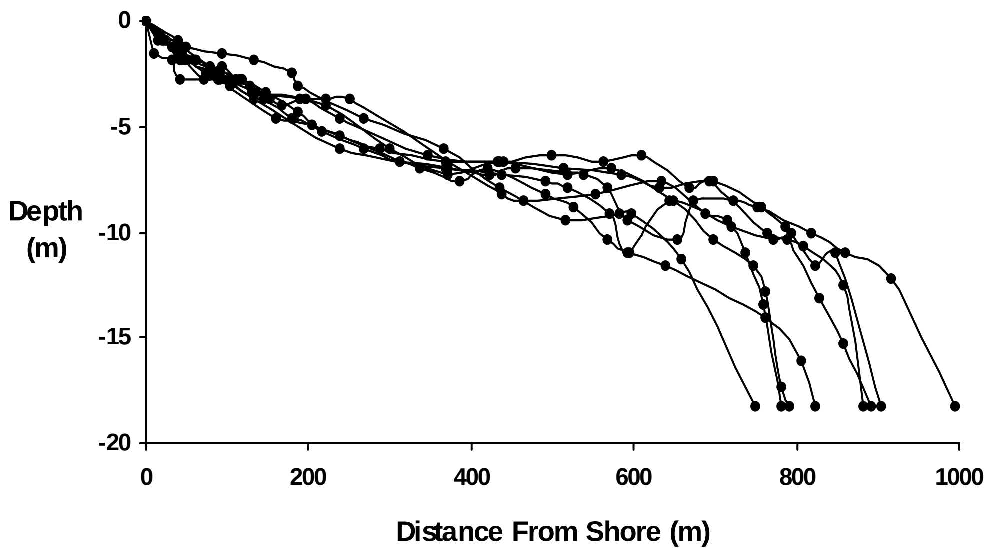


Figure 2. Cross-shelf depth profiles. (Scale of y-axis is expanded 20X).

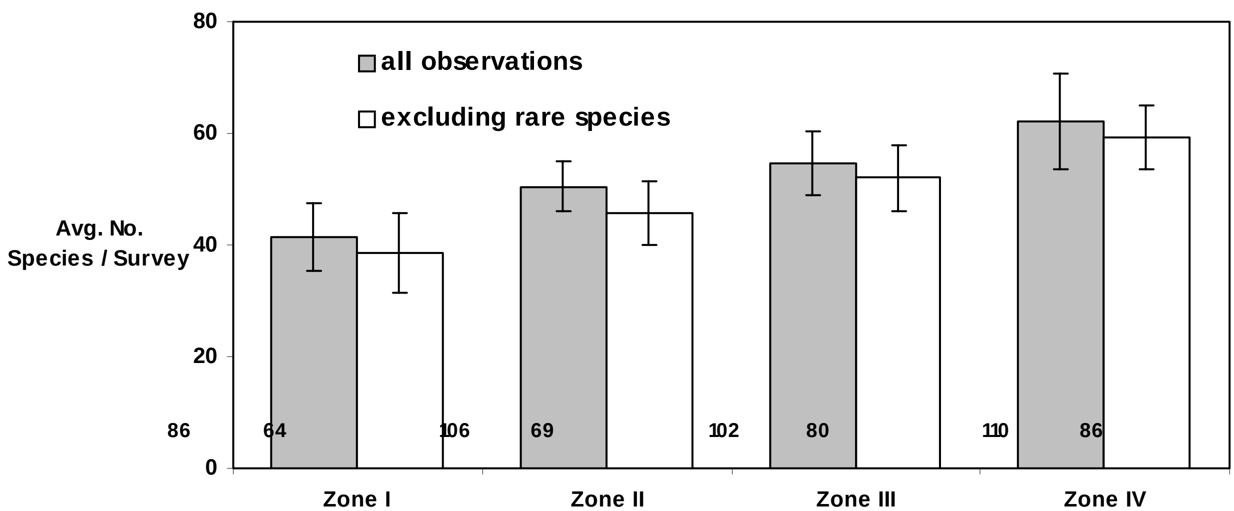


Figure 3. Average fish richness in four habitat zones. Based upon observations for all species (gray columns) or after excluding rare species (white columns). Cumulative number of species is shown. Error bars = standard deviation.

Table 3. Frequency and abundance of fish observed in four habitat zones.

		Zone I		Zone II		Zone III		Zone IV	
Family	**Species**	**%SF**	**AI**	**%SF**	**AI**	**%SF**	**AI**	**%SF**	**AI**
Ginglymostomatidae	*Ginglymostoma cirratum*	-	-	-	-	12.5	0.13	-	-
Dasyatidae	*Dasyatis americana*	-	-	12.5	0.13	12.5	0.13	25.0	0.38
Muraenidae	*Echidna catenata*	37.5	0.63	12.5	0.13	-	-	-	-
	Gymnothorax miliaris	-	-	25.0	0.38	-	-	-	-
	Gymnothorax moringa	12.5	0.13	37.5	0.38	12.5	0.13	12.5	0.13
Ophichthyidae	*Myrichthys breviceps*	-	-	62.5	0.63	-	-	-	-
Congridae	*Heteroconger longissimus*	-	-	12.5	0.38	25.0	0.75	37.5	1.50
Belonidae	*Ablennes hians*	12.5	0.25	12.5	0.25	-	-	-	-
	Platybelone argalus	25.0	0.38	-	-	-	-	-	-
Hemirhamphidae	*Hemiramphus brasiliensis*	-	-	12.5	0.38	12.5	0.38	-	-
Clupeidae	*Harengula humeralis*	37.5	1.88	12.5	0.63	-	-	-	-
	Jenkinsia lamprotaenia	87.5	4.38	12.5	0.50	12.5	0.63	-	-
Atherinidae	*Atherinomorus stipes*	37.5	1.75	14.3	0.50	-	-	-	-
Synodontidae	*Synodus intermedius*	25.0	0.38	37.5	0.50	37.5	0.50	75.0	1.13
Holocentridae	*Holocentrus adcensionis*	12.5	0.13	100	2.38	50.0	1.13	25.0	0.25
	Holocentrus rufus	25.0	0.25	12.5	0.25	75.0	1.50	87.5	2.13
	Myripristis jacobus	-	-	25.0	0.38	37.5	0.75	100	2.75
	Neoniphon marianus	-	-	-	-	37.5	0.75	75.0	1.63
	Plectrypops retrospinis	-	-	-	-	-	-	12.5	0.13
	Sargocentron coruscum	62.5	0.75	50.0	0.75	-	-	-	-
	Sargocentron vexillarium	75.0	1.50	12.5	0.13	-	-	12.5	0.25
Fistulariidae	*Fistularia tabacaria*	-	-	25.0	0.25	-	-	-	-
Aulostomidae	*Aulostomus maculatus*	25.0	0.25	25.0	0.25	25.0	0.50	87.5	1.75
Scorpaenidae	*Scorpaena plumieri*	62.5	1.00	75.0	1.50	25.0	0.25	12.5	0.13
	Scorpaenodes caribbaeus	-	-	12.5	0.13	-	-	-	-
Serranidae	*Cephalopholis cruentatus*	-	-	12.5	0.13	87.5	1.75	100	3.13
	Cephalopholis fulvus	-	-	62.5	1.50	100	2.88	100	2.25
	Epinephelus adcensionis	-	-	-	-	-	-	37.5	0.38
	Epinephelus guttatus	-	-	25.0	0.25	50.0	0.63	12.5	0.25
	Hypoplectrus chlorurus	-	-	-	-	-	-	62.5	1.13
	Hypoplectrus guttavarius	-	-	-	-	-	-	12.5	0.13
	Hypoplectrus indigo	-	-	-	-	-	-	12.5	0.13
	Hypoplectrus nigricans	-	-	-	-	87.5	1.13	50.0	0.75
	Hypoplectrus puella	-	-	-	-	-	-	100	2.13
	Hypoplectrus unicolor	-	-	-	-	25.0	0.25	62.5	0.75
	Liopropoma rubre	-	-	-	-	-	-	25.0	0.25
	Rypticus saponaceus	12.5	0.25	62.5	0.88	12.5	0.13	-	-
	Serranus baldwini	-	-	37.5	0.63	25.0	0.25	-	-
	Serranus tabacarius	-	-	12.5	0.13	25.0	0.38	12.5	0.13
	Serranus tigrinus	-	-	12.5	0.13	87.5	2.50	87.5	2.00
Grammatidae	*Gramma loreto*	-	-	-	-	50.0	1.00	75.0	2.00
Apogonidae	*Apogon binotatus*	-	-	-	-	50.0	1.38	-	-
	Apogon maculatus	-	-	87.5	2.00	12.5	0.25	-	-
Cirrhitidae	*Amblycirrhitus pinos*	-	-	-	-	37.5	0.38	12.5	0.13
Priacanthidae	*Heteropriacanthus cruentatus*	-	-	-	-	-	-	62.5	1.00
	Priacanthus arenatus	-	-	-	-	-	-	25.0	0.25
Malacanthidae	*Malacanthus plumieri*	-	-	75.0	1.50	87.5	2.00	62.5	1.00
Gerreidae	*Diapterus auratus*	12.5	0.38	-	-	-	-	-	-
	Eucinostomus argenteus	12.5	0.25	-	-	-	-	-	-
	Eucinostomus leyfroi	62.5	1.75	12.5	0.25	-	-	-	-
	Gerres cinereus	50.0	0.63	37.5	0.88	-	-	25.0	0.25
Carangidae	*Caranx crysos*	12.5	0.25	25.0	0.25	-	-	-	-
	Caranx latus	62.5	1.25	12.5	0.25	-	-	-	-
	Caranx ruber	37.5	0.88	75.0	1.63	87.5	2.00	100	2.25
	Trachinotus falcatus	50.0	0.88	-	-	-	-	-	-

Table 3 continued.

Family	Species	Zone I		Zone II		Zone III		Zone IV	
		%SF	AI	%SF	AI	%SF	AI	%SF	AI
Lutjanidae	*Lutjanus analis*	-	-	-	-	12.5	0.13	-	-
	Lutjanus apodus	87.5	1.38	-	-	12.5	0.25	100	2.00
	Lutjanus griseus	12.5	0.13	-	-	12.5	0.13	12.5	0.25
	Lutjanus mahogoni	100	3.00	87.5	2.50	87.5	1.63	87.5	2.13
	Lutjanus synagris	-	-	12.5	0.25	-	-	-	-
	Ocyurus chrysurus	37.5	0.50	75.0	1.00	25.0	0.38	50.0	0.75
Haemulidae	*Anisotremus surinamensis*	12.5	0.13	-	-	-	-	-	-
	Anisotremus virginicus	-	-	-	-	-	-	12.5	0.13
	Haemulon aurolineatum	12.5	0.13	-	-	-	-	-	-
	Haemulon carbonarium	87.5	1.75	87.5	1.88	75.0	1.38	87.5	1.50
	Haemulon chrysargyreum	87.5	2.13	-	-	-	-	62.5	1.88
	Haemulon flavolineatum	100	3.63	100	3.50	100	3.63	100	3.00
	Haemulon macrostomus	12.5	0.13	-	-	-	-	12.5	0.13
	Haemulon melanurum	-	-	12.5	0.13	-	-	-	-
	Haemulon parra	12.5	0.25	-	-	-	-	-	-
	Haemulon plumieri	-	-	37.5	0.63	50.0	0.63	87.5	1.38
	Haemulon sciurus	12.5	0.13	62.5	1.13	62.5	1.25	75.0	1.13
	Haemulon sp. (unid. juv.)	40.0	0.63	100	2.00	-	-	-	-
Inermiidae	*Inermia vittata*	-	-	-	-	-	-	37.5	1.38
Sparidae	*Calamus calamus*	-	-	12.5	0.13	-	-	-	-
Sciaenidae	*Pareques acuminatus*	25.0	0.38	62.5	0.88	12.5	0.13	-	-
	Equetus punctatus	-	-	-	-	25.0	0.25	50.0	0.75
	Odontoscion dentex	-	-	-	-	-	-	12.5	0.13
	Umbrina coroides	25.0	0.50	-	-	-	-	-	-
Mullidae	*Mulloidichthys martinicus*	87.5	2.63	100	2.63	75.0	1.75	100	3.13
	Psuedupeneus maculatus	87.5	2.13	100	2.50	87.5	1.63	75.0	1.13
Pempheridae	*Pempheris schomburgki*	87.5	1.75	-	-	-	-	-	-
Kyphosidae	*Kyphosus sectatrix/incisor*	25.0	0.50	-	-	-	-	-	-
Chaetodontidae	*Chaetodon aculeatus*	-	-	-	-	-	-	87.5	1.25
	Chaetodon capistratus	-	-	75.0	1.50	100	2.75	100	2.75
	Chaetodon ocellatus	-	-	37.5	0.38	25.0	0.38	-	-
	Chaetodon sedentarius	-	-	-	-	-	-	12.5	0.13
	Chaetodon striatus	50.0	0.75	75.0	1.63	100	1.88	75.0	1.63
Pomacanthidae	*Holacanthus ciliaris*	-	-	50.0	0.50	37.5	0.50	12.5	0.13
	Holacanthus tricolor	-	-	-	-	75.0	1.38	62.5	1.13
	Pomacanthus paru	25.0	0.25	100	2.00	50.0	0.88	37.5	0.50
Pomacentridae	*Abudefduf saxatilis*	100	3.13	100	2.63	37.5	1.13	75.0	2.25
	Abudefduf taurus	100	2.75	-	-	-	-	-	-
	Chromis cyanea	-	-	-	-	87.5	3.50	100	4.63
	Chromis multilineata	-	-	50.0	1.13	100	3.50	100	4.38
	Microspathodon chrysurus	37.5	0.88	-	-	12.5	0.13	37.5	0.63
	Stegastes dorsopunicans	100	3.50	100	3.00	37.5	0.63	50.0	1.38
	Stegastes diencaeus	-	-	25.0	0.50	100	2.88	87.5	2.50
	Stegastes leucostictus	75.0	1.63	100	2.88	100	1.88	87.5	2.13
	Stegastes partitus	-	-	100	4.50	100	4.88	100	4.75
	Stegastes planifrons	-	-	12.5	0.25	87.5	2.25	100	4.00
	Stegastes variabilis	-	-	-	-	12.5	0.13	25.0	0.38
Labridae	*Bodianus rufus*	-	-	-	-	87.5	1.63	100	2.38
	Clepticus parrae	-	-	-	-	37.5	1.25	100	4.63
	Halichoeres bivittatus	100	4.25	100	4.88	100	4.00	12.5	0.25
	Halichoeres garnoti	-	-	12.5	0.13	87.5	3.50	100	3.63
	Halichoeres maculipinna	87.5	2.63	87.5	2.38	75.0	2.00	37.5	0.75
	Halichoeres pictus	-	-	-	-	62.5	1.25	37.5	0.75
	Halichoeres poeyi	100	2.25	87.5	2.00	-	-	-	-
	Halichoeres radiatus	87.5	2.13	87.5	1.88	37.5	0.63	12.5	0.13
	Thalassoma bifasciatum	100	4.25	100	4.63	100	4.63	100	4.63
	Xyrichtys martinicus	-	-	12.5	0.13	-	-	-	-
	Xyrichtys splendens	-	-	87.5	1.75	-	-	-	-
Scaridae	*Cryptotomus roseus*	-	-	-	-	12.5	0.25	-	-
	Scarus iserti	12.5	0.25	-	-	100	3.13	100	3.25

Table 3 continued.

		Zone I		Zone II		Zone III		Zone IV	
Family	**Species**	**%SF**	**AI**	**%SF**	**AI**	**%SF**	**AI**	**%SF**	**AI**
Scaridae	*Scarus taeniopterus*	-	-	-	-	100	3.50	100	3.75
	Scarus vetula	-	-	-	-	100	2.13	100	2.88
	Sparisoma atomarium	-	-	-	-	37.5	0.75	37.5	1.00
	Sparisoma aurofrenatum	-	-	87.5	2.13	100	3.75	100	3.50
	Sparisoma chrysopterum	-	-	100	2.75	62.5	1.25	37.5	0.50
	Sparisoma radians	37.5	0.88	50.0	1.38	-	-	-	-
	Sparisoma rubripinne	100	3.50	100	3.63	62.5	1.25	62.5	0.88
	Sparisoma viride	-	-	25.0	0.38	100	2.88	100	3.13
	Sparisoma sp. (unid. juv.)	37.5	0.88	100	0.75	-	-	-	-
Opistognathidae	*Opistognathus aurifrons*	-	-	-	-	62.5	1.25	-	-
	Opistognathus sp.	-	-	62.5	0.88	-	-	-	-
Mugilidae	*Mugil curema*	12.5	0.38	-	-	-	-	-	-
Sphyraenidae	*Sphyraena barracuda*	12.5	0.13	12.5	0.13	12.5	0.13	12.5	0.13
	Sphyraena picudilla	-	-	-	-	-	-	12.5	0.25
Scombridae	*Scomberomorus regalis*	-	-	12.5	0.13	25.0	0.38	50.0	0.88
Labrisomidae	*Labrisomus gobio*	12.5	0.25	-	-	-	-	-	-
	Labrisomus nuchipinnis	87.5	1.50	-	-	-	-	-	-
	Malacoctenus aurolineatus	87.5	1.88	12.5	0.13	-	-	-	-
	Malacoctenus gilli	50.0	0.88	12.5	0.25	-	-	-	-
	Malacoctenus macropus	-	-	37.5	0.50	12.5	0.13	-	-
	Malacoctenus triangulatus	37.5	0.38	100	2.38	12.5	0.38	-	-
Blenniidae	*Entomacrodus nigricans*	62.5	1.13	-	-	-	-	-	-
	Ophioblennius atlanticus	87.5	2.63	62.5	1.50	50.0	1.13	-	-
	Scartella cristata	25.0	0.50	-	-	-	-	-	-
Chaenopsidae	*Acanthemblemaria spinosa*	-	-	50.0	1.00	62.5	1.25	25.0	0.50
	Emblemaria pandonis	-	-	12.5	0.25	-	-	-	-
Gobiidae	*Bathygobius soprator*	50.0	1.13	-	-	-	-		-
	Coryphopterus glaucofrenatum	-	-	87.5	2.38	100	3.50	87.5	2.50
	Coryphopterus lipernes	-	-	-	-	12.5	0.13	62.5	1.50
	C. personatus/hyalinus	-	-	-	-	75.0	2.25	87.5	4.25
	Elacatinus genie	-	-	-	-	-	-	12.5	0.25
	Elacatinus evelynae	-	- -	-	75.0	1.63	62.5	1.38	
	Ginsburgellus novemlineatus	50.0	0.88	-	-	-	-	-	-
	Gnatholepis thompsoni		-	87.5	2.88	87.5	2.75	62.5	1.63
	Gobiosoma chancei		-	-	-	12.5	0.25	12.5	0.13
	Gobiosoma multifasciatum	50.0	0.88	-	-	-	-	-	-
	Gobiosoma prochilos	-	-	-	-	12.5	0.13	-	-
Acanthuridae	*Acanthurus bahianus*	100	3.88	100	4.38	100	4.00	100	3.25
	Acanthurus chirurgus	50.0	1.00	87.5	2.13	37.5	0.88	50.0	1.25
	Acanthurus coeruleus	100	2.38	100	2.88	100	3.50	100	3.25
Bothidae	*Bothus lunatus*	50.0	0.50	62.5	0.88	-	-	12.5	0.13
	Bothus ocellatus	-	-	12.5	0.13	-	-	-	-
Balistidae	*Balistes vetula*	-	-	12.5	0.13	25.0	0.38	12.5	0.13
	Melichthys niger	-	-	-	-	-	-	87.5	2.00
Monocanthidae	*Aluterus scripta*	-	-	-	-	-	-	25.0	0.25
	Cantherhines macrocerus	-	-	37.5	0.38	37.5	0.38	62.5	0.88
	Cantherhines pullus	62.5	1.25	75.0	1.25	62.5	0.75	37.5	0.38
	Monacanthus tuckeri	25.0	0.25	25.0	0.25	-	-	-	-
Ostraciidae	*Acanthostracion polygonia*	12.5	0.13	12.5	0.25	12.5	0.13	75.0	1.00
	Lactophrys bicaudalis	25.0	0.25	12.5	0.13	62.5	0.63	50.0	0.63
	Lactophrys trigonus	-	-	12.5	0.13	-	-	-	-
	Lactophrys triqueter	12.5	0.13	50.0	0.88	75.0	1.13	75.0	1.13
Tetraodontidae	*Canthigaster rostrata*	12.5	0.25	50.0	1.00	87.5	1.88	87.5	2.25
	Sphoeroides spengleri	25.0	0.25	12.5	0.13	37.5	0.63	12.5	0.13
	Sphoeroides testudineus	12.5	0.13	12.5	0.13	-	-	-	-
Diodontidae	*Chilomycterus antillarum*	-	-	-	-	25.0	0.25	12.5	0.13
	Diodon holocanthus	12.5	0.13	12.5	0.13	25.0	0.25	25.0	0.25
	Diodon hystrix	37.5	0.50	25.0	0.25	-	-	37.5	0.38

%SF = Percent Sighting Frequency, AI = average Abundance Index

Table 4. Cross-shelf distribution patterns of fish species among habitat zones.

Type of Distribution	Habitat Zones	All Species No.	All Species %	Species with AI* > 1.0 No.	Species with AI* > 1.0 %	Examples
Broad	all zones	35	19.9%	30	31.9%	*T. bifasciatum*, *A. bahianus*
Wide (three zones)	not zone I	27	15.3%	19	20.2%	*C. multilineata*, *H.garnoti*
	not zone IV	5	2.8%	3	3.2%	*J. lamprotaenia*, *O. atlanticus*
	not zone II	4	2.3%	2	2.1%	*L. apodus*, *M. chrysurus*
	not zone III	4	2.3%	1	1.1%	*S. vexillarium*
	Subtotal	40	22.7%	25	26.6%	
Restricted (two zones)	zones III & IV	20	11.4%	14	14.9%	*S. vetula*, *C. cyanea*, *B. rufus*
	zones I & II	16	9.1%	8	8.5%	*H. poeyi*, *S. radians*
	zones II & III	5	2.8%	1	1.1%	*A. maculatus*
	zones I & IV	2	1.1%	1	1.1%	*H. chrysargyreum*
	zones I & III	0	-	0	-	-
	zones II & IV	0	-	0	-	-
	Subtotal	43	24.4%	24	25.5%	
Narrow (one zone)	zone I	20	11.4%	6	6.4%	*A. taurus*, *P. schomburgki*
	zone IV	18	10.2%	6	6.4%	*C. aculeatus*, *I. vittata*, *H. chlorurus*
	zone II	14	8.0%	1	1.1%	*X. splendens*
	zone III	6	3.4%	2	2.1%	*A. binotatus*, *O. aurifrons*
	Subtotal	58	33.0%	15	16.0%	
	Total	176	100.0%	94	100.0%	

* AI = Abundance Index.

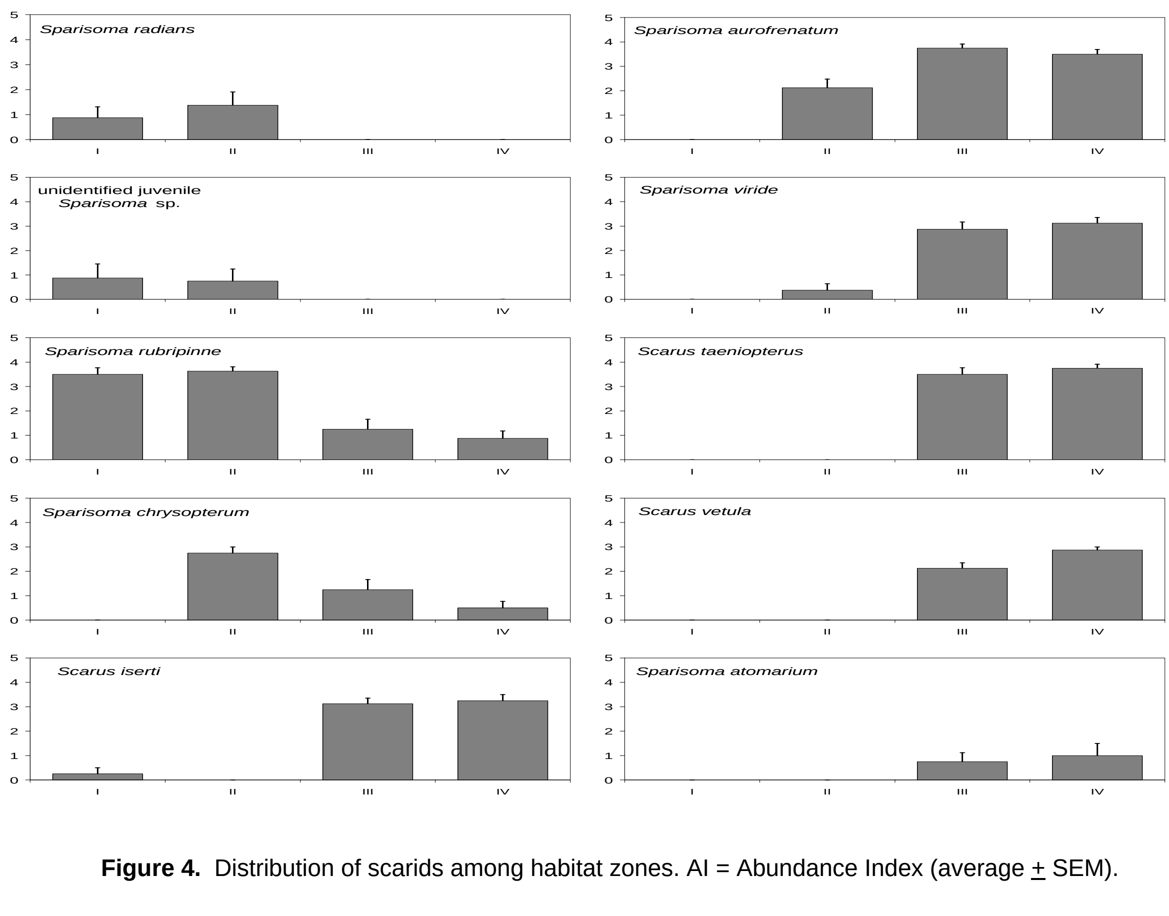


Figure 4. Distribution of scarids among habitat zones. AI = Abundance Index (average ± SEM).

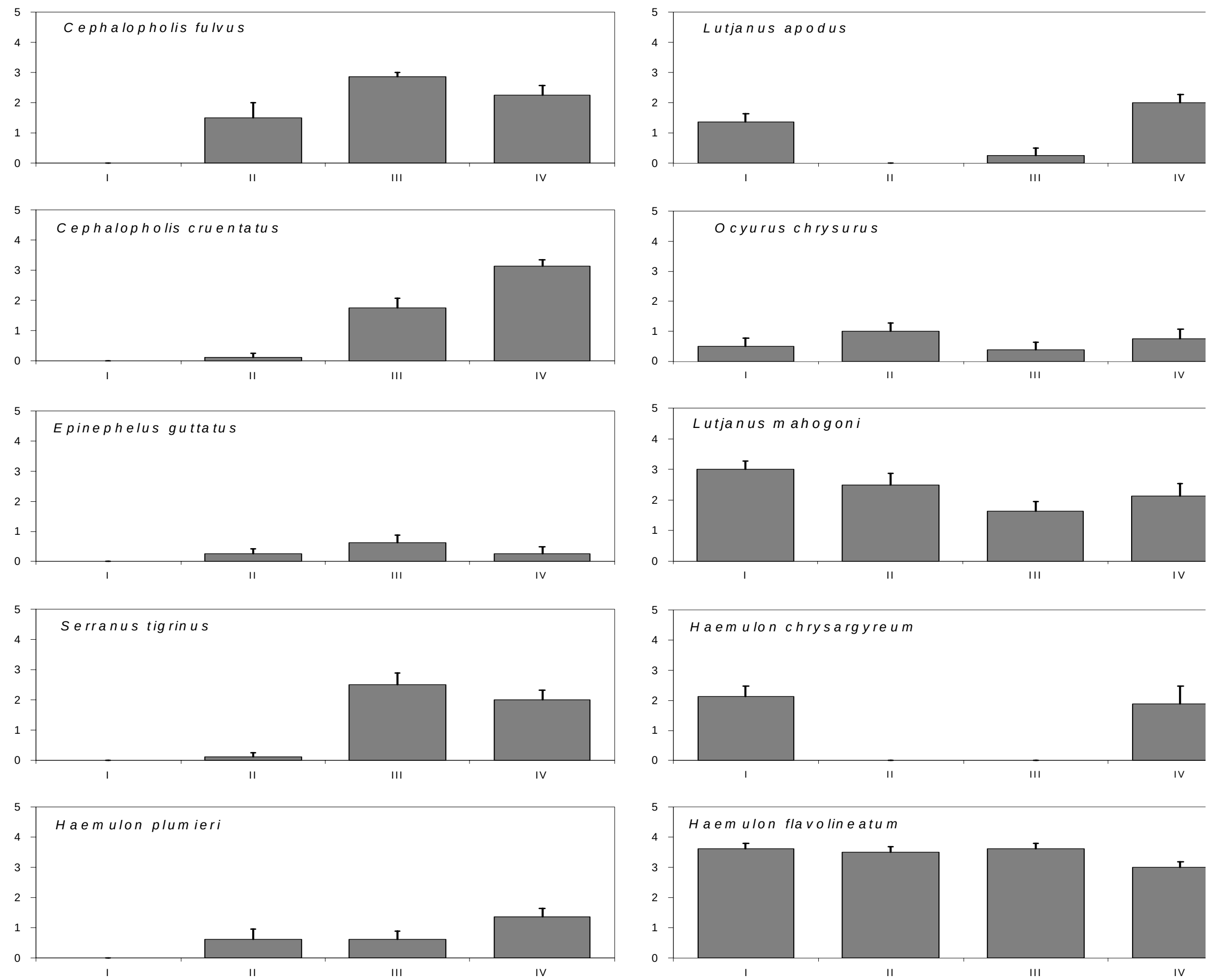


Figure 5. Distribution of select serranids, lutjanids, and haemulids among habitat zones. AI = Abundance Index

DISCUSSION

Previous surveys of western St. Croix have suggested that fish assemblages here are diverse, although these studies were either spatially restricted (a single site at Sprat Hole; Nemeth and Herzlieb 2002, Toller 2002) or conducted at sites adjacent to the Frederiksted Reef (Adams 2001). Results from the present study indicate that this reef system supports a substantially greater number of fish species. Fish richness in the reef crest zone was comparable to that of other coral reefs throughout the U.S. and British Virgin Islands (Nemeth *et al.* 2003). Richness across the entire reef system (all zones combined zones) was only slightly less than that of Salt River Bay (Kendall *et al.* 2005) despite the greater variety of habitats (mangroves and sea grass beds) that occur at Salt River.

Among the habitat zones studied, the richest fish assemblage was found in the reef crest zone. This observation is perhaps not surprising. The reef crest is topographically more complex than the other habitat zones and has a high percentage of live coral cover (Toller In preparation). Reef fish diversity has been positively correlated with both topographic complexity of habitat (Luckhurst and Luckhurst 1978) and with live coral cover (Carpenter *et al.* 1981, Nemeth *et al.* 2003). The reef crest may also provide a favorable foraging area for planktivorous fishes (Toller 2002).

Compared to zones III and IV, total species richness of fishes from the inshore low relief habitat zone (zone II) was high, although average species richness was low. High fish diversity would not be expected given the low coral cover and low topographic complexity of zone II. One explanation is that transient species contribute more to the fish assemblage here than in other habitat zones. Transients may derive from adjacent sand habitat such as *Calamus calamus*, *Bothus ocellatus*, or *Xyrichtys martinicus*. Alternatively, assemblages may include rare species which are ecologically specialized to low-relief habitats.

The intertidal/shallow subtidal habitat zone supported the most distinct fish assemblage among the zones studied. Almost one quarter (20 of 86 species) of the species observed in zone I were not observed in other habitat zones. An additional 16 species were observed in zones I and II only. Many of these species appear to be ecologically specialized to the intertidal/subtidal habitat, such as gobiids (*Bathygobius soporator*, *Ginsburgellus novemlineatus* and *Gobiosoma multifasciatum*), labrisomids (*Labrisomus nuchipinnis*), and blenniids (*Entomacrodus nigricans* and *Scartella cristata*). Other species may use shallow rocky areas as daytime refuges, such as *Pempheris schomburgki* and schooling clupeids and atherinids (*Harengula humeralis*, *Jenkinsia lamprotaenia* and *Atherinomorus stipes*).

Observed patterns of cross-shelf distribution (Table 3 and 4) are only a starting point for more detailed examinations of species-habitat associations. About one-third of species were observed exclusively within a single habitat zone. Most occurred in multiple habitat zones, which suggests interconnection of fish assemblages across the Frederiksted insular shelf. Observations on the distribution of juvenile fish are also suggestive of connectivity among habitat zones. Inshore habitats may serve as nursery habitat for at least some fish species (e.g. *Lutjanus apodus*). However, mangroves and seagrass beds which are considered vital fish nursery habitats in the Caribbean (e.g. Delgado and Stedman 2004) are largely absent from the Frederiksted Reef System. Whether shallow, hard bottom habitats have acted to supplant mangroves/seagrass beds as nursery habitat on the Frederiksted insular shelf requires additional study.

This report provides a preliminary, descriptive account of the Frederiksted Reef System and associated fish assemblages. Far less information exists for this coral reef than for comparable reef systems located elsewhere on St. Croix (e.g. Hubbard 1989a, 1989b, Kendall. *et al*. 2005,). It is hoped that this study will provide the impetus for more detailed studies of the Frederiksted Reef. These data should also aid managers in evaluating impacts of proposed or ongoing anthropogenic activities. At a minimum, this study provides the important first step of documenting the presence of a large and complex reef system which supports a diverse fish assemblage.

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